A Tentative Stratigraphy of, and Geomorphological and Vegetation Temporal Changes on the Wuyung/Sir Richard Peninsula

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Executive Summary

Previous stratigraphic and dating studies conducted primarily on the Sir Richard Peninsula but also on the adjacent Younghusband Peninsula are reviewed. A tentative evolutionary history and stratigraphic analysis is produced for the Sir Richard Peninsula based on new drilling and coring across the Beacon 19 track. Previous research indicates initial retrogradation of a coastal barrier over a palaeo-lagoon system starting ~7,000 to 8,000 years BP in the NW portion of the barrier. In the Beacon 19 Track area, the barrier is tentatively considered to have formed by spit extension and migrated alongshore over riverine/lagoonal sediments. This was followed by a narrow band of progradation. Several dunefield phases were possibly formed over time.

Vegetation and geomorphological changes are also examined, and significant changes have taken place since the 1700's and in the post-1930's period. The Peninsula was characterised by significant areas of active mobile blowouts and parabolic dunes in the northwest portion, and transgressive dunefields in the southeast portion in the 1930's to 1940's. By 1975 these were considerably less active and by 2025 the entire Peninsula, apart from the very distal spit terminus, is largely vegetated. The vegetation cover has increased by at least 30% between 1945 and 2025. Significant invasion of *Thinopyrum junceiforme* (sea wheat grass) has taken place since the early 1980's.

Acknowledgements

We acknowledge the cultural connections to the land and connected waters, as well as the cultural significance of waterbirds that exist between people of the Ngarrindjeri and Boandik Nations across the Coorong, Lower Lakes, and Murray Mouth region. We recognise that First Nations peoples' spiritual, social, cultural, and economic practices come from their lands and waters, and they continue to maintain their cultural heritage, economies, languages, and laws which are of ongoing importance. We are committed to fostering and nurturing ongoing relationships with First Nations communities in the CLLMM region as we collectively work toward healthy, resilient and thriving lands, waters, ecosystems and communities across the region.

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1 Introduction

In this report we review previous geological and geomorphological studies carried out on the Sir Richard Peninsula and provide a tentative evolutionary model of the coastal barrier based on an initial analyses of a coring and stratigraphic study carried out in November, 2025. In addition, we provide a brief examination of vegetation and geomorphological changes that have occurred in the ~last 100 years. The rationale is to better understand the Holocene evolution of the barrier and geomorphological and vegetation historical changes in order to establish a baseline for insights into what future climate and sea level changes might bring. It is not the purpose of this report to examine or guesstimate the nature of possible future changes shaped by environmental drivers but rather to review those major changes that have taken place to date.

2 Methods

In regard to the stratigraphy and evolution portion of this report, the methods utilised to conduct the drilling and coring of the Sir Richard Peninsula are outlined in Das et al. (2025). Further data on which the tentative evolution of the Peninsula is derived have been obtained from a review of the current literature and discussions with Dr Robert Bourman.

In regard to the vegetation cover analyses, the vegetation cover was estimated in ArcGIS Pro using the unsupervised ISO Cluster workflow. All historical imagery was first georeferenced to static objects in current imagery. Once the image tiles were in place the warp was refined using common features in the overlap between scenes. To achieve the highest accuracy for the georeferencing, where tiles had few static persistent objects, neighbouring tiles with solid tie points were used. The overlap helped to improve the positional accuracy.

Once the base imagery was in place, the ISO Cluster classification algorithm was applied with 100 classes. Classes in the output were selected and reclassified to 0 or 1 representing no vegetation and vegetation respectively. The classification was manually refined. For each sample, a vegetation boundary polygon was drawn, and the reclassified raster was clipped. Where image tiles intersected, a hard boundary was drawn and each image was clipped to create a flush join. Cell counts for each class were then used to calculate the approximate percent coverage. The visualisations are suitable for describing distribution and coverage of vegetation. Due to inaccuracies in the georeferencing, direct object comparison through techniques such as intersection is not appropriate. Vegetation change is best monitored through a comparison of coverage percentage and analysis of distribution patterns in the imagery.

In regard to the geomorphological changes, a variety of aerial photographs, including the earliest available, and satellite images were acquired to examine temporal changes.

3 Coastal Barriers and Holocene Sea Levels: An overview

The term "barrier" was originally applied to a coastal deposit that acted as a 'barrier' between the mainland and the sea, or a lagoon and mainland (de Beaumont, 1845; Gilbert, 1885; see Dillenberg and Hesp, 2009 for review). It has subsequently come to mean any shore parallel natural coastal landform created of sand, shells, gravels, boulders etc that has been formed by the action of waves, currents, tides and winds (Hesp and Short, 1999). Barriers may be backed by a swamp, lagoon or lake, but this is not a necessary prerequisite for a barrier. Some barriers may be plastered onto the mainland rocks.

There are several terminologies for coastal barrier types (e.g. Boyd et al., 1992; Morton, 1994; Roy et al., 1994; see review in Hesp and Short, 1999). In this report we recognize three basic types, namely, prograded, retrograded and aggraded barriers. Prograded barriers are barriers that have primarily built seawards over time. There may be periods where erosion and some retreat takes place but the overall dynamic is for the shoreline to build seawards over time. The classic example is one where the barrier is formed by the continuous addition of new foredunes over time to build a foredune plain (Figure 1). A foredune is a dune formed by aeolian (wind blown) sand deposition in pioneer plants above the backshore of beaches (Hesp, 2002).

Figure 1. A prograded barrier comprising multiple foredunes formed over 7000 years at Warnbro Sound, Western Australia.

Retrograded barriers are the opposite; they translate or migrate or recede landwards. A classic example is where a foredune-blowout complex or ridge has gradually translated landwards over a lagoon, or as in the typical east coast USA examples, a low barrier has translated over a marsh by storm or hurricane waves washing sand over the barrier into the adjacent lagoon (Figure 2).

Figure 2. A retrograded barrier at Cape Romain, USA a few days after Hurricane Hugo in October, 1989. Hurricanes and storms drive beach and barrier sands landwards as washover sheets and eventually the back barrier marsh outcrops on the beach.

An aggraded barrier is a barrier that essentially builds in place. It may retrograde or erode some at times, build a little seawards at times, but primarily build upwards over time. A classic example is where a large foredune has been formed in place over the past 7000 years or so (Figure 3).

Figure 3. An aggraded barrier comprising one large foredune-blowout complex at Baudin Bay, Kangaroo Island.

Once a barrier is formed the rate of sediment supply and the various environmental factors operating in the region determine what kind of dunes form on top. Thus, prograded barriers might just have two or three foredunes where sediment supply is very low over the past ~7,000 years, or may have multiple foredunes (sometimes a hundred or more), or moderate to massive largescale dune systems such as parabolic dunefields and transgressive dunefields where sediment supply has been high (Hesp and Walker, 2021; Figure 4).

Most coastal barriers in Australia were formed as sea level rose in the late Pleistocene (roughly >120,000 and <11,700 years ago) and Holocene (>11,700 years to present) transgression following the last Ice Age or Glacial period (Figure 5). As the sea level rose from a glacial low of -120m, beaches and barriers were formed, eroded, and reformed across the exposed shelf (Figure 6). These translating barriers finally stopped at a point where sea level reached its highest position, which in South Australia was around +1.5m or so above the present level (AHD or zero datum; Belperio et al., 2002; Dillenburg et al., 2020).

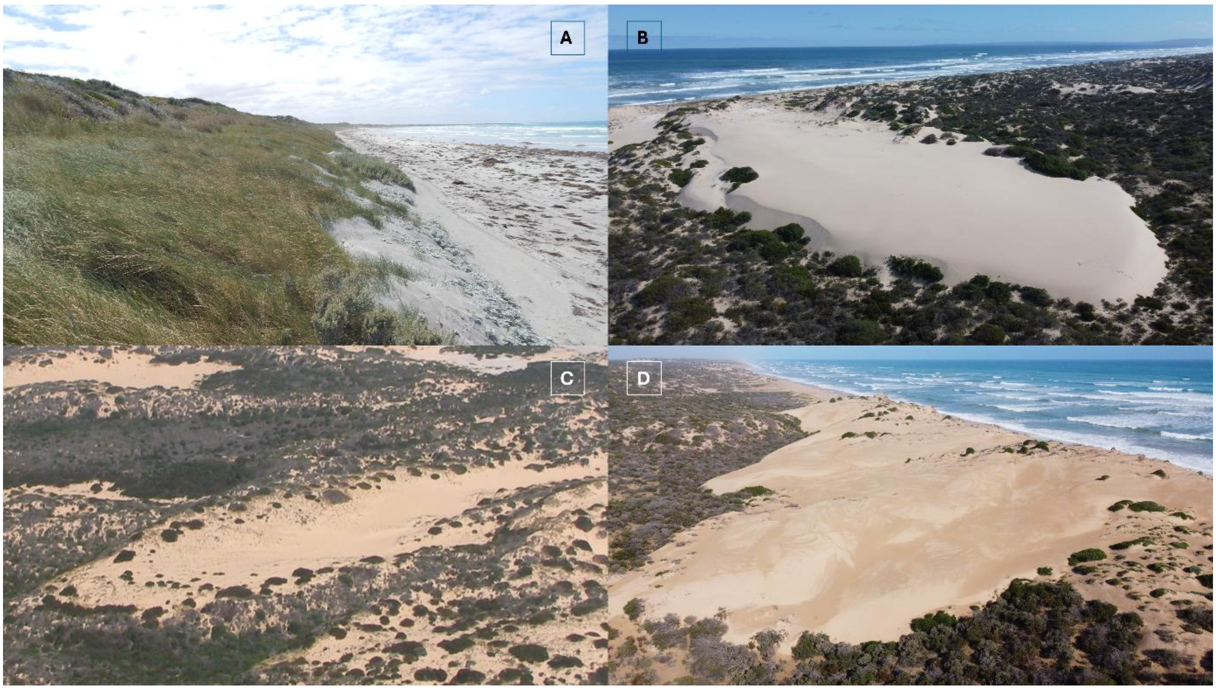


Figure 4. Some examples of dune types on coastal barriers in the SA region. (A) foredune at Rivoli Bay; (B) Recently formed (post 2013) parabolic dune 260m long at Godfreys Landing, Younghusband Peninsula; (C) large, ~600m long parabolic dune in the Younghusband; (D) recently formed transgressive dunefield near 42 Mile Crossing on the Younghusband Peninsula.

Once sea level got to near present, the type of barrier that then was formed depended primarily on sediment supply and environmental factors (winds ands waves). If there was a high sediment supply and relatively low to moderate waves and winds, prograded barriers comprising foredune plains were formed (e.g. The Granites region in the SE portion of the Younghusband Peninsula; Guichen Bay; Rivoli Bay). In higher sediment supply situations and higher wave and wind energy environments, prograded barriers were formed but were characterised by transgressive (large aeolian sand seas) and parabolic dunefields (U- or V-shaped dunes with trailing ridges) (e.g. the Sir Richard and Younghusband Peninsula's). In other cases, very small barriers were formed where there was little sediment availability and either a few dune ridges (typically foredunes) were formed (narrow prograded barrier) or only one foredune was formed as an aggraded barrier (e.g. the small barriers along parts of the Victor Harbor coast). Sea level remained at a high of +1 to 1.5m until about 3,000 years ago when it fell to the present position by about a 1000 years ago or less (Oliver et al., 2020).

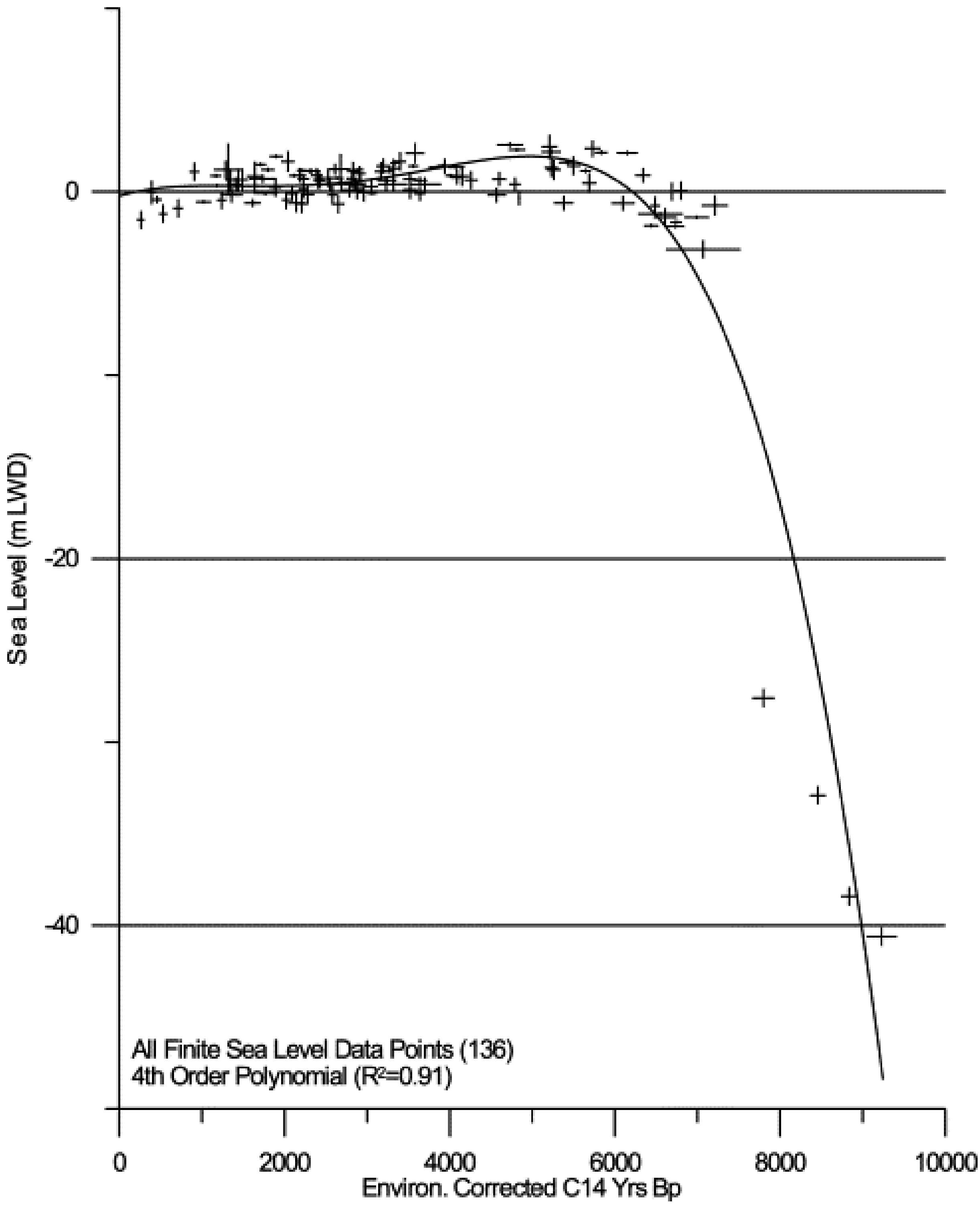


Figure 5. Sea level curve for the 10,000 to present period for South Australia. Source: Belperio et al., 2002.

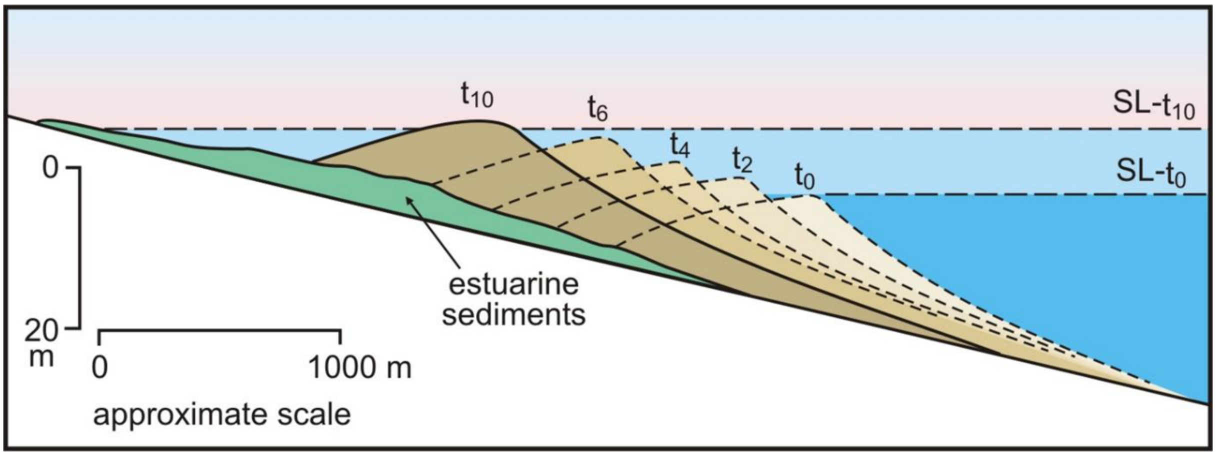


Figure 6: A conceptual diagram of how barriers form and reform as sea level rises during the Holocene transgression. Sea level rises from time zero to time 10. As it does so, the barrier translates upwards and landwards. Commonly a former river valley is flooded as this happens and a new estuary is also formed. Source: P. Hesp.

4 Tentative Stratigraphy and Evolution of the Sir Richard Peninsula

4.1 Previous Dating and Stratigraphy of the Peninsula

Sprigg (1959) conducted a wide-ranging study of the region and the Murray basin. He considered that the Younghusband Peninsula was a beach dune 'range' (= barrier in SA terminology) covered only by a veneer of sand. He noted that remnants of Pleistocene aeolianite dunes were present at 30 miles and 40 miles north of Kingston and he speculated that these may be Robe Range equivalent deposits. The Robe Range aeolian calcarenites have been dated at 80,000 to 100,000 years old (Huntley et al., 1994; Hidayat et al., 2023). No such Pleistocene deposits have been recorded under the Sir Richard Peninsula.

Short and Hesp (1980, 1984) produced a stratigraphic cross-section of the Younghusband Peninsula coastal barrier (Figure 7). This cross-section was based on very few dates, and relied heavily on 1970's-early 1980's understanding of how barriers evolved, and also on NSW-centric models of barrier evolution. In particular, it was generally considered that barriers chiefly comprised of parabolic or transgressive dunefields were inherently associated with shoreline erosion and foredune formation and subsequent collapse. We now know this is not the case for many transgressive dunefields (Hesp, 2013, 20, Hesp and Walker, 2021), and particularly for transgressive dunefield barriers in South Australia (Miot da Silva and Hesp, 20; Hesp et al., 2023; Hesp and Miot da Silva, 2026 in press).

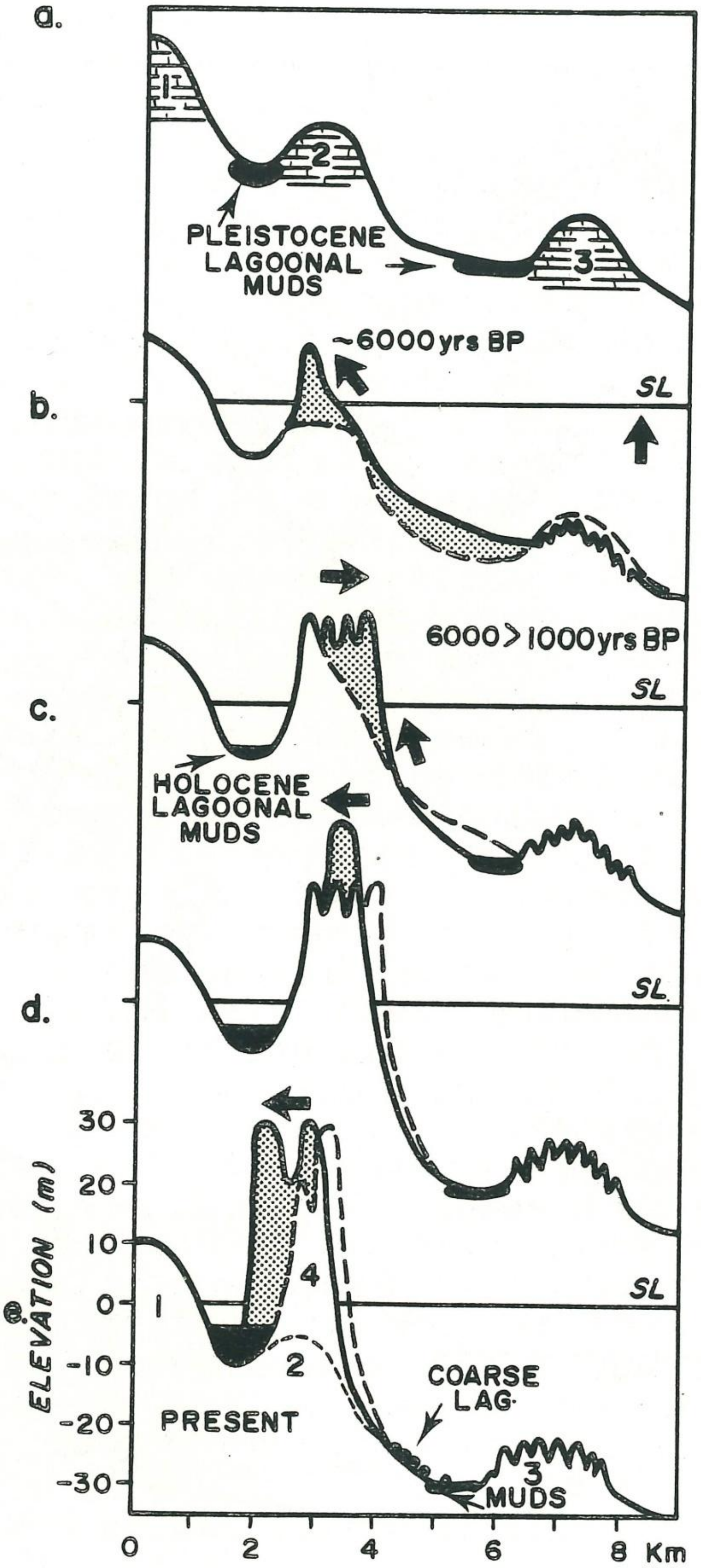


Figure 7. Proposed sequence of Holocene barrier evolution of the Younghusband Peninsula. (a) Pleistocene barriers at low sea level; (b) Holocene sea level transgression and formation of the first portion of the barrier around 6000 years BP; (c) barrier progradation by addition of foredune ridges; (d) transgressive dune phases begin following shoreline erosion; (e) further transgressive dune phases are formed. Source: Short and Hesp, 1984. *Note that the original description of the figure caption has been corrected.*

Von der Borch (1976) cored three locations at Mangins inlet, Lake Trevorrow (~ 90 km SE of the Murray mouth) and Lake McFaiden on the NW margin of the Coorong Lagoon (Figure 8).

Figure 8. Locations of the sites studied by Von der Borch (1976). Lake Trevorrow, Mangins Inlet, and Lake McFaiden.

His generalised stratigraphic cross-sections of Mangins Inlet and Lake McFaiden are illustrated in Figure 9. Note that while von der Borch indicates there is Pleistocene aeolian calcarenite under the modern Younghusband barrier, he did not actually conduct any coring on the barrier and the existence of Pleistocene deposits is therefore speculative.

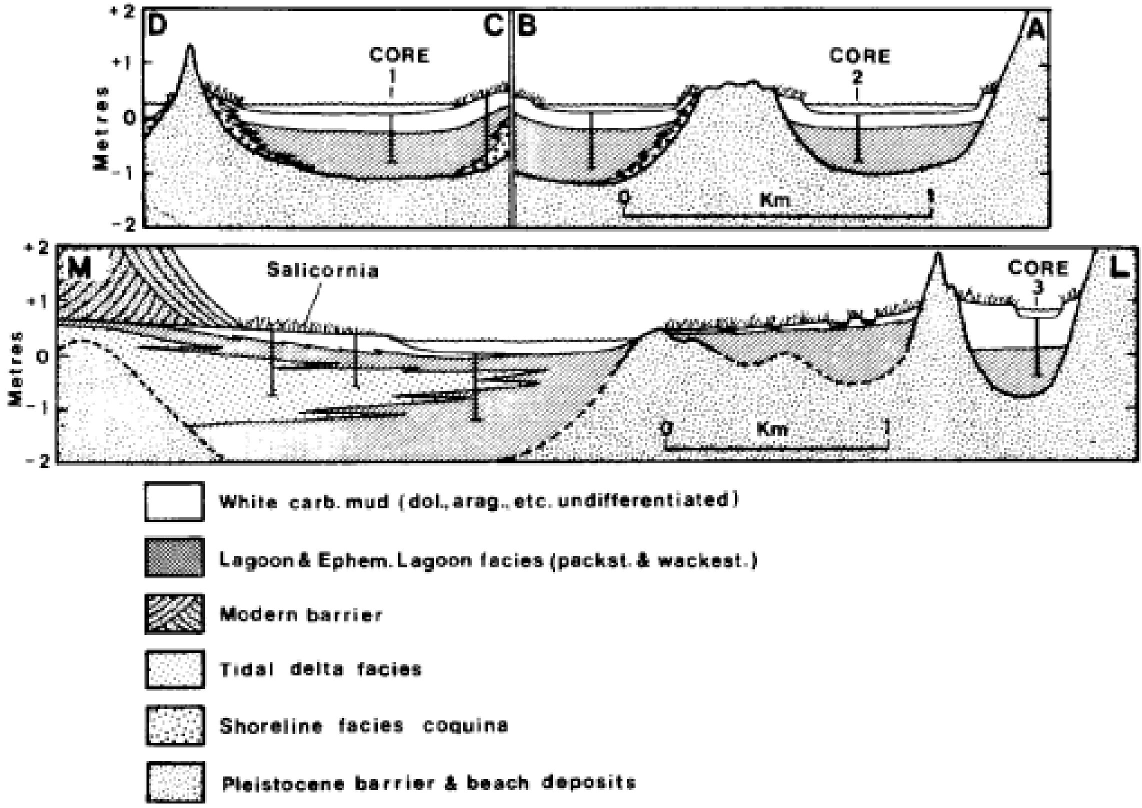


Figure 9. Generalised stratigraphic cross-sections of Mangins Inlet (top) and Lake McFaiden (bottom) areas. The zero point indicates msl. Note that despite the indicated presence of a Pleistocene barrier under the Younghusband Peninsula, no actual cores were taken in that area. Source: Von der Borch, 1976, p. 961.

In the early 1980's A.D. Short conducted a bathymetric and sediment sampling survey off Goolwa (Short and Hesp, 1984). Figure 10 illustrates the profile and sediments. It shows that presumed Pleistocene reef occurs offshore at relatively shallow depths of 20 to 30m. These are associated with presumed Pleistocene muddy lagoonal deposits. This indicates barriers formed at lower sea levels which were indurated (hardened) to the degree that they survived the following Holocene sea level rise or transgression.

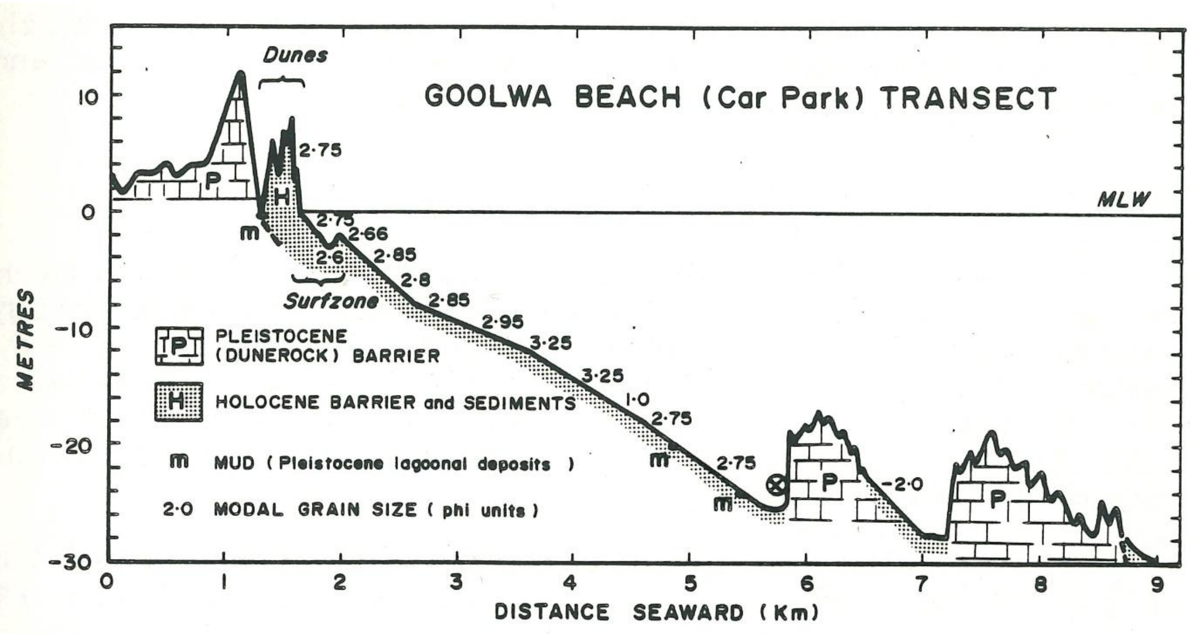


Figure 10. A transect from Goolwa Beach out to 30m water depth. Possible lagoonal muds outcrop in the ~20–25m depths and two presumed Pleistocene reefs (submerged relict barriers?) occur in the 20-30m depths. Source: Figure 17 in Short and Hesp, 1984.

Note that these Pleistocene barriers are not universally present offshore of the Sir Richard to Younghusband Peninsula as Short and Hesp (1984, their Figure 16) did not find them at the adjacent Black Hills transect ~5km SE of the Murray mouth.

4.1.1 Previous Stratigraphic and Geomorphological Research on the Sir Richard Peninsula

Following a major beach erosion event along the Goolwa coast, Dr Robert Bourman and colleagues discovered a deposit interpreted as a back barrier lagoonal facies outcropping on the beach at that location (Figure 11). The deposit included plant fragments, the jawbone of a rodent, and shells (Bourman and Murray-Wallace, 1991, p. 70). They dated the shells by Amino Acid Racemisation (AAR) and obtained a date of 8000 years. They interpreted the deposits as indicating that the coastal barrier was a retrograded barrier at that site; i.e. the barrier has migrated landwards over a palaeo-lagoon (Bourman and Murray-Wallace, 1991, p. 70).

Subsequently, one of the authors (PH) augered a shallow hole in the approximate location of the original find now situated in a swale behind the *Thinopyrum* foredune (which had formed sometime after the 1980's and after the Bourman and Murray-Wallace (1991) find) and obtained various shells that indicate fully estuarine to surfzone conditions. One shell (a paphies species) gave a date of 7460 years BP (+/- 30) (BETA

No. 724017). This indicates that the barrier likely translated or retrograded over a proto-barrier lying seawards of the present shoreline and then over early Holocene surfzone/estuarine and lagoonal deposits. These dates are in line with dates for the earliest sediments deposited in the lower Lakes (Haynes et al., 2018).

The lagoonal deposits have not been found behind the foredune at the Beacon 19 drill site. Therefore, the 8,000–7,400 year old palaeo-lagoon deposits are not universally present under the barrier for its entire length. This is not unlikely given that the Murray river mouth may have been positioned closer to Goolwa in the past (de Mooy. 1952).

Other palaeosols (former soil horizons) occasionally outcrop on the beach (e.g. at 3km SE of Goolwa; Bourman and Murray-Wallace, 1991, their figure 3, p. 71). In addition, Bourman et al. (2000) found a *Allocasuarina* fossil tree stump on the Sir Richard beach. This was dated at 4110 +/- 60 years, and attached shells were dated at 4880 +/- 150 years BP (Wk-4786). This is further evidence indicating that at least the NW portion of the Sir Richard coastal barrier has been retrogradational (receding or translating landwards) for some, and likely all of its existence/evolution. Bourman et al. (2018b) note that the age of the spit varies and becomes progressively younger towards the Murray mouth. TL dates of sediments from the basal, central section, proximal, and distal end of the spit, have ages of 4.0±0.8 ka (W2314), 4.5±1.2 ka (W2315) and 3.6±0.9 ka (W2316) respectively.

Bourman and Murray-Wallace (1991) also published a suite of ^{14}C dates on Donax species taken from various middens along the Sir Richard Peninsula. The ages range from 270 years BP (+/- 70) to 3070 years BP (+/- 70) indicating the barrier has been in existence a minimum age of 3000+ years. Bourman et al. (2000) note that the middens are only found on the proximal half (i.e. the Goolwa side) of the Peninsula. They suggested that migration of the Murray river mouth could have destroyed any middens that may have been present on the distal portion of the Peninsula.

4.1.2 Dates from the adjacent Younghusband Peninsula spit

Harvey et al. (2006) provide multiple dates for the modern spit and adjacent Barkers Knoll area on the tip of the Younghusband Peninsula opposite the Murray mouth. The oldest date found was on a Donax shell located on a deflation area and dated at 5021 +/- 50 years BP. While this indicates a mid-Holocene age for the barrier, caution must be applied as shells of many different ages have been wave transported and deposited on storm beaches in various parts of the barrier (Hesp, 2024).

4.1.3 Dates from The Granites

Dillenburg et al., (2020) drilled and dated the foredune plain at The Granites. They found that the first foredune essentially sat in place from ~5600 – 6000 years ago until around 3500 years ago. Thus, the barrier was an aggraded barrier though this period. This was followed by a rapid phase of progradation where most of the barrier built seawards (Figure 11). Then the barrier went into another very slow progradtaion/aggradation phase where 2 large foredunes were formed post 3000 years ago.

Figure 11. The Granites aggraded-prograded-aggraded foredune plain with OSL dates indicated. Source: Dillenburg, S.R., Hesp, P.A. , et al., 2020. Geochronology and evolution of a complex barrier, Younghusband Peninsula, South Australia. Geomorphology 354.

4.1.4 Historical changes in the position of the Murray mouth and the Sir Richard Peninsula Spit

The mouth of the Murray River may have originally been at or near Goolwa (de Mooy, 1959), or located anywhere along the spit at 7000 to 3,000 year ago. Bourman et al. (2018a) state that the mouth was located 6km NW of the present position some 3000 years ago. In the past 200+ years the mouth of the Murray River has moved considerably over time as shown by Bourman et al. (2016). Figure 12 illustrates their mapping of changes in the period 1839 to 1949. The NW margin of the rivermouth has moved approximately 1.5km in that period illustrating the dynamic nature of such rivermouths.

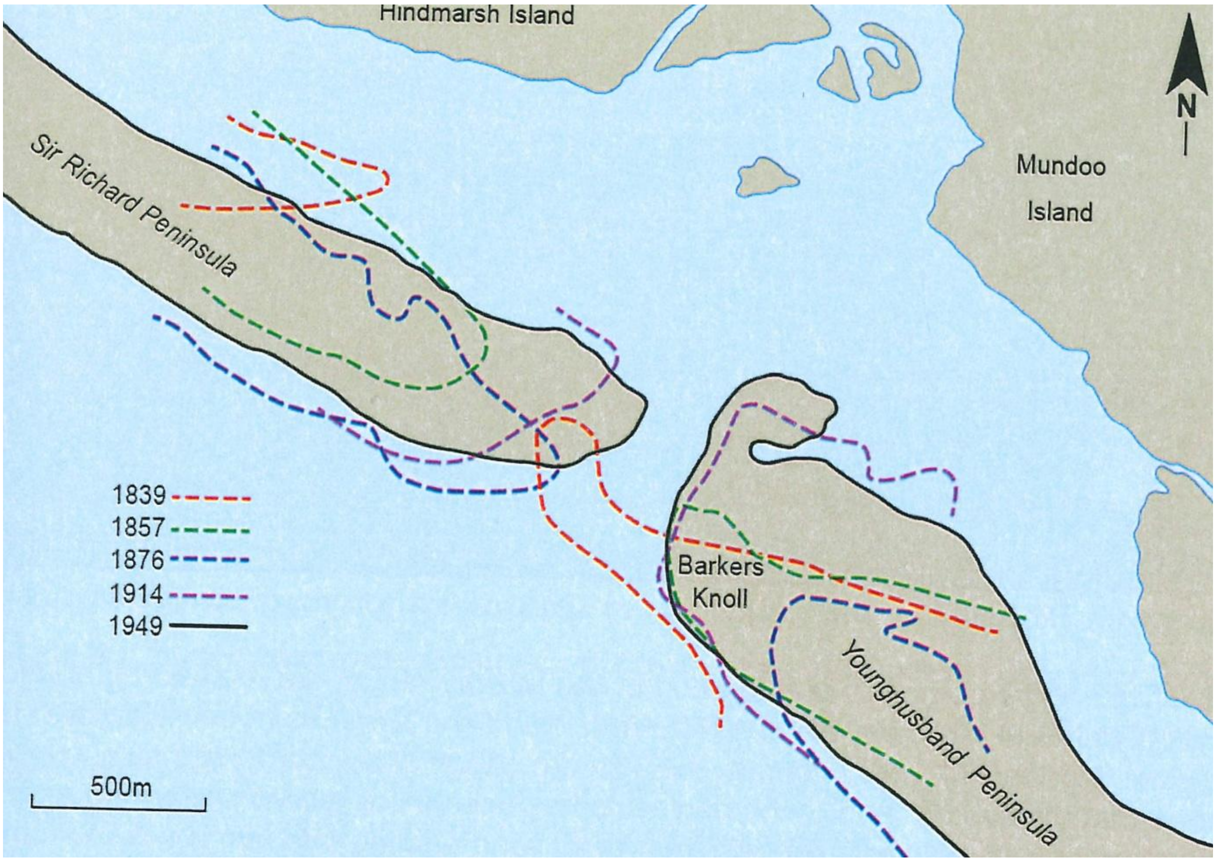


Figure 12. Migration of the Murray mouth, 1839 to 1949. Source: Bourman et al., 2016.

In more recent times, the mouth has also shown considerable changes. For example, following closure of the mouth and opening in 1981, the river mouth migrated to the northwest for several years. Harvey (1996) estimated that the Sir Richard Peninsula had eroded at ~ 80 m yr^{-1}, that 45 ha of dunes were removed and ~3 million m^3 of sediment was recycled or transported elsewhere.

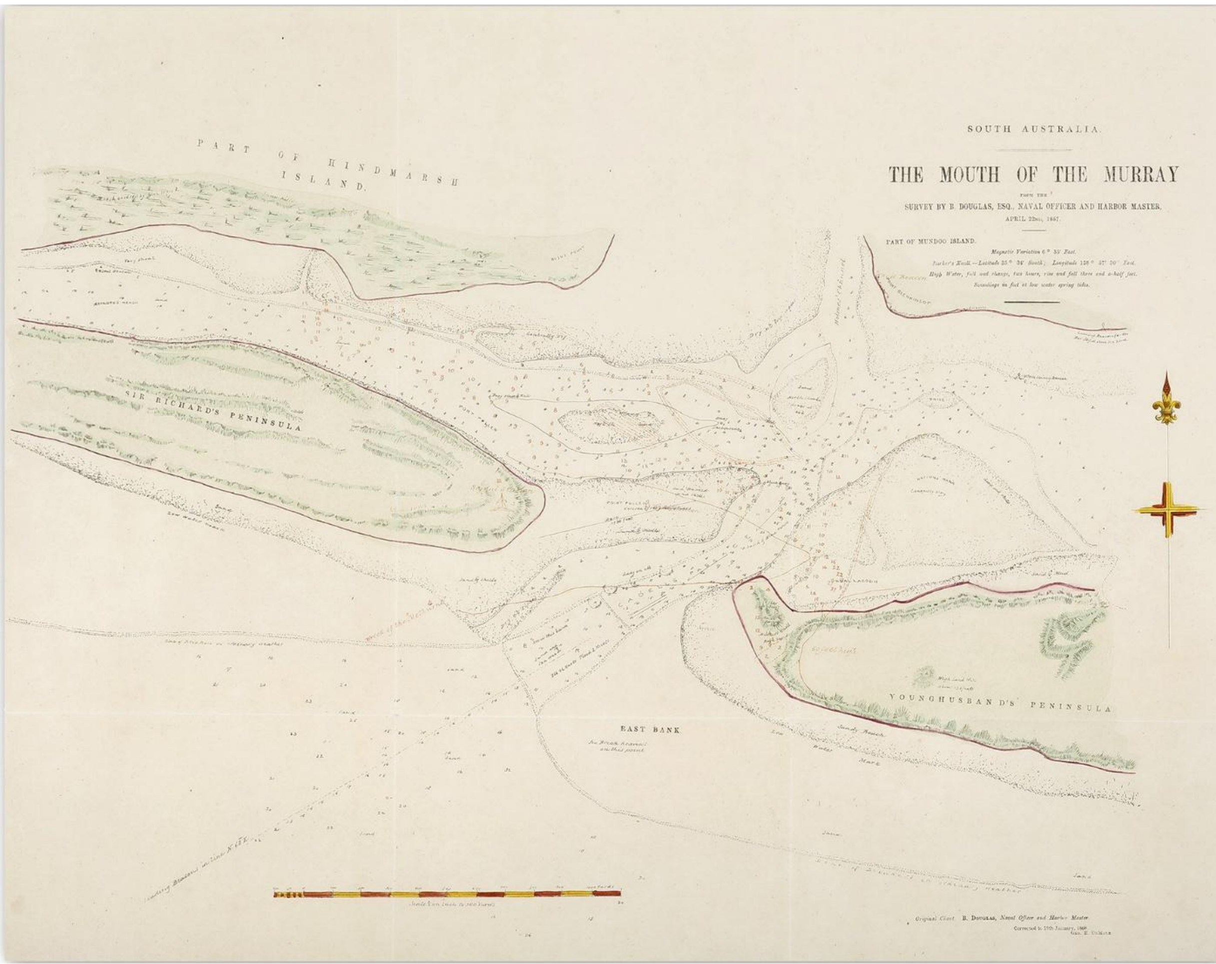


Figure 13. The mouth of the Murray River in 1867. Source: Survey by B. Douglas Esq., Naval Officer and Harbor Master.

4.1.5 Conclusion

Overall, previous research indicates that the Sir Richard Peninsula was forming by around 7,000 years ago. As sea level rose to +1.5m above the present, the initial retrogradational barrier translated over palaeo-lagoon deposits and the first dunes were formed. Subsequently, it is hypothesized that the spit migrated to the SE.

4.2 Tentative Stratigraphy of the Peninsula in the Beacon 19 Track area

4.2.1 Introduction

Six main drill holes have been cored along the Beacon 19 track (Figure 14). The basic core logs are provided in Appendix A (Table A). All cores were taken in plastic tubes, and were immediately wrapped in black plastic. This was done in order to avoid the core sediments having any contact with sunlight which is a necessary prerequisite for carrying out subsequent optically stimulated luminescence dating (OSL) of the sediments. Thus, we only observed a very small portion of the sediments that were cored, and the following stratigraphy is therefore very tentative at the time of writing (December, 2025). The cores will be fully analysed and sampled for dates in 2026.

Figure 15 illustrates a detailed contour map of the area, and Figure 16 a digital elevation model of the area.

Figure 14. Locations on the Sir Richard Peninsula Beacon 19 track where the various drill holes (red circles) and hand augering were carried out. Inset map shows the location of the study area (red triangle) in relation to Adelaide, South Australia. Source: Das et al., 2025.

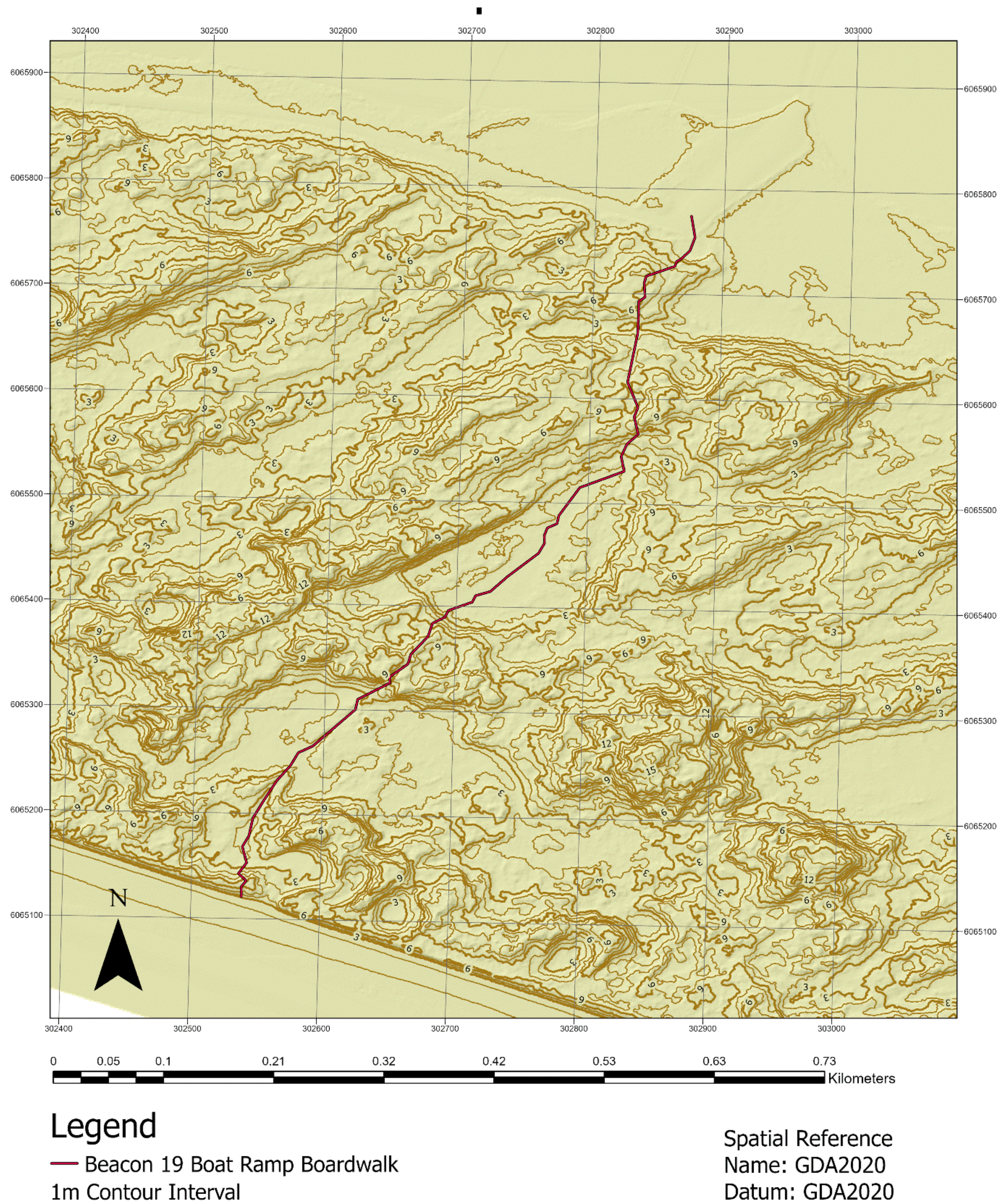


Figure 15: Contour map of the Beacon 19 area produced from 2018 LiDAR data.

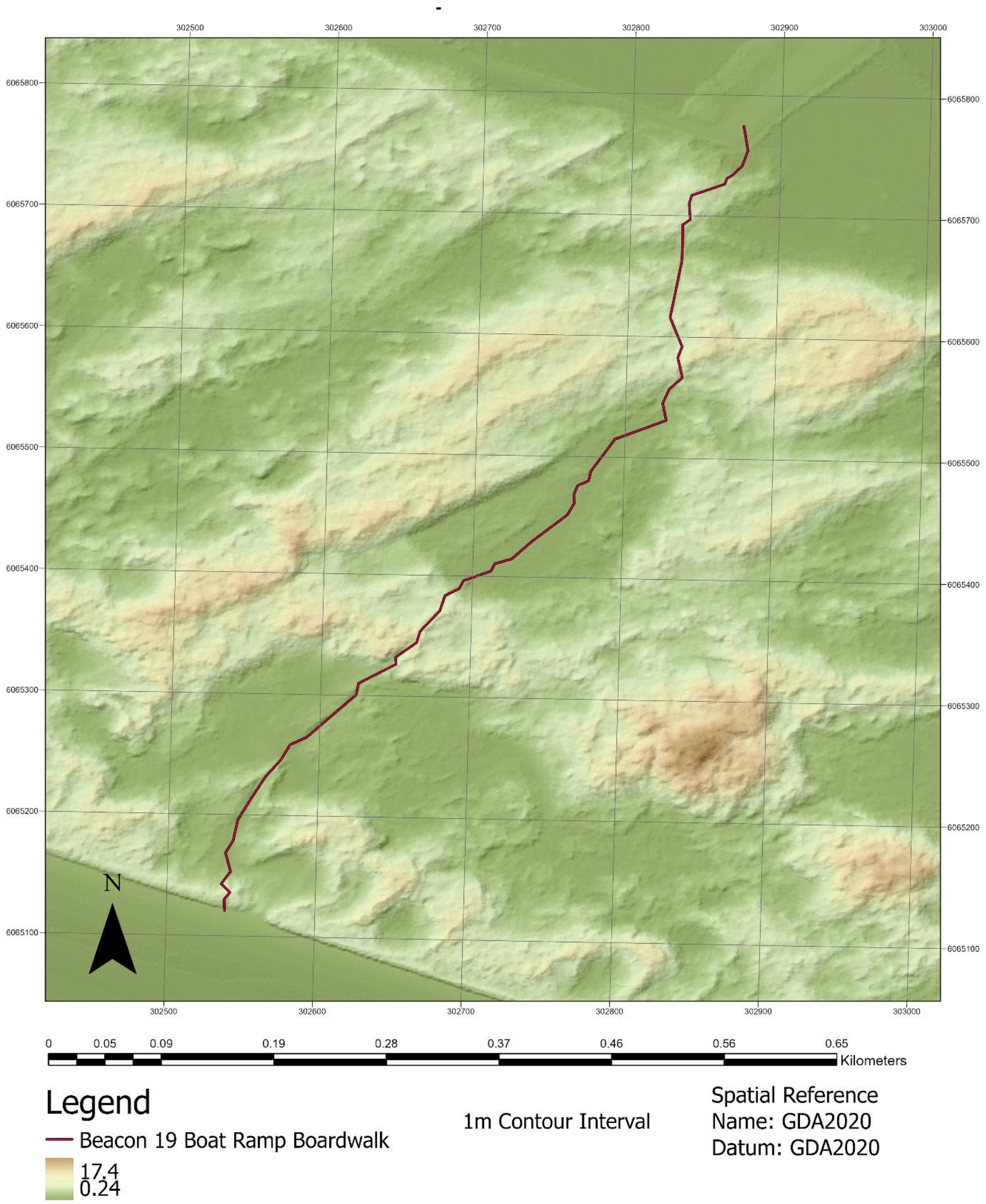


Figure 16: Digital elevation map (DEM) of the Beacon 19 track region on the Sir Richard Peninsula. Data source: 2018 LiDAR provided by the SA State Government.

The contour and DEM maps show that the Beacon 19 site is characterized by a prominent dune ridge on the landward side, crosses a swale and second large dune ridge, then a wide deflation plain, another dune ridge, then deflation plain, and then a foredune/blowout complex.

4.2.2 Stratigraphy of the Beacon 19 Track area

Site 1 was drilled in the river margin flats and was cored to 6m deep. Site 2 on a dune ridge was drilled to 9.6m, Site 3 located in a deflation (wind eroded) plain to 7m, Site 4 on a dune ridge to 8m, Site 5 in the deflation basin behind the foredune to 9m, and Site 6 in the blowout just behind the beach was drilled to m.

In general, Sites 4-6 are composed of yellow to yellow brown sand interpreted as beach and dune sand. The only site where we drilled a second hole and displayed the core was at Site 3 (Figure 14) where the sequence displays an A horizon soil, over dark yellow brown sand, over dark gray fine sand (Figure 17). A shell (possibly *Echino littorina*, a periwinkle) or a nerite was found at the base of the hole, along with broken shell, coarse sand and small pebbles. The sequence is tentatively interpreted as dune sand overlying estuarine or river deposits (Table 1). This interpretation is consistent with interpretations of similar sediments encountered offshore (Pinheiro, 2021).

Figure 17: Core extracted from the deflation plain at Site 3 (see Figure 14 for location). The surface is at the top left. Each section is 1m in length. An A horizon soil has developed in aeolian dune sands and grades downwards into parent, dark yellow brown dune sands. There is then a transition to very dark brown sands underlain by dark grey sediments tentatively interpreted as river sands.

Table 1. Lithology of Site 3.

LITHOLOGY/DESCRIPTION
0–23 cm dark gray sand A horizon
23–30 cm dark yellow brown sand
30–92 cm yellow brown sand
92–102 cm light gray fine sand
102–109 cm iron-stained layer
109–120 cm medium gray sand with black root fragments
120–141 cm dark gray fine sand
141–154 cm diffuse black boundary
154–190 cm medium gray fine sand depth 2.4 m)
At 8.0 m depth – mud balls and small shells estuarine)
At 9.0 m depth – some shells present
Bottom of core consists of coarse sand with shell fragments and whole

The tentative explanation for the evolution of the Peninsula NW of the Beacon 19 track and in the track region is as follows: Perhaps around 3000 years Before Present (BP) or so, the coastal barrier was prograding SE by spit extension. Note that the 3000 year BP time is a guestimate. At this time, the river mouth was being pushed to the SE and the barrier prograded across riverine sediments (the dark grey sands shown in Figure 17). The first dune ridge (Phase I) was formed at this time (Figure 18). Subsequently, perhaps one more dune phase formed and migrated landwards. Sea level likely started to fall towards the present level at around this time (Oliver et al., 2020; Dillenburg et al., 2020). This interpretation is based on the fact that there are currently two separate relatively high dune ridges present near the landward side of the barrier (Figure 19). While sea level was possibly still higher than present, but perhaps when it was at the present level, Phase III transgressive dunes developed. All these phases overlie estuarine/lagoonal/river deposits. The Site 3 drillhole is located at about 450m on Figure 19 so it is interpreted that the barrier was still prograding or extending SE by spit growth at this time. This tentative stratigraphy differs from what has been observed at the 2km south of Goolwa site where lagoonal sediments outcrop on the beach during large storms (Bourman and Murray_wallace, 1981), and lagoonal sediments overlie beach/river mouth sediments at shallow depths in the swale leeward of the foredune at the same site.

Sometime later the barrier then prograded seawards. As it did so, a new transgressive dunefield phase was formed (phase IV). This interpretation is based on the fact that no riverine/lagoonal sediments were encountered in the cores at Sites 4 to 6. The interpretation also comes from the fact that there is currently a separate dune ridge formed some distance seawards of the phase III ridge (Figure 19). Note that we do not know yet how many separate dune building phases there may have been until dates are available, nor are we at all certain of the ages. By around the 1700's a phase of widespread dune erosion occurred and active dunes formed during that time (or earlier) were present into the 1970's (see later section on vegetation and geomorphological changes, and cover photograph from the 1930's). This erosional phase resulted in significant deflation of the Phase 1 to III dunes and the formation of a wide deflation plain, and reworking of the Phase I-II and Phase III dunes into higher more complex dune ridges. The topography that resulted from this phase of erosion and reworking/remobilisation of the dunefield is indicated by the dashed line on Figure 19. This is the modern topography and was derived from the 2018 LiDAR. Finally, a Spinifex foredune/blowout complex formed on the seaward margin and was present in the 1970's. Subsequently, this was added to by the formation of a more stable and higher foredune formed in the invasive plant *Thinopyrum* (Figure 19). As sedimentation took place in the river, the marginal river flats also prograded.

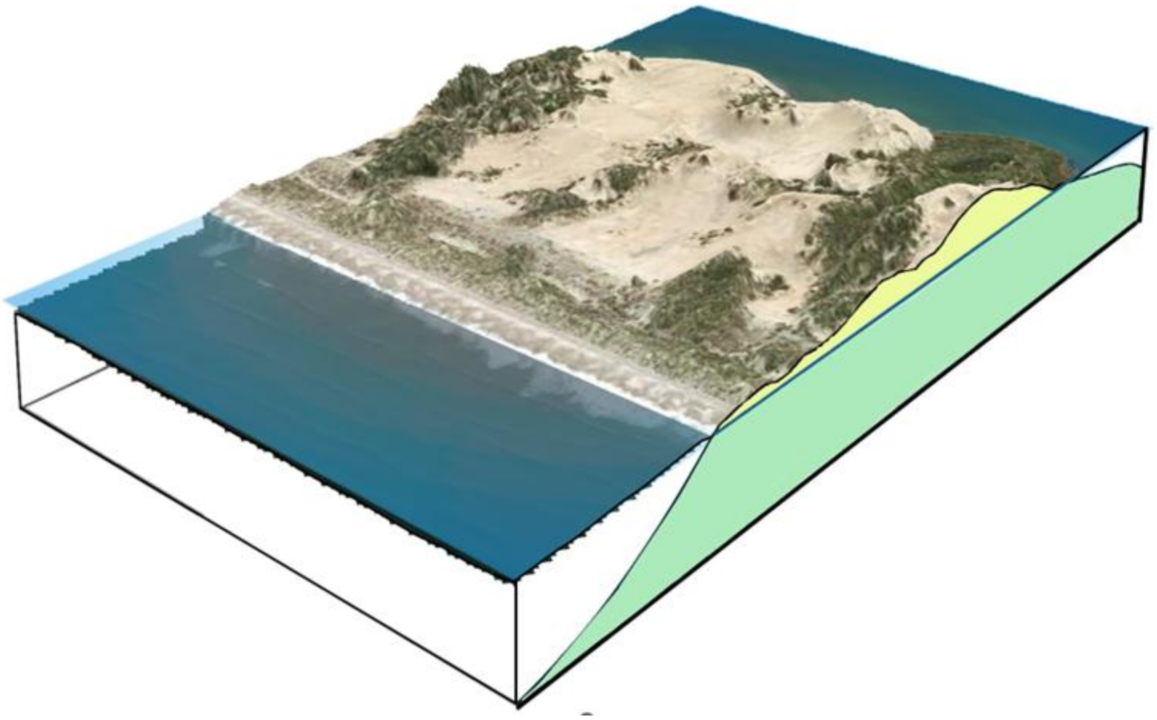


Figure 18: Conceptual view of the Sir Richard coastal barrier at ~7000 years ago showing Phases I and II. Yellow indicates dunes, green indicates riverine and surfzone-nearshore sediments.

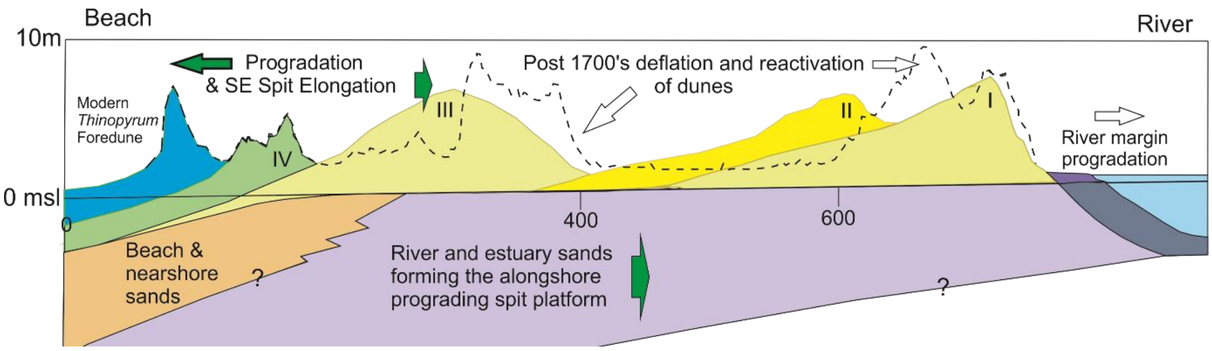


Figure 19: A very tentative interpretation of the stratigraphy and evolution of the Sir Richard Peninsula at the Beacon 19 track area. One or perhaps two phases of dunes Phase I and II dunes were formed over the palaeo-lagoon/river (and likely nearshore) deposits (purple) at present or a slightly higher sea level, and the barrier was at this time an alongshore SE prograding spit barrier. Subsequently, a third dune phase developed as the barrier prograded SE forming phase III. The barrier subsequently prograded both alongshore and seawards to form phase IV and the modern foredune. Sometime before the 1700's a major deflation episode occurred significantly deflating and altering the dune ridges to form the present barrier topography (dashed line). The modern topography (dashed line) is derived from the 2018 LiDAR.

4.2.3 The 2-Stage Evolution of the SR Peninsula- Spit: Initial Retrogradation followed by Spit Progradation

The evolution of the Sir Richard Peninsula actually appears to comprise two parts. The first is the part where the initial retrogradational barrier formed in the NW and extended from Goolwa to somewhere NW of the Beacon 19 Track area. The second is the extension of the barrier to the SE by spit progradation.

Bourman and Murray-Wallace (1991) show that the Aboriginal middens they investigated on the Sir Richard Peninsula are all located on the proximal portion of the barrier, i.e. on the Goolwa side of the barrier. Harvey et al. (2006) state that there are no middens within 5km of the SE tip of the Sir Richard Peninsula. This provides an indication that the more SE portion of the spit is younger, perhaps considerably younger than the NW portion of the barrier.

Thus, the second major evolutionary development of the barrier is related to gradual extension of the spit to the SE over time and post-4,000 (?) to 3,000 (?) years. Figure 20 (1st panel) illustrates the barrier as it may have appeared around ~7000 years ago. The position of the river mouth is speculative; it may have been further SE at this time. Following development and formation of dune phases on the initial barrier, the spit then began to extend or build alongshore to the SE. As this occurred, dune phases developed on the barrier. The barrier formed on top of prograding river sediments which probably overlie beach-surfzone sands. At some point during the latter formation of Phase III (Figure 19), the barrier also prograded seawards, while continuing to extend or prograde alongshore. As this occurred, another phase (Phase IV) of dune formation also took place. The spit then continued to prograde or extend to the SE over time to reach the current position opposite Sugars Beach on Hindmarsh Island (Figure 20).

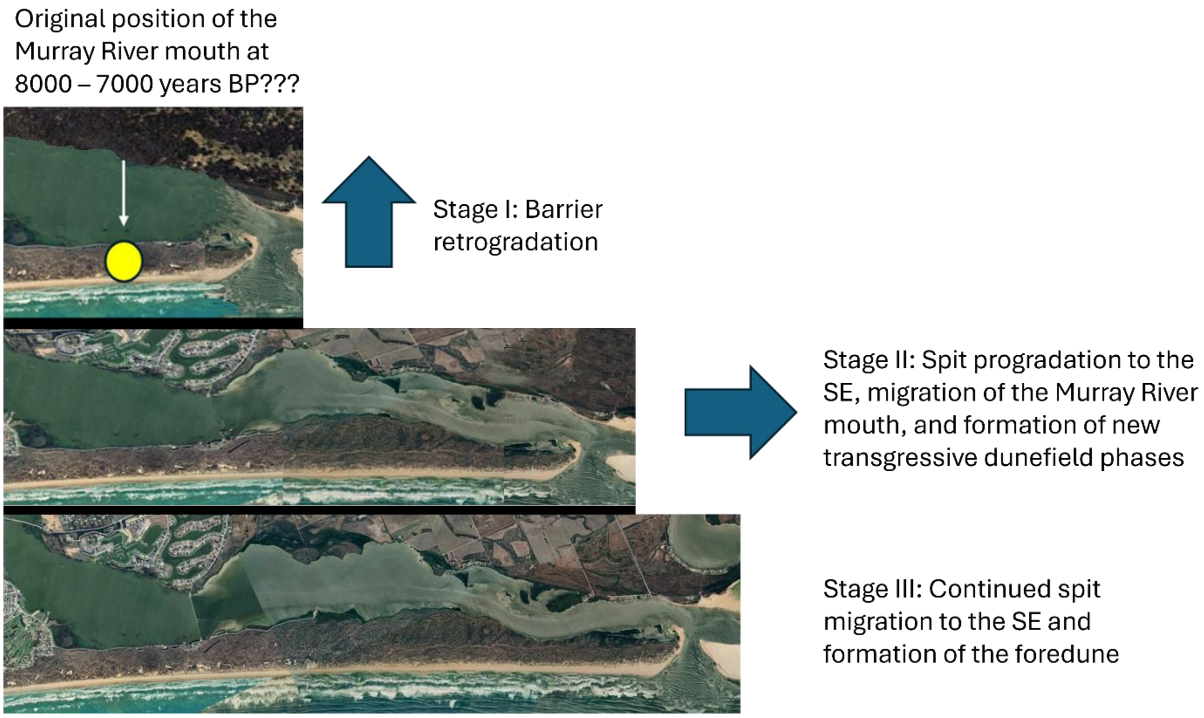


Figure 20. A post-3000 years (or younger)evolutionary scenario for the Sir Richard peninsula. The barrier extending from Middleton to around 4-5km?? SE of the Goolwa Beach entrance is initially formed as a transgressive or retogradational barrier which has translated landwards over lagoonal and river/estuarine sediments. Subsequently, the barrier progrades alongshore and SE by spit extension, pushing the Murray mouth in the SE direction. The position of the 1839 spit terminal point is indicated (spit location source: Thomson, 1975 after Johnston, 1917).

5 Historical Vegetation and Geomorphological Changes on the Sir Richard Peninsula

5.1 Introduction

There have been significant changes in the vegetation cover on, and geomorphology of the Sir Richard and also the Younghusband Peninsula's. The following provides an overview of those changes.

5.2 1800's

Matthew Flinders produced a map of the area in 1802. On it he described the Sir Richard Peninsula as follows: "Low sandy shore topped with hummocks of almost bare sand" (M. Flinders, Chart of Terra Australis, Plate 5; State Library of SA) (Figure 21). Thus, it appears the Peninsula was mostly or largely unvegetated.

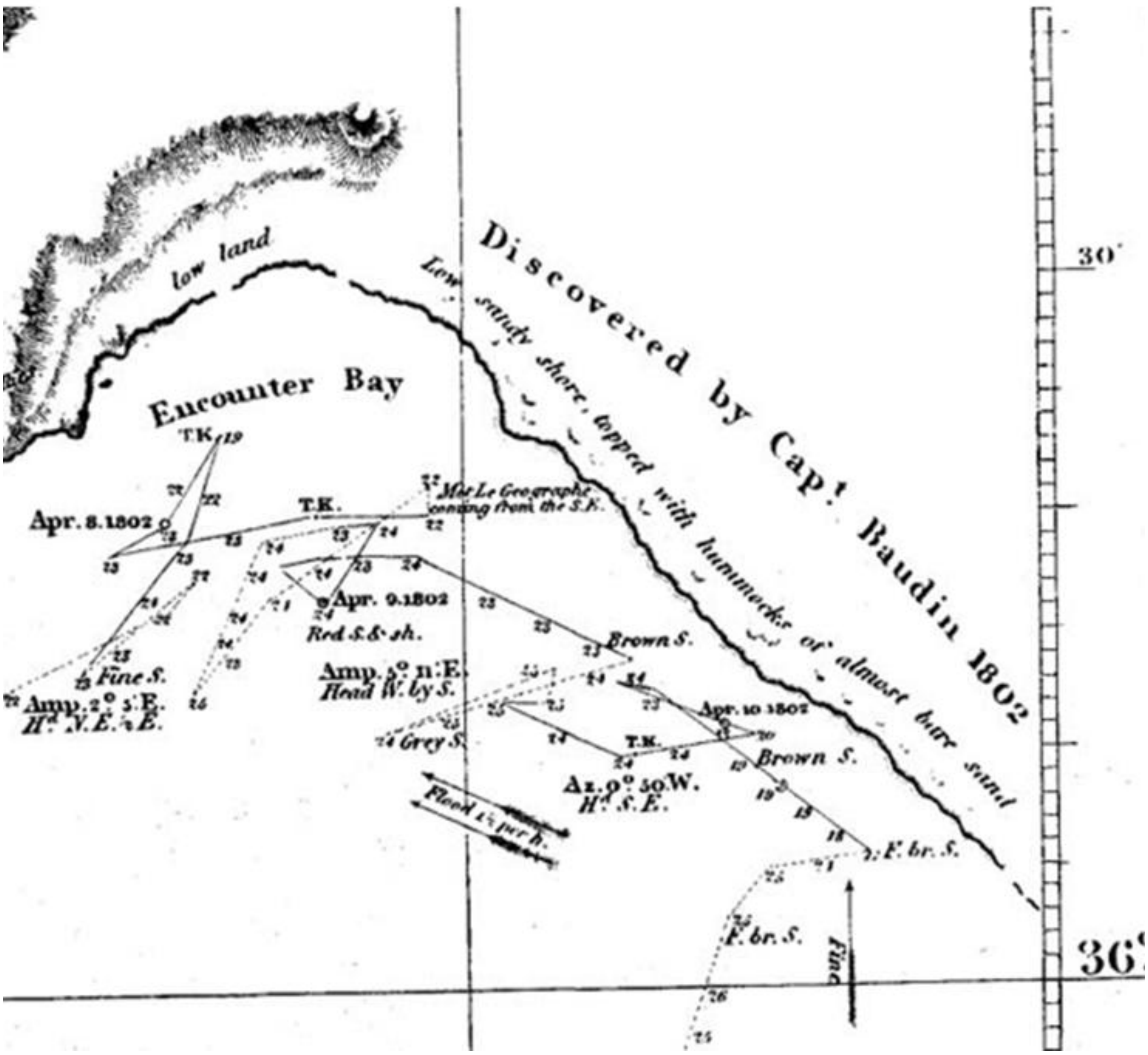


Figure 21. A portion of Matthew Flinders' map of 1802.

5.3 1930's to 1940

"In early 1936 Norman Tindale (1900 -1993) conducted the first aerial reconnaissance of the Younghusband Barrier to publish three articles on traditional land use practices by mid-19th century coastal Ngarrindjeri clan groups (Advertiser 12, 13 & 14 May, 1936). Then an ethnologist who was active in secondary education programs at the South Australian Museum Tindale organized two flights from Parafield aerodrome to photograph the dunes and shorelines across the Lower Murray Lakes and the Northern Coorong and to "delineate the northern extent of the Pleistocene barrier system" from the air. The first trip took place on 3 February from a tigermoth biplane hired from the Royal Aero Club of South Australia and piloted by SML Dunstone, a medical student at the University of Adelaide. The B&W negatives from this flight have recently been catalogued and were made available by Archives SAM due to their historic significance in recording landforms in coastal South Australia. Roughly following the first flight path, the second one took off a month later on 9 March 1936 with pilot Cyril Kleinig at the controls and the renowned aerial photographer D. Darian Smith (1900-1984) who was commissioned by the Advertiser to provide press coverage for the articles that would appear in the newspaper two months later." (Pers. Comm., Roger Luebbers, 2024). One of Tindale's photographs (Figure 22) is shown here just to provide an appreciation of the degree of aeolian dune activity present on the adjacent Younghusband Peninsula barrier, and to illustrate that mobile actives dunes were dominant along the entire two barriers system.

Figure 22. A photograph taken by Tindale in the 1930's along the Younghusband Peninsula.

Figure 23. The approximately same area as shown in Tindale's photograph above in 2019. Source: Google Earth.

Figures 24 and 25 illustrate the Goolwa Barrage being built and the adjacent Sir Richard Peninsula sometime between 1935 and 1940. The picture shows that there were two highly active areas of dunes, a larger wider zone nearer the River, and a narrower zone adjacent to the beach. The vegetation cover is relatively low. While the dune margins of the more Riverward dunes are sinuous and arcuate in places, they are primarily small transgressive dunefields with multiple nebkha (isolated dune hummock formed in a discrete plant or group of plants) or remnant knobs (eroded remnants of former dunes).

Figure 24. An overview of the Sir Richard Peninsula during the construction of the Goolwa barrage some time between 1933 and 1937 (D. Darian Smith photographer). Image BRG 397/2/114A/5 courtesy State Library, SA. View is down River towards the Murray Mouth.

Figure 25. Image looking up River of the Goolwa barrage being built some time between 1933 and 1937 (D. Darian Smith photographer). Image BRG 397/2/114A/2 courtesy State Library, SA.

Figure 26 (below) indicates that the dunes near the Murray mouth were 'possibly' better vegetated than those further NW along the barrier (i.e. towards Goolwa). We say "possibly" because it is virtually impossible to ascertain if pioneer grasses and herbs are present in the larger scale B/W aerial photographs shown below.

Figure 26. Image of the SE end of the Sir Richard Peninsula and Murray mouth some time between 1930 and 1939 (D. Darian Smith photographer). Image BRG 397/2/114B/1 courtesy State Library, SA.

Following the construction of the barrage in the late 1930's, pyp grass (*Ehrharta villosa*) was introduced onto the Peninsula to stabilse the dunes (Hilton et al., 2007). While this process took some time to reduce sand movement (see Figure 28), it eventually resulted in significant stabilisation of the dunefield (Hilton and Harvey, 2002).

5.4 1945 to 1949

The first vertical aerial photography of the region was conducted in 1945. The imagery (Figure 27) shows that there were still multiple active dunefields on the Sir Richard Peninsula.

Figure 28 is an enlarged version of part of Figure 27 and illustrates some features of the dunes present. The dunes indicated at (1) appear to be parabolic dunes but our interpretation is that this is still a transgressive dunefield which is gradually evolving into sub-parabolic or parabolic dunes. It is very common for transgressive dunefields to evolve over time into parabolic dunes or at least arcuate forms as vegetation colonisation takes place. The vegetation colonisation often first takes place along the interdune swales between the higher dune ridges, and as this occurs the unvegetated higher dune ridges advance landwards forming arcuate tongues (see (1) in Figure 28. This has been observed on the Younghusband Peninsula and also the Canunda dunefield system (Moulton et al., 2018, 2020; Benjumea Lopez and Hesp, P.A., 2023; Toffani et al., 2024) . It is common for the transgressive dunefields to be stabilised before they fully evolve into parabolic dunes (i.e. discrete U-shaped dunes with clear trailing ridges).

Figure 27. 1945 image of the Sir Richard Peninsula showing the marked amount of mobile dune activity at that time. The straight line across the River on the photo (left side) is the Goolwa barrage.

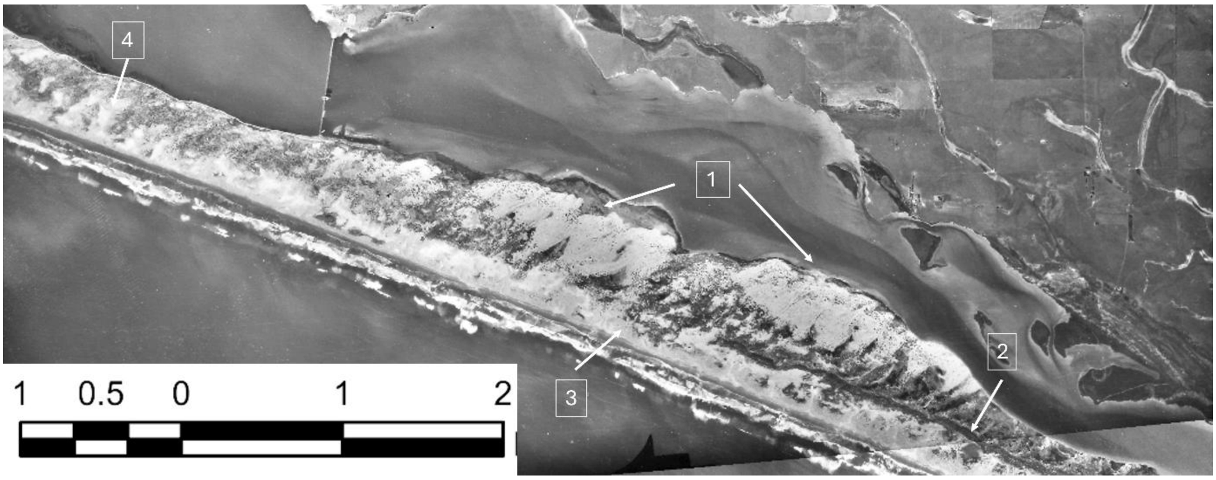


Figure 28: Enlarged image of part of the 1945 image shown in Figure 27 above. (1) transgressive dunefield evolving into parabolic and sub-parabolic dunes; (2) Precipitation ridge (marginal slipface) of the more seaward transgressive dune phase; (3) blowouts and deflation plains and basins formed along the seaward margin of the barrier; (4) parabolic dunes.

The dunes at Goolwa at around this time were also highly active (Figure 29).

Figure 29: A 1949 image (top) and a 2016 image comparison of the Goolwa Beach carpark/SLSC area. Source: Western, M., Bourman, R., Hesp, P (2019) Coastal Adaptation Study for Alexandrina Council (Cell SF3-4 Goolwa Beach) prepared by Integrated Coasts, South Australia.

5.5 1965

Figure 30 illustrates the Peninsula in 1965/66. There is still a considerable area of active mobile dunes. There is a clear curvaceous landward edge (likely a principal slipface – a steep lee dune slope) to the transgressive dune phase extending from the beach to ~half way across the Peninsula in the more SE half of the Peninsula (i.e. the half that is closer to the Murray mouth). This is indicated by (2) in figure 28, and shown in more detail and arrowed in Figure 31. This feature was formerly considered to be a relict foredune ("frontal dune") by Bourman et al. (2016; see their Figure 4.7). Figure 32 shows an oblique image of the sinuous ridge line in 2025.

Figure 30. Uncontrolled mosaic of the Sir Richard Peninsula and Murray mouth compiled in the Office of the Surveyor General, Department of Lands, Adelaide, from aerial photography taken in 18-11-1965 and 18-04-1966 (original scale 1mile to 1 inch).

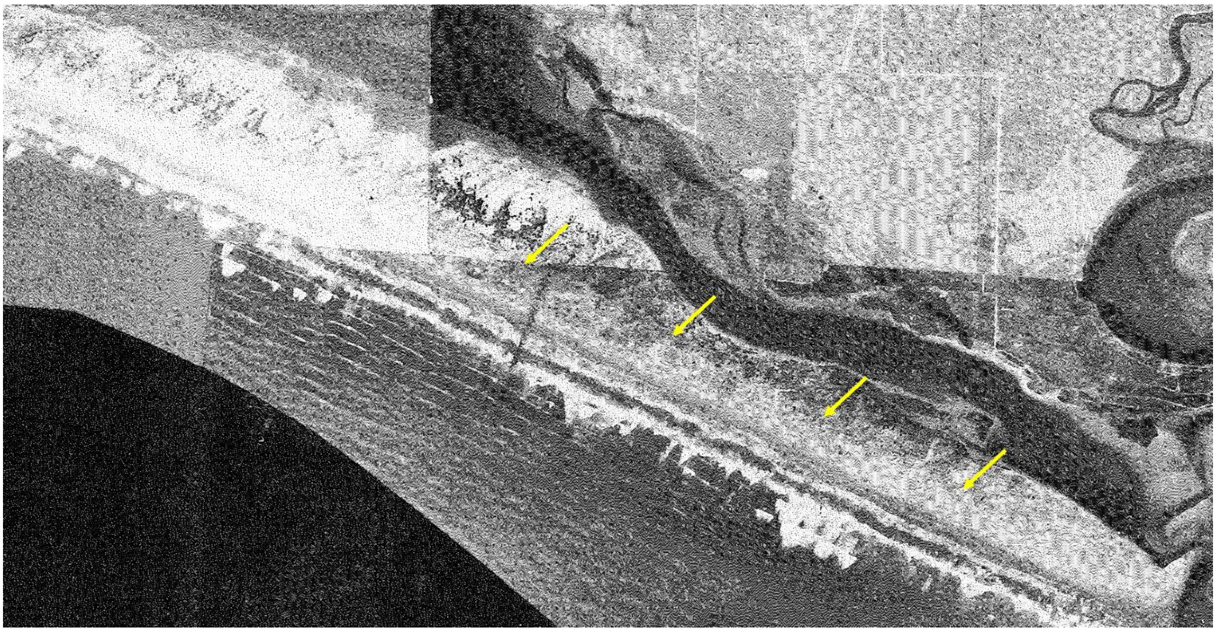


Figure 31: Blowup of the 1965/1966 aerial mosaic showing the active transgressive dune slipface or landward margin (arrowed) of the phase in the SE portion of the Peninsula.

Figure 32: A 2025 image of the 1965–66 transgressive dune phase, now fully vegetated and stabilised. (P. Hesp photograph).

The northwestern half of the Peninsula was characterised by a more complex, chaotic transgressive dune phases with very hummocky topography, blowouts and sub-parabolic dunes interspersed with sand sheets and deflation basins and plains (Figures 30, 31, 33).

Figure 33: A 2025 image of the Peninsula looking towards Goolwa. There is considerably more morphological complexity in this NW portion of the barrier (Photograph P. Hesp).

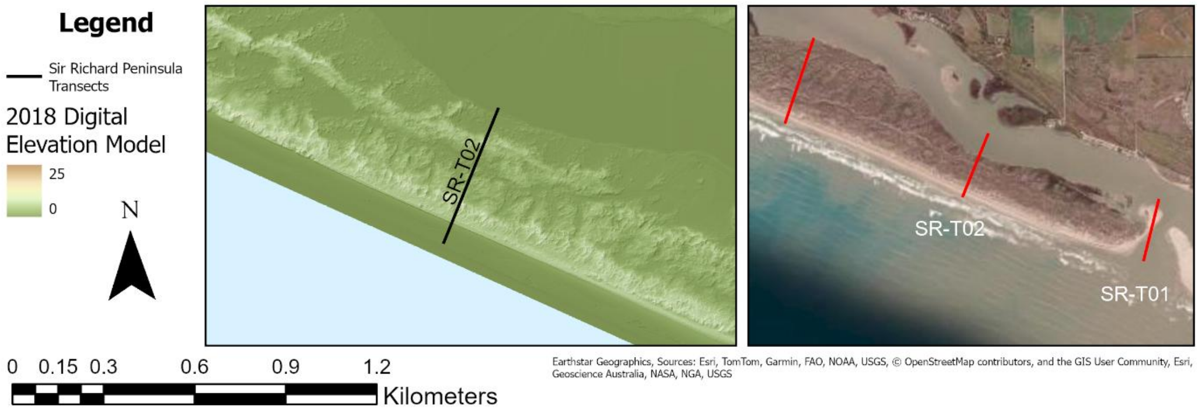
5.6 1975

Figure 34 shows the Sir Richard Peninsula in 1975. By this time the more landward, formerly active dunefield had been considerably vegetated, whereas the more seaward dunefield was still quite active with blowouts, parabolic dunes and sand sheets present. The more landward area may have been more intensely planted with pyp grass than themore seaward region leading to greater stabilisation and subsequent colonisation by native shrubs. The area near the Murray mouth was quite active as a broad sand sheet and although it is difficult to discern any vegetation, it is likely it was at least moderately vegetated with pioneer species (given the view shown in Figure 26).

Figure 34. The Sir Richard Peninsula in 1975. Mosaic produced from vertical aerial photography courtesy of DEW.

5.7 2018

The SA State LiDAR was flown in 2018. Figures 35 to 37 illustrate some cross-sections across the barrier at various locations.



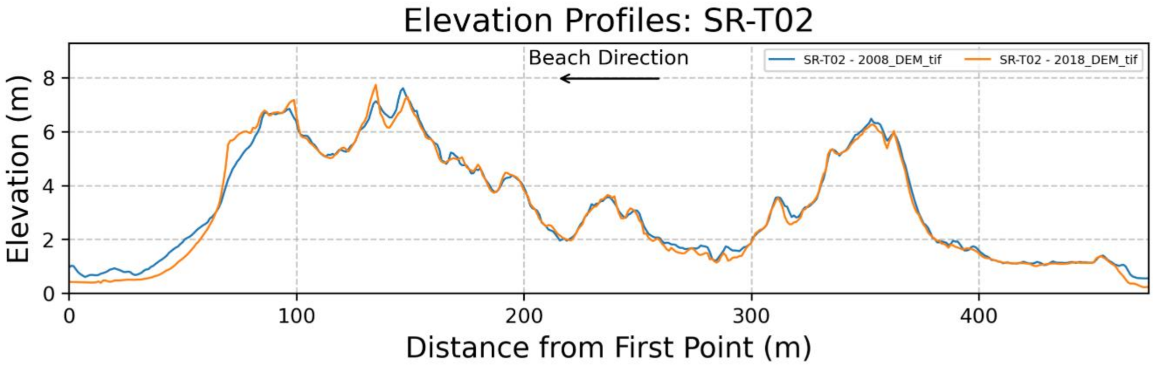


Figure 35: A topographic profile across the Sir Richard Peninsula at SR-T02 approximately 7.8km SE of the entrance of the sand track entrance just adjacent to the Goolwa SLSC. The prominent ridge line shown in Figures 31 and 32 above is located in the 120-220m zone on the topographic profile.

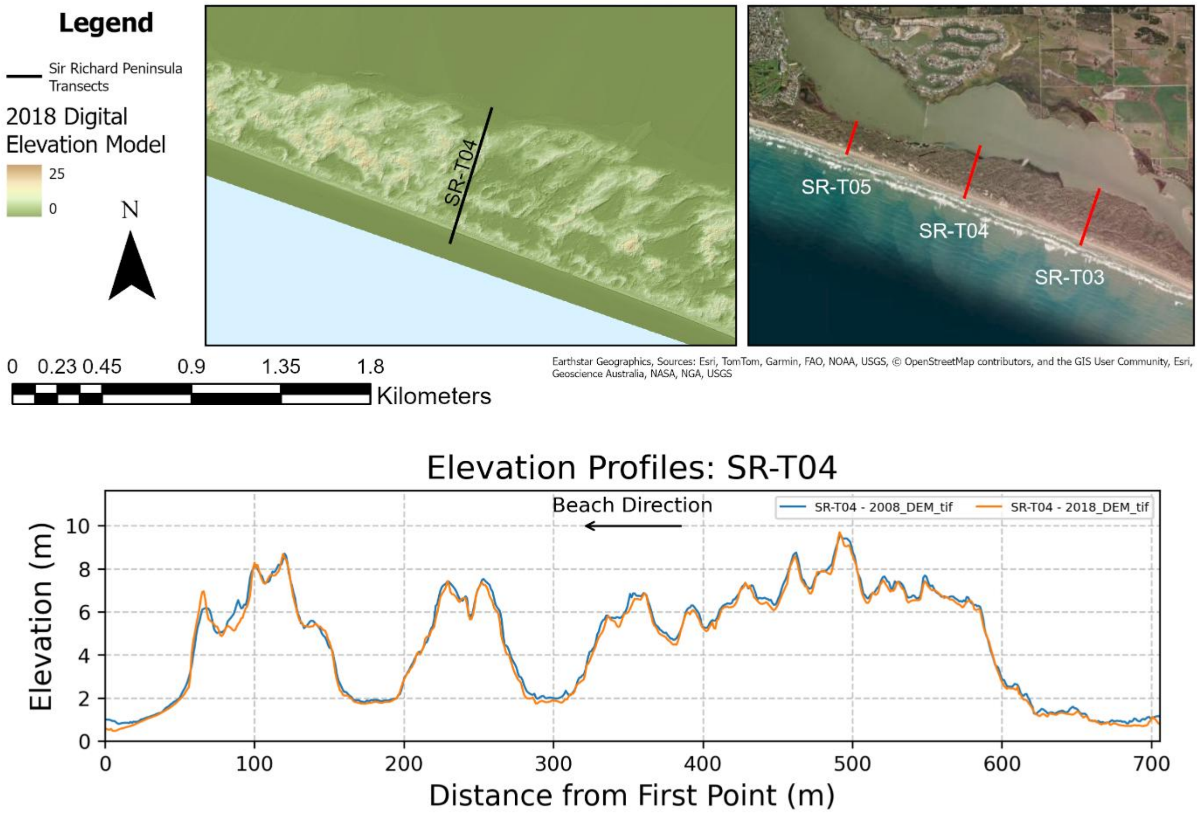


Figure 36: A topographic profile across the Sir Richard Peninsula at SR-T04 approximately 3.7km SE of the entrance of the sand track entrance just adjacent to the Goolwa SLSC. The prominent ridge line shown in Figures 31 and 32 above is located in the 200-300m zone.

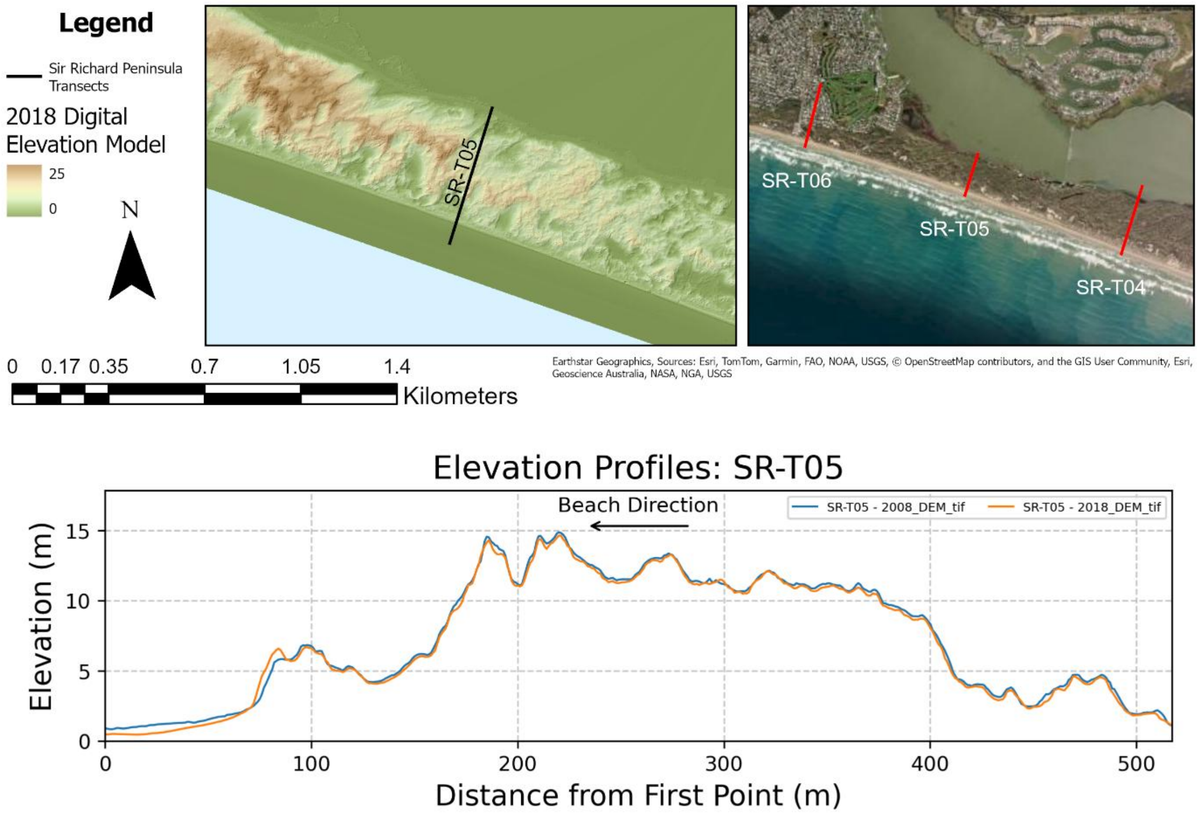


Figure 37: A topographic profile across the Sir Richard Peninsula at SR-T05 approximately 1.8km SE of the entrance of the sand track entrance just adjacent to the Goolwa SLSC.

It is obvious that there are considerable morphological (form) changes along the barrier. These are related to the typical chaotic development of dune landforms and landform units as transgressive dunefields form and migrate or transgress downwind, often cannibalizing earlier, older dunes and dune phases. Subsequent vegetation colonisation processes operate to change the dune forms adding trailing ridges, multiple nebkha, blowouts, and parabolic dunes.

5.8 Vegetation Cover Changes, 1945 to 2025

Figure 38 illustrates the vegetation cover changes that have occurred on the Sir Richard Peninsula between 1945 and 2025. The change has been quite remarkable with a cover change of 18% between 1945 and 1975, and a cover change of 18% between 1975 and 2025. Some of this increased cover is likely related to a reduction of human activities following colonisation and agricultural impacts, and some is likely due to a significant reduction in rabbit numbers over time. Moulton et al (2018) showed that there was a strong correlation between the reduction in rabbit numbers following the various introductions of viruses and measures to reduce or eliminate rabbits on the Younghusband Peninsula Appendix B (Figure B1 and B2) illustrates two examples from the Younghusband Peninsula to indicate that the process of an increase in vegetation cover was fairly universal along the entire SE coastal region.

Brandle and colleagues conducted a vegetation survey of the region in 2002 (Brandle, 2002). They indicated that the principal vegetation community characteristic of the taller sand dune slopes and ridges along the Sir Richard Peninsula comprised very open shrubland to tall shrubland depending on topographic position within the dunes. The overstory structure typically comprises *Olearia axillaris, Myoporum insulare, Acacia longifolia*, and *Leucopogon parviflorus*. The understorey is characterised by *Rhagodia candolleana, Pimelea serpyllifolia and Exocarpos syrticola, Kunzea pomifera, Carpobrotus rossii, Dianella brevicaulis, Muehlenbeckia gunnii* and *Billardiera cymosa*.

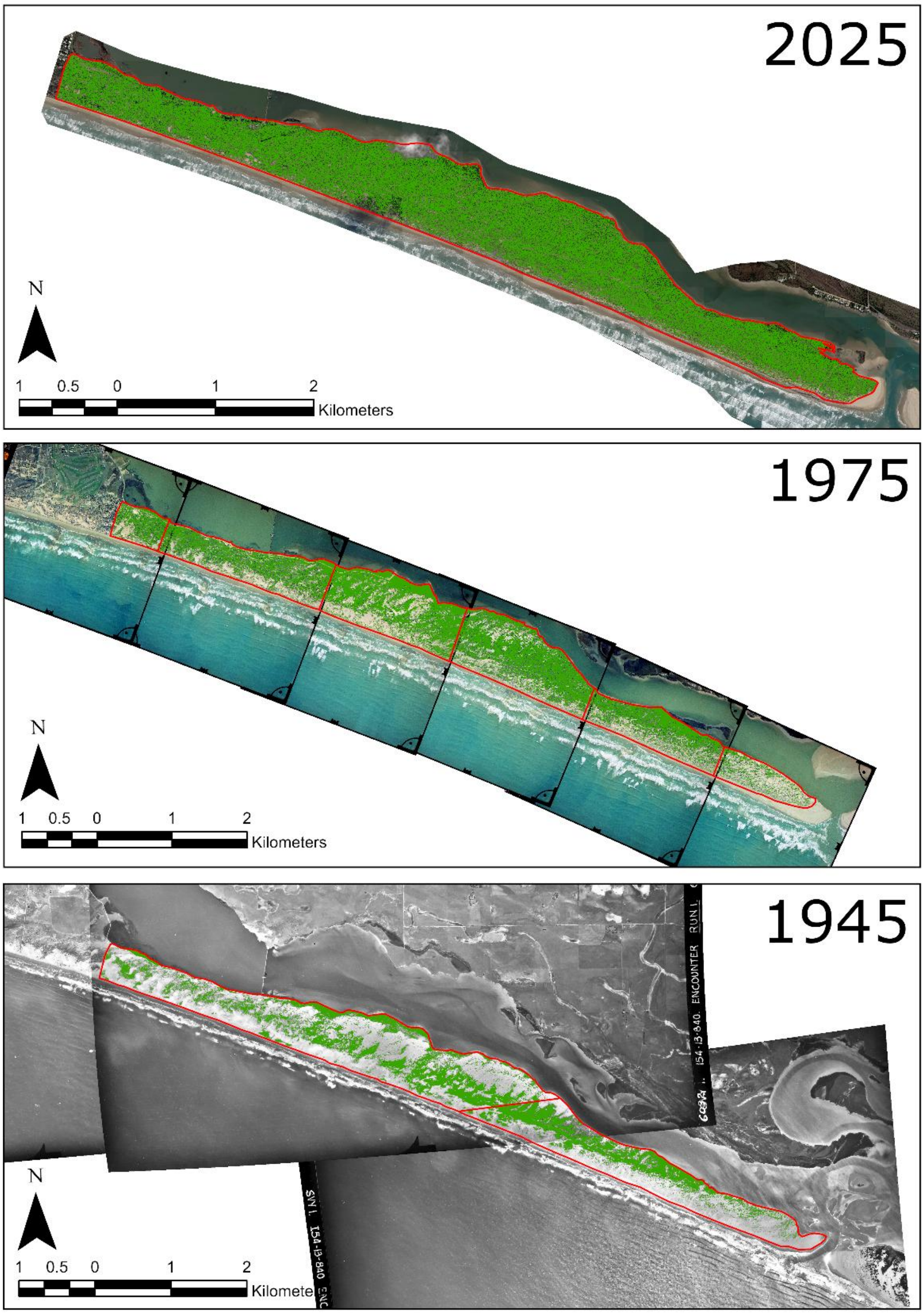


Figure 38: Vegetation cover on the Sir Richard Peninsula from 1945, 1975, and 2025. Total vegetation cover increased by 35% in the 1945 to 2025 period.

5.9 Post 1980's Invasive Species

Hilton and Harvey (2002) state that the foredune stoss face (i.e. seaward slope) was originally dominated by the indigenous dune species *Spinifex sericeus*. It is now dominated by the invasive grass *Thinopyrum junceiforme* (formerly known as *Elymus fractus* [Sand Couch-grass]), native to western Europe and the Mediterranean. and its invasion has significantly reduced the occurrence of *Spinifex*. *Thinopyrum* (sea-Wheat grass) was likely introduced or spread from Victoria possibly originally from ships ballast (Hilton and Harvey, 2002). . There was very little of it present in 1978 when Short and Hesp (1984) conducted their 1978 study of the SE coast. Hilton and Harvey suggest that it likely established on the Sir Richard Peninsula in the early to mid-1980's from sea-rafted rhizome derived from populations to the southeast. It is now (2026) almost a mono-specific stand along most, if not all the Sir Richard Peninsula. The foredune lee slope and adjacent dunes were characterised by a cover of *Olearia axillaris, Ozothamnus turbinatus, Stackhousia spathulata, Austrofestuca littoralis,* and *Leucophyta brownii* (Hilton and Harvey, 2002), but there has been considerable further invasion by *Euphorbia paralias* (Coastal spurge) since the 2000's. The deflation plains and basins are characterised by Isolepis nodosa, while the more inland dunes are characterised by *Leucopogon parviflorus*, *Myoporum insulare,* and *Acacia longifolia* (Hilton and Harvey, 2002). *Ehrharta villosa var maxima* (Pyp Grass), a native plant of South Africa, was introduced in the 1930's on the Sir Richard peninsula (Hilton et al., 2007) and still has a significant presence on the more landward dunes. For example, it is currently common along the landward portion of the Beacon 19 track.

Hilton and Harvey (2002) state that since 1945 the area of unvegetated or bare sand has decreased to around 10 per cent of 1945 levels, and that both Pyp Grass and shrubland have increased in area.

Figure 39: A new foredune post-1980's due to *Thinopyrum* invasion, 5-6m high, 15m wide, and continuous alongshore (P. Hesp photograph, March, 2024). This foredune has been formed on top of and seawards of the original *Spinifex* dominated foredune/blowout complex. Note the line of hummocky dunes and blowouts located behind the foredune; this is the area of formerly mobile dunes shown in Figures 31 and 38.

6 Conclusion

A new tentative evolutionary history and stratigraphic analysis has been produced for the Sir Richard Peninsula which indicates initial retrogradation over a palaeo-lagoon and/or palaeo-river system in the NW, and alongshore SE spit migration and progradation in the Beacon 19 Track region. Several dunefield phases are envisaged but remain to be proved following OSL dating and further examination of the Beacon 19 track cores.

Significant vegetation and geomorphological changes have taken place on the barrier in the historical period. The Peninsula was characterised by large areas of active mobile blowouts and parabolic dunes in the NW portion, and transgressive dunefields in the SE portion in the 1930's. By 1975, these were considerably less active and by 2025 the entire Peninsula, apart from the very distal spit terminus, is largely vegetated. Significant invasion of *Thinopyrum* (sea wheat grass) has taken place since the early 1980's and other invasive species (e.g. *Pyp* grass) have significant presence in some areas. Active management of these invasive species should be considered a priority in the future.

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Appendix A: Summary of Core Logs at the Beacon 19 Track

Table A. Geology of the six sites along the Beacon 19 Track.

SITE	GEOLOGY
Site 1	0-6 SAND grey fine to medium, wet from 0.5m
Site 2	SAND 0-4m, fine to medium, yellow brown, dry, 4-8m, SAND, grey, wet F-C, 8-9.6m, SAND grey wet F-C, with Low liquid [illegible]
Site 3	0-0.5m SAND, grey/brown, fine, moist, 0.5-0.9m SAND yellow brown, moist, fine to coarse, with calcareous shell [illegible]
Site 4	SAND 0-6 yellow brown, F-M, 6-8 SAND grey, wet F-M
Site 5	Sand 0-1, yellow brown, dry F-M, 1-5m SAND grey wet F-M, 5-9m SAND, grey wet, F-M with shell inclusions
Site 6	SAND 0-2 yellow brown dry F, 2-3.5m SAND grey Fine, wet.

Appendix B: Imagery of vegetation Changes on Portions of the Younghusband Peninsula

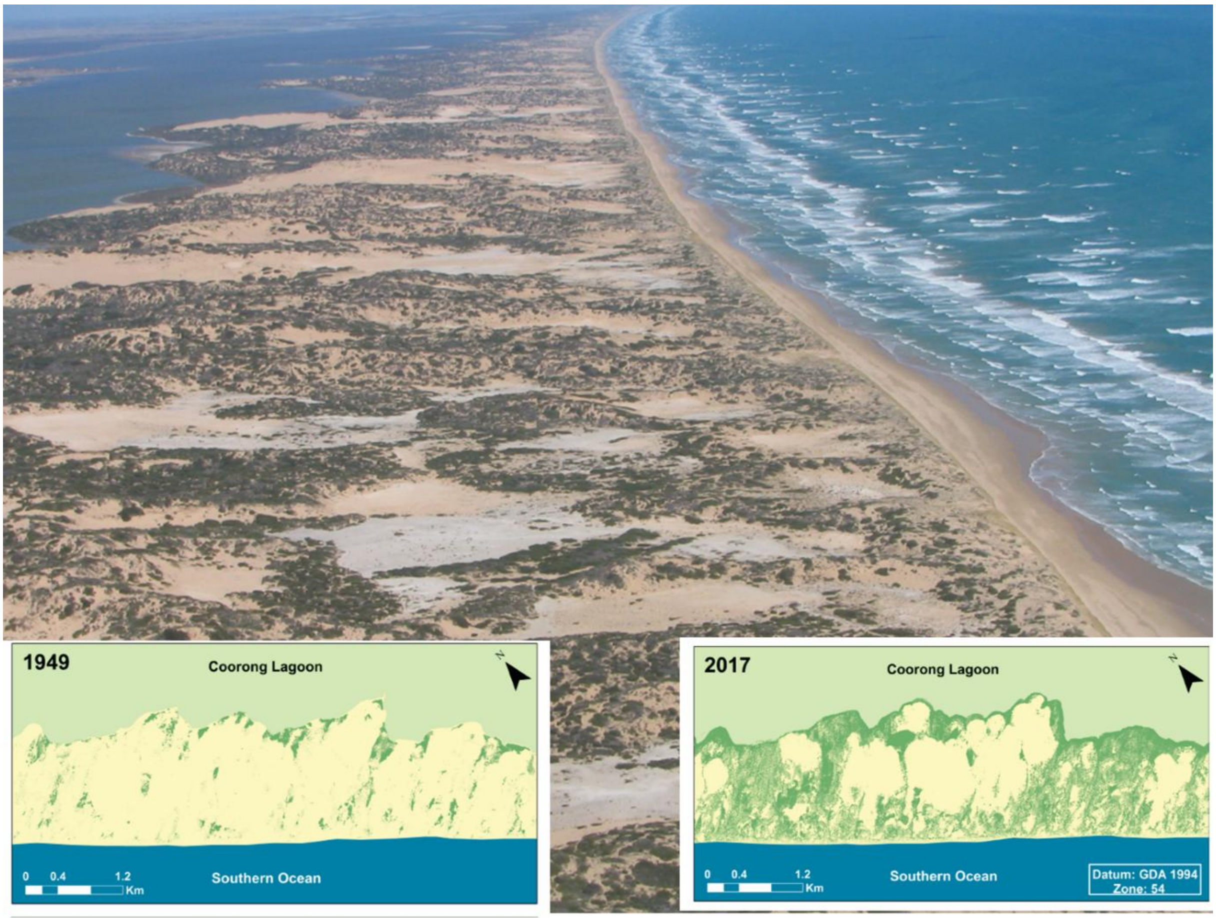

Figure B1. View along the northern part of the Younghusband Peninsula in 2019 with inserts showing vegetation cover of the area in 1949 compared to 2017. Yellow colour indicates bare sand, green vegetation. Inserts source: Moulton et al, 2018. P. Hesp Photograph.

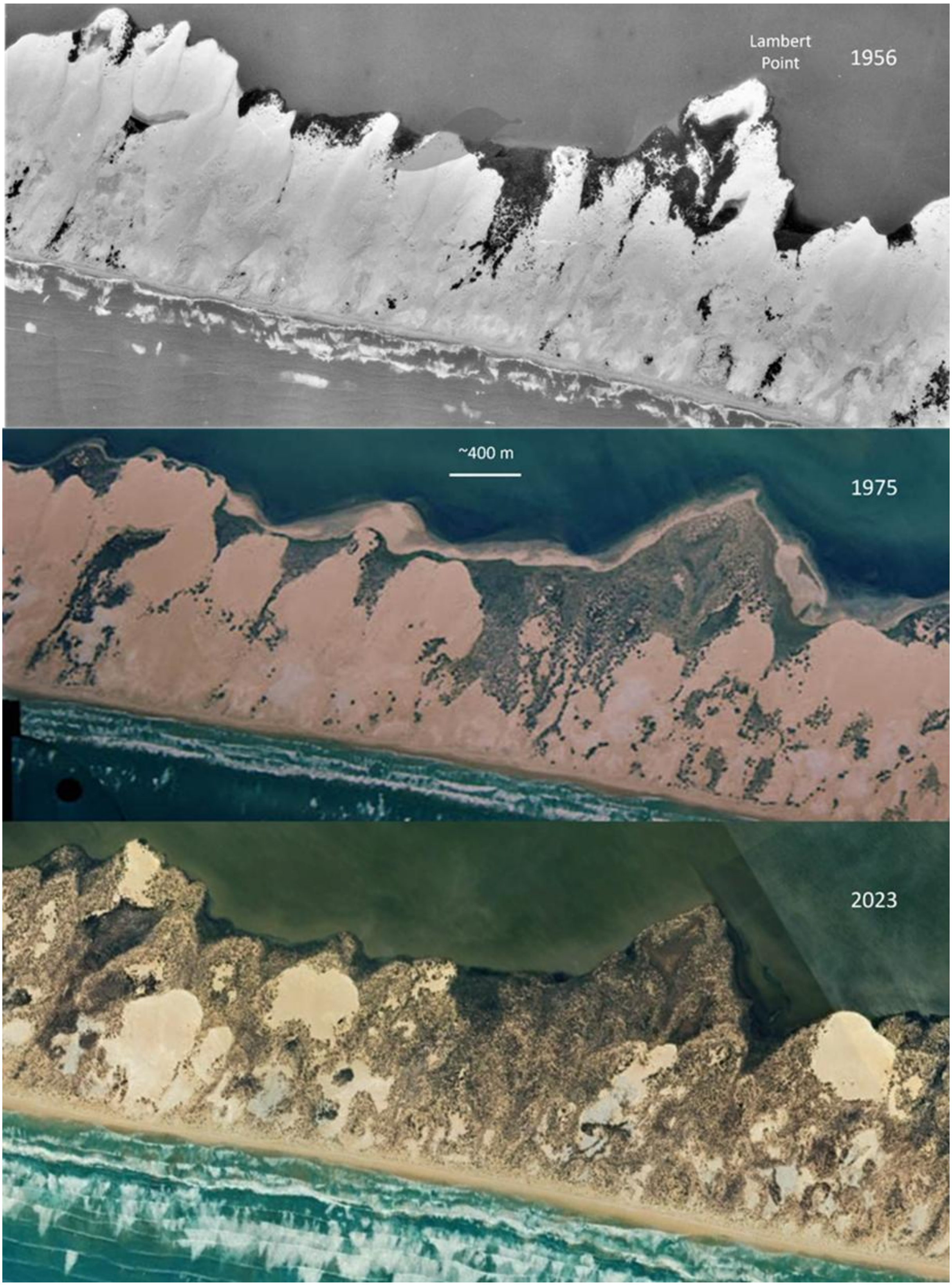

Figure B2. The Lamberts Point region on the Younghusband Peninsula (~36 km SE of the Murray mouth) in 1956, 1975 and 2023 illustrating the enormous vegetation cover changes that occurred over that period. Sources: DEW for 1956 and 1975 aerial imagery, Google Earth 2023 image.

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