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Tsunami Impacts on Biodiversity of Seagrass Communities in the Andaman Sea, Thailand: (1) Seagrass Abundance and Diversity

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Abstract Evaluation of the impact of a catastrophic disturbance on biodiversity is often difficult due to a lack of sufficient quantitative data on biological communities prior to the disturbance. Since 2001, we have been monitoring the abundance and biomass of seagrass and its associated animal community along the Andaman Sea coast of Thailand, an area that was hit by a tsunami originating in the Indian Ocean on Dec. 26, 2004. To quantitatively evaluate the effects of the disturbance on the biodiversity of the seagrass community we carried out a comparative analysis of seagrass species diversity and abundance based on pre-/post-disturbance data at several seagrass beds at Kuraburi, northern Phang-nga (most-affected region) and Trang (less-affected region). Species diversity, coverage and biomass of seagrass declined greatly after the tsunami at one seagrass bed (Thung Nang Dam) in Kuraburi. The effect of the tsunami was less obvious at two other beds a few kilometers away from Thung Nang Dam, and at the seagrass beds in Haad Chao Mai National Park in Trang (located ca. 200km south of Kuraburi), where temporal change before and after the tsunami was the least obvious. A steady decline in biomass was observed in the three seagrass beds that had not been severely affected by the tsunami, possibly associated with other types of disturbance such as river discharge. Analyses revealed that the effect of the tsunami on seagrass ecosystems was highly variable even on small spatial scales, and that other factors causing disturbance to the seagrass beds are important factors of the observed temporal variation.

Key words: Biomass, Physical disturbance, Seagrass, Silt-clay content, Species richness, Temporal change

Introduction

Seagrass beds are a major component in coastal ecosystems, supporting high productivity and biodiversity (Duarte and Chiscano, 1999; Hemminga and Duarte, 2000; Williams and Heck, 2001; Nakaoka, 2005). Despite their importance, seagrass beds are declining rapidly due to a variety of natural and human-induced disturbances (Fortes, 1988; Short and Wyllie-Echeverria, 1996; Duarte, 2002). As seagrass beds can only exist in areas with soft bottom sediments, changes in bottom topography affect distribution and productivity. Sediment environment can be modified by various processes such as wave disturbance due to heavy storms such as cyclones and monsoons (Preen *et al*., 1995), dune migration caused by dominant coastal current (Marbà and Duarte, 1995), and siltation due to massive sediment discharge from rivers (Terrados *et al*., 1997; Bach *et al*., 1998).

The tsunami that hit the coastal areas of the Indian Ocean on Dec. 26, 2004, was the source of catastrophic disturbance to coastal ecosystems and human societies along southeastern Asia shores (Adger *et al*., 2005; Buero, 2005). However, its impact on seagrass ecosystems along the Andaman Sea coast of Thailand was highly variable among seagrass beds. Seagrass beds in Kuraburi, northern

Pang-nga, were greatly affected, whereas those in Haad Chao Mai National Park, Trang, received little impact (Department of Marine and Coastal Resources, 2005). Since 2001, we have been monitoring abundance and biomass of seagrass and the associated animal community in sites along the Andaman Sea coast, which has given us a rare opportunity to quantitatively evaluate the effects of the tsunami disturbance on the biodiversity of seagrass beds.

The aim of the present paper is to examine the impact of the tsunami on species composition, species diversity and the abundance of seagrass by comparing these variables before and after the tsunami. We conducted a series of quantitative censuses at six sites (five seagrass beds) in two regions along the Andaman Sea coast of Thailand that were affected to different degrees by the tsunami. To understand the appropriate spatial scale at which the tsunami impacts vary, the comparisons were made at two spatial scales: (1) among two regions (Kuraburi and Trang) that are separated by 200 km, and (2) among seagrass beds within a river-watershed system (Kuraburi) separated by 1-10 km.

Material and Methods

Study sites

Quantitative census of the seagrass beds began in 2001 in two regions (Trang and Kuraburi) along

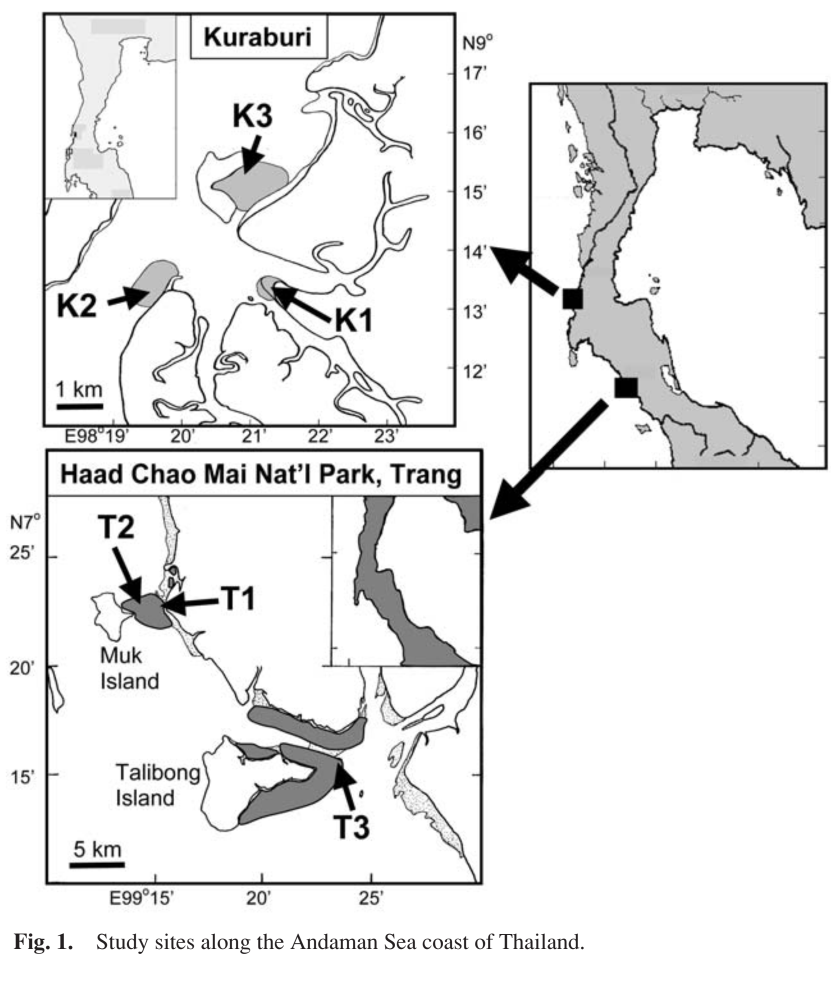

Fig. 1. Study sites along the Andaman Sea coast of Thailand.

the Andaman Sea coast of Thailand (southwestern Thailand), where many seagrass beds with rich flora have been described (Lewmanomont *et al*., 1996; Poovachiranon, 2000) (Fig. 1).

In Trang, seagrass beds occur along the coastline of the Haad Chao Mai National Park. A seagrass bed (Laem Yong Lam) located in the northern part of the park, between Muk Island and the mainland, is known as the largest seagrass bed (ca. 18 km^2) along the Andaman Sea coast of Thailand (Lewmanomont and Supanwanid, 2000; Nakaoka and Supanwanid, 2000). Two sampling sites were established at this seagrass bed: the shallower station (Stn. T1) was located with in the intertidal zone, and the deeper station (Stn. T2) nearer the mean low water level. These two sites were separated by a distances of 1 km. This area has no major river systems, and is thus considered to be the least impacted by terrestrial and riverine inputs (Nakaoka and Supanwanid, 2000; Nakaoka *et al*., 2004). In the southern parts of the park, some beds are found at the mouth of Trang River, one of the largest rivers in southern Thailand. One seagrass bed located between Talibong Island and the mainland was chosen for the monitoring site (Stn. T3) where the greatest influence of river discharge was expected (Nakaoka *et al*., 2004).

In Kuraburi, seagrass beds occur at the mouth of the Khula River. This river is relatively small compared to the Trang River, and thus the seagrass beds in this area are considered to be only medially affected by river discharge (Nakaoka *et al*., 2004). Three isolated seagrass beds at Ko Chong (Stn. K1), Mai Hang (Stn. K2) and Thung Nang Dam (Stn. K3) were chosen as sampling sites. Stn. K1 located at the innermost part, Stn. K2 at the southwestern part, and Stn. K3 at the northeastern part of the river mouth.

Field census

Silt-clay content in the sediments was measured in 2001 at the six sites, at Stns. K3, T1 and T2 in 2005, and at Stns. K1, K2 and T3 in 2006. Sediment samples were collected using a 25 cm-length plastic corer with a 5 cm internal diameter. After drying at 105℃ for more than 24 hours, weight was measured. The silt-clay content was obtained by washing the sediment carefully with running water through a 63 μm-mesh sieve. The samples were dried again under the same conditions and re-weighed. The difference of weights before and after sieving was calculated as the content of silt-clay in the sediment.

The quantitative census of seagrass species composition and biomass at each seagrass bed were carried out in January and December 2001, December 2002 and December 2003 before the tsunami, and between February and March in both 2005 and 2006 after the tsunami. All the censuses were carried out during the dry season (between December and March) when the seagrass community was stable compared to the rainy season (between May and October) (Aryuthaka, C. and Tanaka Y., personal observations). At each station, a sampling plot of 60-100 ha was established. Three to five parallel transects of 100m in length were first set perpendicular to the shoreline at intervals of 25m. Along each transect, five sampling points were set at interval of 25m. As the result, a grid consisting of 15-25 sampling points was established at each station (three to five points parallel to the shoreline, times five points along the depth gradient). At each point three to five 0.5 x 0.5m quadrats were randomly placed.

Species composition of seagrass and ranked estimates of aboveground biomass of each seagrass species were recorded for each quadrat by one of 2-5 observers. Biomass estimates were made with rapid visuals to minimize disturbances to the seagrass beds and time loss caused by seagrass collection at numerous points (Mellors, 1991; Nakaoka and Supanwanid, 2000). Seagrass biomass within each quadrat was ranked between 0 and 10. Later the rank of each observer was converted to biomass by the following process. After the census, 8-15 quadrats of the equal size were placed at a typical position of each station covering the full range of biomass observed during the survey (calibration quadrats), and all observers ranked the seagrass biomass in these quadrats. The aboveground part of the seagrass in each quadrat was then harvested, sorted to species level and dried at 60℃ until it reached a constant weight, and measured on an electrical balance to the nearest 0.01g. Rank estimates were converted to biomass by calculating a regression equation between actual aboveground biomass of seagrass and ranks for each observer. The data were fitted by an allometric equation ($Y = aX^b$ where Y is aboveground biomass, X is rank, a and b are regression coefficients) because this equation gave better fits than a linear equation ($Y = aX + b$) (Nakaoka and Supanwanid, 2000). Data on biomass estimates of each seagrass species per quadrat were averaged for each sampling point, and further averaged for each site.

Results

Visual observation of seagrass vegetation in Kuraburi before and after the tsunami revealed that the seagrass bed in Thung Nang Dam (Stn. K3) received the most severe sediment disturbance, where almost all the seagrass vegetation disappeared after the tsunami. Before the tsunami, the seagrass bed at this site was found between the mainland and the sand dune (Fig. 1), most of the sand dune also disappeared after the tsunami. The seagrass bed in Mai Hang (Stn. K2) was moderately disturbed. Here, new gaps between plants were observed that were made by sediment deposition and erosion. The disturbance in Ko Chong (Stn. K1) was minor, no apparent changes in bottom topography were observed between 2001 and 2005. At Trang, we did not discern major topographical changes in sediment at the seagrass beds where our sampling sites (Stns. T1, T2 and T3) were located.

Silt-clay content of the sediment varied greatly among the sites (Fig. 2). In 2001, the silt-clay content was greatest in the sediments of Stn.T3, followed by those at the three stations in Kuraburi (Stns. K1, K2 and K3), and lowest in the two stations in Laem Yong Lam (Stns. T1 and T2). Temporal change in sediment type was most pronounced at Stn. K3 where the silt-clay content in 2005 was 20% of what it was in 2001 (t-test; t=4.20, p=0.01). In contrast, silt-clay content significantly

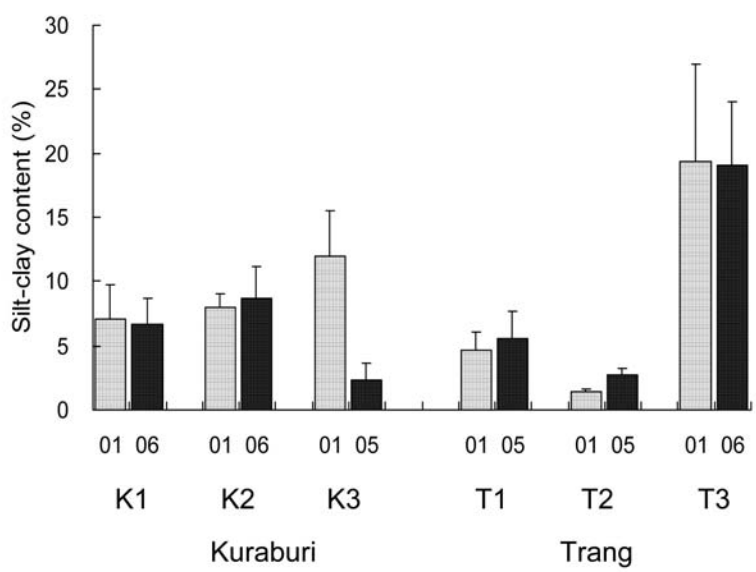

Fig. 2. Temporal variation in silt-clay content (% + SD) of the sediment at the six research sites in Kuraburi and Trang between 2001 (01) and 2005 (05) or 2006 (06).

increased from 2001 to 2005 in Stn. T2 (t-test; t=4.28, p<0.01). In other sites, it did not vary significantly before and after the tsunami (t-test; t=0.22, p=0.84 for Stn. K1, t=0.44, p=0.68 for Stn. K2, t=0.71, p=0.50 for Stn. T1 and t=0.08, p=0.94 for Stn. T3).

A total of nine seagrass species were observed at the six stations during the census conducted between 2001 and 2006 (Table 1). The number of seagrass species and their composition varied greatly among regions and sites. In Kuraburi, three species were found at Stn. K1, seven at Stn. K2 and six at Stn. K3, and in Trang, four species were found at Stn. T1, eight at Stn. T2 and three at Stn. T3. *Enhalus acoroides* and *Halophila ovalis* occurred in all sites including those with low species richness (e.g. Stns. K1 and T3), whereas distribution of mid-sized species, such as *Halodule uninervis*, *Cymodocea rotundata* and *C. serrulata* was restricted to seagrass beds with high species richness (e.g. Stns. K2, K3, T1 and T2). *Thalassia hemprichii* did not occur in the three seagrass beds in Kuraburi. *Halophila beccarii* was found only at Stn. K1. Species richness and species composition of seagrass did not differ before and after the tsunami in most sites except Stn. K3 where only one species (*Halophila ovalis*) was found in 2005 and no species 2006.

Coverage of seagrass, represented by the percent of occurrence among 15-25 sampling points of each site, was stable over time at the three stations in Trang, and at Stn. K2 in Kuraburi (Fig. 3a, 3b). The coverage decreased greatly at Stn. K1 between 2002 and 2005, but it remained the same level between 2005 and 2006. At Stn. K3, the coverage dropped to zero in 2005 and it did not recover in 2006. Correlation between coverage and time was significantly negative for Stn. K3 (Pearson's correlation coefficient, r=0.925, p=0.02), positive for Stn. K2 (r=0.937, p=0.02), and not significant for the other four stations (r=0.86, p=0.06 for Stn. K1, r=0.82, p=0.09 for Stn. T1 and r=0.69, p=0.19 for Stn. T2 and r=0.16, p=0.79 for Stn. T3).

Biomass of seagrass varied greatly among sites and among years, with the highest density consistently recorded at Stn. T2 (72-129g dry weight m^{-2}). Patterns of temporal changes in seagrass biomass also varied among regions and sites (Fig. 3c, 3d). At Stn. K3, biomass dropped to zero in 2005 and did not increase in 2006. Negative correlation between biomass and time was detected at Stns. K3 and T2 (Pearson's correlation coefficient, r=0.97, p<0.01 for Stn. K3 and r=0.93, p=0.02 for Stn. T2). Biomass tended to decrease with time in Stns. K1 and T3 although the correlation was only marginally significant (r=0.84, p= 0.08 for Stn. K1 and r=0.84, p=0.08 for Stn. T3). A temporal pattern in biomass was not obvious at Stn. K2 (r=0.54, p=0.35) and Stn. T1 (r=0.14, p=0.82).

Table 1. Seagrass species composition at six seagrass beds along the Andaman Sea coast of Thailand recorded between 2001 and 2006.

Region	Kuraburi															Trang														
Seagrass bed (Station)	K1 (Ko Chong)					K2 (Mai Hang)					K3 (Thung Nam Dam)					T1 (Laem Yong Lam)					T2 (Laem Yong Lam)					T3 (Ko Talibong)				
Census[#]	1j	1d	2d	5f	6f	1j	1d	2d	5f	6f	1j	1d	2d	5f	6f	1j	1d	2d	5f	6f	1j	1d	2d	5f	6f	1j	1d	2d	5f	6f
Halophila ovalis	o	o	o	o	o	o	o	o	o	o	o	o	o	o		o	o	o	o	o	o	o	o	o	o	o		o	o	o
H. beccarii	o	o	o	o	o																									
Enhalus acoroides	o	o	o	o	o		o	o	o	o			o			o		o	o	o	o	o	o	o	o	o	o	o	o	o
Thalassia hemprichii																o	o	o	o	o	o	o	o	o	o					
Halodule uninervis						o	o	o	o	o	o	o	o									o	o	o						
H. pinifolia								o	o			o									o			o	o	o		o		o
Syringodium isoetifolium						o	o	o	o	o	o	o	o								o	o	o	o	o					
Cymodocea rotundata						o	o	o	o	o						o	o	o	o	o	o	o	o	o	o					
C. serrulata						o	o	o	o	o	o	o	o										o							
Number of species	3	3	3	3	3	5	6	7	7	6	4	5	5	1	0	4	3	4	4	4	6	6	7	7	6	3	1	3	2	3

[#] 1j: January 2001; 1d: December 2001; 2d: December 2002; 5f: February to March 2005; 6f: February to March 2006

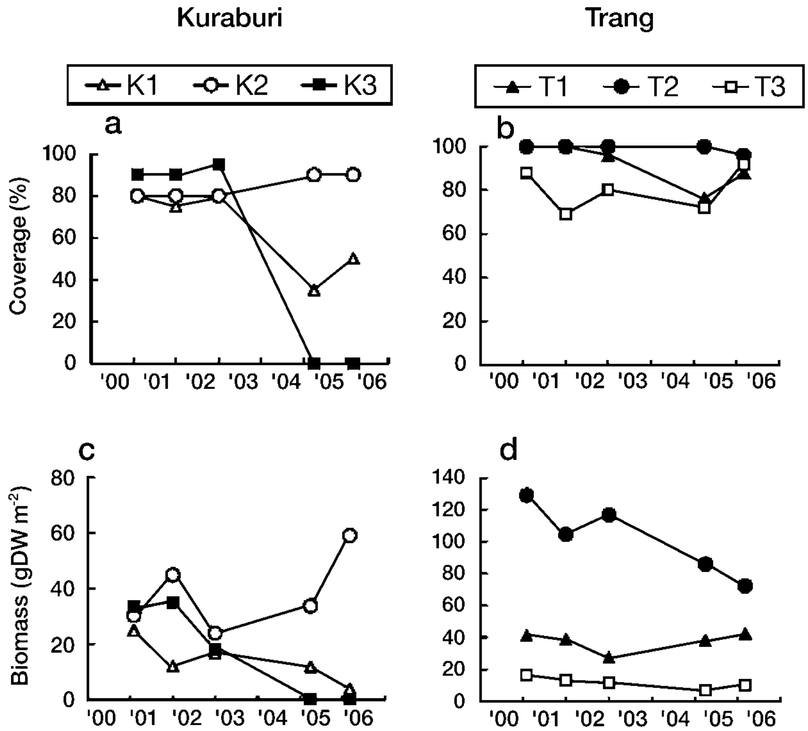

Fig. 3. Temporal changes in seagrass coverage (a, b) and biomass (c, d) at the six research sites in Kuraburi and Trang from 2001 to 2006.

Discussion

The present study revealed that species diversity and abundance of seagrass varied greatly among seagrass beds in different regions and sites, and that the patterns of temporal changes also varied among sites. Before the tsunami, species richness, coverage and the average biomass of seagrass were lowest at Stn. K1 in Kuraburi and at Stn. T3 in Trang. Compared to the other sites these two seagrass beds are locate closer to river mouths (Khula River and Trang River, respectively), and are thus considered to be greater influenced by terrestrial runoff and river discharge (Nakaoka *et al.*, 2004). Siltation due to river discharge and a decrease in water transparency due to sediment re-suspension are commonly observed at river mouths and the resulting decrease in light is considered unfavorable for seagrass survival and growth (Tanaka and Nakaoka, 2006). It is likely that lower diversity and biomass at Stns. K1 and T3 are related to the poor environmental conditions. Terrados *et al.* (1998) conducted large-scale comparisons of seagrass beds in the Philippines and Thailand, and concluded similarly that species diversity and biomass of seagrass were lower in seagrass beds with high siltation. These findings suggest that input of terrestrial-derived matter via rivers has large negative impact on seagrass communities.

Pattern of temporal changes in diversity and abundance of seagrass before and after the tsunami varied greatly among regions and among sites within regions. The drastic decline in species richness, coverage and biomass was observed at Stn. K3 where almost all areas of seagrass vegetation disappeared due to strong physical disturbance caused by the tsunami that changed the topography of the sand dune. At this station, silt-clay content dropped significantly between 2001 and 2005 due to the deposition of sand from the surrounding dunes where the sediment grain size was coarser than that in the seagrass bed. Measurement of water depth and the sediment profile suggests that the seagrass bed was buried under more than 50cm of new sediment (Miyajima, T., personal communication). Ability to tolerate sediment deposition varies among tropical seagrass species as evidenced by experimental burial (Duarte *et al*., 1997). The sediment burial at Stn. K3 was considered to be too deep for any of the six species found there to survive, and this led to the disappearance of the seagrass vegetation at this station.

During the research period significant decreases in coverage and biomass, or its tendency was observed in sites other than Stn. K3, e.g. Stns. K1, T2 and T3. The decline is unlikely related to the direct disturbance by the tsunami because noticeable differences in topography or depth profiles were not found in these seagrass beds during the survey conducted after the tsunami by ourselves and others (Department of Marine and Coastal Resources, 2005). The temporal change in these sites is more likely related to other types of disturbances. At Stns. K1 and T3, siltation and light attenuation associated with river discharge is thought to have had a destabilizing effect on the seagrass beds. At Stn. T2, silt-clay content increased significantly from 2001 to 2005. However, it remains unknown whether the change in silt-clay content was related to change in seagrass biomass at this site.

In conclusion, the present study reveals that temporal changes in species diversity and abundance of seagrass are highly variable among regions and even among seagrass beds within each region, and that the impact of the tsunami was different on different sites, even in the same region. Significant temporal change in seagrass abundance was observed not only at sites that received severe disturbance of the tsunami (e.g., Stn. K3), but also at other sites with less effects of the tsunami, suggesting that other factors causing disturbance to the seagrass beds, such as river discharge and strong waves caused by monsoons, are also important for the temporal variation. Continued monitoring of these seagrass beds is underway to reveal the subsequent recovery processes in seagrass ecosystems and the interactions of different types of disturbances, i.e., catastrophic, long-term natural and human-induced disturbances.

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