Original Research

Post-Tsunami Recovery of Shallow Water Biota and Habitats on Thailand's Andaman Coast

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Received: 2 October, 2008
Accepted: 20 November, 2008

Abstract

There have been very few quantitative studies of the intertidal and shallow water biota of the Andaman Coast of Thailand and thus it was very difficult to provide precise estimates of the impact of the tsunami on coastal resources. Some quantitative data from Laem Son National Park existed, having been collected by the present authors, and these indicated that the most severe impacts were on the intertidal sand beach fauna, on rocky shore assemblages and on the seaward edge of mangrove forests. Inside the forests there was heavy deposition of coarse sediment on the forest floor and this led to changes in the species composition of the infauna. Most, but not all, sea grass beds escaped serious damage.

By 2008 intertidal sediment assemblages contained a similar number of individuals to that recorded before the tsunami. Pre-tsunami data indicate that open coast, estuarine and seagrasses assemblages are naturally highly variable and thus were well adapted to recovering from the tsunami disturbance. Offshore sediments lack pre-tsunami information, but they too appear to be normal. Size frequency analysis of a population of the heart urchin *Brissopsis luzonicus* indicate that some individuals survived the tsunami but that there is heavy domination by the first post-tsunami cohort suggesting heavy colonization of disturbed seafloor. The trees in the seaward fringe of the most exposed mangrove forests still have to recover from tsunami damage, although the benthic fauna within the forest has returned.

Keywords: Thailand, Andaman, tsunami, benthons, recovery

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Introduction

The devastation caused by the tsunami to the coastal villages of the Thai provinces of Ranong, Phuket and Phang Nga was well recorded by broadcast media and newspapers worldwide. Although tourism is important to the south of the area, most of the coastline that was impacted has an economy based on fishing, and hence is dependent on the sustained health of the coastal ecosystem. Thus, following the tsunami there was a concerted effort to carry out a rapid assessment of the damage caused [11]. While such an assessment delivers information on status, without the context of long-term information on natural variability it is difficult to use them to assess the significance of any apparent environmental degradation. With the clear exception of corals [3], long-term pre-tsunami data on the species composition or the abundance of biota in the various coastal habitats were largely lacking and so it was difficult to assess the scale of damage [8]. Subsequently, the same lack of knowledge has impeded the assessment of the process of recovery. Nevertheless, the authors of the present paper have undertaken a series of capacity-building projects (acknowledgements) since 1996 in the area of Laem Son National Park. These projects were primarily aimed at building a capacity to understand and measure changes in the sediment and other intertidal biological assemblages. This paper is able to compare pre-tsunami data with information from the same locations which have re-sampled since the passage of the wave. This comparison permits an assessment of the changes that occurred and their longer-term significance.

Although there are no pre-tsunami data on the soft sediment biota that predominate in the coastal waters of Laem Son National Park, the present authors have also undertaken a post-tsunami offshore survey (beginning in 2007) to assess the current status of the offshore biota three years after the tsunami. While impacts on intertidal habitats were often very clear [9] immediately following the tsunami, it was difficult to assess offshore damage due to a shortage of baseline information. It is certain that some offshore systems were disturbed, as there was clear evidence of offshore molluscs and echinoderms being cast ashore in large numbers (Aryuthaka unpublished). Satellite images also showed that inshore waters in the period after the tsunami were highly turbid (P. Miller, pers. com.). Changes in sediment particle distribution resulting from disturbance or by the resuspension of sediments from the seafloor or the deposition of material from land run-off have the capacity to strongly influence the composition of the seafloor biota and its productivity [5].

It was also difficult to estimate the depth to which the wave may have had an impact on the offshore biota, and hence the fisheries, as there are few measured data on its height or wavelength in the inshore waters of Laem Son. When in deep water, tsunami waves have a long wavelength and low wave height but as water depth shallows, non breaking waves increase in height and hence the depth to which they cause disturbance also increases. It is known that the wave that passed through the village of Kampuan was around 6m in height (Nimsantijaroen pers.com.).

Study Site

The main focus of the studies reported here has been Laem Son National Park, which lies on the Andaman Coast of Thailand and straddles the border between Ranong Province in the north and Phang Nga Province in the south (Fig. 1). Although the park includes the mouth of the Kapoe Estuary, it excludes most of that estuarine system. Laem Son National Park includes more than 50km of mainland coastline, as well as a number of offshore islands with its offshore boundary lying at between 25 and 20 metres in depth.

While sandy beaches cover most of the open coast, a considerable area of the park is mangrove forest. Seagrass beds dominated by *Halophylla* spp. lie close to the mouth of the Kapoe Estuary, while less extensive subtidal beds dominated by *Thalassia* have been reported on the inland face of Ko Kam Yai. Just to the south of the National Park, a seagrass bed at Laem Mae Heng (9.2203ºN, 98.3466ºE) has been sampled regularly by the authors. There are a small number of rocky seashores, as well as patches of low diversity coral on some of the offshore islands.

The National Park has no significant industry, but the coastal fringe is heavily used by aquaculture for the pond culture of prawns, the cage culture of fish and the raft culture of Green-Lipped Mussels.

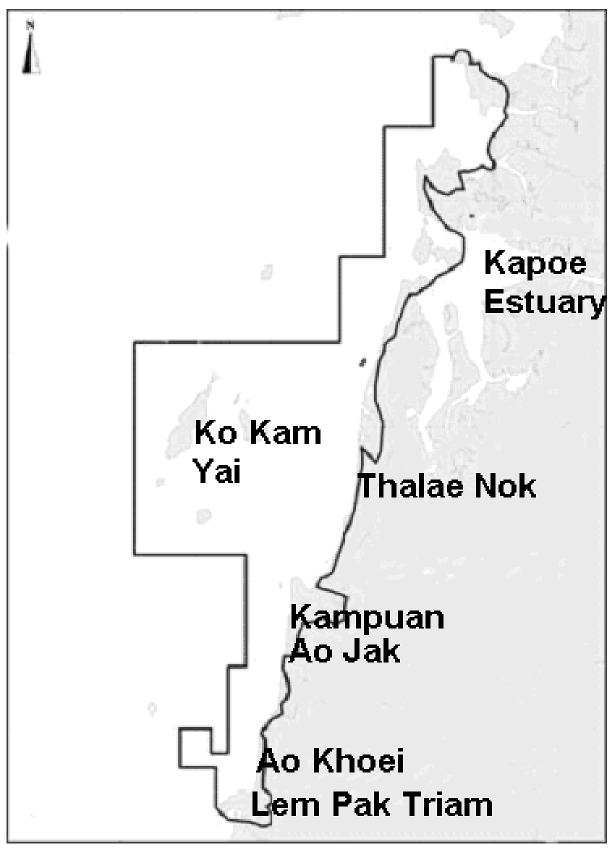

Fig. 1. Map of the study area centred on 9.4780°N, 98.4107°E. The solid line denotes the boundary of Laem Son National Park.

Material and Methods

The samples discussed in this paper were collected as part of two separate sampling programmes (2001-04 and 2006-08) although supplementary evidence from earlier sampling is also considered. In addition, the authors made a single visit to the study area in April 2005 to carry out an initial assessment of the damage to natural marine resources [9]. The comparison of cores taken in 2000-01 with cores collected in 2006-07 cannot indicate the immediate impact of the tsunami, but they can indicate normal variability and the speed of recovery.

In the course of the two sampling programmes, two sets of intertidal sediment samples were collected annually, pre- and post-monsoon, although it was not possible to sample from all sites on each occasion. Four sediment sampling sites (Fig. 1), for which there are fully comparable pre- and post tsunami data, are discussed in this paper. At each site visit five sediment cores of 19.7cm diameter ($304cm^2$) were collected at mid-tide and a further five cores at low-tide. As routine, four cores were analyzed, although a fifth was worked up when there was high inter-sample variance. A supplementary sample was collected for analysis of sediment granulometry. Sediment samples were preserved in 8% formalin and then washed before being sieved over a 0.5mm mesh. A high proportion of species in the study area are undescribed [2], and hence to date animals have only been identified beyond the level of family at a limited number of sites. For the purposes of this paper, changes in biota will be discussed only in terms of the total number of macrofaunal individuals.

In 2001 a sediment map of the area of Laem Son National Park closest to the Kampuan Estuary was constructed on the basis of samples collected along a 1km grid from a long-tail boat using a hand-held Eckman grab. Granulometry was assessed by wet sieving of the contents of a single grab over a stack of sieves at one phi intervals and weighing the residue on each. In November 2007 a seafloor survey of offshore habitats in Laem Son National Park was undertaken using a combination of acoustic ground discrimination, drop-down video and grab sampling from the vessel Ocean One Ranong. During this survey, seafloor samples were collected for both granulometry and for the quantitative analysis of the benthic biota from 103 stations; all direct sampling used a hand-hauled van Veen grab ($0.02m^2$). As before, granulometry was undertaken by wet sieving of the contents of a single grab over a stack of sieves at one phi intervals. Subsequently maps of the distribution of sediment in 2001 and 2007 were constructed in a GIS and areas of greatest change identified by subtraction of one layer from the other.

The offshore macrobenthic biota was characterized on the basis of four combined samples, which were subsequently sieved over a 0.5mm mesh as described above. At each station a single dredge sample was deployed to collect larger bodied species; the majority of this material awaits identification at the time of writing. At a number of stations the heart urchin *Brissopsis luzonicus* and the brittle star *Macrophiothrix* were particularly abundant; these species have been measured to the nearest millimetre and size-frequency histograms constructed.

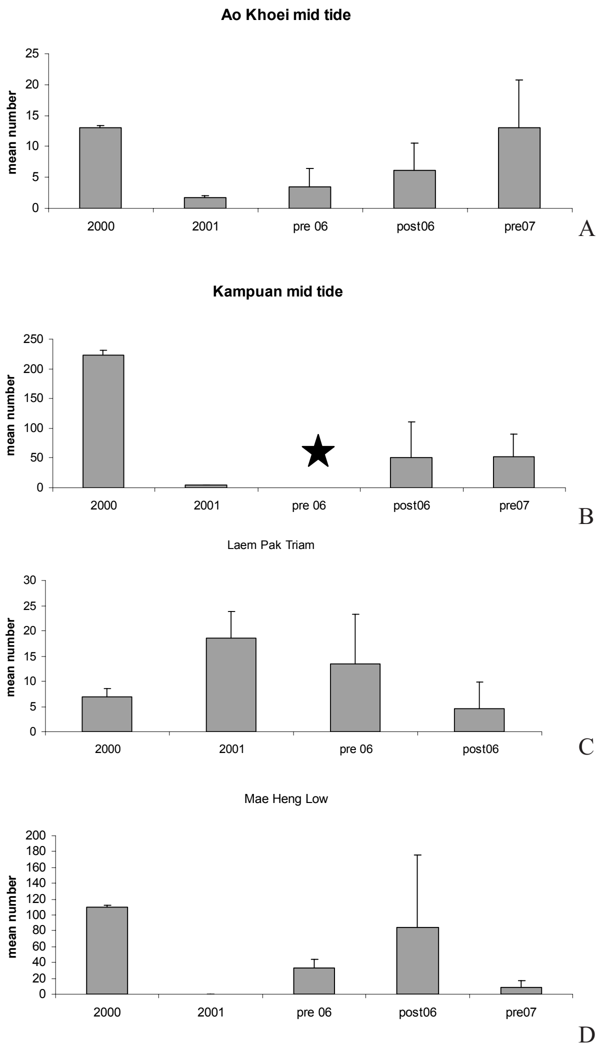

Fig. 2. Changes in the mean (± 95%CI) abundance of all macrofaunal organisms in the periods 2000-01 and 2006-07. Note that the scale on the y-axis differs from site to site and that no data are available for the Kampuan site pre-monsoon 2006 (star).

Results

Intertidal Sediment

The impact of the tsunami on exposed sandy beach differed from site to site, although at most locations there were substantial changes in beach profile. In some locations there was substantial accumulation of sand at and above high water. The inclusion of large numbers of fresh mollusc shells and echinoderm tests indicated that the sand was most likely to have come from the shallow subtidal. Elsewhere, sandy beaches were stripped back to bare rock and sand from the upper shore that was eroded away. As a consequence, there was significant erosion of the coastal fringe and undermining of trees [9].

The impact of the tsunami and the extent of recovery from it can best be illustrated by the comparison of changes in the abundance of macrofauna at four sites between 2000 and 2007. Two of these sites, Ao Khoei and Kampuan, were heavily impacted by the wave, while at Laem Mae Heng and Lem Pak Triam the impact was less intense.

At the exposed sandy beach of Ao Khoei (Fig. 2A), observations in April 2005 indicated that much of the superficial sediment had been lost as a result of the tsunami. Samples taken in 2006-07 showed increasing numbers of animals in successive samplings that could be interpreted as recovery. However, if these post-tsunami findings are placed in the context of cores collected in 2000 (mean 13±0.4 (95%CI)) and 2001 (mean 1.8±0.2) it is evident that the near loss of sediment macrofauna from this shore can take place under circumstances other than a tsunami. In the lower estuarine muddy sand of Kampuan (Fig 2B), post-tsunami numbers of macrofauna (2006 and 2007) were well below those found in 2000 (223±8), but once again extremely low numbers of individuals were taken in 2001 (4±0.04). In this case, records indicate that the sediment of the study site changed after the 2000 sampling from soft mud to muddy sand. Once again, the loss of biota caused by the tsunami was within a previously recorded range. Lem Pak Triam (Fig 2C) is a mid-tide level estuarine site within 10m of a stand of *Rhizophora apiculata* mangroves. By the time the wave reached this site much of its energy had been attenuated. Examination of this figure shows that there was little difference between the abundance of macrofauna in 2001 and that following the tsunami. The seagrass bed at Laem Mae Heng (Fig 2D) was also sheltered from the full force of the tsunami. The abundance of macrofauna at this site shows considerable variability in the years 2000 to 2007. Although numbers in late 2006 do not differ from those in 2000, it should be noted that in 2001 no animals were present in the four cores collected. In this case we know that a period of high onshore winds shifted sand to a depth of some centimetres across the seagrass bed, smothering the biota.

Seagrass

With the exception of Laem Mae Heng (see above), only anecdotal information is available concerning the impact of the tsunami on seagrass assemblages in the study area (UNEP, 2006). This indicates that damage was most severe at the most exposed sites [9], such as Tung Nan Dam, which lies offshore of Laem Mae Heng. Seagrass beds in the Kapoe Estuary and the Kuraburi Estuary (immediately to the south of the study area) were visited and sampled quantitatively by the present authors in 2006, when there was no evidence of significant damage or change of spatial extent.

Mangrove

The most evident impact of the tsunami on the mangrove forest was the destruction of established trees close to the edge of the sea. The severity of the impact related to the degree of exposure to the open sea. In the worst-damaged areas the seaward 30-50 metres of trees were destroyed. By 2008 new mangrove seedlings, as well as those of opportunistic plants such as Acanthus, were appearing among the dead trees. The colonizing mangroves have a greater diversity than the original stands of *Rhizophora* and include seedlings of other species, particularly *Sonneratia, Avicennia, Bruguiera* spp. and *Xylocarpus*. Less evident than the damage to trees was heavy sedimentation of sand on the generally muddy forest floor. This new sediment was sufficiently deep to smother the existing fauna. In April 2006 other species previously unrecorded in the forest were sampled, most notably large numbers of a large and as yet unidentified echiuran worm. These worms were not subsequently recorded and qualitative sampling indicates that the infaunal biota recovered to its original composition by 2006-07.

Rocky Shore

In April 2005 it was noted [9] that the major space-occupying species on the upper- and mid-rocky seashores had been impacted by the tsunami; barnacles (predominantly *Chthamalus malayensis*) had been smothered by deposits of silt and had suffered from scour as boulders were moved around; mats of the mussel *Brachidontes* had been stripped way. The barnacles recovered quickly and in 2008 a strong multi-age class population structure was evident. In contrast, mussels have failed to recover their predominance in the mid-shore. Each year since 2006, small

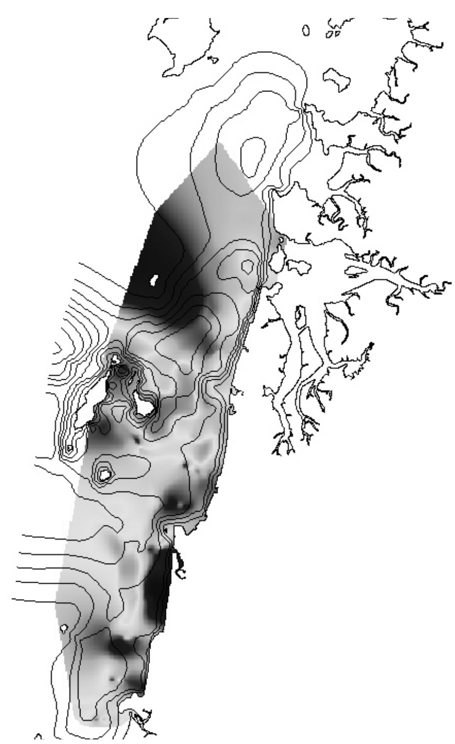

Fig. 3. Changes in the content of silt in offshore sediment between 2001 and 2007. The darker the colour the more change.

mussels have settled within the intertidal barnacle matrix, but so far have failed to establish space-occupying mats. Occasional specimens of *Perna viridis* (Green-Lipped Mussel) have also been observed.

Offshore

While there are differences in the distribution of sediment between the 2001 and 2007 surveys (Fig. 3), it cannot be concluded with any certainty that they are due to tsunami-induced seabed disturbance. The principal differences between the two surveys are as follows:

1. A tongue of soft sediment that was previously mapped to the north of Ko Kam Yai has moved southeast and inshore. Its position is centred on deeper water, but it moves in to the coast close to Thalae Nok.
2. The replacement of the northerly soft sediment by coarser material and the further addition of coarse material immediately to the north.
3. A coarsening of the muddy sand which lay close inshore between the Kampuan Estuary and Ao Jak.

Benthic Fauna

There are no pre-tsunami records of the soft sediment benthic fauna of the inshore waters in Laem Son National Park. The survey of November 2007 indicated that the abundance of the benthic was within the limits that might be expected in undisturbed shallow tropical water. The soft mud inshore of Ko Kam Yai was characterized by abundant heart urchins (*Brissopsis luzonicus*) with as many as four individuals being taken in a single $0.02m^2$ grab. Off the outflow of the Kapoe Estuary, there were dense mats of large brittle stars of the genus *Macrophiothrix*. While the brittle stars were all of similar size (c.20mm disk diameter), it was evident that the heart urchins belonged to multiple year classes. A length frequency diagram based on 164 animals from a single dredge sample is presented as Fig. 4. In interpreting this diagram it has been assumed that the "0" class animals settling in 2007 were too small to be retained by the meshes of the dredge. If this is so, animals between 13mm and 24mm can be allocated to class "1" (2006) settlers while the next peak, by far the biggest, is of animals between 25mm and 39mm settling in 2005, the year following the tsunami. The small number of remaining large animals survived the passage of the tsunami.

Discussion

The tsunami was undoubtedly a human disaster, but the data that are presented above suggest that the acute broad scale disturbance to the marine ecosystem of Laem Son National Park resulted in only short-term damage to sediment habitats. By the end of 2007, if not earlier, most such habitats had either returned to a biota that was numerically similar to that recorded before the tsunami or which had characteristics that did not indicate damage or disturbance. Given the scale of the disturbance, this may seem surprising until it is considered that the impacted habitats are in shallow water or the intertidal, places that are not physically stable [6], and the species living there must be well adapted to the effects of storms and high waves. During the last eight years the abundance of the biota of intertidal sites in Laem Son has undergone substantial changes, but not all were due to the tsunami; the impact of onshore storms was of similar magnitude in 2000 and 2001on an exposed beach, an estuary and a seagrass bed. No data are available on the frequency of such storm events, but they are considerably more frequent events than the passage of a tsunami wave. In water of less than 20m depth storm-related wave-disturbance must also be reasonably frequent. If a species is to persist in an environment that is frequently disturbed, it must have biological traits that permit rapid recovery of populations following disturbance. If this is the case, then the sediment biota of Laem Son National Park might be considered as having evolved adaptations that enable them to survive intense and potentially large-scale disturbances such as monsoon storms, or in this case, a tsunami. Others have noted the ability of soft sediment biota to survive in conditions that might be perceived as severe. For example, Shin [10] investigated offshore marine environments impacted by monsoon storms and noted that the biota persisted, although disturbance had an impact on both species composition and diversity. Elsewhere, the low impact of a storm on the benthic fauna of the temperate waters of Long Island Sound led Dobbs and Vozarik [4] to suggest that the local fauna had both avoidance and survival mechanisms that promoted their persistence.

In the case of intertidal species such as the polychaete *Diopatra*, thalassinid shrimps or ocypode crabs, deep burrowing behaviour appears to have preserved many individuals; in other species recovery was presumably due to larval recruitment. However, the speed at which other intertidal and infralittoral species recovered is difficult to explain without far greater knowledge of their biology. Over 200 km of the Thai coastline was severely disturbed and we have no information on the extent of damage to the beaches of Myanmar, immediately to the north of our study area. If intertidal animals in this area were killed, rapid recovery is most likely to have resulted from larvae already in the water column as the wave passed. Many tropical

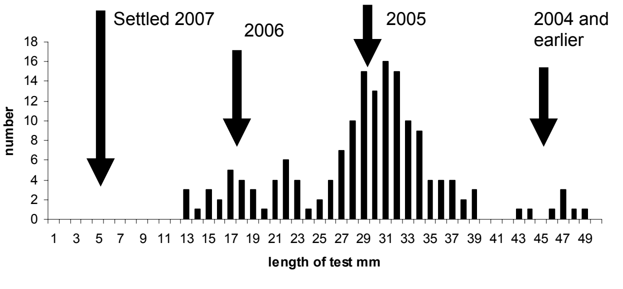

Fig. 4. Size frequency histogram for the burrowing urchin *Brissus luzonicus*. Arrows indicate the most probable year in which settled from the plankton.

species breed as a response to the passage of the monsoon [1] and although few details are known of the timing of breeding in the Andaman Sea, it is reasonable to assume that planktonic larvae were readily available for colonization in early January 2005. If this was the case, then the pool of larvae available for recolonization would be dominated by species spawning towards the end of the monsoon rather than the full range of species normally available over the whole post monsoon period. Such a restriction of the species pool might explain the unusual and temporary success of taxa such as the echiurans in the mangroves of the Kampuan Estuary in the year following the tsunami.

While species living offshore were certainly impacted by the tsunami, as evidenced by large numbers of molluscs and echinoderms that were stranded in deposits of sediment above high water, recolonization of these habitats was less problematic. In the case of the offshore heart urchin *Brissus luzonicus*, it appears that some individuals, either as small animals or post-larvae, survived the passage of the wave and that in 2005 these were joined by a heavy larval settlement coming from individuals living at depths undisturbed by the wave. The deeper offshore populations of other species will similarly have provided recruits to colonize tsunami-disturbed sediment.

By 2008 two major habitats within the Laem Son study area were still to recover, the most important of these being the seaward edge of the mangrove forest where the canopy was once predominantly *Rhizophora mucronata* and *R. apiculata*.

Mangroves occupy the greatest intertidal area in Laem Son National Park and hence play a significant role in the functioning of the inshore ecosystem, but it must be emphasized that catastrophic damage to the forest only occurred in the seaward fringe. The bulk of the forest did not sustain severe damage. By 2008 much of the damaged area remained open sediment partially covered by debris of mangrove roots and stems; nevertheless, some colonization by a broader range of mangrove species than previously, and by other opportunistic plants is currently occurring. It could be some time before the forest fringe recovers, and when it does it is likely to be more diverse than before the passage of the tsunami. On the forest floor the tsunami deposited offshore sediment leading to a change, but there are no baseline data by which the extent of sediment incursion can be measured, and thus it is difficult to estimate the overall impact on the goods and services that the forest delivers to local stakeholders. Nevertheless, data from socio-economic survey of fishing villages (Daungnamon and Hills unpublished) indicate that recovery of inshore fisheries took place relatively quickly following the tsunami, and therefor it might be speculated that any impacts on the export of nutrients from the mangrove forests to offshore waters were not sustained.

Rocky seashores cover only a small proportion of the area of the national park, but nevertheless make an important contribution to its biodiversity. The greatest impacts of the tsunami on this habitat involved the smothering of high intertidal barnacles by silt and the sweeping away of mats of mussels. Mortality among the barnacles was not complete and a significant proportion of individuals were able to breed in 2005, thereby supplying the new recruits that settled and survived on empty rock surfaces. In the case of mussels, losses were more severe and although recruits have been observed annually among the barnacle matrix, numbers have never been sufficient to re-establish the mats that existed before the tsunami. This failure may relate to a poor larval supply caused by the almost total loss of mussels in combination with the rarity of the habitat in which they live.

Much of our interpretation of the extent of the impact and the subsequent recovery of the marine resources of Laem Son National Park are based on the relatively small amount of data that existed prior to the tsunami. The existence of these data demonstrate the utility of a commitment to collect marine information over a protracted period. Few such data sets exist in Thailand, but without information collected during the "Coastal Biodiversity in Ranong" project it would not have been possible to demonstrate the high natural temporal variability within coastal sediment habitats and indicate their apparent resilience. The lack of knowledge of fundamental knowledge on the marine biology of this sector of the Thai coastline which was demonstrated by the passage of the tsunami must raise concerns for the future. The marine climate is changing rapidly (IPCC, 2007 [7]), but it is very difficult to make realistic predictions without a basic knowledge of marine ecosystems and the way in which they function.

Acknowledgements

The data presented in this paper were collected predominantly during two contracts awarded by the European Union, "Coastal Biodiversity in Ranong (2001-04)" and "Tsunami Impacts in Laem Son" (2006-09). Earlier faunistic work was carried out as part of the UK Darwin Initiative project, "Taxonomic information on the Internet."

The authors wish to acknowledge the assistance in the field of many colleagues from Kasetsart University, The Natural History Museum and Plymouth Marine Laboratory.

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