MIGRATION AND WELDING OF AN ESTUARINE BARRIER-SPIT DRIVEN BY DELTA EVOLUTION AND STORMS

Michael Kinsela, University of Newcastle, michael.kinsela@newcastle.edu.au
Chris Owers, University of Newcastle, chris.owers@newcastle.edu.au
Hannah Power, University of Newcastle, hannah.power@newcastle.edu.au
Tom Doyle, Department of Planning & Environment, thomas.doyle@environment.nsw.gov.au
David Hanslow, Department of Planning & Environment, david.hanslow@environment.nsw.gov.au

INTRODUCTION

As sea levels rise globally in response to anthropogenic climate change, coastal depositional systems that persist in dynamic equilibrium with accommodation space, sediment supply and hydrodynamic processes may begin to respond by redistributing sediment, causing erosion or migration of landforms that may have appeared as stable over previous decades to centuries. In contrast, systems that have adjusted to inherited or changing boundary conditions over historical times offer insights on the modes and timescales of potential future change in remobilised coastal systems.

We investigate the coupled evolution of an estuarine sand barrier-spit and tidal delta over the past century, focusing on storm-driven erosion and overwash during recent decades that triggered recurrent barrier migration (rollover), ultimately welding it to the bedrock valley framework. Historical aerial photographs and recent high-resolution satellite and aerial imagery are analysed to map morphological change and calculate decadal trends in shoreline and barrier migration. Ocean wave and water level conditions between image dates capturing notable responses are analysed using wave and tide records from nearby measurement stations.

SETTING

The Deeban sand barrier system is a semi-sheltered wave-dominated barrier-spit located within the entrance of the Port Hacking drowned river-valley estuary in southeast Sydney, Australia (Figure 1). It extends 1.2 km north-west from Bonnie Vale Beach on the southern shore with a curved ocean-facing (eastern) shoreline and barrier width between 50-100 m. The barrier-spit is the supratidal expression of a broader flood-tide delta complex (4 km^2 area) that partially fills the lower estuary.

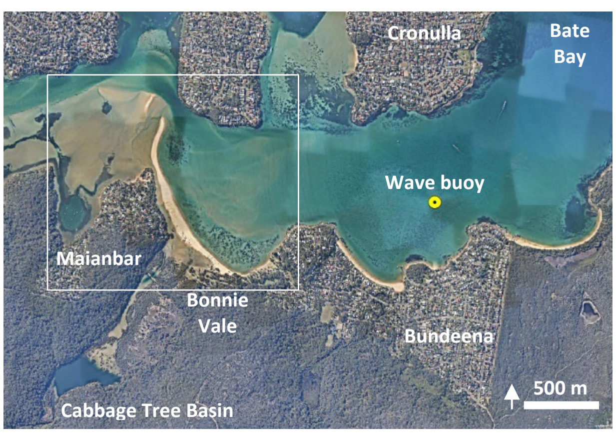

Figure 1 – Location of Deeban barrier-spit and delta inside Port Hacking estuary from a September 2019 aerial image with wave buoy position indicated. Source: Nearmap.

Until recently, a tidal inlet running from the northern end of the spit along the western shore of the barrier separated it from the mainland, connecting Cabbage Tree Basin back-barrier tidal lagoon and mangrove habitat to the estuary.

OBSERVATIONS

In February and May 2020, barrier washover during notable but not exceptional storm events caused the central barrier to roll over and ultimately weld to the mainland (Figure 2). The tidal inlet to Cabbage Tree Basin became heavily constricted after the February event, restricting estuarine water exchange with the tidal lagoon and causing mangrove dieback, and the inlet was completely closed off during the May event.

Figure 2 – Aerial images of the Deeban barrier-spit system from August 2010 (upper) & June 2021 (lower). The white box in Figure 1 shows image extents. Source: Nearmap.

High rainfall between February and May and the constricted tidal inlet allowed the water level to rise in Cabbage Tree Basin and a new inlet opened through the southern end of the barrier during the May 2020 storm event (Figure 2). Rapid response of the new inlet and flood/ebb deltas to the evolving hydrodynamic regime caused significant erosion of Bonnie Vale Beach and its foreshore campground, and the burial of seagrass meadows on the estuary flood delta complex. Sand and rock bags were deployed along Bonnie Vale Beach and the southern shore of the new inlet to stabilise the shoreline and mitigate impacts to the campground.

Review of historical aerial imagery shows that the modern barrier-spit with back-barrier tidal inlet to Cabbage Tree Basin formed sometime after 1930 and before 1950 and persisted in that general state until the 2020 welding event (Figure 3). The earliest aerial imagery (1930) shows an open entrance to Cabbage Tree Basin fronted by sand shoals and a NW-SE oriented sand spit to the north. These 'Middle Ground' sand shoals are thought to have formed from the dredging and dumping of some 350,000 tonnes of sand in 1901-02 to improve navigability (Albani & Cotis, 2014).

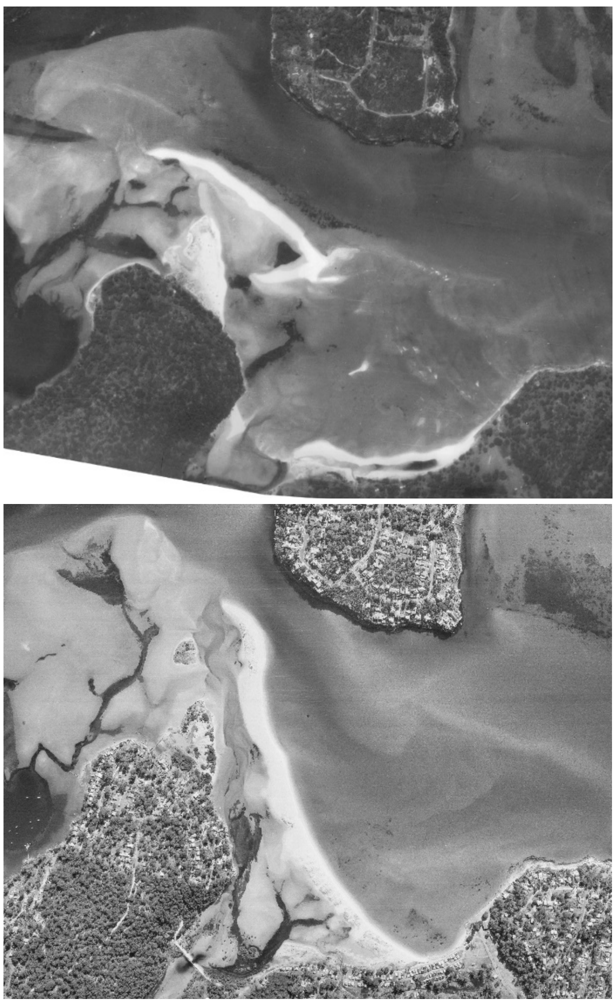

Figure 3 – Historical aerial images of Deeban barrier-spit and sand shoals captured in 1930 (upper) & 1970 (lower). Sources: Shire Maps and NSW Spatial Services.

METHODS

Airborne Lidar surveys with dual topography and bathymetry sensors covering the entire NSW coast were carried out by Fugro Australia under contract to the NSW Government in 2018 (Kinsela et al. 2022a). The mapping included estuary entrances and covered the Deeban flood-tide delta complex and barrier-spit system (Figure 4a), which was surveyed on 18/8/2018. The Lidar survey provides a detailed baseline terrain model of the site prior to the 2020 storms and a review of Nearmap imagery between August 2018 and February 2020 shows only minor change during the winter of 2019.

Field terrain surveys were carried out in December 2020 and June 2021 after the rollover and welding of the barrier-spit in May 2020. Bathymetry surveys were carried out using two jet skis equipped with RTK-GNSS positioning and CeeScope single-beam echosounder systems. The surveys covered the delta sand shoals fronting the barrier-spit at 10 m line spacing (Figure 4b) and the June 2021 jet ski survey operation was captured in Nearmap imagery seen in Figure 2. Topography surveys were carried out on foot using RTK-GNSS systems along cross-shore transects at 20 m spacing (Figure 4b). Terrestrial laser scanner surveys were also carried out during both field survey campaigns. The December 2020 survey was limited to accessible terrain whereas the June 2021 survey covered the entire barrier-spit and the northern and southern back-barrier and inlet environments.

A Sofar Spotter wave buoy was deployed in 6.1 m water depth within the estuary entrance at the location shown in Figure 1 on 30/6/21 to develop a relationship between the offshore wave climate and shallow-water waves incident on the delta complex and barrier-spit (Figure 4c). The wave buoy was temporarily removed between 7/12/21 and 1/3/22 due to summer vessel traffic. The deployment remains active and has collected almost 12 months of data at the time of writing. Wave buoy deployment and wave data processing methods have been described by Kinsela et al. (2022b).

The evolution of the flood delta and barrier-spit system over the past century is captured in historical aerial imagery from 1930, '51, '56, '61, '65, '70, '79, '83, '90, '94, 2002 and 2005. Nearmap provides high-resolution (0.6 m) relatively frequent (few-several months) aerial imagery coverage of the site from 2010 to present. Planet provides slightly coarser but more frequent (every few days and monthly cloud-free mosaics) satellite imagery covering the site. SkySat was also tasked to image the site in April, May and June 2021 to capture detailed satellite imagery around the time of field operations.

All of the aerial and satellite imagery described above was acquired, georeferenced (where necessary) and integrated in a GIS. The imagery was carefully reviewed to identify and describe morphological change between successive images and to isolate barrier response to storm events captured by higher frequency imagery. Offshore wave data from the Sydney (Long Reef) wave buoy and ocean water level data from the Bundeena and Sydney Harbour tide gauges were analysed to identify high sea level and wave conditions coincident with event responses. Image segmentation was used to map change in sub-aerial (barrier-spit) and sub-aqueous (delta shoal) morphology through time and to track barrier and shoreline migration.

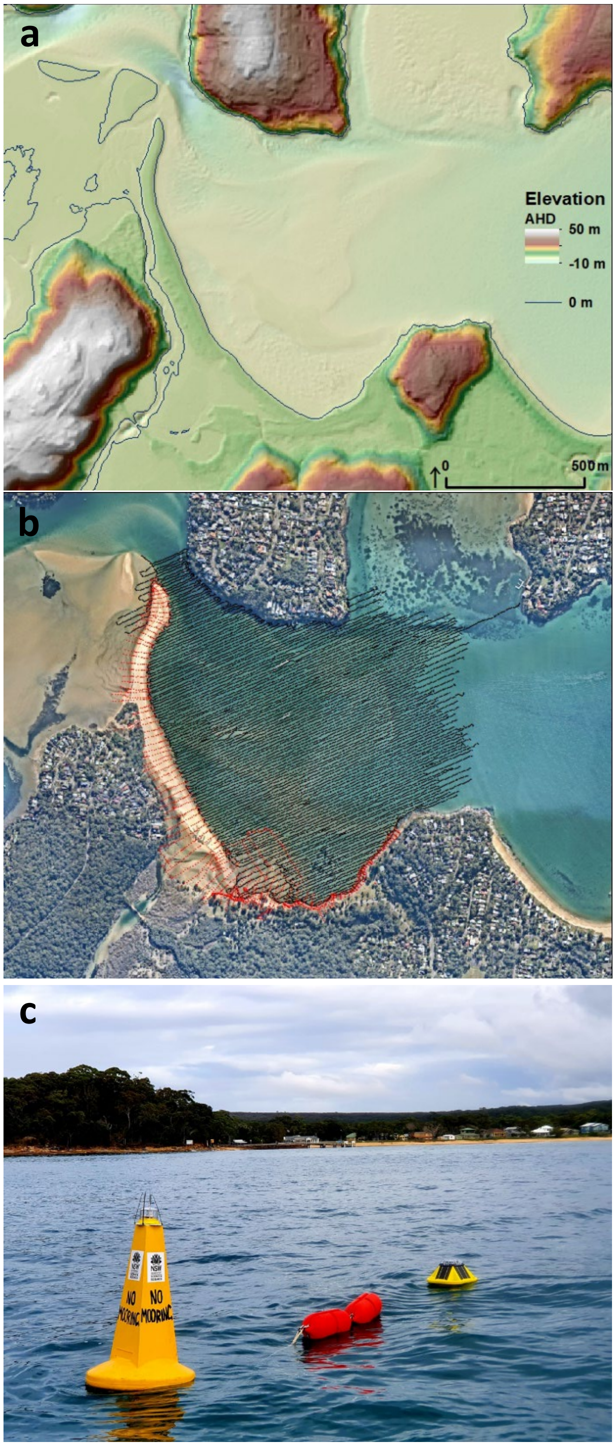

Figure 4 – (a) Seamless topography-bathymetry elevation model from the 2018 airborne Lidar survey; (b) June 2021 RTK-GPS ground survey (red) & single beam echosounder jet ski survey (black) overlaid on concurrent aerial imagery (Nearmap); (c) wave buoy at location shown in Figure 1.

RESULTS AND DISCUSSION

From its formation prior to 1950 perhaps in response to the dumping of dredged sand on the Middle Ground shoals, the Deeban barrier-spit gradually migrated west towards Maianbar, although at variable rates that appear to result from event-driven evolution and interventions in the estuary sediment system. Large storms during the late 1960s and early 1970s appear to have caused washover and some narrowing of the tidal inlet. During the 1980s and 1990s the barrier-spit migrated gradually west with the tidal inlet constricting from its earlier broad meandering form to a more narrow and linear channel. Large storms during the late 1990s again appear to have caused extensive washover. Since that time, sand dredged from the navigation channel at the north end of the spit has been removed from the system to nourish the Cronulla beaches creating a terminal sink for barrier sand.

The past decade of frequent high-resolution imagery concurrent with ocean wave and tide measurements allows for a more detailed analysis of morphodynamics. The sensitivity of the barrier-spit to high waves and sea levels is clear, with such conditions enabling the erosion and flattening of dunes, extensive washover deposition, and resultant barrier rollover. Dune development and vegetation varied spatially and temporally over the life of the barrier-spit, with progressive loss of dunes allowing high-tide barrier breaching in 2014 (Albani & Cotis, 2014).

The gradual and event-driven migration of the Deeban barrier over several decades culminating in the abrupt rollover and welding to the mainland illustrates the sensitivity of estuarine barriers to exceedance of threshold conditions during high wave and water level events. This example highlights the potential benefits of early intervention to proactively manage future coastal hazards by supporting barrier resilience and mitigating tipping-point change. Here, dune management to promote barrier stability, shoreline and inlet monitoring to track change and identify trigger points, and a system sand management plan, all could have preserved the barrier-spit in its recent historical state and avoided reactionary measures including foreshore hardening (Taylor et al., 2020).

ACKNOWLEDGEMENTS

The authors thank Stephen Holtznagel, Tim Ingleton, Neil Doszpot, Brad Morris and the NSW Department of Planning and Environment (DPE) Coastal and Marine Science team for contributions to field survey and wave buoy data. The NSW National Parks and Wildlife Service and DPE Spatial Science are also thanked for data and information. NSW Manly Hydraulics Lab (MHL) collect and process offshore wave buoy and tide gauge data on behalf of DPE. NSW Roads and Maritime assisted with placement and monitoring of the wave buoy.

REFERENCES

Albani & Cotis (2014): Port Hacking: Past and Present of an Estuarine Environment. Sutherland Shire Council and the University of New South Wales.

Kinsela, Hanslow, Carvalho et al. (2022a): Mapping the Shoreface of Coastal Sediment Compartments to Improve Shoreline Change Forecasts in New South Wales, Australia, *Estuaries and Coasts*, vol. 45, pp 1143-1169.

Kinsela, Morris, Ingleton et al. (2022b): Nearshore wave buoy data for coastal research and management in southeast Australia, *Scientific Data*, in press.

Taylor, Doyle, Devlin & Withycombe (2020): Bonnie Vale Coastal Processes and Sea Level Rise Adaptation. BMT.