Resiliency of Singkil Coastal Vegetation due to Natural Catastrophes

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Abstract: *Aceh Singkil west coast of Northern Sumatra was affected by natural catastrophes both tsunami and coastal deformation. Apparently most of the inter-tidal vegetation communities suffered because of the inundation intensity and duration changed. Investigation was carried on the structure and composition of littoral and mangrove forests in Singkil coast for 52 and 49 months after the 2004 and 2005 natural catastrophes, respectively. In each vegetation type, data were collected from four sampling plots, each measuring 30 m x 30 m. The sampling plots were separated into 10 m x 10 m sub-plots for matured trees and 5 m x 5 m sub-plots for smaller trees or shrubs. All plants within the subplots were identified and counted. Pure stand of littoral forests were dominated by Casuariana equisetifolia in the mature stage and Cerbera manghas in regeneration stages as natural regeneration. In the mangrove area, most of the mangrove trees such as Bruguiera gymnorrhiza, B. parviflora, and Rhizophora apiculata dead. Sonneratia caseolaris was higher survival rate compared than mangrove trees. B. gymnorrhiza seedlings were growing well. Mangrove palm Nypa fruticans populations were recorded growing well and with a good resiliency and persistence. In fact some of coastal vegetations both in coastal dry lands and in wetland forests have a good capacity to naturally restore and grow after the environmental destruction. From ecological point of view, these plant species should be selected for rehabilitation program in the natural catastrophes both tsunami and coastal subsidence as the impact of large earthquake could be reduced.*

Keywords: *Coastal Forest, Coastal Subsidence, Earthquake, Mangrove Forest, Tsunami*

1. Introduction

The Indian Ocean tsunami on 26 December 2004 and subsequently followed by the Nias tsunami on 28 March 2005 not only caused human fatalities and hardship. However, they also caused destruction of the coastal vegetation and other natural resources. The tsunamis were generated by earthquakes of moment magnitude 9.0 and 8.7, the west coast of northern Sumatra for the Indian Ocean tsunami and Nias tsunami, respectively. It resulted in casualties estimated at more than 220,000 (Athukorala and Resosudarmo, 2006, Wilkinson *et al.*, 2006; Yanagisawa *et* *al.*, 2009). The large earthquake also caused coastal deformation, such as land subsidence about 1.0 m occurred at Singkil coastal zone. In contrast, land up lift of about 1.5 m occurred at North coast of Nias (Briggs *et al.*, 2006).

According to Dye (2006), disturbance is an important factor in structuring ecological communities, which exert its influence through changes to the physical environment and to the trajectories of succession processes. Therefore, disturbances can cause major changes in plant communities depending on their nature, intensity, extent, frequency, seasonality, and the resilience properties of the component species (Ross *et al.*, 2004, Coates *et al.*, 2006). Alongi (2008) stated that change is a natural attribute of Earth's ecosystems, with organisms responding and adapting to spatial and temporal patterns in climate and other physical characteristics, including tectonic events, atmospheric and oceanic circulation, and landform settings are counted. Biological and ecological changes are often the result of individual, population, or community attributes such as tolerance to physicochemical factors, the ability to compete for limiting resources, and functional processes, such as ingestion, growth, respiration rates. These changes occur within a milieu of natural disturbance to the ecological equilibrium or 'steady-state' as pointed by Odum and Barrett (2004).

Obviously remarkable changes in physical environment and earth ecosystem had been occurred due to tsunami and land subsidence-affected Singkil coast, which might affect the vegetation of the area. Due to the earthquake, the land in the area had been subsidence of about 1.0 m and most of the inter-tidal vegetation communities suffered because of the change of inundation intensity and frequency. Therefore, it is important to measure the persistence and resilience of the coastal vegetation after the natural catastrophes as one of directions in the rehabilitation and management of the tsunami and coastal deformation.

2. Materials and Method

Field survey was carried out during April 2009 or around 52 and 49 months after the 2004 and 2005 tsunami disaster, respectively. This study was done at two types of coastal area, i.e. mangrove forests as coastal wetland vegetation and littoral forests as coastal dryland vegetation. The research site is part of Rawa Singkil sanctuary, Aceh, Indonesia.

In each site, four sampling plots, each measuring 30 m x 30 m, were established to assess the species composition and vegetation structure. By nested sampling method, the sampling plot was separated 10 m x 10 m sub-plots for mature trees (diameter at breast height or DBH is more than 5 cm) and 5 m x 5 m subplots for young tress/regeneration (DBH less is less than 5 cm) or shrub. All mature trees with in the sub-plots 10 m x 10 m, including living and standing dead trees, was identified and counted. Then, all young trees in the smaller sub-plots were also identified and counted.

The density relative of all recorded species was calculated using the formula of Cox (1985) to know the dominant species at each growth stage. The persistence level of each tree species in the form of ratio of dead trees to mature trees was measured to know the variation between the forest types. The resiliency of each species, as measured by the ratio of young trees to mature trees was also recorded for different sampling sites.

3. Results

3.1 Species Composition and Structure

The distribution of trees and juvenile or shrubs species are presented in Table 1 and 2. Seven and eight species of tree/palm were recorded in mangrove forests and littoral forest, respectively. In mangrove forests, *S. caseolaris* was the dominant species having maximum density (average of 255.5 living trees/ha) followed by mangrove palm *Nypa fruticans* (189.0 living mature plants/ha).

All mature trees of *F. microcarpa* were found dead (Table 1) and it was not found in the regeneration (Table 2). Other species, except *N. fruticans,* have some of tree individual were dead, too. On the other side, *R. apiculata* was not found in mature trees (Table 1) but it was found in young tree stage/regeneration (Table 2). The mangrove fern *Acrosticum aureum* population occupied the open areas left by mangrove plant communities.

In the littoral forest, *C. equisetifolia* was found as dominant species in all sampling plot having 253 living trees/ha in average followed by *H. tiliaceus* (61.3 stem/ha) (Table 1). Some of the tree species in littoral forests, such as *Mallotus* sp., *Terminalia catappa*, and *Vitex pinnata* were found less in number (Table 1). However, *Mallotus* sp. and *T. catappa* were not found growing in regeneration stage. Therefore, the species will be lowest sustaining in the next period. On the other hand, some species, such as *C. equisetifolia*, *C. manghas*, and *H. tiliaceus* had a good ability to regenerate and might be high level to sustain at future.

3.2 Persistence

Persistence refers to constancy over time, regardless of environmental perturbation (Alongi, 2008). Based on ratio of dead trees to mature trees in mangrove forests

Table 1. Distribution of mature trees species of each sampling plots (stem/ha)

No.	Species	Plot 1		Plot 2		Plot 3		Plot 4		Average	
		L	D	L	D	L	D	L	D	L	D
A. Mangrove forests											
1.	*Bruguiera gymnorrhiza*	44	89	11	111	0	0	0	0	13.8	50.0
2.	*Bruguiera sexangula*	0	0	0	0	0	0	11	22	2.8	5.5
3.	*Cerbera manghas*	0	0	0	0	111	33	11	0	30.5	8.3
4.	*Ficus microcarpa*	0	44	0	0	0	0	0	0	0.0	11.0
5.	*Nypa fruticans*	0	0	256	0	500	0	0	0	189.0	0.0
6.	*Sonneratia caseolaris*	22	0	22	100	367	44	611	11	255.5	38.8
	Total	67	144	289	211	978	78	633	33	491.5	113.5
B. Littoral Forests											
1.	*Casuarina equisetifolia*	156	0	311	44	256	89	289	0	253.0	33.3
2.	*Cerbera manghas*	0	0	44	0	56	0	122	0	55.5	0.0
3.	*Hibiscus tiliaceus*	0	0	167	0	67	0	11	0	61.3	0.0
4.	*Mallotus* sp.	0	0	0	0	0	0	11	0	2.8	0.0
5.	*Scaefola taccada*	0	0	22	0	0	0	0	0	5.5	0.0
6.	*Terminalia catappa*	0	0	0	0	11	0	0	0	2.8	0.0
7.	*Vitex pinnata*	0	0	0	0	22	0	0	0	5.5	0.0
	Total	156	0	544	44.4	411	88	433	0	386.3	33.3

Note: L = Living trees; D = Dead Trees

Table 2. Distribution of regeneration species or shrubs of each sampling plots (stem/ha)

No	Species	Plot 1	Plot 2	Plot 3	Plot 4	Average
A. Mangrove forests						
1.	*Bruguiera gymnorrhiza*	14,444	5,556	0	0	5,000.0
2.	*Bruguiera sexangula*	0	0	0	1,244	311.0
3.	*Cerbera manghas*	0	0	2,267	0	566.8
4.	*Ficus microcarpa*	0	0	0	0	0
5.	*Rhizophora apiculata*	44	0	0	0	11.0
6.	*Nypa fruticans*	0	8,400	13,333	0	5,433.3
7.	*Sonneratia caseolaris*	0	1,111	3,467	4,889	2,366.8
8.	*Acrostichum aureum*	924	660	704	396	671.0
	Total	14,488	15,067	19,067	6,153	14,359.8
B. Littoral Forests						
1.	*Casuarina equisetifolia*	3,333	5,022	0	2,400	2,688.8
2.	*Cerbera manghas*	0	44	0	2,400	611.0
3.	*Hibiscus tiliaceus*	0	2,444	0	1,111	888.8
4.	*Mallotus* sp.	0	0	0	0	0.0
5.	*Morinda citrifolia*	0	44	0	0	11.0
6.	*Scaefola taccada*	0	2,356	0	0	589.0
7.	*Terminalia catappa*	0	0	0	0	0.0
	Total	3,333	9,910	0	5,911	4,788.5

Note: Plot 3 at littoral forest was ex-burned. All tree regeneration within the plot dead

(Figure 1A), the mangrove palm *N. fruticans* was highest level in persistence followed by *S. caseolaris* as mangrove tree.

The species of *Ficus microcarpa* was not persisted since all the trees of *F. microcarpa* were found dead. Earthquake and tsunami disaster caused most of the *B. gymnorrhiza* and *B. sexangula* dead. Therefore, the species have low level in persistence. In contrast, all tree species of littoral forests have a high level of persistence (Figure 1B).

There was no dead tree in littoral forest, except in species of *C. equisetifolia*. Only a few number of *C. equisetifolia* trees were found dead after tsunami and earthquake disaster.

3.3 Resiliency

Resilience means the ability to recover from disturbance to some more or less persistent state (Gunderson *et al.*, 2002). Based on the results, it is obvious know that mangrove tree species *Bruguiera gymnorrhiza* and mangrove palm *Nypa fruticans* have a good resilience after earthquake and tsunami. The species *S. caseolaris, C. manghas* and *B. sexangula* were in mid level of resiliency but no resiliency was recorded in *F. microcarpa* (Figure 2A).

In the littoral forests, *C. equisetifolia* had a good resiliency after tsunami wave. The middle level in resiliency was in *C. manghas*, *H. tiliaceus*, and *S. taccada* (Figure 2B). These tree species are pioneer plants that which growing well in the less shading area.

4. Discussion

Mangrove resistance and resilience to relative sea-level rise over human time scales are a result of four main factors (Gilman *et al.*, 2008): (i) the rate of change in sea-level

Figure 1. Comparison between mature living trees and dead trees of each study site: mangrove forests (A) and littoral forests (B) (see description within text). Note: Bg. = *Bruquiera gymnorrhiza*; Bs. = *B. sexangula*; Cm. = *Cerbera manghas*; Fm. = *Ficus microcarpa*; Ra. = *Rhizophora apiculata*; Nf. = *Nypa fruticans*; Sc. = *Sonneratia caseolaris*; Ce. = *Casuarina equisetifolia*; Ht. = *Hibiscus tiliaceus*; Ms. = *Mallotus* sp.; Mc. = *Morinda citrifolia*; St. = *Scaefola taccada*; Tc. = *Terminalia catappa*; Vp. = *Vitex pinnata*.

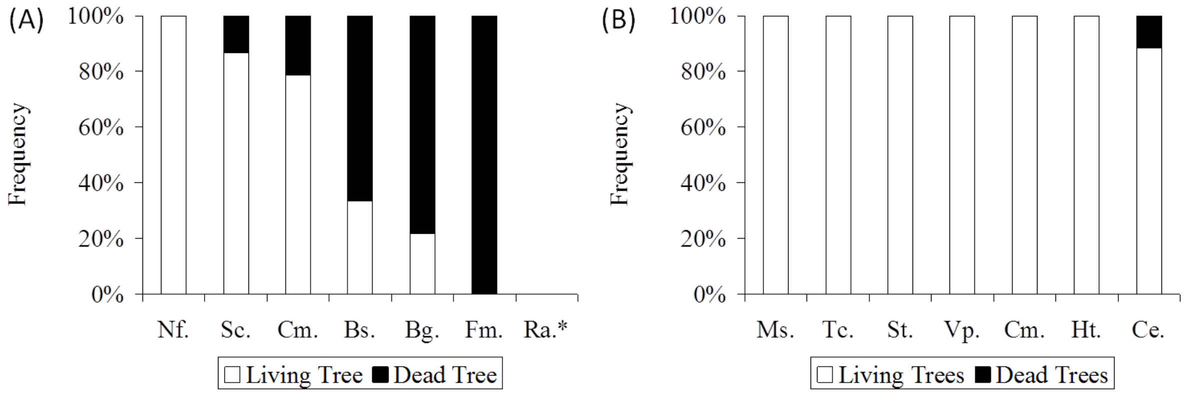
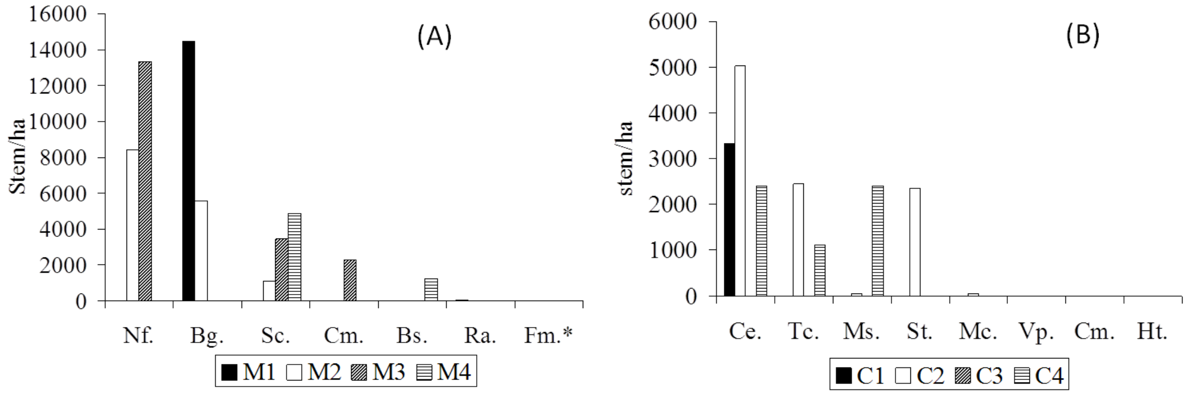


Figure 2. Density of juvenile species of each study site: mangrove forests (A) and littoral forests (B) (see description within text).



relative to the mangrove sediment surface determines mangrove vulnerability (Gilman *et al.*, 2007a). (ii) Mangrove species composition affects mangrove responses because different mangrove vegetation zones have different rates of change in sediment elevation (Krauss *et al.*, 2003; Rogers *et al.*, 2005; McKee *et al.*, 2007), some zones are more resistant and resilient to rising sea-level. Because mangrove species have differences in time required to colonize new habitat that becomes available with relative sea-level rise, the species that colonize more quickly may outcompete slower colonizers and become more dominant. (iii) The physiographic setting, including the slope of land upslope from the mangrove relative to that of the land the mangrove currently occupies, and presence of obstacles to landward migration, affects mangrove resistance (Gilman *et al.*, 2007b). Finally, (iv) cumulative effects of all stressors influence mangrove resistance and resilience. Mangroves are not expected to respond in accordance with Bruun rule (a predictive model of beach erosion) assumptions because mangroves have different sediment budget processes than beaches, and because predictive models of coastal erosion produce inaccurate results for small-scale, site-specific estimates (Pilkey and Cooper, 2004).

To date, the land subsidence in the area about 1.0 m (Briggs *et al.*, 2006) has not influence on littoral forests because the site is higher than high tide. On the other hand, the land subsidence has influence on mangrove forests due to the tidal inundation, frequency and duration after tsunami increased rather than before tsunami.

Gilman *et al.* (2008) reviewed the mangrove responses to changes in relative sea-level. There are three general mangrove responses to sea-level trends, i.e. (1) stable site-specific relative sea-level, (2) site-specific relative sea-level falling, and (3) site-specific relative sea-level rising. In our site, the site-specific relative sea-level rising because of the land subsidence after earthquake and tsunami disaster. Therefore, tidal inundation, frequency and duration increased if compare than after natural disaster.

Based on Gilman *et al.* (2008) review, if sea-level is rising relative to the elevation of the mangrove sediment surface, the mangrove's seaward and landward margins retreat landward as the mangrove species maintain their preferred hydro-period. The mangrove may also expand laterally into areas of higher elevation. Krauss *et al.* (2008 stated that environmental conditions for recruitment and establishment of mangroves in new areas that become available with relative sea-level rise include suitable hydrology and sediment composition, competition with non-mangrove plant species and availability of waterborne seedlings.

Alongi (2008) stated that mangroves can demonstrate persistence at timescales over which morphological evolution of shorelines occur. This statement does not exclude the fact that mangroves are often pioneers, colonizing newly formed mudflats, but shifts in intertidal position of existing mangroves do occur in the face of environmental change. While occurring in a variety of settings dominated by rivers, tides, waves, carbonate deposits, or a composite of dominant physical factors, mangrove development in relation to sea-level may take one of six patterns: (a) with a sea-level rise and other physical conditions held constant, the mangrove surface accretes asymptotically until accumulation of sediment raises the forest floor above tidal range; (b) with constant rise in sea-level, the floor of a maturing forest continues to accrete at a pace similar to sea-level rise; (c) with an irregular rise in sea-level, the forest floor accretes at intervals of time above tidal range (these intervals are when peat accumulates); (d) with a stable sea-level but with episodic subsidence, the forest floor accretes back to tidal range; (e) with a rising sea-level and episodic subsidence, mangrove response is complex, but the pattern is still one of overall accretion; and (f) with a rise in sea-level but no change in sedimentary volume, the forest floor is set back or abandoned.

The seaward mangrove margin migrates landward from mangrove tree dieback due to stresses caused by a rising sea-level such as erosion resulting in weakened root structures and falling of trees, increased salinity, and too high a duration, frequency, and depth of inundation (Naidoo, 1983; Ellison, 1993; Lewis, 2005). Mangroves migrate landward via seedling recruitment and vegetative reproduction as new habitat becomes available land-ward through erosion, inundation, and concomitant change in salinity (Semeniuk, 1994). In our research site, mangrove tree *R. apiculata* and mangrove palm *N. fruticans* was found to migrate land-ward via seedling recruitment, naturally.

Depending on the ability of individual mangrove species to colonize newly available habitat at a rate that keeps pace with the rate of relative sea-level rise (Field, 1995; Duke *et al.*, 1998; Di Nitto *et al.*, 2008), slope of adjacent land and presence of obstacles to landward migration of the landward mangrove boundary (Gilman *et al.*, 2008), some mangroves will gradually be reduced in area, may revert to a narrow fringe, survival of individual trees or experience local extirpation.

5. Conclusion

Disturbance habitat of coastal forest in Northern Sumatra due to earthquake and tsunami disaster caused change in plant community, especially in mangrove forests. Mangrove tree *R. apiculata* and mangrove palm *N. fruticans* was found to shift landwand via seedling recruitment, naturally.

Most of the coastal forests at more than 4 years after the natural disaster were able to naturally restore and grow after previously environmental destruction, i.e. 2004 and 2005 earthquakes and tsunamis. Therefore, from ecological view, these plant species can be selected for rehabilitation program in the tsunami-affected area. The rehabilitation program should also consider on coastal change due to land subsidence. Subsequently species-site matching is needed in species selection for rehabilitation.

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