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Tsunami Impacts on Biodiversity of Seagrass Communities in the Andaman Sea, Thailand: (2) Abundance and Diversity of Benthic Animals

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Abstract Seagrass beds support highly productive and diverse animal communities. Extreme physical disturbances such as tsunamis are expected to affect the abundance and diversity of both the seagrass and the infaunal community. To examine the effects of a tsunami on infaunal seagrass communities, we compared the communities in seagrass beds before and after the tsunami that hit the Andaman Sea coast of Thailand on December 26th, 2004. Infauna were collected in 2001 and again in 2005 from inside and outside seagrass vegetation. Polychaetes were the most abundance taxa, followed by crustaceans. Density of macrobenthic animals varied greatly among sites, among areas inside and outside the vegetated areas and between the two years. The density increased over time in the areas with seagrass while it decreased in the non-vegetated areas, suggesting that the tsunami impacted the two areas differently. Multivariate analysis on the polychaete assemblage revealed that temporal changes in assemblage structure differed between vegetated and non-vegetated areas, and that the degree of temporal changes in assemblage structure was not necessarily related to the magnitude of the tsunami.

Key words: Physical disturbance, sediment, polychaetes, infauna, abundance, multivariate analysis, temporal change

Introduction

Seagrasses are marine flowering plants that occur in the near shore around the world (Hemminga and Duarte, 2000; Green and Short, 2003). Seagrasses are major primary producers, supporting the high productivity of associated animals including commercially important fish and large invertebrates (Heck *et al.*, 2003), and endangered marine mammals such as dugongs and manatees (Mukai *et al.*, 2000). They also support a wide variety of infaunal and meiobenthic/macrobenthic epifaunal organisms (Kikuchi and Pérès, 1977; Williams and Heck, 2001; Tanner, 2005). Seagrass beds are susceptible to various natural and human-induced disturbances, such as cyclones, monsoons, fishing activities, eutrophication, dredging and coastal development (Short and Wyllie-Echeverria, 1996; Duarte, 2002). These disturbances are expected to affect not only the seagrasses, but also the abundance and diversity of the associated infauna.

Effects of physical disturbance on infauna have been extensively studied for various types of soft-bottom communities (see Lenihan and Micheli, 2001, for a review). It is noteworthy that physical disturbance can affect infaunal community structure not only directly by changing survivorship of each component species, but also indirectly by altering the abundance and performance of dominant and/or keystone species (Kneib, 1988; Hamilton, 2000). In the cases of infaunal animals in seagrass beds the

presence or absence of seagrass vegetation is expected to modify the degree of impact by physical disturbance. This is because the vegetation acts as a buffer, reducing water current velocity and sediment erosion rate (Fonseca and Fisher, 1986; Koch and Gust, 1999; Madsen *et al.*, 2001).

Coastal southeastern Asia, especially along the Andaman Sea of Thailand and Indonesia, was greatly affected by the December 26th, 2004 tsunami. A broad-scale coastal census conducted after the tsunami revealed that its effects on seagrass beds were spatially variable, with some seagrass beds disappearing while others were only negligibly impacted (Department of Marine and Coastal Resources, 2005). In 2001 we monitored the species composition and abundance of seagrass associated animals at several seagrass beds in these regions. By repeating this study in 2005 we had the rare opportunity to evaluate the changes by quantitatively comparing data from both before and after the tsunami.

Following the companion paper that reports the varied impact of the tsunami on seagrass assemblage structures (Nakaoka *et al.*, 2007, this volume); this paper examines the effects of the tsunami on seagrass infaunal communities, with a focus on polychaetes assemblages. Patterns of temporal changes in infaunal community were compared 1) between two seagrass beds that received different degrees of disturbances, and 2) between vegetated and non-vegetated areas within each seagrass bed. The goal of this study was to determine if the impact of a tsunami varies with the presence or absence of seagrass vegetation.

Material and Methods

Study site

Study sites were located in seagrass beds at the river mouth of Kuraburi, Phang-nga Province, along the Andaman Sea Coast of Thailand (see Fig. 1 of Nakaoka *et al.*, 2007). In this region,

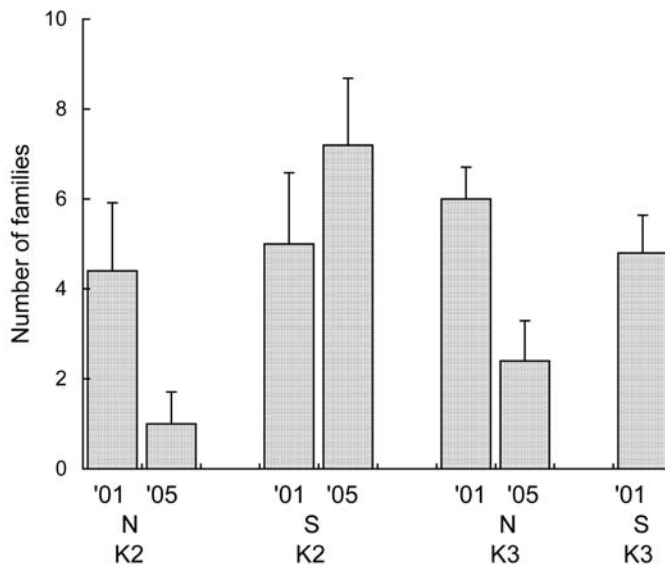


Fig. 1. Taxa richness of polychaete (represented by the number of families per core) collected from the two vegetation types (S: seagrass-vegetated; N: non-vegetated) at two sites (K2 and K3) in 2001 and 2005. Bars denote standard deviation of the mean.

mangroves cover the upper intertidal zone while several seagrass beds persist from the lower intertidal to the shallow subtidal zone. Seven seagrass species occur in these beds, including *Halophila ovalis*, *Enhalus acoroides*, *Syringodium isoetifolium*, *Halodule uninervis*, *H. pinifolium*, *Cymodocea rotundata* and *C. serrulata*. One seagrass bed was sampled in each of the following areas: K2 (Mai Hang; 9°13'25"N; 98°19'40"E) and K3 (Thung Nang Dam; 9°15'02"N; 98°20'30"E). Concurrent surveys of seagrass vegetation revealed that K3 received the most disturbances by the tsunami, with the disappearance of almost all the seagrass. The K2 seagrass bed received moderate disturbance, with fresh un-vegetated gaps within the seagrass vegetation (Nakaoka *et al.*, 2007).

Sampling procedure

Infauna was sampled in January 2001 (approximately 4 years before the tsunami) and in February 2005 (2 months after the tsunami) either under emerged conditions during low tides, or under submerged conditions by snorkeling. At each site, sampling occurred in an area of ca. 50m by 50m that contained both seagrass vegetation and non-vegetated gaps. K2 consisted of mixed vegetation of *Halophila ovalis*, *Cymodocea serrulata*, *C. rotundata* and *Halodule univervis* (ca. 10-15cm in shoot height) at intertidal to shallow subtidal zone (0.5m deep at MLW). The bottom was covered by medium-coarse sand with a silt-clay content of 8.0% in 2001 and 8.7% in 2006 (Nakaoka *et al.*, 2007). K3 contained *Cymodocea serrulata* vegetation (> 30cm in shoot height) in shallow subtidal area (0.5-1m deep at MLW) in 2001; the vegetation was totally lost in 2005. The silt-clay content was 12.0% in 2001 and 2.4% in 2005. The decrease was due to massive sand deposition caused by the tsunami (Nakaoka *et al.*, 2007).

In each site, replicate cores were collected randomly within the seagrass vegetation (seagrass area) and without vegetation (non-vegetated area) using a PVC corer with a diameter of 15cm. Cores were inserted into the sediment to a depth of 20cm, resulting in a sampling area of 177cm² and 2540cm³ in volume. Five replicates were taken in each vegetation type in 2001 and 2005. At K3 in 2005, samples were collected only from non-vegetated areas because no vegetated areas remained. Samples were sieved through a 0.5mm mesh sieve. All animals retained on the sieve were transferred to polyethylene bags and fixed with a 10% seawater formalin solution. In the laboratory, infauna were sorted and transferred to 80% ethanol for identification and counting. All organisms were classified to higher taxonomic groups (polychaetes, crustaceans, molluscs and other taxa), while polychaetes were further identified to at least the family level.

Data analysis

Average density (the number of individuals per 0.01/m²) of the benthic communities and taxa richness of polychaetes (the number of families per core) was calculated for all following 7 groups of samples; with all combination of two sites (K2 and K3), two vegetation types (S: seagrass and N: non-vegetated) and two years (2001 and 2005) except the seagrass vegetation at K3 in 2005. The density data were log-transformed prior to statistical analyses to secure homogeneity of variances (tested by Cochran's test). At K2, variation in the densities of total macrofauna, polychaetes and crustaceans and in polychaete taxa richness was tested by two-way ANOVA using year and vegetation type as fixed factors. At K3, one-way ANOVA was used to test variation among three groups of samples collected from different vegetation types and in different years (K3-S-01, K3-N-01 and K3-N-05). In cases where significant variation was detected by one-way ANOVA, post-hoc comparisons were carried out using Tukey's method.

For polychaetes, the data were further analyzed using multivariate analysis. The similarity of polychaete assemblage was calculated using Bray-Curtis dissimilarity index for all the pairs of 7 groups. Two types of similarity matrices were made using non-transformed abundance data (classified by family) and presence/absence data (by family) to examine whether relative abundance of

Table 1. Density and taxa composition of macrobenthic animals in seagrass-vegetated and non-vegetated areas in 2001 and 2005 at two seagrass beds in Kuraburi, Thailand.

Site	Vegetation type	Year	Density (/0.01m ² ± SD)				
			Polychaetes	Crustaceans	Molluscs	Others	Total
K2	Seagrass	2001	50 ± 5	25 ± 4	5 ± 1	3 ± 1	83 ± 7
		2005	131 ± 11	61 ± 13	7 ± 2	50 ± 5	249 ± 17
	Non-vegetated	2001	47 ± 16	10 ± 2	1 ± 0	0 ± 0	58 ± 8
		2005	7 ± 1	0 ± 0	0 ± 0	0 ± 0	7 ± 1
K3	Seagrass	2001	39 ± 2	11 ± 2	5 ± 1	3 ± 1	58 ± 3
	Non-vegetated	2001	47 ± 2	6 ± 2	2 ± 1	4 ± 2	59 ± 4
		2005	15 ± 1	2 ± 0	4 ± 1	3 ± 1	24 ± 2

Table 2. Results of two-way ANOVA testing the variation in density of benthic animals and taxa richness of polychaetes between years and vegetation types at K2 (Mai Hang).

	df	MS	F	<i>p</i>
log (Density of total macrofauna)				
Year	1	0.09	1.62	0.221
Habitat	1	3.18	54.55	<0.001
Interaction	1	1.86	31.88	<0.001
Residuals	16	0.06		
log (Density of polychaetes)				
Year	1	0.05	0.77	0.392
Habitat	1	1.62	27.74	<0.001
Interaction	1	1.26	21.68	<0.001
Residuals	16	0.06		
log (Density of crustaceans)				
Year	1	0.01	0.09	0.770
Habitat	1	2.15	28.07	<0.001
Interaction	1	0.61	7.92	0.012
Residuals	16	0.08		
Taxa richness of polychaetes				
Year	1	1.80	0.96	0.342
Habitat	1	57.80	30.83	<0.001
Interaction	1	39.20	20.91	<0.001
Residuals	16	1.88		

Table 3. Results of one-way ANOVA testing the variation in density of benthic animals and taxa richness of polychaetes between samples collected from different years and vegetation types at K3 (Thung Nang Dam). In post-hoc comparisons, the pairs of samples without significant differences are underlined. See text for the sample code.

	df	MS	F	<i>p</i>	Post-hoc comparisons (by Tukey method)
log (Density of total macrofauna)					
Sample	2	0.20	12.44	0.001	<u>K3-N-01</u> <u>K3-S-01</u> K3-N-05
Residuals	12	0.12			
log (Density of polychaetes)					
Sample	2	0.24	31.39	<0.001	<u>K3-N-01</u> <u>K3-S-01</u> K3-N-05
Residuals	12	0.01			
log (Density of crustaceans)					
Sample	2	0.15	1.93	0.188	–
Residuals	12	0.08			
Taxa richness of polychaetes					
Sample	2	16.80	25.20	<0.001	<u>K3-N-01</u> <u>K3-S-01</u> K3-N-05
Residuals	12	0.67			

component families and family composition vary similarly between years, sites and vegetation types. Variation in similarity was graphically depicted using non-metric multi-dimensional scaling (MDS) ordination method based on 20 iterations of data (Clarke and Warwick, 2001). The multivariate analysis was carried out using the software PRIMER-E (ver. 5; Plymouth Marine Laboratory, UK).

Results

A total of 258 and 279 infaunal individuals were collected in 2001 and 2005, respectively. Polychaetes were dominant at almost all sites and vegetation types in both 2001 and 2005 (Table 1), occupying 57% of the total macrobenthos in 2001 and 61% in 2005. Crustaceans were the second dominant (28% in 2001 and 13% in 2005). Other organisms included molluscs (bivalves and gastropods), nemerteans and sipunculid worms, actinarians, brachiopods, echinoderms and amphioxus.

Infaunal density varied greatly among sites, between vegetation types, and between the two years (Table 1). Densities of total macrofauna, polychaetes and crustaceans were the highest in the seagrass area of K2 in 2005, and the lowest in the non-vegetated area of K2 in 2005. In K2, patterns of temporal changes differed between vegetation types, as shown by significant year-by-vegetation type interaction in two-way ANOVA (Table 2). The densities decreased greatly in non-vegetated area, whereas it increased in seagrass vegetation. These patterns of variation were similar among total macrofauna, polychaetes and crustaceans.

In K3, the densities of total macrofauna and polychaetes in non-vegetated area decreased greatly from 2001 to 2005. One-way ANOVA detected significant variation among three groups of samples in the densities of total macrofauna and polychaetes, and post-hoc comparisons revealed that the difference was significant between non-vegetated areas in 2001 and 2005, and between seagrass area in 2001 and non-vegetated area in 2005, but not between seagrass and non-vegetated areas in 2001 (Table 3). For the crustacean density, no significant variation was detected among the three groups of samples (Table 3).

Table 4. Number of individuals of polychaetes families found from two seagrass beds (K2 and K3) in Kuraburi, Thailand.

Families	K2		K2		K3		K3	
	Seagrass		Non-vegetated		Seagrass		Non-vegetated	
	2001	2005	2001	2005	2001	2001	2005	
Ampharetidae	0	0	0	0	1	0	0	
Amphinomidae	1	0	1	0	1	0	0	
Capitellidae	0	1	2	0	5	10	0	
Cirratulidae	4	1	0	0	1	3	2	
Dorvilleidae	0	0	0	0	0	1	0	
Eunicidae	0	0	0	0	1	0	0	
Flabelligeridae	0	0	0	0	1	0	0	
Glyceridae	9	19	22	3	12	6	2	
Hesionidae	0	0	0	0	0	1	0	
Lumbrineridae	2	2	2	0	0	1	2	
Magelonidae	0	0	0	0	0	1	0	
Maldanidae	2	2	2	0	1	0	0	
Nephtyidae	0	0	1	0	0	0	1	
Nereididae	1	11	0	0	0	0	1	
Onuphidae	0	4	0	0	0	0	0	
Opheliidae	13	59	5	4	0	2	4	
Orbiniidae	7	4	6	0	8	5	1	
Paraonidae	0	0	0	0	0	6	0	
Pilargidae	0	1	0	0	0	0	0	
Polynoidae	0	2	1	0	0	1	0	
Sabellidae	0	0	0	0	0	1	0	
Sigalionidae	0	0	0	0	0	1	0	
Spionidae	11	21	5	0	3	5	2	
Sternaspidae	0	0	0	0	0	1	0	
Syllidae	0	4	0	0	2	1	0	
Terebellidae	0	0	0	0	3	1	0	
Total	50	131	47	7	39	47	15	

Polychaetes were classified into 26 families. The dominant family and family composition varied greatly among sites and vegetation types. At K2, ophelids were the most dominant in seagrass vegetation, followed by spionids and glycerids, whereas in non-vegetated area, glycerids were dominant in 2001 followed by orbiniids. Only two families occurred at non-vegetated areas of K2 in 2005. At K3, glycerids were the dominant group in seagrass vegetation, followed by orbiniids and capitellids, whereas capitellids were dominant at non-vegetated areas in 2001 and ophelids in 2005 (Table 4).

Taxa richness of polychaetes at family level showed different patterns of temporal changes between sites and between vegetation types (Fig. 1). At K2, the results of two-way ANOVA showed

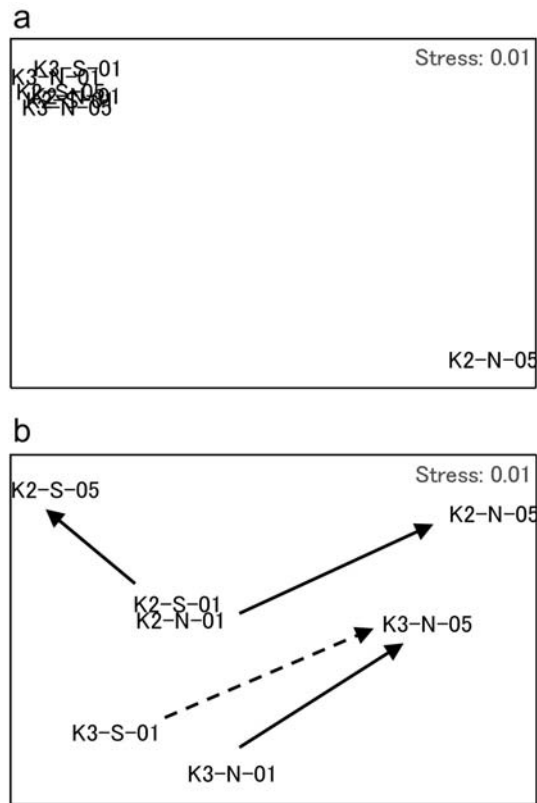


Fig. 2. MDS ordination of polychaete assemblage in seagrass-vegetated (S) and non-vegetated (N) areas at two sites (K2 and K3) in 2001 (01) and 2005 (05). MDS plots were made based on (a) presence/absence data, and (b) non-transformed abundance data.

significant year-by-vegetation type interactions (Table 2). Taxa richness decreased in the non-vegetated area, whereas it increased in the seagrass vegetation. Mean taxa richness was higher in the seagrass area than in the non-vegetated area for both years. At K3, taxa richness varied significantly among three groups of samples (Table 3). It was higher in the seagrass-vegetated and non-vegetated areas in 2001 than in the non-vegetated area in 2005, whereas no significant difference was detected between the former two groups of samples.

Variation in similarity was graphically represented using non-metric multi-dimensional scaling (MDS) ordination method (Fig. 2). MDS plot based on the presence/absence data revealed that polychaete assemblage in the non-vegetated area at K2 in 2005 was totally different, whereas other groups were similar to each other (Fig. 2a). MDS plot based on abundance data showed a different pattern of variation where direction of temporal changes in polychaetes assemblage was different between the seagrass-vegetated area at K2, and non-vegetated areas at K2 and K3 (Fig. 2b). At K2, polychaete assemblage structure was more similar between seagrass and non-vegetated areas in 2001 than in 2005.

Discussion

Patterns of temporal changes in macrobenthic abundance and polychaete assemblage structure varied between the two seagrass beds in Kuraburi. Comparative analysis on seagrass biomass and coverage before and after the tsunami at these sites revealed that the seagrass bed in K3 was more severely affected by the tsunami than K2 (Nakaoka *et al.*, 2007). Based on the seagrass changes, we expected the impact to infaunal communities to be greater at K3. Surprisingly, the non-vegetated areas at K2 had the largest decline in faunal abundance and taxa richness of polychaetes. This suggests that temporal changes in infauna were not necessarily related to the magnitude of the tsunami disturbance. Various factors can simultaneously affect temporal changes in infaunal abundance and community structure, such as physical disturbance caused by monsoon storms, and sedimentation due to river discharge during rainy seasons, and changes in food availability and predation pressures (e.g., Virnstein, 1977; Breitbart, 1996; Frost *et al.*, 1999; Nakaoka *et al.*, 2004). These causes have an influence on macrobenthic faunal community composition via modification of both the physical nature of habitats and biological interactions.

One of the notable findings in the present study is that the patterns of temporal changes in benthic abundance and polychaete diversity differed between vegetated and non-vegetated areas. Increase in density and taxa richness was observed in the seagrass area at K2, and a large decline in abundance in the non-vegetated areas at K2 and K3. It is likely that the presence of seagrass buffered the impacts of the physical disturbance to the infauna in K2 where the disturbance by the tsunami was considered moderate. It has been reported that the presence of seagrass canopy efficiently attenuates waves and reduces current velocity (Koch and Gust, 1999; Verduin and Backhaus, 2000; Madsen *et al.*, 2001; Komatsu *et al.*, 2004) and that complex networks of belowground rhizomes and roots can prevent sediment erosion (Fonseca and Fisher, 1986; Fonseca, 1989).

Abundance of infaunal animals and polychaete diversity were greater in the vegetated areas than the non-vegetated areas of K2, which supports the general hypothesis that seagrass presence enhances infaunal abundance and taxa richness (Orth, 1992; Boström and Bonsdorff, 1997; Hemminga and Duarte, 2000; Nakaoka, 2005). The result is consistent with that obtained in adjacent areas of our study site along the Andaman Sea Coast of Thailand. For example, Nakaoka (2001) found that taxa richness of infauna was eight-fold greater in seagrass vegetation than in surrounding non-vegetated areas in a seagrass bed in Trang, southwestern Thailand, and Nakaoka *et al.* (2002) reported that abundance and taxa richness of infauna was greater in intact seagrass vegetation compared to non-vegetated gaps caused by dugong foraging at the same seagrass bed. At K3, however, density and taxa richness was similar between the two vegetation types in 2001. Here, seagrass coverage rapidly expanded in the late 1990's due to sand dune development surrounding the seagrass bed (S. Nimsantijaroen, personal communication). It is plausible that succession of infaunal assemblages occur more slowly than that of seagrasses, which may have resulted in similar stages of succession being sampled in the infaunal communities inside and outside the seagrass vegetation at K3 in 2001. Ongoing monitoring of seagrass and associated animals at K3 will clarify how benthic communities respond to seagrass recovery after a massive disturbance.

Polychaetes assemblages collected in the study sites resemble those of other sites in southern Thailand (Angsupanich and Kuwabara, 1995; Prajongsak, 2000; Barrio Froján *et al.*, 2005). Multivariate analysis showed different patterns of similarity between the two data types (the abundance data and the presence/absence data). The greatest difference in similarity for non-vegetated areas at K2 in 2005 from other samples was due to very low number of taxa for this group of samples (only two families). Excluding this sample, similarity among samples based on the presence/absence data were smaller compared to that based on the abundance data. This suggests that changes in

similarity of polychaete assemblage were caused by changes in relative abundance of component species, but not by changes in species composition.

In conclusion, the present study reveals that patterns of temporal changes in abundance and diversity of infaunal assemblages are highly variable among sites, and that the degree of temporal changes in assemblage structure was not necessarily related to the magnitude of the tsunami disturbance. More importantly, our results suggest that the presence or absence of seagrass vegetation can alter the patterns of temporal changes in infaunal assemblages, which may highlight the importance of seagrass for coastal management, such as in retarding physical disturbance in environments, and in maintaining the stability of biodiversity. Continued monitoring of biodiversity is underway to reveal the subsequent recovery processes of seagrass-associate fauna in relation to those of seagrass vegetation.

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