Monitoring beach morphology changes and coastal sediment balance from Prachuap Khiri Khan, Thailand

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Abstract

Coastal erosion has been reported to be a severe geological hazard in some coastal areas along the Thailand coast. Whether the coastline has really suffered continuous erosion due to a long-term loss of natural sediment from beach zone or it occurred shortly after the human induced activities is still a moot question, which is being debated at present. This paper reviews our findings in a long-term systematic monitoring of beach morphology changes in the areas where severe erosion has been reported. Remotely-sensed data were integrated for evaluating a long-term sediment cycle. For short-term evaluation, we tested the yearly beach profiles and calculated the changes in the coastal area at Pranburi beach ridges plain and at the semi-enclosed bay of Prachuap Khiri Khan, western Thailand. As a result, foreshore profiles at Pranburi area show that the annual depositional rate is more than that of erosion. The northwardly coastal sediment movement at Pranburi area occurs only in rainy season and a yearly balance of sediment here shows a little change in sediment gained and lost. The Prachuap Khiri Khan Bay is in a long-term equilibrium. We conclude in general that a long-term sediment dynamics along both coastal segments are stable, but contain a complexity due to a local difference in shoreface configuration. Our result proves that both long-term and short-term systematic approaches in analyzing coastal sediment balance are essential to understand better the dynamics of natural sediment movement that may or may not be due to erosion.

Keywords: sediment budget, beach profiling, Pranburi, coastal erosion

1. Introduction

The earliest historical study in shoreline changes was generally conducted by comparing series of topographic maps dating back to the late 1800’s, not only in Thailand, but also in the world coastal studies. Basically, series of topographic maps are useful for examining long-term trends (10-100 years span) in shoreline change since the maps were produced. However, errors in shoreline location derived from maps may be attributed to surveyor error in identifying the shoreline feature, distortion of source maps (folding, tearing, shrinkage), and changes in the reference datum (Anders and Byrnes, 1991; Choowong, 2002a; Choowong and Charusiri, 2005). In Thailand since the 1990’s, series of topographic maps have been employed to document shoreline positions and changes in order to judge those positions have shifted due to erosion (Vongwisetsomjai *et al*, 1988). This, sometimes, led to some mistakes in the interpretations especially for the calculation in area of shoreline changes. Rate of shoreline erosion was, therefore, equivocal.

The comparison of topographic maps produced in different periods can be helpful in evaluating shoreline changes. But better accuracy needed can come from systematic comparison of aerial photographs or remotely-sensed data as suggested by Crowell *et al*. (1991). This is because aerial photographs needed to be first transformed to map coordinates using ground control points before a proxy for the shoreline position changes is ready to be analyzed.

Aerial photographs, were generally prepared more frequently than those of topographic maps and therefore, they provided a more detailed understanding of short-term (1-10 years span) shoreline variability. However, it has been noted that for unrectified aerial photographs, accuracy within or between images is limited by scale differences, by camera geometry, by ground relief (Crowell *et al*., 1991; Dolan *et al*., 1980; Hapke and Richmond, 2000), as well as due to the precision of the digitizing equipment and of the operator in following the trace of the High Water Level (HWL) (Anders and Byrnes, 1991). This limitation is significant and we have taken this into account for this study.

We propose in this paper that once we had a better understanding of the nature of sediment dynamics on different coastal morphology, we will be able to make precise interpretation on whether or not the coastal erosion occurred due to long-term natural processes or by short-term human-induced activities (Choowong, 2009). Therefore, we selected two typical coastal types of Prachuap Khiri Khan for testing and comparing the yearly sediment cycles. Pranburi coastal zone exhibiting long beach ridges plain will be a reasonable ground to test the effect of longshore current. Prachuap Khiri Khan Bay however is a closed-system where sediment transport within the bay may reflect short-term cycles. We used Thailand’s sea-level datum from Koh Lak at Prachuap bay as a reference for all shoreline measurements in this paper.

2. Study areas

Prachuap Khiri Khan is located on the upper peninsula that lies on the western side of the Gulf of Thailand (GOT) and bounded by latitude 10^0 57’ to 12^0 39’ north and longitude 99^0 8’ to 100^0 04’ east with an area of approximately 6357.62 km^2. Topographically, Prachuap Khiri Khan coastal plain is in the elevation ranging from 0-10 m above the present mean sea level. We focused on two coastal areas; Pranburi area (Figure 1A and 1B) and Prachuap Bay (Figure 1C and 1D). Pranburi area is dominated by truncated beach ridges plain with a small sand spit developing in the north. The area preserved at least three major erosional events,- detected from air-photos,- which probably occurred in Holocene (Songmuang, 2005). The semi-enclosed Prachuap Bay was divided into two segments by the tidal channel. Within the bay at the southern part of tidal channel, the coast was reported to have suffered severe erosion (Vongwisetsomjai *et al.*, 1988). Sinsakul *et al.* (2001) reported that in the same coastal zone of the bay the beach has suffered erosion at the rate of 1-5 m/year, whereas deposition occurred to the north of erosion zone with a similar rate of 1-5 m/year. At the Pranburi coastal plain, most of the beach zone was reported to have been severely eroded at rate of 1-5 m/year (Sinsakul *et al*., 2001).

3. Wind and wave conditions

The study areas are located in tropical climate with two major wind and wave conditions. Southwest monsoon winds and rains occur regularly between mid-May and October, causing floods on land. In Thai’s history, tropical storms occur occasionally and are less severe than typhoons. Northeast monsoon often hits the coast between November and mid-February. The rainy season from mid-May to November is characterized by moderate to heavy rain as a result of air masses traversing. The southwest winds also generate moderate waves. However, typhoons are rarely generated as a result of the retreat of southwestern monsoon during September to October, which bring strong winds and intense waves. Conversely from November to mid-February, the northeast monsoon represents a reversal period of air movement. Waves are generally small. Winds are normally moderate in the northeast monsoon season with stronger winds during the end of the season (Vongvisessomjai *et al.*, 1988). Rainfall is maximum in September up to 2,200 mm/year. The average rainfall is about 1,400 mm/year and about 90% of the precipitation falls in the rainy season. Tidal range around the western coast of GOT is average 1.2 m (Choowong, 2002a; 2002b; 2002c;

Choowong *et al*., 2004; Royal Thai Navy, 2004).

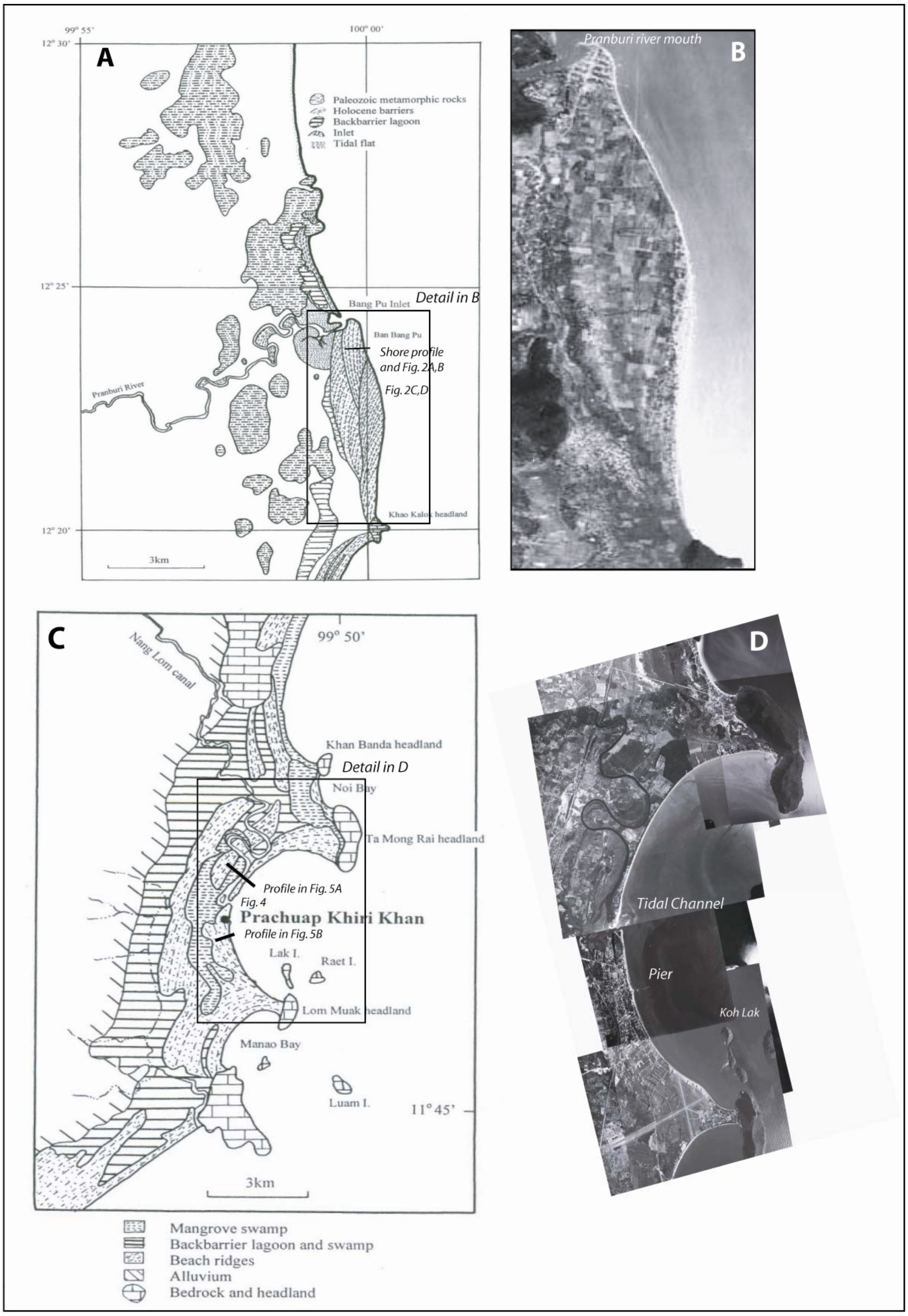

Figure 1: Geomorphological maps and aerial photographs of Pranburi truncated beach ridges plain (A and B) and Prachuap Khiri Khan Bay (C and D).

4. Materials and method

4.1 Analysis of remotely-sensed data

Data set analyzed in this paper came from both satellite and air-photos images. Aerial photographs used include series of images from VAP 61 Project with a scale of approximately 1:50,000 and images taken in 2002. Large scale (1:15,000; NS3 Project) images were also employed as supplementary data for landform classification in the focused areas. Satellite images (IKONOS and Landsat 5TM) were also employed. Errors associated with remote-sensing images were eliminated before features were identified within the image by using recent techniques involving softcopy photogrammetry. Digital stereo images were used to make geo-reference and remove distortion followed the suggestion by Overton and Fisher, 1996; Larson *et al.*, 1997; Hapke and Richmond, 2000; Hapke *et al.*, 2005). Elevation contours were generated on the photograph. The creation of a digital terrain model and shoreline position or a specified contour was measured basically from the stereo pair.

4.2 Positioning shoreline and beach profiling

Shoreline positions in our areas were measured from ground-based surveys along the cross-shore profiles. Closely spaced profiles with high accuracy GPS (Morton *et al.*, 1993) were also collected and used for detailed studies of a short-term variation in shoreline change. A single transect along the length of the beach (100 m and more in length), and a complete detailed mapping of beach topography was carried out. Additionally, sediment augering was performed to confirm types of beach deposits in particular landforms localities.

Beach steps in our areas are relatively small morphological features and usually found on steep, coarse-grained sand, and on gently-sloping. In order to measure beach steps, we divided beach zone into three segments: (1) a step face or steep, seaward-facing slope facet with dip-angles slightly less than the angle of repose of the sediments; (2) a crestal region that grades smoothly from the top of the angle-of-repose slope (the crest) landward to the mid-foreshore slope; and (3) a nearly-horizontal base segment that abuts the angle-of-repose slope and often extends well into the surf zone. Sometimes the only visible evidence of a beach step or incipient beach step is a narrow alongshore-trending deposit of coarse sediments or shell fragments manifest as a subtle textural gradation across the lower foreshore slightly below mean water level.

5. Results

5.1 Remotely-sensed data

5.1.1 Pranburi Area

There are two primary types of coastal landform at Pranburi area; (1) truncated beach ridges plain and (2) tidal flat and lagoon. The orientation of truncated beach ridges here is slightly curved and changes from a north–south to a northwest–southeast direction. The direction of a net longshore sand pathway is recently in the north-south direction. The beach ridge plain superimposes on alluvium substrate. Highly weathered alluvium looks likely to be the major terrestrial source for sediment transportation along this coastline. This is also indicated by the truncated morphology of beach ridges with erosional lines. Longshore currents had changed at least three possible times after the mid Holocene (Songmuang, 2005). In the economic area within Pranburi truncated beach ridges plain, sea wall was constructed but a high rate of sediment movement exists, especially during storm period (Figure 2).

Spatial calculation of accretion and erosion by comparison of air-photos taken in different periods of time shows that the deposition occurred in the north as small sand spit growth of about 47,263 m^2. Erosion appeared in the middle part of outer beach ridge plain with area of 79,085 m^2 lost. This reflects northward migration of sediments.

Figure 2: Field observation at the outer part of Pranburi truncated beach ridges plain (see location of photos in fig. 1A). Beach profiling line is located in A. Submerged sand bar recorded in 2005 is in B. Northward migration of longshore drift in 2003 is clearly preserved as a new cuspate beach form and sea wall construction 2003 as indicated in C. Translation of submerged sand bar landward made emerged sand bar clearly seen during low tide in 2005 and back barrier lagoon has started its formation since 2004. All these photographs look to the north.

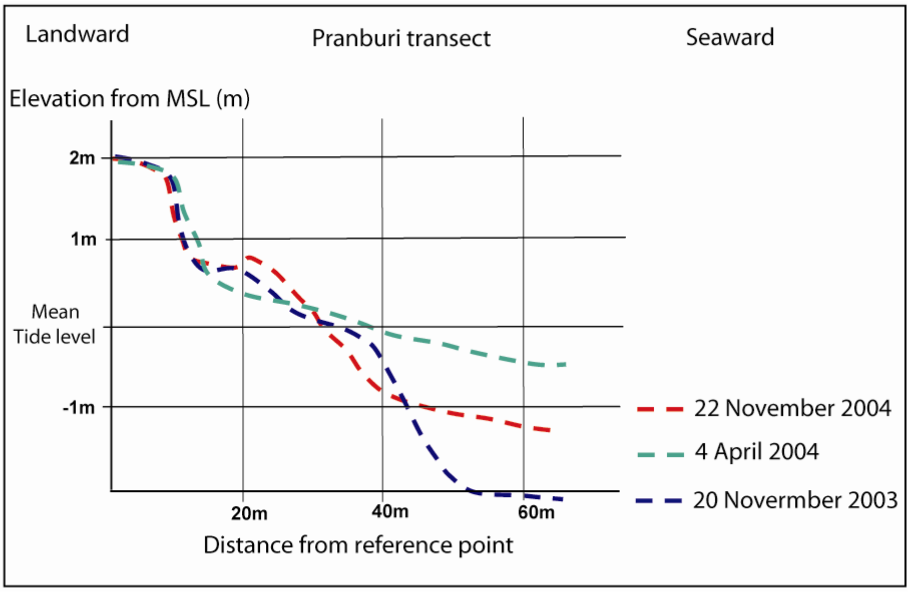

Figure 3: Beach face and shoreface slope have no significant change at Pranburi transect from November 2003 to 2004 (see location of profile in fig. 1A and 2A). Submerged sand bar slightly migrated approximately 20 m landward from November 2003 to November 2004. Within a year cycle, this coastal segment reveals deposition is greater than erosion.

5.1.2 Prachuap Khiri Khan Bay

The highlands to the west of the bay are composed of Permo-Carboniferous sedimentary rocks. Permian limestone forms prominent coastal headlands and islands, which seem to control the direction of wave reflection, littoral sediment movement and the pattern of barrier sand accumulations along the coast. The area is composed of both depositional and erosional features. The barrier system, one clear depositional landform, contains prograded beach ridges intervening with swales. Semi-enclosed bay here connected the mainland and islands by tombolo both at the northern and the southern part of the bay.

Only one tidal channel dominates in the middle part of the bay. It runs and meanders across the alluvial plain and ends with small delta lobes at the mouth. This channel supplies abundance of terrestrial sediment to the coast presently. The morphology of delta lobes has a short-term change through the year (Figure 4). Longshore current is likely to be responsible for the northwardly movement of delta sediments. Submerged series of sand bar also are exposed during low tide. They show a northwardly migration.

Figure 4: Oblique aerial view of Klong Bang Nang Rom tidal channel in the middle part of Prachuap Khiri Khan Bay. Tidal delta here supplies extensive amount of sediment into the bay. Morphology of tidal delta changed from November 2003 (A) to 2004 (B). 2003 emerged sand bar shows migration northward.

5.2 Beach profiling

5.2.1 Pranburi Area

In analyzing the morphology of shoreface changes through time, for instance, from the initial surveys in November 2003 to April 2004, it seems likely that the toe of shoreface showed a sign of accretion more than erosion (Figure 3). However along the surveyed line, between April 2004 to November 2004, the erosion was markedly over steepened. This was a clear indication of a seasonal change of sediment budget to the coastline. As a whole, results in measuring shoreface profile from November 2003 to November 2004 revealed that the accretion of the shoreface has continuously occurred to the north. On the other hand, some retreats of shoreface appeared in the south. Therefore in overall scale, it appears to be a trend for northward ongoing net shoreface accretion in this area.

A surge during storm wave could, however, severely damage any construction along the coastline as seen at the southern part of beach ridge plain where massive amount of beach sediments was eroded away, unless sea wall was constructed. Field observation confirmed that during storm events, the oblique wave has played a significant role in moving beach sediment out from the southern part of this truncated beach ridge plain (also see in figure 2C and D). This causes erosion continuously because sediment supply was reduced. However, our result in evaluating a yearly shoreface adjustment shows no significant sign of severe erosion. Making inappropriate orientation of sea wall is more likely the cause of short-term non-balance in sediment movement than long-term natural sediment dynamics in this area.

5.2.2 Prachuap Khiri Khan Bay

Prachuap Khiri Khan (north) area

This segment has shown a clear and consistent trend of little shoreface erosion over the one year period since the monitoring commenced (Figure 5A). For example, in November 2003 to April 2004, the shoreface showed mostly seaward inclination. Then, during April 2004 to November 2004, the accretion occurred but did not have much influence for changing the whole shoreface morphology. As a result, in one year period from November 2003 to November 2004, the erosion was slightly recorded in this coastal segment, unlike the result we have recognized of long-term monitoring from aerial photographs before the construction of pier in the middle part of the bay.

Prachuap Khiri Khan (south) area

This southern segment showed a clear trend of landward accretion over one year r (Figure 5B). The shoreface in November 2003 was eroded and then accreted back to have as equivalent elevation with the measurement done by April 2004. However, from April 2004 to November 2004, the average trend of slope gradient was slightly increased landward. There appears to be a trend for ongoing net shoreface accretion. Once again, this result is inconsistent with what we have seen from a long-term monitoring from remotely-sensed data.

6. Discussion

Spatial calculation of a long-term change of shoreline using air-photos of different periods showed that the accretion and erosion from both areas are almost similar in value. Beach profiling also reveals a little change in volume of sediment. This situation suggested that Prachuap Khiri Khan Bay is stable and has remained in equilibrium in terms of sediment balance. Some lack of balance in shore face configurations from the north segment may occur after the construction of pier that behaves like a sediment trap and leading to more of sediment deposition in the south. In short, at Prachuap Khiri Khan Bay, constructing the pier clearly reduced northwardly longshore drift and sediment transportation. Results of shoreface measurement can be used to infer the seasonal and yearly changes of beach morphology. Long-term measurement is recommended and is necessary to predict a scenario and the accurate rate of coastal erosion or deposition.

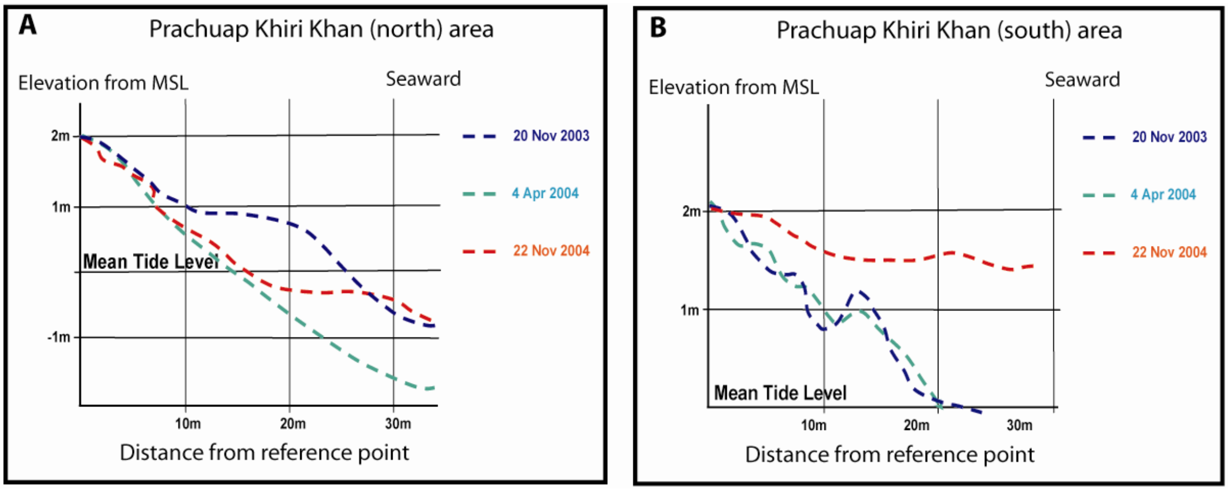

Figure 5: Monitoring beach profile from November 2003 to 2004 at Prachuap Khiri Khan Bay (see location of beach profile in fig. 1C). The southern part of the bay was reported to have been eroded, but the situation is now changed. At the northern part of the bay, sediments at shoreface decreased (A). Massive amount of shoreface sediment increased at the southern part of the bay (B). This indicates the changes of volume of sediment accretion after pier were constructed.

Since the systematic study of sediment dynamics is a must, necessarily the first step before we judge which areas have been affected by severe erosion. This paper provides a key catalogue and the way to approach the most accurate rate of change in the sediment budget. We hope that our example in testing coastal dynamics in the two typical coastal landforms will bring insight to the decision-maker to give high priority for a detailed systematic study before the decision to make any construction or planning starts. However, it is important to note here that the areas we tested are stable due to their sediment types and a long-term compaction, unlike the other parts of the GOT where local subsidence is likely. We suggest therefore that the more secure measurement may be one another approach to reach the best solution in evaluating the dynamic of the coast.

7. Conclusions

1. Results from our work confirm that a yearly sediment dynamics within the shoreface slope is a cycle. Both deposition and erosion have been noted at Pranburi and Prachuap Bay. This reflects that the rate of coastal erosion from both areas needs revision.
2. Sediment transport direction in both areas depends largely on shoreface and beach morphology. We can estimate direction of sediment transportation by using depositional styles of coastal sediments they have formed since the mid-Holocene till the present. This long time span estimation will tell us all about a long-term history of shoreline changes through time. This should be done from each local and individual area that will be very important key to understand the former transportation cycles and trend of erosion and deposition.
3. The way to calculate the precise rate of beach accretion and erosion need to be initiated from a small-scale study (short-term) in the changes of shoreface configuration (i.e., seasonal or annual changes), and then expanded to large-scale or the long-term measurements. In order to calculate sediment volume, small sectors and much more ground shoreface surveys are necessary.
4. Calculation of spatial changes only from remote sensing data is still questionable in term of methodology and the reliability of the calculation. To avoid any errors the systematic short- and long-term field surveys must be applied together.

8. Acknowledgements

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