CoastAdapt

Climate change impacts on beaches and estuary sediments

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Impact Sheet 1

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Contents

Disclaimer

Sediment – what is it and where does it come from?

The term sediment generally refers to inorganic and previously organic loose material that is, or has been, mobilised by physical agents including wind, waves, currents and gravity. Sediment is primarily characterised by its size and composition.

Descriptors of sediment grain size (diameter) range from clay (<4 µm) through silt (4 to 63 µm) and sand (>63 to 2000 µm) to gravel (>2 to 256 mm) (see Table 1). Some coastal environments, such as the deeper central basins of estuaries, are dominated by finer clay and silt sized material. Whereas other coastal environments, such as open coast beaches and rock platforms, are dominated by coarser sand and gravel-sized material.

Table 1: A typical grain size scale used to classify sediment size. Source: Friedman and Sanders 1978.

Gravel	Large cobbles	>128 – 256 mm
	Small cobbles	>64 – 128 mm
	Very coarse pebbles	>32 – 64 mm
	Coarse pebbles	>16 – 32 mm
	Medium pebbles	>8 – 16 mm
	Fine pebbles	>4 – 8 mm
	Very fine pebbles	>2 – 4 mm
Sand	Very coarse sand	>1000 – 2000 µm
	Coarse sand	>500 – 1000 µm
	Medium sand	>250 – 500 µm
	Fine sand	>125 – 250 µm
	Very fine sand	>63 – 125 µm
Mud	Silt	4 – 63 µm
	Clay	< 4µm

Sediment composition can include a wide variety of materials that reflects the geological history of the sediment. On a global scale, about 90-95% of sediment in the present-day coastal zone is derived from the chemical and physical breakdown of continental rocks into grains that consist of either a single mineral or subset of the minerals present in the original rock. As a consequence, the two most common minerals found in coastal sediments globally are quartz and clay minerals (Woodroffe 2002; Figure 1). Numerous other minerals may also occur in relatively minor amounts. This continent-derived sediment is delivered to the coast mostly by rivers..

In coastal environments where sediment composition is not dominated by a continental rock source— which includes a large section of the Australian coastline— the sediment is derived from either the hard body parts of marine organisms (e.g. shells and coral) or precipitated directly from seawater (e.g. ooids). The most common mineral found in these sediments is carbonate (Figure 1).

More than half of Australia's sandy coastline is composed of carbonate-rich sediment (Figure 2). Along the high energy open coastline of southern Australia, the carbonate source is the adjacent coastal shelf and includes the hard body parts of calcareous algae, bryozoans, molluscs, foraminifera and other organisms (James and Bone 2010).

In the protected gulfs and bays of the southern and western coastline the carbonate source is seagrass meadows and their associated infauna; including coralline algae, bryozoans, gastropods, bivalves and benthic foraminifera (Short 2014). Along Australia's western, northern and north eastern coastline, the source of carbonate sediment is from fringing coral reefs.

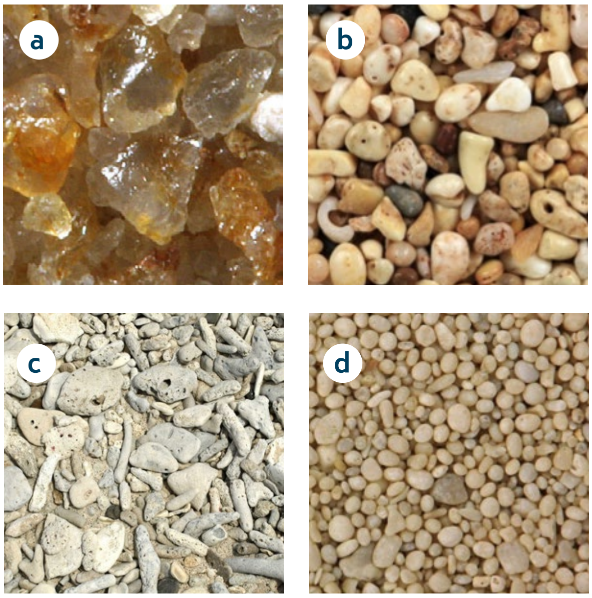

Figure 1: Photographs showing examples of quartz-rich and carbonate-rich coastal sand and gravel (clockwise).

(a) Sand composed of angular quartz grains typical of beaches adjacent to some of Australia's rivers.

(b) Sand composed of well-rounded, broken shell fragments typical of some beaches along Australia's temperate coasts.

(c) Gravel composed of sub-angular to well-rounded coral fragments typical of some beaches along Australia's tropical coast where there are adjacent fringing coral reefs.

(d) Sand grains composed of very well-rounded ooids that have precipitated from seawater, typical of some beaches on Australia's arid coast adjacent to broad shallow bays subject to high evaporation.

Sources: (a) Sand Atlas © Siim Sepp (www.sand-atlas.com/en/shape-of-sand-grains), (b) Sand Atlas © Siim Sepp (http://www.sand-atlas.com/en/shape-of-sand-grains/), (c) © 2016 Pixabay (https://pixabay.com/en/coral-coral-stones-beach-sand-334638/), and (d) Sand Atlas © Siim Sepp (www.sandatlas.org/limestone). Links accessed 19 May 2016.

In contrast, eastern Australia receives greater rainfall and has more rivers delivering continent-derived sediment to the coast (Figure 2). Consequently, quartz is generally the most abundant mineral type on eastern Australian beaches, but on average the sediments contain 20% carbonate and in some places this proportion can be much larger (Short 2006).

In coastal depositional environments there is generally a mixture of quartz, carbonate and clay minerals that vary in their relative proportions from place to place. As the name suggests, clay mineral grains have sizes less than 63 μm. Quartz and carbonate mineral grains are more resistant to breakdown and so they generally occur as sand. Gravel-sized sediment can include carbonate as whole shells or shell and coralline fragments, and continental rock fragments consisting of many mineral types.

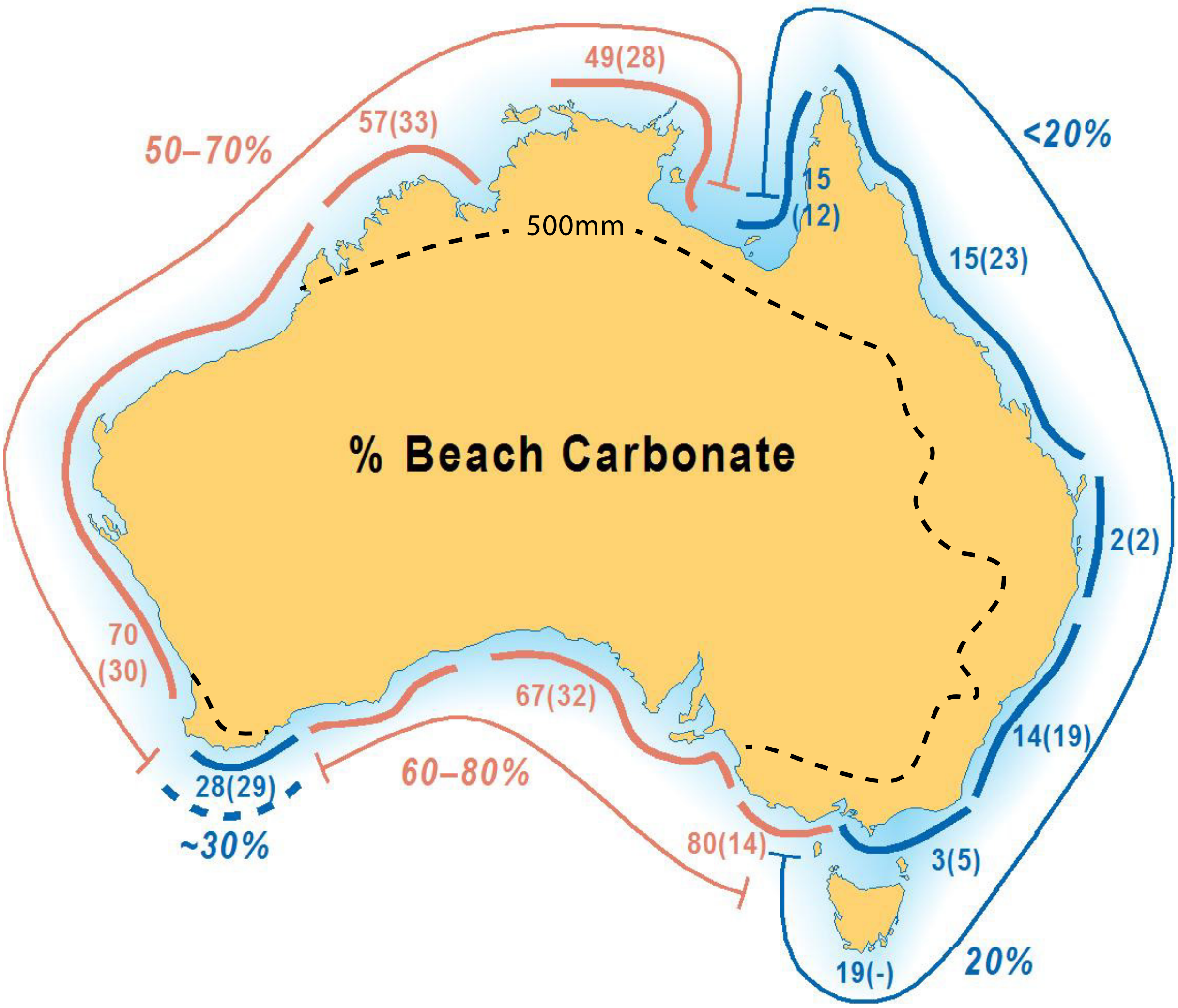

Figure 2: Percentage of carbonate in beach sands around Australia's coastline. Regional means and standard deviations (brackets) are indicated. The 500 mm rainfall isoline (dashed) indicates the wetter eastern coastline of the continent. Source: Short and Woodroffe 2009.

Why is knowledge of sediment important to coastal managers?

There are many reasons why coastal managers need to have an understanding of sediment types; three of the key reasons are listed.

An important physical attribute of many coastal habitats

The individual landforms of a larger morphodynamic system are generally associated with a narrow range of characteristic sediment size classes. For example, foredunes in a coastal barrier system are composed of fine to very fine sand, whereas intertidal flats in an estuary system are often composed of silt and clay (mud; Table 1).

A landform and its associated sediment determine the important physical attributes of a habitat. For example, intertidal mud flats are physical attributes of many mangrove habitats. Similarly, sandy foredunes are physical attributes of many coastal woodland and scrub habitats (Figure 3). Characterising the physical attributes of habitats, including the sediments, can be key to understanding spatial patterns of biodiversity.

An important component of ecosystem cycles

Nutrients occur in part as particles of organic detritus that are incorporated into the bed sediment of estuaries and coastal wetlands. The organic detritus either enters these systems from catchment runoff or results from the growth and die-off of algae and other flora and fauna within the estuary or wetland itself. Important for ecosystem health, these various biogeochemical processes related to these nutrients occur within bed sediments and the immediately overlying water column.

When the natural balance of nutrients is upset, however, these processes can have damaging effects. Excessive dissolved nutrients in the water column can lead to algal blooms, which result in increased particulate nutrients returning to the bed sediment. This increased microbial activity consumes oxygen, which can deplete oxygen levels in the overlying water column and cause fish kills.

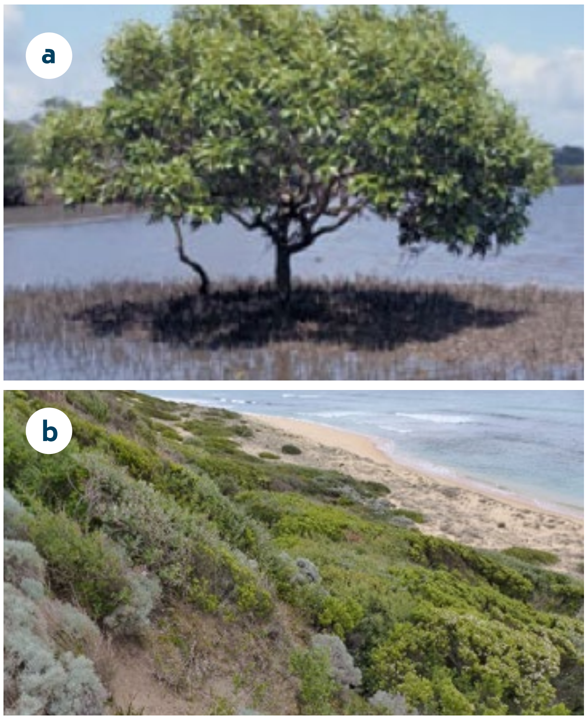

Figure 3: Morpho-sedimentological units, defined as coupled landform and sediment type, determine the physical attributes of habitats. Figure 3a shows intertidal mudflats which are the physical attributes of many mangrove habitats. Figure 3b shows sandy foredunes which are the physical attributes of many woodland and scrub habitats. Sources: (a) © State of Queensland, Department of Agriculture and Fisheries 2015 (https://www.daf.qld.gov.au/fisheries/habitats/marine-plants-including-mangroves/common-mangroves/grey-mangrove), (b) © Craig Boase (https://wildsoutheast.wordpress.com/). Links accessed 19 May 2016.

It determines the form and dynamics (morphodynamics) of beaches

In addition to wave characteristics (wave height and wave period), the size of the beach sediment influences the beach form and behaviour. For a given set of wave conditions, steep beaches are generally associated with coarser sand and gravel and gently sloping beaches are associated with finer sand. Beaches with an intermediate slope and nearshore bars are generally composed of medium sands; these are the most dynamic beaches and thus are associated with the greatest storm erosion hazard. Beaches that are safer for recreational swimming are related to the beach type, and thus the combination of sediment and wave conditions (Short 1999).

Climate impacts on coastal sediment

Global climate acting over geological time scales plays a direct role in determining the nature and availability of sediment. This climate control is largely exercised through:

- Atmospheric temperatures and humidity which influence the rates of chemical weathering of continental rocks to produce sediment.
- Changes in ocean chemistry and the impact on biological carbonate production and dissolution, as well as changes in ocean temperatures, which influence the chemical reaction potential to precipitate non-biological carbonate.
- Rainfall and runoff from continents influencing the rates of sediment delivery to the coast.

These are listed in order of length of time involved. Climate change predictions for the next century or so will have their greatest influence on coastal sediment through changes in ocean chemistry and rainfall and runoff because these processes are associated with the shortest time scale. Time scales associated with chemical rock weathering are so long that any influence will not become apparent until well beyond current planning and adaptation timeframes.

Coastal sediment budgets

The direct effect of climate change on delivery of sediment to the coastal zone can be explored using the sediment budget concept. Sediment budgets can be determined for a nested coastal system such as a coastal embayment for example, which might include one or more beaches, estuaries or river deltas (Figure 4). Similarly a budget can be determined for any of the components within the system.

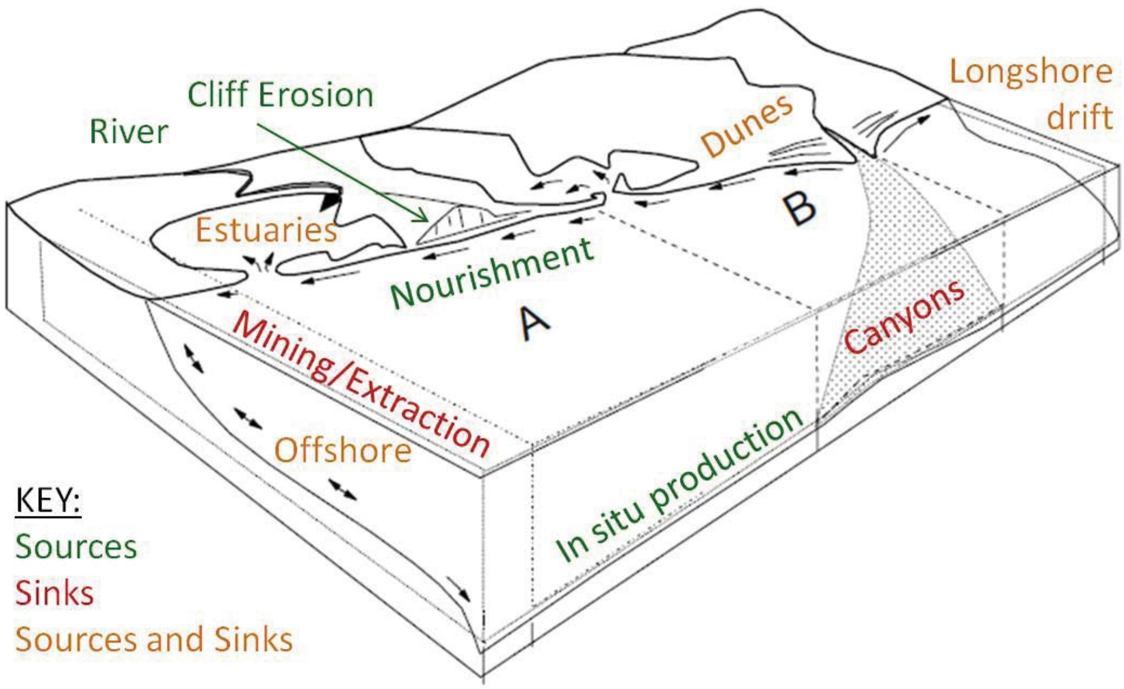

Figure 4: Conceptualised coastal sediment budget showing sediment sources, transport pathways and sediment sinks. Climate change can potentially influence the rate of sediment supply from sources and to sinks. This potentially leads to landform adjustments due to changing patterns of erosion and deposition. Source: Woodroffe et al. 2012.

A sediment budgeting exercise involves identification and (relative) quantification of all the sediment sources, transport pathways and sinks. Generally, sediment sources for the coastal zone include rivers, cliff erosion, in situ biogenic production, and input from the shelf and adjacent embayments. Sediment sinks generally include dunes, tidal inlets and estuaries, the shelf and adjacent embayments.

Changes in the rate of sediment supply can result in changes in the size, shape and presence of morphological features through sediment erosion and accretion. Erosion occurs locally in the system where the sediment delivery rate is less than the rate of removal of sediment. Accretion occurs locally where the delivery rate is greater than the removal rate.

Beach sediments and climate change

Recent and projected climate change is causing the sea level to rise, and as this continues it is anticipated that the shoreface seaward of the surf zone will be either a sink or a source for beach sediment, depending on the circumstances. Geological evidence of coastal response to historical sea-level rise suggests that different responses will occur depending on the shoreface slope.

On steeply sloping shorefaces, storm-driven net sediment transport seaward may be predominant, which means the lower shoreface will act as a sink for beach sediment (Figure 5a).

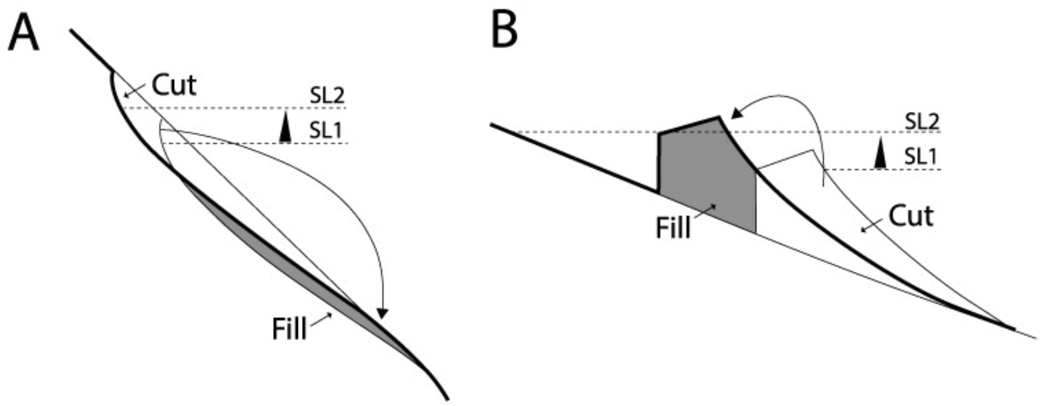

Figure 5: Potential styles of beach response to sea level rise, with decreasing substrate slope from left to right. Sea level rise is indicated by sea level SL1 increasing to SL2. (A) Steeply sloping substrate with offshore transport under sea level rise and the lower shoreface becoming a sediment sink. (B) Gently sloping shoreface with onshore transport under sea level rise and the shoreface becoming a sediment source. Source: Cowell et al. 1995.

On gently sloping shorefaces, as the present day coastline is inundated by sea-level rise, net sediment transport landward by constructive wave conditions may be predominant, which means the lower shoreface will act as a source for beach sediment (Figure 5b). Note that this does not necessarily mean that there will not be shoreline recession. Large-scale coastal behaviour is presently an active area of research and there is ongoing debate regarding the circumstances under which the lower shoreface will act as a source or sink for beach sediment with rising sea level.

At locations where present day rivers are contributing sediment directly to the open coast and regional rainfall is expected to change, there may be a significant change in the sediment budget. If regional rainfall and runoff are expected to increase there may be increased sediment delivered to the coast, and vice versa if they are expected to decrease. A moderating factor will be the response of catchment vegetation to climate change, which can considerably influence the sediment load carried by rivers.

A reduction of the sediment supply by a river to the open coast can cause beach erosion; initially adjacent to the river mouth and then progressively in the downdrift direction as the sediment supply rate from the river is reduced below the sediment removal rate by waves. Alternatively, an increase in river sediment supply can further nourish beaches adjacent to the river mouth initially and then progressively downdrift (Figure 6).

Whether a beach system erodes or accretes, the intertidal beach habitat adjacent to the shoreline will still exist; it will simply migrate with its infauna presumably moving with it. Shoreline recession that results from a reduced supply of beach sediment will progressively reduce habitat related to coastal dune fields.

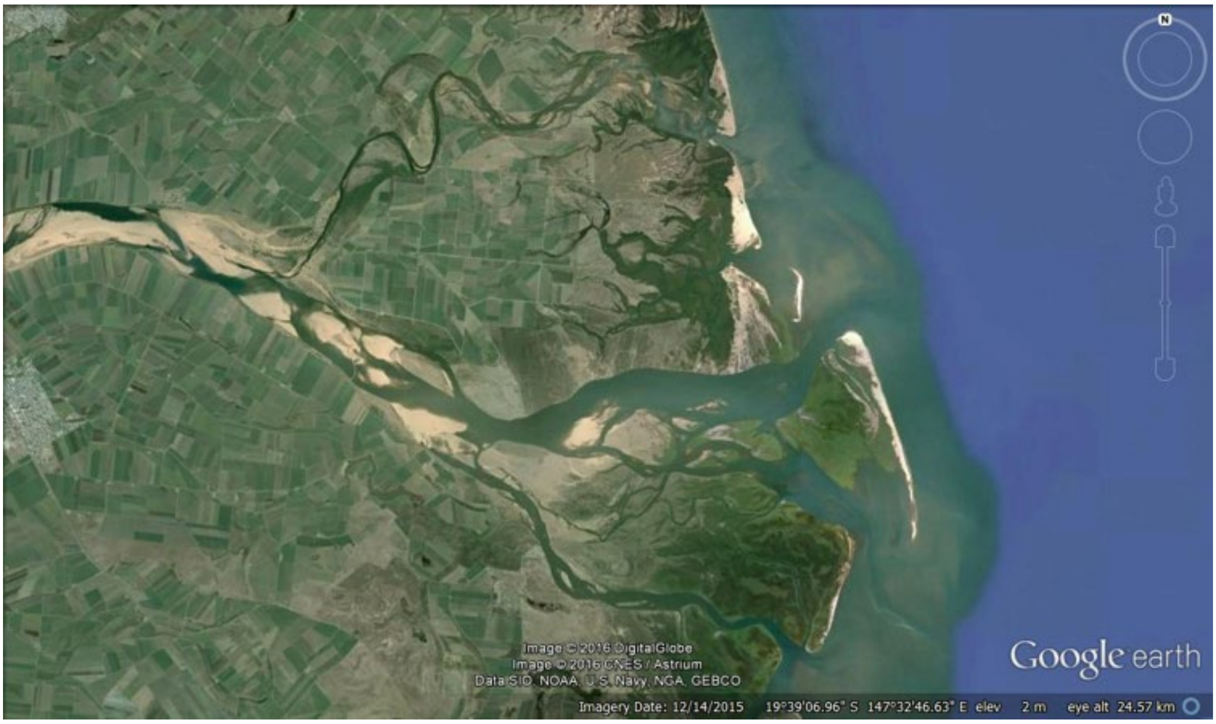

Figure 6: The Burdekin River presently delivers sediment directly to the open coast building a wave-dominated delta. Delta sands are deposited in shoals immediately seaward of the river mouth, which are re-worked by waves and currents along the coastline. Presently the river's sediment delivery rate exceeds the removal rate by waves, thus the coastline immediately adjacent to the river mouth is accreting. This naturally nourished zone is also progressively nourishing downdrift beaches with sediment. Rainfall projections for the Burdekin region indicate a -15% to +10% change on 1990 values out to the end of the century for a medium emissions scenario (CSIRO and Bureau of Meteorology 2015). This could result in a larger reduction or smaller increase in runoff and sediment delivery rate to the coast over the coming decades, which would compound with any sediment loss potentially arising from sea level rise. Source: © Google Earth (accessed 13 May 2016).

The actual outcome of a climate-induced change to a beach's sediment budget will depend on the net effect of all the budget components. Sea-level rise impacts on the shoreface may increase the negative or partially reverse the positive impact of a change in river sediment supply, if the rise in sea level results in the loss of beach sediment to the shoreface or dunes. Sustained changes in wave direction may cause a change in the rate of alongshore sediment supply from one embayment to the next, or a reversal in that supply. These are just a few examples of the numerous outcomes possible when all permutations of the relevant sources and sinks for a given system are considered.

Estuary sediments and climate change

As described previously, if regional rainfall and runoff are expected to increase then there may be increased sediment delivered to the landward end of estuaries, and vice versa if they are expected to decrease.

In addition, sea-level rise will potentially change sediment delivery into the estuary from the open coast. For some estuaries it will deepen the entrance channel, thus improving the hydraulic efficiency, whereas for other estuaries shoaling may keep up with sea-level rise and there may be little change. Increasing the hydraulic efficiency of an entrance can lead to stronger tidal currents, greater sediment transport rates and significant changes to estuary morphology.

Whether an estuary acts as a significant sink or a source for open coast sediment depends on whether the tidal currents through the entrance are flood- or ebb-dominant, which depends in a complex manner on the internal estuary morphology. As a general rule, a barrier-type estuary (Figure 7) without large intertidal areas is flood dominant and one with large intertidal flats is ebb dominant. Sea-level rise has the potential to shift the tidal regime of an estuary entrance from flood- to ebb-dominant, or vice versa, thus impacting the overall estuary (and open coast) sediment budget.

In many estuaries there are strong gradients in sediment grain size that are associated with changes in habitat type. For example, sediment can change from sand in the flood tide delta near the ocean entrance to mud in the central basin of the estuary and back to sand in the river delta feeding into the landward end of the estuary (Figure 7). As climate change impacts the sediment supply rate to the estuary and sea-level rise changes the entrance conditions, this sediment zonation will adjust commensurately with the morphological adjustments. This can have a knock-on effect; changing the relative size, location and connectivity of habitats within the estuary.

Climate change is also likely to impact biogeochemical cycles that occur within the bed sediment. Increased water temperatures can lead to longer periods of stratification. Stratification prevents mixing and exposure of bottom water to the atmosphere to become re-oxygenated. Consequently, extended periods of stratification will result in pore water within the sediment becoming progressively depleted of oxygen as microbes process the nutrients in the sediment. Turning sediment pore water anoxic can facilitate further chemical processes that may release toxic contaminants from the sediment into the water column.

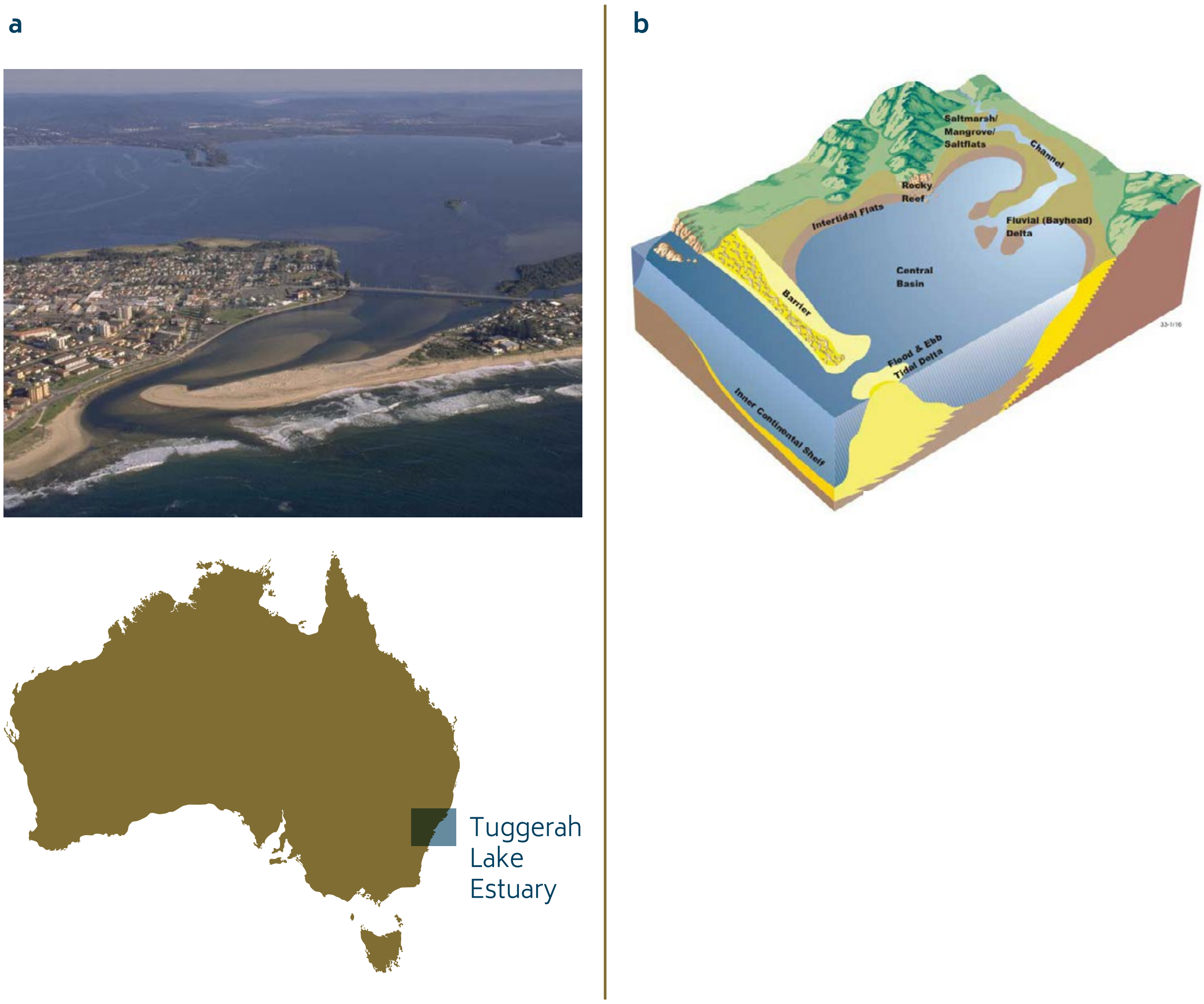

Figure 7: Estuary processes.

(a) Tuggerah Lake estuary is presently being infilled from the landward end by sediment delivered from rivers building sandy fluvial (bayhead) deltas and also from the seaward end by waves and tides building a sandy flood tide delta. Silts and clays coming down the rivers also reach the intertidal mud flats and central basin of the estuary and settle there. Source: : © State of New South Wales and Office of Environment and Heritage 2016.

(b) There are a wide range of other morphological units and associated sediment types in estuary systems. Jointly these morpho-sedimentological units define the physical attributes of habitats. Coastal rainfall projections for this region are increased summer and autumn rainfall and reduced winter and spring rainfall. It is not clear, but there may be a change in sediment delivery rate to the fluvial deltas and central mud basin over the coming decades due to these changes in rainfall and runoff (CSIRO and Bureau of Meteorology 2015). Sea level rise along this section of the coastline is projected to be larger than the global average. If sediment supply along the open coast does not keep up, this will deepen the estuary entrance and increase tidal exchange between the estuary and ocean. This will compound the adjustments in estuary morphology and associated sediment zonation resulting from climate change impacts on river sediment supply. Source: © OzCoasts (Geoscience Australia) 2016.

Summary

Treatment of the topic in this paper is not exhaustive. It briefly highlights some of the reasons why understanding sediment-related processes is important when managing the coastal zone. Furthermore, it demonstrates that climate change and sea-level rise over the next century will have direct and indirect impacts on coastal sediments.

Sediment includes a range of grain sizes broadly described as mud, through sand, to gravel. Coastal sediment is composed of numerous mineral types, but is predominantly a mix of quartz, carbonate and clay minerals. In highly productive environments such as estuaries and coastal wetlands, sediments also include a significant proportion of particulate nutrients or organic matter.

Over management time frames, sea-level rise will result in the most significant impacts to coastal sediment budgets in Australia, potentially reversing the role of present day sediment sources and sinks. Projected changes to rainfall and runoff along Australia's east coast have the potential to change the rate of sediment supply to estuaries and the open coast by rivers. Where river sediment supply is minimal along Australia's carbonate-rich southern, western and northern coastlines, climate change impacts on rates of carbonate production may have an effect on sediment supply.

Changes to coastal sediment budgets drive a response in coastal morphology and related sediment zonation. One of the knock-on effects from this response is that there could be changes to the size, location and connectivity of habitat types within coastal systems.

The connection between estuarine sediments and the overlying water column, which is facilitated by biogeochemical processes, will also be impacted by climate change. Increases in temperature and salinity may extend periods of estuary stratification, which will promote the development of anoxic sediment pore water and the release of toxins from the sediment.

Effective coastal management needs to consider sediments and related processes and the likely impacts of climate change. These impacts are difficult to generalise, however, because regional and site specific factors have a strong influence. Management of a particular coastal system should include site-specific investigation of sediments and related processes to a level commensurate with the risk level required to be managed.

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