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# The influence of coastal reefs on spatial variability in seasonal sand fluxes

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ABSTRACT

The effect of coastal reefs on seasonal erosion and accretion was investigated on 2 km of sandy coast. The focus was on how reef topography drives alongshore variation in the mode and magnitude of seasonal beach erosion and accretion; and the effect of intra- and inter-annual variability in metocean conditions on seasonal sediment fluxes. This involved using monthly and 6-monthly surveys of the beach and coastal zone, and comparison with a range of metocean conditions including mean sea level, storm surges, wind, and wave power. Alongshore 'zones' were revealed with alternating modes of sediment transport in spring and summer compared to autumn and winter. Zone boundaries were determined by rock headlands and reefs interrupting littoral drift; the seasonal build up of sand over the reef in the south zone; and current jets generated by wave set-up over reefs. In spring and summer, constant sand resuspension and northerly littoral drift due to sea breezes allowed a sand ramp to form in the South Zone so that sand overtopped the reef to infill the lagoon. This blocked the main pathway for sand supply to downdrift zones which subsequently eroded. In autumn and winter, with the dominance of northwesterly storms and reversal in the direction of littoral drift, the South Zone eroded and sand travelled through the lagoon in the current jet to nourish the northern beaches. Inter-annual and seasonal variation in sea level, storm frequency and intensity, together with pulsational effects of local sand fluxes at Yanchep due to inter-seasonal switching in the direction of littoral drift determined marked differences in the volumes of seasonal sand transport. These seasonal 'sediment zones' highlighted interesting and unexplored parallels between coasts fronted seaward by coral reefs and rock formations.



## 1. Introduction

Perched beaches are underlain or fronted seaward by hard structures that are shallowly buried or outcrop above the sediment (Gallop et al., 2012b). 75% of the world's coast is rocky (Davis, 1996) and global estimates of the area of coral reef coverage range between 112,000 to 393,0000 km$^2$ (Spalding and Grenfell, 1997). Beaches can be perched on all types of rock, such as beachrock that occurs in tropical as well as temperate regions such as Australia, Greece, Brazil, Israel and the Seychelles (e.g. Vousdoukas et al., 2007); limestone such as in southwestern Australia (Playford et al., 1975; Gallop et al., 2011a,b); and sand stone such as in Recife, Brasil (Branner, 1904). Many beaches that are perched on structures in the cross-shore direction also have lateral structural boundaries that form embayed and pocket beaches. These beaches are associated with interrupted longshore sediment transport due to their indentation; trapping-effects and hence limitations in sediment exchange to adjacent beaches (Storlazzi and Field, 2000; Ranasinghe et al., 2004; Bowman et al., 2009). The presence of reefs and platforms, and the lithological mix is a key determinant of coastal complexity (Porter-Smith and McKinlay, 2012) and there is a large gap in knowledge of how reefs and platforms affect sediment transport (Larson and Kraus, 2000; Stephenson and Thornton, 2005; Naylor et al., 2010). McNinch (2004) stated that while many coastal geologists have suggested that framework geology plays a key role in determining large-scale and long-term shoreline behaviour (e.g. Demarest and Leatherman, 1985; Riggs et al., 1995; Kraus and Galgano, 2001); it is unknown how it influences shorter-term coastal morphodynamics, although the extent, and mechanisms are still unclear. For example, in Hawaii, many beaches are eroding creating a societal hazard while others are accreting despite an increase in mean sea level (MSL) (Norcross et al., 2002). Moreover, often eroding and accreting beaches are adjacent to each other presumably because of variability in sediment supply due to spatially-variable topography (Fletcher et al., 1997). Therefore, to investigate how coastal reefs influence coastal morphodynamics over months and seasons, the current research focused on Yanchep Lagoon in southwestern Australia, where sandy beaches are perched on calcarenite limestone reefs.

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The coast of southwestern Australia consists of low bluffs and extensive limestone reefs and platforms alternating with sandy beaches (Bird, 1985; Semeniuk and Searle, 1987; Collins, 1988). Spring and summer are dominated by strong, southerly sea breezes that blow parallel to the coast and result in northerly littoral drift. Winter is dominated by storms, often from the northwest which can reverse the direction of littoral drift (Kempin, 1953; Masselink and Pattiaratchi, 2001). There are limited records of temporal variability in beach morphology in Western Australia, but it has been suggested that a key driver of beach growth and recession is cumulative longshore winds (Clarke and Eliot, 1983; Eliot and Travers, 2011). The rate of northerly littoral drift in southwestern Australia due to the longshore energy flux driven by wind waves was estimated as 150,000 $m^3$ $yr^{-1}$ by Pattiaratchi et al. (1997), and between 138,000 and 200,000 $m^3$ $yr^{-1}$ by Tonk (2004). On a beach perched on a limestone platform in Cottesloe (Fig. 1a), plentiful sediment supply in summer in combination with smaller and less-steep waves and less storm surges causes the limestone platform to be covered in sand. This sand is eroded in autumn and winter due to more frequent storm-surges, steeper waves, and northwesterly winds (Doucette, 2009). On a finer temporal scale, the influence of sea breezes and storm events on sand transport was investigated hourly and daily at Yanchep Lagoon in 2010 (Gallop et al., 2011a,b; 2012a). Longshore variation in reef topography had a dominant influence on the mode and magnitude of cross-shore and longshore sand transport due to wave refraction, current jets and scour-steps. Research reported in the current paper examines the cumulative effect of sea breezes in spring and summer; and of storm events during autumn and winter on the coastal morphology at Yanchep Lagoon.

The aim was to investigate the effect of reefs on seasonal erosion and accretion. Objectives were to: (1) examine how alongshore variation in reef topography drives alongshore variation in the mode and magnitude of seasonal beach erosion and accretion; and (2) understand the effect of intra- and inter-annual variability in metocean conditions on seasonal sediment fluxes. To achieve this, sub-aerial beach surveys were undertaken monthly for two years, and hydrographic surveys were measured five times during late summer and late winter, out to 10 m above MSL. Numerical models using XBeach (Roelvink et al., 2009, 2010) were used to determine how the coastal reefs influence currents at Yanchep.

## 2. Study area

### 2.1. Geological setting

The coastal bathymetry of southwestern Australia is dominated by a series of shore-parallel reefs of calcarenite limestone. These reefs are present from 20 km offshore (Fig. 1a; Playford et al., 1975; Semeniuk and Johnson, 1982), to the coast such as at Yanchep, located 60 km north of the City of Perth (Fig. 1a, b). The beaches of Yanchep Lagoon face southwest and consist of well-sorted medium sand with $d_{50}$ of 0.4 mm (Murphy, 2011) made of mostly quartz and skeletal material (Semeniuk and Johnson, 1982). The topography of the reefs varies alongshore, with higher, more continuous reefs in the south that enclose a coastal lagoon; and deeper, patchy reefs towards the north (Fig. 1b). There is a 'bombora', defined as a small shallow reef that creates a surf break, north of the lagoon exit that focuses wave energy on the reef where they break; and forces swell to refract. At the northern end of the beach, the Club Capricorn groyne was built in 1971.

### 2.2. Climatology

Southwestern Australia is influenced by three wind systems: sea breezes; low-pressure storms; and high-pressure calm periods (Steedman and Craig, 1983). Spring and summer (September to February) are dominated by strong and persistent south–southwesterly sea breezes. On a typical sea breeze day, morning winds are easterly with

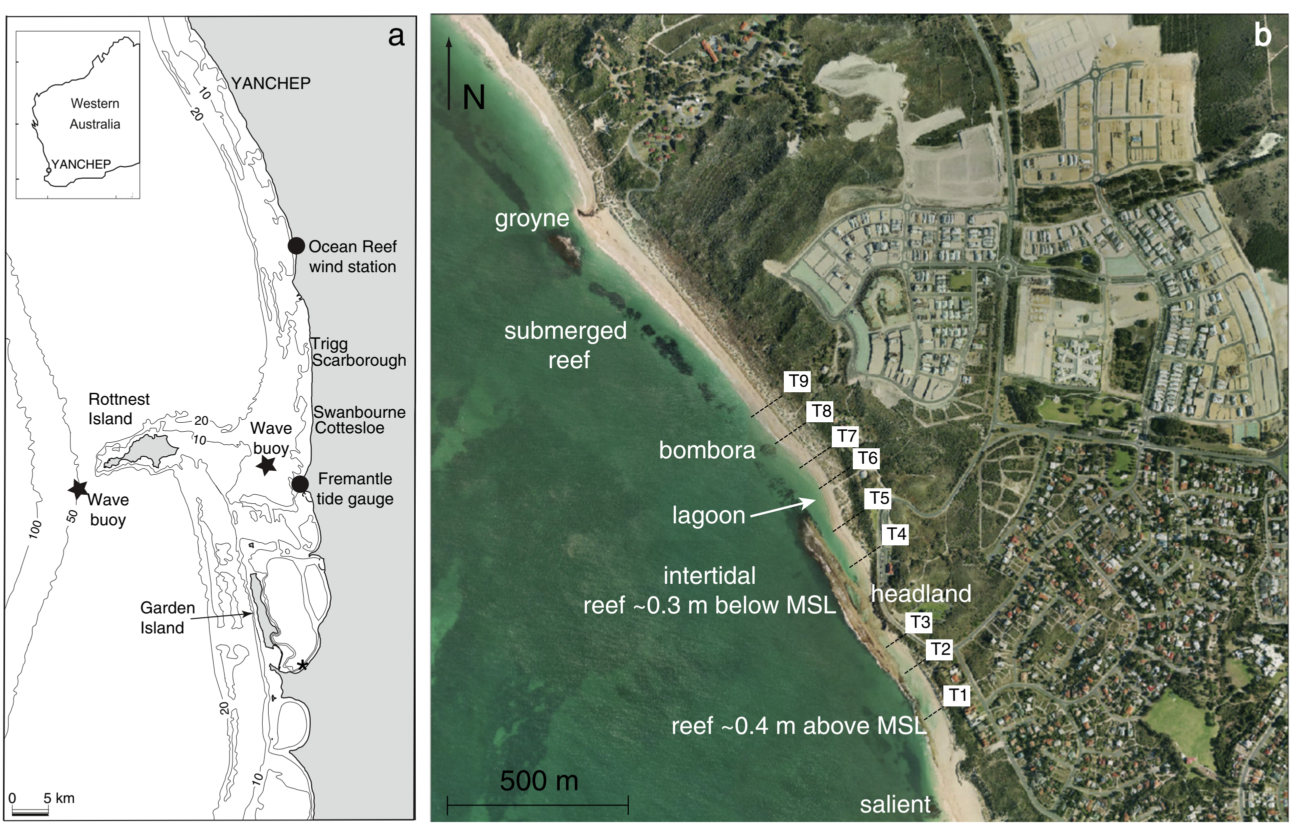


**Fig. 1.** (a) Western Australia and sites of interest; and (b) sub-aerial beach transects at Yanchep Lagoon that were surveyed monthly (photo source: Landgate).