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Original Research

Monitoring of Sandy Beach Meiofaunal Assemblages and Sediments after the 2004 Tsunami in Thailand

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Abstract

Three sandy beaches on Phuket and Kho Khao islands, Thailand, were monitored annually to study the short- and long-term impacts of the 2004 tsunami on their meiofauna assemblages and sediment characteristics. The sediment grain size compositions changed significantly within one year after the tsunami (improved sorting and less negatively skewed distributions), but meiofauna assemblages did not. The fast recolonization of the beaches after the tsunami confirmed that meiofauna is highly resilient to ecosystem disturbances. The tsunami was not observed to have a long-term impact on meiofaunal assemblages.

Keywords: tsunami, meiofauna, sandy beach, sediment grain size, Andaman Sea

Introduction

The frequent occurrence of disturbances is one of the main characteristics of coastal ecosystems. Effects of these will depend on the type and intensity of the disturbance, and will cause different responses depending on the level of community organization [1, 2]. There are three major groups of disturbances: natural physical disturbances, biological disturbances and those resulting from anthropogenic impact [3]. Wind and associated storms, currents and waves clearly represent some of the major physical forces affecting coastal ecosystems. They often result in sediment resuspension, which can result in changes in nutrients, light, and organic matter availability [2]. Consequences of much greater severity can potentially be caused by another natural physical force – tsunami waves. These are generated by the sudden vertical displacement of columns of water following earthquakes, volcanoes, landslides or specific meteorological phenomena [4]. These very long waves move rapidly across the ocean, and when they approach shallow coastal waters, wave height increases substantially, reaching as much as tens of meters. Tsunami waves are powerful enough to transport large boulders on land [5-7], as well as damage marine coastal ecosystems like coral reefs, beaches, mangroves and sea grass beds [8-11]. Tsunamis can both directly and indirectly impact various components of the environment and human life, with many short- and long-term consequences [9, 12].

One of the world's largest tsunami waves in recent decades was generated by an earthquake on December 26, 2004. The tsunami waves that struck the coasts around the Indian Ocean, affected Indonesia, Thailand, Sri Lanka and India. In Thailand, the maximum wave run up height reached as much as 19.6 m above sea level [13]. Over 900 km of coastline was affected, and long, open beaches were the coastal ecosystems that suffered the main impact of the tsunami [14]. The most common effect was extensive beach erosion. In many places the beach belt was almost completely eroded, and the removed material was deposited in

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flooded areas [9]. However, a few weeks after the tsunami, the natural recovery of beaches was observed [15], which raises questions about their ecological status.

For many years sandy beaches had been regarded as marine deserts by many biologists [16]. Nowadays, they are unquestionably considered to be highly diverse zones, teeming with microscopic and macroscopic life [17]. One of the most abundant beach inhabitants are small metazoans called meiofauna. The meiofaunal communities of sandy beaches are diverse in taxonomic composition and have complex three-dimensional patterns. In some cases, they may even exceed the macrofauna in biomass and make a significantly greater contribution to the processing of carbon by benthic communities than the larger macrofauna [17, 18]. Moreover, due to their small size, short life cycles, and lack of planktonic stages, meiofauna are useful in assessing environmental disturbances [19, 20]. Based on these attributes, meiofaunal communities were chosen for evaluating tsunami impact on the Thailand sandy beaches. Insight into community composition may help to assess environmental changes caused by tsunami waves and, hence, to evaluate meiofauna resilience and recovery after such a disturbance. According to our knowledge, no reports of the long-term effects of the December 26, 2004 tsunami on meiofauna communities exist. The short-term effects were described only by Altaff et al. [21] and Kotwicki and Szczuciński [15]. The general conclusions of these studies were that the recovery of the meiofauna is very quick; nevertheless, their response over longer periods remains unknown. The major objective of the present study was to present long-term data to assess the impact of the tsunami on the sandy beach meiofaunal assemblages and sediment characteristics, as one of the physical factors influencing meiofaunal distribution.

Study Area

The Andaman Sea coast of the Malay Peninsula presents various types, from steep rocky shorelines with pocket beaches, to few-kilometers-wide flat coastal plains with adjacent long sandy beaches or extensive tidal flats. The area has a tropical climate with two monsoonal winds: the northeast during mid October to March and the southwest during May to September. The southwest wind generates the highest waves along the coast. The tide is mixed semidiurnal with a relatively high tidal range between 1.1 and 3.6 m [22].

Three beaches with various degrees of exposure to the open sea, distance from river mouths, anthropogenic impact, and degree of erosion due to the tsunami waves (Table 1) were selected for the study. One beach was located on Kho Khao Island, and two beaches were on Phuket Island (Patong and Tri Trang beaches), the largest island of Thailand (Fig. 1a). The Kho Khao beach is on the northwestern coast of Kho Khao Island (Fig. 1b) and is characterized by the highest wave energy. Patong beach is situated in the vicinity of the city of Patong and is one of the most famous of Phuket's beaches, with the largest concentration

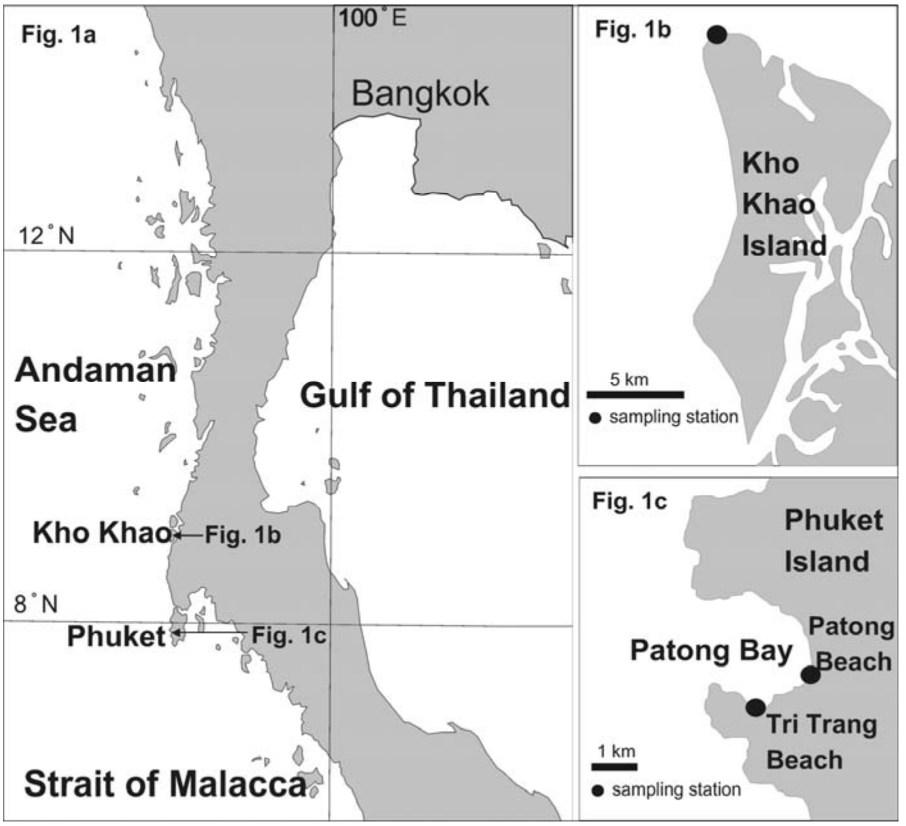

Fig. 1. Location of the study areas along the Andaman Sea coast (Fig. 1a), and of monitored beaches on Kho Khao Island (Fig. 1b) and Phuket Island (Fig. 1c).

Table 1. Basic data on sampling sites.

Location	Coordinate		Intertidal zone width (m)*	Tsunami run up (m)*	Exposure to open sea	Anthropogenic impact
	Latitude N	Longitude E				
Kho Khao beach	9° 00'	98° 15'	10	4.7-6.5	high	small
Patong beach	7° 53'	98° 17'	19	3	moderate	high
Tri Trang beach	7° 53'	98° 16'	15	4.5-5	small	moderate

* - presents data after Kotwicki and Szczuciński [15], so the width of intertidal zone is as it was in February 2005. The tsunami run up is the difference between the elevation of the maximum tsunami penetration and the elevation of the shoreline at the time of the tsunami attack height.

Table 2. Total mean abundance (individuals per 10 cm^2) of meiofaunal major taxa at the investigated beaches.

Taxon	**KHO KHAO**				**PATONG**				**TRI TRANG**			
	2005*	**2006**	**2007**	**2008**	**2005***	**2006**	**2007**	**2008**	**2005***	**2006**	**2007**	**2008**
Nematoda	106	29.3	430	470.3	163.7	312	704.3	112.7	2705	154.3	73	57.7
Harpacticoida	2.7	4.7	18.3	37.3	57.3	6.3	57.7	10.7	402	58	138	120.3
Gastrotricha	1	0.3	0.3	57.3	-	1	8.7	19	-	3.3	3	-
Turbellaria	54.3	0.7	4	27.3	222	98.7	11	38.7	90.3	9	-	4.3
Polychaeta	3	-	2.7	1.7	1.7	1.3	-	-	72	3	14.3	7.7
Acari	-	-	0.3	1	-	-	-	-	-	1	1	23
Oligochaeta	-	-	0.3	-	-	37.3	0.3	-	8.3	2	36.3	-
Ostracoda	0.3	-	1	3.3	0.7	-	0.3	-	6.3	-	2	13
Chironomidae	-	-	-	-	-	-	0.7	-	-	-	-	-
Tardigrada	0.3	-	-	17.3	-	-	-	-	2.3	2.3	6.3	63
Larwa insecta	-	-	1.3	-	-	-	0.3	-	-	1	0.7	-
Bivalvia	0.3	-	-	-	-	-	-	-	-	-	-	-
Isopoda	-	-	-	0.3	-	-	-	-	-	-	-	0.3
Nauplii copepoda	-	1	38.7	78	8.7	1.3	6.7	18.3	11.7	115	64.3	33
Nauplii cirripedia	-	-	-	-	-	-	-	-	-	-	-	14
total	**168**	**36**	**497**	**694**	**454**	**458**	**790**	**199.3**	**3298**	**349**	**339**	**336.3**

*data published in Kotwicki and Szczuciński [15]; - taxon absent in the studied year.

of tourists. A small river mouth is located at its southern end. The Tri Trang beach is a small pocket beach, located ~ 3 km southwest of the Patong site. It is situated on a small peninsula on the southern part of Patong Bay (Fig. 1c). All of the locations were significantly altered by the tsunami waves, even though they represent different degrees of exposure to the sea. The highest tsunami waves (more than 7 m) and an almost completely eroded beach zone were observed at Kho Khao Island [9]. In the following years, the width of its intertidal zone increased significantly. Tri Trang beach was partly protected from the tsunami waves thanks to a shallow zone 1km in width that is exposed during the lowest tides. However, because the beach is located on the northern shore of a low-lying peninsula, it was completely flooded by waves coming from both the south and north [23]. Less severe consequences of the tsunami waves were observed at Patong beach, which was only partly eroded; shortly after the tsunami it was artificially nourished with local sand [15].

Materials and Methods

The three studied beaches were first sampled in February 2005 approximately 50 days after the December 26, 2004 tsunami event (data published in Kotwicki and

Szczuciński [15]). To monitor the potential tsunami long-term effects of the tsunami all the locations were sampled annually during the same season in February of 2006, 2007 and 2008. Each beach was sampled during low tide at three tide level positions: low (LW), mean (MW), and high water (HW).

Samples for meiofauna analysis were taken using a meiocore sampler with an inner diameter of 3.6 cm and a sampling surface ~10 cm^2. The upper 5 cm of sediment was taken for analysis. Samples for faunal composition were fixed in formalin and stained with Bengal Rose. In the laboratory, a standard decantation technique was used to extract the animals from the sediment [24]. Meiofauna that passed through a 500 µm sieve and were retained on a 32 µm sieve were counted and identified to a major higher taxonomical level under a stereo microscope.

To determine the grain-size distribution, sediment samples were taken from the upper 5 cm around the meiocore sampler, dried, and sieved through thirteen 0.5 phi intervals. The conversion of micrometers into phi values is based on:

$$\text{phi } (\Phi) = -\log_2 D$$

...where D equals the size in millimeters. The grain-size statistics were calculated using the logarithmic method of moments with Gradistat software [25]. The sediments were classified according to Folk and Ward [26].

To compare meiofaunal assemblages and sediment parameters between different sampling years, beaches, and sea level positions, the PRIMER software package was used. The data were double root transformed, which reduced the influence of the most numerous taxa and gave a more balanced view of the community structure. The similarities between samples were calculated using the Bray-Curtis index (for faunal samples) and Euclidean distance (for environmental data), and viewed with the ordination of non-metric multi-dimensional scaling (nMDS). One-way analysis of similarities ANOSIM [27], was used to test a priori differences in meiobenthic composition and sediment characteristics between the investigated years and locations. ANOSIM uses the test statistic R, which estimates the difference between average rank similarities among pairs of replicates within groups and between groups. Thus, it can range from -1 to 1, where R equal 0 indicates great similarity, while the largest differences exist closer to R=1 [28].

Results

Meiofauna Analysis

Thirteen major meiofaunal taxa and two larval stages were recorded during the four years of monitoring (Table 2). From five to ten taxa were recorded per investigated beach. Only two groups, Nematoda and Harpacticoida, were present throughout the whole investigated period at the studied beaches. Turbellaria and Copepoda naupli were also very common taxa, as they were present in 91% of the analyzed samples. Most of temporary meiofauna (e.g. Chironomidae, Isopoda, Nauplii cirripedia) appeared only occasionally and in very low quantities. The maximum total meiofauna abundance was noted at Tri Trang beach in 2005 (3298 indiv./10 cm^2), while the lowest values were recorded at Kho Khao beach in 2006 (36 indiv./10 cm^2).

Kho Khao beach was dominated by nematodes, which together with the second most abundant taxa, comprised more than 90% of the total meiofauna. Shortly after the tsunami, turbellarians followed nematodes in regard to abundance. One year later, harpacticoids were very common, while in 2007 and 2008 Copepoda nauplii was the second most abundant group. The lowest meiofauna density and the lowest number of recorded taxa (5) were observed in 2006. The spatial meiofauna density distribution pattern at this beach was characterized by the lowest densities at high water level throughout investigated period, whereas the mean water level corresponded to the highest densities. No Copepoda nauplii representatives were observed at high water positions.

At Patong beach, the meiofaunal assemblages consisted mainly of Nematoda and Turbellaria (Table 2). The first dominated in all the years, with abundances exceeding 55%, except in 2005, when turbellarians were the most abundant. The highest meiofaunal density was recorded in 2007 (790 indiv./10cm^2), when the highest number of taxa (9) was also observed. Meiofaunal distribution at different sea level positions revealed the lowest abundance at the high water mark. In 2006 and 2008 almost no meiofauna were found at these stations (3 indiv./10cm^2 in both cases). The highest densities of 707 and 1061 indiv./10cm^2 were recorded at MW in 2005 and 2007, respectively. The same was true for LW with densities of 850 and 585 indiv./10cm^2 in 2006 and 2008, respectively.

The dominant meiofaunal taxons at Tri Trang beach varied during the study period. Two first years were characterized by the domination of Nematoda, which was followed by Harpacticoida in 2005 and Copepoda nauplii in 2006. In 2007 and 2008 Harpacticoida was the most common taxa, while the second dominant groups were Nematoda and Tardigrada, respectively. Moreover, the year 2008 was the only when Cirripedia nauplii was observed. In comparison with the other investigated beaches, a low number of Turbellaria was recorded at Tri Trang. After extraordinarily high meiofauna density in 2005, a ten fold decrease was observed in the following years with abundances ranging from 336 to 349 indiv./10cm^2. These years were also characterized by the same number of taxa (10) recorded at Tri Trang beach. Meiofauna density across the intertidal zone varied irreguraly. The lowest densities were recorded at all water levels (e.g. at MW in 2005, at LW in 2006, at HW in 2007), while the highest were noted twice at the mean water mark (2006 and 2007) and twice at the low water position.

Grain Size Analysis

The sediments of the studied beaches were composed mostly of quartz grains. Only sand from Tri Trang beach was enriched with carbonate components, mostly crushed

Table 3. Sediment type and grain size statistics of the analyzed samples; sediment types: F- fine sand, M- medium sand, C- coarse sand, V.C- very coarse sand; the position of sampling points HW – high water, MW – mean water, and LW – low water.

Beach		Sediment type				Mean				Sorting				Skewness			
		2005	2006	2007	2008	2005	2006	2007	2008	2005	2006	2007	2008	2005	2006	2007	2008
KHO KHAO	HW	C	F	F	F	-0.16	2.42	2.52	2.40	1.81	0.38	0.37	0.38	-0.62	-0.82	-0.22	0.09
	MW	C	F	M	M	0.62	2.5	1.43	1.93	1.29	0.36	1.12	0.88	-0.83	0.02	-0.37	-0.38
	LW	V.C	F	C	V.C	-0.66	2.46	0.54	-0.06	2.01	0.43	1.00	0.62	-0.21	-0.62	1.63	0.13
PATONG	HW	F	F	F	F	2.39	2.18	2.29	2.59	0.72	0.77	0.79	0.50	-2.95	0.14	-1.17	-0.20
	MW	M	F	M	F	1.38	2.35	1.66	2.65	1.53	0.69	1.25	0.57	-0.95	-0.54	-0.23	-0.23
	LW	M	F	F	M	1.58	2.28	2.14	1.65	1.41	0.83	1.30	1.42	-0.83	-0.35	0.52	-0.42
TRI TRANG	HW	M	M	M	M	1.28	1.37	1.17	1.51	1.44	0.55	0.46	0.47	-2.58	-0.29	0.49	-0.10
	MW	M	M	C	C	1.39	1.26	0.82	0.72	1.00	0.59	0.46	0.93	-3.21	-0.61	0.73	-0.41
	LW	M	C	V.C	C	1.54	0.7	-0.13	0.08	0.89	0.61	0.33	0.59	-3.03	0.24	-0.47	0.98

shell fragments. The analyzed samples ranged between fine and very coarse sand (Table 3). The finest sediments were at Patong beach and the coarsest at Kho Khao beach. The sediment sorting varied widely from very poorly sorted to very well sorted. The beach sediments collected in 2005, shortly after the tsunami, were generally poorly sorted and after one year their sorting had improved significantly (Fig. 2). In 2005 almost all the beach sediments were very coarsely skewed, whereas during the following years their grain size distributions were mostly symmetrical or even finely skewed (Fig. 2). With respect to sediment sampling position, a regular tendency was observed with the coarsest sediment at LW and with the finest at HW.

In February 2005, the Kho Khao beach was composed of poorly and very poorly sorted coarse and very coarse sand. The grain size distribution was coarse skewed except in the LW sample, which was symmetrical. After one year, the beach had changed significantly and was composed of well-sorted fine sand. In 2007 and 2008, while the beach became wider, a trend in sediment properties developed. At HW the beach was composed of symmetrical, well-sorted fine sand; at MW it was symmetrical and poorly- to moderately-sorted medium sand; and at LW it was moderately-sorted coarse and very coarse sand, the distribution of which was very finely skewed (2007) or symmetrical (2008).

The sediments at Patong beach revealed smaller variations than those on Kho Khao Island. Shortly after the tsunami they were composed of poorly sorted and coarse skewed medium sand, except at the high water level, where moderately sorted and very coarse skewed fine sand was found. They changed in the following year and varied a little later on. All the samples from 2006-08 belonged to fine sand, with the exception of two medium sand samples from MW in 2007 and LW in 2008. The sediment was poorly sorted to moderately- well sorted, with the first usually at LW. Their grain size distributions were mostly symmetrical, with the exception of single samples being fine or coarsely skewed.

After the tsunami, in 2005 Tri Trang beach was composed of poorly to moderately- sorted and very coarse skewed medium sand. During the following years, MW and LW sediments become coarser, while HW was still composed of fine sand. Generally, the sorting of the sediments improved and was between moderately well sorted and very well sorted. The grain size distributions were also more positively skewed than in 2005.

Comparison of Meiofaunal Assemblages and Sediment Characteristics

Despite the fact that some differences in taxonomical composition and meiofauna densities were noted in subsequent years among the investigated beaches the ANOSIM test (Table 4) indicated barely separated groups (global R< 0.25 in all cases). Multivariate analysis (nMDS) revealed that meiofaunal assemblages do not differ significantly (Fig. 3a). The same analysis of sediment properties proved

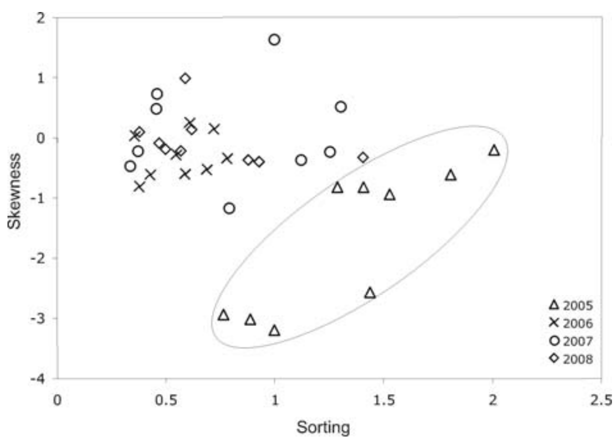

Fig. 2. Sediment sorting and skewness (Φ scale) of beach samples collected in the following years.

that samples collected in 2005, about 50 days after the tsunami event, were different from those collected in the following years (Table 4). On the nMDS plot samples from 2005 form a separate group (Fig. 3b). The remaining samples are classified at the opposite site of the plot, forming one combined group. Similarly to the comparison of the meiofauna assemblages, no significant differences were noted in sediment characteristics among investigated beaches and sea level positions (Table 4).

Discussion

Short-Term Impact of the Tsunami

The December 26, 2004 tsunami waves affected a wide array of coastal communities, ranging from meiofauna to large aquatic birds and mammals [14, 21]. The waves were recorded around the world and negatively impacted animal populations even 6,500 km from the epicenter of the tsunami-generating earthquake [29]. It is likely that the impact on the communities closer to the epicentre was even larger.

Many studies show that meiofauna are strongly resilient and their recovery potential after short-term disturbances is high. In most cases, meiofauna recovers in a few weeks, in days or even hours [30-32 and references there]. A very quick response and recolonization was confirmed by a study conducted on the Indian coast after flooding by a 6 m high tsunami wave [21]. Soon after the tsunami density of meiofauna was significantly different compared to densities observed before, nevertheless only one week was needed to achieve typical abundance values. Observations made by Kotwicki and Szczucinski [15], which indicated that beaches had fully functional meiofaunal communities in terms of taxon presence and density 50 days after the tsunami, correspond well with the conclusions drawn from the Indian beach study. The present study also confirms this statement. According to meiofaunal assemblages, 2005 was not significantly different from the following years (ANOSIM test, p>0.05). It seems that the tsunami had a minor impact on meiofaunal abundance. The total mean densities recorded in the present study (36-3298 indiv./10 cm^2) are of the same order of magnitude as the meiofauna densities reported in the literature regarding other tropical locations; however, they are not in the highest range [33, 34]. Just after the tsunami, the density at Tri Trang beach was much higher than in subsequent years, which might be explained by e.g. additional food supply. Lee et al. [32] who studied meiofaunal recolonization after iceberg scouring on a shallow Antarctic coast, observed a peak in meiofaunal occurrence 30 days after the impact. There was, however, an abrupt decrease in abundance in the following month. Later on, meiofaunal density remained at an average level.

What causes such quick meiofaunal recolonization? Since planktonic larvae are absent from the meiofauna, the active and passive transport of juveniles and adults might be crucially important to their population performance [35]. Nematodes, the major component of meiofauna assemblages in almost all marine habitats, including those of the present study, are probably moved by passive transport in the bedload and water column [36]. Moreover, they are not restricted to the sediment surface layer like many other taxa, and many species have relatively deep vertical

Table 4. Results of ANOSIM test comparing similarities of samples within groups and between groups.

	Meiofauna		Granulometric statistics	
	R	p	R	p
Global test BEACH	0.145	0.002	0.136	0.003
Global test SEA LEVEL	0.124	0.009	0.023	0.224
Global test YEAR	0.082	0.051	0.312	0.001
Pairwise contrasts				
05, 06			**0.483**	**0.001**
05, 07			**0.37**	**0.001**
05, 08			**0.388**	**0.002**
06, 07			0.08	0.114
06, 08			-0.037	0.678
07, 08			-0.068	0.832

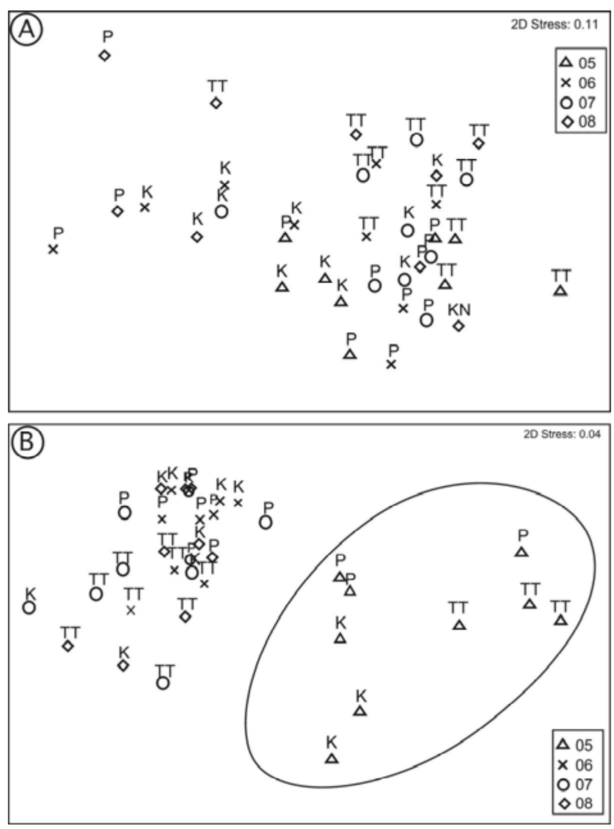

Fig. 3. nMDS plots of Bray-Curtis similarities (A) and Euclidaean distance (B) of double root transformed: A- densities of major meiofaunal taxa and B- grain size statistics in samples (P- Patong beach, TT- Tri Trang beach, K- Kho Khao beach).

distributions within the sediment [37]. The second dominating group, harpacticoids, tend to reside near the sediment surface and many species are good swimmers [38]. They can move passively with eroded sediments when currents are rapid. Thus, it is likely that many organisms were transported on waves and with sediments carried by the tsunami from the deeper part of the Andaman Sea, or took shelter in deeper sediments to avoid the unfavorable conditions.

Rapid post-tsunami recovery in the case of beach macrofauna has also been documented by Kendall et al. [39]. Four months after the main tsunami hit, the common faunal species had returned and the main zonation patterns had been re-established.

Long-Term Impact of the Tsunami

In order to estimate the recovery of meiofaunal communities after the tsunami event and determine the impact in the long-term environmental context, it would be valuable to have data of natural temporal variations in periods without major disturbances. Unfortunately, information regarding the faunal composition and density on sandy beaches on the western coast of Thailand is very limited, especially in the case of meiofauna investigations. Other studies have generally indicated that meiofaunal densities are largely determined by the quantities of food available (e.g. organic content, bacterial density, diatoms), in both the sediments and in water column [32, 40-42]. Nevertheless, food resources are not the only limiting factor for meiofauna taxa [41] and several varied factors can occur that influence meiofauna communities, e.g. predation [43] or hydrodynamics [44]. The latter was proposed as a mechanism determining the assemblage structure at unstable, tidal beaches; however, this assumption has never been tested in experimental studies. Thus, the annual pattern of meiofaunal assemblages can differ greatly from year to year. Interannual changes in meiofauna abundance and taxonomical composition can be observed at the studied beaches; however, differences are not statistically significant (Table 4). The same holds true for spatial variations. Although beaches present slightly different environmental conditions (Table 1), their meiofaunal communities differ only within a small range. This raises the question of sediment properties, which are considered to be one of most important factors for the abundance and composition of meiofaunal organisms.

Comparison of pre- and post-tsunami beach sediments in the Thailand area revealed there was an increase in the coarse fractions, often with increased shell debris and distinct layering [39]. The beach sediments in 2005, shortly after the tsunami, were generally poorly sorted and very coarse skewed (Table 3, Fig. 2). Both parameters indicate that sediment transport and deposition occurred under high energy conditions. The tsunami wave eroded beaches significantly when it approached the coast [9, 45]. However, later the beach zone was passed over by several uprush and backwash wave phases. The high water velocity meant that the finer sediment fraction was absent and the sediments were very coarsely skewed. The water flowing from the sea and from the land over the beach zone resulted in the deposition of sediments from various environments. This, along with changing water flow velocities, meant that the deposits were poorly sorted. In this situation, one might also expect the grain size to be the largest. However, it should be remembered that a tsunami transports and deposits sediments that are available in a certain setting. So, for example, if there was no coarse grain sand on the adjacent shelf, nearshore, or on land, it could not have been deposited on the beach. The Andaman Sea coast is open to large waves from the SW during the summer monsoon. These waves were probably responsible for the successive development of beach sediments on the coast and, as soon as one year later, the sediments were much better sorted and their grain size distribution was much closer to symmetrical. Interannual changes in post-tsunami period (2006-08) were much smaller than the change during the first year. However, as shown above, changes in sediment grain size are not followed by variations in meiofauna abundance and taxa, and were not the major limiting factor.

Conclusions

The 2004 tsunami had a significant impact on beach sediments, which probably will last until the following SW monsoon period with higher waves. Although sediment grain size is believed to influence the meiofauna community, in the present study variations in meiofauna seem to be independent. The rapid beach recolonization following the tsunami confirmed the thesis that meiofauna are highly resilient. The tsunami had no notable long-term tsunami impact on the meiofaunal assemblages. Rather some variations in the density and taxonomical composition resulted from natural seasonal and spatial fluctuations. However, meiofaunal diversity and biomass might not be impacted by physical disturbances, but some effects still might be seen in community structure [31]. The authors are convinced that the detailed taxonomic analysis focusing on dominant meiofaunal groups like nematodes and harpacticoids are highly recommended for future studies.

Acknowledgments

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