

THE RELATIVE CONTRIBUTIONS OF WAVE POWER AND SEA LEVEL TO COASTAL EROSION IN REEF-FRONTED SANDY BEACHES

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INTRODUCTION

Coastal erosion in sandy beaches can be caused by numerous factors. Examples include wave energy, sea level, riverine runoff, terrain subsidence, and climate oscillations. Fringing reefs impose an additional layer of complexity to the morphodynamics of such systems. They act as rigid structures that can both dampen wave energy and induce intricate wave-induced circulation patterns. It has been hypothesized that, when compared to open-ocean beaches, wave-induced erosion at reef-fronted beaches is more sensitive to changes in the sea level. The reason for this is that fringing reefs can act as a physical barrier that shelters the shoreline from incoming wave energy, thereby leading to lower shoreline variability during periods of low sea level and higher shoreline variability during periods of high sea level. It has not been quantified, however, what are the relative contributions of wave power and sea level on sandy beaches fronted by fringing reefs, nor a systematic comparison between reef-fronted and open-ocean sandy beaches has been conducted. The aim of this research is to compare three distinct beaches with increasing abundances of fringing reefs to quantify such relative contributions to test this hypothesis.

METHODOLOGY

We investigated three beaches along the Perth metropolitan coastline: (1) Floreat Beach, with no reefs; (2) Pyramids Beach, with an intermediate abundance of reefs; and (3) Garden Island, with a high abundance of reefs (Figure 1). Their shoreline time series were extracted from satellite imagery publicly available for the period between 1987 and 2020 (Vos et al., 2019). A total of 150 synthetic transects per beach were evaluated over 3 km of coastline (uniform spacing of 20 meters between each transect). Hourly sea level data were extracted from the Fremantle tide gauge, managed by the Western Australia Department of Transport (WA DoT). Wave data (significant height, average period, and peak direction) were extracted from ERA5 reanalysis datasets for a coordinate 60 km offshore. From these, the directional wave power was calculated then, for each beach, decomposed into cross-shore and alongshore components based on the average shoreline orientation of each beach. We employed an Empirical Orthogonal Function (EOF) analysis on the transects time series (Miller & Dean, 2006). Across all beaches, the first EOF spatial mode represented the overall beach width. We modeled the first EOF temporal mode (normalised to mean 0 and standard-deviation 1) with a linear regression of a surface of the form $f(x,y)$ defined as $s = A + (B + Cy)x$, where x is the cross-shore component of the monthly-averaged wave power (normalised to standard-deviation 1), y is the monthly-averaged sea level (normalised to mean 0 and standard-deviation 1), and A , B , and C are

constants that define the optimal surface fit. This formula can be thought of as a constant shoreline A plus an expression $(B + Cy)x$ that represents the rate of change of the shoreline due to wave power, being C a term that quantifies how sensitive the wave-induced erosion is to different sea level conditions. As such, the term C is expected to increase with the abundance of fringing reefs. The relative contribution of wave power was defined as the expression $(\partial s / \partial x)^2 / ((\partial s / \partial x)^2 + (\partial s / \partial y)^2)$ and the relative contribution of sea level was defined as the expression $(\partial s / \partial y)^2 / ((\partial s / \partial x)^2 + (\partial s / \partial y)^2)$. Such derivatives can be interpreted as sensitivities due to wave power (x) and sea level (y). Also, as each of these fractions ranges from 0 to 1 and, when added, they add up to 1, each one of these relative contribution terms can also be interpreted as percentages. Finally, as both wave power (x) and sea level (y) change with time, we considered the average values of these squared as the representative ones for the relative contributions of wave power and sea level.

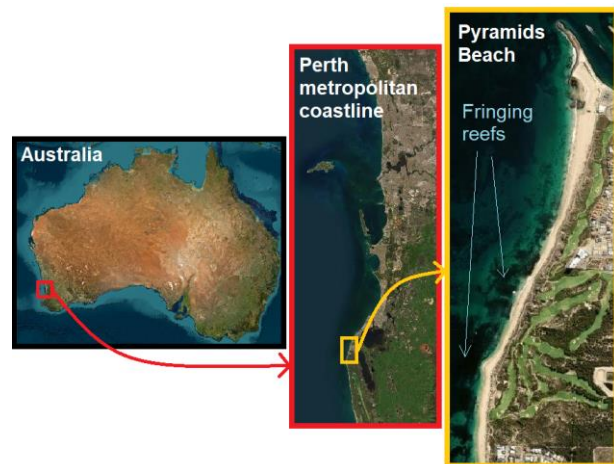


Figure 1 - Aerial view of Australia (left), the Perth metropolitan coastline (middle), and Pyramids Beach (right), one of the three beaches considered in this study, which features an intermediate abundance of fringing reefs.

PRELIMINARY RESULTS AND DISCUSSION

The first EOF mode explains 75% of Floreat Beach, 52% of Pyramids Beach, and 54% of Garden Island. The C parameter from the regression equation, which indicates how sea level affects wave erosion, increased with the abundance of fringing reefs, as expected. Its values were -0.05 for Floreat Beach (no reefs), -0.18 for Pyramids Beach (intermediate abundance of reefs), and -0.21 for Garden Island (high abundance of reefs). The relative contributions of wave power and sea level were, respectively, 99% and 1% for Floreat Beach, 86% and 14% for Pyramids Beach, and 63% and 37% for Garden

Island. As such, the overall beach width, represented by the first EOF mode, always presented itself as more sensitive to wave power than to sea level. However, the relative contribution of sea level increases as the abundance of fringing reefs increases, which corroborates the initial hypothesis. That is, these results indeed suggest that fringing reefs act as physical barriers during low sea level periods, protecting the shoreline from wave energy. Consequently, these results also provide quantitative insights on how coastlines that are currently being sheltered by fringing reefs might behave during extended periods of elevated sea levels.

REFERENCES

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