THE SEDIMENT BUDGET AS A MANAGEMENT TOOL: THE SHOALHAVEN COASTAL COMPARTMENT, SOUTHEASTERN NSW, AUSTRALIA

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Abstract

Sediment budgets are fundamental approaches in coastal studies for allowing estimates of volumes of sediments entering and exiting a selected area of the coast, resulting in net erosion or accretion of that compartment under consideration. This assessment is crucial for understanding current processes and predicting future effects of sediment-impact activities, promoting the sustainability of coastal environments over the next centuries. In this paper we present a series of preliminary spatial, sedimentological and geophysical analyses undertaken in order to understand the sources, sinks, transport and pathways for the sediment budget of the Shoalhaven coast, a compartment whose sediment provision is supplied primarily by the Shoalhaven River (draining a catchment of 7,151 km^2) and that stretches ~32 km from the rocky headland of Black Head at Gerroa (north) to the Beecroft Peninsula near Currarong (south). Analysis included the use of sub-bottom profiler, ground penetrating radar, RTK-GPS, aerial photographs, satellite images, LiDAR, echosounding, computer modelling, as well as grain size parameters from ~200 sediment (and mineralogy for selected) samples from the estuary, beach and shoreface.

Introduction

Coastal systems are evolving over varying time scales, and the form of the shoreline is responding to the major processes acting upon it (Woodroffe and Leon, 2010). After the destructive effects of storms in 1967, 1972 and 1974, there has been increased awareness of the importance of management of the coast in NSW, Australia. More recently, the challenges associated with rising sea levels, changing wave climate, and unforeseen weather patterns confront decision-makers especially at the state and local government levels.

One way to reduce the long-term risk to the coast and improve coastal management and planning is to adopt a framework that integrates understanding of coastal behaviour so that it can be incorporated into management decisions. One way of doing so is by developing a sediment budget study of that selected part of the coast

Sediment budgets are a fundamental element of coastal sediment process studies encompassing many applications (Komar, 1998) in geomorphology and engineering through application of the primary conservation of mass equation (Rosati, 2005). It involves understanding of the sediment sources, sinks, magnitude and transport for a selected compartment of the coast, within a period of time, which may vary from short to long-term periods, providing useful insights for coastal management.

The sediment budget is a balance of volumes of sediments and determines whether the shoreline will prograde, remain stable or erode over the long term. It provides a useful insight into the management of coastal compartments (Komar, 1996), distinct sectors of the coastline that are bounded by headlands and rock reefs (or other obstructions) that interrupt longshore transport. The landward and seaward limits are set by the rear of the barrier system and the shoreface, where waves act upon sediment, respectively.

Despite being well documented, as in CERC (1977), the procedure to be followed in constructing a sediment budget is challenging (Woodroffe, 2002) and includes determining the appropriate boundaries of the budget, defining the range and magnitude of sediment transport, representing the uncertainty associated with values and assumptions and testing in relation to variations in the temporally-changing values. Once the conceptual sediment budget has been completed, data are assimilated to validate the conceptual model rather than to develop the model (Rosati, 2005).

The budget is calculated over the net quantity of sediments that cross the boundaries of the sector. The methodology, in summary, consists of quantifying the amount of sediment in a sector and calculates the addition (sources) and subtraction (sinks) due to relevant drivers and processes such as: fluvial, biogenic and geologic (dune/terrace/headland erosion) input; longshore, cross-shore and aeolian transport; estuarine sink; and human activities (Thom, 2014).

The Shoalhaven Coastal Compartment stretches ~32 km from the rocky headland of Black Head at Gerroa (north) to the Beecroft Peninsula near Currarong (south), in the wave-dominated microtidal coast of southeastern NSW. In between these two ends, two headlands (Crookheaven Heads and Penguins Head) subdivide this compartment into three sand deposits: Seven Mile Beach and Comerong Island (SMBCI), Culburra Beach and Warrain-Currarong Beach.

The Shoalhaven River is the most important feature associated with this compartment and one of the largest rivers in southern New South Wales, with a catchment of 7,151 km^2. It rises in the Paleozoic Lachlan Fold Belt (composed of Ordovician metasediments, Siluro-Devonian volcanic rocks and Devonian granites in the upper and middle catchment), and traverses the Sydney Basin, composed of Permo-Triassic sandstones and siltstones, in its lower reaches (Nott, 1992). The river is considered to have supplied sand that contributed to the construction of ~40 ridges that nowadays form SMBCI, as the shoreline prograded 1,350 m seawards over a period that started around 6,640 +/- 220 years BP according to radiocarbon dating published in the early 1980s (Thom et al. 1981).

In the Shoalhaven sector of the coast (Figure 1), the following significant components of the sediment budget are identified as sources: fluvial sand and mud supply; erosion of river flanks (mostly along Berry's canal); sediment supply from rock headland erosion; and biogenic production. Sink components include: estuarine deposition; the flood-tidal delta, the loss of sand from the beach to the barrier system; and dredging around Pig Island. Areas of exchange of sediments which can act as sources and/or sinks include the beach-shoreface and the shoreface-inner shelf.

It has been calculated previously that the average bed sediment transport of the Shoalhaven River is of the order of 100,000 m^3y^{-1}, with a similar figure representing the transfer from the immediate beach berm to the foredunes by aeolian transport. It has been estimated that this average annual supply of sediments from the river would produce beach progradation of the order of 1 my^{-1}, and that the maximum transport flux of sand deposited in the littoral zone at Shoalhaven Heads is about 350,000 m^3y^{-1} with a northward component of 60% of this value (DPW, 1977).

In this paper we present a series of preliminary spatial, sedimentological and geophysical analyses undertaken in order to understand the sources, sinks, transport and pathways for the sediment budget of the Shoalhaven coast.

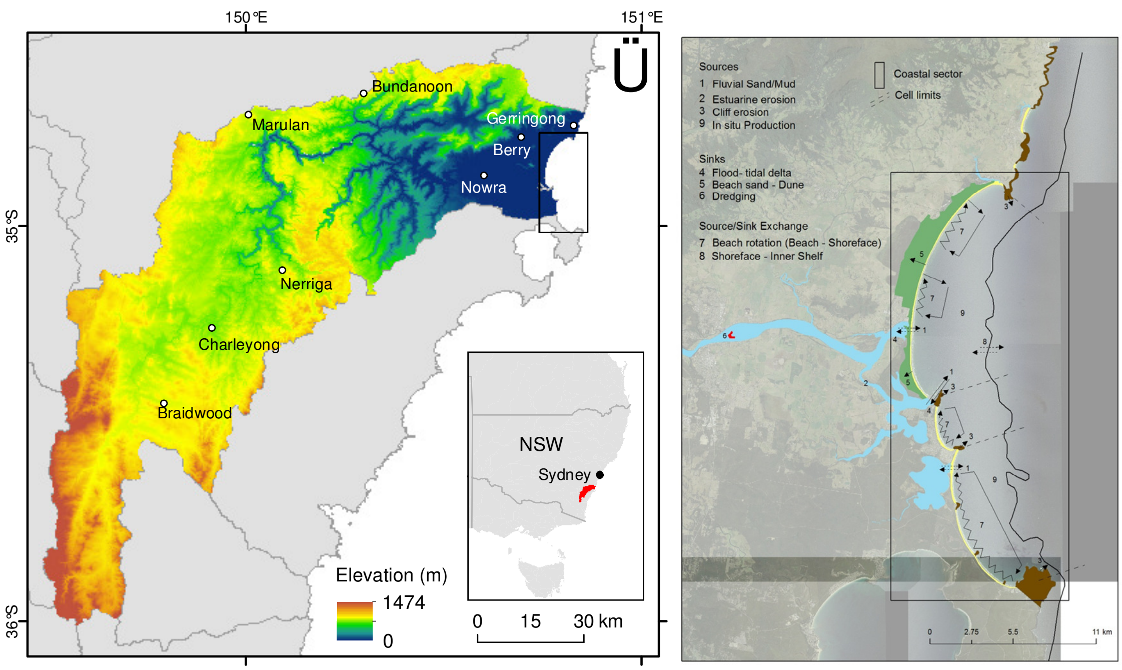

Fig.1: Shoalhaven catchment and Sediment budget compartment scheme

Methods

Landsat imagery, aerial photography, Light Detection and Ranging (LiDAR) and bathymetry data were used for spatial analyses. An historical retrospective of breaching at Shoalhaven Heads was developed using aerial photography and Landsat imagery that started in 1949 and 1972, respectively. LiDAR data were provided by the Shoalhaven Council and the NSW Land and Property Management Authority (LPMA). The Shoalhaven Council contracted AAM Hatch Co. to collect the data from a fixed wing aircraft on 21/08/2004, while the LPMA started a standard LiDAR survey on 17/12/2010 and finished on 13/04/2011.

The 2004 and 2010/2011 data were used to assess net erosion along Berry's canal. A comparison between TINs derived from different years was done in order to identify and quantify the widening of the artificial canal. The 2010/2011 was also used to calculate barrier and beach volume and to identify morphological features.

Previous bathymetric surveys conducted by OEH in 1989, 2006 and 2012 provided information about sediment delivery to the coast, transport and nearshore profile.

A catchment model (SWAT) was built to simulate sediment yield to the estuary. Bathymetric and Sub-bottom profile data was collected to calibrate the model and account for rate of infilling of Tallowa Dam (catchment area of ~5600 km^2).

Sub-bottom profiling was also deployed on the Shoalhaven estuary, while Ground Penetrating Radar was undertaken at Seven Mile and Warrain beaches.

A comprehensive suite of estuarine, beach and offshore surficial sediments (n=206) was collected. Samples on the upper/middle estuary were collected in September 2013, while samples from the lower estuary were collected in December 2013. Beach samples (n=34) were collected in the swash zone in July 2014 and offshore samples (n=49) were collected at variable water depths (max 29 m) in May and July/2014. Samples were washed for salt extraction, subsampled and dried. Approximately 150 g of sample was dry sieved at 1 phi intervals. Size fractions finer than 0 phi were determined by laser (Mastersizer). 24 selected samples were examined for mineralogical composition using X-ray diffraction (XRD). The <0 phi fractions were ground using Tema, and cross-contamination was avoided between samples. Following XRD analysis, samples were corrected to the appropriate 2 theta spacing using Traces software, and quantification of mineral phases was performed by expressing the composition of crystalline material within each sample as percentage of dry weight using Siroquant software. For each sample, background values were subtracted and analysis conducted until minimum chi-square values were obtained.

Monthly beach profiles using RTK-GPS that started in February 2011 and ended in December 2012 at Seven Mile Beach-Comerong Island, were extended to include the north, middle and south of Culburra and Warrain-Currarrong beaches in December 2013 onwards. Due to the ongoing collection of data only data from 2011 and 2012 will be presented here. Time lapse cameras were also set up at Gerroa and Culburra beach in early 2013 to record changes in beach morphology.

A finite-difference numeric model (STWAVE) based on the wave action balance equation was built to estimate nearshore wave propagation.

Spatial analyses

The Landsat archive and aerial photographs have shown that the river mouth at Shoalhaven Heads was opened in 1961, 1974-1980, 1988-1994, at the end of 1999 and 2013. Historical comparison of LiDAR data demonstrated source of sediments as a result of erosion taking place on both flanks of Berry’s canal between 2004 and 2010/2011. For an extended analysis of breached time, entrance modification and canal erosion see Carvalho and Woodroffe (2013).

LiDAR data also showed that the 17 km long Holocene barrier system adjacent to Seven Mile Beach-Comerong Island (Figure 2) consists of a series of 38 inner-ridges to the outer-foredune ridge that were deposited over a period that started around 6,640 +/- 220 years BP according to radiocarbon dating published in the early 1980s, as the shoreline prograded 1,350m seawards. The highest ridge is found in the foredune, and reaches 13.5 m above AHD and is located in the middle of the embayment. It decreases in height towards the south (8.8 m) and north (5.3 m) ends of Seven Mile Beach and reaches

6.6m in the middle of Comerong Island. The innermost ridge is located 1190m landwards from the foredune ridge, to the north of Shoalhaven River mouth, and decreases in distance from the shoreline towards the north. This pattern seems to continue towards Comerong Island despite the absence of this ridge due to past erosion caused by lateral migration of the river. Ridge alignment, continuity and height trends corroborate with previous conclusions that past processes were significantly similar to those in the present, and that the Shoalhaven River is the principal factor influencing barrier progradation (Wright 1970).

The receded barrier (PWD, 1980) at Culburra reaches ~15 m height in the north and middle, reducing to 1/3 of its height to the south. The stationary barrier width of Warrain-Currarrong is only 200 m and heights are higher towards the north.

Past bathymetric surveys between 1989 and 2012 showed the transport of sand deposited in the nearshore area in front of Shoalhaven Heads and a displacement of 1.4 x 10^6 m^3 of sand from a 2 x 10^6 m^2 area (Figure 3).

Catchment modelling

Preliminary hydrologic results show that the catchment model composed of 32 Sub-Basins and 218 Hydrologic Response Units is able to successfully represent monthly discharge (R^2= 0.78) as simulated for gauging station 215004 depict in Figure 4, however further calibration is needed as the model is over predicting results.

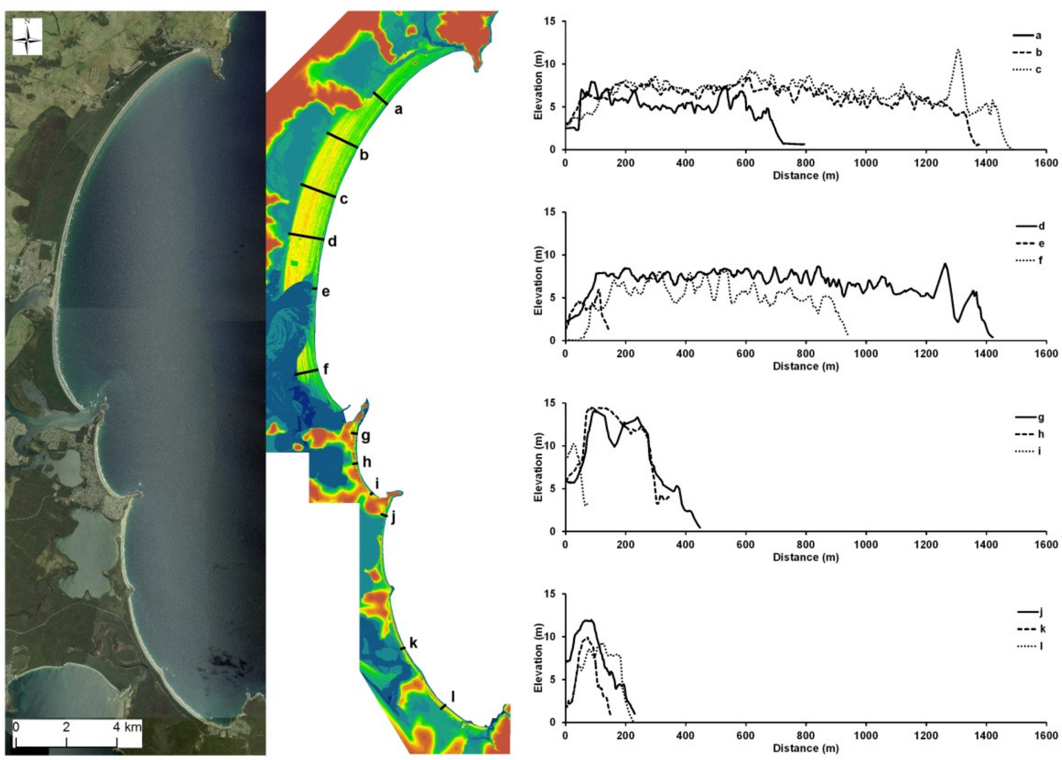

Fig.2: Air photography of the Shoalhaven Coastal Compartment (left), LiDAR data (middle) and cross-sections showing different morphologic types of barriers (right).

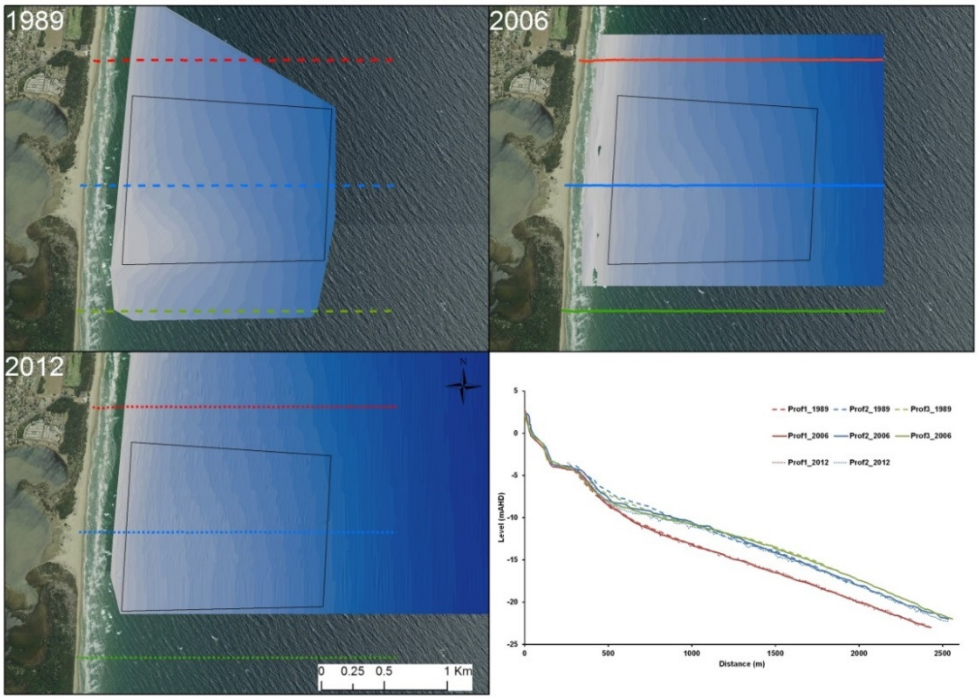

Fig.3: Bathymetric variation between 1989, 2006 and 2012. Areas used for volume calculation are shown in black outline polygon. Nearshore profiles are shown in red, blue and green lines and plotted on the bottom right corner graph.

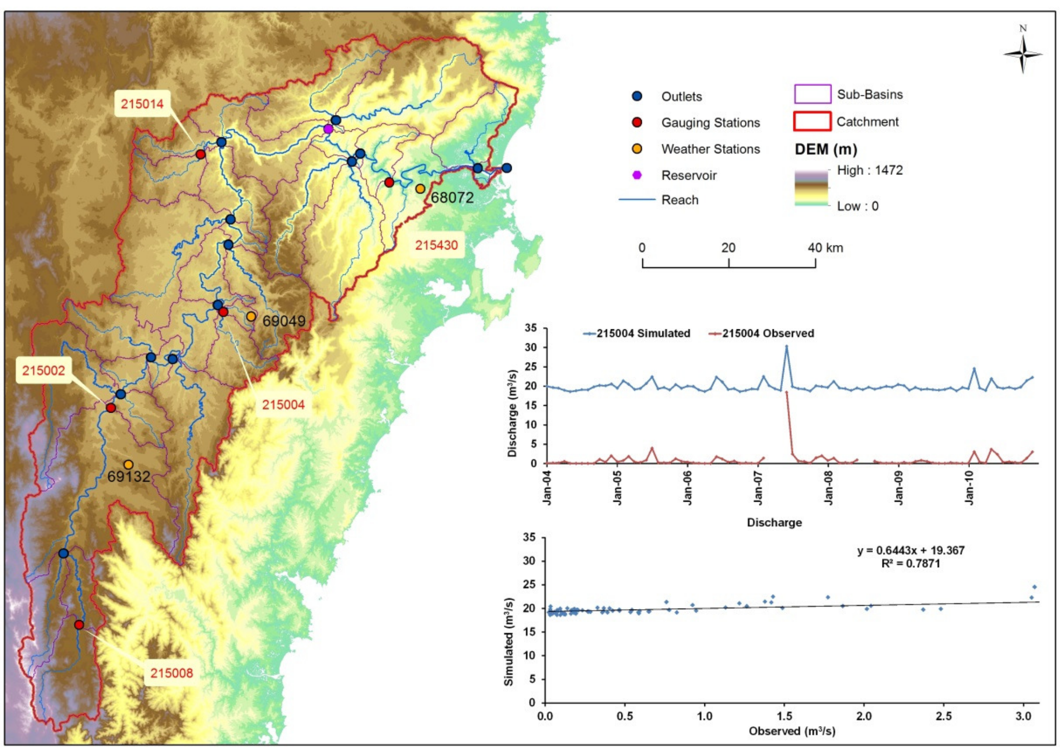

Fig.4: SWAT model monthly simulation during 2004-2010. Simulated x Observed discharge results for Gauging Station 215004 is graphed.

Wave modelling

Wave refraction scenarios for different wave directions are depicted in Figure 5. Under average wave height (1.6 m) and period (9.5 s) waves originated from the south refract at Jervis Bay and attenuation occurs throughout the coastal compartment. Higher waves reach the northern part of Seven Mile Beach. Predominant south-southeastly waves also refract at Jervis Bay but higher waves reach the entire area apart from Currarong. Easterly waves cause convergence of the wave rays and therefore higher waves reach Gerroa, Comerong Island and North Warrain Beach. Waves coming from the northeast are attenuated near Gerroa but amplified at Warrain.

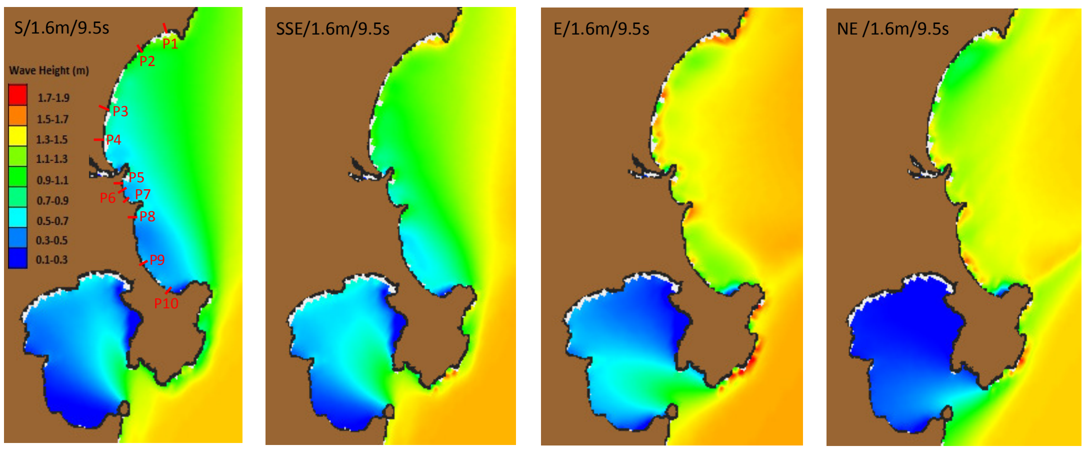

Fig.5: Wave refraction for different direction modelled scenarios. Location of beach profiles is shown on the left.

Beach monitoring

The beach state at the beginning of 2011 contained cross-sections that varied from a low-gradient (0.04 -Profile 1) to relatively high-gradient beachface (0.1 -Profile 3). Examination of changes in beach profiles and volumes between Feb/2011 and Dec/2012 revealed detailed short-term quantitative information depicted in Figure 6.

A trend of erosion could be observed on Profiles 1 and 2 whereas deposition was observed on Profiles 3 and 4 (Figure 6b). Profile 2 showed the greatest spread of beach volume (σ= 18.4 m^3/m), followed by Profiles 1 (σ= 16.5 m^3/m), 3 (σ= 9.3 m^3/m) and 4 (σ= 7.5 m^3/m).

During the the first two years of monitoring, 5 major storms hit the coast on 20-24/7/2011 (1.9 x 10^5 kW/m), 7-9/3/2012 (1.5 x 10^5 kW/m), 5-7/6/2012 (2.3 x 10^5 kW/m), 1/8/2012 (1.2 x 10^5 kW/m) and 11-12/10/2012 (1.3 x 10^5 kW/m). Interestingly, both the Jul/2011 and Mar/2012 storms, the second and third strongest storm of the entire period, respectively, didn't affect the subaerial beach at all. In fact, Profiles 2, 3 and 4 increased in volume immediately after the Jul/2011 storm. On the other hand, the Jun/2012 storm caused major erosion especially on Profiles 1, 2 and 3. These facts can be partially explained by an elevated water level during the June/2012 storm, when the highest tide was 0.7 m and 0.3 m higher than the tides in Jul/2011 and Mar/2012, respectively, enabling waves to extend further landwards.

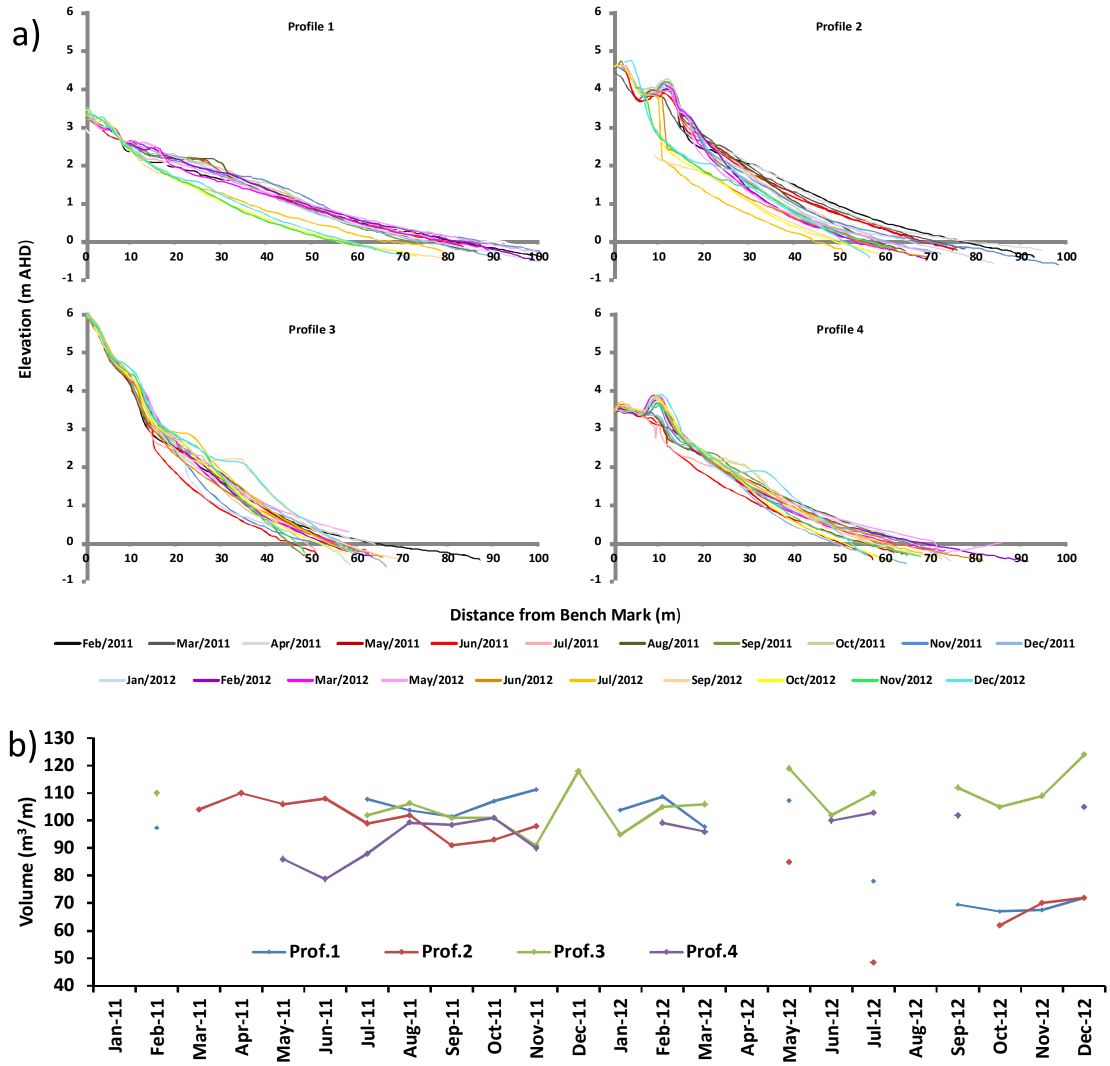

Fig.6: a) Monthly beach profiles using RTK-GPS; b) Monthly beach profile volume change above 0m AHD.

Sedimentology and mineralogy

Grain size analysis showed that the mean grain size ranged from -0.4 φ to 6 φ on the estuary, 1 φ to 2.4 φ on the beach, and -0.6 φ to 3.2 φ offshore (Fig.7). Due to the presence of consolidated rocky bottoms, some offshore samples could not be recovered.

The general estuarine pattern is characterised by a decrease in granulometry from coarse sand in the upper estuary to medium sand at both Shoalhaven and Crookhaven Heads. In the upper part of the estuary, coarse sand prevails with very coarse sand in the shallow water and finer fractions (medium to very fine sand) in the pools. The most diverse textural part of the river is located between Pig Island and the 10 km upstream of

Nowra Bridge. In this part, the river bank is composed of medium sand intercalated with finer sediments down to medium silt.

Downstream from Pig Island, medium sand prevails and the texture becomes finer near both entrances, reaching coarse silt just before Shoalhaven Heads and fine sand in front of Orient Point. Towards both entrances, the granulometry increases again to medium sand due to the penetration of marine sand transported by waves and wind at Shoalhaven Heads and the flood tide delta at Crookhaven Heads. Sediments were moderately sorted in the upper estuary, mostly poorly sorted upstream of Comerong Island, and moderately sorted to moderately well sorted around both entrances. The very poorly sorted mud sediments just west of Shoalhaven Heads can be explained by the low hydrodynamic conditions experienced in this area after the gradual closing of the entrance during the months prior to sampling.

In general, the beach granulometry is symmetrical, mesokurtic and gets coarser towards the northern ends of Culburra and Warrain-Currarong, and finer towards both ends of SMBCI. The coarsest beach sample of all was located near Lake Wollombola (1 φ). At SMBCI, the coarsest sample was located 1.5 km north of the Shoalhaven Heads entrance (1.21 φ), but medium sands inferior to 1.5 φ are found up to 5 km northwards of that. Beach samples are mostly moderately well sorted, with well sorted samples towards the northern ends of the embayments. The beach samples at SMBCI exhibited a similar pattern of longshore variation in grain size as disclosed by Wright (1970).

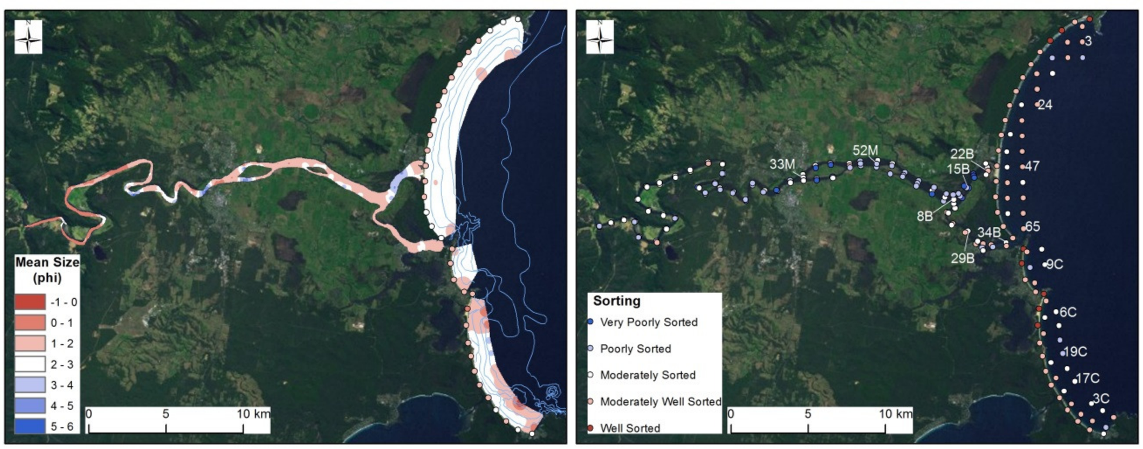

Fig.7: Modern surficial textural distribution of estuarine, beach and offshore sediments in the Shoalhaven costal compartment. Mean grain size (left) and Sorting degree (right). Samples analyzed for mineralogy are labelled.

Offshore granulometry was more homogeneous at SMBCI (mean = 2.4 φ and σ= 0.2 φ) and Culburra (mean = 2.3 φ and σ= 0.3 φ) than Warrain-Currarong (mean = 1.9 and σ= 0.6 φ). At SMBCI, finer sand was found adjacent to Comerong Island and around the 20m depth in the middle of the embayment, whereas coarser sands were found close to a rock reef near Gerroa and near the river entrance at Crookheaven Heads. The two shallow samples located at both ends of Culburra were composed of medium sand. Fine sands were found on the other three samples of this embayment, with ~10% of mud content in the deeper samples. At Warrain-Currarong, shallow water sands increased in size towards the north of the embayment, whereas coarser sands were found close to the offshore rock reefs and near Currarong. Two offshore samples adjacent to Kinghorne point were composed of very fine sand with mud content of 24%. The majority of the offshore samples was moderately well sorted (n=25) or moderately sorted (n=18), however poorly sorted samples also occurred (n=6). No trend in longshore sorting was observed for offshore samples. In general, the deep samples are less sorted at Culburra and Warrain-Currarong than at SMBCI.

As expected, quartz (64.3-89.9%) and feldspar (5.4-19.7%) are the most abundant minerals found throughout the study area (Table 1).

In the estuarine samples, Albite and Orthoclase are the more common form of feldspar with concentrations of up to 5.3% and 6.1%, respectively. Labradorite was also present in all samples but never more than 2.8%, while Microcline's concentration reached 1.9% in sample 29B, but wasn't present in sample 22B. Carbonates were absent, apart from 0.3 % found in sample 15B (Calcite) and 22B (Mg Calcite). Clay minerals were present in the form of Muscovite, Illite and Kaolinite. Muscovite was absent in samples 22B and 29B but its concentrations were the highest in the other samples, reaching 10.1% of the total weight in sample 15B.

Table 1: Mineralogy of surficial sediments (wt.%)

Sample	Chi-square	Quartz	Feldspars	Calcite	Mg Calcite	Muscovite	Illite	Kaolinite
33M	2.43	79.4	9.4	0	0	5.2	4	2.1
52M	3.11	79.6	14.4	0	0	3.3	1.6	1.1
8B	2.4	81.9	10.2	0	0	3.8	2.8	1.4
15B	2.41	64.3	16	0.3	0	10.1	5.8	3.6
22B	3.23	89.6	8.2	0	0.3	0	1.5	0.5
29B	3.17	89.9	8	0	0	0	1.3	0.8
3C	3.93	68.2	9.1	7.9	10.8	0	2.8	1.1
17C	2.68	90	6.3	0.5	1	0	1.9	0.2
19C	2.8	72.5	15.7	3.5	5.3	0	2.5	0.3
6C	3.22	87.7	5.4	1.7	2.5	0	2.3	0.4
9C	2.7	78.3	11.6	2.6	4.5	0	2.6	0.3
65	3.23	73.8	19.7	0.1	1.2	3	1.5	0.6
47	2.54	85.2	9.5	0.1	0.4	0	3.5	1.4
24	2.59	82.6	9.9	0.5	1.3	0.8	3.9	1
3	2.51	68.9	14.9	3.4	6	4.6	1.6	0.6

In the offshore samples, Orthoclase is the more common form of feldspar in 6 samples, its concentration varies from 2.4 to 5.4%. Microcline was predominant in sample 65 (13.8%), whereas Albide predominates in samples 24 and 3. Labradorite was also found in 7 samples but never exceeded 2.7%. Calcite and Mg Calcite were present in all samples and were responsible for more than 18% in sample 3C, but constitute less than 2% of the total weight in samples 17C, 65, 47 and 24. Illite and Kaolinite are also present in all samples, whereas Muscovite was only present in samples 65, 24 and 3.

Ongoing and future investigations

Far from being exhaustive, the analyses presented previously comprehend part of an ongoing research conducted as part of a PhD thesis, whose time frame for conclusion is schedule for the first semester of 2016.

More sedimentological and mineralogical analyses are being carried out such as carbonate content and roundness, while others such as SEM of Quartz grains and XRF are scheduled for later in 2014. Offshore use of sidescan, echosounder and sub-bottom profiler to better understand bedforms, transport and volume of sand available are planned for 2015, as well as estimation of longshore transport and bed shear stress, the calibration of the catchment model and the construction of estuarine, aeolian and shoreface models. Beach monitoring of the 10 profiles between Gerroa and Currarrong will be carried out until November 2015.

Conclusions

Management of the coast demands knowledge of the sediment budget of the compartment studied. This work presents preliminary results, ongoing investigations and planned research to understand sources, sinks, processes and magnitudes of sediment in the coastal area between Gerroa and Currarrong, southeastern Australia.

A suite of techniques including spatial, sedimentological, mineralogical and geophysical analyses is currently being used to model the Shoalhaven catchment and estuary, barrier-beach and nearshore process, in order to provide useful insights for coastal management.

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