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A Geomorphic Investigation of Shoreline Change at Garden Island Sands, Southern Tasmania

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Front Cover: Top: Aerial photographs of Garden Island Sands in 1948 (RHS) and 2015 (LHS); **Bottom:** Large mature tree on the foredune at Garden Island Sands, undermined by recent erosion (Photo date 3rd Aug. 2022).

CONTENTS

SUMMARY

Garden Island Sands is a large and nearly full sand-trapping embayment on the north shore of the lower Huon River estuary. Increasing erosion of the beach and its backing shore-parallel foredune - including the undermining and collapse of large mature trees growing on the foredune - has been a significant concern at Garden Island Sands Beach during recent years. This report was commissioned by the community group *Friends of Garden Island Creek Inc*. (FOGIC) to investigate the causes, magnitude, and rate of this erosion.

Analysis of 34 ortho-rectified (distortion-corrected) air photos plus a recent survey of Garden Island Sands provides a quantifiable history of shoreline, beach and dune behaviour from 1948 until 2022. For the purposes of this analysis the shoreline at Garden Island Sands Beach is defined as the seawards *in situ* vegetation line and currently mostly corresponds to a prominent erosion scarp along the seawards front of the foredune.

The air photo history demonstrates that a significant change in long-term shoreline behaviour along most of the beach commenced around the year 2000. Prior to 2000, the shoreline position had been mostly stable or only slowly receding since at least 1948, with some notable erosion and recovery cycles around this dominant shoreline behaviour. However, around the year 2000 there was a significant change to a more persistently and rapidly eroding shoreline recession trend which has continued to the present. Temporary sand bars largely filling the mouth of Garden Island Creek estuarine lagoon (at the south-east end of the main beach) have been recorded by air photos several times since 2001 but are absent from all earlier air photos since 1948. These are inferred to be composed of sand mobilised by the increased beach erosion since 2000 (see section 3.4.2).

These shoreline behaviour changes are identifiable from the air photo sequence data in retrospect but would probably not have become obvious to casual observers on the ground until sometime after 2000, when the impacts of the increased erosion started to "emerge" above the normal variability of prior beach erosion and accretion (recovery) cycles to which local observers would have been accustomed. Inspection of the air photo records suggests that the "time of emergence" for the changed beach behaviour probably occurred roughly around 2010 to 2015.

Several sub-ordinate shoreline behaviour patterns and changes are also evident from inspection of historical air photos and of the beach itself (see sections 3.2 and 3.4.2), with the most notable of these being a pattern of less erosion and recession along the north-western third (approximately) of the beach and foredune than elsewhere. This has been a long-term pattern along the beach since at least 1948 which continues at the present and is probably attributable to greater sheltering of that part of the beach from the dominant westerly to south-westerly locally generated wind–waves which are inferred to be the main agent of the observed erosion.

The observed change in the long-term behaviour of Garden Island Sands Beach implies a significant long-term change in some process or condition driving geomorphic processes at the beach. Sea level is the only major geomorphic process control known to have been changing in recent decades (by rising at both global and local scales) which provides a plausible mechanism of the observed beach and dune changes (see section 3.6.2). Some evidence is suggestive of possible wind (and thus wind-wave) speed and/or direction changes at Garden Island Sands since 2015 (see section 3.4.2), however no observational data on this is known to the writer, moreover it would not explain the significant changes in beach behaviour fifteen years earlier around 2000.

Sea-level rise provides a plausible explanation of the observed changes at Garden Island Sands beach because of two key effects of rising mean sea-level on sandy beaches, namely that it causes:

1. more frequent erosion to higher levels on the beach profile than before (even with no change in actual storm wave frequency and magnitude) because waves of any given size can run and erode further to landwards and higher on the shore profile than previously over the deepened water.

and because it allows:

2. the creation of more accommodation space for eroded sand by deepening water over depositional sandy bottoms including sand bars, which at Garden Island Sands is deduced to allow increasing amounts of eroded sand to be permanently sequestered in two "nested" sand sinks or traps within the overall sand trap that is Garden Island Sands. These nested sinks are in the estuarine lagoon, and a large sand bar offshore from the main beach).

These two factors mean that in a coastal environment such as Garden Island Sands, sea-level rise results in more erosion of the beach and dune than previously, and also that greater proportions of the eroded sand than previously are trapped in local sand sinks instead of being returned to rebuild the beach and dune before the next large erosion event occurs. These processes cause the shoreline (beach and dune) to begin to recede or to recede more rapidly as sea-level rise itself occurs at increased rates. In the case of Garden Island Sands, the increasing rate of global mean sea-level rise that was measured during the 1990s (see section 2.4.4) was evidently sufficient to tip the rate of (previously slow) shoreline recession into a significantly faster rate by around the year 2000. The air photo analysis shows that faster rate of shoreline recession has continued up to the present (alongside continuing increase in the rate of sea-level rise: see section 2.4.4).

No other plausible explanations of the change in shoreline behaviour at Garden Island Sands have been identified (see section 3.6.3). If this explanation of the observed changes is valid, the observed rapid recession can be expected to continue well into the future because it is driven by global mean sea-level rise which itself is continuing at an increasing rate (IPCC 2021).

Of particular concern from a coastal hazard perspective is that the air photo analysis shows that increased foredune scarp recession since 2000 has already removed variously 7 to 12 metres width of the dune front (the least from the north-western part of the beach, the most from the central to south-eastern parts of the beach). This amounts to the loss so far of one third to one half of the total original width of the foredune as it was during the year 2000. Moreover, the first set of profiles surveyed across the dune (see section 3.3) indicate that the erosion has already passed the highest crest of the original dune and is now progressing through the backslope (landwards side) of the original dune. This means the ground surface is getting lower as the erosion scarp recedes further to landwards, hence with each successive storm erosion event there is now an increasing risk that storm waves will finally be able to break through the remaining (lower) dune and allow storm waves to wash over into the residential areas behind causing flooding and other water damage.

From the perspective of coastal hazard management at Garden Island Sands, a high priority is therefore to reduce the risk of residential properties being damaged if the remaining (now lower) foredune barrier is breached by storm waves. There is arguably a need to address this priority before much more foredune erosion and recession has occurred. Sandbagging may be an achievable interim measure to manage this hazard while consideration is given to longer-term options.

1.0 INTRODUCTION

1.1 Purpose

This report was commissioned by the community group *Friends of Garden Island Creek Inc*. (FOGIC) to investigate the geomorphic (land forming) characteristics and processes of Garden Island Sands Beach in south-eastern Tasmania.

Significant and apparently increasing beach and foredune erosion has been of concern to local residents and landowners for some years. Of particular concern is that the erosion damaged a former boat ramp resulting in its removal, with the result that access to the beach and boating opportunities has become difficult for many local residents and visitors.

The primary purpose of this report has been to investigate the causes, magnitude, rate, and likely future impacts of this erosion. This information is needed to provide a basis for identifying and planning appropriate responses to the erosion.

It should be noted that the author of this report is a geologist and geomorphologist but is not an engineer. Hence no specific engineering designs for managing beach erosion are provided, however the information provided will enable the implications and consequences of the various options for managing the erosion to be assessed.

Note also that whereas this report is focussed on understanding the nature and causes of beach and shoreline erosion at Garden Island Sands Beach, other coastal hazards may also affect the beach and surrounding areas. These in particular include increasing groundwater levels, salty groundwater penetration and coastal (storm surge) and river flooding. These are briefly noted in Section 3.7; however, these issues were beyond the scope of this report and are not further discussed here.

1.2 Coastal Setting

Garden Island Sands is a small residential settlement at Garden Island Sands Beach (adjacent the outlet of Garden Island Creek) on the north shore of the lower Huon River estuary in south-eastern Tasmania. The estuary opens into D'Entrecasteaux Channel about 4.5 kilometres southeast of Garden Island Sands. The beach is accessed by Lowes Road, a short gravel road off the Channel Highway about 25 km south-east of Huonville and 42 km south of Hobart.

Garden Island Sands Beach is set within a very complex "ria" coast comprising drowned river valleys and estuaries which formed at periods of lower global sea-level during past glacial climatic phases and were subsequently drowned as sea-level rose under the warmer climatic conditions of the present interglacial phase (see also Section 2.4.4). The roughly WNW-ESE oriented beach is about 440 metres long and faces southwards onto the Southern Ocean via the southern end of D'Entrecasteaux Channel. Although this means the beach is exposed to swell waves driving directly up D'Entrecasteaux Channel from the Southern Ocean, the nearby Garden Island also provides the beach some sheltering from swells.

The Garden Island Sands Beach is a natural asset of considerable aesthetic and recreational value to the Garden Island Sands community.

1.3 Investigations undertaken

The information provided in this report is based on the following work by Chris Sharples:

1. A review of existing (published) geological and geomorphic mapping and other information pertaining to Garden Island Sands Beach.
2. A review (and field observations) of beach test pit results obtained by Bill Cromer (geologist) in a concurrent and related geological investigation for *Friends of Garden Island Creek Inc*. (Cromer 2023).
3. Field inspections of Garden Island Sands Beach and surrounding areas, including the use of a sea kayak to investigate shallow intertidal and subtidal sands offshore from the beach, as well as on the facing cobbly-sand spit on Garden Island and in the Garden Island Creek estuarine lagoon.
4. A time series of 34 air photos ranging in age from 1948 to 2021 were ortho-rectified and analysed together with a field-surveyed (GNSS) 2022 foredune scarp position. This information was used to determine the history of shore behaviour and change at Garden Island Sands Beach over the last 74 years. The air photos were also used to test for changes in offshore and estuarine shallow-water sand bars over the same period.
5. Together with surveyor Nick Bowden, back-dune survey marks were installed, and four high-resolution profiles were surveyed across the foredune and beach. These provide a basis for local volunteers to monitor future beach and shoreline changes from the 2022 baseline by repeating the profile surveys at regular intervals as part of the TASMARC beach monitoring project (www.tasmarc.info).

This work was undertaken concurrently with additional geological and hydrological investigations by Bill Cromer (environmental, engineering and groundwater geologist), which have informed this report and are cited where relevant.

1.4 Terminology and Acronyms used

The following technical terms and acronyms are used in this report and are briefly explained here to assist readers. This is not a comprehensive list of terminology relevant to coastal landforms, merely a list of potentially unfamiliar terms used in this report)

Accommodation space This term refers to the space available for sand (or other sediment) to settle out and accumulate in a marine environment. The vertical limits of sand accumulation on the seabed are determined by the “mobilisation depth” (or “closure depth”) to which waves, currents and tides can move sand (or other specified sediment). Below that critical depth – which varies from place to place and at different times depending on tides, wave, and current activity – sand may settle out and be stored indefinitely, however above that depth sand will be constantly or intermittently mobile until it reaches another location (e.g., deeper water or a beach) at which it can settle out. However, when a net rise in sea-level occurs, this creates additional accommodation space (i.e., water depth) for sand to accumulate below the “mobilisation depth”. When and where this occurs an enlarged or rejuvenated sand sink is created which may trap more sand than it previously had the capacity to hold.

Accretion Accumulation or deposition of sediment (e.g., sand accretion on a beach or dune).

Average Equivalent to “mean”. The sum of a collection of numbers divided by the count of numbers in the collection; commonly used to identify a central tendency in a dataset. See also “Median”.

BoM The Australian Bureau of Meteorology.

Change of Behaviour (COB) The time at which a long-term record of landform behaviour shows a major long-term change of behaviour occurring, for example a switch from dominantly depositional sand accretion to dominantly erosional sandy landform behaviour. However, note that the change to a new trend may take some years or decades to become obvious to casual observers because of short term variability (such as short-term erosion and deposition cycles) obscuring the new trend (see also "Time of Emergence" below).

DPIPWE The former Tasmanian Department of Primary Industries, Parks, Water & Environment, now the Tasmanian Department of Natural Resources and Environment (NRE)

Dynamic equilibrium A term to describe systems exhibiting cyclic or episodic change around a long-term net stable state. A beach undergoing cyclic erosion and recovery around a long-term stable position is an example of dynamic equilibrium.

ENSO El Nino Southern Oscillation; A major inter-annual Pacific – scale climatic cycle with affects sea-level variability, wave climate, and other climatic factors on Australian coasts.

Erosion The removal of material by natural processes such as wave attack. For example, beach or dune erosion.

Flood tide delta A body of sediment (e.g., sand) transported into a tidal inlet by flood tide currents and deposited there either temporarily or permanently.

Fluvial A geomorphic term pertaining to running water and river or stream landforms.

Foredune A shore-parallel dune ridge immediately behind and inland of the wave-washed beach face, comprising sand blown inland by onshore winds from the dry upper beach face, and captured amongst vegetation growing inland of normal storm wave run-up limits.

Incipient foredune A small "embryo" foredune beginning to accumulate in front of a larger, older foredune which has been scarped by wave erosion. The incipient foredune is the first stage in recovery of the eroded foredune, as sand begins to be captured by vegetation that is beginning to re-establish in front of the erosion scarp.

GMSL, GMSLR Global Mean Sea Level, Global Mean Sea Level Rise

GNSS Global Navigation Satellite System. A widely used high accuracy survey technology which was used in this project to survey profiles across the beach and foredune, and to map the current (2022) foredune scarp position along the whole beach length.

LIDAR is an acronym of "light detection and ranging" or "laser imaging, detection, and ranging". Lidar uses mostly airborne laser imaging techniques to map ground topography at high resolution.

LIST Land Information System Tasmania. A very wide range of mapped data on Tasmania is available on the LIST website at www.thelist.tas.gov.au

Littoral Pertaining to shores and shoreline zones.

Mean Equivalent to "average". The sum of a collection of numbers divided by the count of numbers in the collection; used to identify a central tendency in a dataset. See also "Median".

Median A description of central tendency in a collection of numbers which is often used for data with anomalous outlying values that may skew the central tendency as measured by a “mean” or “average”. The median is the middle value in a collection of numbers.

NRE The Tasmanian Department of Natural Resources and Environment. Previously the Tasmanian Department of Primary Industries, Parks, Water & Environment (DPIPWE).

Progradation Progressive addition or accretion of sediment on a shoreline over years or decades, causing the shoreline to grow in a seawards direction (e.g., beach progradation).

Recession Progressive removal or erosion of sediment from a shoreline, causing the shoreline to recede in a landwards direction over years or decades. Recession is typically the cumulative result of multiple erosion events over a significant period of time.

Ria Complex coastal planform resulting from the drowning of deeply incised river landscapes during periods of higher relative sea-level, such as the present inter-glacial climatic phase.

Swell waves Waves generated by winds blowing across long oceanic fetches. These waves may propagate thousands of kilometres beyond the ocean regions in which they were generated.

TASMARC The TAsmanian Shoreline Monitoring and ARChiving project. A beach monitoring project which commenced in 2004 as a project of the Antarctic Climate and Ecosystems Co-operative Research Centre (ACE-CRC) at the University of Tasmania. The project is based on community “citizen science” groups surveying beach profiles at intervals, with the data being processed and made available for open public access at www.tasmarc.info .

Time of Emergence (ToE) The time at which a new natural process such as a new climatic trend or new landform behaviour trend becomes obvious to the casual observer above the noise of short-term natural variability which may have at first made the new trend hard to detect. The significance of the “Time of Emergence” concept in climate change studies was discussed by Hawkins and Sutton (2012)

Wind-waves Although swell waves (see above) are strictly speaking wind waves, the latter term is usually reserved for waves generated by local winds over local fetches of the order of kilometres.

1.5 Acknowledgements

I thank Peter Devine (Geodata Services, Tasmanian Department of Natural Resources and Environment for his assistance in obtaining scanned historical air photos from the large NRE air photo archive. I also thank Bill Cromer, Elliott Cromer, and Nick Bowden for their assistance with field work and surveys.

Kelsie Fractal and Angela Bird of the Friends of Garden Island Creek Inc. (FOGIC) community group organised the opportunity for the investigations in this report to be undertaken, and their assistance and enthusiasm for the project has been greatly appreciated.

2.0 GEOMORPHOLOGY – DESCRIPTION AND PROCESSES

2.1 Introduction

This report chapter describes the landforms of Garden Island Sands Beach and its environs, and the natural processes which shape and may modify those landforms. This descriptive information is based on existing information as referenced, together with field observations and inferences by the writer (Chris Sharples). This information provides the necessary basis for Chapter 3 which interprets the causes and implications of landform changes that have occurred at Garden Island Sands Beach within recent decades.

The term "Garden Island Sands" is taken here to refer to a related cluster of sandy landforms including a beach, foredune, and extensive estuarine, intertidal, and subtidal sand flats. These sandy landforms are located within a deep rocky embayment between Randall's Bay and Charlotte Cove in the Lower Huon River estuary and are partly protected from wave action by the large rocky Garden Island offshore (see air photos Figure 7 & Figure 8). Taken together these sand accumulations comprise a large sand-trapping coastal embayment from which it is likely that little sand is lost offshore or alongshore. However, at a smaller scale there is evidence of complex movements of sand within the Garden Island Sands landform system (see section 2.4.6) which – amongst other things – have in recent decades been depleting the beach and foredune of sand in response to increasing erosion and recession of the shoreline.

2.2 Geological setting

The best available geological mapping for the Garden Island Sands area is the 1:50,000 scale Kingborough and Dover geological map sheets (Farmer 1981; Farmer & Forsyth 1993) which are reproduced here as Figure 1 below.

Based on this mapping, Garden Island Sands Beach, and all surrounding areas within the scope of this report are underlain by dolerite bedrock of Jurassic age (see Figure 1). This dark bluish to dark-brown igneous rock type outcrops along sloping shorelines both west and east of the beach, and northwards along the eastern shore of Garden Island Creek estuarine lagoon (see Figure 2). Garden Island is also comprised of dolerite bedrock which outcrops along a large proportion of the islands shore. The rocky dolerite shores adjacent the beach and lagoon are moderately sloping hard rocky shorelines which are generally highly resistant to wave attack and erosion (although overlying soil horizons may at some time be expected to begin exhibiting erosion in response to wave attack at higher levels than previously in response to sea-level rise). Dolerite bedrock is assumed to underlie the beach at some depth greater than 2, but was not encountered in 6 test pits excavated by Cromer (2023) in sand and pebbly sand to depths of about 2 metres at intervals along the back of Garden Island Sands Beach.

Soft clay-rich Permian-age feldspathic sandstones outcrop about a kilometre west of Garden Island Sands where they form coastal cliffs and steep slopes adjacent Randall's Bay, but these are not encountered in the Garden Island Sands embayment. At Randall's Bay these cliffs are overlain by a thin veneer of unlithified gravels dominantly comprising rounded quartz pebbles of possibly Pleistocene-age and glacio-fluvial origin (see Figure 1). Similar veneers are not known to be exposed close to Garden Island Sands at present. However, excavations by Cromer (2023) at Garden Island Sands Beach showed that a layer of rounded quartz pebbles in a sandy and shelly matrix underlies geologically recent (Holocene-age) beach sands below about a metre depth (see Section 2.3.1 below). These may have been transported to the Garden Island Sands embayment by waves or other processes from deposits similar to those still exposed at Randall's Bay, during an earlier (but still geologically recent) phase of landscape development.

2.3 Landforms and Sediments

2.3.1 Beaches and Rocky Shorelines

Garden Island Sands Beach is located on the north shore of a partly sheltered coastal embayment behind and north-east of Garden Island (see Figure 1 & Figure 2). The beach is bounded to the northwest and southeast by moderately sloping hard rocky dolerite shores, which also extend northwards up the eastern side of the long narrow Garden Island Creek estuarine lagoon (see Figure 1 & Figure 2). The dolerite is inferred to underlie the whole beach at depths of greater than 2 metres, based on temporary beach excavations by Cromer (2023) which encountered only loose unconsolidated sand and pebbly sand to that depth.

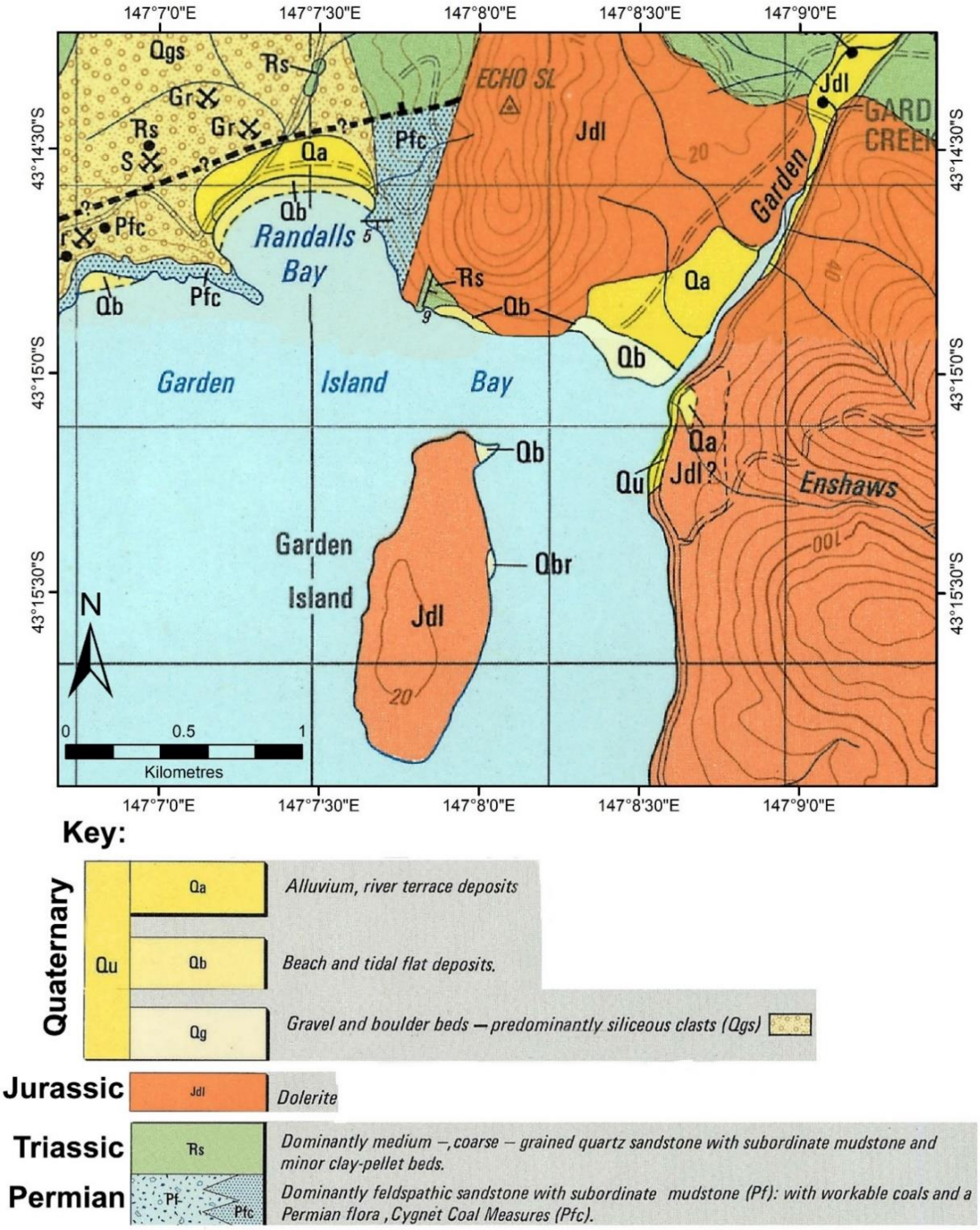

Figure 1: Geological Map of Garden Island Sands Region. Map copied from Kingborough and Dover 1:50,000 geological map sheets (Farmer 1981; Farmer & Forsyth 1993). Better scale (1:25,000) published geological mapping is currently unavailable for this area.

Garden Island Sands Beach is a 470 metres long, south- to south-southwest facing beach of fine-grained yellow-grey sand. Short (2006, p.141) has classified the beach as a steeper "reflective" upper beach (low-energy and wave-dominated) fronted by very broad (~400 metre wide) intertidal to sub-tidal sand flats. At the time of writing (2022), the beach above the low tide terrace is notably narrower (~3-4m) and wetter in its central to south-eastern areas (Figure 3) than it is near its wider (~8-9m) and drier north-west end (Figure 4). This pattern of a wider and drier

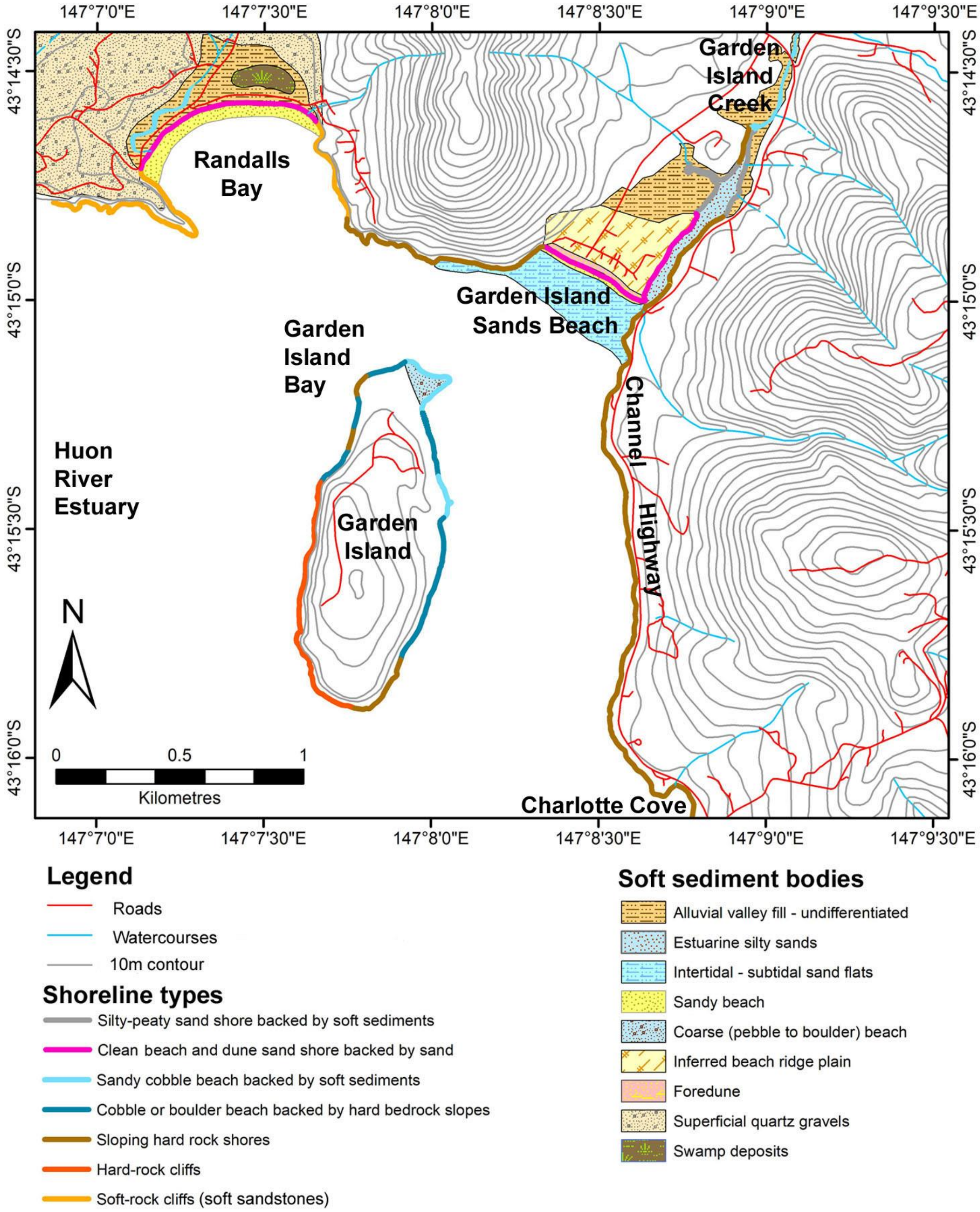

Figure 2: Shoreline types and onshore to shallow-water soft sediment bodies in the Garden Island Sands area. Shoreline types mapping is based on original field and air photo mapping by C. Sharples (including Sharples, Mount & Pedersen 2009, with map updates) and soft sediment bodies mapping is based on 1:50,000 mapping by the Geological Survey of Tasmania (Kingborough and Dover sheets, Farmer 1981; Farmer & Forsyth 1993). Co-ordinate system is geographical co-ordinates (WGS84 datum).

Figure 3: View eastward along the east end of Garden Island Sands Beach at close to low tide (3rd January 2022). This view shows a damp narrow upper sandy beach above the very broad flat wet sandy low tide terrace which here exhibits pebbles and shelly material. The cut woody debris artificially piled against the foredune on the left is covering a very fresh erosion scarp of recent origin (see also Figure 5).

Figure 4: View westwards along the west end of Garden Island Sands Beach at close to low tide (3rd January 2022). Compared to the eastern end of the beach (see Figure 3 above), this view clearly shows a much wider and drier upper beach above the broad flat wet low tide terrace to the left. Although an old erosion scarp is visible in the foredune at the right, it is becoming buried beneath the accreting incipient foredune at its foot, which has grown as sand has been returned to the beach following the last erosion event. This older and more recovered dune scarp contrasts with relatively fresh recent erosion scarping in the central to eastern part of the beach (see Figure 5).

beach towards its north-western end is seen in many (but not all) of the air photos from 1948 onwards and appears to have been a frequent (but not permanent) state of this beach since at least the earliest air photo in 1948. A good example is seen on the 18th Feb. 1967 air photo provided as Figure 13 elsewhere in this report. This pattern is inferred to be at least partly due to sheltering of the western end of the beach from the dominating westerly and south-westerly wind-waves (see section 2.4.2) by the rocky headland immediately west of the beach.

In contrast, inspection of the air photo time-series suggests that the central to south-eastern part of the beach is today persistently and notably narrower and lower (wetter) than it normally was prior to the last two decades (typically a dry upper beach 5 – 7 m wide in the 1960s and 1970s compared to about 3 – 4 m wide in the last few decades), with an average high tide today reaching almost to the foot of the foredune erosion scarp (see Figure 5). As demonstrated in section 3.4.2 below, the central to eastern part of the beach has undergone more erosion and shoreline recession since the year 2000 than the more sheltered western part has.

Six excavations to about two metres depth spaced along the back of the beach by Bill Cromer during 2022 (Cromer 2023, incl. Attachment 4) demonstrated that the beach comprises about a metre depth of unconsolidated light greyish-brown fine to medium grained and mostly shell-free sand, overlying at least a metre of unconsolidated grey or light grey fine to medium grained sand with trace silt, some shelly material and at least 10% well-rounded pebbles of quartzite, sandstone, siltstone and dolerite. This pebble material evidently relates to an early phase in the accumulation of sand in the Garden Island Sands embayment and could be derived from the same quartz-rich pebble beds that are exposed on the surface near Randall's Bay (see section 2.2).

A few discontinuous patches of quartz-pebbly material also occur on the present-day beach surface (see Figure 3), however given that the *in situ* pebble layer at the beach is buried beneath a metre of clean sand, it is possible that the surface patches are derived from artificial fill previously placed on the beach and foredune as protection against erosion.

The south-eastern extremity of the beach is a small sand spit protruding part-way across the mouth of the adjacent Garden Island Creek estuarine lagoon from its western side ('D' on Figure 15). Air photo inspection shows that this spit has been present persistently since at least 1948 although it has varied considerably in size from time to time (see Figure 29). It is inferred that the spit at times grows ("accretes") partly across the estuarine lagoon mouth from its west side, is trimmed by intermittent erosion events, tidal currents and flood discharges from the lagoon, but then recovers again from sand drifting south-east towards it along beach, particularly after beach erosion events. The persistence of this small spit at the south-eastern extremity of the beach is deduced to be an indicator of the predominance of a north-west to south-east littoral drift of sand along the beach (see also discussion of dominant wave directions in section 2.4.2).

Cuspate beach spit A small pointed or "cuspate" spit of mixed cobbles and sand has accumulated on the mostly rocky shore of Garden Island, directly south-west of and opposite from Garden Island Sands Beach (see Figure 1 and Figure 12). Field inspection during August 2022 revealed that the spit is comprised of mainly well-rounded dolerite and other cobbles, with fine sand patches at its tip and along the eastern side of spit. This is a distinctive feature whose shape and composition implies significant wave action from both the west and east sides of Garden Island (not necessarily at the same time), converging at the position of the spit (see also discussion in section 2.4.2 "Wave Climate" below).

2.3.2 Foredune

Nearly the full length of the beach is backed by a shore-parallel sand ridge which is a sandy foredune rising 1.0 to 1.5 m high above the back of the beach. The foredune is inferred to have grown by the accretion of sand blown landwards off the upper beach and captured by backshore vegetation after the backing sand plain had ceased to infill and prograde (see section 2.3.3 below). This probably occurred when the rate of sand delivery to the shore slowed after the end of the last post-glacial marine transgression circa 6000-7000 years ago (see section 2.4.4). No palaeosols (fossil soil horizons) were noted in the scarped dune face. Dating of the ages of beach ridges and foredunes is possible using optically stimulated luminescence (OSL) dating or other methods and could further illuminate the beach history described in Chapter 3.0 of this report, but was beyond the scope of this report.

Nick Bowden and Chris Sharples surveyed profiles across the foredune at four locations on 12th August 2022, and these are presented on Figure 17 (in section 3.3). The four profiles show a foredune ridge 10 to 20 metres wide (perpendicular to the shoreline) which slopes down to landwards from a high point at the crest of a seawards-facing erosion scarp immediately backing almost the full length of the beach (see Figure 5). The air photo analysis detailed in section 3.4.2 of this report shows that the present (2022) scarped front of the foredune is located variously 7 to 12 metres landwards of the position of the dune front in 2000[1]. This amounts to the loss so far of between one third to one half of the total width of the foredune since the year 2000.

The central to south-eastern two thirds of the beach mostly exhibited a fresh or "active" foredune erosion scarp with little slumping or incipient foredune accretion when inspected during 2022 (as shown in Figure 5). This part of the foredune has lost the greatest width since 2000. In contrast the foredune scarp along the north-western third of the beach was at the same dates looking less active

Figure 5: Landwards view of freshly eroded foredune scarp in the central area of the beach at close to low tide (3rd January 2022). This freshly eroded scarp is of similar size, character and freshness to that shown in Figure 3 (above) but has not been covered with cut branches. The woody debris scattered across the beach in this view mainly comprises mature trees formerly growing on the foredune, which have been undermined and toppled by storm wave erosion in recent times (precise storm dates unknown).

[1] The air photo analysis provided in section 3.4.2 shows that in some areas there was considerable short-term variability (erosion and recovery) in shoreline (dune-front) position between 1948 and 2000, but little long-term change. However, from 2000 onwards there has been significant progressive recession of most of the shoreline up to the present (2022). Consequently, the total shoreline recession distances from 2000 to 2022 are similar to the totals from 1948 to 2022 along much of the beach.

and more rounded, with significant sand accreting over the scarp in the form of an incipient foredune (see Figure 4). This part of the foredune has lost less width since 2000.

In recent years numerous mature trees formerly growing on the foredune have been undermined by wave erosion along the more recently eroded central to south-eastern parts of the foredune. These trees have collapsed onto the beach (see Figure 5 and front cover), where they have been partly cut up and piled against the erosion scarp in an effort to provide some protection (Figure 3).

2.3.3 Backshore sand plain

Clean fine-grained sand underlies a plain extending 250 to 350 metres inland (northwards) from Garden Island Sands Beach (see Figure 2). The sand is exposed in river erosion scarps for about 350 metres inland along the western shore of the Garden Island Creek estuarine lagoon. High resolution LIDAR Digital Terrain Modelling shows several broad, low, and roughly shore-parallel but curving ridges on the sandy backshore plain (see Figure 6). These do not appear to extend across the whole plain but may have been disturbed or destroyed in parts by artificial earthworks.

The location of the sand plain directly landwards of the beach and foredune, together with the presence of multiple semi-parallel sand ridges, are characteristic of the beach ridge plains that have formed behind many Australian beaches (e.g., see Oliver et al. 2017 for more details of a representative Tasmanian beach ridge and foredune system at Seven Mile Beach in south-eastern Tasmania). These landforms result from a continuation of onshore transport of sand after the last post-glacial marine transgression ceased about 6000 to 7000 years ago, causing average sea-level to stabilise at close to its present level (see section 2.4.4). With abundant sand available on the bed of the lower Huon estuary adjacent the Garden Island Sands embayment (see section 2.3.4, Figure 7, and Figure 8), wave action over several following millennia would have continued to push sand

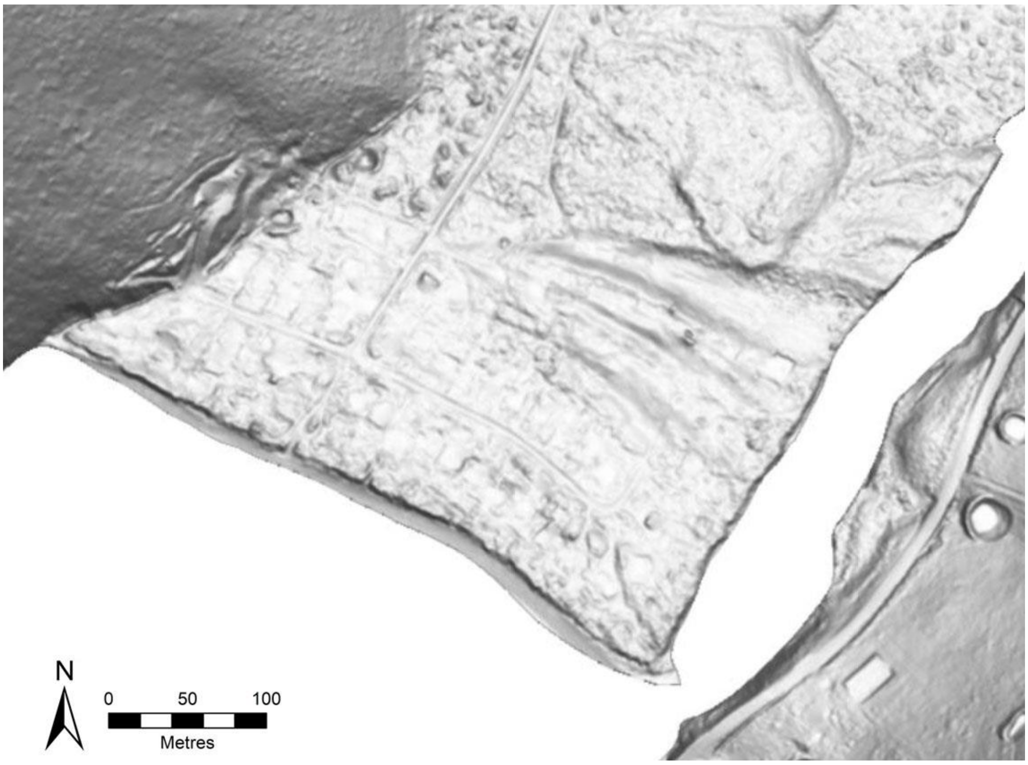

Figure 6: Onshore physiography of the Garden Island Sands Beach area. Hill-shaded LIDAR Digital Terrain Model sourced from the LIST website (www.thelist.tas.gov.au). Several low but distinct curvilinear and roughly shore-parallel ridges are visible on the broad backshore sandplain (compare Figure 2). These are interpreted as likely beach-ridges which originated as beach berms at various stages during the progradation (seawards accumulation) of the sand plain. Any former beach ridges immediately behind the beach have probably been artificially flattened in the course of roading and building construction in that area.

onshore resulting in continuing shoreline progradation (seawards growth) until an equilibrium was eventually reached between the available offshore sand and the wave energy available to move sand onshore (see also section 2.4.6 below regarding the history of sand accumulation at Garden Island Sands). The current foredune at Garden Island Sands probably then began to form - at a slower rate but essentially remaining in its current position - from the much-reduced rate of sand supply to the beach. Observed beach behaviour since 1948 (see section 3.4.2) suggests that eventually the sand supply was sufficiently reduced as to result in a reversal of sand accumulation and the beginning of a slow shoreline recession trend prior to 2000 as identified in the air photo record (see section 3.4.2).

A notable feature of the Garden Island Sands sandplain is that the relatively high-resolution LIDAR physiography of the plain (Figure 6) shows no indication (such as truncated beach ridges) that the Garden Creek estuary and its tidal mouth have ever been located anywhere other than hard up against the rocky shoreline beyond the eastern extremity of the sandplain and beach, where they are located at the present time (Figure 2 and Figure 6). This is an important observation because it suggests that the dominant sand transport direction in the nearshore zone close to the beach is a west to east sand movement driven by dominantly westerly to south-westerly wind-waves (see section 2.4.2) which has kept the creek estuary and its tidal mouth forced as far east as is possible.

The inferred outline of the development of the sandy plain described above is based on more detailed studies of other beach ridge plains elsewhere in Australia, with similar land forming processes inferred to apply to Garden Island Sands on the basis of similar landforms and coastal processes.

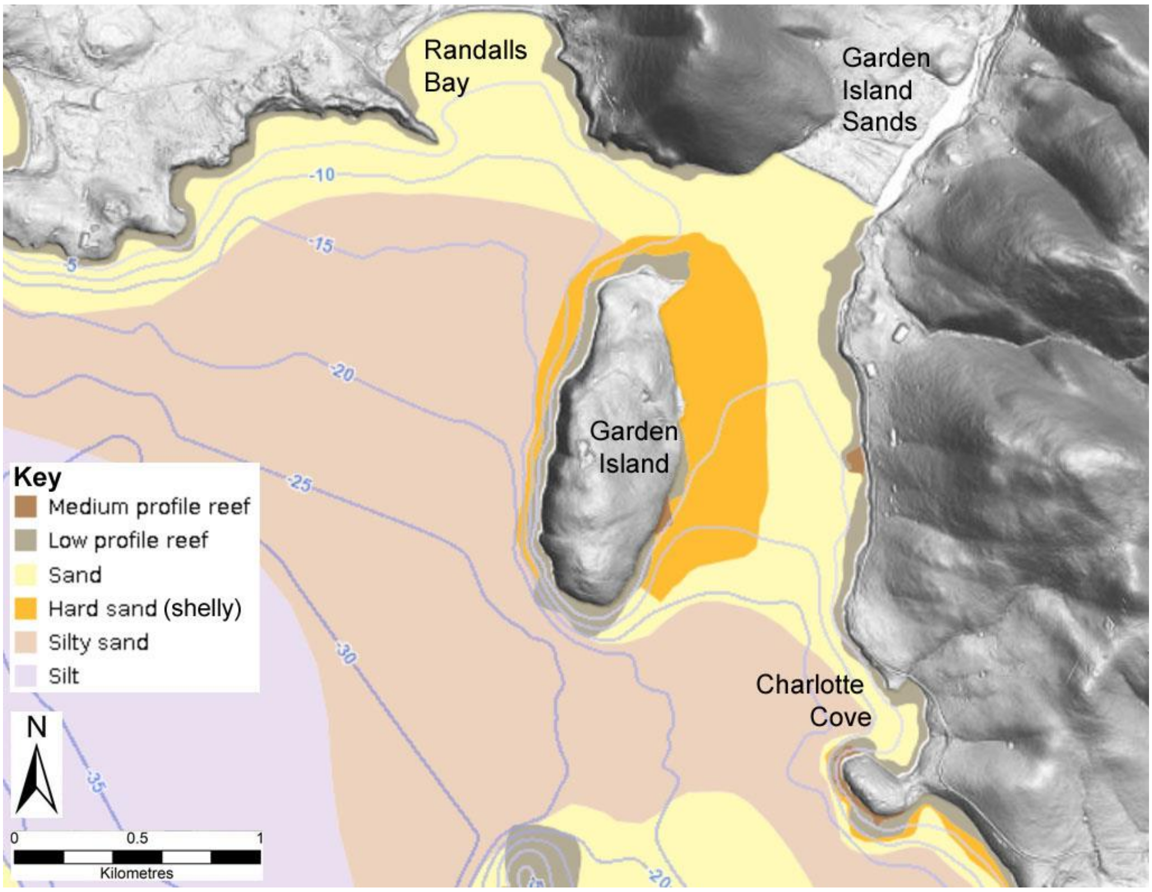

Figure 7: Bathymetry and marine bottom sediments of Garden Island Sands region, Lower Huon River estuary. Five-metre bathymetric contours (blue) and 1:25,000 scale marine sediment (habitat) mapping © Seamap Project, Tasmanian Aquaculture and Fisheries Institute (TAFI), University of Tasmania. Onshore physiography depicted using Lidar topography. Mapping copied from the LIST website (www.thelist.tas.gov.au).

2.3.4 Offshore intertidal to sub-tidal sands

Seabed substrate and habitat mapping by the Seamap project (Tasmanian Aquaculture and Fisheries Institute (TAFI), University of Tasmania) shows that most of the Huon Estuary seabed offshore from Garden Island Sands Beach and from Garden Island itself is mantled by unconsolidated sands, shelly sands, and silty sands (see Figure 7). The only exceptions to this are narrow subtidal rocky reefs close to rocky shorelines (Figure 7). These sandy bottom sediments extend to 30 metres depth southwest of Garden Island in the central part of the Huon estuary channel, and slope downwards into the channel at moderate gradients along most of the Randall's Bay to Charlotte Cove coast surrounding Garden Island Sands (see Figure 7).

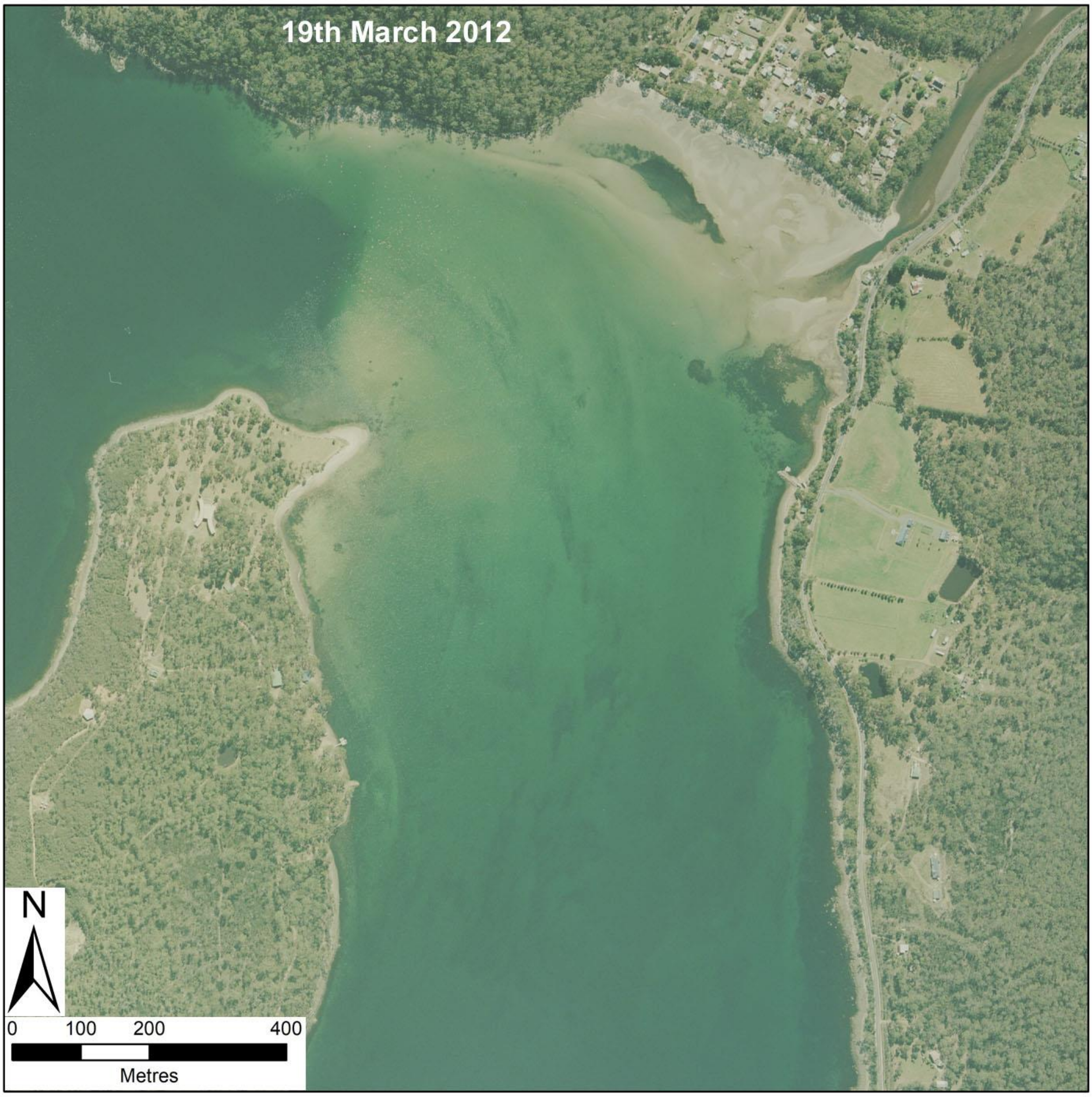

Figure 8: Distribution of shallow sandy seabed in relation to Garden Island and Garden Island Sands Beach. This image is a vertical colour air photo dated 19th March 2012 which provides a particularly clear view of the shallow sandy seabed free of surface water reflections (compare Figure 7). This view demonstrates the "sand trap" nature of the area between Garden Island and the Garden Island Sands Beach embayment. Most of the very 'bright' sand close to the vegetated shoreline is submerged in very shallow water but may be partly or wholly exposed at low tide. Dark patches in the sandy seabed are mainly seagrass beds. Air photo © NRE.

Figure 9: Air photo of Garden Island Sands showing shallow sub-tidal sand bar features. Original photo dated 19th Decd. 2015 (top) and annotated version (bottom) showing ephemeral sandy flood-tide delta in estuarine lagoon and shore-parallel shallow offshore sand bar encroaching landwards over the margins of a large seagrass bed. Air photo © NRE

However bathymetric contouring (Figure 7), aerial photography (Figure 8) and the writers' personal observations (from kayaking) demonstrate that bottom gradients are much flatter and water depths to the sandy seabed are much shallower over much of the coastal embayment between Garden Island and Garden Island Sands Beach. In that area water depth is mostly less than 5 metres depth and is less than one metre (at mid-tide) for a distance of several hundred metres offshore from the beach. There is no apparent evidence of bedrock control producing the mostly shallow seabed seen in this area; instead, the most likely explanation is that the Garden Island Sands area is a large sand trap (or "sink") into which sandy sediments from further offshore have been driven and piled up by the dominant wave climate over a period of millennia as sea-levels rose to their present level circa 6000-7000 years ago after the last glacial climatic phase. It is inferred that the coastal planform and dominant wave directions have resulted in sand being pushed into this area over a period of millennia, but also mostly prevent sand from escaping this "sand trap" area (see further discussion of these processes in sections 2.4.2 *Wave climate* and 2.4.6 *Sand Transport and Budget*).

An important feature of the sand accumulation in the Garden Island Sands area is a prominent sand bar approximately 100 to 200 metres offshore and roughly parallel to Garden Island Sands Beach (see Figure 9). When observed on 14th Sept 2022, the bar was a very shallow discontinuous accumulation of clean fine-grained yellow-brown sand that was partly exposed above water level at mid-tide directly offshore from the Garden Island Creek mouth, and elsewhere was as shallow as only 0.2 m water depth. Low swell waves were breaking across the shallowest point of the bar. The full extent of the bar was not mapped; however, the water is deeper on both the beach and island sides, and seagrass beds on the beach side of the bar appear to be somewhat protected from wave action by the bar. It is likely the sand bar absorbs some of the energy of waves approaching the beach, albeit large storm waves would undoubtedly partly or wholly excavate the bar itself, resulting in increased wave attack on the beach and foredune.

It is evident that the pattern of tidal currents, wind- and swell-waves combine to determine the shape and position of this bar, which is a prominent topographic feature storing a large amount of sand within the Garden Island Sands embayment. It is assumed that the offshore sand bar is a permanent or semi-permanent feature of the embayment, albeit no clear evidence of the degree of short-term physical variability of the feature was identified from the air photo time series or any other source of information. Further discussion of the sand transport processes maintaining this feature are provided in section 2.4.6 below, and discussion of the possible role of this feature in the response of Garden Island sands to sea-level rise is provided in section 3.6.2.

2.3.5 Estuarine Lagoon

The following discussion is mainly focussed on landforms and sediments associated with the Garden Island Creek estuarine lagoon; river flow and discharges associated with this lagoon are briefly addressed in section 2.4.5 below.

The estuarine lagoon of Garden Island Creek is a tidal water body approximately 750 metres long by 50 to 90 metres wide, forming the lower reaches of Garden Island Creek which is sourced about 11 kilometres further north at Woodbridge Hill. Water depths in the lagoon have not been measured. Sloping dolerite bedrock shores are exposed along the lower 400 metres of the lagoons eastern shore (see Figure 2), preventing the river channel from moving any further east. The western shore of the lower lagoon exposes clean and readily erodible coastal sands (Figure 2) which however show no indication (in their surface forms – see Figure 6) of the estuarine channel and lagoon having previously been situated any further west than it is now. This supports the inference that the river and lagoon mouth has always been forced hard against the dolerite bedrock on its eastern side by a strong south-eastwards littoral drift of sand along the Garden Island Sands Beach (see also sections 2.3.3 and 2.4.6). The shores along the upstream half of the estuarine lagoon are dominantly fine silty and peaty sands (Figure 2), part of which are marginal to an artificially drained marshy area (see Figure 10).

Two large sediment bars are clearly evident within the lagoon in most air photos and are indicated at "A" and "B" on Figure 10. These were inspected by the writer using kayak access and comprise silty sands covered by shallow water and partly exposed at low tide. This suggests that they have little or no capacity to accommodate additional sediment, at least at present sea levels. The two silty sand bars are offset and separated from each other by a slightly meandering central channel which is indicative of the bars being characteristically fluvial (riverine) "point bar" landforms rather than dominantly tidal features (such as flood tide deltas). It is therefore likely that much of the fine silty sand of which the point bars are composed is derived from terrestrial catchment erosion rather than from marine sources.

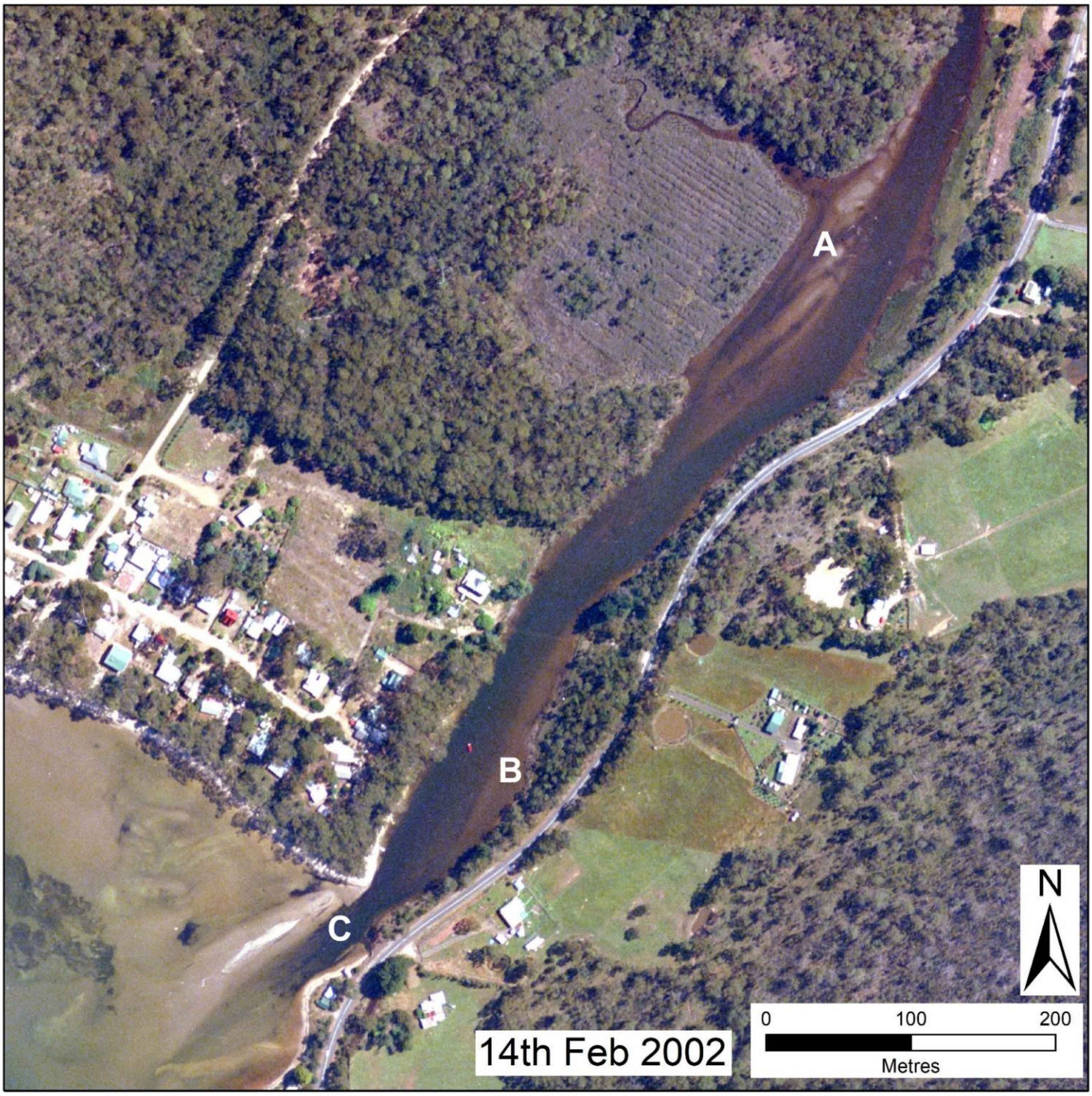

Figure 10: Air photo image of the Garden Island Creek estuarine lagoon, indicating persistent features. The two prominent fine silty-sand point bars (labelled here as A and B) have held roughly the same positions in the lagoon from the earliest (1948) till the latest (2021) air photos. In contrast, whereas the tidal lagoon mouth (C) was deep and open in all air photos from 1948 until 2001, subsequent air photos show intermittent blocking by a large sand bar (or "flood-tide delta") across the mouth of the lagoon (see also Figure 29 in section 3.4.2). Air photo film–frame 1354-45, dated 14th Feb. 2002, © NRE; see also details in Appendix 1.

Anecdotal information from local residents indicates that in historical times some shipping was able to regularly enter the estuarine lagoon and use jetty's there as sheltered anchorages, however this has not been possible for some (uncertain) time due to increasing silting of the estuarine lagoon. As has occurred in many Eastern Australian estuaries since early colonial times, it is likely that historical land clearance resulting in a phase of catchment erosion (Prosser & Winchester 1996) has in the past been responsible for supplying an increased silty-sand sediment load to the lagoon. Although there is little evidence of continuing transport of significant amounts of sandy or silty sediment down Garden Island Creek today, it is likely the point bars are largely composed of sediments derived from that earlier phase of anthropogenic catchment erosion, which have not yet been flushed out of the lagoon by tidal or river currents.

In contrast to the large fluvial point bars, sediments deposited into the estuarine lagoon by tidal currents appear to be less extensive and have likely been mainly restricted to the outlet area of the lagoon downstream of the main point bars. A small sand spit at the south-east end of Garden Sands Beach which is interpreted to be built of sands drifted south-eastwards along the beach has been observed to protrude varying distances across the mouth of the estuarine lagoon in all air photos from 1948 onwards (see “C” on Figure 10), however the tidal mouth of the lagoon was seen to be open in all air photos from 1948 until 2001.

However - as discussed and illustrated in section 3.4.2 including Figure 29 – several air photos from 2001 onwards have clearly shown a sandy flood-tide delta or sand bar intermittently but fully blocking the mouth of the lagoon. This feature is inferred to be indicative of larger and more frequent erosion events at Garden Island Sands after 2000 which have delivered more sand via littoral (alongshore) drift to the lagoon mouth than previously (see section 3.4.2). Flood tide (ingoing) tidal currents have moved and deposited this sand temporarily into the main tidal channel, however these features have not been permanent and are not seen in all photos after 2001 (see Figure 29). This indicates that river current discharges and/or tidal ebb currents have been capable of flushing all or most of the sand blockages out of the lagoon mouth.

The implication of the discussion and observations above is that there is currently only very limited (if any) space left in the Garden Island Creek estuarine lagoon to accommodate increasing amounts of eroded sand transported from the eroding beach and dune face and into the lagoon by tidal currents. However, ongoing global sea-level rise is (amongst other things) having the effect of increasing water depth in tidal lagoons, and this can be expected to have been creating more accommodation space at Garden Island Creek estuarine lagoon (at least in its lower reaches near the mouth) in which eroded sand can settle out and be permanently sequestered (Hennecke & Cowell 2000). This effect has probably been limited to date but can be expected to continue creating more accommodation space in the lagoon as sea-level continues to rise (see Section 2.4.4). The implications of this for coastal erosion at Garden Island Sands is discussed further in section 3.6.2.

2.4 Coastal Processes

2.4.1 Wind and aeolian processes

Wind may affect coastal processes in two important ways, namely by generating local wind waves (which may erode or otherwise transport sand) and by directly transporting sand from the dry upper beach to the foredune or further inland via aeolian (wind-blown) transport.

No long-term wind records are known to be publicly available for locations near Garden Island Sands. However, Garden Island Sands is centrally located between two regional coastal Bureau of Meteorology (BoM) weather stations at Dennes Point (north Bruny Island) and Cape Bruny (south Bruny Island). Wind records from these two stations are shown on Figure 11 below.

Both records show dominant westerly to south-westerly winds with a strong northerly wind component, suggesting these are characteristic wind patterns for the south-east Tasmanian coastal region and thus likely to be similar in the Garden Island Sands area. A notable south-easterly afternoon wind component in the Dennes Point record is not present at Cape Bruny and may be a local Dennes Point phenomenon, possibly afternoon sea breezes.

If northerly winds are significant at Garden Island Sands Beach (as they are at Dennes Point and Cape Bruny), they probably have little effect on the sandy landforms and beach processes because they will mostly be blowing from onshore to offshore. This means the winds have little capacity to mobilise sand from the foredune (as they blow onto the vegetated and thus protected side of the dune) or from the beach (which is sheltered from northerly winds by the foredune). Any waves generated by the offshore-directed winds will be of negligible size close to the shore, and further offshore will move away from the beach rather than towards it.

In contrast, westerly to south-westerly winds are likely to be the most important winds affecting Garden Island Sands, consistent with their importance in both the Dennes Point and Cape Bruny wind records, and the fact that regional westerly air flows are a dominant influence on Tasmania’s weather generally (Grose et al. 2010). These winds may blow somewhat obliquely onshore at Garden Island Sands but are a key agent of foredune recovery from erosion since they can blow dry upper beach sand onto the foredune face where it can accumulate as a new incipient foredune and rebuild the dune face after erosion events (see Figure 4 above). In some locations strong onshore winds may also erode dunes, causing blow-outs and deflation hollows, however inspection of historic air photos indicates that this does not appear to have been a significant process at Garden Island Sands during the air photo period since 1948.

However, probably the most important role of wind in the Garden Island Sands coastal environment is its importance in driving locally generated wind waves. West-south-westerly winds in particular have a relatively long fetch across the Huon estuary to Garden Island Sands and thus are likely to produce some of the most energetic waves reaching Garden Island Sands beach. Locally wind-generated waves reaching Garden Island Sands may cause beach and foredune erosion when they are higher and more energetic (under stormy conditions) or may conversely push eroded sand back onto the beach from offshore sand bars and flats when they are lower and less energetic. In either case, westerly to south-westerly wind waves are likely the dominant driver of the prevalent north-west to south-east drift of sand along the nearshore (littoral) zone at Garden Island Sands Beach (see section 2.4.6). The following section 2.4.2 provides further discussion of the significance of locally generated wind waves at Garden Island Sands.

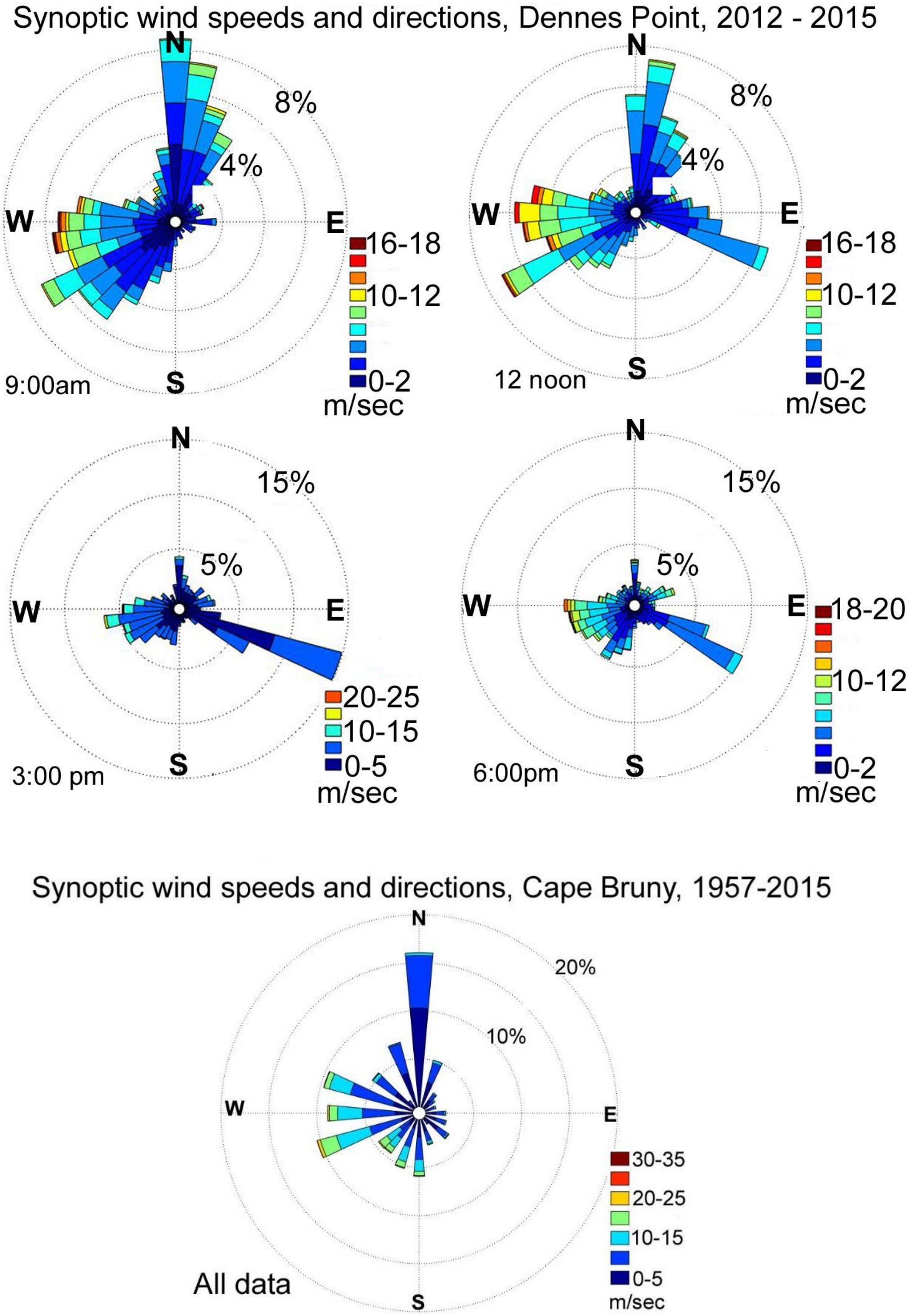

Figure 11: Wind data from the Dennes Point (top) and Cape Bruny (bottom) Bureau of Meteorology (BoM) weather stations. Garden Island Sands is centrally located between these two BoM south-east coastal weather stations in south-eastern Tasmania. Both records show dominant westerly to south-westerly winds with a strong northerly wind component, suggesting these are characteristic wind patterns for the south-east region and thus likely to be similar in the Garden Island Sands area. A notable south-easterly afternoon wind component in the Dennes Point record is not present at Cape Bruny and is evidently a local phenomenon, possibly afternoon sea breezes. Plots prepared from original BoM data by Chris Sharples.

2.4.2 Wave climate

Two dominant wave types reach Garden Island Sands Beach, namely oceanic swell waves and locally generated wind-waves. Wave conditions observed at Garden Island Sands by the writer on 14th Sept 2022 included both wave types and were probably typical for the locality. These comprised persistent low swell waves driven northwards directly up the channel on east side of Garden Island, breaking at about 0.2m height across the whole beach embayment on the shallow sand bar 150-200m offshore from the beach (see Figure 9). At the same time, intermittent south-westerly winds were intermittently generating south-westerly wind waves approaching the beach past the north end of Garden Island and breaking close to the beach at heights of up to roughly ~0.1 – 0.2m high. Figure 13 shows an example of both wave types arriving at the beach.

It is notable that a small cuspate sandy-cobble spit on the north end of Garden Island (see Figure 12 and notes in 2.3.1) is shaped by the differing wind-wave and swell-wave sets interacting as they come round the north side of the island, and as such marks the dividing point between sections of the island shore that are dominated by the two wave sets.

Storm wave activity – both from storm swells and locally-generated stormy wind-waves – is inferred to be the dominant cause of beach and dune erosion at Garden Island Sands (as is the case for most beaches). To the writer's knowledge no storm event records are available for Garden Island Sands. However, the dominant storm wave directions are inferred likely to be similar to the dominant fair-weather wave directions, albeit stormy locally generated wind-wave directions are likely to vary more than the longer storm swells whose directions are "trained" by their long run up D'Entrecasteaux channel. The following wave climate description for Garden Island Sands has been inferred from air photos, regional wind records (see section 2.4.1 above) and on-site observations (see also Figure 12 and Figure 13).

Swell waves

The whole length of Garden Island Sands Beach is directly exposed to swell waves that have propagated 30 km northwards directly up D'Entrecasteaux Channel from the Southern Ocean to arrive somewhat attenuated (weakened) and trained (straightened) at the beach via the channel on the eastern side of Garden Island (see Figure 12). In contrast, swells passing on the western side of Garden Island reach nearby Randall's Bay on a similarly direct pathway (Figure 12), but only refract very weakly around the north-western side of Garden Island to reach Garden Island Beach with minimal energy. Consequent, it is deduced that most swell waves (whether smaller fair weather swells or higher and more energetic storm swells) arrive at Garden Island Sands from almost the same direction (as shown on Figure 12 & Figure 13) after having penetrated northwards up the broad channel on the east side of Garden Island.

Wind waves

Wind waves may be occasionally generated by winds coming from any direction, however given the inferred dominantly westerly to south-westerly local winds in the lower Huon estuary region (see Section 2.4.1 above), the dominant locally generated wind waves reaching Garden Island Sands are expected to be mainly driven from westerly to south-westerly directions. See Figure 12. Although the more south-westerly fetches are relatively short, winds blowing from westerly to west-south-westerly directions may have fetches of up to 6 kilometres across the Lower Huon River estuary, potentially generating large energetic wind waves at the beach under storm wind conditions (see Figure 12).

As is evident from inspection of Figure 12 and Figure 13, the middle to eastern part of Garden Island Sands Beach is more exposed to these wind-wave directions, whereas the western end is comparatively sheltered from them by the curve of the rocky shore west of the beach. This exposure pattern corresponds well to the differing degrees of present-day erosion observed along

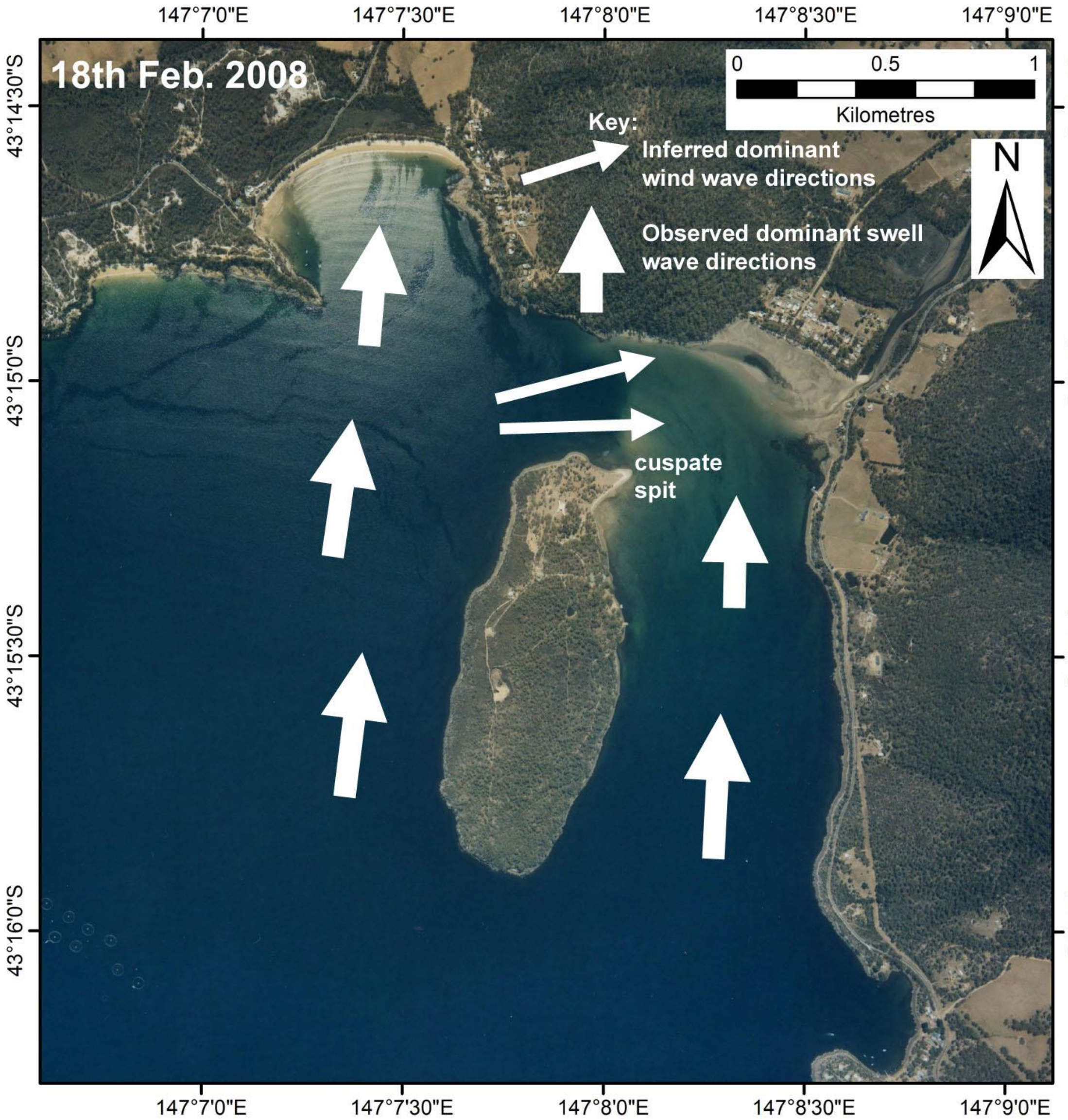

Figure 12: Diagrammatic representation of the dominant directions of swell and wind waves reaching Randall's Bay (LHS) and Garden Island Sands Beach (RHS). The observed swell wave direction indicated shows little variation in direction since it is trained and attenuated by a long refraction pathway up southern D'Entrecasteaux Channel. Whereas the whole beach is exposed to the dominant swell waves propagating northwards up the east side of Garden Island, the inferred dominant wind-wave directional range (westerly to south-westerly) results in the west end of the beach being most sheltered (by a rocky shoreline) from the dominant wind waves which impact most directly on the middle to eastern section of the beach. (air photo dated 18th Feb 2008, air photo film–frame 1430_222, © NRE; see also details in Appendix 1).

the beach (see Section 3.2) and to the degree of past shoreline recession along the beach (see Figure 18 and discussion in Section 3.4.3). This implies that locally generated westerly to south-westerly wind waves are probably the dominant agent of erosion and change on Garden Island Sands beach. That is, although the whole beach length is equally exposed to the most direct swell waves that reach Garden Island Sands, the pattern of shoreline erosion instead reflects the varying degree of wind-wave exposure along the beach, suggesting that the latter has typically had more control over the dominant historical and recent erosion pattern than do the swell waves. In part, this may be because swell waves lose a lot of their energy over the 30 km pathway from the southern Ocean to Garden Island sands via D'Entrecasteaux Channel, as well as losing further energy breaking on the shallow sand bar 100 to 200 metres off the beach (see section 2.3.4 and Figure 9). However, large swell storm waves have also often caused significant erosion on south-eastern Tasmanian beaches,

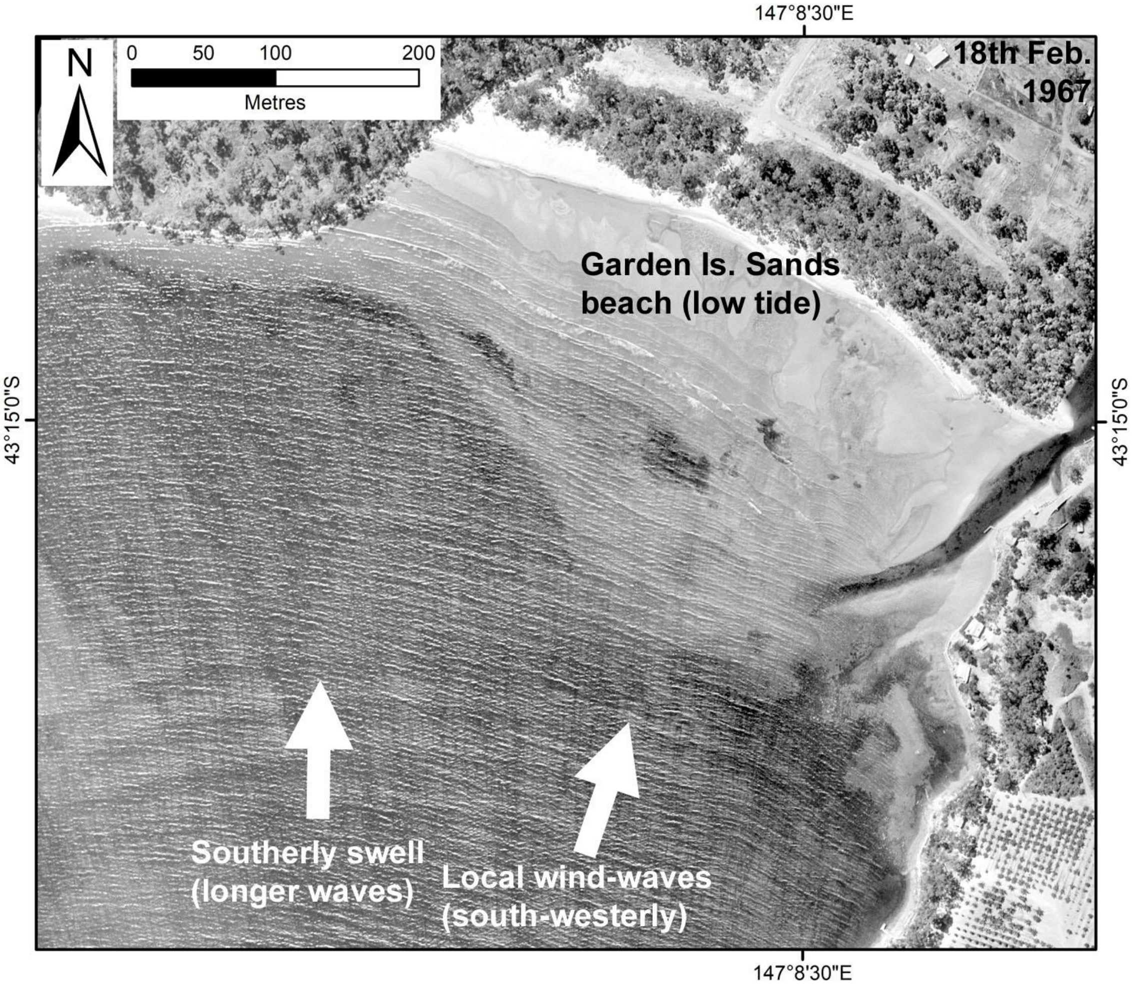

Figure 13: Air photo of Garden Island Sands Bay with both swell and wind-waves visible. This image highlights the longer-wavelength swell-waves which have propagated northwards up D'Entrecasteaux Channel and directly up the east side of Garden Island to the beach, as well as the shorter-wavelength locally-generated wind-waves which in this photo are seen propagating from a south-south-westerly direction reflecting the wind direction at the time this photo was taken (dated 18th Feb 1967, air photo film–frame 489-162, © NRE; see also details in Appendix 1). This photo also illustrates the greater wave-sheltering that has typically been found at the west end of Garden Island Sands Beach (see section 2.4.2 text). The wide expanse of dry upper beach sand accumulated at the west end of the beach is notable on this photo and implies that more sheltered conditions dominate that area than the wave patterns seen on this photo seem to suggest. Thus, it is likely that the dominant wind-wave direction is often more westerly than the south-westerly direction seen here. That would afford more shelter at the west end of the beach resulting in less erosion and more sand accumulation there, as is seen in this photo.

even after refracting and attenuating for significant distances up tidal embayments (as happened at Roches Beach in Frederick Henry Bay during July 2011, for example).

Nonetheless, as suggested above the locally generated westerly to south-westerly wind waves are deduced to dominantly drive the sandy coastal processes at Garden Island Sands. Not only do the dominantly westerly to south-westerly wind waves drive the important north-west to south-east littoral drift of sand along the beach (see section 2.4.6), but these waves are also the key agents of both erosion and recovery of the beach and foredune. Steep energetic stormy wind waves - often on elevated tidal levels because of stormy low-pressure systems – will readily erode the beach and foredune, carrying sand offshore in their energetic backwash. However lower, less energetic fair weather wind waves and swell waves may gradually drive sand back to the beach (as well as alongshore) after it has been eroded and dumped offshore by storm wave backwash.

2.4.3 Tidal Processes

The spring to neap tidal range at Garden Island Sands is approximately 1.3 to 0.3 metres (Short 2006, p. 141). This commonly results much of the central to eastern part of Garden Island Sands Beach exposing only a few (horizontal) metres of sand at high tide (see Figure 3 and section 2.3.1), yet allows exposure of lower beach sands over some tens of metres to seawards at low tide along the whole beach.

Tidal currents visibly move in and out of the mouth of the Garden Island Creek estuarine lagoon during each tidal cycle. No measurements of the tidal current flow rates or tidal prism (amount of water moved) are available, however visual inspection indicates that sand is moved by the tidal currents in the vicinity of the lagoon mouth. No attempts to measure tidal water movements within the lagoon are known to the writer, however the observation that large sediment bars inside the lagoon are geomorphically more akin to fluvial point bars than to tidal flood-tide deltas (see section 2.3.5) is suggestive that tidal currents are probably not very effective beyond a few tens of metres inside the lagoon mouth.

2.4.4 Sea-level variability

Global mean sea-level (GMSL) stood approximately 130 m below present levels during the Last Glacial Maximum (LGM) circa 20,000 years before the present (BP), but rose during the post-glacial marine transgression to reach approximately its present level by mid-Holocene time, circa 6000 - 7000 years BP (Lambeck & Chappell 2001; Lewis et al. 2013). After over 6000 years of relative stability, GMSL commenced a significant renewed rise from the 1800s (Woodworth 1999). The rate of this rise has increased over the Twentieth Century (Church & White 2006; Church & White 2011), albeit with some inter-decadal variability. Tide gauge and satellite altimetry data shows that by 2009, GMSL had risen 21 cm since 1880, and the average rate of global mean sea-level rise (GMSLR) over the whole Twentieth Century was 1.7 mm yr^{-1} (Church & White 2011). However, GMSL has continued to accelerate over the satellite altimetry era since 1993 (Watson et al. 2015), from 2.2 ± 0.3 mm yr^{-1} in 1993 to 3.3 ± 0.3 mm yr^{-1} in 2014 (Chen et al. 2017) and is continuing to increase.

A comparison between modern and historic (1840s) tide gauge records from Port Arthur have demonstrated that sea-level rise on the south-east Tasmanian coast over the last ~150 years has been comparable to the GMSL record (Hunter, Coleman & Pugh 2003). The nearest measured long-term (multi-decadal) sea level data to Garden Island Sands is from the Hobart port tide gauge record, located in the broad lower Derwent River estuary about 40 km north of Garden Island Sands. The net rate of mean sea-level rise indicated by a linear regression fit to the Hobart tide gauge record is 1.68 mm/yr^{-1} over the period 1962-2004 (original data processed by Dr John Hunter, oceanographer), which is comparable with the global-average rise of 2.0 ± 0.3 mm yr^{-1} over the 1966 – 2009 period (White et al. 2014).

Analysis of tide gauge data from around Australia (Figure 5 in Burgette et al. 2013) has shown that sea-level “noise” (i.e., variability related to seasonal, interannual and decadal processes, particularly the El Nino Southern Oscillation) is minimal in Tasmania compared to most northern and western Australian coasts. These data imply firstly, that local relative sea-level variability in the Hobart region of SE Tasmania (including Garden Island Sands) is dominantly attributable to global mean sea-level rise (GMSLR) rather than other more local causes, and secondly that Tasmanian shoreline behaviour is less influenced by regional sources of sea-level variability such as ENSO than are most other Australian shores where this source of coastal process noise is more likely to mask any sea-level rise signature in shoreline behaviour.

2.4.5 River discharge and flooding

The following brief note is focussed on river flows and discharge effects in Garden Island Creek; fluvial (riverine) sediments and landforms have been discussed in section 2.3.5 above.

Garden Island Creek is a freshwater river (or creek) with a catchment area of the order of about 35 square kilometres of mixed native forest and some cleared agricultural land. The river reaches the sea at Garden Island Sands where it has an estuarine lagoon which is described in Section 2.3.5 above. Average and flood stream flow and discharge data are not known to be available for Garden Island Creek (based on checking the NRE Tasmania Water Information Web Portal https://portal.wrt.tas.gov.au/Data on 3rd February 2023).

The observation that large sediment bars inside the Garden Island Creek estuarine lagoon are geomorphically more akin to fluvial point bars than to tidal flood-tide deltas (see section 2.3.5) is suggestive that river water discharges probably dominate over tidal currents in most of the lagoon except close to the tidal mouth (albeit no salinity measurements or other stream flow or water chemistry data is known to be available for the lagoon). This suggests that most sand brought into the lagoon mouth on flood-tide currents is likely to be rapidly flushed out again by the combined power of river and ebb tide currents. This suggestion is supported by the apparent failure of occasional sand bars deposited at the lagoon mouth after 2001 to persist at that location (see section 3.4.2, Figure 29). However, increasing accommodation space for sediment in the lagoon as a result of sea-level rise may allow small but increasing amounts of sand introduced into the lagoon from beach erosion to persist there despite the flushing action of fluvial discharge and ebb tidal currents (see section 3.6.2).

2.4.6 Sand transport and budget

Unconsolidated sand is a highly mobile sediment, and all sandy shores undergo some degree of sand movement - at least superficially - driven primarily by wind, waves, and tidal currents. These sand transport processes determine the form and scale of sandy shores, and the "sand budget" of a beach. This term refers to the net balance of sand gains and losses over time. Whereas many beaches are mostly stable, with either negligible or approximately equal gains and losses of sand, some beaches may undergo significant net gains or losses of sand over time. These conditions result in either gaining ("prograding") or losing ("receding") beaches.

Of particular interest from a coastal hazards perspective are locations at which changing conditions may result in a long-term switch from a stable beach to a losing (receding) beach. As described in Section 3.4.2 (below), an historic air photo time series shows that since circa 2000, Garden Island Sands Beach has undergone a change in its long-term behaviour, from being a stable or slightly receding beach to being a dominantly eroding and significantly receding beach. Understanding the reasons for such a change of long-term behaviour requires an understanding of the local sand transport and budget processes. This section summarises what is known or can be inferred of these for Garden Island Sands Beach, in order to provide a basis for the discussion of likely causes of the observed change provided in section 3.6 below.

The following discussion is a qualitative assessment of sand transport processes at and near Garden Island Sands Beach which the writer has deduced from interpretation of geomorphic features and processes (as described in sections 2.3 and 2.4 of this report), in the light of what is known about sand movement and budget processes elsewhere on the Tasmania coast. Although it is possible to measure coastal sand movement, accumulation, and erosion more quantitatively, this requires techniques which are generally expensive and time-consuming, and were beyond the scope of this project.

Overall Garden Island Sands embayment sand trap ("sink")

The Garden Island Sands embayment behind (north-east of) Garden Island is a large sand sink or sand-trapping coastal area separated from Randall's Bay to the west and Charlotte Cove to the south by long rocky shores (see Figure 2). Within the overall sand trap, sand circulates into and out of the Garden Creek estuarine lagoon and a large sand bar 100-200 metres off the beach, which are inferred to be a smaller nested "leaky" sand traps which intermittently both gain and lose sand from other parts of the embayment (see Figure 14 below).

The sand source for the Garden Island Sands embayment is inferred to be the sandy floor of the adjacent Huon estuary (see Figure 7). During each past low sea stand associated with the multiple repeated Pleistocene-age glacial climatic phases that have affected the Tasmanian landscape over the last 2.6 million years or so, glacial meltwater and outwash rivers (the proto-Huon) deposited sands eroded by glaciers from glaciated inland areas onto what were then coastal river plains but which are today "drowned" about 130 metres below present sea-level (Corbett 2019; Lambeck & Chappell 2001; Lewis et al. 2013). As the post-glacial global sea levels rose following the end of each glacial period, much of the sand now trapped in the embayment behind Garden Island is inferred to have been pushed landwards and into the embayment from the Huon estuary floor on the rapidly rising water levels by swell waves, locally generated wind waves and tidal currents (see Figure 12).

Sea level last stabilised at approximately its present level around 6000-7000 years ago (Lambeck & Chappell 2001; Lewis et al. 2013) after which the initially-abundant nearshore supply of sand into the sand-trapping embayment would have gradually reduced over several thousand years until an equilibrium was eventually reached between the available offshore sand and the wave energy available to move sand onshore. It is likely that there is today only a much-reduced sand exchange involving only small losses and gains between the sand trapping embayment and surrounding deeper sandy bottoms in the Huon estuary. The Garden Island Sands embayment is now nearly filled with sand, resulting in very shallow water depths over much of its area (see Figure 14). Despite this there is no evidence of significant sand losses from the embayment, with the coastal planform (shape) and dominant wave directions tending to push sand into but not out of the embayment[2] (see Figure 12, Figure 13), which is effectively a closed sediment compartment (Thom et al. 2018). With probably only very small sand gains and losses, the overall sand budget for the Garden Island Sands embayment is inferred to be balanced or nearly-balanced (stable).

Sand transport processes within Garden Island Sands embayment

The north-western quarter (approximately) of Garden Island Sands Beach appears to be relatively sheltered from both wind waves and swell waves by the combined sheltering effects of Garden Island, the rocky headland immediately west of the beach (see section 3.2 and 3.4.2) and an offshore sand bar (see Figure 9 in section 2.3.4). Consequently, the north-western quarter of the beach has historically shown – and currently continues to show - less evidence of erosion and shoreline recession than the rest of the beach (see sections 3.2 and 3.4.2) and is more frequently accreting rather than losing sand.

In contrast the longer central to south-eastern part of the beach is more strongly exposed to short steep westerly to south-westerly wind waves as well as to swell waves (see section 2.4.2). Multiple

[2] It is conceivable that river flood discharges and ebb tide currents emerging from the mouth of Garden Island Creek lagoon (within the embayment) could push some sand completely out of the overall embayment, however this would require considerable energy and appears unlikely or an infrequent occurrence at best, albeit this possibility has not been tested.

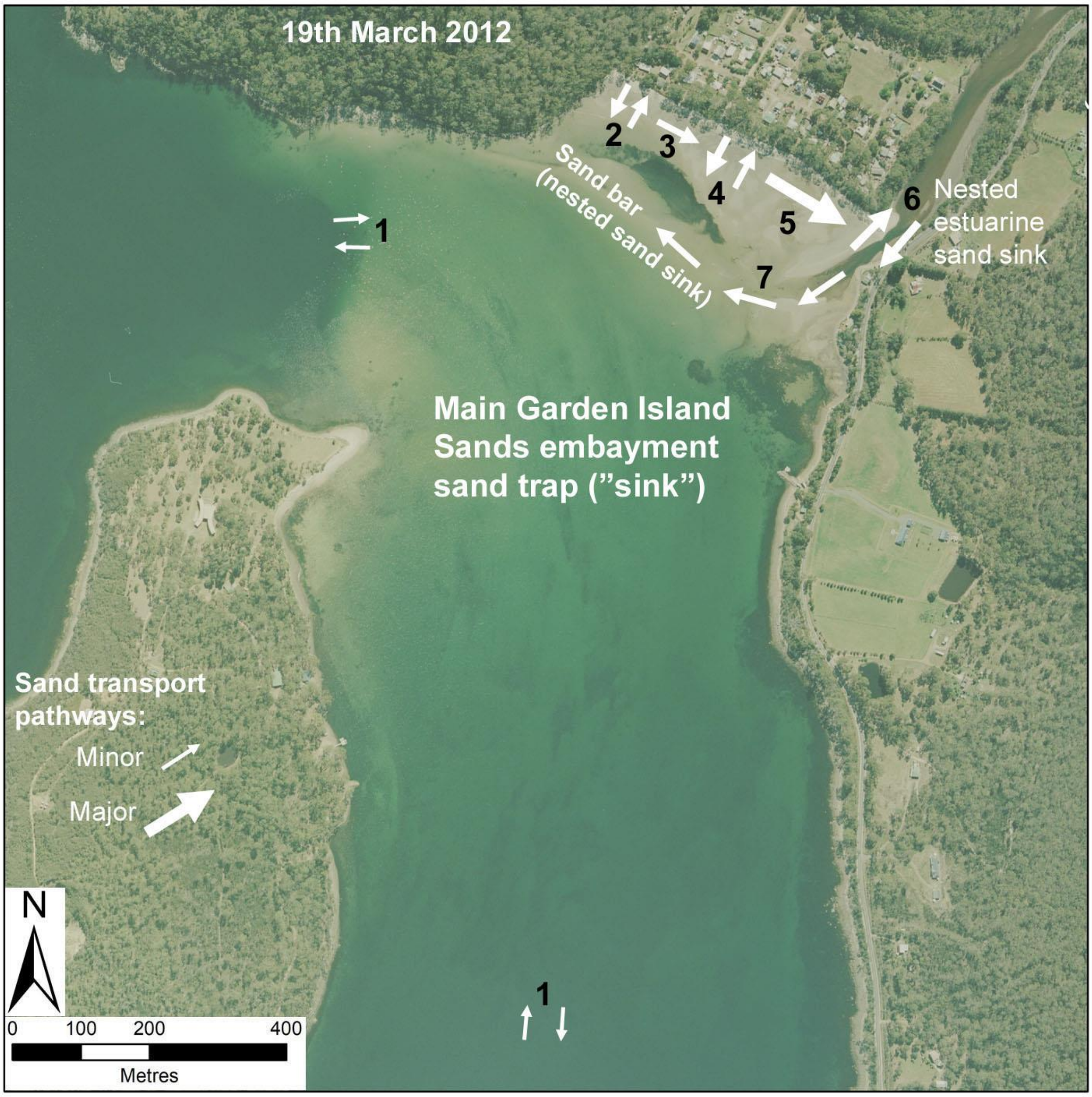

Figure 14: Deduced key sand transport pathways in the Garden Island sands embayment. Numbered arrows indicate key processes as follows: **1:** Minor (only) gains to or losses from whole embayment; **2:** Minor erosion and recovery of beach & dune sands at sheltered NW end of beach; **3:** Minor south-eastwards longshore drift of storm-eroded sand from sheltered NW end of beach; **4:** Strong erosion of exposed beach and dune in central to south-east part of beach, with some post-storm recovery (sand returned to beach), but: **5:** inferred major south-eastwards littoral drift of eroded sand during and after erosion events; **6;** drifted eroded sand builds spit at lagoon mouth, some is transported into lagoon by tidal currents but mostly then expelled back out of lagoon by tidal currents and river discharges; **7:** Sand expelled from estuarine lagoon eventually worked into large offshore sand bar by waves and tidal currents. Some of this sand is probably eventually but slowly returned to beach by wave action. Indicated sand bars have potential to be "rejuvenated" nested sand sinks in response to sea-level rise (see section 3.6.2). Aerial photo dated 19th March 2012, © NRE.

lines of evidence[3] indicate that these waves drive a dominantly north-west to south-east littoral current resulting in drift of sand south-eastwards along the beach. It can be reasonably inferred (in the absence of any physical observations) that whenever a (storm wave-driven) beach and foredune

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[3] These include the inferred direction of littoral drift that should result from the dominant westerly wind-waves breaking and pushing sand along the beach (see section 2.4.2), the persistent location of the Garden Island Creek mouth which is and has historically been pushed hard up against the rocky shoreline on its eastern side (see section 2.3.3), and the historically persistent accretion of a small highly variable sand spit partway across the creek lagoon mouth at the south-eastern (downdrift) extremity of the beach (see "D" on Figure 15 in section 3.2, and also section 3.4.2).

erosion event occurs, the eroded sand will be dumped in the nearshore zone by storm wave backwash. Some of this sand will be returned to the beach by fair weather waves after the erosion (storm) event finishes, but a large proportion of the eroded sand will also be transported alongshore in a south-easterly direction by the nearshore littoral drift currents both during and after the storm.

Some of this sand accumulates in the small spit at the south-eastern extremity of the beach, and some of it can be assumed to be drawn from there into the mouth of the Garden Island Creek estuarine lagoon by flood-tide currents. Depending on how much space (depth of water) is available in the lagoon some of the transported sand may settle out permanently in the lagoon, or else the excess sand will subsequently be moved back out of the lagoon by ebb tide currents. Given the large amount of sand available in the Garden Island Sands embayment as a whole, it is probable that the estuarine lagoon has mostly been filled with as much sand as it can hold over most of the air photo period. This means that sand drawn into the lagoon by tidal currents has mostly been unable to settle into sufficiently deep accommodation space from which water currents cannot remove it and has instead been soon flushed back out of the lagoon mouth by ebb tide currents and/or by river discharge currents. It is likely that river flood discharges episodically flush more sediment out of the lagoon than usual, creating some additional accommodation space for more sand to be permanently sequestered in the lagoon, however it is also likely that the longer-term result (not taking into account the effects of progressive net rise in sea level) is that roughly equal amounts of sand are transported from the beach area into the lagoon, and then back out of the lagoon. See also estuarine lagoon discussion in section 2.3.5 above.

As noted above, sand flushed out of the lagoon by river discharge and tidal currents is unlikely to be entirely lost from the Garden Island Sands embayment but rather is likely to be circulated within the embayment by wave and tide-driven currents. It is likely that the notable sand bar located about 100 to 200 metres offshore and parallel to the Garden Island Sands Beach (see Figure 9 in section 2.3.4) is at least partly comprised of sand flushed out of the lagoon and then moved (along with other sands) by wave action. Some of this will probably be eventually returned to the beach face by wave action.

However, ongoing sea-level rise is deduced to be creating additional accommodation space for sand by deepening the water within both the estuarine lagoon of Garden Island Creek and over the large sand bar in the Garden Island embayment (Figure 9). This means that as sea-level continues to rise these two features are inferred to be increasingly functioning as “nested” sand sinks within the overall sand trap of the Garden Island Sands embayment and are likely to be significant factors on the increased shoreline erosion seen at Garden Island Sands since 2000. This likelihood is further discussed in section 3.6.2 below.

3.0 GARDEN ISLAND SANDS SHORELINE CHANGE HISTORY (1948 – 2022)

3.1 Introduction

Increasing foredune erosion causing the undermining and collapse of large mature trees has been a significant concern at Garden Island Sands for some years. It is unclear from anecdotal reports how long this has been noticeable, however interpretation of air photo data (described in section 3.4.2 below) suggests that a notable change of shoreline behaviour – namely a significant increase in the rate of shoreline erosion and retreat - began circa 2000. However, whilst the change of behaviour is easily detectable from air photo records (under appropriate analysis: section 3.4.2), it would probably not have become obvious to casual observers until sometime later, when the impacts of the increased erosion started to "emerge" above the normal variability of prior beach erosion and accretion (recovery) cycles to which local observers were accustomed. From inspection of the air photo records (see Figure 23 and Figure 26), the "time of emergence" (Hawkins & Sutton 2012) for the changed beach behaviour probably occurred roughly around 2010 to 2015.

The following subsections describe contemporary observations of the condition of the Garden Island Sands beach and foredune (section 3.2), profile surveys documenting the current physical conditions (Section 3.3), and an analysis of beach behaviour since 1948 based on all available historic air photos (section 3.4). Combined with available information relevant to geomorphic (landform) processes (sections 2.3 & 2.4), this data is used to better understand the nature and history (since 1948) of landform processes and changes at Garden Island Sands (as summarised in section 3.5). Section 3.6 explores the possible causes of the observed changes in long term behaviour.

3.2 Current (August 2022) beach and foredune condition

The state of the Garden Island Sands beach and foredune was systematically examined and photographed by Chris Sharples on 3rd August 2022. The condition of these landforms on that date is shown on Figure 15 (following) and is summarised as follows:

The north-western extremity of the upper beach for about 20 metres length was dry and about 8 metres wide above a flat wet low-tide terrace of sand. The beach ends against rocky shoreline dolerite outcrops, with a small stream emerging to flow across the extreme end of the beach. The backing foredune was a stable sandy ridge with no sign of recent erosion, rising a metre or so high behind the northwest part of the beach (see Figure 15 "stable sandy shore"). However, this dune (or ridge) is partly composed of gravel, which indicates artificial origin at least in part.

The north-western quarter (~100 m) of the upper beach was mostly dry over a width of ~8 – 10m above the wet low tide terrace (see also Figure 4) and was backed by a relatively old foredune erosion scarp which shows evidence of significant recovery, having been partly buried by an incipient foredune which has accreted following the last erosion event that affected this part of the beach (see Figure 15 including photo A).

The central to south-eastern three-quarters (~300m) of the upper beach was typically quite narrow (3 – 4 m wide) and wet above the wet low tide terrace of sand. The upper beach was entirely backed by a fresh vertical erosion scarp up to 1.5m high (see Figure 3, Figure 5, and see Figure 15 including photos B and C).

The south-eastern extremity of the beach (~20-30m long) was a small actively accreting sandspit dominated by marram grass (which is indicative of relatively recent sand accumulation) and protruding partway across the mouth of the Garden Island Creek estuarine lagoon (see Figure 15,

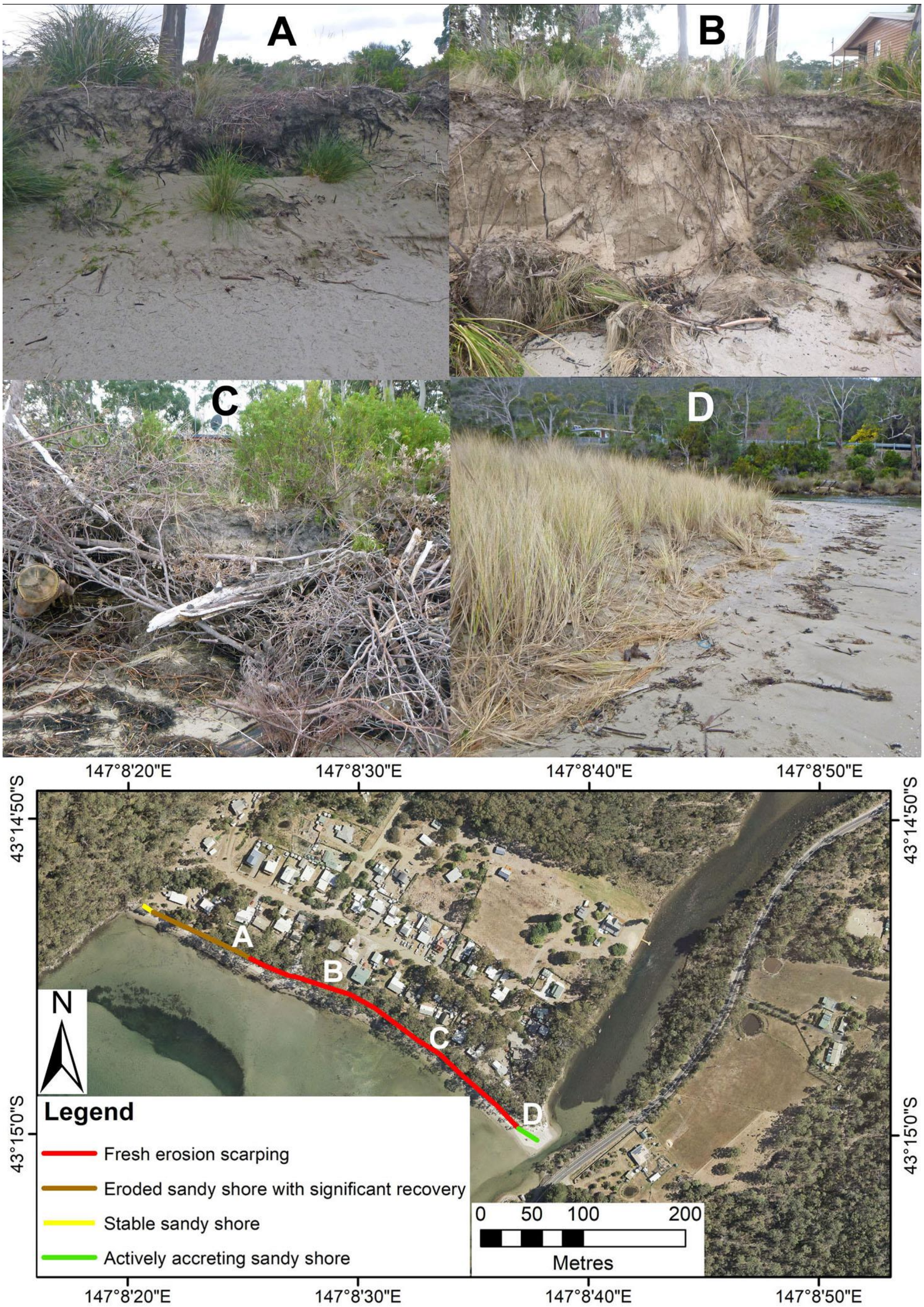

Figure 15: Foredune erosion status at Garden Island sands beach at 3rd August 2022. Map figure shows shore-parallel variation in foredune erosion status as mapped in the field by Chris Sharples. Background aerial photo is dated 19th December 2015. Labelled photos show four key examples of erosion status as follows: **A:** Old erosion scarp with significant wind-blown sand accretion in front (an "incipient foredune"), indicating little recent erosion and some beach and dune recovery along this part of the foredune face ("Eroded sandy shore with significant recovery". **B:** Fresh (active) vertical scarp face with vegetation-bound sand slab collapses at the base ("Fresh erosion scarping"). **C:** Fresh erosion scarp (as per B) with toppled and artificially cut vegetation piled in front as temporary protection ("Fresh erosion scarping" with artificial protection). **D:** Actively accreting (growing) sand spit at lagoon mouth with only minor signs of erosion ("Actively accreting sandy shore"). The short section of "stable sandy shore at the west end of the beach is a low section of foredune covered in artificial gravel fill with no current indications of erosion or accretion of sand.

including photo D). Some small erosion scarps were evident in parts, however sand accretion was the dominant landform condition here as at August 2022.

These conditions indicate that as of August 2022 the north-western quarter (approximately) of the beach and dune was being eroded less frequently or less energetically (or both) than the more actively eroding central to south-eastern three quarters of the beach and dune. The north-western extremity was essentially stable (partly due to artificial intervention), and the south-eastern extremity was actively accreting sand into a small spit protruding partway across the mouth of the Garden Island Creek estuarine lagoon. As discussed further in section 3.4.2, these current variations in geomorphic conditions along the beach strongly reflect variation in the historical behaviour of different parts of the beach since at least 1948.

3.3 Surveyed beach profiling (TASMARC)

The form and position of the Garden Island Sands beach and foredune as at 12th August 2022 has been precisely recorded by profile surveys at four transects spaced along the beach (see Figure 16 & Figure 17 below). Resurveys along the same survey transects at intervals in the future will enable precise measurement of any future landform changes to be made. It is intended that these surveys can be accurately carried out by volunteers (e.g., local residents) and the data be incorporated into the publicly available TASMARC database (www.tasmarc.info). Further documentation of these surveys is provided below and in Appendix 4 of this report, as well as in Cromer (2023, Attachment 3).

Four permanent TASMARC survey markers were established at Garden Island Sands Beach on the 12th of August 2022 by Chris Sharples and Nick Bowden. These consisted of screws on treated pine posts dug in on the back (landwards) slope of the foredune. Nick Bowden and Chris Sharples

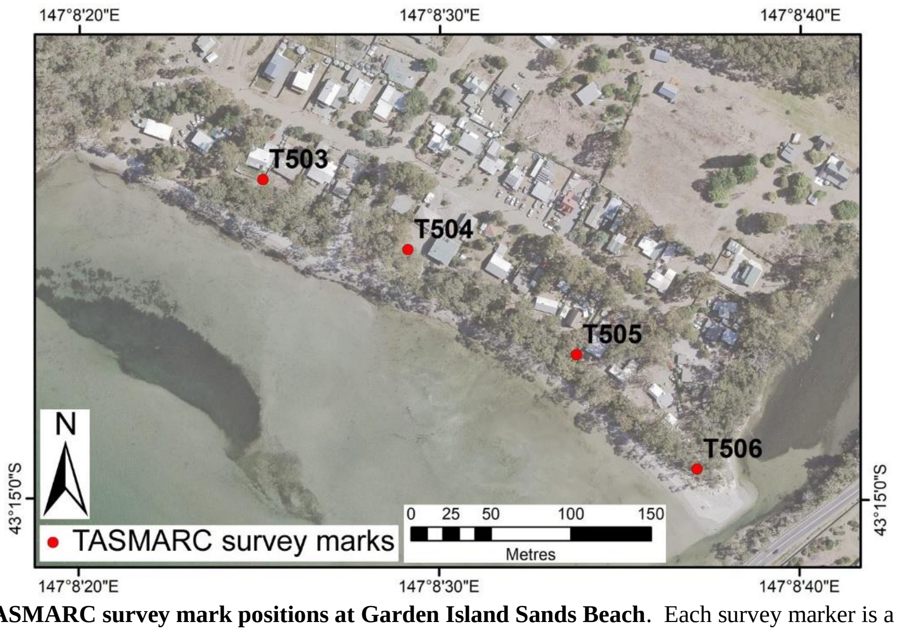

Figure 16: TASMARC survey mark positions at Garden Island Sands Beach. Each survey marker is a treated pine post embedded securely in the ground with a stainless-steel screw in the top of the post indicating the precise surveyed marker position. The survey transects extend seawards from the marks, normal (perpendicular) to the shoreline. Background image is the 19th of December 2015 air photo (© NRE). For larger version of this figure see Appendix 4.

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[4] "TASMARC" is the TAsmanian Shoreline Monitoring and ARChiving project. This is a beach monitoring project which commenced in 2004 as a project of the Antarctic Climate and Ecosystems Co-operative Research Centre (ACE-CRC) at the University of Tasmania. The project is based on community "citizen science" groups surveying beach profiles at intervals, with the data being processed and made available for open public access at www.tasmarc.info.

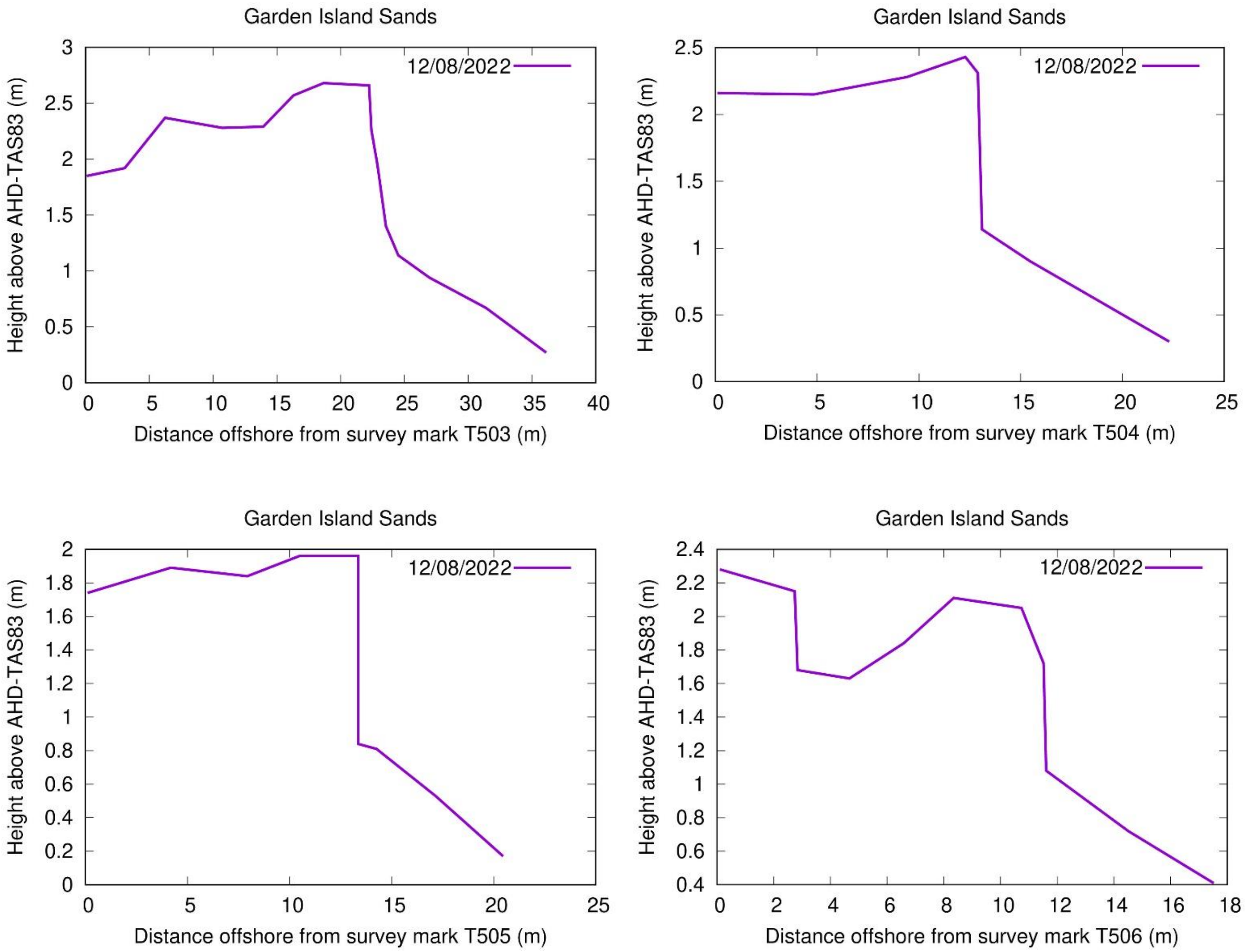

Figure 17: The first TASMARC profiles surveyed from the 4 survey markers at Garden Island Sands Beach, on 12th August 2022. Survey plots prepared by Nick Bowden; scales are in metres. Note that the vertical scale is exaggerated compared to the horizontal scale, which makes all landform features appear steeper and higher than they really are (albeit the vertical erosion faces are indeed as steep as they appear, but their height relative to the horizontal scale is exaggerated).

then surveyed profiles along transects running directly seawards from each mark using Total Station methods. The profiles run across the foredune and beach surface to the lowest seawards point accessed on the beach. The position of each survey mark was subsequently surveyed into the State Permanent Marker (SPM) network on 25th August 2022 by Elliott Cromer using professional GNSS survey methods. The surveyed position of each mark is estimated to have an error margin of ±50 millimetres relative to the metric Map Grid of Australia (Zone 55, GDA2020 datum). The locations of the survey markers are provided in Appendix 4 Table 5, and are indicated on Figure 16 above. The original survey data sheet for each survey marker and the initial profile surveyed along each transect on 12th August 2022 is also reproduced in Appendix 4.

The initial survey profiles are reproduced in Figure 17 above. These can be considered as baseline cross-sections ("profiles") of the beach and foredune against which all future surveys along the same transects from the same survey marks can be compared to detect changes. However, it is important to note that these profiles do not depict the beach and dune in any sort of "original" state, but rather show the state of the beach and dune during 2022 after about 2 decades of accelerated erosion (as determined from air photo analysis in section 3.4.2 below). For instance, the air photo analysis indicates that the foredune shown on the plots from survey marks T504 and T505 (Figure

17) has lost approximately half of its bulk and width since 2000 through accelerated erosion (see further below).

The profiles plotted on transects T503, T504 and T505 all depict recent near-vertical erosion scarps on the seawards face of the dune. The scarp at T503 is not quite vertical due to some slumping and incipient dune accretion in front of the scarp. This transect is located within the western part of the beach (near 'A' on Figure 15) which has both historically and currently been less prone to erosion than the central to eastern parts of the beach (see section 3.2). Comparison of the TASMARC plot (Figure 17) with digitised air photo shorelines (vegetation lines equivalent to the seawards front of the foredune) indicate that the foredune at T503 has lost about 8 metres of its width since 2001, with about 20 metres width remaining.

In contrast, the scarps at T504 and T505 are fresh, completely vertical and are located within the central to western part of the beach which has shown greater rates of erosion both historically and recently (see Sections 3.2 & 3.4.2, and Figure 15). Notably, all three profiles (T503, 504, 505) slope down to landwards from the crest of their erosion scarps. This implies that erosional recession of the foredune has already removed the entire front slope of the foredune and is now progressively eroding through the backslope of the foredune. Comparison of the TASMARC plots from T504 & T505 (Figure 17) with digitised air photo shorelines (vegetation lines equivalent to the seawards front of the foredune) indicate that the foredune fronts at T504 and T505 have lost 12 m and 10m of their width respectively since 2001, with about 10m and 13m respectively remaining.

The profile plotted on transect T506 has been surveyed across part of the small but highly variable grassy sand spit at the eastern extremity of the beach. This sandy feature at times partly grows across the mouth of the Garden Island Creek estuarine lagoon from its western side but may then be removed by creek and tidal discharges from the lagoon (see 'D' on Figure 15, and also Figure 29). Although the position of this spit has been slowly receding landwards along with the rest of the beach, it also has continued to exhibit larger and more rapid cycles of erosion and accretion than the rest of the beach (Figure 20 bottom plot). One result of this is that the overall dune surface still continues to rise inland, unlike the other three profiles noted above. This is probably because after erosion events this location receives large volumes of the sand eroded from the rest of the beach, which drifts dominantly eastwards towards the lagoon (as discussed in section 2.4.6) and can rapidly accumulate (accrete) at this location. The T506 plot shows both a current erosion scarp on its seawards (RH) side, and also an older scarp face about 10 metres inland from the current scarp. This is interpreted as the result of a large erosion event, which was then followed by the spit accreting rapidly with sand drifted east from the erosion of the main beach, but fast enough as to not first fully cover the prior scarp. In this interpretation the small current seawards scarp is the result of a later and probably lesser erosion event.

3.4 Air photo history

Air photo analysis has provided the most important and reliable information currently available on the behaviour of Garden Island Sands beach and foredune since 1948. The following subsections outline the methods used (section 3.4.1) and the results obtained (section 3.4.2).

3.4.1 Methods

This subsection briefly summarises the methods used to extract this information from the historic air photo record for the Garden Island Sands. Further description and explanation of the methods used is provided in Appendix 3. Appendix 1 lists details of all the air photos used for this project, and Appendix 2 lists the digitised shoreline position files (shapefiles) prepared using the ortho-rectified air photos.

Scanned copies (mostly at 2039 dpi) of all air photos covering Garden Island Sands Beach at scales of 1:45,000 or (mostly) better were obtained from the Department of Natural Resources and Environment Tasmania (NRE), which is the custodian of most historical air photos of Tasmania. Air photos from 39 dates were obtained, ranging from 1948 until 2021. Several of these were already ortho-rectified[5] by NRE, and one of these with good contrast and resolution (19th Dec. 2015, with 0.1m pixels) was selected as a reference image against which all other unrectified air photos were geo-registered[6] and ortho-rectified by Chris Sharples using Landscape Mapper™ software. This reference image was assigned a relative position error margin of 0.0 m by convention. Well-defined fixed features (e.g., distinctive coastal rock outcrops) on the reference photo were selected as ground control points (GCPs) to enable ortho-rectification of other photos in the time series relative to the reference photo. For each ortho-photo, position error margins were measured solely by one operator (Chris Sharples) as the mean (average) of the relative apparent displacement of at least 10 reference points (not the GCPs used in ortho-rectification) from their position on the reference photo. These photogrammetric error margins are arguably the main source of uncertainty for the shoreline position proxy and data source used, albeit more sophisticated uncertainty analyses are possible (Fletcher et al. 2011).

A shoreline behaviour history for Garden Island Sands Beach was compiled by using the seawards *in-situ* (living) vegetation line visible on the air photos as a standard shoreline position indicator or proxy (Boak & Turner 2005). The vegetation line is mostly a good indicator of eroded and receded shores (indicated on air photos by the vegetated top of a foredune erosion scarp) or of accretion and progradation of dunes and beaches (indicated by a lightly or heavily vegetated incipient dune front). Examples of both were mapped at various dates from the air photos used in this project. Some advantages of and limitations on the use of this shoreline proxy are described in Appendix 3

At each air photo date, a line representing this feature was manually digitised (as an ESRI shapefile) over the ortho-rectified air photo along the full approximately 500m length of Garden Island Sands Beach. Despite the presence of overhanging tree and shrub canopies as well as shadows obscuring parts of the vegetation line in most photos, sufficient sections of the identifiable vegetation line were visible in most photos as to allow most of the line to be reasonably interpolated between its visible sections[7].

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[5] Ortho-rectification is the process of removing certain inherent distortions from air photos so as to produce an accurate 2-dimension image of features on the ground surface in their correct positions and shapes relative to each other.

[6] Geo-registration assigns map co-ordinates to an ortho-rectified air photo so that it can be correctly positioned and oriented in mapping software.

[7] Some apparent anomalies resulting from using the vegetation line as a shoreline indicator were identified. For example, in some earlier photos, bare sand (possibly windblown?) behind the west end of the beach seems to extend some metres landwards behind the crest of the foredune in parts of the beach with no clear scarp, particularly at the western end of the beach. In this case the shoreline position (vegetation line) is not

The shoreline feature (vegetation line) was manually digitised as a line for each air photo date using a consistent process performed by only one operator (Chris Sharples). During the process of shoreline digitising, several air photos were rejected by reason of poor image quality (see Appendices 1 & 2), with the result that the final air photos used for shoreline behaviour analysis comprised photos from 34 dates ranging from 1948 to 2021.

In addition, the equivalent present-day shoreline feature (mostly the vegetated top edge of a fresh foredune erosion scarp) was surveyed in the field on 25th August 2022 by Elliott Cromer using high-accuracy survey methods, and this survey has been converted to a shapefile and added to the digital shorelines listed in Appendix 2. This most recent shoreline brings the total of digitised shoreline positions used for shoreline history analysis to 35 at dates ranging from 1948 to 2022.

Shoreline change over time was measured using the *Shoreline History* App developed by Dr Michael Lacey at the University of Tasmania. Shoreline change was measured as horizontal movement (landwards or seawards) of the digitised shoreline position over time along each of a series of 18 shore-normal digital transects spaced 25 m apart along the whole Garden Island Sands Beach shore (see Figure 19). See also Appendix 3 for further explanation and illustrations of the analysis method used.

Visual inspection of the shoreline history plots allowed grouping of transects with differing internally coherent histories in different parts of the beach (see Figure 19 and Figure 28). The median of the shoreline positions at each date across all transects in each group was then plotted to provide a final quantitative shoreline history summary for each coherently behaved group of transects. Figure 24 provides the final data plot for one of the two main sections defined for Garden Island Sands Beach in this fashion, with air photo position error bars derived as described above. From these plots, further analyses have been performing in some cases, including linear regression plots (or fits) to whole plots (Figure 24) or to sections of plots visually identified as representing long term changes in beach behaviour (e.g., see Figure 25). See also Appendix 3 for further explanations and examples of the data analysis methods used in this work.

Additional aspects of the history of beach changes at Garden Island Sands Beach have been analysed using the original shoreline plots (e.g., Figure 18 and Figure 27) and the original air photo imagery itself (e.g., Figure 29). These methods are described as needed in Section 3.4.2 following.

3.4.2 Air photo history results

As described in section 3.4.1 above, shoreline positions (defined as the *in-situ* seawards vegetation line) were plotted and digitised from each aerial photo used (listed in Appendices 1 & 2), together with an equivalent ground-surveyed 2022 shoreline. The resulting 35 shorelines dating from 1948 to 2022 are all shown plotted together on Figure 18 below. Eighteen 25m-spaced shore-normal transect lines were digitally generated across the full set of historic shorelines. These were used to measure and plot shoreline histories (movements or changes) along each transect as shown on Figure 19 and Figure 20 (see also section 3.4.1 above and Appendix 3 for further explanation of these data analysis methods).

Beach behaviour summary

Based on visual inspection of shoreline history plots along all transects, the beach was divided into 4 sections whose transect plots are grouped according to distinctive shoreline behaviour histories. These are shown as 4 separate inset shoreline history plots on Figure 19 and Figure 20. The same figures also show the earliest (15th Dec. 1948) and most recent (25th Aug. 2022) digitised

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the front of the dune as it is in most cases, however anomalies such as this were uncommon and probably do not significantly effect the interpretation of long term (multi-decadal) shoreline change trends.

shorelines, whose differences highlight some of the key historical differences between the 4 distinctive sections of the beach. The historical behaviour of each of the 4 distinctive sections based on visual inspection of the plots is briefly outlined below, and following sub-sections describe the data analysis used to define the historical shoreline behaviour more rigorously and quantitatively within the two main (longest) beach sections (transects 3-6 and 6–17).

Transects 1-2 ***Far north-western end of beach / dune:*** The beach shoreline (vegetation line) around transects 1 & 2 (see Figure 18 and Figure 20) showed highly variable behaviour between 1948 and 1966, with both apparent recession and then progradation (with incipient dune expansion) over a range of nearly 9 metres. The (dry) beach face itself was also quite variable in width over about the same period, ranging from about 15m wide on transect 1 in 1948 to 30 m wide on the same transect in 1967. However subsequent to 1966, the shoreline variability changed to a slow progressive trend of dominantly shoreline recession (see Figure 20). The net shoreline recession over the whole 1966 to 2022 period was up to 14 metres with little variability in the long-term rate of recession, and in particular no major change of behaviour around 2000 (as did more notably occur on transects 3 to 17: see below).

Transects 3–6 ***North-western part of beach:*** Like the area of transects 1 & 2, the shoreline position and beachface width in the adjacent area of transects 3 to 6 also shows notable variability (erosion then recovery) in the early period of the air photo record until circa 1965. However, in contrast to the north-western end of the beach, from 1965 until around 2000 the shoreline positions at transects 3 to 6 shows some notable short-term variability (cyclic shoreline erosion and recovery), which the plot indicates is a "dynamic equilibrium" around a stable to possibly slightly receding long-term (multi-decadal) shoreline position. Then a notable change of behaviour occurred circa 2000, following which the shoreline behaviour has been dominated by a significant erosion and net recession trend which is continuing at present (see Figure 19 top plot and Figure 23), albeit at a slower rate than the central to south-eastern part of the beach (see below). This section of the beach comprises much of the same beach and dune section whose present-day condition is classified as "Eroded sandy shore with significant recovery" on Figure 15 above.

Transects 6 – 17 ***Central to south-eastern main part of beach:*** This is the longest coherently-behaved section of the beach and foredune, and shows both the greatest amount of historical shoreline recession (see Figure 18) as well as the most freshly active current erosion (see Figure 15). The shoreline history plots for this long section of the beach (Figure 19 bottom plot and Figure 26) show some cyclic variability (erosion and recovery) around a long-term stable to possibly slightly receding shoreline position from at least 1948 until circa 2000. Then around 2000 there is a distinct change to a rapidly receding shoreline trend which has continued up to the present. This shoreline behaviour history is (after 1965) similar to that seen on the adjacent transects 3-6 (see above) but shows a more rapid rate of shoreline recession since 2000 than the latter, and fresher more active foredune erosion scarps at the present time (2022).

Transect 18 ***South-eastern extremity of beach:*** This transect crosses a small sandspit which is the extreme south-east end of the beach and protrudes partly across the mouth of the Garden Island Creek estuarine lagoon. For context, this transect has been plotted along with the adjacent transect 17 (Figure 20 bottom plot), with which it shares a similar behaviour history. Visual inspection of the shoreline history plot indicates highly variable short-term erosion and accretion (recovery) cycles throughout most of the air photo period, with a slight overall trend of shoreline recession over the whole period. At a more detailed level the plot is also suggestive of a dominantly stable ("dynamic equilibrium") average shoreline position from 1965 to 2000 followed by a minor net shoreline recession trend from circa 2000 until 2022. However, there is less confidence in this interpretation at this location due to the limited data available. Indeed, careful inspection of the plot suggests a significant net recession from 2000 to 2022 on transect 17 but not significantly on transect 18. The highly variable short-term behaviour of this part of the beach is consistent with it being a small sand spit at the mouth of the adjacent lagoon and thus likely to be regularly scoured

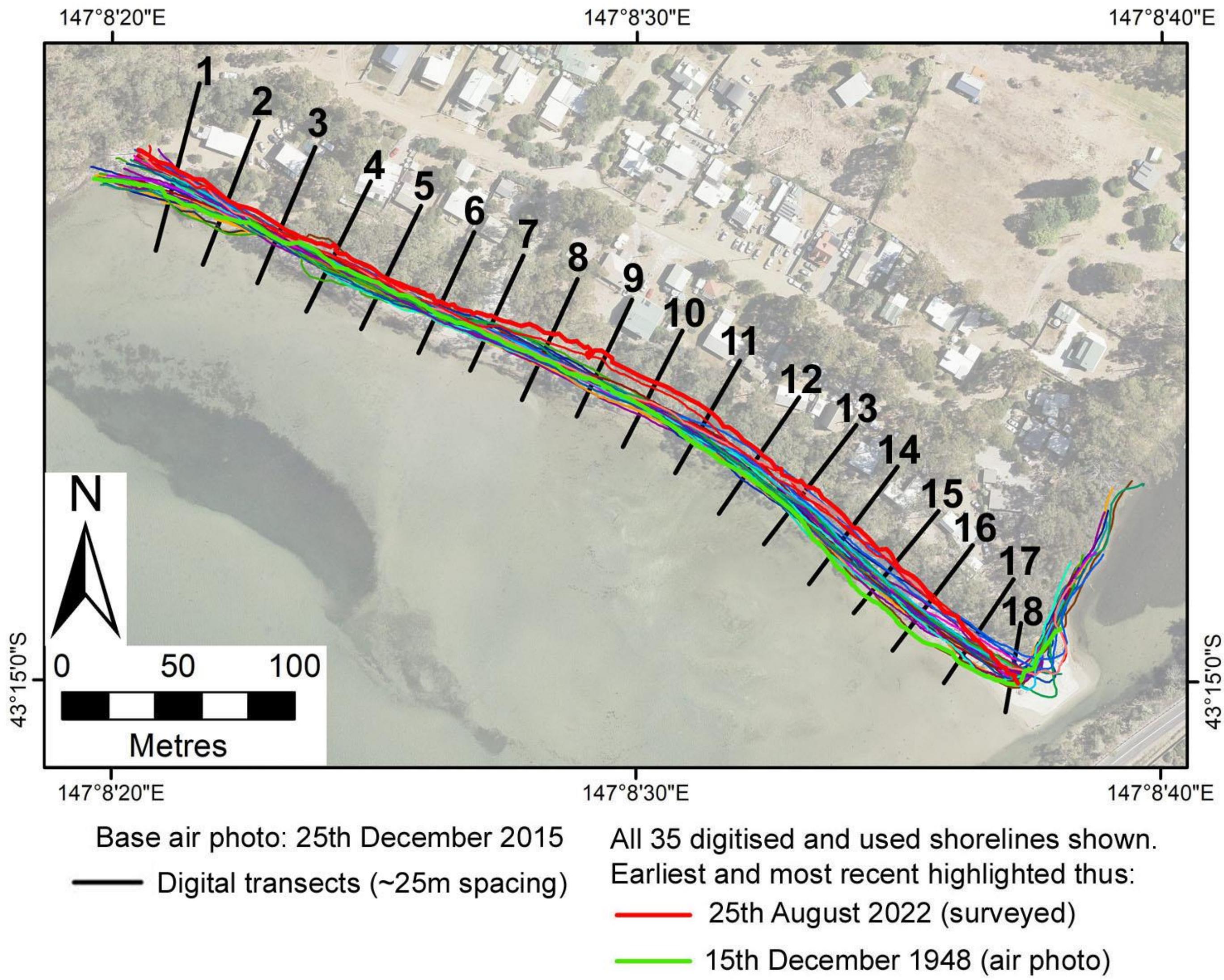


Figure 18: Air photo figure showing all 35 used and digitised shorelines plotted together. Digital transects (as used to construct shoreline history plots on Figure 19 and others) are shown for reference. This shows the variability of the mapped shoreline positions, from the earliest air photo date (15th Dec 1948: thick green shoreline) until the most recent equivalent surveyed shoreline (25th August 2022: thick red shoreline). Note that the wider shoreline variability zone (approximately the central to south-eastern 2/3rds of the beach) corresponds closely with a more active "fresh erosion scarp" zone indicated on Figure 15 above, whereas the narrower shoreline variability zone to its north-west corresponds to the less active "eroded sandy shore with significant recovery" on Figure 15. Background image is the 25th December 2015 air photo (© NRE).

and eroded by river discharges and tidal currents, but also receiving a large supply of eroded sand from the beach after erosion events that drifts south-eastwards along the beach and 'piles up' at the lagoon mouth (see section 2.4.6). The current condition of this part of the beach during 2022 was classed as "actively accreting" (see Figure 15), albeit some older and more recent erosion scarps were also visible on parts of the sand spit (see Figure 17, TASMARC profile T506).

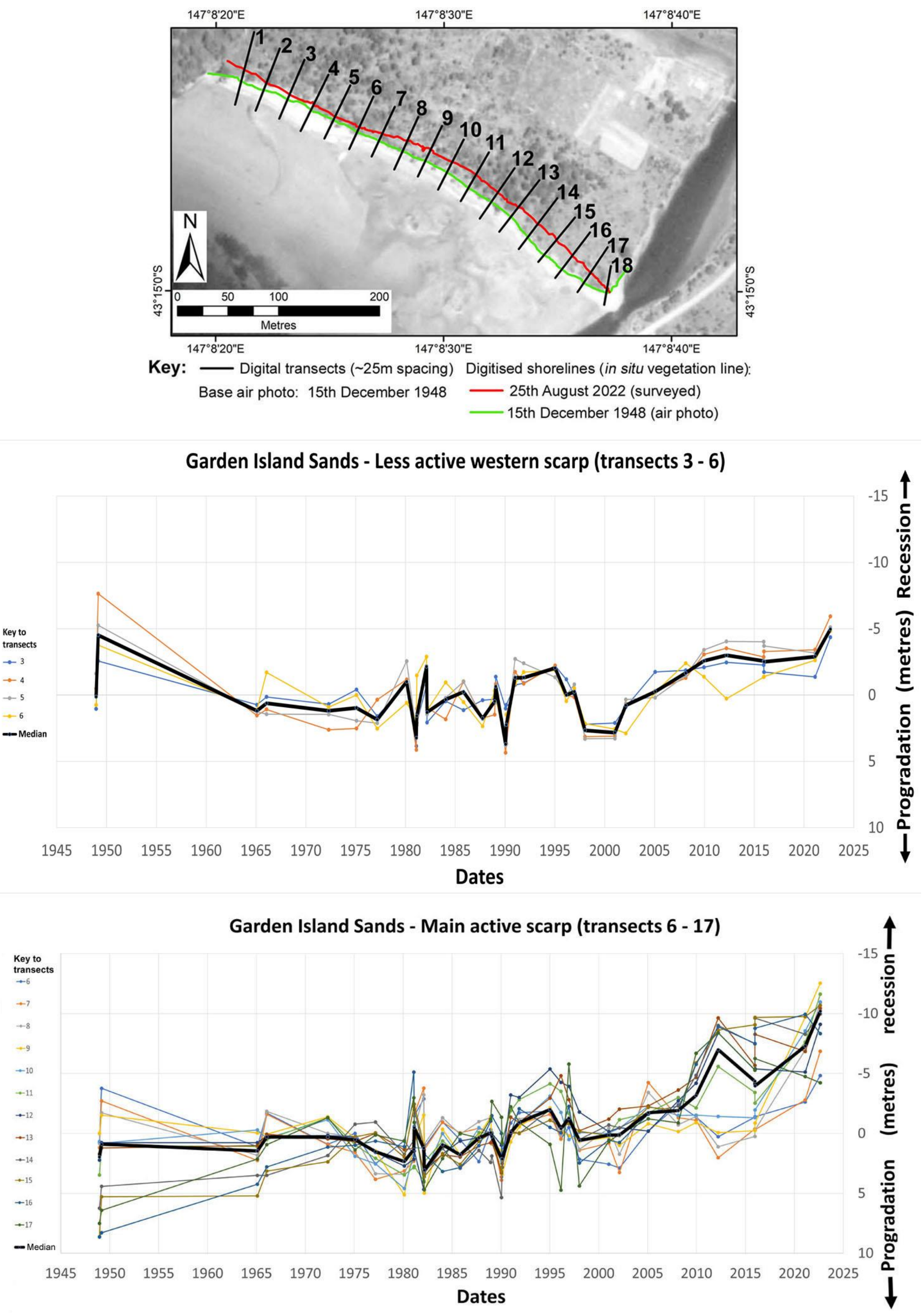
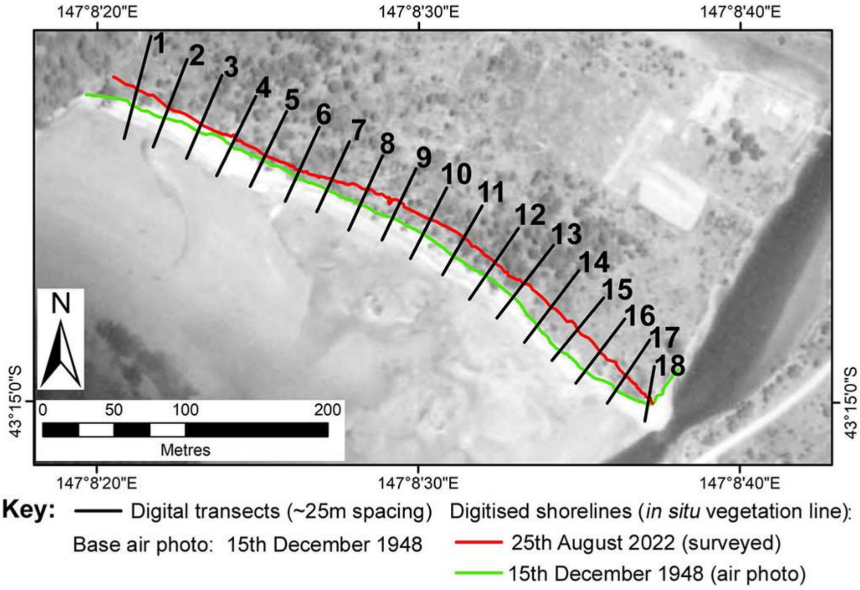
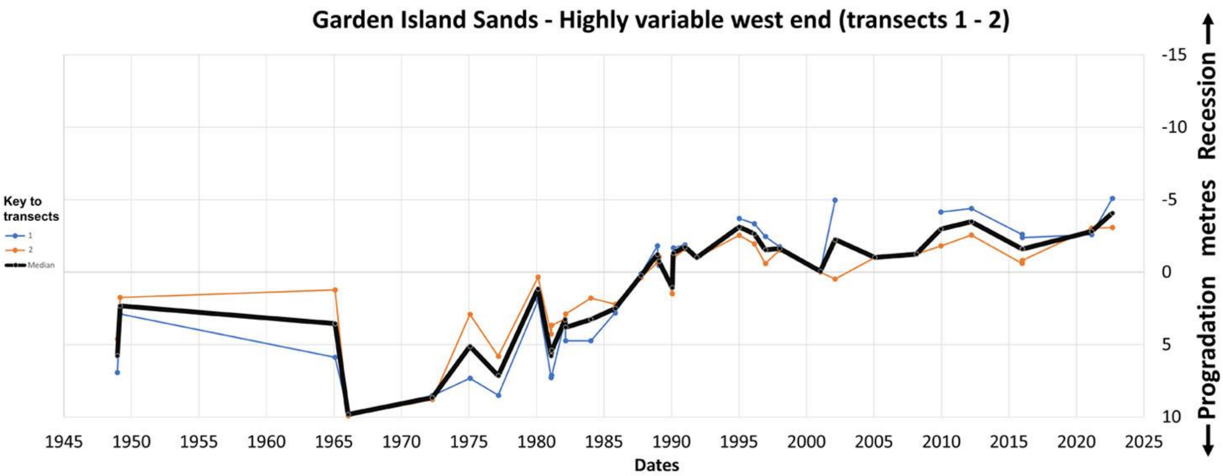


Figure 19: Shoreline history plots for Garden Island Sands Beach: Main transect groupings. These plots show the beach history (changes in shoreline position) along each transect, grouped into the main active beach section at transects 6-17 and the less active north-western section at transects 3-6). These sections correspond closely to the current variations in condition along the beach as shown on Figure 15 above. The shorter, different and at times more variable beach ends (transects 1 & 2, and 18) show more variable behaviour and are plotted separately in following Figure 20. The transect map at top shows the location of the transects along which these shoreline histories were plotted and maps the position of the earliest (green) and most recent (red) shoreline positions along the whole beach. See Appendix 3 for further explanation of how these plots are constructed.





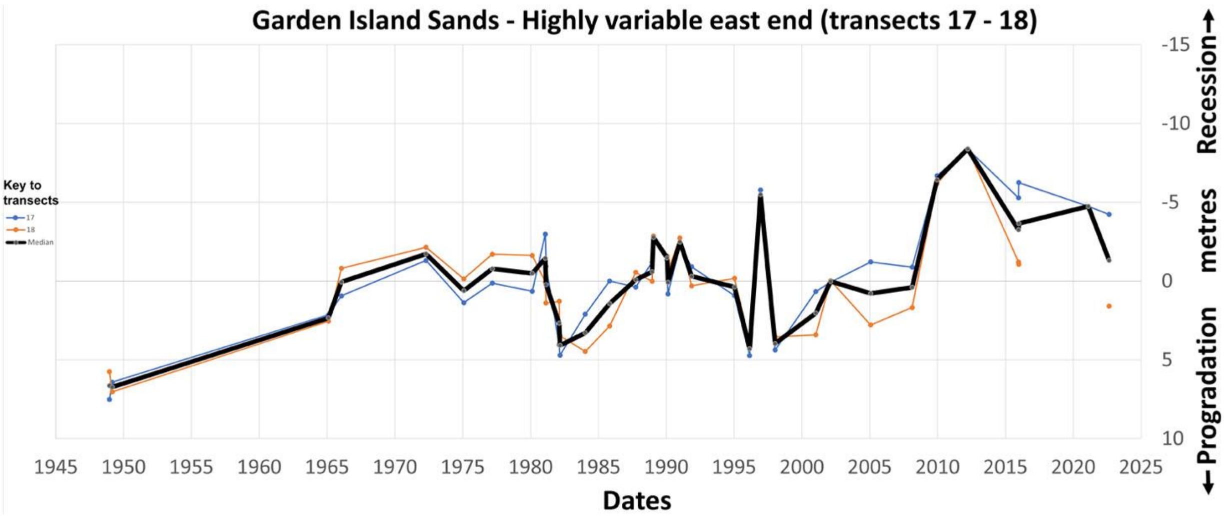


Figure 20: Shoreline history plots for Garden Island Sands Beach: Minor transect groupings of highly variable beach ends. Refer to preceding text descriptions for explanations of these plots. Transect map at top shows the location of the transects along which these shoreline histories were plotted and maps the position of the earliest (green) and most recent (red) shoreline positions along the whole beach. See Appendix 3 for further explanation of how these plots are constructed.

Statistical analysis: Main beach behaviour zones

The following discussion provides additional details supporting the identification of the main shore behaviour patterns described above, namely those identified on transects 3 to 6, and 6 to 17. The following plots and details use photogrammetric error margins and linear regression fits to assess the statistical significance and reliability of the main historical trends identified in the Garden Island Sands Beach data, as outlined above.

Transects 3-6 – *North-western part of beach:* *Early variability then dynamic equilibrium around a stable to slightly receding shoreline from 1965 to circa 2000, followed by a distinct change of behaviour to a moderate rate of progressive shoreline recession up to the present.*
Figure 21 to Figure 23 below show the same data for these transects as that provided in Figure 19 (top plot) above, but summarised by using only the median shoreline position across all the transects at each date rather than all the individual transect plots. Also shown here are the photogrammetric error margin bars at each air photo date (see section 3.4.1 and Appendix 1).

Figure 21 shows a single linear regression line fitted to the whole dataset. Whereas the linear fit suggests a slow overall net recession over the whole data period, the Pearson correlation co-efficient is quite low ($R^2 = 0.1136$) and evidently biased by some early (pre-1965) apparent outlying data points. Hence this fit appears unreliable.

However, visual inspection of the data is suggestive of a relatively stable long-term shoreline position from 1965 to 2000, with notable but short-term beach erosion and recovery cycles, followed by a distinct change to continuous shoreline recession trend after 2000. The statistical significance of this apparent change of behaviour was tested by applying separate ("piecewise") linear fits to the data before and after 2000, both unweighted (Figure 22) and weighted (Figure 23) according to the measured error margins at each photo date. Both methods yield a high Pearson correlation co-efficient on the post-2000 data indicating a statistically significant recession trend ($R^2 = 0.8001$ to 0.7862). Low correlation co-efficients ($R^2 = 0.0500$ unweighted and $R^2 = 0.0474$

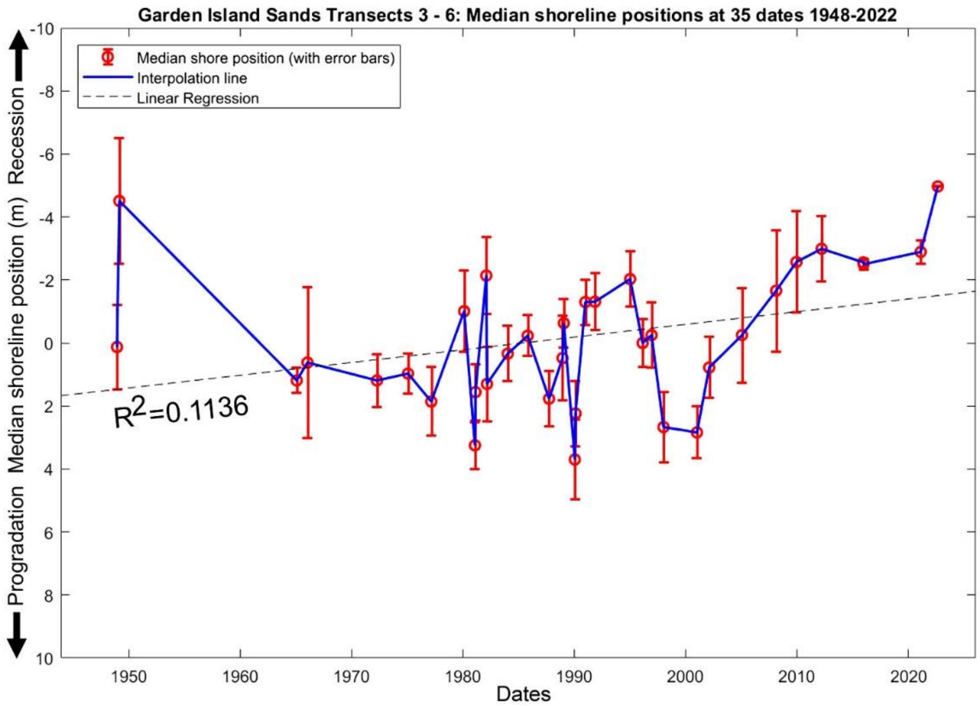


Figure 21: Garden Island Sands less active scarp (transects 3 – 6) median shoreline position history plot. Data error margins (see appendix Table 3) and unweighted linear fit to entire history plot shown. Overall, only a very weak trend towards recession is evident from the overall linear fit, and it is arguable that no long-term trend is present. Nonetheless following plots test for a plausible change of behaviour around 2000, as is seen in the main active area of this beach (see Figure 25 & Figure 26 below).

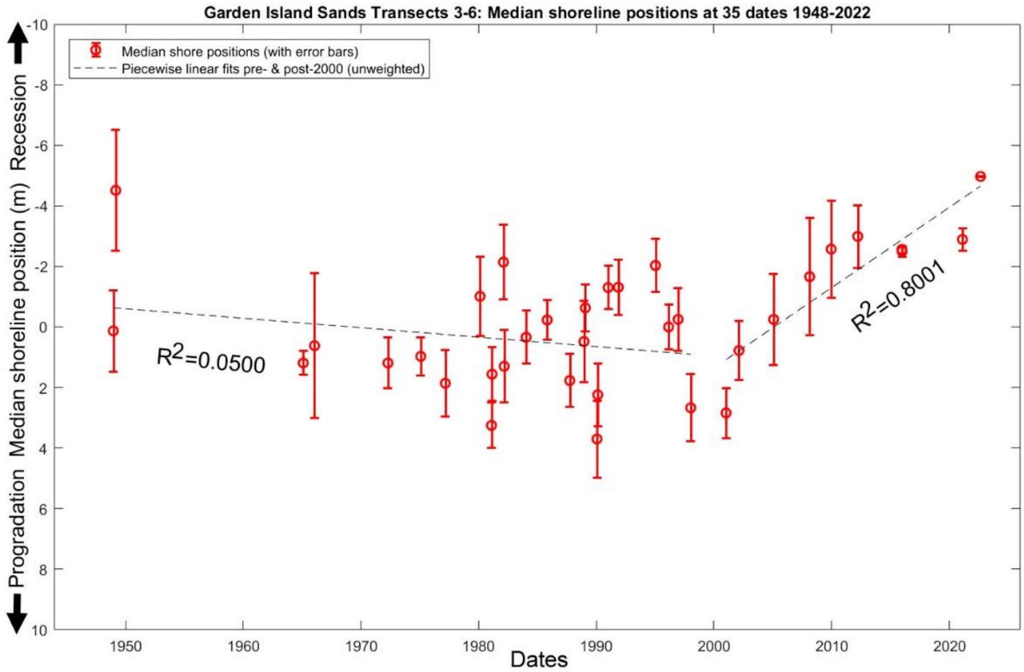


Figure 22: Garden Island Sands less active scarp (transects 3 – 6) median shoreline position history plot with piecewise linear fits. The piecewise fits around 2000 show no significant trend before 2000, but a strong trend towards shoreline recession after 2000, as is also seen in the more active part of this beach (see Figure 25 & Figure 26 below).

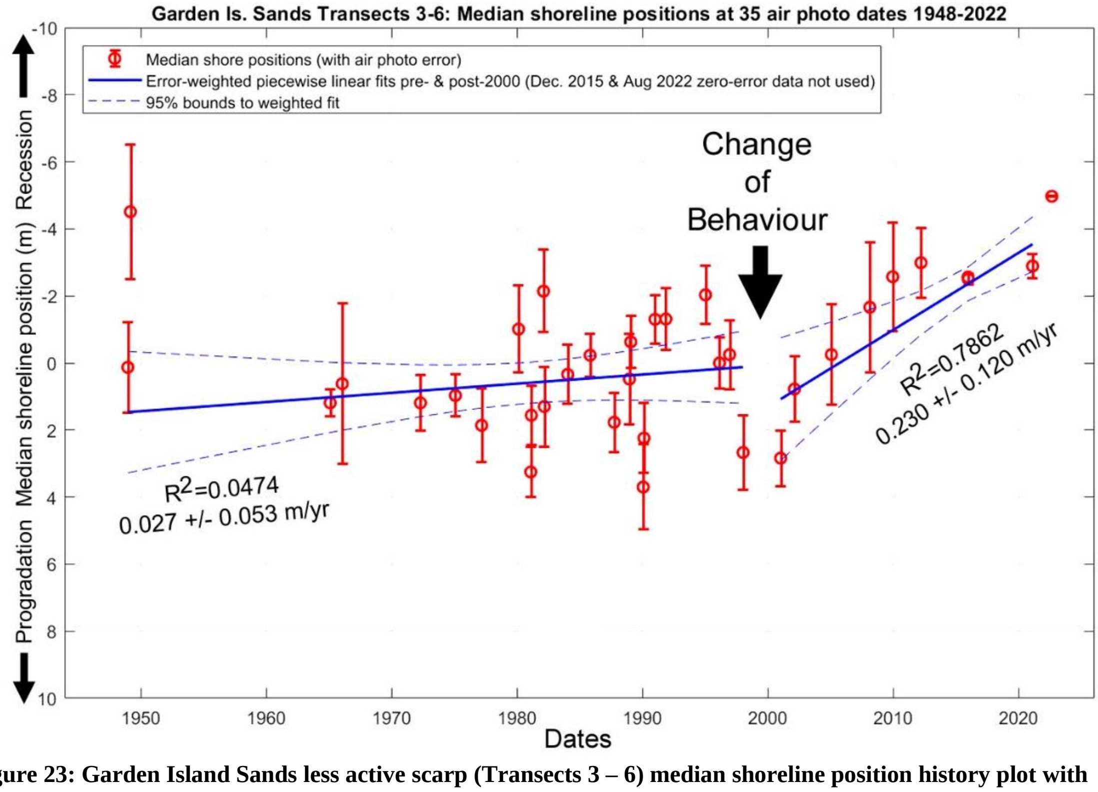


Figure 23: Garden Island Sands less active scarp (Transects 3 – 6) median shoreline position history plot with error-weighted piecewise linear fits. This is the same data shown in Figure 21 above, but with interpolation lines between data points omitted. This figure shows error-weighted linear fits before and after a visually determined apparent long-term change of behaviour around 2000. A clear Change of Behaviour around approximately 2000 is indicated, from a stable or slightly receding pre-2000 shoreline position to a strongly receding post-2000 shoreline position (with a high degree of confidence indicated by the R2 (Pearson) correlation co-efficient). However, whereas a Change of Behaviour is clearly indicated there has not yet been a "Time of Emergence" since the new post-2000 recession trend has not yet emerged above the pre-2000 noise (error margins). Also note that the R^2 (Pearson) correlation co-efficient for the strongly receding post-2000 section is less than that calculated for the unweighted version above (Figure 22) because two zero-error points in that section had to be disregarded to avoid biasing the error weighting.

error-weighted) for the pre-2000 linear fits are at least partly a result of several very outlying early data points, but visual inspection of these linear fits plausibly indicates a stable to slightly receding long term shoreline trend (with notable short-term erosion and recovery cycles) for the pre-2000 parts of these datasets.

In summary, the air photo data derived from photogrammetric analysis of shoreline changes along the north-western part (transects 3 to 6) of Garden Island Sands Beach plausibly supports the interpretation of a stable to slightly receding shoreline position (with short term erosion and recovery cycles) from at least 1965 until circa 2000, followed by a significant change of behaviour circa 2000 to a strong shoreline recession trend which has continued up to the present. This is a similar but slower post-2000 recession trend to that which has occurred in the central to south-eastern part of the beach (on transects 6 to 17; see below).

Transects 6-17 – *Central to south-eastern main part of beach:* *Stable to possibly slightly receding shoreline until circa 2000, then an abrupt change of behaviour to rapid progressive shoreline recession up to the present.*
Figure 24 to Figure 26 below show the same data for these transects as that provided in Figure 19 (bottom plot) above, but summarised by using only the median shoreline position across all the transects at each date rather than all the individual transect plots. Also shown here are the photogrammetric error margin bars at each air photo date (see section 3.4.1 and Appendix 1).

Figure 24 shows a single linear regression line fitted to the whole dataset. The Pearson correlation co-efficient of this linear fit ($R^2 = 0.5567$) is indicative of a significant net shoreline recession over the whole data set from 1948 to 2022. Moreover, the error margin range of data points at both the older and most recent ends of the data do not overlap, indicating that at least the apparent net recession between 1948 to 2022 is real.

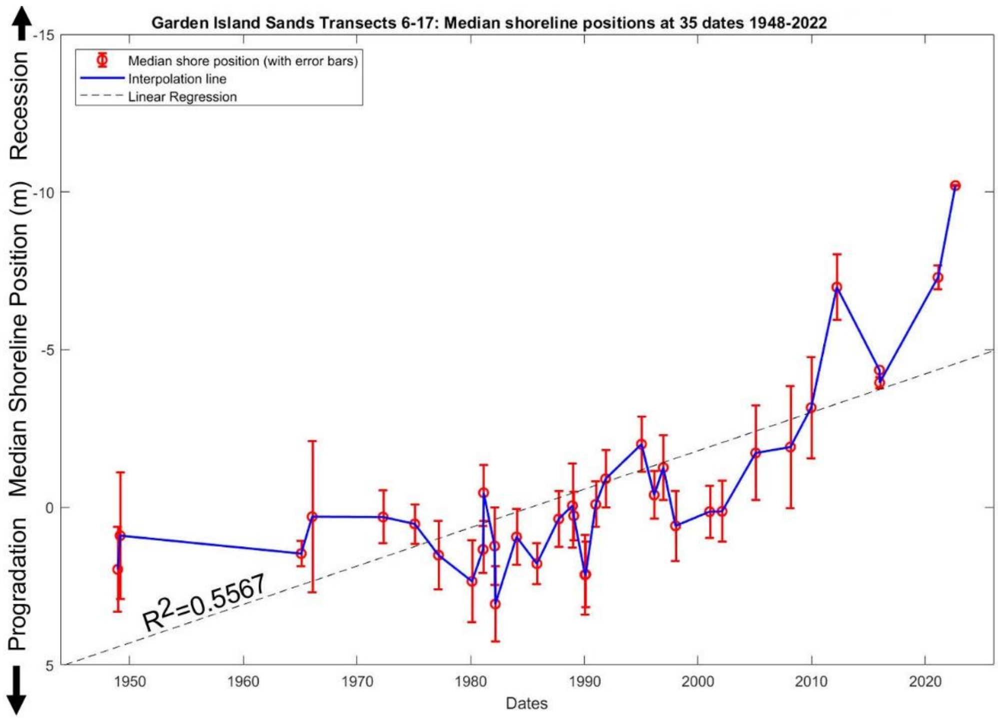


Figure 24: Garden Island Sands main active area (Transects 6 – 17) median shoreline position history plot. This is the same data as shown in Figure 19 (lower plot) above. Data error margins (see Appendix 1 Table 3) and unweighted linear fit to entire history plot shown. An apparent increase in the rate of shoreline retreat is evident around 2000. The significance of this is tested in the following Figure 25 and Figure 26 plots.

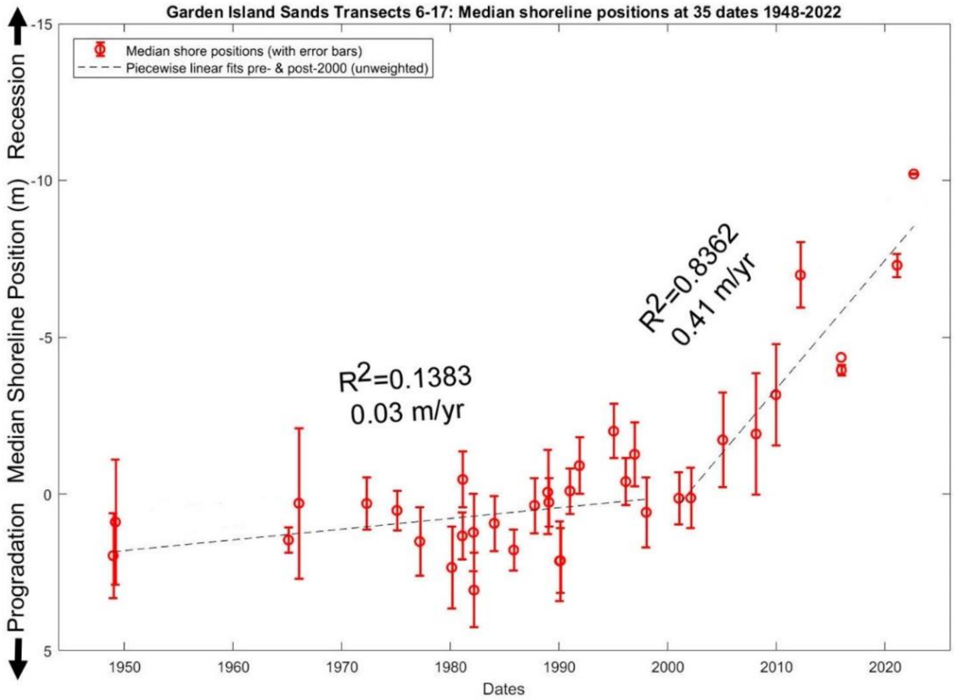


Figure 25: Garden Island Sands main active area (Transects 6 – 17) median shoreline position history plot with piecewise linear fits. This is the same data shown in Figure 24 above with interpolation lines between data points omitted. This figure shows unweighted piecewise linear fits before and after a visually determined apparent long-term change of behaviour around 2000. This yields a weaker pre-2000 linear fit, but the new post-2000 trend has a much better linear fit (R^2 correlation co-efficient) than does a single overall linear fit to the whole dataset. This supports the inference that a major and fairly abrupt change of behaviour occurred around 2000,

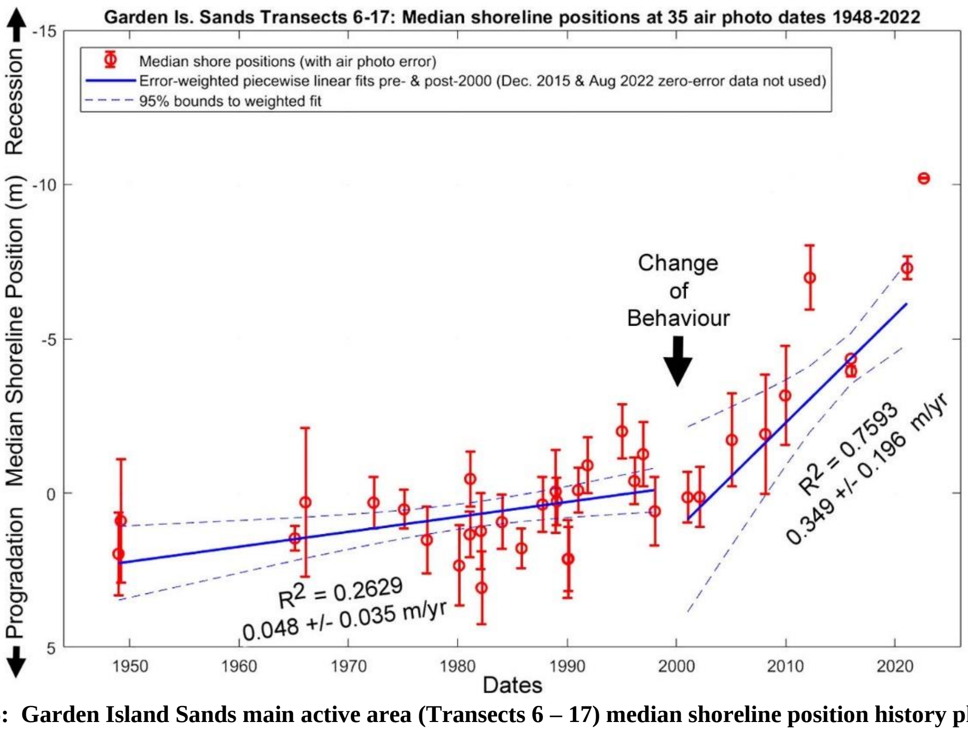


Figure 26: Garden Island Sands main active area (Transects 6 – 17) median shoreline position history plot with error-weighted piecewise linear fits. This is also the same data shown in Figure 24 above with interpolation lines between data points omitted. This figure shows error-weighted piecewise linear fits before and after a visually determined apparent long-term change of behaviour around 2000. This yields a stronger pre-2000 linear fit to a stable to slightly receding trend than the unweighted plot (above) and a slightly lower but still very strong post-2000 linear fit to a recession trend. Note that the R^2 co-efficient for post-2000 data is less than for the unweighted version (previous figure) because two zero-error points (the 19th Dec. 2015 reference image shoreline and the GNSS-surveyed 25th Aug. 2022 shoreline) plotted in that section had to be disregarded to avoid biasing the error weighting procedure.

However visual inspection of Figure 24 does show considerable overlap of the error margins between 1948 and 2000, and the data plot is suggestive of a different (roughly stable) data trend before 2000 compared to a strong recession trend after 2000. The statistical significance of this apparent change of behaviour was tested by applying separate ("piecewise") linear fits to the data before and after 2000, both unweighted (Figure 25) and weighted (Figure 26) according to the measured error margins at each photo date. Both methods yield a high Pearson correlation co-efficient on the post-2000 data indicating a strong recession trend (R^2 = 0.7593 to 0.8362). Correlation co-efficients of R^2 = 0.1383 (unweighted) and 0.2629 (error-weighted) for the pre-2000 data suggest a weaker but still significant stable to slightly receding pre-2000 shoreline behaviour trend with more short-term variability due to normal erosion and recovery beach cycles.

In summary, the air photo data derived from photogrammetric analysis of shoreline changes along the central to south-eastern parts (transects 6 to 17) of Garden Island Sands Beach supports the interpretation of a stable to slightly receding shoreline position (with short term erosion and recovery cycles) from at least 1948 until circa 2000, followed by significant change of behaviour circa 2000 to a strong shoreline recession trend which has continued up to the present. This is a similar but faster post-2000 recession trend to that which has occurred in the north-western part of the beach (on transects 3 to 6).

Summary of statistical analysis

Overall, both transect groups (3–6 and 6-17 as per plots) show a distinct Change of Behaviour around 2000, from a stable to slightly receding long-term pre-2000 shoreline position (with short-term erosion and recovery or accretion cycles) to a strongly and progressively receding post-2000 shoreline position; however, the rate of shoreline recession is much greater (~0.35 m/yr) on transects 6 to 17 than on transects 3 to 6 (~0.23 m/yr). This difference corresponds to the observed level of contemporary erosional activity in these respective sections today, with old erosion scarps showing accretional recovery at transects 3 to 6 while a fresh active erosion scarp shows no sign of foredune recovery at transects 6 to 17 (compare Figure 15 in section 3.2 to Figure 18 in section 3.4.2).

Spatial variability of recession within the main recession zone (transects 6 – 17).

Within the main recession zone described above (transects 6 to 17), visual inspection of the changing shoreline positions over the last two decades demonstrates an additional complexity in shoreline behaviour. This is that two noticeable episodes of more rapid beach and dune recession have occurred in two different parts of the zone at two different times. These are:

- During the period 2008 to 2012 a period of more rapid shoreline recession occurred in the area of transects 14 to 17 (south-east part) compared to the rest of the beach (see Figure 27 shoreline position changes and Figure 28 shoreline history plots below);

and:

- During the period 2015 to 2022 a phase of more rapid shoreline recession occurred in the area of transects 7 to 11 (central part) compared to the rest of the beach (see Figure 27 shoreline position changes and Figure 28 shoreline history plots below).

It is notable that the area of transects 14 to 17 which experienced the greatest recession in the period 2008 to 2012 is also where the greatest amount of historical recession over the whole air photo period (1948 to 2022) has occurred (see Figure 18). In contrast, the increased recession on transects 7 to 11 during 2015 to 2022 has been a more anomalous erosion period for that part of the beach (Figure 18), which otherwise had undergone relatively little shoreline recession from 1948 until 2015 (see shorelines on Figure 18 and top plot on Figure 27). However, this anomalous recent erosion phase has coincided with reduced erosion in the historically more receded area of transects 14-17, suggesting the possibility that a significant long-term switch in shoreline erosion spatial patterns has occurred at Garden Island Sands Beach since 2015.

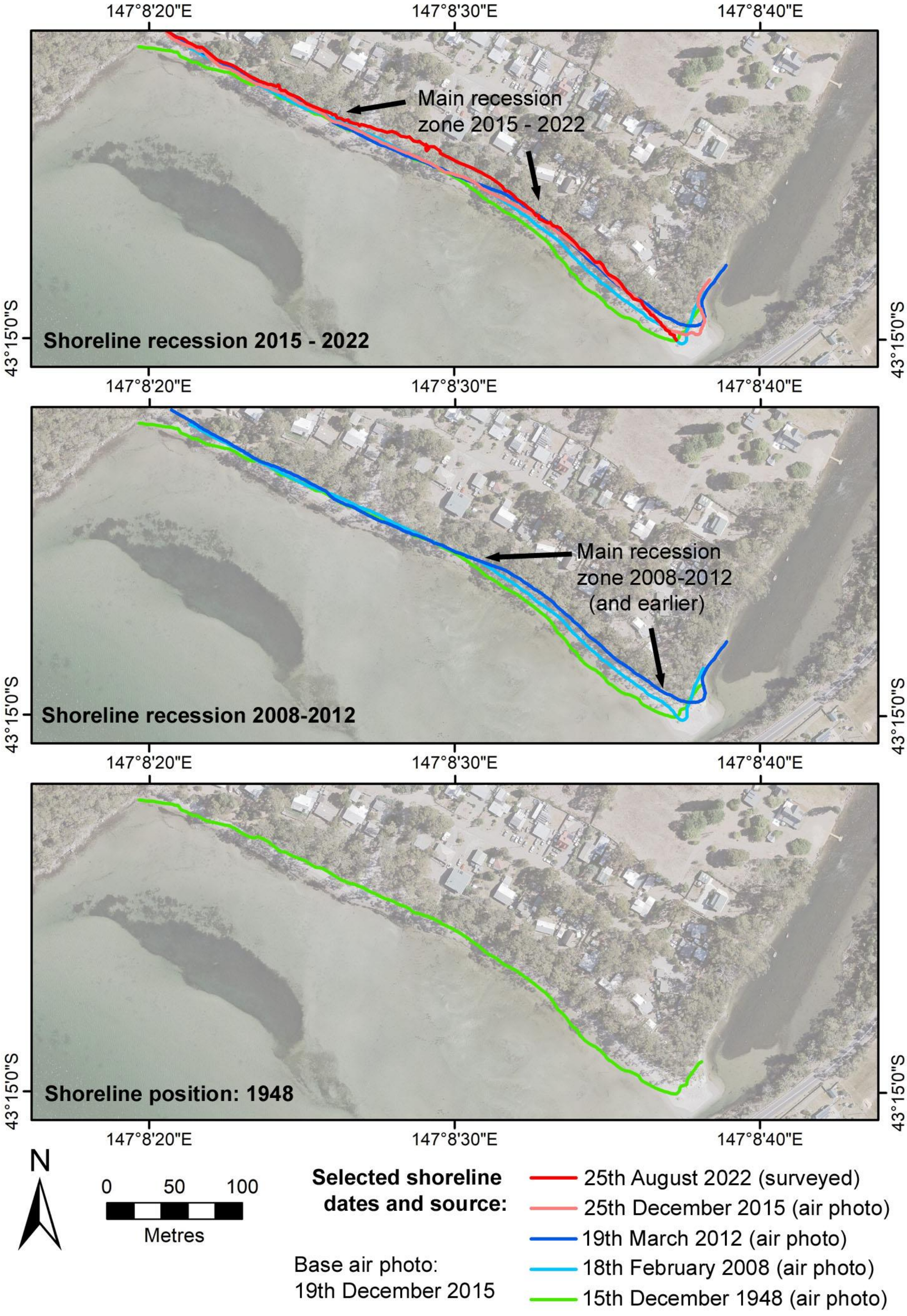


Figure 27: Air photo figure with digitised shorelines highlighting two areas of shoreline recession with differing histories. See also Figure 28 which displays the same histories as plots of shoreline movement along transects. The main recession zone in 2008-2012 is also where most of the recession since 1948 has happened (including during the July 2011 erosion event). In contrast shoreline positions in the 2015 – 2022 recession zone changed little from 1948 until 2015, then have receded dramatically during recent years (while recession in the 2008-2012 recession zone has been negligible).

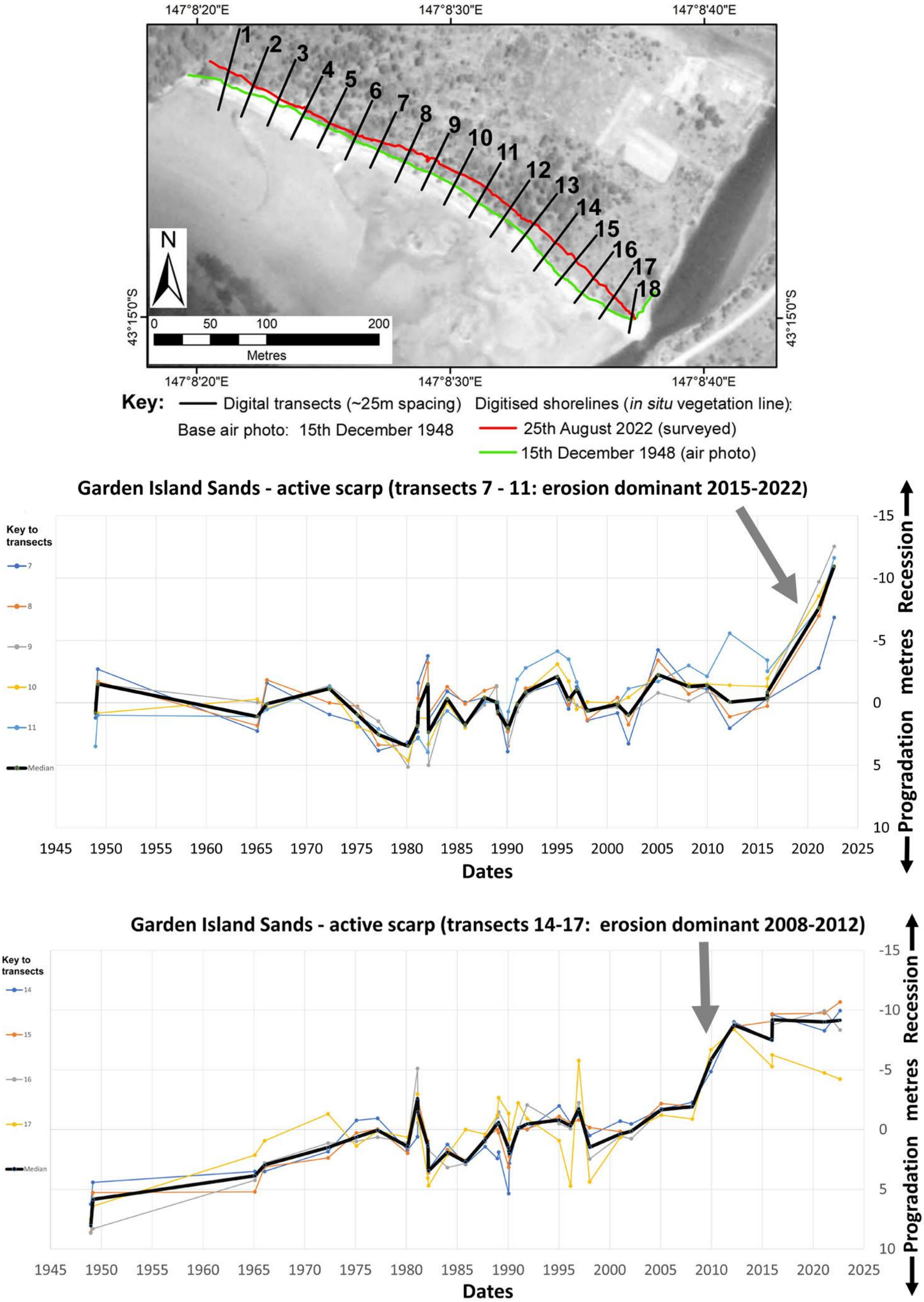


Figure 28: Shoreline history plots – Subsidiary groupings within main active section. These sub-sections show different timings for their most important recession phases: transects 14 – 17 is where most recession since 1948 occurred, including during 2008-2012 (compare Figure 27). Transects 7 – 11 didn't recede significantly until 2015-2022, then has receded dramatically since (also compare Figure 27).

Although it is arguably too soon to confirm that any long-term change in erosion patterns has occurred since 2015, the fact that some change in the spatial focus of erosion at Garden Island Sands Beach has occurred – whether it is merely a short-term variation or a new long-term trend - warrants notice and should be considered in planning any response to shoreline erosion at Garden Island Sands.

The cause of the observed variability in the spatial focus of erosion and recession at Garden Island Sands is not clear at present. However, the fact that the change manifests as a spatial shift in the focus of erosion along the beach is strongly suggestive that it is related to storm wave changes, given that wave direction changes are the most readily apparent and likely cause of any spatial variability of erosion along the beach. If this is the case, wind waves are more likely responsible than swell waves, given that the long swell wave refraction pathway of swells through D'Entrecasteaux Channel to Garden Island Sands means little directional variability in these waves is likely at Garden Island Sands (see section 2.4.2), albeit changes in local sand bars could at times result in differing amounts of swell wave energy reaching different parts of the shore.

As noted in section 2.4.2 above, the broad spatial distribution of erosion at Garden Island Sands suggests that locally generated westerly to south-westerly wind waves (rather than swell waves) are probably the main agent of shoreline erosion at the beach. Given that wind wave directions will vary rapidly with wind direction changes, a changing focus of wave erosion at the beach could be explained by a significant and perhaps long-term change in the dominant wind directions at Garden Island Sands. Thus, the north-westwards change in the focus of erosion along Garden Island Sands Beach observed between 2008-2012 and 2015-2022 (see Figure 27) could be explained by a shift of the inferred dominant westerly to south-westerly wind directions (see section 2.4.1) in a more southerly direction. This is a plausible possibility, however at the present time the writer is unaware of any analysis of Tasmanian wind records to test for such changes, and such an analysis was beyond the scope of the project reported on here. However, such analyses are likely to yield significantly improved understanding of Tasmanian beach erosion processes in future.

Shoreline and sand bar variability in Garden Island Creek estuarine lagoon

Visual inspection of the whole series of air photos from 1948 to 2021 (as listed in Appendix 1) was used to test for any significant changes to the Garden Island Creek estuarine lagoon over that 73-year period (Figure 29 following shows selected examples from the air photo time series).

Map Figure 2 (section 2.3.1) depicts the distribution of shorelines composed of hard rock (dolerite), clean sand and peaty silts around the downstream 1 kilometre of the Garden Island Creek estuarine lagoon (as mapped by Chris Sharples using kayak access during 2022). Erosion scarps are visible in the sandy and peaty-silt shoreline sediments at various locations around the lagoon, with some being relatively fresh and others partly rounded and vegetated inactive scarps. It is likely many of these erosion scarps result mainly from river discharge flood events, although coastal storm surges may also play a role. These estuarine erosion scarps have not been further investigated,

Air photo Figure 10 (in section 2.3.5 "Estuarine Lagoon" above) shows two large point-bar style silty-sand bars in the estuarine lagoon, which are labelled "A" and "B" on the figure. River bars of this type may migrate progressively downstream in meandering or slightly meandering rivers at varying rates depending on grainsize, river discharge and other factors. However, a brief visual comparison of all the air photos available for Garden Island Creek estuarine lagoon from1948 to 2021 (see selected example photos on Figure 29 following) did not identify any major changes on the size or location of these bars over that period.

In contrast, a notable change to sand bars at the lagoon mouth (labelled "C" on Figure 10) was identified over the air photo period. As noted in section 2.3.1, the extreme south-eastern end of Garden Island Sands beach is a small and highly variable sand spit which at times extends partway across the mouth of the Garden Island Creek Lagoon. However, a deep tidal channel generally remains at the mouth due to river discharges and tidal currents being sufficiently strong as to keep the mouth scoured open.

Inspection of all the available air photos showing the lagoon mouth (see Appendix 1) reveals no instance of a shallow or exposed sand bar extending fully across the lagoon mouth from 1948 until after 1998. That is 28 air photo dates across at least 50 years with no evidence of sand bars blocking the lagoon mouth. However, inspection of all subsequent air photos reveals 4 out of 10 available air photo dates from 9th January 2001 until 10th Feb 2021 which do show a shallow or exposed sand bar fully blocking the mouth of the estuarine lagoon. See example photos compiled at Figure 29 (below). A further (fifth) ephemeral sand bar was observed by the writer during early 2022 (see Table 1 below)

The blocking sand bars appear to be "flood-tide deltas" formed when excess sand is available immediately outside the estuarine lagoon (e.g., due to beach erosion), and so is transported into the lagoon by floodtide (ingoing) currents. However, it is evident from the air photo sequence that these blocking sand bars or 'flood-tide deltas" have only been intermittently present after 2001, which suggests that while they may occasionally form in the lagoon mouth (probably due to excess sand availability resulting from a beach erosion events), they still continue to be largely scoured out again and eventually removed, most probably by regular ebb-tide (out-going) currents and occasional river flood discharges. It is likely that the long narrow form of the lagoon contributes to a more concentrated flow of river discharges and outgoing tidal currents than would be the case in a broader lagoon with low-energy backwaters in which sand could more readily settle and remain. Hence the narrow form of the lagoon is likely to contribute to more rapid flushing of excess sand from the lagoon, including temporary build-ups of eroded sand in the mouth of the lagoon.

This evidence is suggestive of a long-term change in the sand budget at Garden Island Sands, with a change after 1998 (and possibly as late as 2001) to an increased supply of sand to the estuarine lagoon resulting in temporary sand bars blocking the lagoon mouth, albeit these continue to eventually be scoured away by tidal currents and/or river discharges. Given the air photo evidence (above) of significantly increased beach and foredune erosion at Garden Island Sands after 2000, this appears to be the most likely source of an increased supply of sand to the lagoon mouth via south-eastwards littoral drift along the eroded beachface.

Table 1: Air photo dates with or without sand bar fully across lagoon tidal entrance. Air photo dates refer to air photos listed in Appendix 1. Note that a small accretionary sand spit at the south-eastern extremity of the beach has extended partway across the lagoon mouth from the beach at all dates, but prior to 2001 this still left a deep tidal channel open at the mouth (see Figure 29). However, from 2001 onwards, there have been intermittent times when a shallow or exposed sand bar extended fully across the entrance (or very nearly so). Examples are shown on Figure 29; and this table identifies all air photos (and a recent fieldwork date) showing this sand bar.

Dates	Sand bar present fully across lagoon mouth?	Notes
15th Dec. 1948 to 9th Jan. 1998	No	Deep tidal channel at lagoon mouth open at all air photo dates.
9th Jan 2001	Yes	Shallow sand bar fully across mouth – first occurrence seen on air photos.
1st Feb. 2002 to 25th Jan 2005	No	Tidal channel entrance open at all air photo dates
18th Feb. 2008	Yes	Very small tidal channel visible at mouth.
15th Dec. 2009 to 19th Mar. 2012	No	
19th & 25th Dec. 2015	Yes	
10th Feb. 2021	Yes	
3rd Jan. 2022	Yes	Field observation – C. Sharples
14th Sept 2022	No	Field observation – C. Sharples (indicates sand bar flushed out sometime between 3rd Jan and 14th Sept 2022)

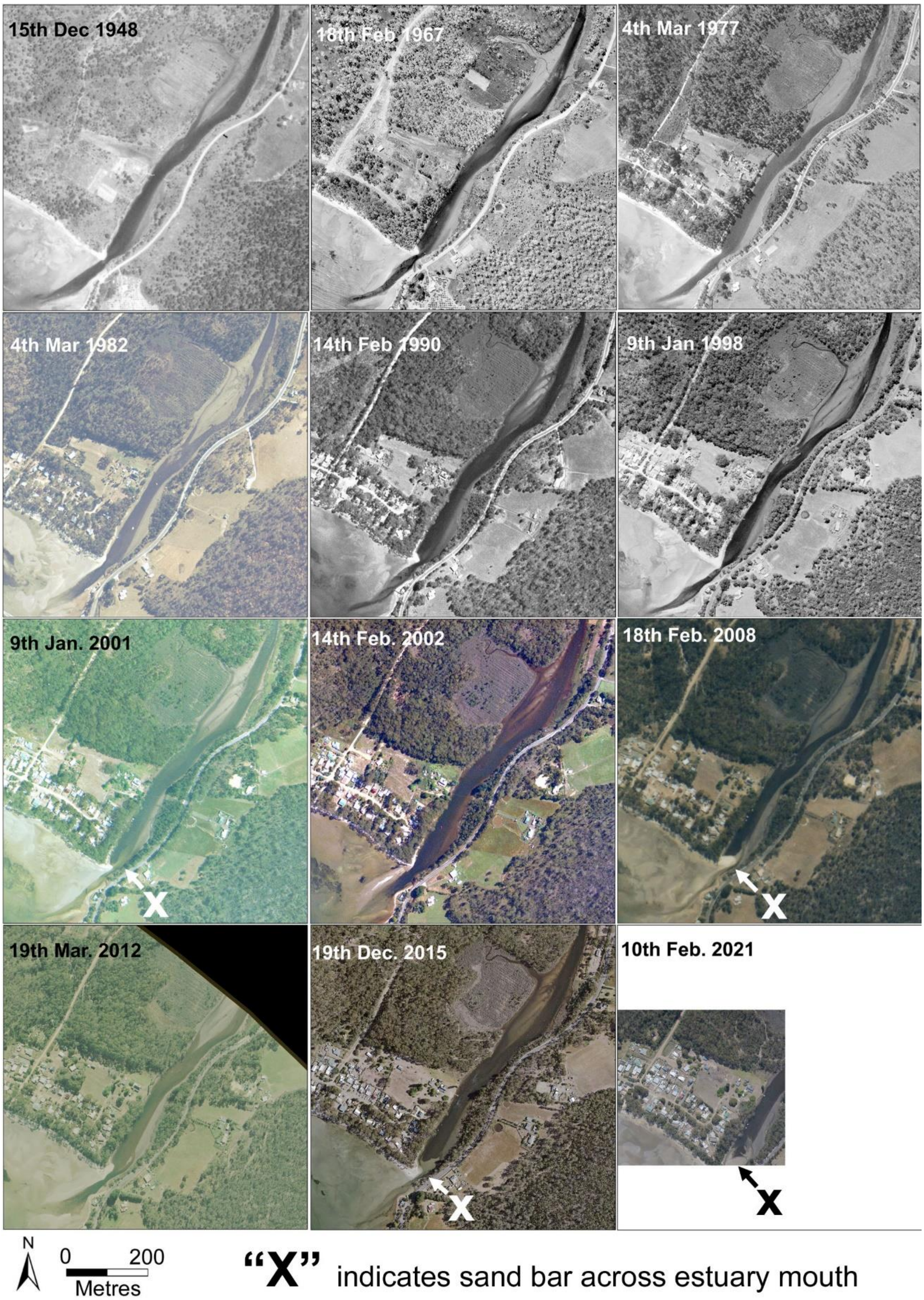


Figure 29: Selected air photo images of the Garden Island Sands Creek estuarine lagoon 1948 – 2021. Key aspects of this air photo time series include the persistence of the approximate location and extent of the two long silty-sand bars offset along opposite shores of the lagoon inside its mouth, and the persistence of the deep open tidal channel mouth of the lagoon at all air photo dates from 1948 until at least 1998. However, a significant change occurred after 1998, when the lagoon mouth has been intermittently but repeatedly filled by temporary sand bars (indicated by "X") which do not appear to be present at any air photo dates prior to 2001. Increased adjacent beach and foredune erosion from circa 2000 onwards appear to be the mostly likely source of such an increased sand supply to the lagoon.

3.5 Summary: Key elements of Garden Island Sands Beach shoreline behaviour history

Key elements of the shoreline behaviour history of Garden Island Sands Beach are summarised as follows. These findings are based on the more detailed analysis and discussions above in sections 3.2 (current shore conditions), 3.3 (TASMARC beach profiling) and 3.4.2 (air photo history), in the light of the descriptive geomorphic (landform) and processes information in section 2.0 above.

The air photo data demonstrates two distinct phases of significantly differing beach behaviour affecting most of Garden Island Sands Beach except the north-western and south-eastern extremities. These two phases have occurred along the length of beach covered by transects 3 to 17 (as shown on Figure 18) during the period since (and probably prior to) the earliest air photos (1948) up until the most recent shoreline position survey (2022). These phases are:

1. From at least 1948 until circa 2000 the beach and foredune maintained a stable or only slowly receding shoreline position, albeit with notable short-term erosion and recovery episodes super-imposed on this.
2. Following a notable change of behaviour around 2000, the beach and foredune have been progressively and relatively rapidly eroding and receding. This recession trend has continued to the present, with some variation in rates of recession along different parts of the beach (see below).

These two phases of beach behaviour are most clearly identified on the shoreline history plots on Figure 23 and Figure 26, but are also clearly seen in the shoreline history plots on Figure 19 (in section 3.4.2 above).

In contrast, the north-western extremity of the beach - mainly in the area of transects 1 and 2 (see Figure 18) - showed highly variable behaviour between 1948 and 1966, with both apparent recession and then progradation over a range of up to 9 metres seawards and landwards. After 1966 this end of the beach has dominantly shown a slow progressive recession trend over the whole period up to the present, but without the notable change of behaviour around 2000 that occurred along most of the beach (see shore history plot on Figure 20).

The south-eastern extremity of the beach – mainly in the area of Transect 18 (Figure 18) – also showed somewhat different behaviour to the rest of the beach over the whole air photo period from 1948 to 2022. The shoreline history plot (Figure 20) indicates highly variable short-term erosion and accretion (recovery) cycles throughout most of the air photo period, with a slight overall trend of shoreline recession over the whole period. This end of the beach is a small sand spit at the mouth of the adjacent Garden Island Creek estuarine lagoon which has been regularly scoured and eroded by river discharges and tidal currents but has also received large supplies of sand from the beach, especially following erosion events, which has drifted south-eastwards along the beach and 'piled up' at the lagoon mouth (see section 2.4.6).

In respect of the main receding section of the beach covered by transects 3 to 17 (see Figure 18), the dominant long-term change of behaviour around 2000 (from stable or slightly receding to more rapidly receding) has also shown some notable sub-ordinate variations in the rates and spatial pattern of shoreline recession, as follows:

1. During the whole period for which air photo and surveyed evidence of shoreline behaviour is available (1948 to present), the beach and foredune have exhibited a notably slower rate of recession with less shoreline change overall at transects 3 to 6 (roughly the north-west quarter of the beach), than it has at the more rapidly-receding transects 6 to 17 (the main central to south-east part of the beach). Compare Figure 23 and Figure 26. The beach at transects 3 – 6 is currently (2022) showing a wide dry sandy beach and some recovery

from old erosion scarps in the form of incipient foredune accretion. In contrast the main receding section (transects 6 – 17) is showing fresh erosion scarps, no sign of sand accretion and recovery, and a low narrow wet beachface. The inferred reason for the historically persistent lesser erosion and recession at transects 3 – 6 is that this section of the beach is more sheltered than transects 6 – 17 are by the rocky headland to its west. This headland shelters the north-western part of the beach from the westerly to south-westerly wind-waves that are probably responsible for most of the erosion along the beach (see section 2.4.2).

Within the less receded area (transects 3 – 6), the digitised air photo shorelines (vegetation lines equivalent to the seawards front of the foredune) demonstrate a net horizontal shoreline recession ranging between 7 and 9 metres from 2001 until 2022. Comparison of the TASMARC beach profile plots (Figure 17) with digitised air photo shorelines indicate that the foredune at T503 (near transect 4) has lost less than a third (8 metres) of its width since 2001, with about 20 metres width remaining.

In the more receded area (transects 6 – 17), the digitised air photo shorelines demonstrate a net horizontal shoreline recession ranging between 7 and 12 metres from 2001 until 2022. Comparison of the TASMARC plots from T504 & T505 (Figure 17) with digitised air photo shorelines indicate that the foredune at T504 (near transects 8 & 9) and T505 (near transect 13) has lost about half (12 m and 10m respectively) of its width since 2001, with about 10m and 13m respectively remaining.

2. Within the main zone of shoreline recession from 2000 onwards (transects 6 to 17), the main focus of erosion has shifted from the south-eastern half of the zone (transects 12-17) to the centre of the beach at transects 7-11 (see Figure 27). During 2008 to 2012, the shoreline receded about 5 to 7 metres in the area of transects 12 to 17, while the area from transects 7 to 11 showed negligible change. Then – conversely - during 2015 to 2022, the shoreline in the area of transects 7 to 11 receded about 8 to 11 metres while the shoreline from transects 12 to 17 showed very little change.

   It is noteworthy that the earlier (2008-2012) recession focus (transects 12-17) is also the area in which the greatest overall shoreline recession from 1948 to present has occurred. In contrast the later recession focus (transects 7 – 11) exhibited very little recession at all from 1948 until 2015 when this area became the main focus of erosion (see Figure 18 and Figure 27). This is suggestive that the change of the focus of erosion and recession within the main erosion zone could be a long-term change. Given that the main driver of erosion at Garden Island Sands is inferred to be locally generated wind-waves (see section 2.4.2), such a change could indicate a long-term change in dominant wind direction and/or extreme wind speeds, and thus the dominant storm wind-wave heights and directions. However, it is probably too soon to be confident that the change seen is long-term and not merely short-term variability superimposed on the longer-term erosion pattern that has held since at least 1948.

An additional notable change in beach behaviour at Garden Island Sands Beach has been the appearance of intermittent sand bars across the mouth of Garden Island Creek estuarine lagoon (see Figure 1, Figure 2 and Figure 29). These do not appear on any historical air photos from 1948 until 2001, but then from 2001 until 2021 they appear on four air photos. They are evidently short-lived intermittent features as they do not appear on other air photos during the same period (see Figure 29). Although it is not possible to be certain that similar features did not occur prior to 2001, the sampling of times provided by the air photo time series is suggestive that these features did appear at about the same time as the better-established change in beach behaviour to more rapid active shoreline erosion and recession (circa 2000). It is inferred these sand bars result from larger-than-previously erosion events causing more eroded sand to drift south-eastwards along the beach during and after erosion events, temporarily blocking the estuarine lagoon mouth until tidal and river discharge currents can flush them out again.

3.6 Causes of landform change at Garden Island Sands Beach

3.6.1 Introduction

The 74-year air photo and survey history of shoreline behaviour at Garden Island Sands Beach demonstrates a major long-term change in beach processes during that period, namely a change around 2000 from a long (at least 52 years 1948-2000) period of mostly stable or only slowly receding shoreline positions, to a long (22 years 2000-2022 and continuing) period of progressive and significantly more rapid erosional recession of the beach shoreline (section 3.4.2).

This major change from one long-term beach behaviour to another is indicative of a significant change in a major driver (cause) of shoreline behaviour over those 74 years, or perhaps of correlated changes in several related drivers. This report section identifies a range of conceivable causes of the observed change and evaluates their plausibility. In summary, an early shoreline response to Global Mean Sea-Level Rise (GMSLR) provides a plausible explanation of the observed changes involving a process driver (sea-level) known to be actively changing (rising) on Tasmanian coasts (see section 3.6.2). No other plausible changing driver likely to be effective at Garden Island Sands has been identified (see section 3.6.3).

3.6.2 A model for a response to sea-level rise at Garden Island Sands

Tide gauge and satellite altimetry data shows that Tasmanian coastal waters (including Garden Island Sands) have experienced a long-term average sea-level rise since the 1800's that is comparable to Global Mean Sea-Level Rise (GMSLR). This global rise averaged 21cm by 2009 (Church & White 2011) and is continuing at an increasing rate (see details in section 2.4.4 above). Although a vertical rise in sea-level of this magnitude may seem small, it can have significant effects on soft sandy coastal landforms in at least two ways, namely:

1. It causes waves of any given size to reach higher on the shore profile than they previously could over the deepened nearshore waters, resulting in more frequent beach and foredune wave erosion events at higher levels and further to landwards than previously (Zhang, Douglas & Leatherman 2004).

and:

2. Deepening water can create more shallow offshore accommodation space to 'sequester' (or trap) greater portions of the increasing amounts of sand excavated from the beach and foredune by the more frequent and larger erosion events (Hennecke & Cowell 2000).

Even a mean sea-level rise of only 21 centimetres on a gently sloping beach such as Garden Island Sands allows waves of any given size to run that much higher over the deepened nearshore waters, and so to reach some metres further landwards than the same waves could have run on the slightly lower mean sea-levels of the 1800's. Thus, more frequent, and larger erosion events may occur at the shoreline even with no significant change in the actual frequency and magnitude of storm waves arriving at Garden Island Sands Beach. This effect is the primary reason why global mean sea-level rise is expected to cause increasingly widespread coastal erosion and recession, as was originally shown by Bruun (1962).

Nonetheless, in many "closed" coastal compartments or embayments, no progressive shoreline recession in response to sea-level rise has yet been seen because the (increasing amount of) eroded sand is not permanently lost from the beach system but is merely dumped just offshore in shallow bars and then subsequently returned to the beach by fair weather swells quickly enough to rebuild the beach and dune before the next major erosion event occurs. However, in some "leaky" coastal compartments increasing proportions of the eroded sand may be quickly lost before it can be returned to rebuild the beach (e.g., Roches Beach in Frederick Henry Bay), or may be lost into a variety of local sand "sinks" or "traps" from which the sand cannot later be returned to the beach. These sorts of beaches with "losing" sand budgets are more prone to showing early net sand losses in response to increased erosion rates related to sea-level rise, and thus may show increased and progressive shoreline recession in response to sea-level rise (Sharples 2020; Sharples et al. 2020).

Garden Island Sands appears to be a good example of a "closed" sandy compartment which as a whole today receives only negligible sand gains and does not leak significant amounts of sand (see section 2.4.6). As noted above many closed compartments have stable sand budgets which quickly return eroded sand to the beach and so have not yet shown a recessional response to sea-level rise. However, Garden Island sands is somewhat unusual in that it has at least two "nested' sand sinks within it that can be expected to permanently trap increasing amounts of eroded sand as sea-level rise increases the water depth over them and thus increases the available accommodation space. This is inferred to prevent a portion of the progressively increasing amount of eroded sand from being returned to rebuild the eroded beach and dune faces. These nested sinks comprise limited but increasing accommodation space for additional sand in the Garden Island Creek estuarine lagoon (see section 2.3.5), and the large sand bar area 100 to 200 metres offshore from the beach (see section 2.3.4).

Given these two key factors related to sea-level rise – increasing shoreline erosion and the potential for an increased capacity of local sand sinks to absorb greater amounts of the increasing eroded sand without returning it to the beach and foredune - the following model is proposed as a plausible explanation of the long-term change of behaviour observed at Garden Island Sands (see also explanatory Figure 30).

1. Prior to the year 2000, from at least 1948 most of Garden Island Sands beach was either maintaining a stable average position or else had a slowly receding average shoreline position, with notable cyclic beach erosion and recovery events super-imposed on these long-term trends. Sand eroded in major storm events was being returned to the beach fast enough to fully rebuild the beach and dune (or nearly so) before the next major erosion event occurred. Only small amounts of sand were being permanently lost into the nested sand sinks (see above), consistent with the relatively slow rate of sea-level rise over most of the Twentieth Century (see section 2.4.4).

2. However, by around 2000, higher wave erosion events were more frequently eroding the beach and foredune, resulting from and commensurate with the increasing rate of global mean sea-level rise by that time (see section 2.4.4). As a result, increased amounts of eroded sand were being moved offshore by storm wave backwash or were being drifted alongshore by the dominant south-eastwards littoral drift along the beach (see section 2.4.6). This increased amount of eroded sand was beginning to temporarily accumulate in sand bars across the mouth of the Garden Island Creek estuarine lagoon, that had not previously been recorded (see section 3.4.2). Although these bars were evidently subsequently scoured out by tidal currents and river discharges, an increasing proportion of the eroded sand is deduced to have begun to be permanently sequestered in the increased accommodation space resulting from sea-level rise within the lagoon (see section 2.3.5) and in the shallow sand bar between the beach and Garden Island itself (see section 2.3.4). As a result, less eroded sand was ultimately returned to rebuild the beach and foredune before the next major erosion event, so that there was no longer a full or nearly full recovery of the beach and dune between large erosion events. Instead, there was a significant increase in the rate of net shoreline recession at Garden Island Sands Beach (see Figure 19 & Figure 26). An increased rate of shoreline recession has persisted at Garden

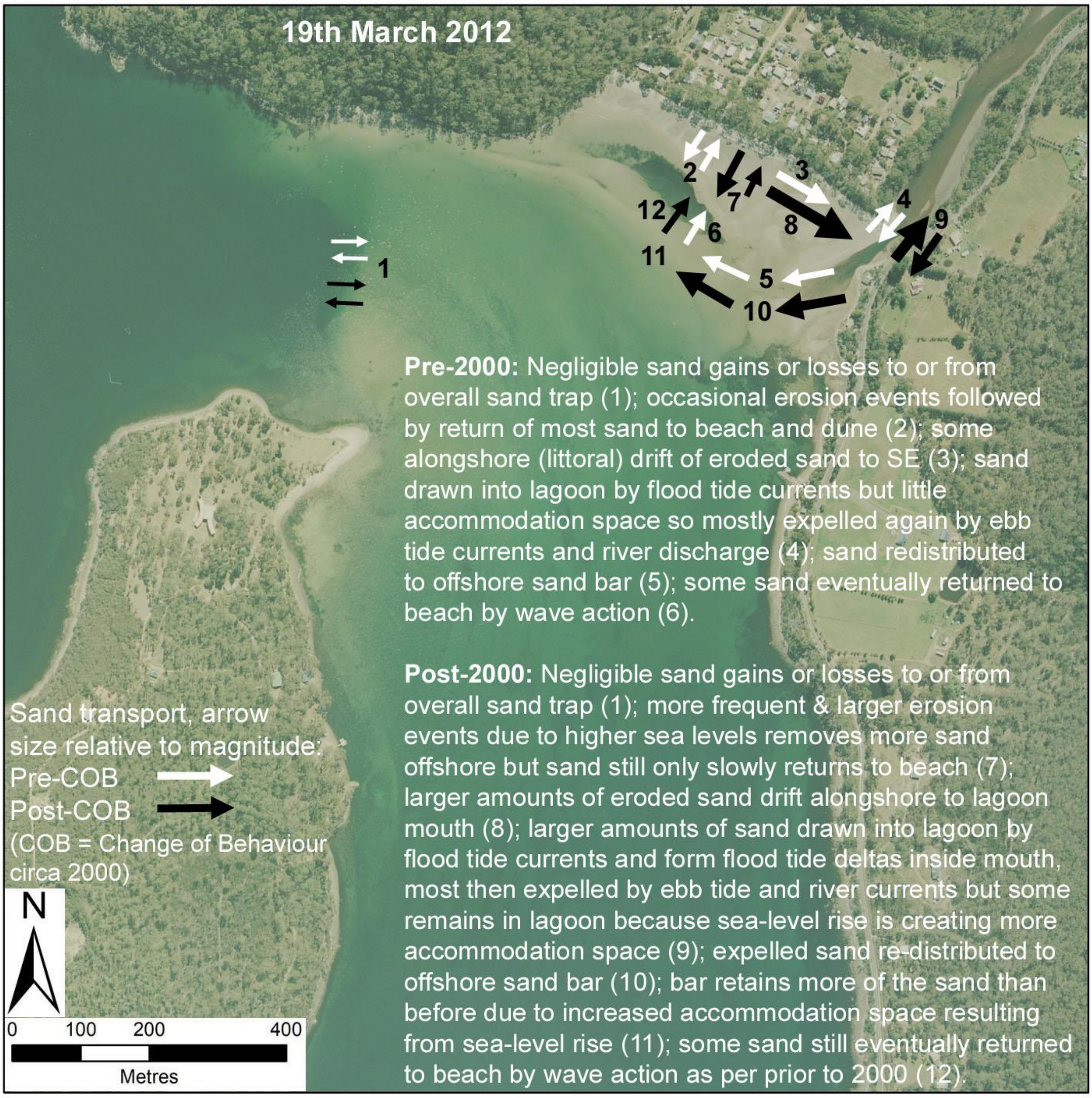


Figure 30: Diagrammatic model of the inferred explanation for post-2000 shoreline changes at Garden Island Sands Beach. See also accompanying text explanation. The background air photo is dated 19th March 2012, © NRE.

Island Sands Beach from its onset about 2000 until the present (2022 – 2023) and is continuing.

3. Partial sheltering of the north-western area of the beach from westerly or south-westerly wind waves (see section 3.2) has resulted in a lesser rate and severity of shoreline recession in the area of transects 1 to 6 (see Figure 18). Much of this area (transects 3-6) has receded at an average rate of 0.23 metres per year since 2000 (see Figure 23). Most of the remainder of the beach (transects 6 to 17) has receded at a more rapid rate averaging 0.35 metres per year (see Figure 26) since 2000, resulting in removal of up to half of the 2000 foredune width in this area by 2022 (see section 3.3).

4. Within the most rapidly receding part of the beach shoreline (transects 6 to 17) there has been a change in the spatial focus of the maximum rate of erosion along the beach since 2015 (see details in section 3.4.2). However, it is too early to confidently speculate on whether this represents a long-term change of shoreline behaviour or is simply the result of shorter-term variability in the driving processes (e.g., storm wind-wave directions).

5. This model implies that the underlying driver of the changes of shoreline behaviour observed at Garden Island Sands since 2000 is long-term progressive sea-level rise. Since global mean sea-level rise is expected to continue for at least several centuries due to the thermal inertia of ocean waters (IPCC 2021)), shoreline recession at Garden Island Sands can also be expected to continue at a similar or possibly increasing rate until a natural limit is reached (such as a resilient rising bedrock slope) or erosion is artificially prevented by some means such as engineering works (see also Section 4.2).

Model testing The model proposed could be tested by taking sand cores from the sand bars in the lagoon and from the offshore sand bar (which are likely the main “nested” sand sinks with increased capacity due to SLR and are central to the model presented here). Dating of the sand in these cores (by available methods such as Optically Stimulated Luminescence or OSL) should show a rapid initial accumulation of sand circa 6000-7000 years BP (possibly over older Last Interglacial sands from circa 125,000 years ago), tapering off to a very slow sand accumulation after several thousand years until quite recently (see section 2.3.4), then a rapid increase in sand accumulation from around 2000 until the present. However, such work was beyond the scope of this project.

3.6.3 Can other factors explain the observed change of shoreline behaviour?

A range of other coastal process drivers have been identified as conceivable causes of the observed changes at Garden Island Beach. Upon examination none of these appear plausible as alternative explanations of the changes. These conceivable drivers of change are set out in Table 2 (following), along with comments on their plausibility as explanations. No other possible explanations have been identified; however, no guarantee is given that the table provided is exhaustive.

Table 2: Evaluation of alternative conceivable drivers of long-term shoreline behaviour changes at Garden Island Sands Beach.

Potential driver of change	Evaluation
Vertical Land Movement (VLM) is a common driver of increased coastal erosion in many parts of the world where coastal land is subsiding at rates of the order of several millimetres per year.	*Not supported.* Best current estimates of Tasmanian VLM are negligible rates of <1.0 mm per year (Riddell, King & Watson 2020), and there is no known evidence of increased local subsidence in the Garden Island region. VLM tends to be a long-term process, which does not explain the onset of significant erosional recession at Garden Island Sands around 2000.
Episodic or cyclic sea-level variability related to ENSO but not GMSLR. Known to affect beach erosion and accretion on eastern Australian coasts (Barnard et al. 2015).	*Not supported for Tasmania*. ENSO is a less important cause of sea-level variability on Tasmanian coasts compared to most Australian coasts (Burgette et al. 2013). However this is a cyclic phenomenon on inter-annual timescales which does not explain the observed one-time change of long-term shoreline behaviour at Garden Island Sands Beach circa 2000.

Increased wind speeds and/or changing wind directions resulting in increased wind-wave erosion at Garden Island Sands Beach.	*Not supported.* Increased wind speeds from the 1980s onwards attributable to climate change have been observed in western Tasmania coastal Bureau of Meteorology wind records (Kirkpatrick et al. 2017; Sharples et al. 2020), but have not been detected in south-eastern Tasmania wind records (Sharples 2020). A change in the spatial focus of erosion at Garden Island Sands Beach circa 2015 could possibly be attributable to wind changes (see section 3.4.2), but (1) is not supported by any wind measurements known to this writer, (2) is too recent to be confirmed as a long-term change, and (3) is too recent to explain the major change of beach behaviour from 2000 onwards.
Swell direction variability, which may trigger changes to focus of erosion and accretion of sand along a beach.	*Not supported*. Generally, an episodically variable process on inter-annual time scales, which does not explain the one-time circa 2000 change of long-term shoreline behaviour at Garden Island Sands Beach. Swell reaching Garden Island Sands Beach is attenuated and trained within southern D'Entrecasteaux Channel, resulting in little variability by the time it reaches Garden Island Sands Beach.
Increase in swell storm magnitudes and frequencies, which might trigger more erosion.	*Not supported.* No evidence of changes in Tasmanian region to date, to the writers' knowledge. Any such changes likely to be of negligible effect at Garden Island Sands Beach since swell reaching the beach is significantly attenuated by the time it has entered and refracted northwards up D'Entrecasteaux Channel.
Movement of large sand "waves" or "slugs" along the coastline causing alternating beach erosion and accretion cycles as they are driven past individual beaches and headlands.	*Not supported.* Mostly characteristic of some energetic swell-dominated coasts (e.g., northern NSW), unlikely to be a significant phenomenon at Garden Island Sands Beach and no evidence of any such features. Generally, a repeating and cyclic phenomenon which does not explain the one-time 2000 change of shoreline behaviour at Garden Island Sands Beach.
Artificial changes and structures.	*Not supported.* Only minor artificial structures are present at or near Garden Island Sands Beach (e.g., a small jetty south-east of the beach). None of the known coastal structures are likely to significantly obstruct sand movement or cause sand erosion, nor are any known to have a circa 2000 construction or removal date which might explain a circa 2000 change of shoreline behaviour.

3.7 Other hazard issues

This report focusses on understanding the nature and causes of shoreline erosion at Garden Island Sands Beach. However, it should be noted that several other coastal hazard issues may also be significant for the beach and adjacent settlement. These are briefly noted below, and it is recommended these be considered in any comprehensive coastal hazard planning for Garden Island Sands.

These hazards are:

1. *Coastal inundation* (flooding) resulting from storm surge conditions, noting that this will be progressively exacerbated by continuing sea-level rise. The LIST website (www.thelist.tas.gov.au) provides what is essentially a first pass or "bathtub inundation model" identifying coastal inundation hazard bands for all Tasmanian coasts. However the mapping is here referred to as "first pass" because more sophisticated "dynamic" flood modelling is needed to account for the effects of water velocities, tidal and river currents on actual time-varying flooding patterns.

2. *Groundwater intrusion* Higher and more saline coastal groundwaters are a consequence of sea-level rise which may have a range of effects including vegetation dieback, interference with septic systems and increased backshore flooding. Groundwater monitoring (using boreholes) may be a useful method of assessing the degree of groundwater hazard likely at paces such as Garden Island Sands.

3. *River flooding* resulting from high rainfall events in the Garden Island Creek catchment may also cause flooding of parts of the low-lying plain behind Garden Island Sands Beach. Such flooding may be exacerbated when it occurs simultaneously with a coastal storm surge or with an incoming (flood) tide causing the river flood discharge to back up in the estuarine lagoon.

4.0 FUTURE MANAGEMENT OF GARDEN ISLAND SANDS BEACH AND DUNE

4.1 Introduction

The key outcome of the data analysis and explanatory model provided in section 3.0 (above) is the recognition that Garden Island Sands Beach is an "Early Responder" to the renewed global mean sea-level rise that has now been in progress since the 1800s, and which has notably accelerated since the 1990s (see section 2.4.4). Bruun (1962) famously identified increased shoreline erosion and shoreline recession as a major physical response to be expected on soft erodible shorelines subject to sea-level rise. Although most sandy shorelines on the Tasmanian coast are not yet showing a physical response that can plausibly be attributed to global mean sea-level rise, a small number are doing so (Sharples 2020; Sharples et al. 2020).

Ongoing sea-level rise to higher levels than have been reached so far is expected to eventually cause increased erosion and recession of most Tasmanian beaches. However, at the present relatively early stage of renewed global sea-level rise only beaches whose "sand budget" makes them particularly sensitive to losing sand into sand sinks are yet showing a noticeable recessional response. Garden Island Sands Beach is one of these, as described in section 3.6 above.

The increased erosion and recession of Garden Island Sands Beach which has occurred since circa 2000 poses a number of hazards and concerns for both residents and other users of the beach. These include:

- Narrowing of the beach face along much of the central to south-eastern beach area has resulted in a lower and wetter beach face with less recreational amenity for users;
- Increasing difficulty accessing the beach for many people due to the continuing erosion and scarping of the foredune; and
- Increasing likelihood that storm erosion events will eventually remove enough of the foredune barrier to begin washing over and scouring out its low points, allowing storm waves to inundate and erode parts of the backshore area currently occupied by houses and roads.

A major concern for local residents and beach users is that the increased erosion during the last two decades damaged a boat ramp which was providing access to the beach. Removal of the damaged boat ramp has limited beach access for many including older people, and the replacement of some form of access that will not be subject to erosion damage is now considered a high priority by the local community.

4.2 Future geomorphic changes at Garden Island Sands Beach

Since global mean sea-level rise is expected to continue for at least several centuries due to the thermal inertia of ocean waters (IPCC 2021)), shoreline recession at Garden Island Sands can also be expected to continue at a similar or possibly increasing rate for at least decades into the future, unless it is deliberately prevented by some means such as engineering. On multi-decadal to century timescales, shoreline recession and flooding by rising sea levels at Garden Island Sands would ultimately be halted or drastically slowed by resilient dolerite bedrock rising behind the sandy and alluvial sediment infill at Garden Island Creek (about 600 metres north-east of the current shoreline: see Figure 1 & Figure 2). However, decisions about how to respond to the hazards to assets posed by ongoing shoreline recession will inevitably be needed well before that limiting factor is actually reached.

Within the next few decades, it can be anticipated that shoreline recession at Garden Island Sands Beach will proceed at similar rates to that observed from 2000 to 2022 (see section 3.4.2), perhaps with some acceleration. In keeping with past trends since 1948, recession rates are likely to be slower along the more sheltered beach section from transects 3 to 6, and more rapid along the main receding section from transects 6 to 17 (see Figure 18). Average rates of recession in these sections after circa 2000 were approximately 0.23 metres per year across transects 3 – 6 (Figure 23), and about 0.35 metres per year across transects 6 to 17 (Figure 26), with faster rates at some points. As has been the case during the last two decades (see 3.4.2) there may at times be some variation in the sections of the beach between transects 6 and 17 that have the greatest erosion and recession impacts (see Figure 27).

Of particular concern from a coastal hazard perspective is that the air photo analysis shows that increased foredune scarp recession since 2000 has already removed variously 7 to 12 metres width of the dune front (the least from the north-western part of the beach around transects 3 to 6, the most from the central to south-eastern parts of the beach between transects 6 to 17). This amounts to the loss so far of roughly between one third and one half of the total original width of the foredune as it was during the year 2000.

Moreover, the first set of TASMARC beach and dune profiles surveyed across the dune (see section 3.3) indicate that the shoreline erosion has already passed the highest crest of the original dune and is now progressing through the backslope (landwards side) of the original dune. This means the ground surface is getting lower as the erosion recedes further to landwards, hence with each successive storm erosion event there is now an increasing risk that storm waves will finally be able to break through the remaining (lower) dune and allow storm waves to wash over into the residential areas behind the breached dune barrier. This will cause flooding and other water damage including erosion and further scouring (erosion) of overwash gullies through the remaining dune barrier. It is likely that the rates and patterns of shoreline erosion would change considerably following such a breaching of the foredune barrier.

4.3 Priorities and options for future management

The writer is a geomorphologist and not an engineer, hence does not provide recommendations for the design and construction of protective coastal structures. The purpose of this final section is to highlight a number of options and priorities worthy of consideration from a geomorphic perspective.

The available responses to coastal erosion (and other) hazards are "traditionally" grouped as "Defend, Adapt or Retreat", where these terms refer to:

Defend: Harden or protect a shore to prevent hazards (e.g., storm waves) from damaging assets;
Adapt: Design assets to endure hazards (e.g., rising seas and storm waves) without damage; and:
Retreat: Move assets away from high hazard zones.

It may be difficult to determine which of these options is most appropriate because of lack of understanding of the hazards in question. For example, a common mistake it to attempt to protect assets using under-engineered protection works which are subsequently destroyed by following erosion events. There are no perfect solutions to eroding beaches – each potential solution has both benefits and costs. However, a useful approach to better understanding how a shoreline such as Garden Island Sands Beach is responding to drivers of change such as sea-level rise is to monitor the beach behaviour over time. See further below re monitoring.

A key community priority for Garden Island Sands in the near-term is to re-instate and retain access to the beach, for example by a ramp or steps over the foredune erosion scarp which is currently making access difficult for some beach users.

However, at the same time and for the same reason, as noted above another high priority is to reduce the risk of residential properties being damaged if the remaining (lower) foredune barrier is breached by storm waves. As noted above, this hazard is exacerbated by the fact that the original foredune (as it was around the year 2000) has been considerably cut back during the last two decades and is now potentially able to be breached by smaller storm waves than would have been needed two decades ago. There is arguably a need to address this priority alongside the need for beach access before much more foredune erosion and recession has occurred. Appropriate responses will be determined through consultation with relevant experts, however as a starting point it is worth noting that sandbagging may be an achievable interim measure to manage this hazard while consideration is given to longer-term options.

Monitoring

Ongoing monitoring of the beach and foredune at Garden Island Sands is a useful way of both measuring and documenting the continuing response of the shoreline to sea-level rise, and also of monitoring the effectiveness and durability of any engineering solutions that may be adopted. Three particularly useful monitoring options that are well suited to volunteer non-specialist community groups are noted here:

1. *Ground level beach photography*. Ground-level oblique photography at regular intervals using fixed viewpoints to enable extraction of beach change information from the photographs. A framework for this sort of monitoring is provided by the University of NSW CoastSnap app. (see www.coastsnap.com).

2. *Aerial photography*. Vertical beach photography using aircraft or drones is a powerful method of continuing to acquire the same sort of data as has been used by this report up to 2022. However, this data can be relatively expensive to acquire.

3. *Surveyed beach profile surveys*. Regular surveying of profiles over the beach and dune from fixed survey reference points, allowing sensitive detection of changes between surveys. The TASMARC project (see www.tasmarc.info) provides an existing framework for this type of beach monitoring which has been designed to be suitable for community volunteer groups to undertake, with the resulting data being publicly available from the project website. Four TASMARC survey marks have been established at Garden Island Sands and initial beach and dune profiles were surveyed by Nick Bowden (surveyor) and Chris Sharples on 12th August 2022. It is intended to provide surveying training for interested local volunteers to undertake ongoing monitoring of Garden Island Sands Beach by this method.

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APPENDIX 1: AIR PHOTOS ORTHO-RECTIFIED

Table 3: Original air photos and ortho-photos produced for Garden Island Sands. All ortho-photos listed in this table are geo-registered to the UTM Map Grid of Australia (MGA) co-ordinate system (Zone 55), based on the GDA94 datum.

Photo Date	**Original DPIPWE air photos (film-frame) / Ortho-photo file name**	**Final image resolution (original scan resolution if downsized) / pixel size (m) of final ortho-photo**	**Original photo scale**	**Mean measured feature position error (± metres) for ortho-photo** [No. of measured feature position reference points]	**Comments**
15th Dec 1948	171-143 (Run 11) / *GardenIslandSands_15thDec1948_MGA55*	2039 dpi / 0.7 m pixel size	1:15,840	1.35 m [8]	Ortho-rectified by Chris Sharples
2nd Mar 1949	182-2 (Run 11A) / *GardenIslandSands_2ndMar1949_MGA55*	2039 dpi / 0.7 m pixel size	1:15,840	2.0 m [10]	Ortho-rectified by Chris Sharples
4th Feb 1965	435-63 (Run 23) / *GardenIslandSands_4thFeb1965_MGA55*	2039 dpi / 0.2 m pixel size	1:15,840	0.4 m [12]	Ortho-rectified by Chris Sharples
21st Jan 1966	456-106 / *GardenIslandSands_21stJan1966_MGA55*	2039 dpi / 0.5 m pixel size	1:31,680	2.4 m [12]	Ortho-rectified by Chris Sharples.
18th Feb 1967	489-162 / *GardenIslandSands_18thFeb1967_MGA55*	2039 dpi / 0.22 m pixel size	1:15,840	1.0 m [9]	Ortho-rectified by Chris Sharples.
18th April 1972	601-52 / *GardenIslandSands_18thApr1972_MGA55*	1500 dpi (2039 dpi) / 0.36 m pixel size	1:15,840	0.84 m [11]	Ortho-rectified by Chris Sharples. Beach central.
31st Jan.1975	665-41 / *GardenIslandSands_31stJan1975_MGA55*	2039 dpi / 0.58 m pixel size	1:40,000	0.63 m [12]	Ortho-rectified by Chris Sharples.
4th Mar 1977	719-125 / *GardenIslandSands_4thMar1977_MGA55*	2039 dpi / 0.40 m pixel size	1:30,000	1.09 m [12]	Ortho-rectified by Chris Sharples.
6th Jan 1979	772-197 / *GardenIslandSands_6thJan1979_MGA55*	2039 dpi / 0.50 m pixel size	1:40,000	0.85 m [13]	Ortho-rectified by Chris Sharples.
14th Feb. 1980	817-126 / *GardenIslandSands_14thFeb1980_MGA55*	2039 dpi / 0.62 m pixel size	1:45,000	1.3 m [12]	Ortho-rectified by Chris Sharples.
3rd Feb 1981	867-167 / *GardenIslandSands_3rdFeb1981_MGA55*	2039 dpi / 0.22 m pixel size	1:15,000	0.75 m [13]	Ortho-rectified by Chris Sharples.
13th Feb 1981	870-121 / *GardenIslandSands_13thFeb1981_MGA55*	2039 dpi / 0.20 m pixel size	1:15,000	0.62 m [12]	Ortho-rectified by Chris Sharples.
20th Feb 1981	872-168 / *GardenIslandSands_20thFeb1981_MGA55*	2039 dpi / 0.42 m pixel size	1:32,000	0.89 m [12]	Ortho-rectified by Chris Sharples.
10th Feb 1982	904-189 / *GardenIslandSands_10thFeb1982_MGA55*	2039 dpi / 0.56 m pixel size	1:42,000	1.23 m [12]	Ortho-rectified by Chris Sharples.
4th Mar 1982	917-211 / *GardenIslandSands_4thMar1982_MGA55*	1500 dpi (2039 dpi) / 0.51m pixel size	1:30,000	1.19 m [12]	Ortho-rectified by Chris Sharples.

14th Jan 1984	978-199 / *GardenIslandSands_14thJan1984_MGA55*	1500 dpi (2039 dpi) / 0.38 m pixel size	1:20,000	0.88m [15]	Ortho-rectified by Chris Sharples.
29th Oct 1985	1042-221 / *GardenIslandSands_29thOct1985_MGA55*	2039 dpi / 0.2 m pixel size	1:15,000	0.65m [13]	Ortho-rectified by Chris Sharples. Same date & run frame 156 more marginal and not used.
30th Sept 1987	1092-136 / *GardenIslandSands_30thSept1987_MGA55*	2039 dpi / 0.56 m pixel size	1:42,000	0.88m [13]	Ortho-rectified by Chris Sharples.
15th Dec 1988	1124-60 / *GardenIslandSands_15thDec1988_MGA55*	1500 dpi (2039 dpi) / 0.75 m pixel size	1:42,000	1.34 [9]	Ortho-rectified by Chris Sharples. Colour, marginal position.
25th Jan 1989	1128-162 / *GardenIslandSands_25thJan1989_MGA55*	1500 dpi (2039 dpi) / 0.75 m pixel size	1:42,000	0.77 [13]	Ortho-rectified by Chris Sharples. Colour, fairly central
22nd Jan 1990	1148-65 / *GardenIslandSands_22ndJan1990_MGA55*	2039 dpi / 0.41 m pixel size	1:31,000	1.27m [10]	Ortho-rectified by Chris Sharples. Beach position is marginal, but good scale
14th Feb 1990	1150-186 / *GardenIslandSands_14thFeb1990_MGA55*	2039 dpi / 0.56 m pixel size	1:42,000	1.04 [16]	Ortho-rectified by Chris Sharples. Beach is more central than Jan 1990 image.
2nd Jan 1991	1162-121 / *GardenIslandSands_2ndJan1991_MGA55*	2039 dpi / 0.3 m pixel size	1:24,000	0.72 m [14]	Ortho-rectified by Chris Sharples
14th Nov 1991	1173-95 / *GardenIslandSands_14thNov1991_MGA55*	2039 dpi / 0.6 m pixel size	1:42,000	0.91 m [13]	Ortho-rectified by Chris Sharples. Fairly central
10th Jan 1995	1228-125 / *GardenIslandSands_10thJan1995_MGA55*	1500 dpi (2039 dpi) / 0.39 m pixel size	1:20,000	0.87 m [15]	Ortho-rectified by Chris Sharples.
23rd Feb 1996	1249-157 / *GardenIslandSands_23rdFeb1996_MGA55*	1500 dpi (2039 dpi) / 0.36 m pixel size	1:20,000	0.75 m [16]	Ortho-rectified by Chris Sharples.
13th Dec 1996	1256-30 / *GardenIslandSands_13thDec1996_MGA55*	1500 dpi (2039 dpi) / 0.42 m pixel size	1:24,000	1.03 m [16]	Ortho-rectified by Chris Sharples. 1256-29 similar but frame 30 has better view onto shoreline under trees.
9th Jan 1998	1285-12 / *GardenIslandSands_9thJan1998_MGA55*	2039 dpi / 0.4 m pixel size	1:24,000	1.11 m [14]	Ortho-rectified by Chris Sharples.
9th Jan 2001	1343-25 / *GardenIslandSands_9th Jan 2001_MGA55*	1500 dpi (2039 dpi) / 0.4 m pixel size	1:24,000	0.83 m [17]	Ortho-rectified by Chris Sharples. Colour, good scale, good spread of GCP's. Used in preference to 21st Jan 2001 photo.
21st Jan 2001	1344-69		1:24,000	n/a	Not ortho-rectified or used. Marginal, can't get good GCPs for most of photo, very close in time to 1343-25 and same scale;
1st Feb 2002	1353-90 / *GardenIslandSands_1stFeb2002_MGA55*	1500 dpi (2039 dpi) / 0.4 m pixel size	1:20,000	1.4 m [17]	Ortho-rectified by Chris Sharples
14th Feb 2002	1354-45 / *GardenIslandSands_14thFeb2002_MGA55*	1500 dpi (2039 dpi) / 0.4 m pixel size	1:20,000	0.97 m [15]	Ortho-rectified by Chris Sharples
25th Jan 2005	1390_234_op.ecw / *GardenIslandSands_25thJan2005_MGA55*	2039 dpi / 0.5m pixel size	1:42,000	1.50 m [17]	Ortho-rectified by NRE Poor accuracy at Garden Island sands compared to other 4 NRE orthos.
18th Feb 2008	1430_222_op.ecw /	2039 dpi / 0.5m pixel size	1:24,000	1.93m [16]	Ortho-rectified by NRE. Poor accuracy compared to more

	GardenIslandSands_18thFeb2008_MGA55			Crap accuracy in parts (up to 4 m errors)	recent NRE orthos at Garden Island Sands.
15th Dec 2009	1440-237 / *GardenIslandSands_15thDec2009_MGA55*	1500 dpi (2039 dpi) / 0.8 m pixel size	1:42,000	1.61m [15] Crap accuracy in parts (up to 3.1m errors)	Ortho-rectified by Chris Sharples
19th Mar 2012	1469-220 / *GardenIslandSands_19thMar2012_MGA55*	1500 dpi (2039 dpi) / 0.56 m pixel size	1:24,000	1.04m [15]	Ortho-rectified by Chris Sharples.
19th Dec 2015	Eggs_and_Bacon_Bay_19_12_2015.ecw / *GardenIslandSands_19thDec2015_MGA55*	n/a / 0.1m pixel size	1:400	Reference photo: 0.0m error by definition	Extensive area digital ortho-rectified image by NRE
25th Dec 2015	FranklinExtract_25-12-2015.ecw / *GardenIslandSands_25thDec2015_MGA55*	n/a / 0.1m pixel size	1:400	0.17 m [12]	Extensive digital ortho-rectified image by NRE – cropped to Garden Island Sands
10th Feb 2021	GardenIslandSands_10cm_2021.ecw / *GardenIslandSands_10thFeb2021_MGA55*	n/a / 0.1m pixel size		0.37 m [6]	Whole local area digital ortho-rectified image by NRE
End (as of July 2022)					

APPENDIX 2: SHORELINES DIGITISED

Table 4: Digitised shoreline shapefiles produced for Garden Island Sands Beach (using ortho-photos listed separately in Appendix One Table 3). All shapefiles listed in this table are geo-registered to the UTM Map Grid of Australia (MGA) co-ordinate system (Zone 55), based on the GDA94 datum.

Date of air photo(s)	**Shoreline shapefile**	**Shoreline digitised by**	**Comments**
General comments all dates: Shoreline positions interpolated beneath overhanging tree and shrub canopies (common throughout beach history) when reasonable to do so; strong tree shadows and seagrass wrack in some air photos also needed to be carefully differentiated from *in situ* vegetation. Actual shoreline (*in situ* vegetation line) was easy to pick in some photos, difficult in others.			
15th Dec. 1948 (air photo 171-143)	GardenIslandSands_MGA55_19481215.shp	Chris Sharples (2022)	Limited photo contrast and detail. Little overhanging trees or shadows.
2nd Mar. 1949 (air photo 182-2)	GardenIslandSands_MGA55_19490302.shp	Chris Sharples (2022)	Limited photo contrast and detail. Little overhanging trees or shadows.
4th Feb 1965 (air photo 435-63)	GardenIslandSands_MGA55_19650204.shp	Chris Sharples (2022)	Lots of tree shading over beach, confusing in parts, but generally veg line (shoreline) is fairly distinct. Some beach scarping avoided.
21st Jan 1966 (air photo: 456-106)	GardenIslandSands_MGA55_19660121.shp	Chris Sharples (2022)	Some beach shadow (not too much); shoreline (veg line) fairly distinct along east half of beach, more difficult to pick along western half due to overhanging veg.
18th Feb 1967 (air photo: 489-162)	GardenIslandSands_MGA55_19670218.shp	Chris Sharples (2022)	Lots of shadows on beach, difficult to pick actual vegetation line in most areas. Visually anomalous plot – shoreline not used
18th April 1972 (air photo: 601-52)	GardenIslandSands_MGA55_19720418.shp	Chris Sharples (2022)	Lots of tree shadows on beach and prominent beach scarp. With these features accounted for, shoreline (veg. line/foredune scarp) is moderately clear along much of beach.
31st Jan.1975 (air photo: 665-41)	GardenIslandSands_MGA55_19750131.shp	Chris Sharples (2022)	Tree shadows on beach; parts of shoreline distinct but some difficult to pick. Beach scarp avoided.
4th Mar 1977 (air photo 719-125)	GardenIslandSands_MGA55_19770304.shp	Chris Sharples (2022)	Some tree shadows on beach, most of shoreline (veg. line) fairly distinct.
6th Jan 1979 (air photo: 772-197)	GardenIslandSands_MGA55_19790106.shp	Chris Sharples (2022)	Shadows from west prominent, not much shadow on main beach. However, shoreline difficult to pick along most of beach, and plot is anomalous. Shoreline not used.
14th Feb. 1980 (air photo: 817-126)	GardenIslandSands_MGA55_19800214.shp	Chris Sharples (2022)	Lots of beach shadows, shoreline (veg. line) position fairly clear in most areas
3rd Feb 1981 (air photo 867-167)	GardenIslandSands_MGA55_19810203.shp	Chris Sharples (2022)	Long tree shadows on beach, shoreline (veg. line) position fairly clear in most areas.
13th Feb 1981 (air photo 870-121)	GardenIslandSands_MGA55_19810213.shp	Chris Sharples (2022)	Short westerly tree shadows on beach. Shoreline difficult to pick on this photo. Visually anomalous plot – shoreline not used .
20th Feb 1981 (air photo 872-168)	GardenIslandSands_MGA55_19810220.shp	Chris Sharples (2022)	Seagrass wrack lines on beach, long tree shadows on beach. Shoreline clear in some areas, not others.
10th Feb 1982 (air photo 904-189)	GardenIslandSands_MGA55_19820210.shp	Chris Sharples (2022)	Seagrass wrack lines on beach, long tree shadows on beach. Shoreline clear in some areas, not others.

4th Mar 1982 (air photo 917-211)	GardenIslandSands_MGA55_19820304.shp	Chris Sharples (2022)	Shoreline position clear in most areas (prominent fresh erosion scarp) despite tree shadows and canopies.
14th Jan 1984 (air photo 978-199)	GardenIslandSands_MGA55_19840114.shp	Chris Sharples (2022)	Shoreline position fairly clear in most areas.
29th Oct 1985 (air photo 1042-221)	GardenIslandSands_MGA55_19851029.shp	Chris Sharples (2022)	Shoreline position fairly clear in most areas (prominent fresh erosion scarp).
30th Sept 1987 (air photo 1092-136)	GardenIslandSands_MGA55_19870930.shp	Chris Sharples (2022)	Shoreline detectable in parts, extrapolated in many places through tree canopies and shadows.
15th Dec 1988 (air photo: 1124-60)	GardenIslandSands_MGA55_19881215.shp	Chris Sharples (2022)	Shoreline position fairly clear in many areas, resolution a bit poor but OK.
25th Jan 1989 (air photo: 1128-162)	GardenIslandSands_MGA55_19890125.shp	Chris Sharples (2022)	No much shadow on beach, shoreline position reasonably clear.
22nd Jan 1990 (air photo: 1148-65)	GardenIslandSands_MGA55_19900122.shp	Chris Sharples (2022)	Shoreline position hard to pick in part, reasonably clear elsewhere.
14th Feb 1990 (air photo: 1150-186)	GardenIslandSands_MGA55_19900214.shp	Chris Sharples (2022)	Shoreline position reasonably clear in most areas. .
2nd Jan 1991 (air photo: 1162-121)	GardenIslandSands_MGA55_19910102.shp	Chris Sharples (2022)	Lots of shadow on the beach, however shoreline (veg. line) mostly fairly easy to map.
14th Nov 1991 (air photo: 1173-95)	GardenIslandSands_MGA55_19911114.shp	Chris Sharples (2022)	Coarse resolution, not much shadow on beach, but overhanging canopies obscure shoreline. Shoreline (veg. line) fairly clear along a large portion of beach.
10th Jan 1995 (air photo: 1228-125)	GardenIslandSands_MGA55_19950110.shp	Chris Sharples (2022)	Colour, shoreline (veg. line) distinct along much of beach. GOOD reliable shoreline
23rd Feb 1996 (air photo: 1249-157)	GardenIslandSands_MGA55_19960223.shp	Chris Sharples (2022)	Colour, Lots of shadow but shoreline (veg. line) distinct along much of beach. Large amounts of seagrass wrack on beach.
13th Dec 1996 (air photo 1256-30)	GardenIslandSands_MGA55_19961213.shp	Chris Sharples (2022)	Lots of shadow but shoreline (veg. line) distinct along much of beach.
9th Jan 1998 (air photo: 1285-12)	GardenIslandSands_MGA55_19980109.shp	Chris Sharples (2022)	Beach partly shadowed by trees; shoreline hard to pick in many areas fairly distinct in some parts.
9th Jan 2001 (air photo: 1343-25)	GardenIslandSands_MGA55_20010109.shp	Chris Sharples (2022)	Much of shoreline is fairly distinct, shadows on beach fairly easy to pick.
1st Feb. 2002 (air photo: 1353-90)	GardenIslandSands_MGA55_20020201.shp	Chris Sharples (2022)	Colour, fairly clear shoreline (veg. line). But poor error margin and anomalous plot – shoreline not used.
14th Feb. 2002 (air photo 1354-45)	GardenIslandSands_MGA55_20020214.shp	Chris Sharples (2022)	Colour. Good shoreline visibility in some areas, poor in a few.
25th Jan 2005 (air photo 1390_234_op.ecw)	GardenIslandSands_MGA55_20050125.shp	Chris Sharples (2022)	Poor quality photo, but shoreline distinct in most sections, interpolated elsewhere.
18th Feb 2008 (air photo 1430_222_op.ecw)	GardenIslandSands_MGA55_20080218.shp	Chris Sharples (2022)	Shoreline distinct in some sections, interpolated elsewhere.
15th Dec 2009 (air photo 1440-237)	GardenIslandSands_MGA55_20091215.shp	Chris Sharples (2022)	Shoreline mostly distinct, not much shadowing.
19th Mar 2012 (air photo: 1469-220)	GardenIslandSands_MGA55_20120319.shp	Chris Sharples (2022)	Most of shoreline visible with high confidence.
19th Dec. 2015 (air photo: Eggs_and_Bacon_Bay_19_12_2015.ecw)	GardenIslandSands_MGA55_20151219.shp	Chris Sharples (2022)	Reference air photo. Shoreline extrapolated between good visible sections – much obscured by tree canopies and shadows.

			East end accreting adjacent estuarine lagoon mouth.
25th Dec 2015 (air photo: FranklinExtract_25-12-2015.ecw)	GardenIslandSands_MGA55_20151225.shp	Chris Sharples (2022)	Much of shoreline visible but also much obscured by tree canopies and shadows. Considerable incipient foredune expansion obvious adjacent estuarine lagoon mouth.
10th Feb 2021 (air photo: GardenIslandSands_10cm_2021.ecw)	GardenIslandSands_MGA55_20210210.shp	Chris Sharples (2022)	Much of shoreline obscured by tree canopies and shadows, Extrapolated between visible sections.
25th Aug. 2022 (Field surveyed)	GardenIslandSands_MGA55_20220825.shp	Elliott Cromer & Chris Sharples 25th Aug. 2022	Scarp position (along scarp crest) captured with GNSS by Elliott Cromer (i.e., field-surveyed, not derived from aerial photography, but the feature mapped is the same feature that was digitised from ortho-photos in every other shapefile listed in this table). This is a very accurate shoreline position (error margin <10mm).

APPENDIX 3: EXTRACTION OF SHORELINE BEHAVIOUR INFORMATION AND HISTORIES FROM AIR PHOTO TIME SERIES

This appendix provides some additional information about the air photo shoreline history methods described briefly in section 3.4.1 and applied in section 3.4.2 of this report. The example figures used in this appendix are from Roches Beach (south-east Tasmania), however the same methods were used to analyse the Garden Island Sands Beach air photo information. These methods were developed by the writer and colleagues at the University of Tasmania, including Dr Michael Lacey (who wrote the *Shoreline History* Python script to measure shoreline positions along multiple shore-normal transects) and Dr Christopher Watson (assistance with *Matlab*™ scripting).

Repeated vertical aerial photography since 1948 has been a key source of shoreline behaviour data for this study. A time series comprising every available photo of adequate photogrammetric quality was used. All aerial photography used has been geo-referenced and ortho-rectified, mostly by the writer using *Landscape Mapper*™ software and ground control points identified on an existing reference ortho-photo. This and several other air photos were already available as ortho-photos previously prepared by NRE (details of all air photos used are provided in Appendix 1). Photogrammetric position error margins for each ortho-rectified air photo were quantified by measuring and taking the average of the apparent displacement of 10 or more well-defined fixed reference features visible on each air photo from their positions on the selected reference photo (identified in Appendix 1).

On each ortho-photo, the seawards vegetation limit (or line) was digitised as the shoreline position proxy (Boak & Turner 2005) for that date (see Figure 31 below). With a shoreline position digitised as a roughly shore-parallel line for each date, the landwards or seawards movement of the shoreline between consecutive air photo dates was interpolated along regular 25-metre-spaced shore-normal digital transects (Figure 32, LHS, note in this example 100m spaced transects used for Roches Beach). Each transect plot was normalised for comparison between transects by plotting shoreline positions along each transect relative to the median shoreline position on that transect (e.g., Figure 32, upper RHS). Groups of transects showing coherent behaviour over time were grouped into a single summary plot for each such shoreline section by plotting the medians of all transect shoreline positions at each air photo date (e.g., Figure 32, lower RHS; Figure 33).

The resulting shoreline history plots were analysed for long-term behaviour trends using a combination of visual inspection and linear regression analysis (to assess the numerical probability of apparent trends being real). Three simple types of long-term shoreline behaviour trend were identified in the data, namely linear shoreline position stability, progradation or recession trends. Some real and apparent variability around each linear trend was expected as a result of factors including short-term erosion and accretion cycles, erosion scarp slumping and air photo ortho-rectification errors.

Given the expected real shoreline position variability and the limited frequency of air photos, it was considered problematical to attempt to identify trends of greater complexity than linear (such as 2nd order polynomial trends). The measured air photo error margins were important to the analysis as 'reality checks' on identified shoreline behaviour trends and were used both for visual evaluation of apparent trends and also for numerical error-weighted linear trend analysis. For example, if a possible long-term linear recession or progradation trend exhibits less overall shoreline position change (landwards or seawards) than the scale of most of the air photo error margins, then it is not demonstrated to be a real trend. Conversely an apparent trend involving significantly greater shoreline position change than the air photo error margins is more likely to be a real trend.

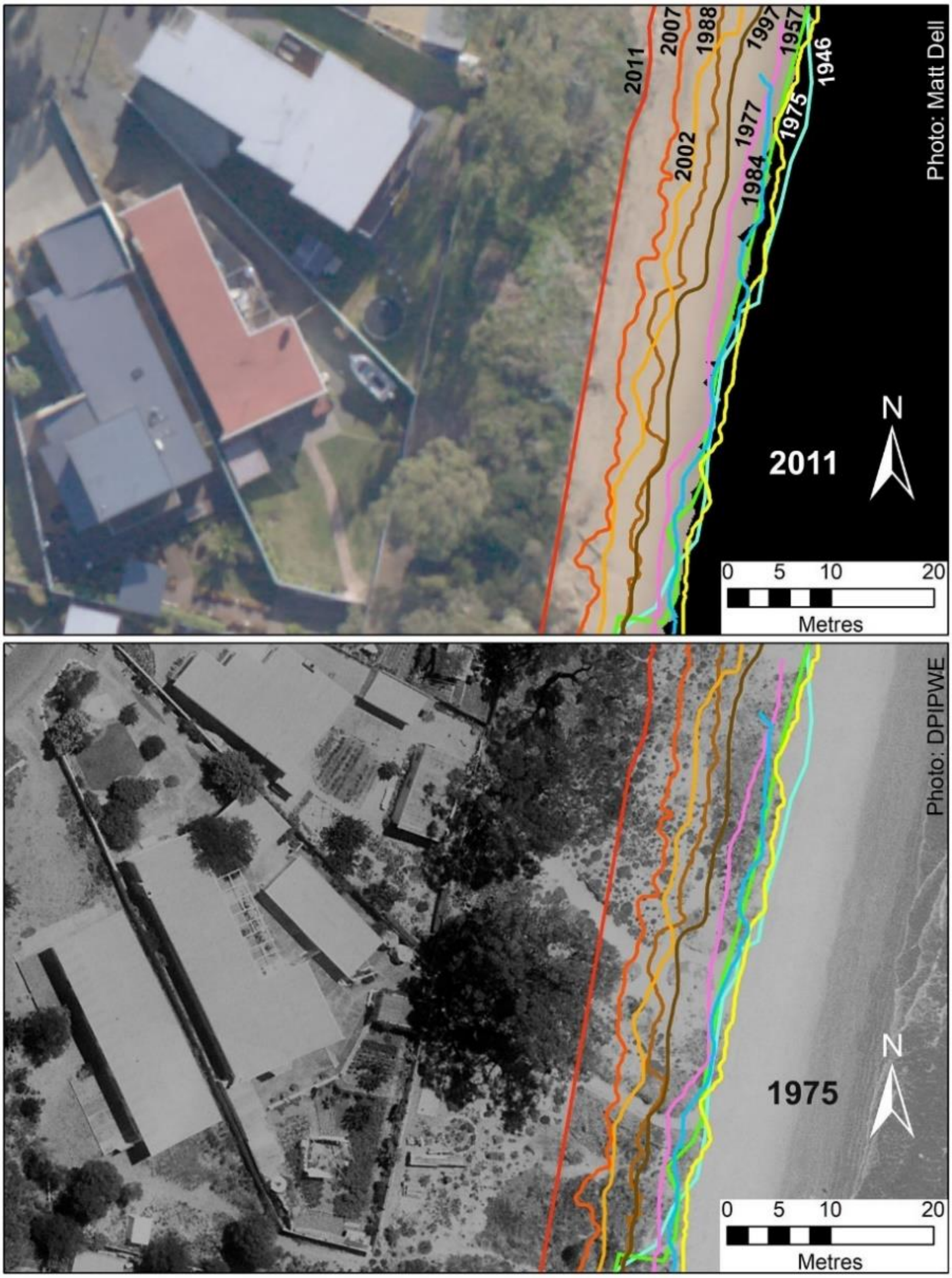

Figure 31: Example of a selected sequence of digitised shoreline positions at Roches Beach (Tasmania) from a time series of ortho-rectified air photos from 1946 to 2011, demonstrating how the vegetation line used as the shoreline proxy tracks shoreline change. The air photos used to digitise the 1975 and 2011 shorelines are shown to illustrate the shoreline position change between 1975 and 2011. Note that while the vegetation lines shown demonstrate an overall recession trend after 1984, they also demonstrate a shorter period of foredune accretion (shoreline progradation) within that period. More detail of shoreline position change is seen when all 30 air photo dates available for this section of shoreline are used (see Figure 33).

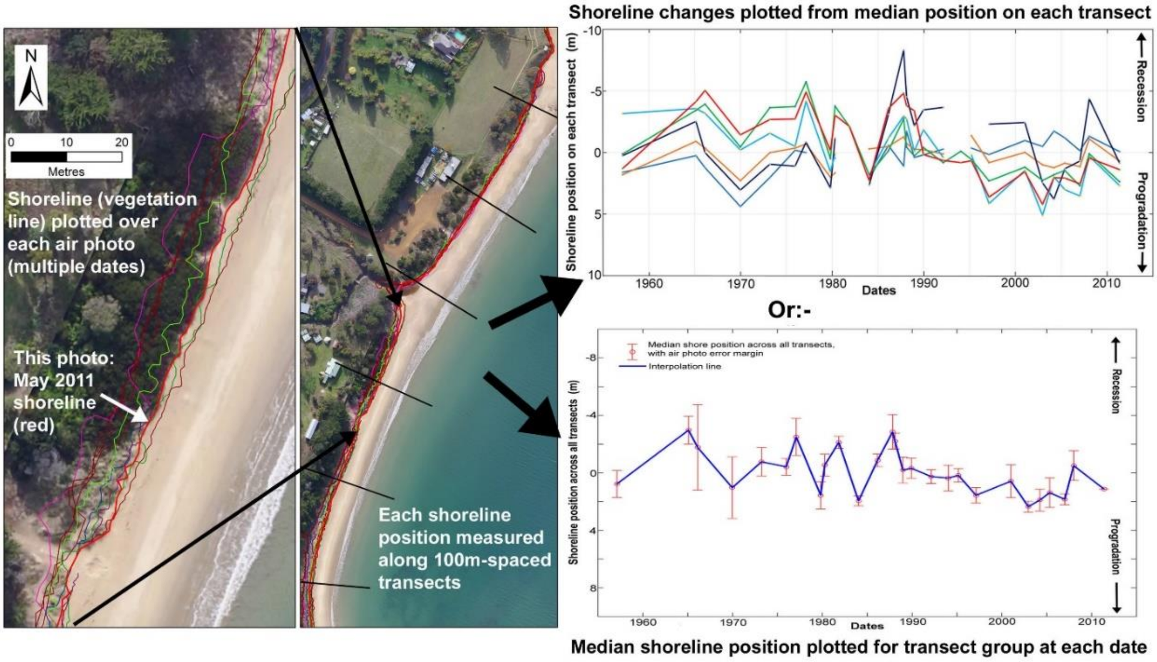

Figure 32: Figure illustrating the extraction of beach behaviour data from a time series of 27 aerial photo dates for Roches Beach North. This figure shows two ways of plotting the shoreline behaviour of Roches Beach N., which has undergone cyclic erosion and recovery events over a 50-year period with an essentially stable or slightly prograding underlying long-term trend. Shoreline position changes with time can be plotted along each transect within the beach section for individual comparison (top plot), or the median shoreline position at each date across all transects can be plotted to yield a summarised shoreline behaviour plot for the whole beach section (bottom plot).

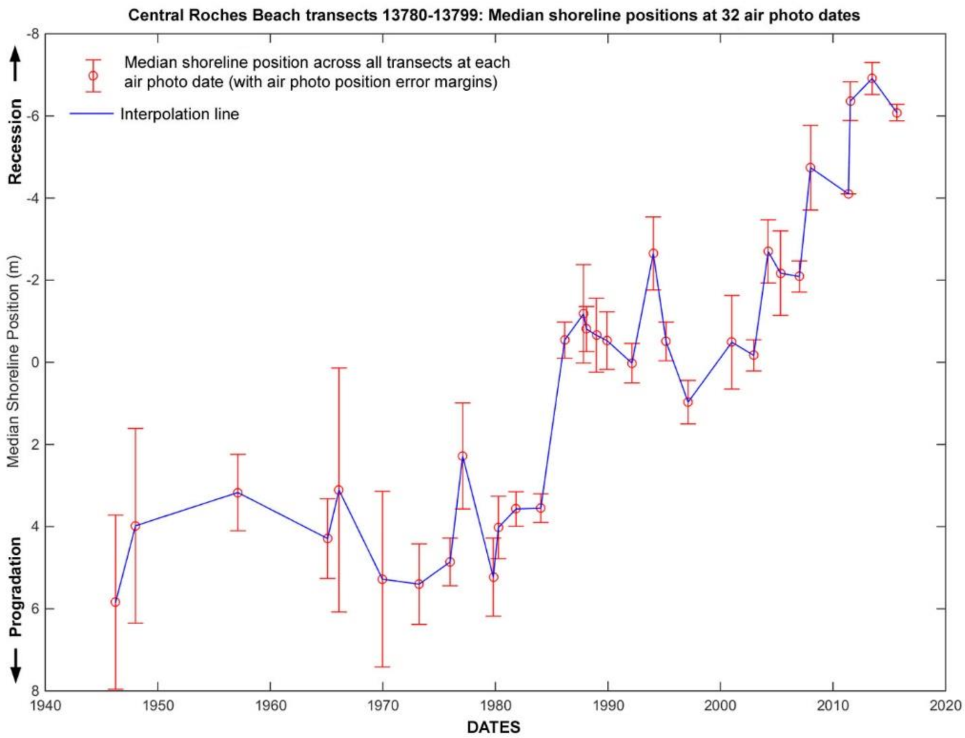

Figure 33: This summary plot of the median shoreline position at each of 32 air photo dates across 21 transects shows a marked long-term change of shoreline behaviour in the central (main) part of Roches Beach. The beach was essentially stable for over 30 years prior to 1985, with some erosion and accretion episodes around a roughly stable shoreline position. After 1985, the beach showed a markedly changed behaviour trend for 26 years to 2011, comprising a dominant recession trend much larger than the air photo error margins, with some partial recovery episodes but never full recovery to the pre-1985 shoreline position. This behaviour trend ceased after a large erosion event during 2011 because the local government began artificially replenishing the dune and beach face, so that subsequent beach behaviour can no longer be considered as a natural geomorphic response.

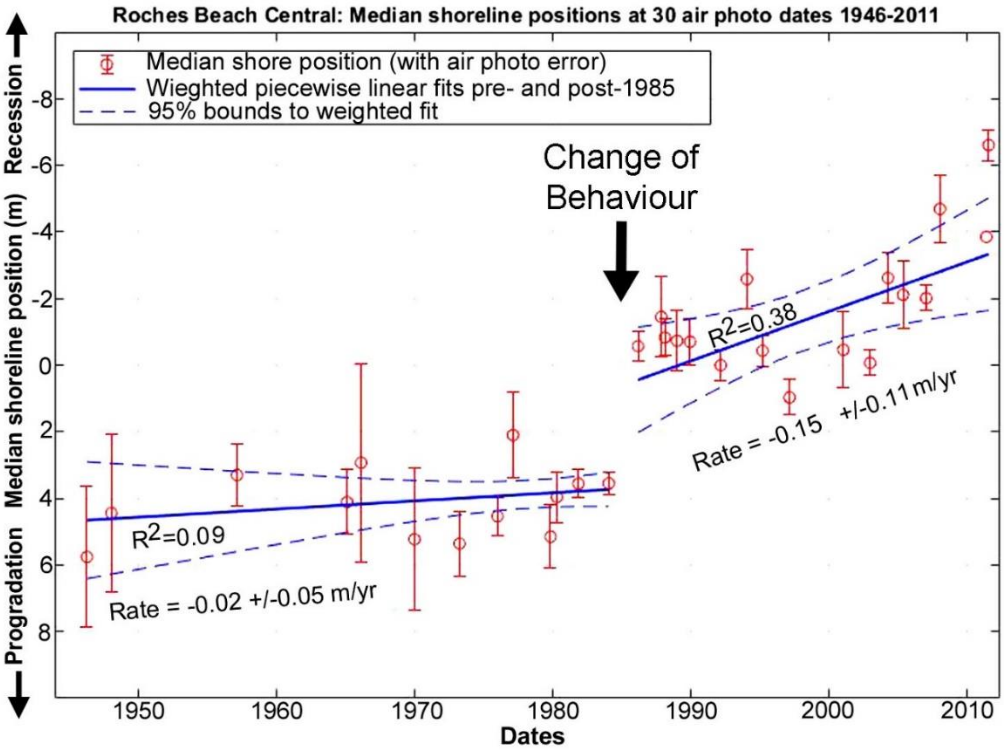

Figure 34: Shoreline history for Roches Beach central section (transects 13780 – 13801 except 13798). Median shoreline position across all used transects at each of 30 air photo dates (1946-2011), showing air photo position error bars at each date. Piecewise linear fits around 1985 shown weighted by error margin, with 95% bounds to weighted fit indicated.

At Roches Beach North, a single linear shoreline behaviour trend was identified over the whole air photo period (circa 65 years; see Figure 32 RHS). This demonstrates a stable or possibly slightly prograding long-term linear trend over the whole air photo period, with inter-annual variability of greater amplitude than the majority of error margins and thus inferred to be real shoreline position variability. The short-term variability at this site is most likely mainly a result of episodic beach erosion and recovery cycles.

By contrast, visual inspection of the shoreline behaviour plot for the main central part of Roches Beach at Figure 33 is strongly suggestive of a switch circa 1985 from a long – term (multi-decadal) stable trend to a long-term receding trend. In this case, piecewise linear regression (before and after 1985) was used to verify the statistical significance (Pearson correlation co-efficient) of the two trends, together with an error-weighted piecewise regression to further verify the validity of the apparent switch in shoreline behaviour (see Figure 34).

The use and limitations of vegetation line as shoreline proxy

Boak and Turner (2005) identified at least 16 types of shoreline features that could be mapped as proxies for the shoreline position. This study has used one of these, the seawards *in situ* vegetation line, for two main reasons, namely:

1. The vegetation line is generally a reliable indication of shoreline recession or progradation because under most circumstances it moves seawards in response to coastal accretion and progradation and landwards in response to erosion and recession. Hence, changes in the position of the vegetation line over time provide the type of shoreline behaviour history information this study has required, namely information on long-term shoreline trends of recession, stability or progradation.

2. The vegetation line is generally a high-contrast feature which can be readily mapped even on photos of relatively poor resolution and contrast, which is often the case for older air photos. Hence using this proxy allows the usable air photo time series to be extended to the earliest dates possible. This proxy may be mappable on older photos of poorer quality that may not support determination of some other shoreline proxies such as those based on specific contours or digital elevation models created from stereo air photos. The vegetation line may thus provide valid shoreline position data at more dates than some other methods can achieve.

The main limitation of using the vegetation line as a proxy for shoreline position change is that although it moves landwards in an effectively instantaneous manner during erosion events, there is generally a time lag before new vegetation establishes sufficiently to be visible on prograding shores (Boak & Turner 2005; Hanslow 2007). In addition, vegetation line position may be affected by other processes unrelated to sea-levels and wave erosion, including dune deflation and artificial disturbances (Hanslow 2007).

In regard to lag times in vegetation recovery and seawards growth, these are typically of the order of several months to several years. However, given that some of the time gaps between air photos used in this study are of a similar scale, and in addition that this study has been focussed on identifying long-term trends (10 years +) rather than analysing short-term (e.g., annual or inter-annual) variability in beach behaviour, the issue of vegetation growth lag times is unlikely to have significantly affected the main results obtained by this study.

Use of the vegetation line as a shoreline position proxy may also be subject to uncertainties such as operator error in digitising the position of the line. This particular uncertainty was minimised by only one operator digitising the shorelines used for this project using a consistent method. Beyond this, the use of a photogrammetric error margin (as described above) arguably captures the most important spatial uncertainty for the analyses undertaken, albeit more sophisticated uncertainty analyses can be applied (e.g., see Fletcher et al. 2011, p. 18).

APPENDIX 4: TASMARC SURVEY PROFILES

"TASMARC" is the TAsmanian Shoreline Monitoring and ARChiving project. This is a beach monitoring project which commenced in 2004 as a project of the Antarctic Climate and Ecosystems Co-operative Research Centre (ACE-CRC) at the University of Tasmania. The project is based on community "citizen science" groups surveying beach profiles at intervals, with the data being processed and made available for open public access at www.tasmarc.info. Section 3.3 of this report provides beach and dune profile plots surveyed across Garden Island Sands for this project, together with discussion of these. This appendix documents the survey data, which is expected to provide the starting point for monitoring the beach and dune condition into the future.

Four TASMARC survey markers were established at Garden Island Sands Beach on the 12th of August 2022 by Chris Sharples and Nick Bowden. These were located on the back (landwards) slope of the main foredune and their locations are shown on Figure 35 below, as well as in Cromer (2023, Attachment 3); the latter reference also provides photographic documentation of each survey marker. Nick Bowden and Chris Sharples then surveyed a profile along a transect running seawards (perpendicular or "normal" to the shoreline) from each marker. The profiles run across the foredune and beach surface to the lowest seawards point accessed on the beach. The data (survey measurement) records for these first and (at the time of writing) only surveyed profiles undertaken on 12th August are provided below in this appendix. The plots drawn from these surveys are provided in report, section 3.3 (Figure 17).

The position of each survey marker was subsequently surveyed to ±50 millimetres accuracy on 25th August 2022 by Elliott Cromer using the State Permanent Marker (SPM) network. These high-resolution survey marker positions are tabulated in Table 5 below and in Cromer (2023, Attachment 3).

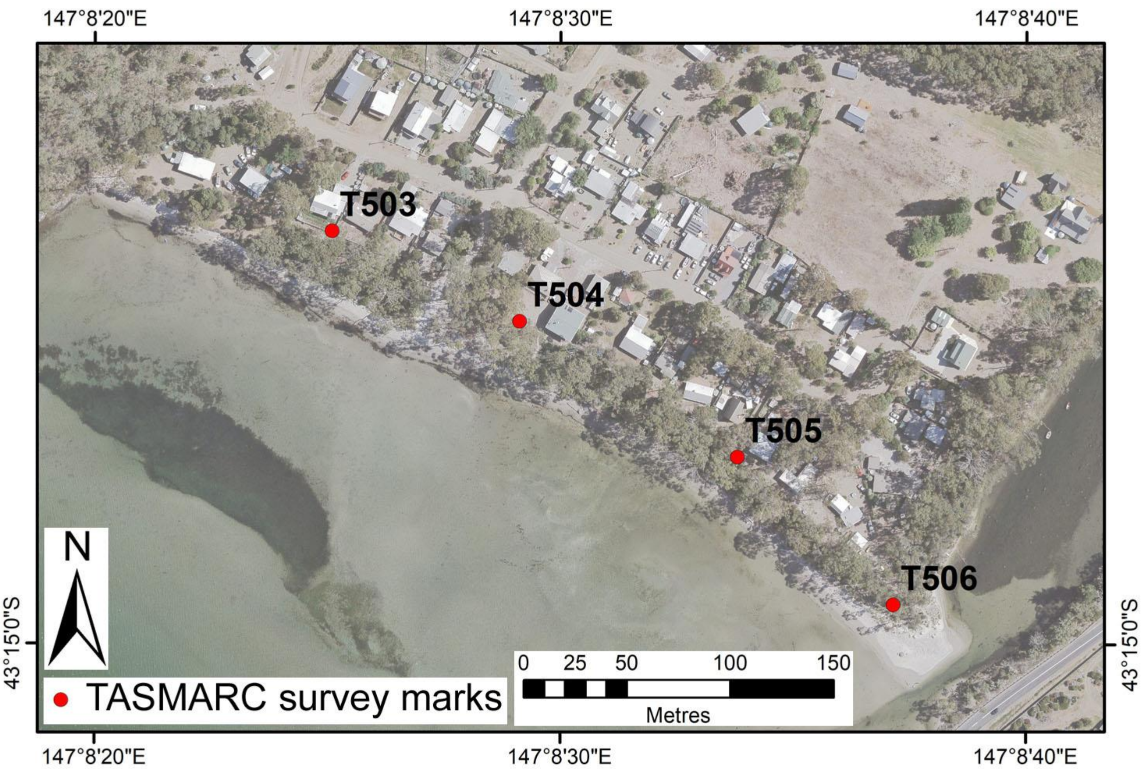

Figure 35: TASMARC survey mark positions at Garden Island Sands Beach. Each survey marker is a treated pine post embedded securely in the ground with a stainless-steel screw in the top of the post indicating the precise surveyed marker position. The survey transects extend seawards from the marks, normal (perpendicular) to the shoreline. Background image is the 19th of December 2015 air photo (© NRE).

Table 5: GNSS-surveyed co-ordinates of each TASMARC transect survey mark at Garden Island Sands. The survey marks are located at the landwards end of each transect, which runs seawards normal to the shoreline from each mark. The eastings and northings are metric co-ordinates of the Universal Transverse Mercator Map Grid of Australia Zone 55 (MGA55, GDA2020 datum).

Transect	Easting	Northing
T503	511389.856	5211612.855
T504	511480.624	5211569.065
T505	511585.965	5211503.179
T506	511661.358	5211431.634

Data Sheets for first transect profiles surveyed at Garden Island Sands Beach

The following four datasheets provide the survey data for the original TASMARC profiles surveyed on 12th August 2022 at Garden Island Sands Beach. These were measured normal (perpendicular) to the shoreline on each transect from the survey marker over the foredune and down the beach as far as practical on the day (i.e., to close to the water edge at the time surveyed).

Datasheet for 12th August 2022 survey based on Survey Marker T503

FORMAT VERSION 3.0
SITE NAME Garden Island Sands
SURVEY MARK T503
OBSERVERS Nick Bowden Chris Sharples
LATITUDE
LONGITUDE
EASTING 511389.856
NORTHING 5211612.855
HORIZONTAL DATUM GDA2020
UTM ZONE 55
VERTICAL DATUM AHD-TAS83
HEIGHT 2.77
START DATE/TIME 2022/08/12
END DATE/TIME 2022/08/12
TIME ZONE HOURS 10
TRUE BEARING TRANSECT DEGREES 200
SURVEY METHOD Total station
INSTRUMENT DESCRIPTION Topcon GTS-303
LEVEL MISCLOSURE MM
CREATION DATE 2022/11/13
#
IDENTITY PLATE T503
SURCOM ID
#
COLUMN 1 Horizontal distance from survey mark (m)
COLUMN 2 Vertical height above datum (m)
COLUMN 3 how-to-use flag (2 = use columns 1 and 2 (i.e. a levelling measurement),
1 = use column 1 only (i.e. a tape measurement or a comment)
0 = don't use data (i.e. erroneous data))
COLUMN 4 etc. any comments on this location (words separated by spaces;
if more than one word, all comment enclosed in quotes)
#
The perceived high water mark is indicated as follows:

#
<Start of line> <horizontal distance> <vertical height> 2 HWM
#
T503 is an stainless steel screw in the top of a square treated pine post
Coordinates of T503 determined by RTK GPS on 22/08/2022
#
SPM7504 adopted as coordinate and height origin
MGAE 512302.138 MGAN 5212334.085 AHD-TAS83 7.32
#
If/when it is necessary to establish a new mark, it is given a new ID.
It is always situated on an extension of the transect, at or landward
of the original SURVEY MARK. The horizontal distance in COLUMN 1 is,
however, always relative to the original SURVEY MARK.
#
0 2.77 2 T503
0.10 1.85 2
3.08 1.92 2
6.24 2.37 2
10.72 2.28 2
13.93 2.29 2
16.30 2.57 2
18.66 2.68 2
22.23 2.66 2
22.41 2.26 2
22.89 1.95 2
23.55 1.40 2
24.52 1.14 2
26.97 0.94 2
31.40 0.67 2
36.12 0.27 2

Datasheet for 12th August 2022 survey based on Survey Marker T504
FORMAT VERSION 3.0
SITE NAME Garden Island Sands
SURVEY MARK T504
OBSERVERS Nick Bowden Chris Sharples
LATITUDE
LONGITUDE
EASTING 511480.624
NORTHING 5211569.065
HORIZONTAL DATUM GDA2020
UTM ZONE 55
VERTICAL DATUM AHD-TAS83
HEIGHT 3.17
START DATE/TIME 2022/08/12
END DATE/TIME 2022/08/12
TIME ZONE HOURS 10
TRUE BEARING TRANSECT DEGREES 215
SURVEY METHOD Total station
INSTRUMENT DESCRIPTION Topcon GTS-303
LEVEL MISCLOSURE MM
CREATION DATE 2022/11/13
#
IDENTITY PLATE T504

SURCOM ID
#
COLUMN 1 Horizontal distance from survey mark (m)
COLUMN 2 Vertical height above datum (m)
COLUMN 3 how-to-use flag (2 = use columns 1 and 2 (i.e. a levelling measurement),
1 = use column 1 only (i.e. a tape measurement or a comment)
0 = don't use data (i.e. erroneous data))
COLUMN 4 etc. any comments on this location (words separated by spaces;
if more than one word, all comment enclosed in quotes)
#
The perceived high water mark is indicated as follows:
#
<Start of line> <horizontal distance> <vertical height> 2 HWM
#
T504 is an stainless steel screw in the top of a square treated pine post
Coordinates of T503 determined by RTK GPS on 22/08/2022
#
SPM7504 adopted as coordinate and height origin
MGAE 512302.138 MGAN 5212334.085 AHD-TAS83 7.32
#
If/when it is necessary to establish a new mark, it is given a new ID.
It is always situated on an extension of the transect, at or landward
of the original SURVEY MARK. The horizontal distance in COLUMN 1 is,
however, always relative to the original SURVEY MARK.
#
0 3.17 2 T504
0.10 2.16 2
4.85 2.15 2
9.41 2.28 2
12.28 2.43 2
12.90 2.31 2
13.10 1.14 2
15.48 0.90 2
22.30 0.30 2

Datasheet for 12th August 2022 survey based on Survey Marker T505
FORMAT VERSION 3.0
SITE NAME Garden Island Sands
SURVEY MARK T505
OBSERVERS Nick Bowden Chris Sharples
LATITUDE
LONGITUDE
EASTING 511585.965
NORTHING 5211503.179
HORIZONTAL DATUM GDA2020
UTM ZONE 55
VERTICAL DATUM AHD-TAS83
HEIGHT 3.14
START DATE/TIME 2022/08/12
END DATE/TIME 2022/08/12
TIME ZONE HOURS 10
TRUE BEARING TRANSECT DEGREES 210
SURVEY METHOD Total station
INSTRUMENT DESCRIPTION Topcon GTS-303

LEVEL MISCLOSURE MM
CREATION DATE 2022/11/13
#
IDENTITY PLATE T504
SURCOM ID
#
COLUMN 1 Horizontal distance from survey mark (m)
COLUMN 2 Vertical height above datum (m)
COLUMN 3 how-to-use flag (2 = use columns 1 and 2 (i.e. a levelling measurement),
1 = use column 1 only (i.e. a tape measurement or a comment)
0 = don't use data (i.e. erroneous data))
COLUMN 4 etc. any comments on this location (words separated by spaces;
if more than one word, all comment enclosed in quotes)
#
The perceived high water mark is indicated as follows:
#
<Start of line> <horizontal distance> <vertical height> 2 HWM
#
T505 is an stainless steel screw in the top of a round treated pine fence post
Coordinates of T503 determined by RTK GPS on 25/08/2022
#
SPM7504 adopted as coordinate and height origin
MGAE 512302.138 MGAN 5212334.085 AHD-TAS83 7.32
#
If/when it is necessary to establish a new mark, it is given a new ID.
It is always situated on an extension of the transect, at or landward
of the original SURVEY MARK. The horizontal distance in COLUMN 1 is,
however, always relative to the original SURVEY MARK.
#
0 3.14 2 T505
0.10 1.74 2
4.18 1.89 2
7.93 1.84 2
10.48 1.96 2
13.36 1.96 2
13.36 0.84 2
14.26 0.81 2
17.15 0.53 2
20.46 0.17 2

Datasheet for 12th August 2022 survey based on Survey Marker T506
FORMAT VERSION 3.0
SITE NAME Garden Island Sands
SURVEY MARK T506
OBSERVERS Nick Bowden Chris Sharples
LATITUDE
LONGITUDE
EASTING 511661.358
NORTHING 5211431.634
HORIZONTAL DATUM GDA2020
UTM ZONE 55
VERTICAL DATUM AHD-TAS83
HEIGHT 3.12
START DATE/TIME 2022/08/12

```
# END DATE/TIME 2022/08/12
# TIME ZONE HOURS 10
# TRUE BEARING TRANSECT DEGREES 235
# SURVEY METHOD Total station
# INSTRUMENT DESCRIPTION Topcon GTS-303
# LEVEL MISCLOSURE MM
# CREATION DATE 2022/11/13
#
# IDENTITY PLATE T505
# SURCOM ID
#
# COLUMN 1 Horizontal distance from survey mark (m)
# COLUMN 2 Vertical height above datum (m)
# COLUMN 3 how-to-use flag (2 = use columns 1 and 2 (i.e. a levelling measurement),
#                     1 = use column 1 only (i.e. a tape measurement or a comment)
#                     0 = don't use data (i.e. erroneous data))
# COLUMN 4 etc. any comments on this location (words separated by spaces;
# if more than one word, all comment enclosed in quotes)
#
# The perceived high water mark is indicated as follows:
#
# <Start of line> <horizontal distance> <vertical height> 2 HWM
#
# T506 is an stainless steel screw in the top of a square treated pine post
# Coordinates of T505 determined by RTK GPS on 25/08/2022
#
# SPM7504 adopted as coordinate and height origin
# MGAE 512302.138 MGAN 5212334.085 AHD-TAS83 7.32
#
# If/when it is necessary to establish a new mark, it is given a new ID.
# It is always situated on an extension of the transect, at or landward
# of the original SURVEY MARK. The horizontal distance in COLUMN 1 is,
# however, always relative to the original SURVEY MARK.
#
0 3.12 2 T506
0.10 2.28 2
2.74 2.15 2
2.84 1.68 2
4.67 1.63 2
6.59 1.84 2
8.35 2.11 2
10.74 2.05 2
11.52 1.72 2
11.61 1.08 2
14.51 0.72 2
17.52 0.41 2
```