ANALYSES OF BEACH AND NEARSHORE PROFILES AND SHORELINE MAPPING FROM HISTORICAL IMAGERY, ROBE SOUTH AUSTRALIA

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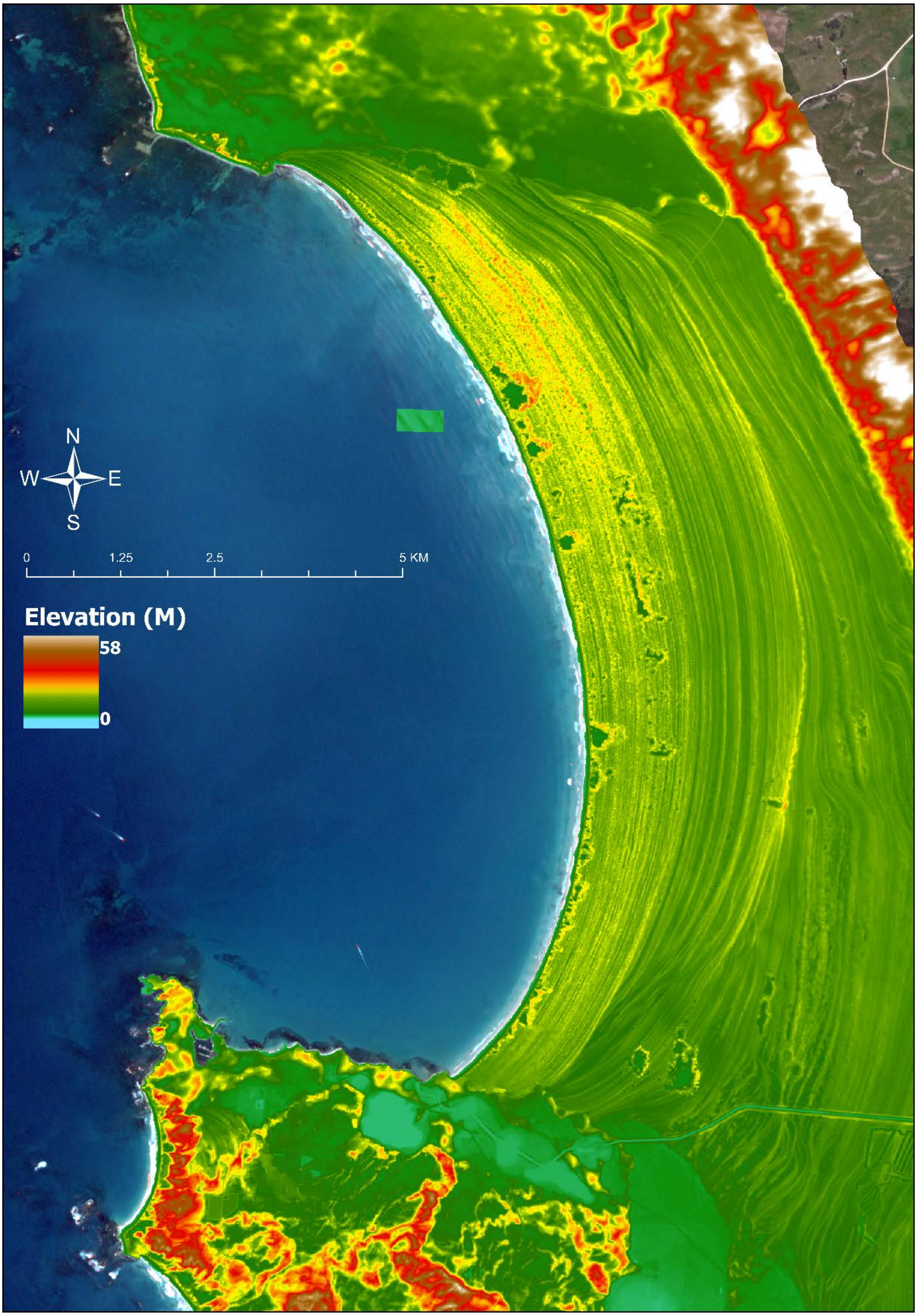

ANALYSES OF BEACH AND NEARSHORE PROFILES AND SHORELINE MAPPING FROM HISTORICAL IMAGERY, ROBE SOUTH AUSTRALIA

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INTRODUCTION

This study examines the historical changes to beaches and cliffs in the Robe DC region utilising oblique and vertical aerial photography, satellite imagery, and Department of Environment and Water (DEW) topographic and bathymetric profile data.

CLIMATE AND OCEANOGRAPHY

The region is exposed to some of the world's largest waves in the Southern Ocean (Hemer *et al*., 2008; Hemer and Griffin 2010), with deep-water waves commonly exceeding 5 meters (Short, 1988). Wave measurements at Cape du Couedic on Kangaroo Island, (295 km NW from the study site), show an annual average significant wave height of 2.7 m, with a 12 s period and a predominant primary swell direction coming from the Southwest quadrant (Hemer *et al*., 2008). Seasonal changes in swell direction are minimal, with a tendency of slightly more westerly swells occurring in winter (higher waves), and more southernly swells occurring in summer (smaller waves) according to Hemer *et al.* (2008). SWAN modelling completed for the Cape Jaffa Marina EIS indicates that swell waves up to 4m in height could enter Guichen Bay, although the shallow nearshore gradient and variable presence of reefs would likely reduce waves of this height reaching the Robe area beaches (Figures 1 and 2).

The tidal regime for the region is micro-tidal (0.8m) and semi-diurnal.

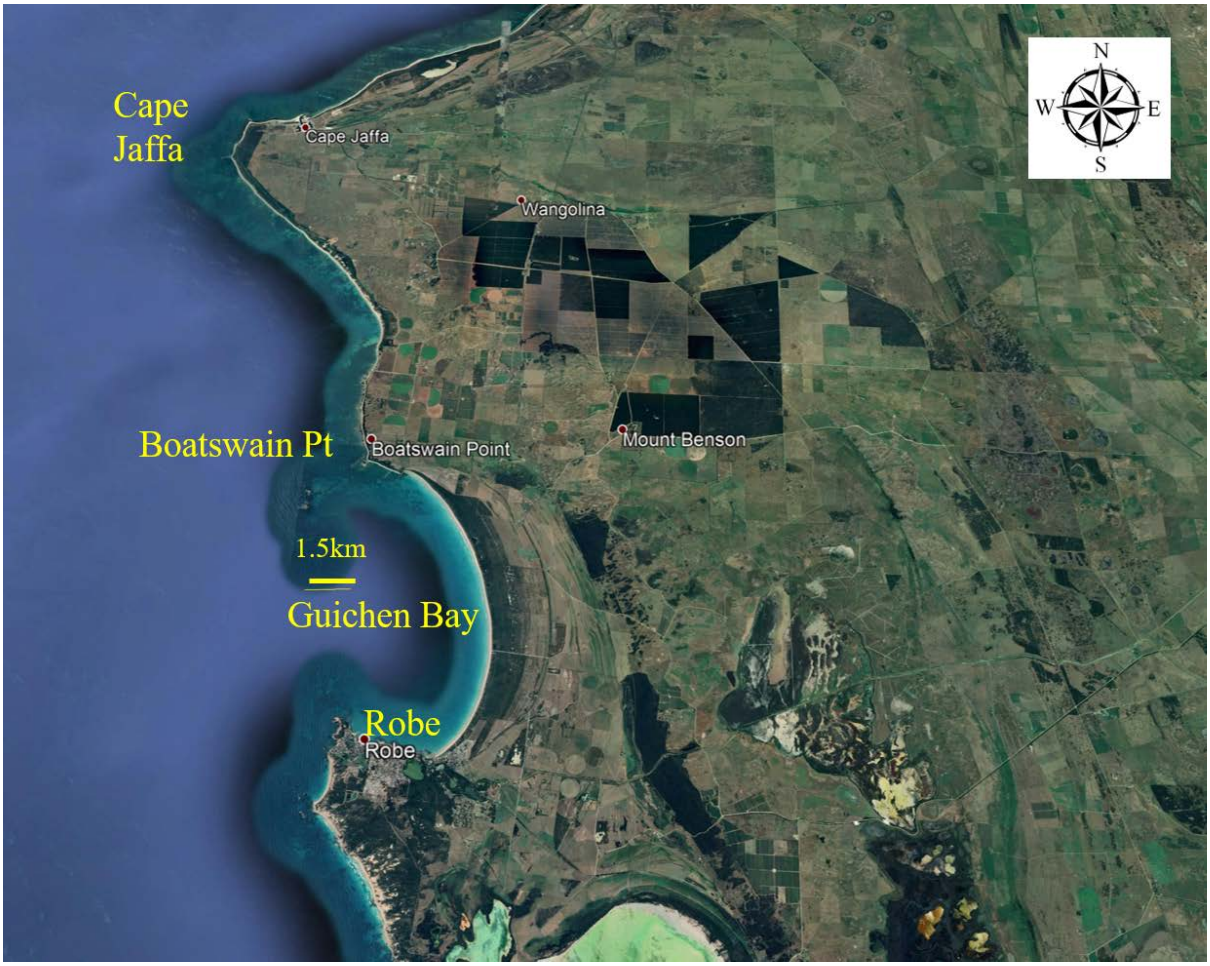

Figure 1: Robe and adjacent region.

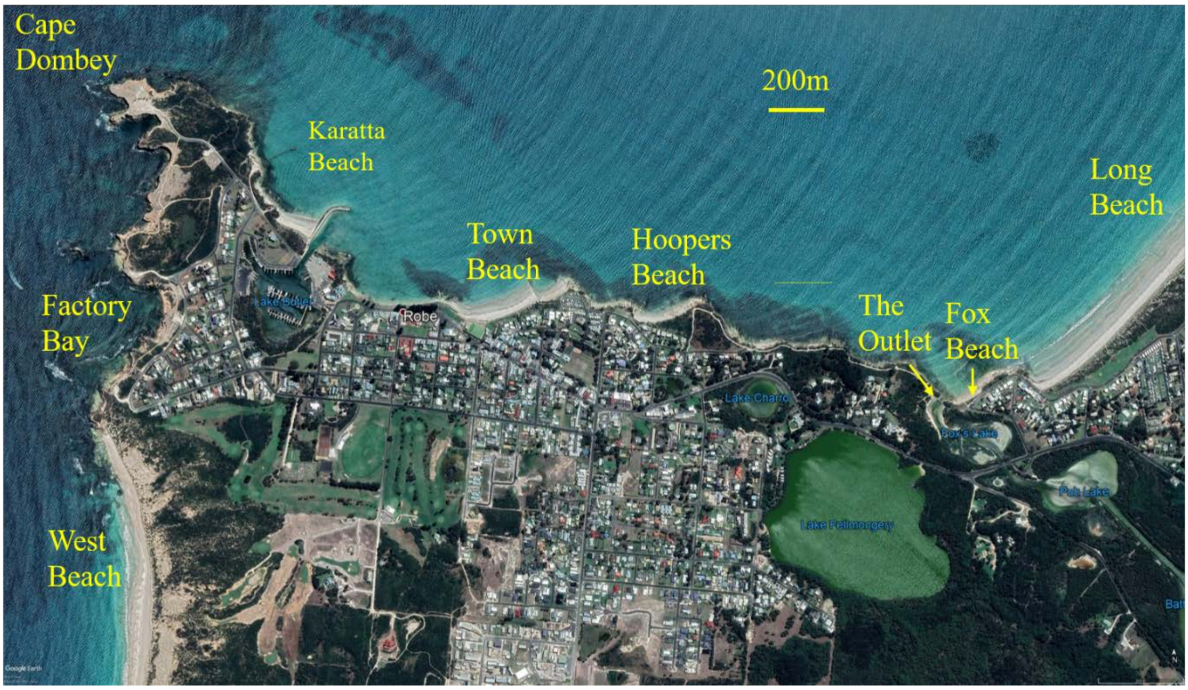

Figure 2: Robe township beaches and locations cited in the text.

Data from the meteorological station at Cape Jaffa (~25km north of Robe; Figure 1), shows that the Robe region is subjected to winds from the S to SW quadrant (Figure 3a), comprising 45.5% of the total winds in the region with an average wind speed of 7 ms^{-1}. Although southerly winds are most prevalent (11.95% of the occurrences), winds from SSW (9.20%), SW (8.17%), WSW (7.57%) and W (7.48%) are also common and have a high potential for aeolian sediment transport (Figure 3b). Northerly winds are also frequent (8.6%) but have a lower transport potential (Figure 3b) than winds from the previously mentioned directions. Using methods in Fryberger and Dean (1979) as modified by Miot da Silva and Hesp (2010), it is possible to determine the aeolian (wind blown) potential for sediment transport for each wind direction and produce a sand rose (Figure 3b). The threshold velocity (V_t) for sand transport was determined based on the mean grain size of the study area following methods in Miot da Silva *et al*. (2012) and is 6.35 ms^{-1}. From this analysis the net aeolian sediment transport resultant (i.e. aeolian transport amount in vector units and direction) may be calculated. The net vector transport direction is to the NE (Figure 3b).

GEOLOGY AND GEOMORPHOLOGY OF THE ROBE REGION

The Robe region displays a complex geomorphology characterised by Pleistocene (last 2 million years to 10ka) limestone coastal barriers forming cliffs, reefs, islands and dune systems, and Holocene (~10,000 years to present) coastal barriers and dune systems.

The Murray Basin and Coorong to Mount Gambier coastal plain contains a massive sequence of coastal barriers (locally termed 'ranges'), the oldest of which dates back to the Pliocene (Idnurm and Cook, 1980). These barriers were each formed at high sea level events roughly occurring every hundred thousand years, and comprise coastal dune systems separated by inter-barrier depressions and plains (Sprigg, 1979; Murray-Wallace et al., 1999).

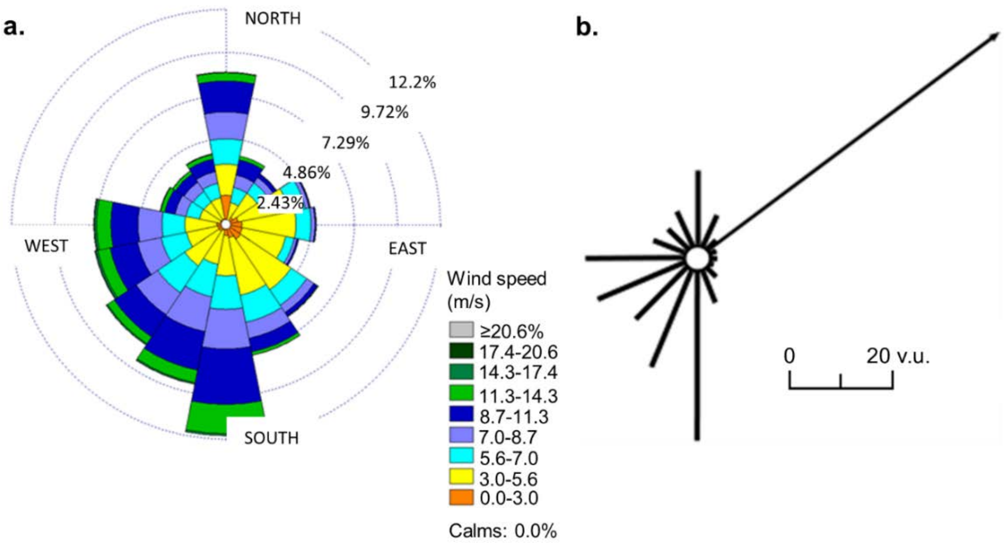

Figure 3: (a) Wind rose and (b) Sand rose (based on m sec^{-1} data) for the study area, where the arrow indicates the aeolian sediment transport resultant. (Wind data from Cape Jaffa Meteorological Station - 1991 to 2017 - Bureau of Meteorology [2017]).

Pleistocene Coastal Systems

The immediate backbone to the Robe region locally is an extensive coastal barrier comprising transgressive dunefields. This lithified (cemented) aeolian calcarenite (wind blown, cemented, calcareous sands) dune system known as the Woakwine Range, was formed around 120,000 years ago during the previous high sea level event – the Last Interglacial (Huntley et al., 1993; Huntley et al., 1994; Murray-Wallace et al., 1999; Figure 4).

Following this high sea level event, sea level began to fall, and as it did so, new dunes were formed which blew landwards forming the Robe Range. This coastal barrier has also been lithified to form a aeolian calcarenite (limestone) system which dominates the coast along the Robe to Beachport coast and beyond. The Robe Range formed several km seawards of the Woakwine Range and an extensive interbarrier depression was formed between the Robe and the older Woakwine Range.

The Robe Range is a complex barrier system comprising at least two older units termed Robe II and Robe III (Schwebel, 1984). Robe II is ~80,000 years old (formed when sea level approximately at -19m below present sea level), while Robe III is considered to be around 100,000 years old when sea level was ~11m below present sea level (Schwebel, 1984; Huntley et al., 1994; Banerjee et al., 2003). Excellent views of some of the dune units and interleaved buried soils of the Robe Range may be found at Cape Dombey on the walk to the Obelisk.

Holocene Coastal Systems

As sea level rose from around -120m below present sea level (psl) ~18,000 years ago to the present level, beaches and dunes would have formed, been eroded, and reformed as the sea rose across the former exposed shelf. Winds would have transported eroding dunes landwards ahead of the rising sea level. When sea level was ~ -20 to -30m below psl, it is likely that

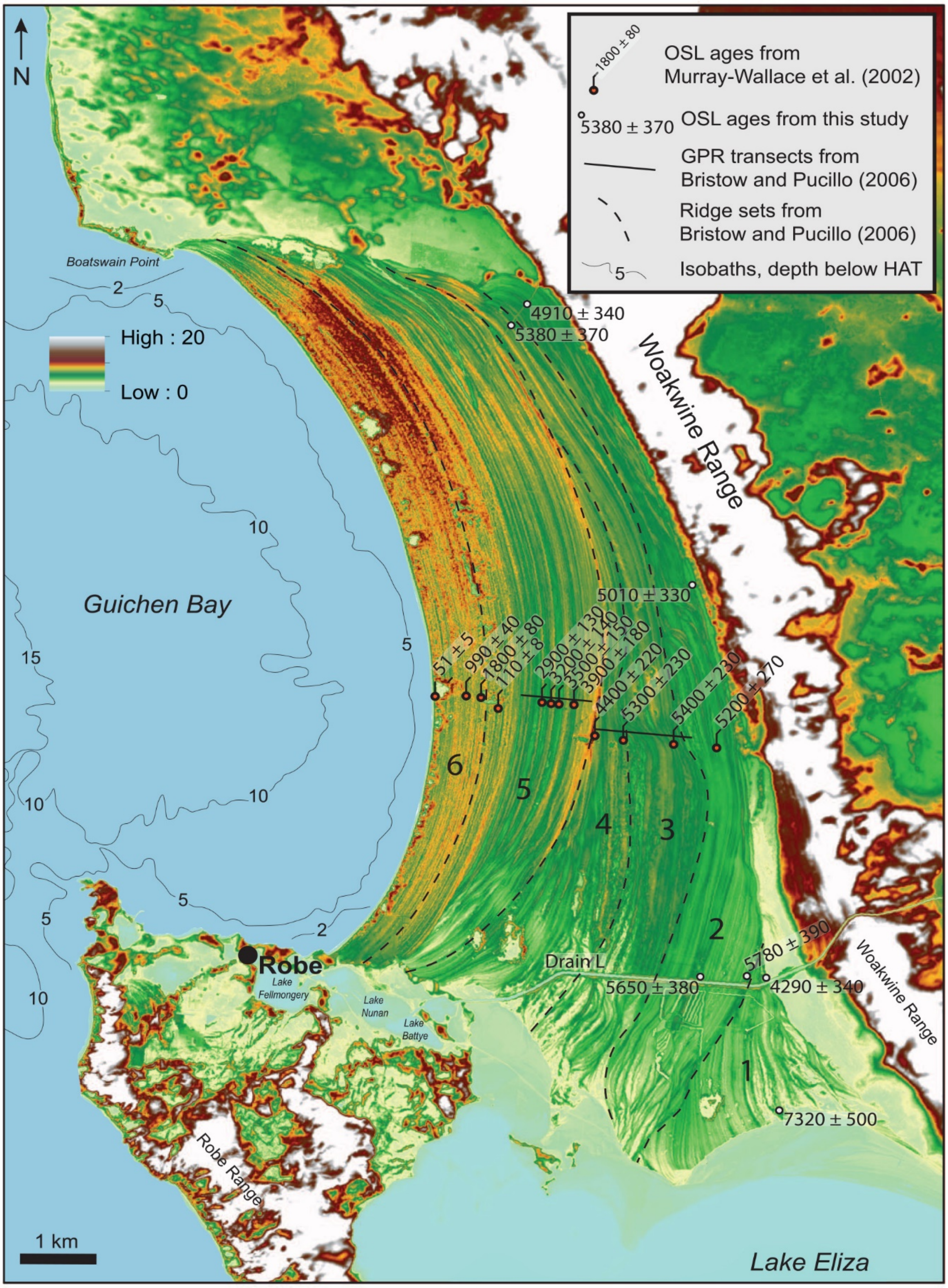

Figure 4: LiDAR digital elevation model of Guichen Bay, Robe and adjacent areas. The Last Interglacial Woakwine Range coastal barrier and post-Last Interglacial/Interstadial Robe Range coastal barrier are also indicated. The interbarrier depression lying between the Woakwine and Robe ranges is occupied by Lakes Charra, Felmongery, Fox's, Pub, Noonan, Battye, and Eliza. Ages of the Guichen Bay foredune ridges are also shown (Source: Oliver et al., 2020).

some of the dunes would have migrated landwards onto the Robe Range and formed climbing dunes over that range. These are termed Robe I dunes by Schwebel (1984), and the oldest dune sediments are around 10,000 years old (Figure 4).

As sea level continued to rise to the present level and beyond (up to ~ +1.3 – 1.5m above psl), waves eroded the Robe Range limestones and formed cliffs, islands and reefs, most of which are still eroding today.

The interbarrier depression lying between the Robe and the Woakwine ranges and between Robe and Beachport was flooded by the rising sea level around ~7,500 years Before Present (BP). It was open to the sea at both ends and this protected marine environment lasted until about 4000 years ago at the Robe end (when foredune progradation in Guichen Bay blocked the entrance), and 2000 years ago at the SE end, when sedimentation caused it to be sub-divided into multiple lakes including Lakes Robe, Eliza, St. Clair, and George (Cann et al., 1999; Murray-Wallace, 2018; Figure 4).

The Robe Range originally extended from Cape Thomas to Cape Dombey across the mouth of Guichen Bay (Figure 5). During the latter part of the recent sea level transgression (sl rise), this portion of the Robe Range was breached and/or flooded by the Holocene transgression and rising sea level around pre-8000 years ago. Guichen Bay was formed as a result, and a significant coastal barrier was formed in the bay.

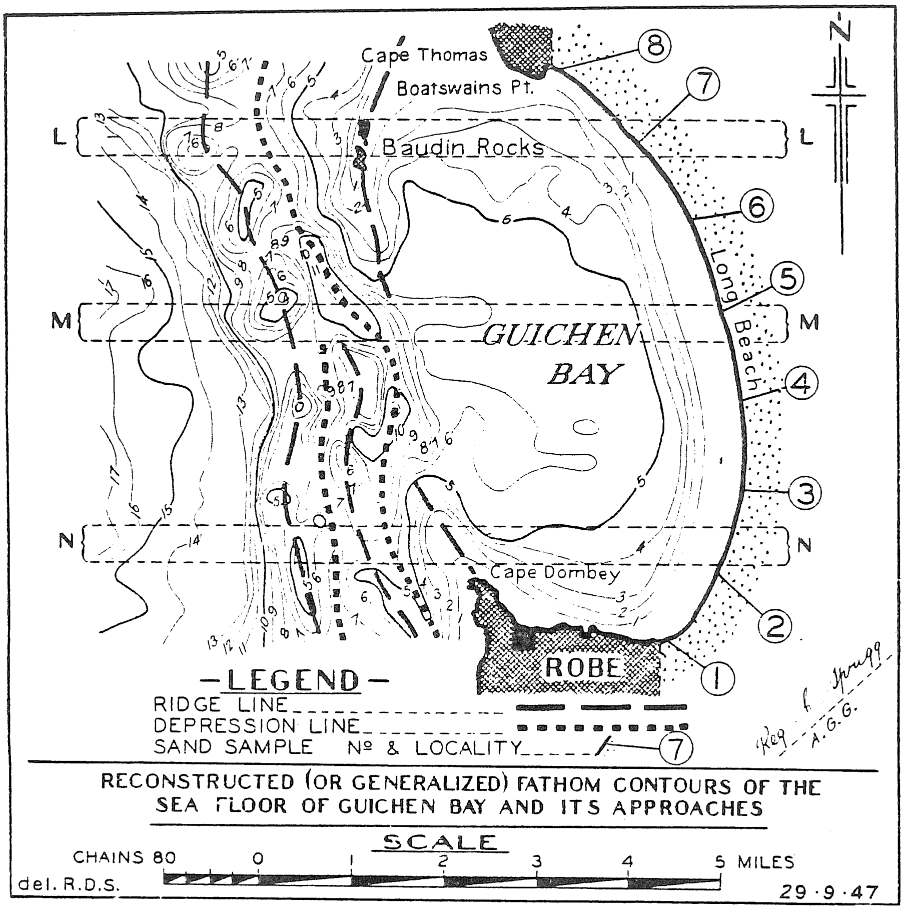

Figure 5: Guichen Bay bathymetry map (in fathoms) drawn in 1947 and produced in Sprigg (1952). Note the complex submerged Robe range barrier extending across the mouth of Guichen Bay.

Guichen Bay is ~8.5km long and faces into the west. The coastal barrier comprises a relict foredune plain fronted by a modern, active foredune formed along the backshore of Long Beach (Figure 4). Foredunes are formed by aeolian sand deposition in pioneer plants growing on the backshore (Hesp, 2002). The Guichen Bay foredune plain has therefore been formed by the continuous formation of foredunes over time (Figure 4). The sediment forming this extensive coastal plain was derived from erosion of the Robe Range cliffs and reefs and also supplied from shelf sediments (Short, 2020).

The coastal barrier is ~5km wide at its widest and there are approximately 90 foredune ridges forming the foredune plain (also known as a 'beach ridge plain'). The first beach formed around 7,500 to 8,000 years B.P. and in the 7,500 to 4000 years B.P. the plain prograded rapidly. One new foredune ridge was added on average every 80 years at least from about 4,000 years B.P. ago to the present (Thom et al., 1981; Murray-Wallace et al., 2002; Bristow and Pucillo, 2006; Oliver et al., 2020; Figure 4). Sea level rose to around +2m above psl at ~ 3,500 years BP according to Oliver et al. (2020), and then fell, reaching the present sea level around 1000 years ago. Bristow and Pucillo (2006) estimated that the sediment supply into the bay was between 40,000 and 50,000 m^3 $year^{-1}$, and that rate has remained consistent from around 5000 years ago to the late Holocene.

The Guichen Bay barrier terminates in the northwest near Boatswain point. The coast then trends WNW at this point to Cape Thomas, and then north towards Aram Cove (Figure 4). The Holocene coastal barrier along this strip is very narrow and comprises a modern small active foredune, one or two relict foredune ridges, and a relict blowout. From Cape Thomas to the north, and then to the NW to Cape Jaffa there are several small cuspate forelands (or salients) which show slight changes over time perhaps indicating SSE to NNW sediment transport.

The Cape Jaffa to Kingston coastal segment in the southern portion of Lacepede Bay is characterised by a prograded barrier similar to Guichen Bay, but narrower. The barrier comprises a 3km wide suite of spits and low foredune ridges. These have been formed over the same 8,000 year period that the Guichen bay barrier and foredune ridge plain was formed.

Significant sediment transport occurs along the low energy, seagrass dominated coastal segment from Cape Thomas to Cape Jaffa and further alongshore towards Kingston SE. Short (2020) indicates that the sediment transport rate is ~ 10,000 m^3/year given the buildup of sediment against the Cape Jaffa marina training wall (built in 2008).

The Coorong coastal plain is gradually uplifting over time, and the rate of uplift at Guichen Bay is 0.07 mm per year (Belperio, 1995; Murray-Wallace et al., 2002). However, global sea level has risen ~25cm since 1880. The present rate of sea level rise is 1.5–4 mm/year between 1965 and 2016 in South Australia (Green et al., 2018) depending on location, so even at the lowest rate of sl rise (1.5mm/year), the rate of uplift will only slightly slow the rate of sea level rise at Robe.

BEACH and CLIFF DYNAMICS OF THE ROBE REGION

Figure 6 shows the location of the DEW topographic/bathymetric profiles which are utilised in this study. Appendix 2 contains all the geo-rectified imagery used in this study in a separate file.

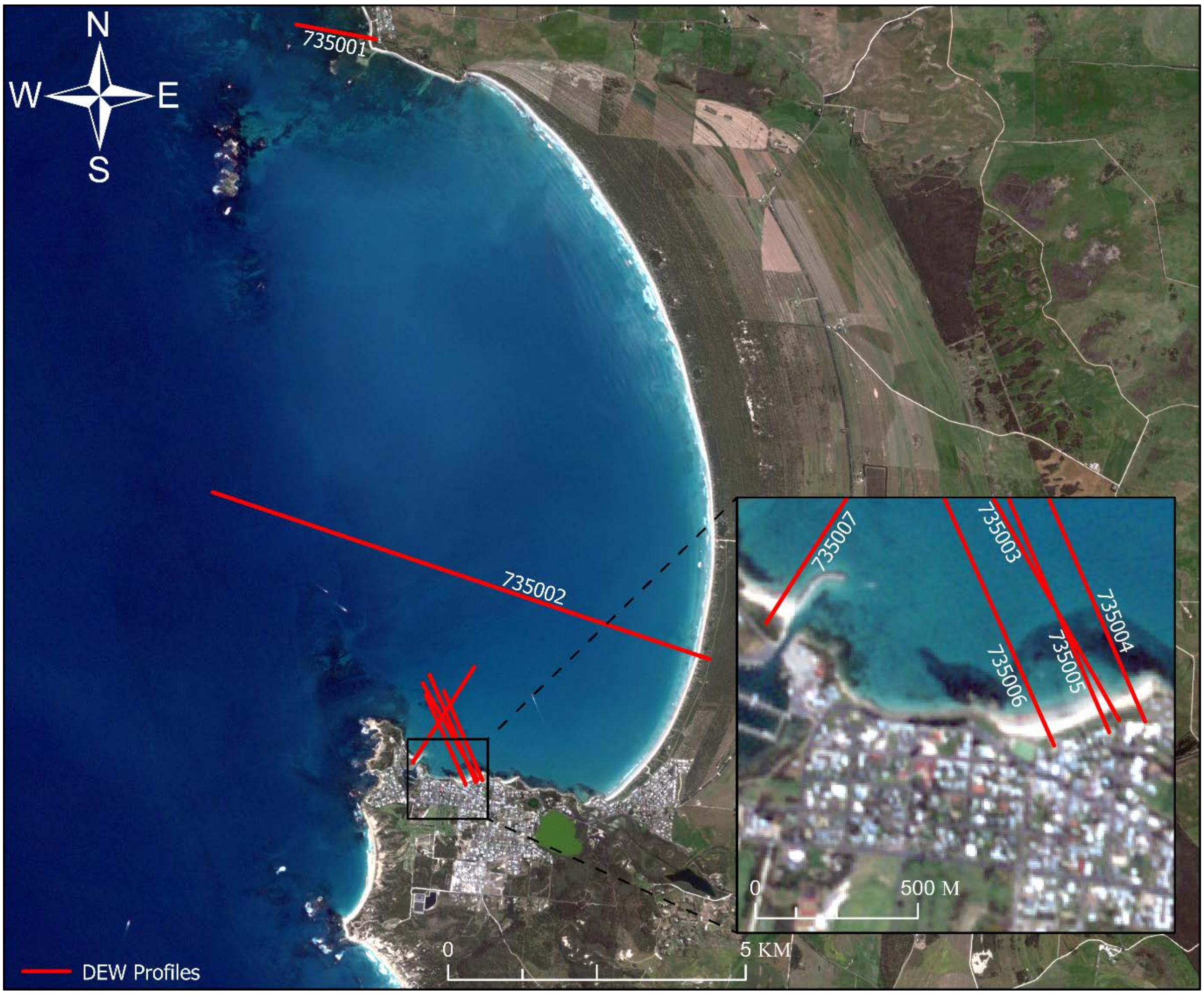

Figure 6: Location of the DEW topographic/bathymetric profiles.

West Beach

West Beach comprises a high energy sand and reef dominated surfzone, backed by an erosional foredune and vegetated and active parabolic dunes and blowouts. Figure 7 illustrates the dunefield in 1945 and shows that the dunefield was very active with multiple parabolic dunes, deflation basins and blowouts present. By 1975, the dunes were still largely active, but by 2020, they are now significantly stabilised, although multiple active blowouts and some parabolic dunes are still present.

Figure 8 illustrates shoreline change based on mapping the edge of vegetation between 1946 and 2019. The beach has been stable to slightly accretional over that period of time.

Figure 7: View across Robe in 1945 showing the active dunefield adjacent to West Beach.

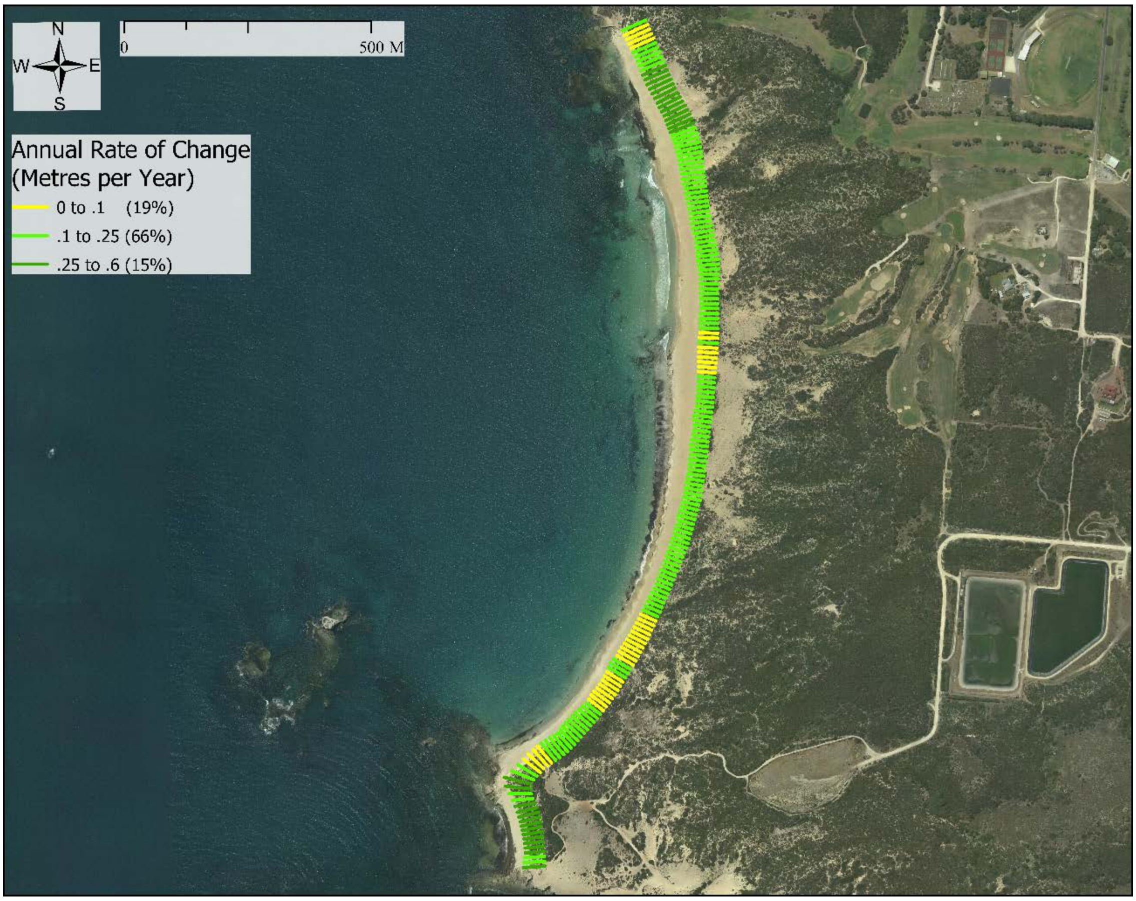

Figure 8: Shoreline change at West Beach from 1946 to 2019. The beach is stable to slightly accretional.

Cape Dombey and adjacent cliffs

The aeolian calcarenite limestone forming Cape Dombey and the adjacent area is relatively young (~100,000 to 80,000 years old), and while it is characterised by a very hard calcrete cemented surface, the majority of the aeolian calcarenite is relatively weak and quite erodible given the high wave energy environment which it faces. Wave cut notches, caves, pipes, and holes are common along this portion of the coast, and the extensive wave cut platforms testify to the extent of wave erosion that has occurred in the past 8-10,000 years.

Comparing the position of the old gaol in relation to the adjacent cliff line indicated on the 'Hundred of Waterhouse' survey map of 1896, and the 2018 Google Earth image, it appears the cliffs have retreated ~0.24m/year in the vicinity of the Obelisk.

Figure 9: Photographs of the Obelisk from around 1950 until April, 2018 showing the retreat of the aeolian calcarenite cliffs. The cliff seawards of the eastern base of the Obelisk was ~ 26.5m wide in 1950, and ~8m wide in 2018, a rate of erosion of 0.27 m/year.

The Obelisk was built in 1855, has a 5m x 5m base and is 12.2 m high, and provides an excellent fixed spot from which to reasonably measure cliff line change in a high energy section of the rocky coast at Robe. Fotheringham (2009) estimated that the Cape Dombey headland is eroding at rates ranging from 30 mm/year (exposed locations) to 2mm/year (sheltered locations). Figure 9 illustrates the retreat of the headland adjacent to the Obelisk, and indicates that the headland has lost about 60% of its length seawards of the Obelisk since 1950 (a rate of 0.9% per year).

If the erosion rate of 0.9%/year estimated from the photography in Figure 9 continues unabated, the Obelisk will likely fail around 2060. If the erosion rate is closer to 0.24m/year to 0.27 m/year as estimated from comparison of the 1896 historical survey map and the photography in Figure 9, then the Obelisk will fail in around 2047 – 2050.

Figure 10 illustrates the Obelisk in a vertical image taken on the 4th June 2020. It may be seen that the north and south facing margins of the Cape are narrower than the east facing portion, and the shortest distance to the southern edge of the Cape from the SE edge of the obelisk is only 1.92m. If these margins are eroded at the same rate as the east facing portion of the Cape, and fail first, then the Obelisk will likely fall in ~ 2028.

Figure 10: Vertical image of the Obelisk (base is 5m x 5m) taken on June 4th, 2020. Note the possible crack (arrowed) just 1.5m seawards of the eastern base.

Note that the erosion rate could actually increase with sea level rise and higher wave energy at the cliff base, and/or the cliff could fail sooner if the base is further undermined, the crack indicated in Figure 10 widens, or solution holes/pipes within the limestone lead to partial or total collapse.

The 1896 survey map of the 'Hundred of Waterhouse' Cape Dombey area shows that active drifting sands were present along the clifftops to the immediate south of Cape Dombey. These may have been naturally active, but it is as likely that human activities resulted in their activation, or at least contributed to it prior to 1896.

Karatta Beach

Karatta Beach is the westernmost beach of Robe township situated between the jetty and the Robe marina breakwater (Figure 2). Figure 11 illustrates the Karatta Beach- Lake Butler vicinity in 1869 and shows that it had what appears to be either a well developed foredune or older vegetated dunes at the time.

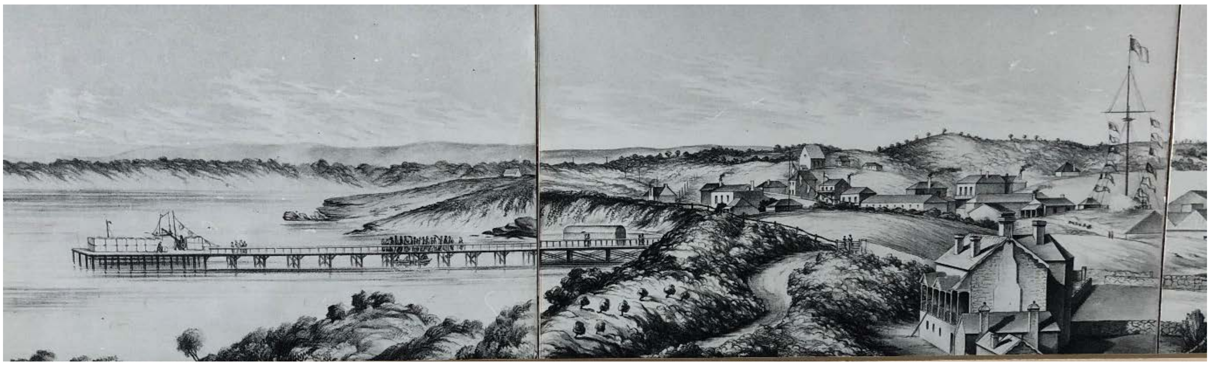

Figure 11: Lithograph created in 1869 of Karatta House, Karatta Beach, Lake Butler and vicinity.

The breakwater for the marina/harbour/Lake Butler was constructed in 1964 according to a brochure provided by the Robe Council (https://www.robe.sa.gov.au/__data/assets/pdf_file/0025/418345/The_Obelisk.pdf). The small bay beaches to the west of the breakwater have accreted since that time, indicating that sand was, and likely still is being transported into Guichen Bay by easterly flowing currents. Short and Hesp (1980) estimated that approximately 10,000 m^3 of sand had accumulated on the updrift western side of the breakwater since construction. The sediment may be being provided by the erosion of aeolianite reefs, the multiple shore rock platforms, and cliffs and stacks in the local area, as well as from biogenic production from reef and nearshore dwelling fauna. In 1976, Fotheringham (1976) reported that the beach had extended around 50m beyond a small headland which originally marked the eastern boundary.

Figure 12 illustrates four profiles at Karrata Beach extending from February, 1986 to March, 2016. In general, the beach is accreting and prograding. The 2016 profile is lower than the 2010 profile due to sand being removed for nourishment, and the impact of the 2016 storms. Note that there is likely a survey error around 10-20m distance on the 2010 profile. The beach prograded around 14m between 2016 and 2019 at the 0m AHD point.

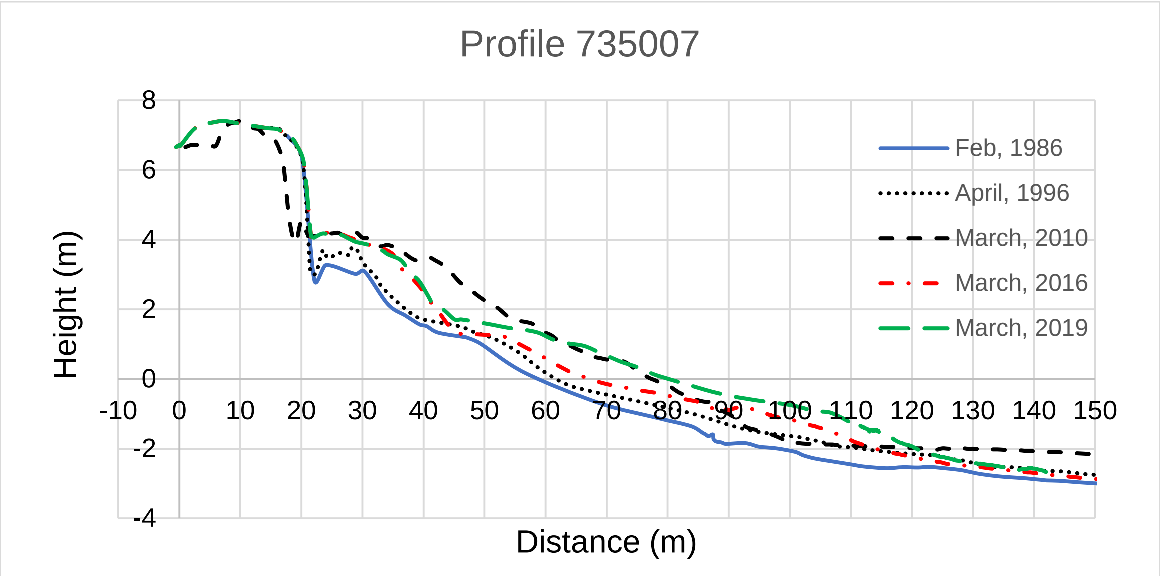

Figure 12: Four DEW profiles for Karatta Beach extending from 1986 to 2016.

Figure 13: Karatta Beach in 2019 with 1969 and 1978 shorelines indicating the edge of vegetation overlaid on the aerial imagery.

Figure 13 illustrates Karatta Beach in 2019 with the edge of vegetation plotted on that imagery from 1969 and 1978. The shoreline has significantly accreted or prograded to the east and west of the centre of the beach.

Town (aka Front) Beach

The beach/rocky shore that extends along the front of Mundy Terrace east of the marina breakwater to the eastern headland (Figure 2) has two names, Town Beach and Front Beach, and is hereafter referred to as Town Beach. Town Beach originally has a “row of sand-hills of sufficient height to exclude the view of the sea (Bermingham, 1961, p.28). A bathymetric chart of the Robe area produced in 1870-1871 shows that Town Beach was a sandy beach at the time in front of the old seawall (Short and Hesp, 1980). In 1874, the townsfolk removed the dunes fearing encroachment, and erected a seawall. Following this, the beach eventually disappeared and the seawall failed several times (Fotheringham, 1976). Figure 14 illustrates the wall in 1930, and shows that very little sand, if any, was present at the base of the wall at that time.

Figure 14: The Robe seawall in the 1930's.

Figure 15: Town Beach in 1945.

Figure 15 illustrates Town Beach in 1945 and it may be seen that the dune system is still relatively intact from the middle towards the NE portion of the bay, but very narrow and partially disturbed/removed in the western margin of the bay.

Fotheringham (1976) stated that sand nourishment was taking place in 1976 in front of Town Beach due to the coastal erosion occurring there. Due to the continuing erosion on the beach, a groyne was emplaced in the mid-1980's (R. Tucker pers. comm.), nourishment occurred (for example, recently in 2017), and a seawall and ramp was completed in March, 2019 to protect the western portion of the beach from further erosion.

Figure 6 indicates the locations of the DEW survey profiles surveyed by the Department since 1977 or later. There are four DEW survey lines located on Town Beach, three of which have the same orientation (735004, 735005, 735006) while 735003 is adjacent to the groyne and is oriented on a NW direction.

Figure 16 illustrates profile 735006 and shows that the beach is essentially locked onto a reef at ~ - 3m below AHD. The beach has experienced relatively large changes over time traversing up to 50m horizontally between 1984 and 2019.

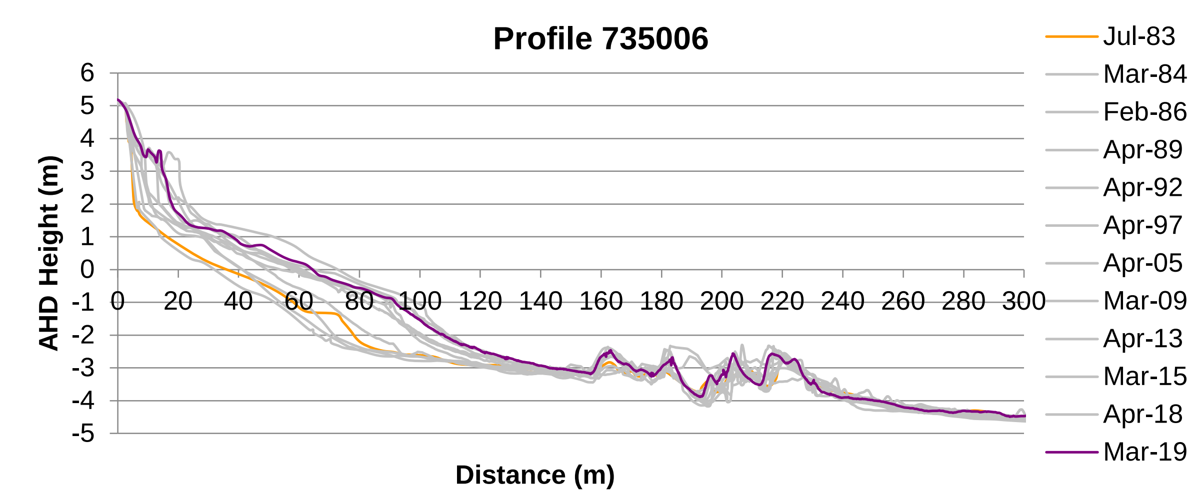

Figure 16: Profile 735006 in the middle of Town Beach. The nearshore reef is essentially holding the lower toe of beach-surfzone in place.

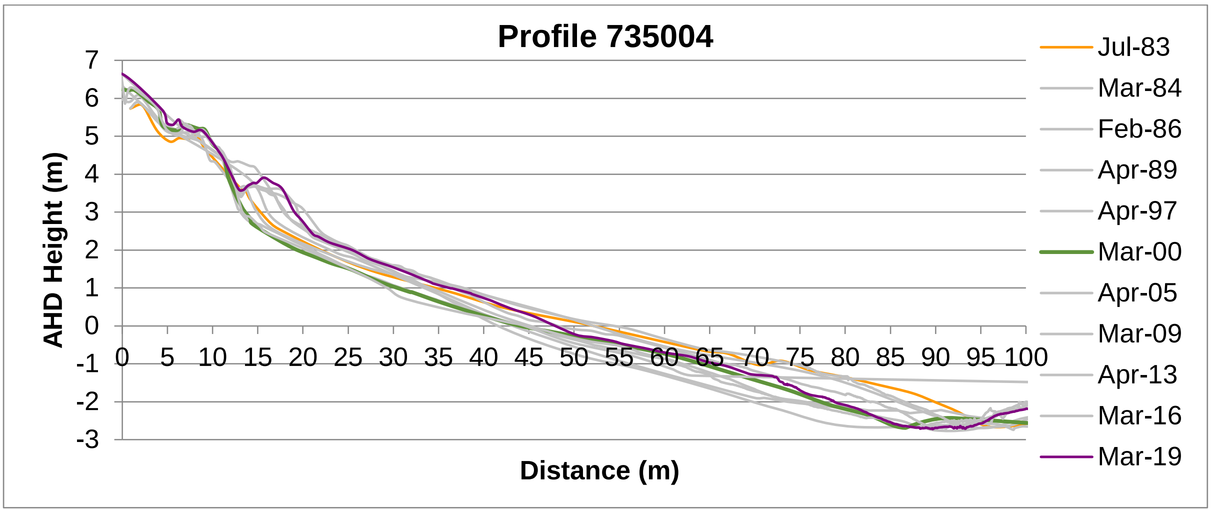

Figure 17: Profile 735004 located east of the Town Beach groyne.

Figure 17 illustrates Profile 735004 located in the middle of the Town Beach segment to the east of the Town Beach groyne. The beach was ~15m less wide in 1992 than in 2009, but has been more stable, or has experienced less horizontal and vertical movement over time compared to the portion of Town Beach located to the west. The most recent profile (2019) shows an accreted beach profile above 0m AHD compared to 1992 or most profiles.

Figure 18: Historical shorelines of Town Beach from 1969 and 1978 overlaid on a vertical aerial photograph from 2019.

Figure 18 illustrates shorelines from 1969 and 1978 on the 2019 imagery. These shorelines were derived by mapping the seaward edge of vegetation. The western portion of the beach has built out since 1969-1978 as a function of the emplacement of the groyne, and the more eastern portion of the beach has remained roughly stable to mildly erosional in the very eastern end.

Hoopers Beach

Hoopers Beach was not developed at all in 1945 (Figure 19), but by 1975 had several houses built on the foredune/back-dune complex (Figure 20).

Hoopers Beach has also been retrograding or eroding since at least the mid 1970’s again likely due to the restriction in sediment supply created by the marina breakwater construction. Civil and Environmental Solutions (2018a) indicate that the dune toe has receded by 2.5-3m in the 2015 to 2018 period. There is no DEW topographic/bathymetric profile at Hoopers Beach. Profile 735004 is the nearest adjacent profile (located on the eastern end of Town Beach), and it shows a recession rate of -2.0m in the period 2013 to 2018, an erosion rate of 0.4 m/year. Hoopers Beach was most recently nourished with sand from Karatta Beach in May, 2019 and 23rd May, 2020.

Figure 19: Hoopers Beach in 1945.

Figure 20: Hoopers Beach in 1975.

Figure 21 illustrates shorelines from 1969 and 1978 on the 2019 imagery of Hoopers Beach. These shorelines were derived by mapping the seaward edge of vegetation. The analysis indicates long term retreat of the shoreline or edge of vegetation in 2019 of a maximum of ~4-5m compared to the earlier dates.

Fox's Beach and The Outlet

Fox's Beach is a small ~200m long pocket beach situated between two low limestone headlands at either end, and is adjacent to the outlet channel to Fox's Lake. A shallow reef extends NNW from the NNE end of the bay, and shore platforms extend along the NNW facing cliff margin on the SW side of the bay (Figures 2, 22).

Figure 21: Historical shorelines of Hoopers Beach from 1969 and 1978 overlaid on a vertical aerial photograph from 2019.

Figure 22: Fox's Beach, Fox's Lake, and the outlet in 1945. Note that the foredune is significantly cliffed or scarped at this time.

The beach has been experiencing erosion for some time, and, for example, the foredune displays a significant scarp (cliff) in 1945 (Figure 22). By 1975, a scarp is also present and the foredune has less vegetation cover and is more erosional, particularly at the southern end (Figure 23). The rate of erosion accelerated from ~ 2015 according to Mr. R. Sweetman, former CEO (DC Robe). Civil and Environmental Solutions (2018) stated that the existing back of beach position is approximately 2.5-3m landward of where it was in 2015, and that the estimated eroded volume at 2018 was 2000m^3 since 2016.

Figure 23: Fox's Beach, the Outlet and Fox's lake in 1975. The cliffs at either end of the beach are more prominent perhaps suggesting lowering of the sand surface since 1945.

Figure 24: Shorelines from 1969 and 1978 on the 2019 imagery of Fox's Beach.

Figure 24 illustrates 1969 and 1978 shorelines derived by mapping the seaward edge of vegetation over the 2019 imagery. As indicated by the DEW topographic profiles, there has been significant erosion since 1978. In particular, as erosion has proceeded, the NW reef is acting as a pseudo-groyne and erosional ‘edge effects’ are occurring in the NW corner of the bay (arrowed) which is now retreating more rapidly.

As noted above, and also by Civil and Environmental Solutions (2018b), the large storms of 2016 combined with record tide levels produced significant erosion along this, and other Robe beaches. Fox’s Beach was most recently nourished with sand from Karatta Beach on the 23rd May, 2020. A storm which occurred in the week of 25th to 31st May, 2020 eroded a significant portion of the nourishment fill resulting in a pronounced scarp (Figure 25).

Figure 25: Scarped nourishment fill on the 3rd June, 2020 at Fox’s Beach.

Figure 26 illustrates beach changes from 1945 to 2019 and indicates that the rates of erosion vary alongshore depending on whether reef, rock platform and cliff is present of not. The highest rates of erosion (up to 0.23 m/year) have occurred on the sandy beach portion.

Figure 26: Shoreline change at Fox’s Beach determined from an analysis of changes in the edge of vegetation on the aerial photography from 1946 to 2019.

The limestone cliffs just north of Fox’s Beach and extending around the front of the corner of the Esplanade display several deep caves with wide overhanging calcrete sections above them (Figure 27. There are some large solution pipes in this area also. It is unknown how deep these caves may penetrate inland, and the risk to road stability may possibly be significant.

Figure 27; (A) General view of the cliff and caves fronting the corner of the Esplanade; (B) view into the caves that extend several metres towards the road under the overhang. Photos taken June, 2020.

Long Beach

The Guichen Bay coastal plain is fronted by a small active foredune which lies seaward of a much larger relict foredune. The latter was active in 1975 (Figure 21), and partially active in 1978 when Short and Hesp (1980) visited the site (Figure 28). The modern, much smaller active foredune formed sometime after that period indicating there may be a continuing small sediment supply into the Bay, or that the new foredune formed following a period of erosion of the larger, older, now relict foredune. If the latter is the case, then the modern foredune merely represents sediment being returned to the beach post-storm(s).

Figure 28: Long Beach access road, mid Guichen Bay, 1975. The foredune displays a relatively steep seaward slope and multiple blowouts along its length.

A

Figure 29: (A) Long Beach foredune in 1979, and (B) in June, 2020 (in approximately a similar location) taken from the SE section of the bay. The incipient foredune has increased in size and volume since the 1979 photograph was taken.

The DEW survey line (735002) begins ~2.2km north of the SE end of the Guichen Bay and extends seawards in a WNW direction (Figure 6). The first profile was surveyed in 1977, and it has been surveyed intermittently since then.

Figure 30 illustrates all the profiles obtained since 1977 and shows that while there is reasonable bar movement and accretion-erosion in the surfzone-nearshore associated with periods of calms versus storm events, the Long Beach system appears to be relatively stable over time, and may even be slightly accretional given the size of the foredune growth since 1978.

Figure 31 compares two profiles in higher resolution taken in 1977 and 2010 and shows that there is very little net change during that period. The latest 2019 profile (Figure 30) at +2m AHD which is approximately the toe of the foredune/landward limit of the backshore (active beach) is situated in the middle of all the profiles, indicating a relatively mean stable position of the toe of the foredune at this position on Long Beach.

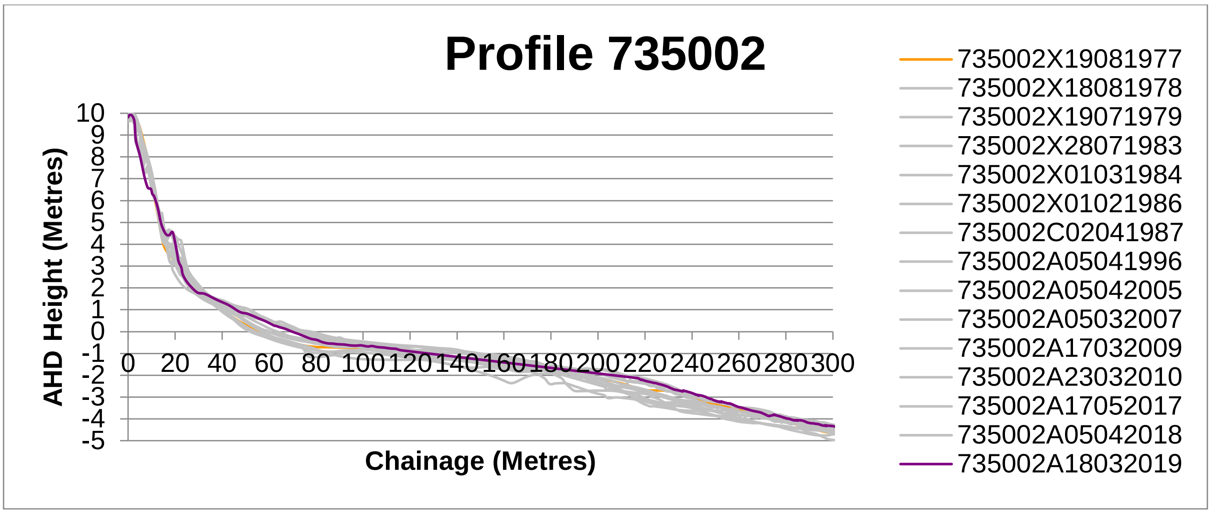

Figure 30: DEW survey profiles for Long Beach from April, 1977 to March, 2019.

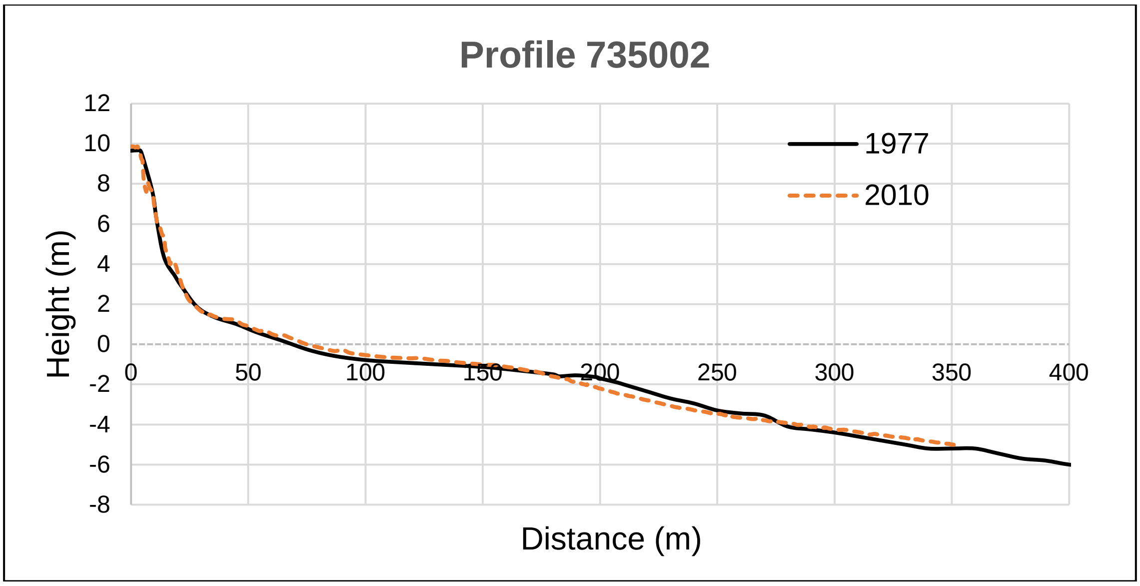

Figure 31: A comparison of the Long Beach profiles between April, 1977 and March, 2010.

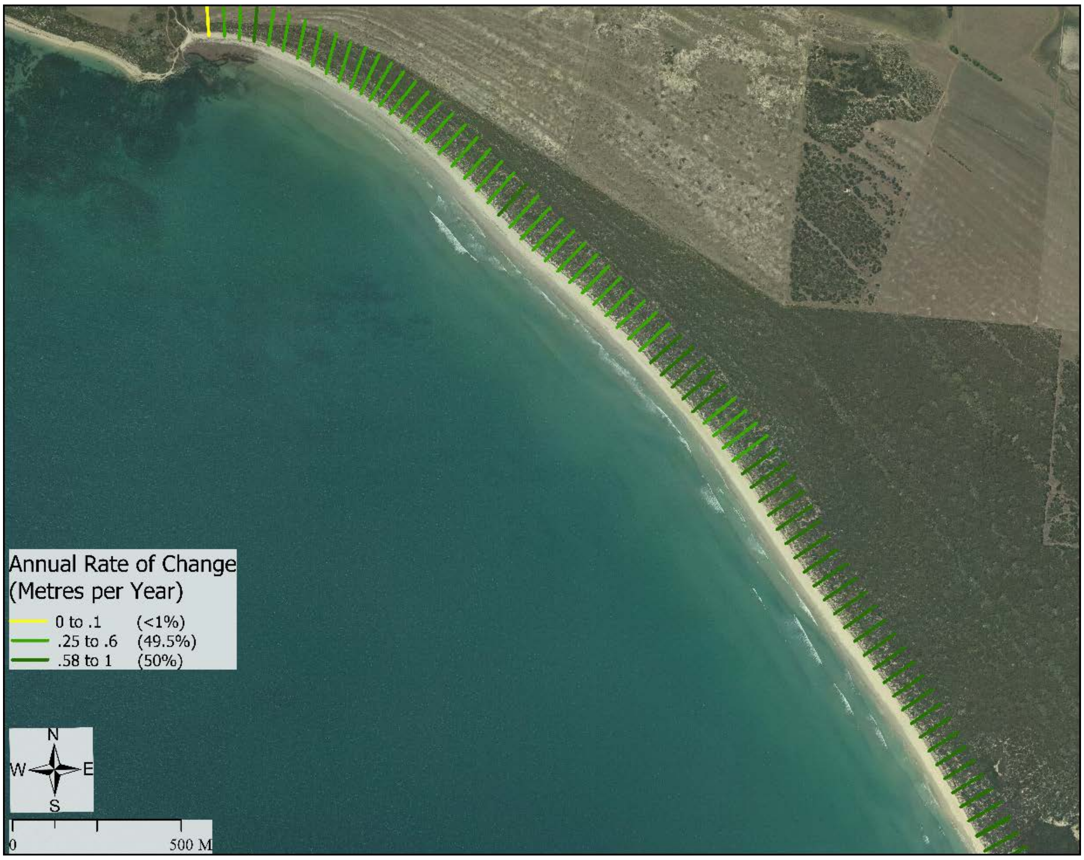

Figure 32: Shoreline change along the northern portion of Long Beach determined from an analysis of changes in the edge of vegetation on the aerial photography from 1946 to 2019.

Figure 33: Shoreline change along the middle portion of Long Beach determined from an analysis of changes in the edge of vegetation on the aerial photography from 1946 to 2019.

Figure 34: Shoreline change for the southern portion of Long Beach determined from an analysis of changes in the edge of vegetation on the aerial photography from 1946 to 2019.

Figures 32, 33 and 34 illustrate shoreline changes along Long Beach as indicated by the seaward edge of vegetation determined from aerial photography and satellite imagery between 1946 and 2019. The shoreline ranges from stable to accretional up to 0.6 m/year.

Boatswain to Cape Jaffa

The Department of Environment and Water (DEW) have monitored a survey line or profile at Boatswain since 1977. The line crosses a narrow sandy beach and then crosses a reef dominated nearshore zone (Figures 6 and 35). The profiles show that there has been around 2.2m recession at the dune toe between 1977 and 2010 which equals an erosion rate of ~0.06 m/year (Figure 36). The rate of erosion between 2010 and 2018 has increased to ~0.1 to 0.2 m/year for the toe of the foredune at +2m AHD and dune slope at +4m AHD respectively.

Figure 35: Boatswain and Cape Thomas. (A) photograph taken in 1979, and (B) Google Earth image in 2018. Note the increase in vegetation cover, and the vegetation colonisation of the blowout east of Boatswain by 2018.

Figure 37 illustrates shoreline changes from 1946 to 2019 based on surveying the edge of vegetation. The shoreline change is highly variable alongshore with the most significant erosion (up to 0.23 m/year) taking place adjacent to the Boatswain village. Table 1 in Appendix 1 indicates the statistics associated with the shoreline analyses of change.

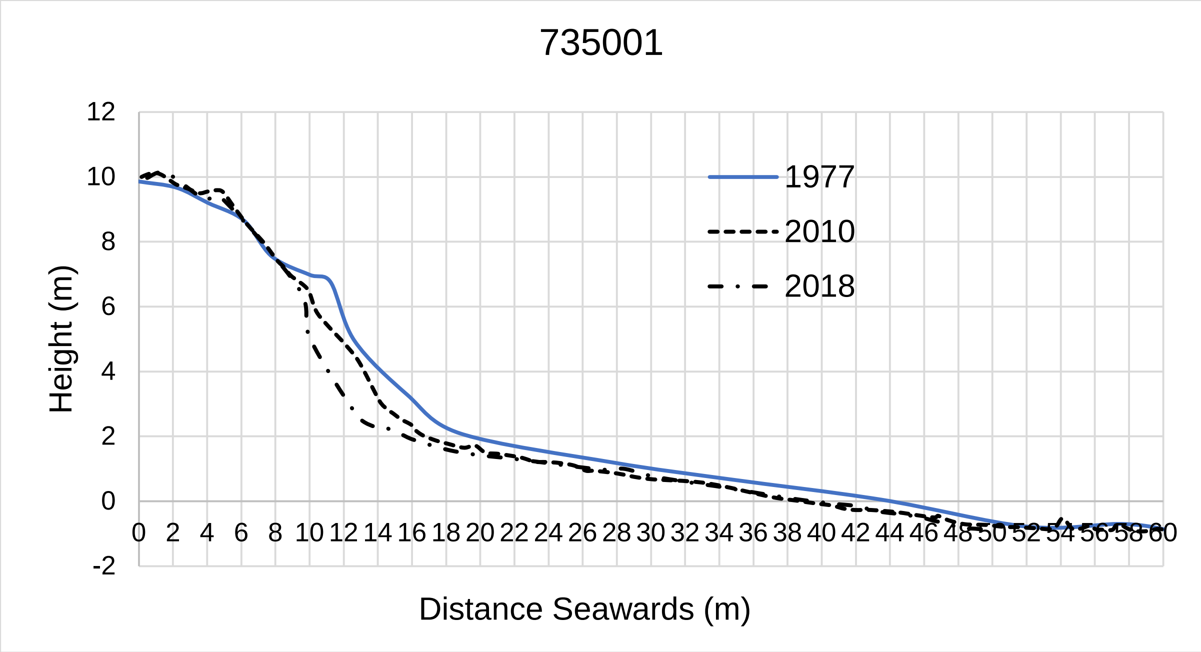

Figure 36: A comparison of the April, 1977, April, 2010, and April 2018 DEW surveys of Boatswain showing net recession of the beach and dune over time.

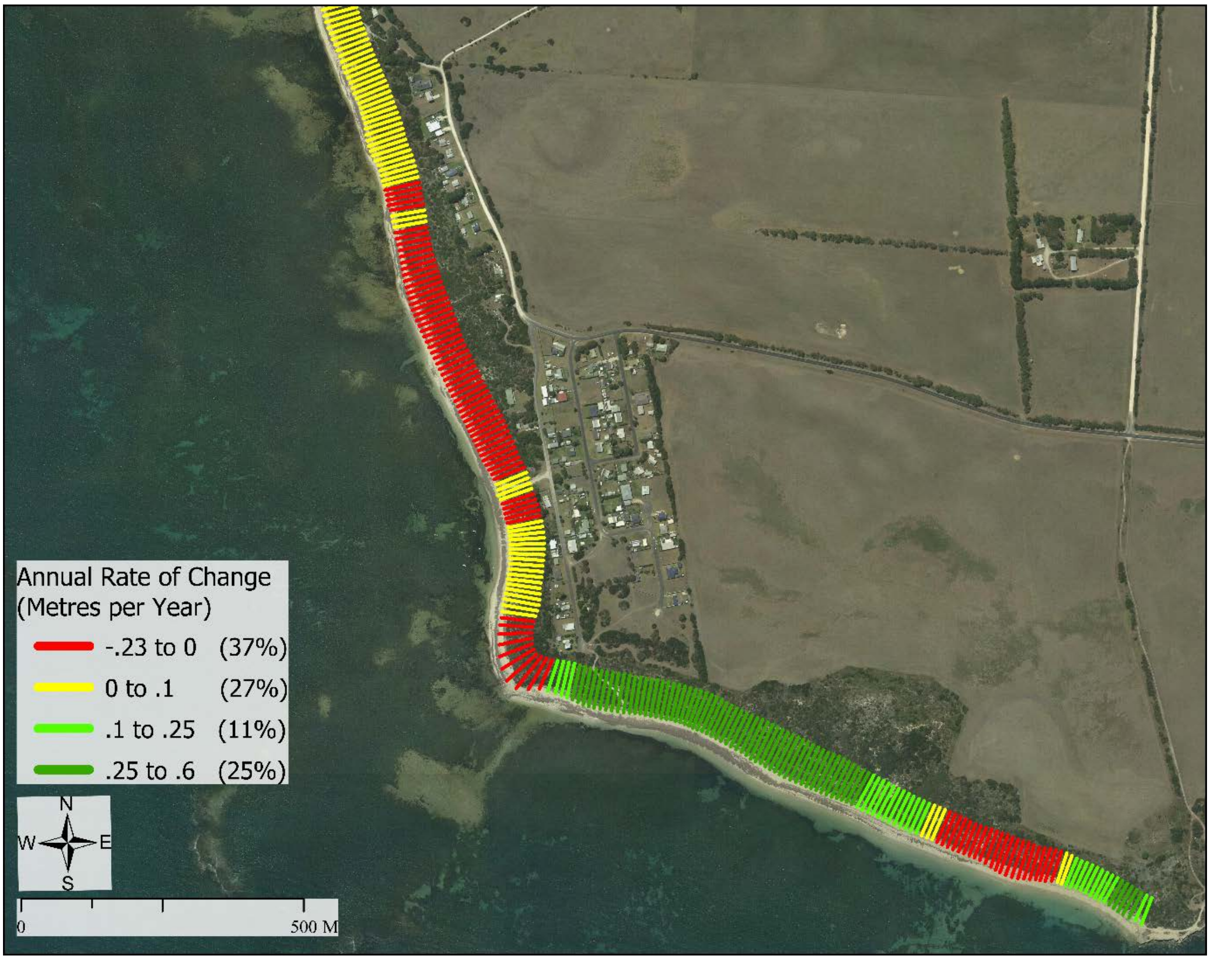

Figure 37: Shoreline change at Boatswain determined from an analysis of changes in the edge of vegetation on the aerial photography from 1946 to 2019.

CONCLUSIONS

Cape Dombey and the adjacent limestone cliffs are eroding at rates between 0.33 mm/year (Fotheringham, 2009) to ~0.24 to 0.27 m/year (this study). The cliffs are undercut in many locations, display deep caves (and possibly covered holes), and experience random cliff collapse. They are generally dangerous locations, and further efforts may be required to protect the public from accessing certain areas. The Obelisk will likely fall off the Cape as early as 2028 and latest by ~ 2047 – 2058.

Town Beach, Hoopers Beach and Fox's Beach have been eroding for many years likely as a result of the construction of the marine training wall. The rate may have accelerated in recent years, partly due to the intense storm season in 2016, but perhaps also due to sea level rise. As sea level increases, wave energy reaching the shore will increase leading to surfzone and beach adjustment due to normal waves, but also to more significant erosion during storms. Fox's Beach may also be affected by ebb tidal flows out of The Outlet which could potentially increase in velocity due to the higher water levels in Fox's Lake associated with a higher sea level. Ideally new topographic/bathymetric survey lines should be established as soon as possible across and off Hoopers and Fox's Beaches in order to monitor future changes.

Long Beach appears to be stable to slightly accretional at this time.

Boatswain experienced a low rate of erosion (~ 0.06 m/year) in the period 1977 to 2010, and between 2010 and 2018 the rate has increased substantially to ~0.2 m/year.

It is possible we are seeing more beach and dune erosion just due to sea level rise of ~25cm since 1880. Two further factors may be at play here (and elsewhere). Sea level has been around the present level for around 8,000 years. So, in addition to sea level rise, waves acting on the reasonably easily erodible aeolian calcarenite and limestone reefs may have eroded those reefs to a point where they are now lower than previously, and storm waves in particular are able to penetrate further shorewards than previously, resulting in greater shore erosion. In addition, as sea level rises, higher energy waves will act on the extensive rock platforms and reefs, potentially leading to higher rates of erosion than previously occurring, thus, leading to lowering of the reefs and greater wave energy reaching the adjacent shorelines. Even if the reefs are relatively resistant, higher sea levels will mean more water volume crossing the reefs and nearshore during storms potentially resulting in greater beach erosion.

All sandy beaches and their foredunes can and generally will translate landwards and upwards as sea level rises IF there is space for them to do so, and a minimum supply of sediment is returned to the beach following storm erosion (i.e. the storm eroded sediment is not entirely removed from the beach-surfzone system). While ample space is available for this natural process to occur along the majority of Long Beach, and to a lesser extent at Boatswain, there is zero to minimal space for this to happen at Town, Hoopers and Fox's Beaches'. Nourishment of these beaches will have to be regularly carried out if they are to continue to operate as sandy beaches, and to protect landward infrastructure. If sea levels rise to +1.0m or more by 2100, and if the rate of sea level rise increases in the post-2050 period, holding those beaches by nourishments alone may not be enough to protect the infrastructure.

ACKNOWLEDGEMENTS

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REFERENCES

Banerjee, D., Hildebrand, A.N., Murray-Wallace, C.V., Bourman, R.P., Brooke, B.P., Blair, M., 2003. New quartz SAR-OSL ages from the stranded beach dune sequence in south-east South Australia. Quaternary Science reviews 22: 1019-1025.

Belperio, A.P., 1995. Quaternary. In: Drexel, J.P., Preiss, W.V. (Eds.), The Geology of South Australia, Vol. 2. The Phanerozoic. South Aust. Geol. Survey Bull. 54.

Bermingham, K., 1961. Gateway to the South East. South Eastern Times Ltd., Millicent.

Bristow, C.S., Pucillo, K., 2006. Quantifying rates of coastal progradation from sediment volume using GPR and OSL: the Holocene fill of Guichen Bay, south-east South Australia. Sedimentology 53: 769-788.

Cann, J.H., Murray-Wallace, C.V., Belperio, A.P., Brenchley, A.J., 1999. Evolution of Holocene coastal environments near Robe, southeastern South Australia. Quaternary International 56: 81-97.

Civil and Environmental Solutions, 2018a. Hooper Beach, Robe Dune Erosion Assessment Report. Prepared for DC Robe, 42pp.

Civil and Environmental Solutions, 2018b. Fox Beach, Robe Dune Erosion Assessment Report. Prepared for DC Robe, 41pp.

Fotheringham, D.G., 1976. Geographical Variation in Coastal Dunes at Robe. Unpub. B.A.(Hons.) Thesis, Flinders University.

Fotheringham D.G., 2009. Cliff top erosion adjacent Cape Dombey, Robe, South Australia. Coastal Management Branch Technical Report 2009/08, 17 pp.

Fryberger, S. G., Dean, G. (1979). Dune forms and wind regime. In: McKee E.D. (Ed.), A study of Global Sand Seas, U.S. Geological Survey Professional Paper 1052 (pp. 137-169). Washington, D.C.: U.S. Government Printing Office.

Green, G., Townsend, M., Cichon, C., Smith, B., Taylor, F., Carrangis, T., Carruthers, S., (DEW), 2018. Technical information for the 2018 climate change (sea level) trend and condition report card. DEW Technical Note 2018/46.

Hemer, M. A., Griffin, D. A., 2010. The wave energy resource along Australia's southern margin. Journal of Renewable and Sustainable Energy, 2(4), 043108.

Hemer, M. A., Simmonds, I., Keay, K., 2008. A classification of wave generation characteristics during large wave events on the Southern Australian margin. Continental Shelf Research, 28(4), 634-652.

Hesp, P. A. (2002). Foredunes and blowouts: initiation, geomorphology and dynamics. Geomorphology, 48(1-3), 245-268.

Huntley, D.J., Hutton, J.T., Prescott, J.R., 1993. The stranded beach-dune sequence of south-east South Australia: A test of thermoluminescence dating, 0-800ka. Quaternary Science Reviews 12: 1-20.

Huntley, D.J., Hutton, J.T., Prescott, J.R., 1994. Further Thermoluminescence dates from the dune sequence in the southeast of South Australia. Quaternary Science Reviews 13: 201-207.

Miot da Silva, G., Hesp, P. A., 2010. Coastline orientation, aeolian sediment transport and foredune and dunefield dynamics of Moçambique Beach, Southern Brazil. Geomorphology, 120(3-4), 258-278.

Murray-Wallace, C.V., 2018. Quaternary History of the Coorong Coastal Plain, Southern Australia: An Archive of Environmental and Global Sea Level Changes. Cham: Springer Intl. Pub., 229pp.

Murray-Wallace, C.V., Banerjee, D., Bourman, R.P., Olley, J.M., Brooke, B.P., 2002. Optically stimulated luminescence dating of Holocene relict foredunes, Guichen Bay, South Australia. Quaternary Science Reviews 21: 1077-1086.

Murray-Wallace, C.V., Belperio, A.P., Cann, J.H., Huntley, D.J., Prescott, J.R., 1996. Late Quaternary uplift history, Mount gambier region, South Australia. Zeitschrift fur Geomorphologie N.F. Supple.-Bd. 106: 41-56.

Murray-Wallace, C.V., Belperio, A.P., Bourman, R.P., Cann, J.H., Price, D.M., 1999. Facies architecture of a last interglacial barrier: a model of Quaternary barrier development from the Coorong to Mt Gambier coastal plain, southeastern Australia. Marine Geology 158: 177-195.

Oliver, T.S.N., Murray-Wallace, C.V., Woodroffe, C.D., 2020. Holocene shoreline progradation and coastal evolution at Guichen and Rivoli Bays, southern Australia. The Holocene 30 (1): 106-124.

Schwebel, D.A., 1984. Quaternary stratigraphy and sea level variation in the southeats of South Australia. In: Thom, B.G. (Ed.), Coastal Geomorphology in Australia, Academic Press: 291-311.

Short, A.D. 2020. Australian Coastal Systems. Beaches, barriers and Sediment Compartments. Coastal Research Library.

Short, A.D., Hesp, P.A., 1980. Coastal engineering and morphodynamic assessment of the coast within the South East Coast Protection District, South Australia. Final report. Coastal Protection Board, Department of Environment and Planning, Adelaide, 234 pp.

Short, A.D., Hesp, P.A., 1984. Beach and dune morphodynamics of the south east coast of South Australia. Coastal Studies Unit Technical Report 84/1, University of Sydney, Sydney, 142 pp.

Sprigg, R.C., 1979. Stranded and submerged sea-beach systems of southeast South Australia and the aeolian desert cycle. Sedimentary Geology 22: 53-96.

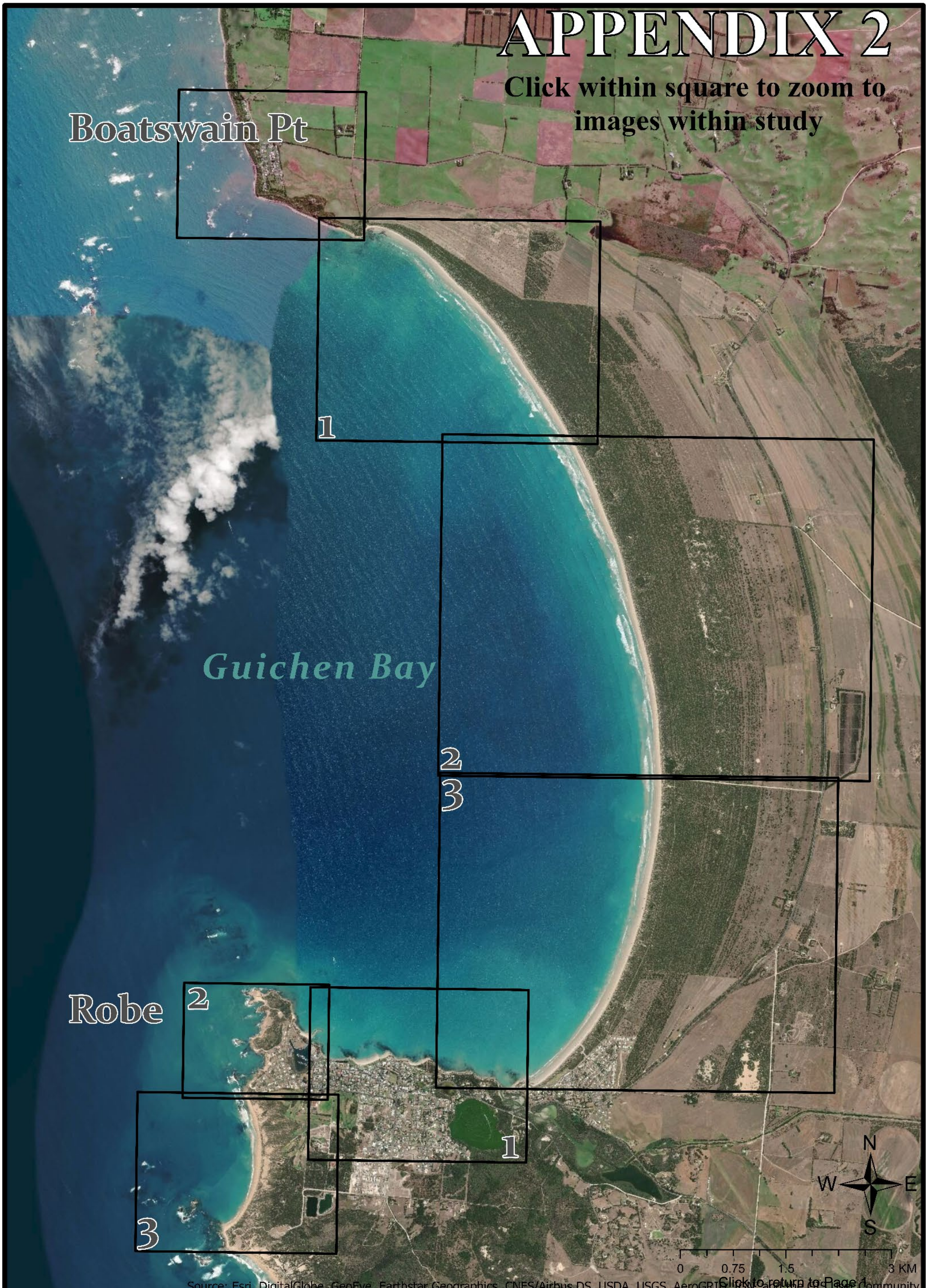
Thom, B.G., Bowman, G.M., Gillespie, R., Temple, R., Barbetti, M., 1981. Radiocarbon dating of Holocene beach-ridge sequences in south-east Australia. Monograph No. 11, Dept. of Geog., RMC, UNSW, Duntroon, 36pp.

APPENDIX 1: STATISTICS RELATED TO THE AERIAL PHOTOGRAPHIC ANALYSES OF SHORELINE CHANGE

Cell	**Er (%)**	**Ac (%)**	**NSM (m) Ac**	**LRR (m/yr) Ac**	**NSM (m) Er**	**LRR (m/yr) Er**
Boatswain Point	37	63	12	.2	-7	-.06
Guichen 1	-	100	34	.56	-	-
Guichen 2	-	100	49	.64	-	-
Guichen 3	-	100	21	.4	-	-
Robe 1	100	-	-	-	-5	-.1
Robe 2	-	-	-	-	-	-
Robe 3	-	100	14	-	-	-

Table 1 *- Statistics generated by the Digital Shoreline Analysis Systems for each area within study. The edge of vegetation shorelines are categorised as total percentage of transects evaluated to be Erosional (Er) or Accretional (Ac) based on their Linear Regression Rate (LRR) and Net Shore Movement (NSM). The NSM shows the total movement in metres from oldest to youngest shoreline, analysed from 1946 to 2019. The LRR shows the rate of change, metres per year, analysed from the shorelines sourced from imagery from 1946, 1969, 1978, 1982, 1995, 2003, 2009, 2012 and 2019.*

APPENDIX 2: PDF CONTAINING 1946 TO 2019 GEO-RECTIFIED IMAGES OF THE STUDY AREA (Separate File).


APPENDIX 2
Click within square to zoom to images within study
Boatswain Pt
Guichen Bay
Robe
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1.5
3 KM
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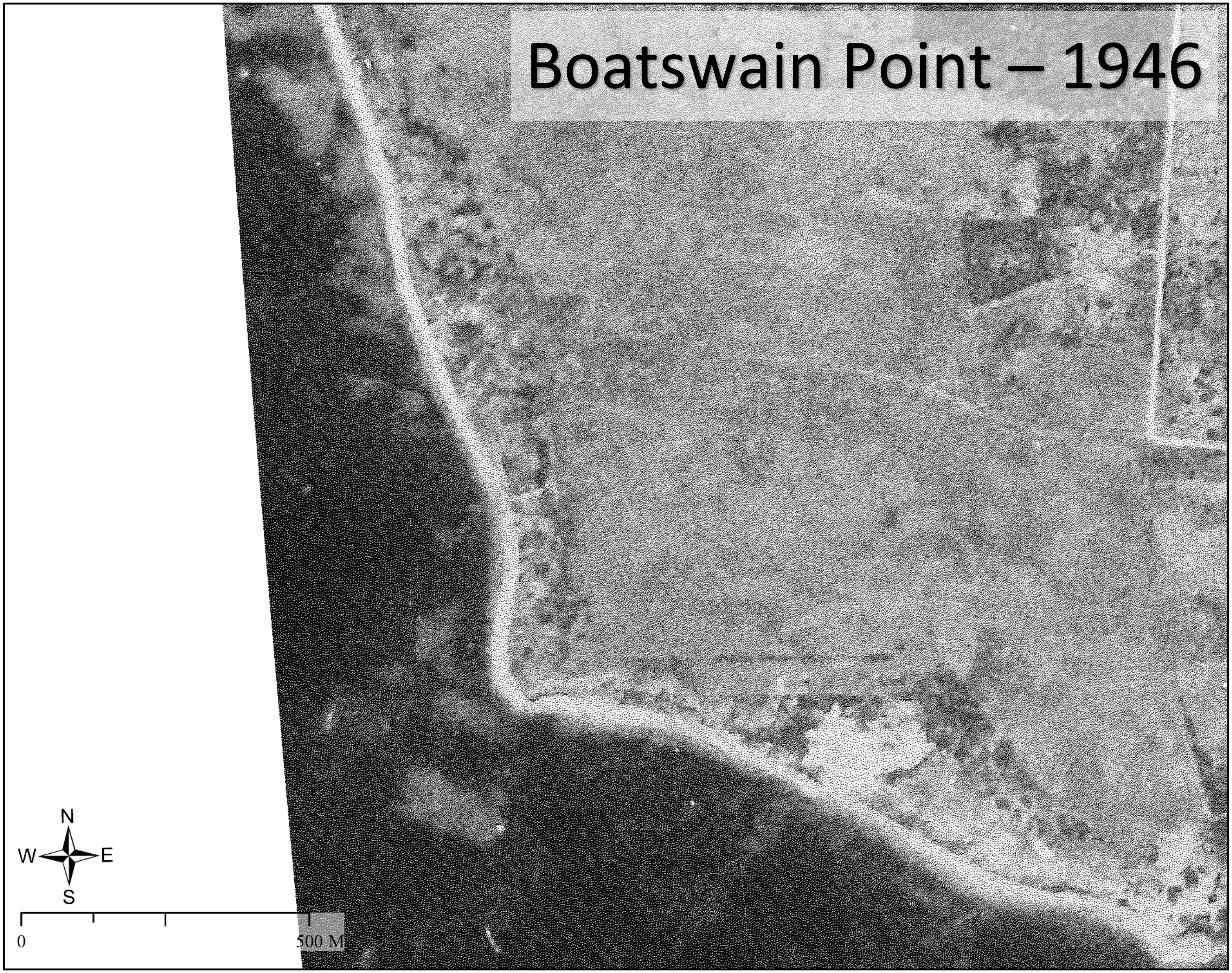
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



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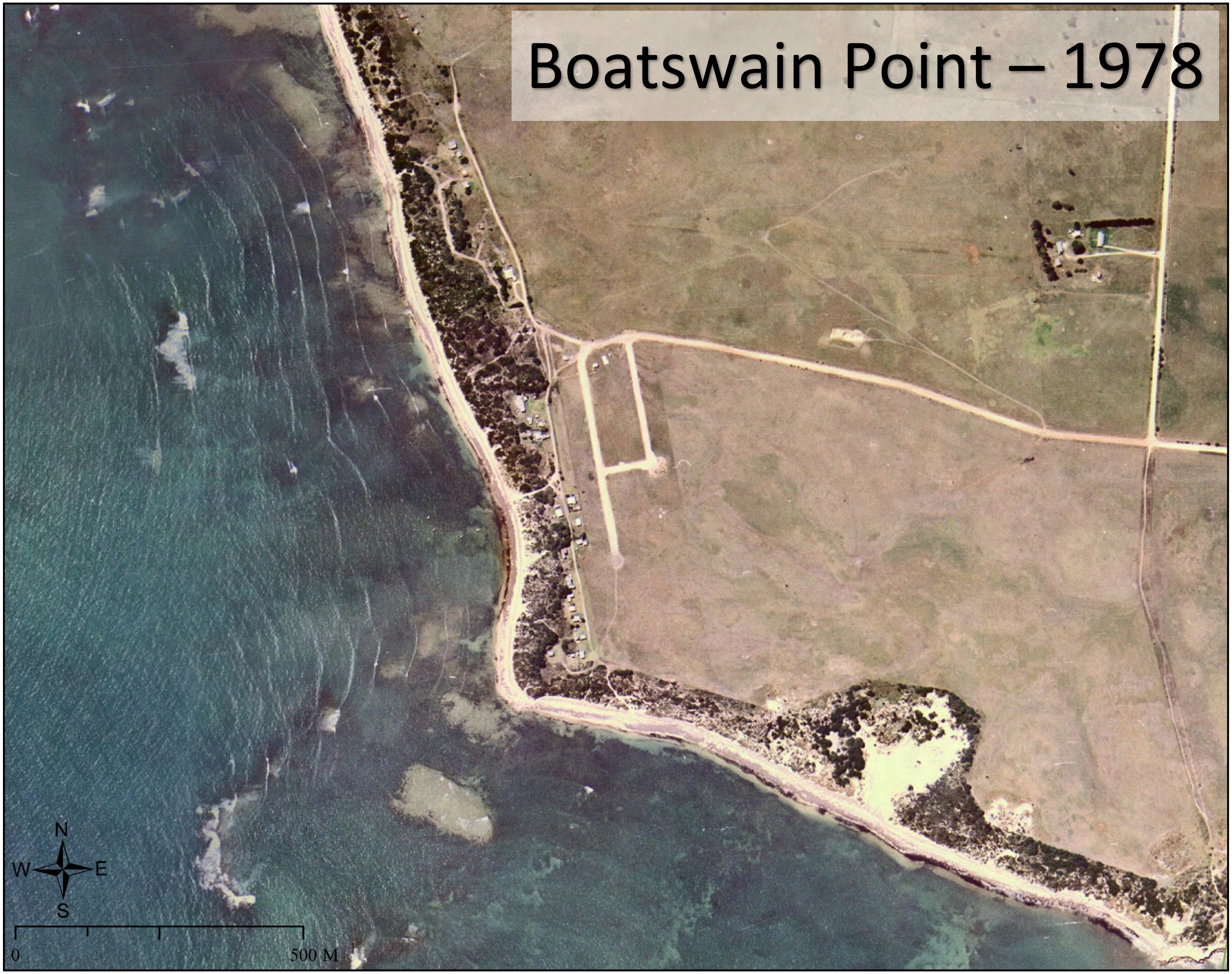

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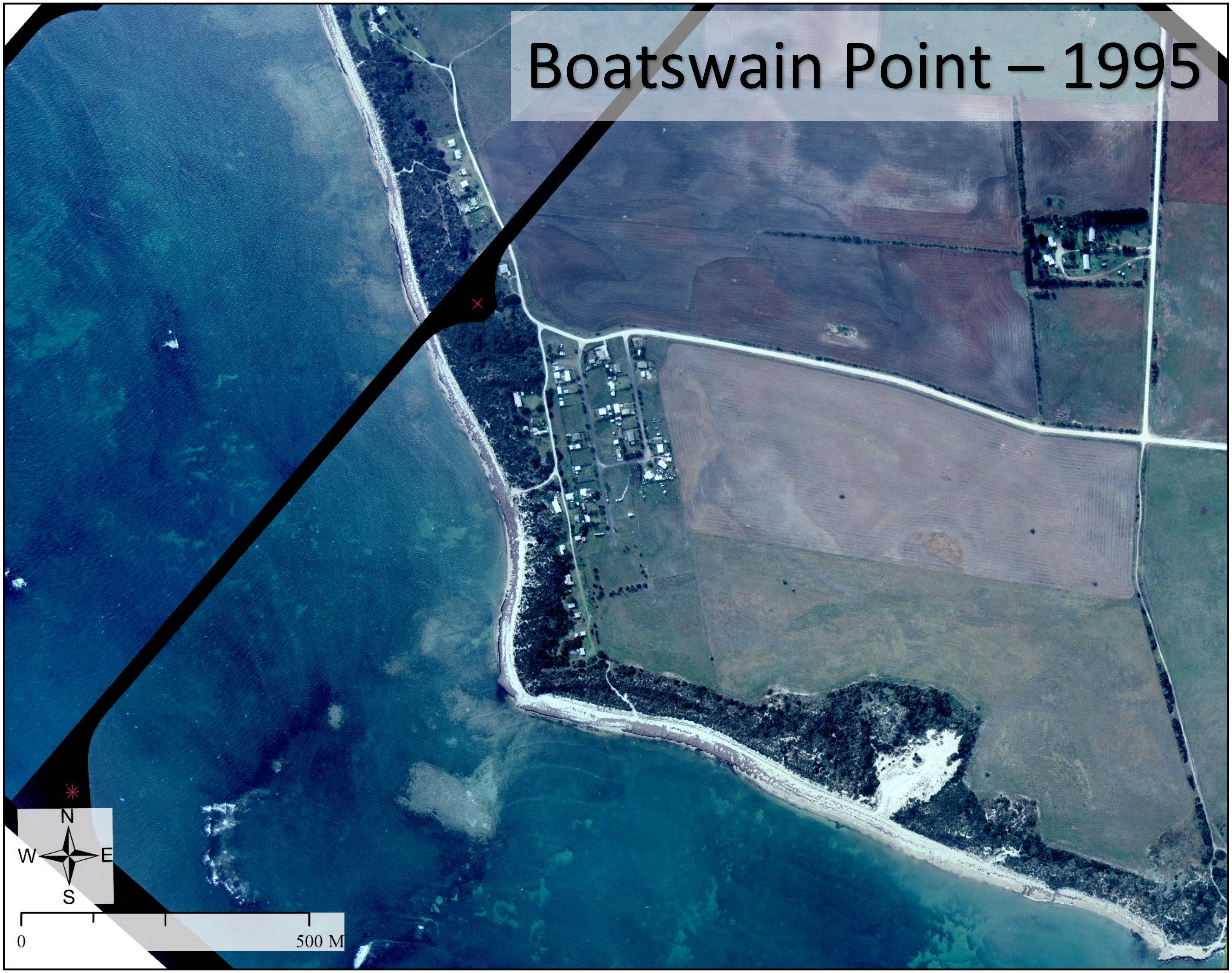

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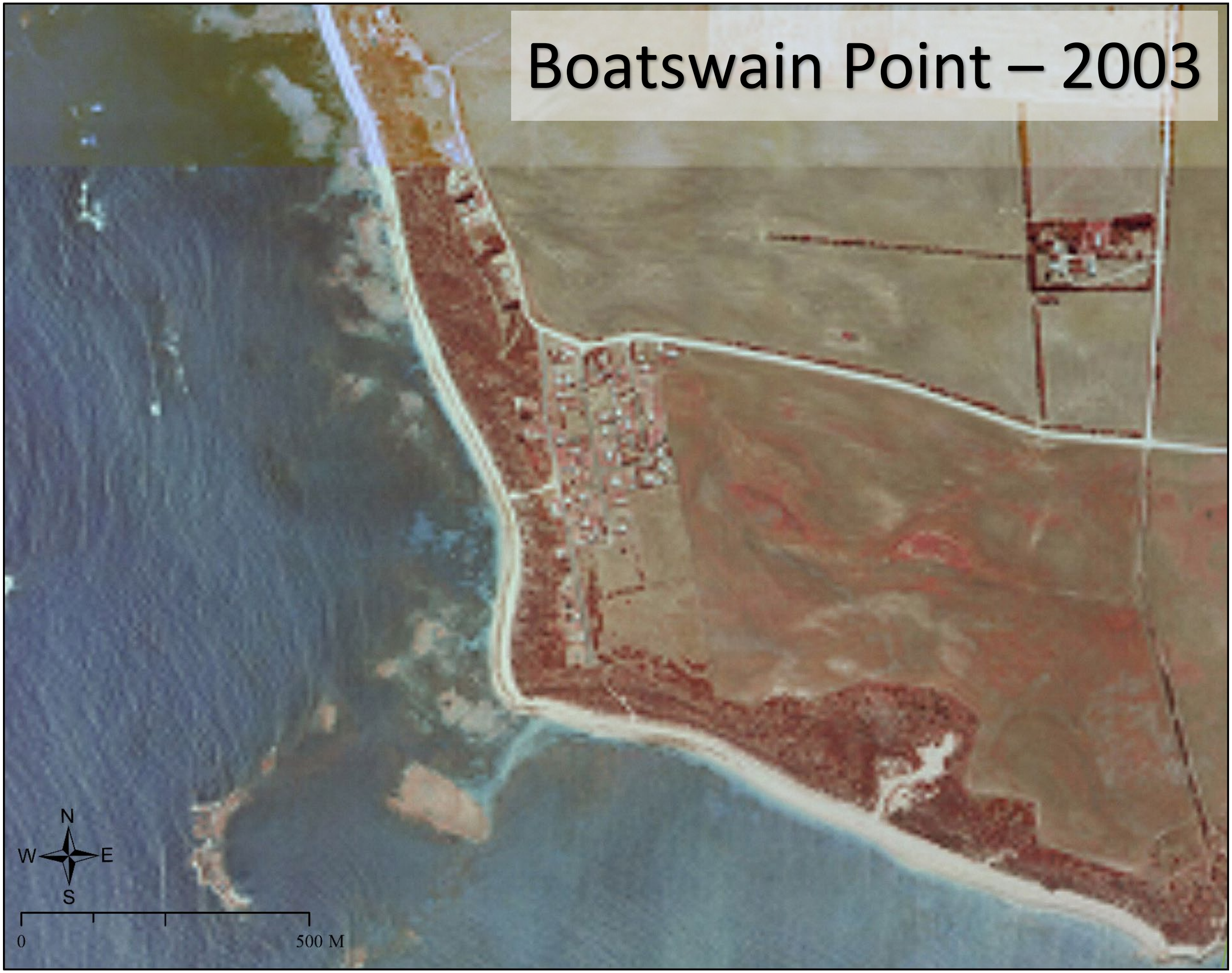

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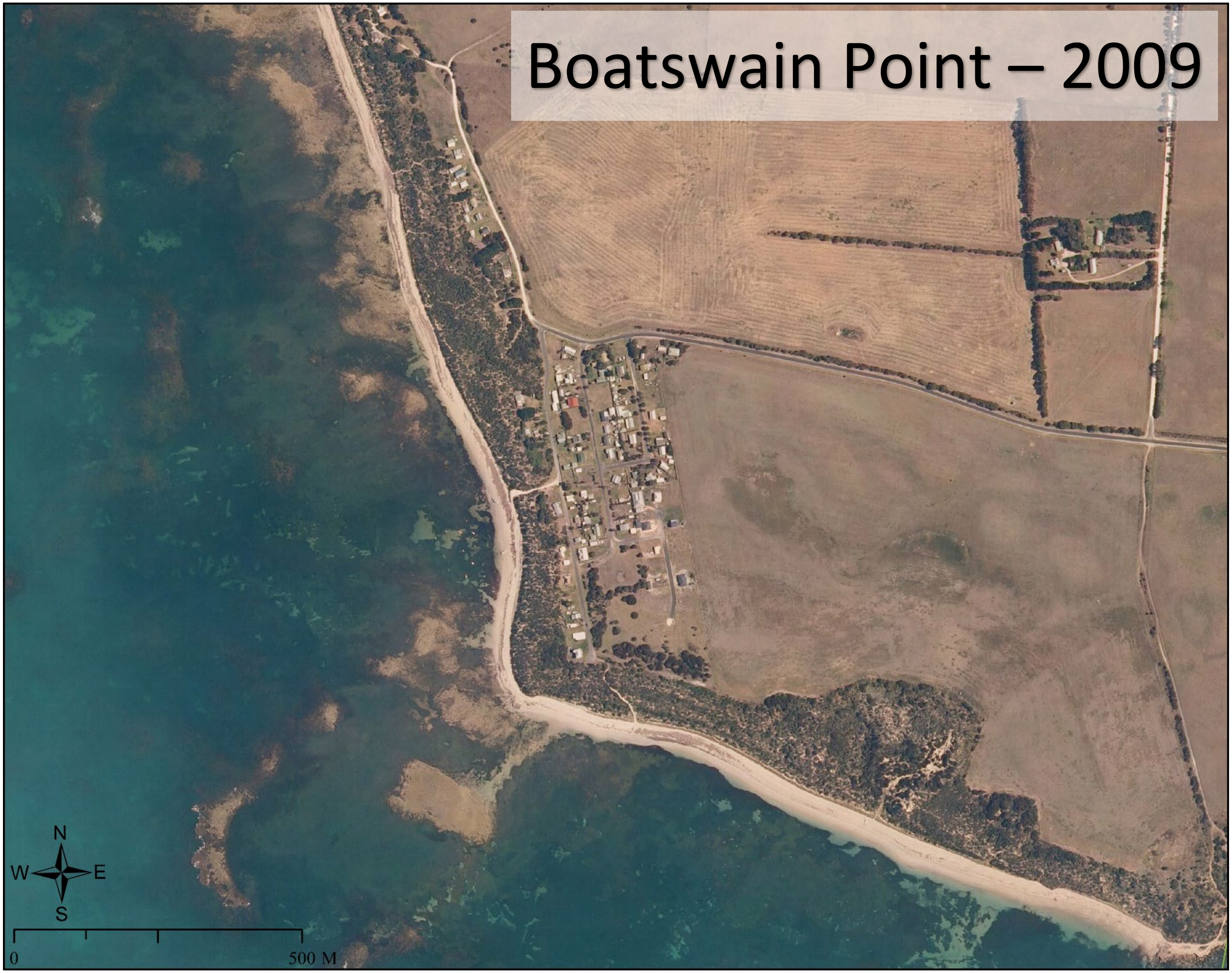

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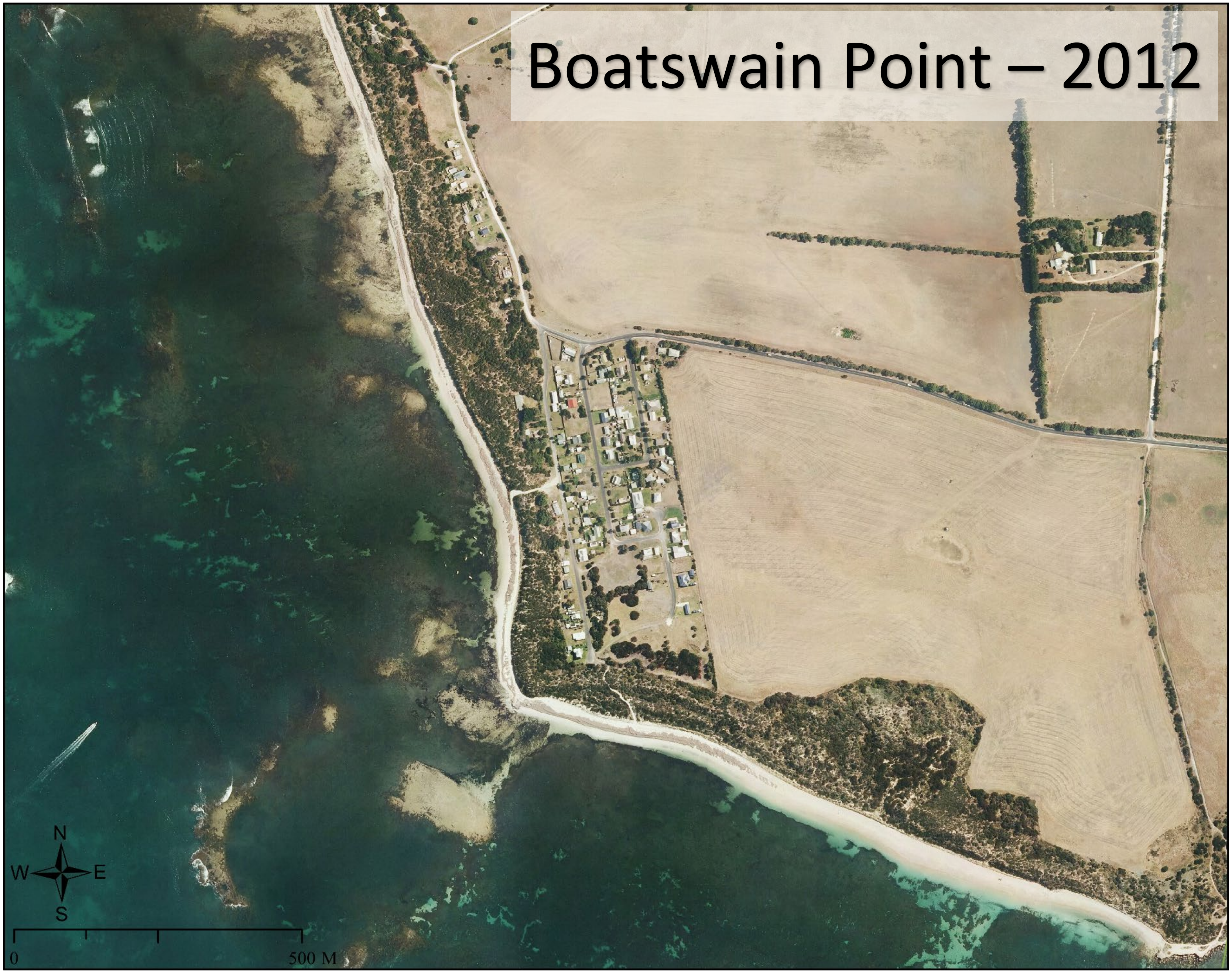

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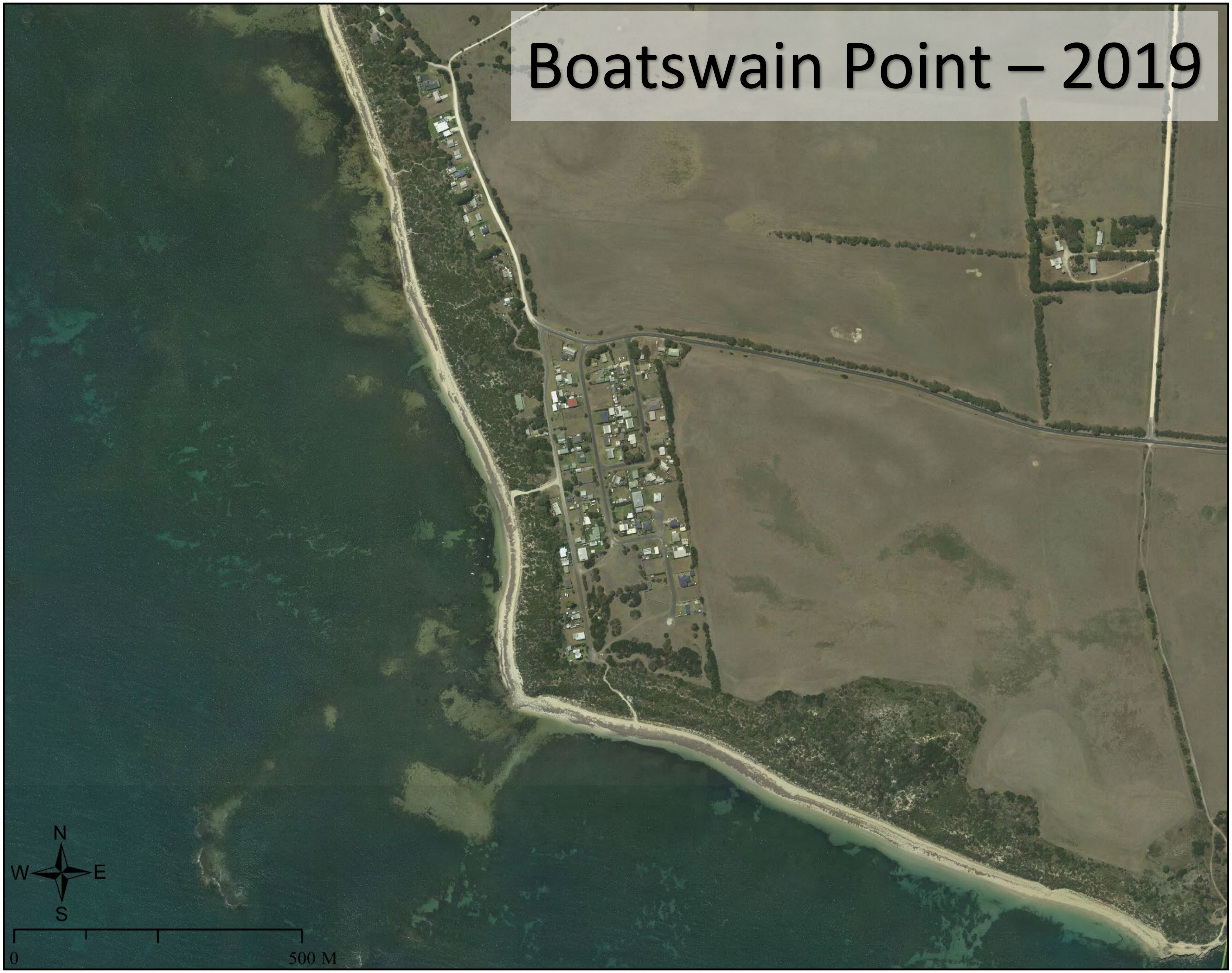

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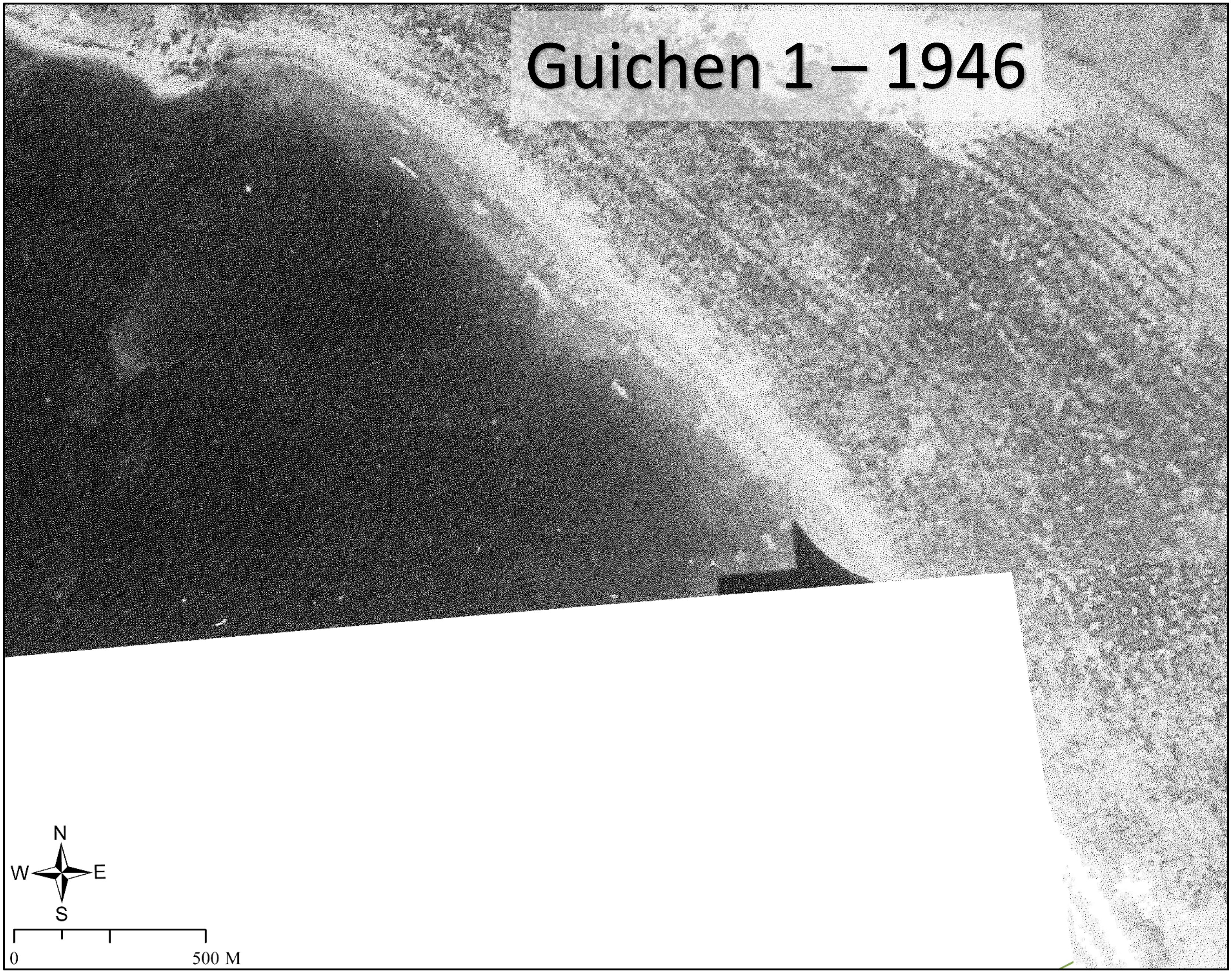

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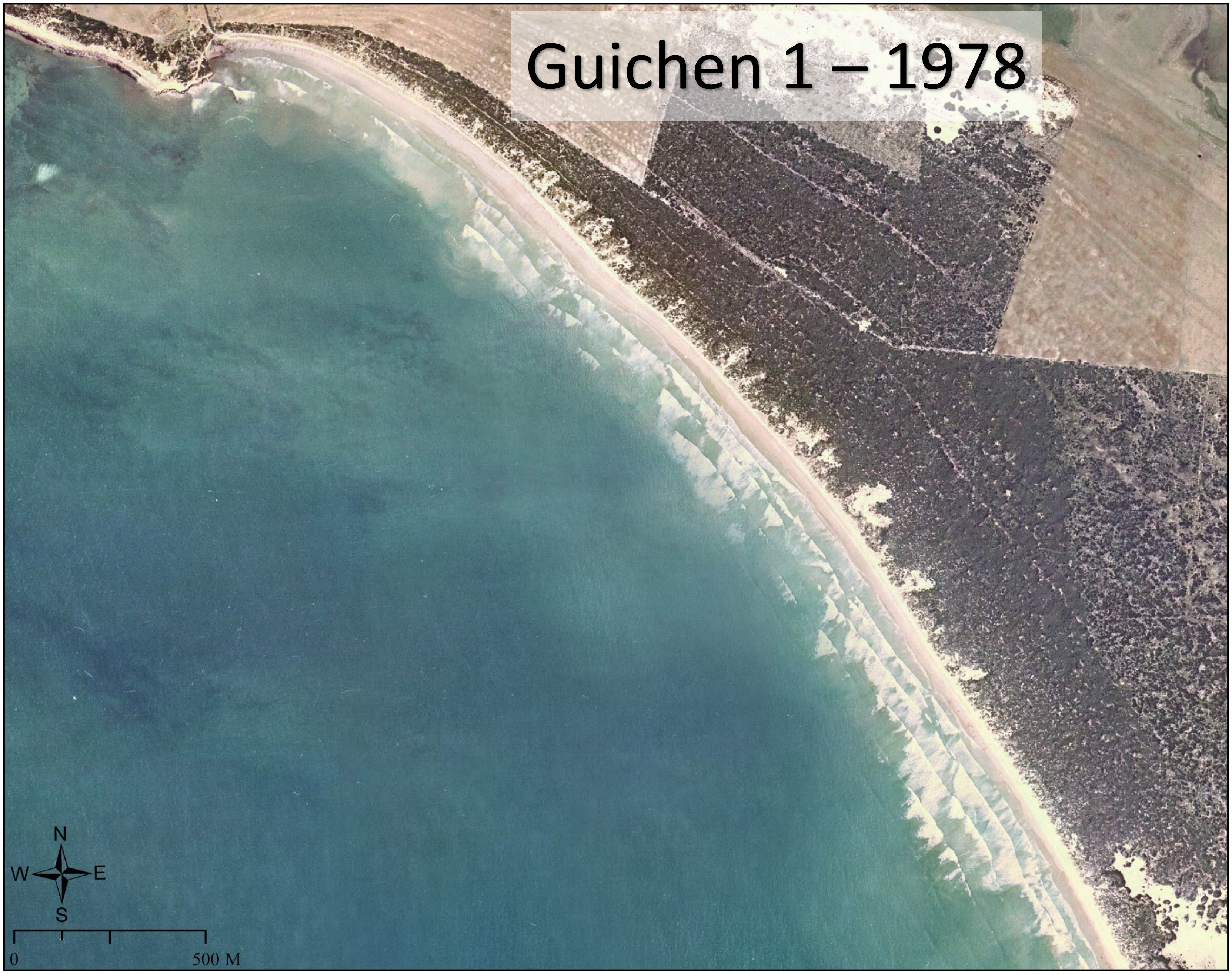

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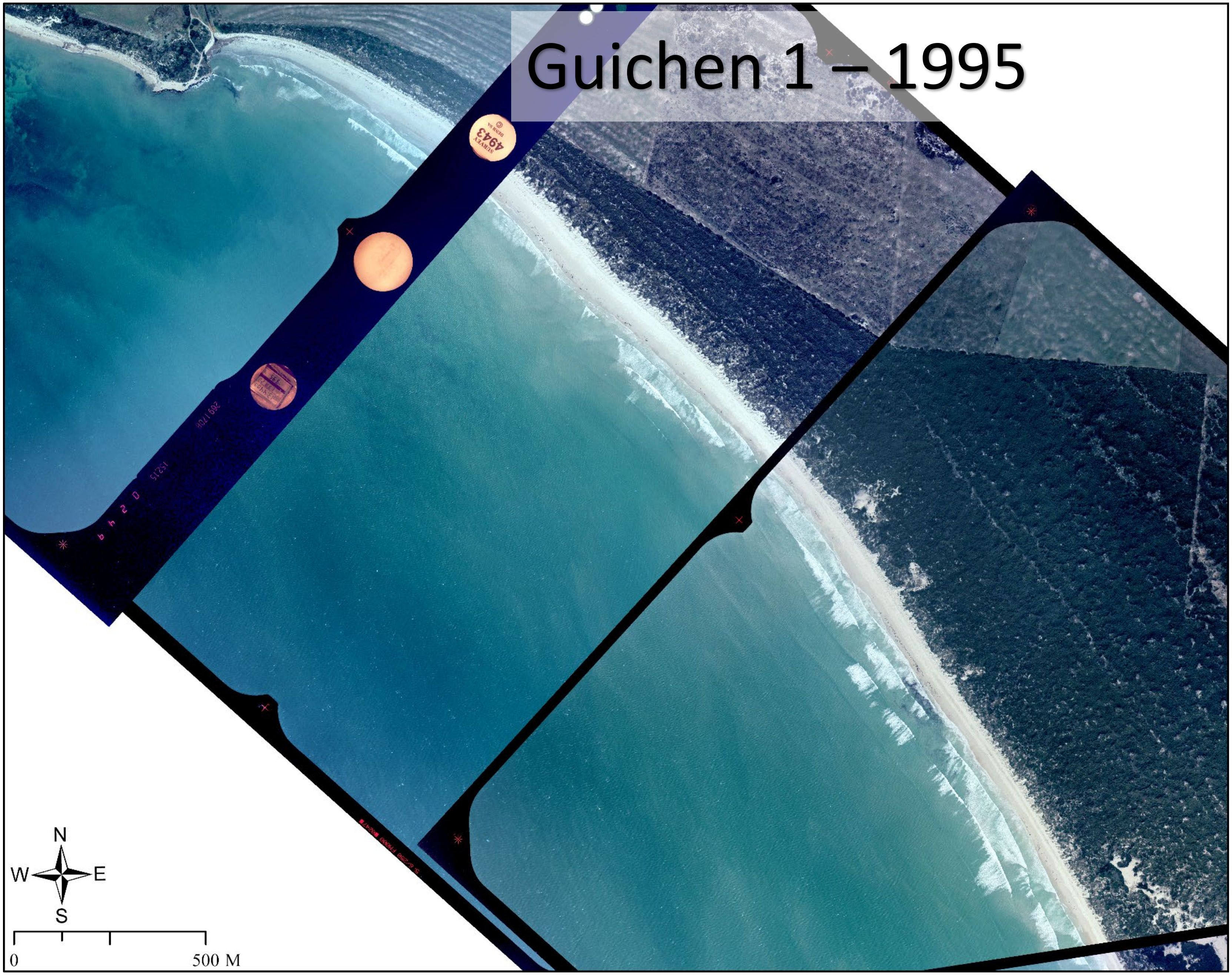

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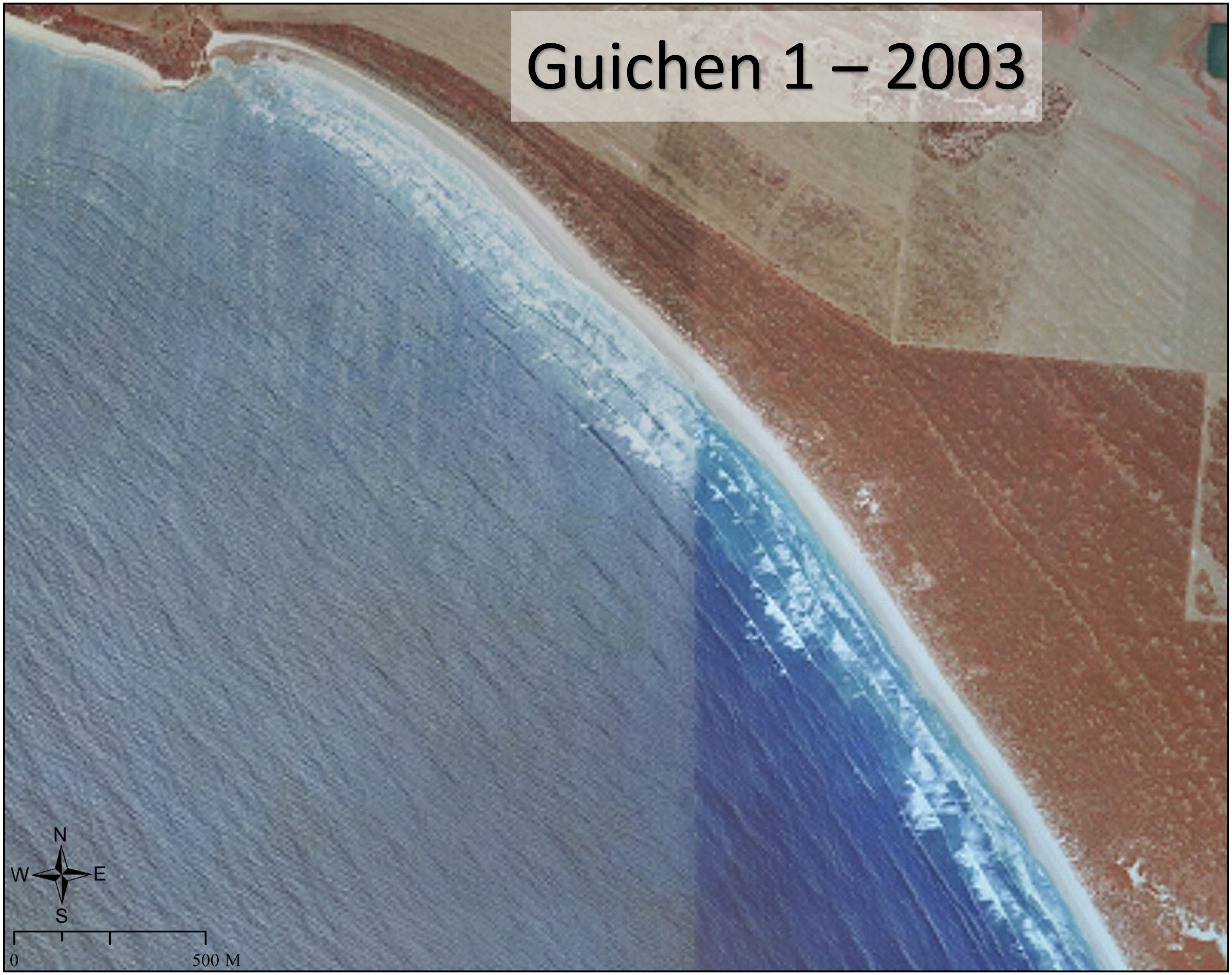

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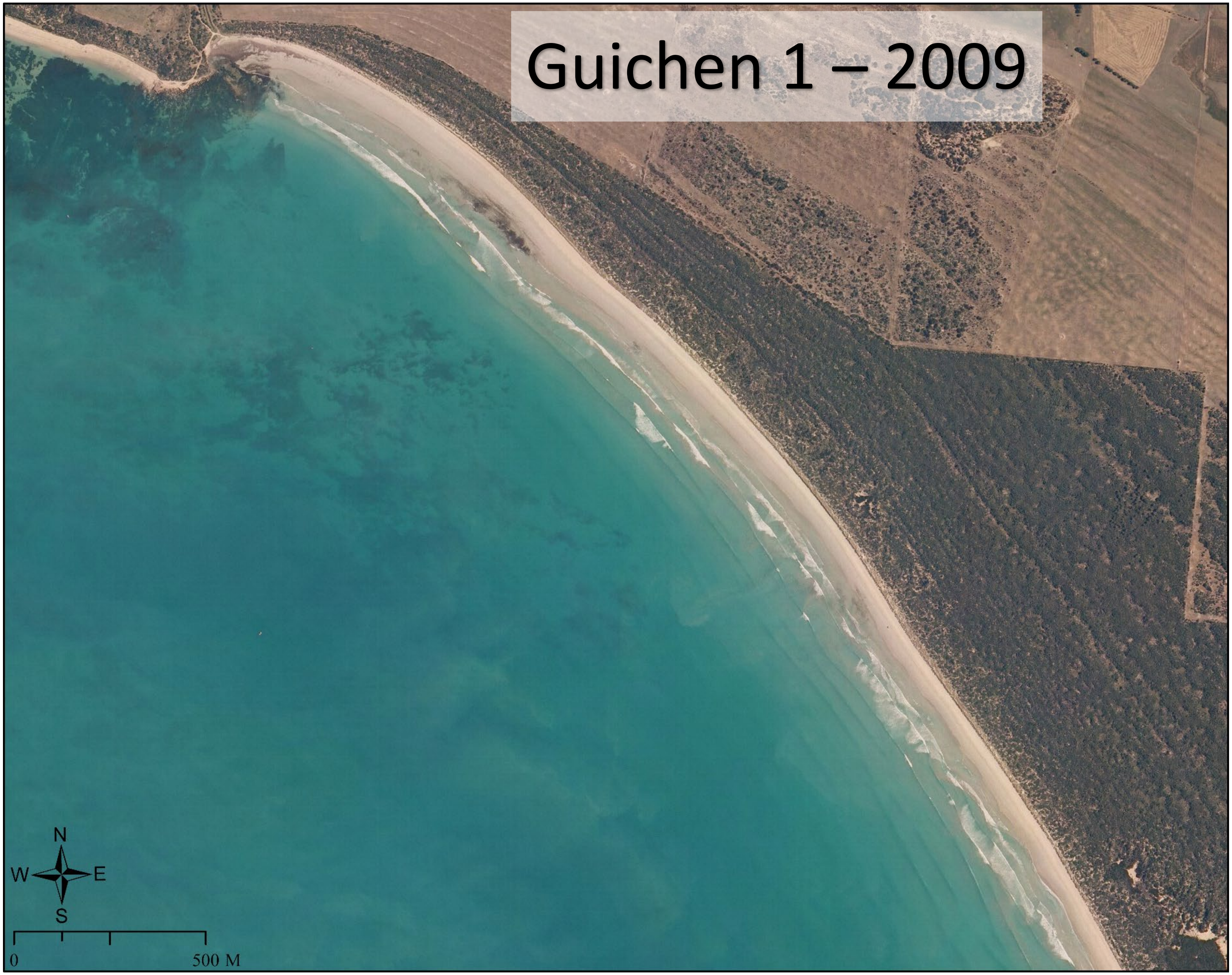

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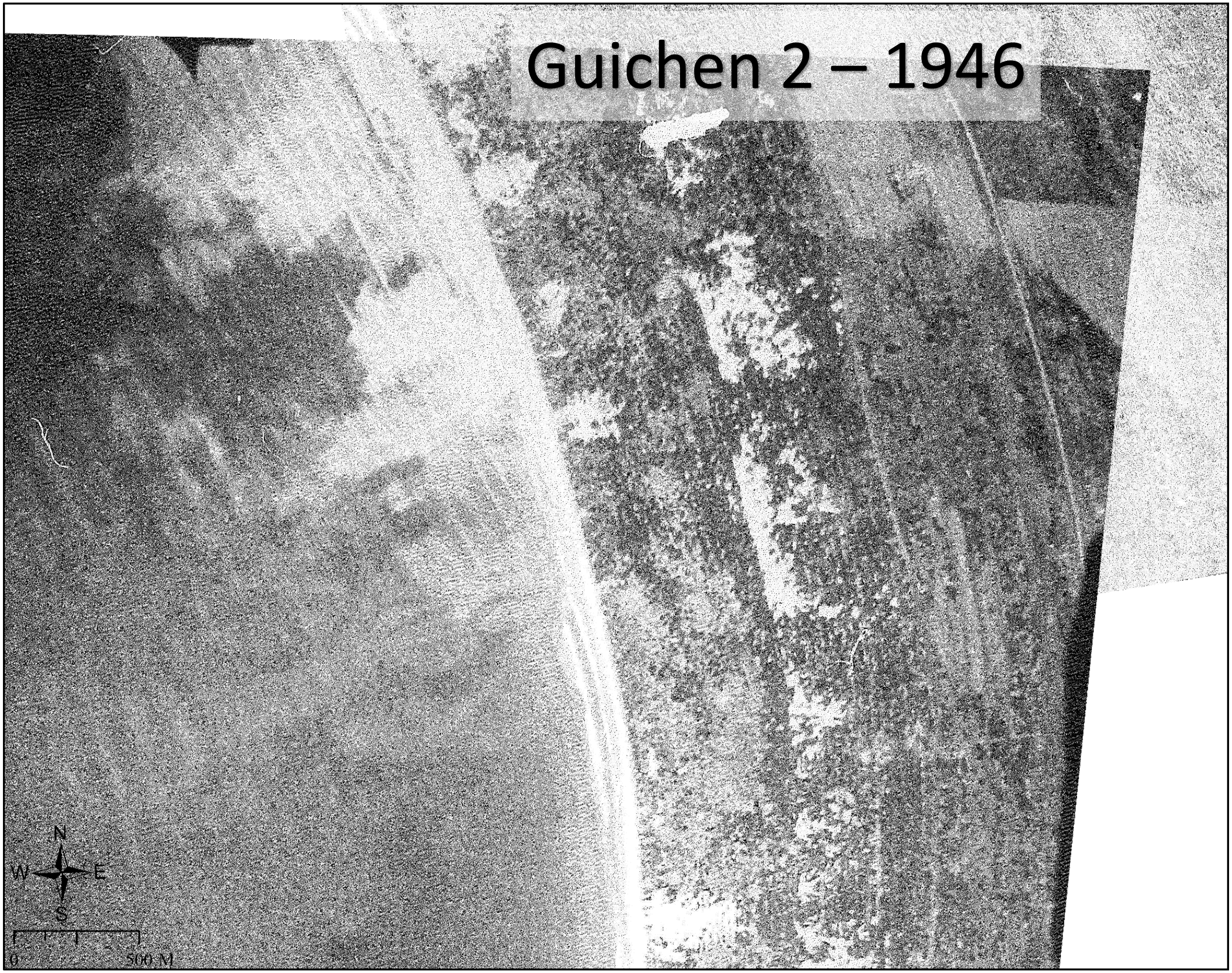

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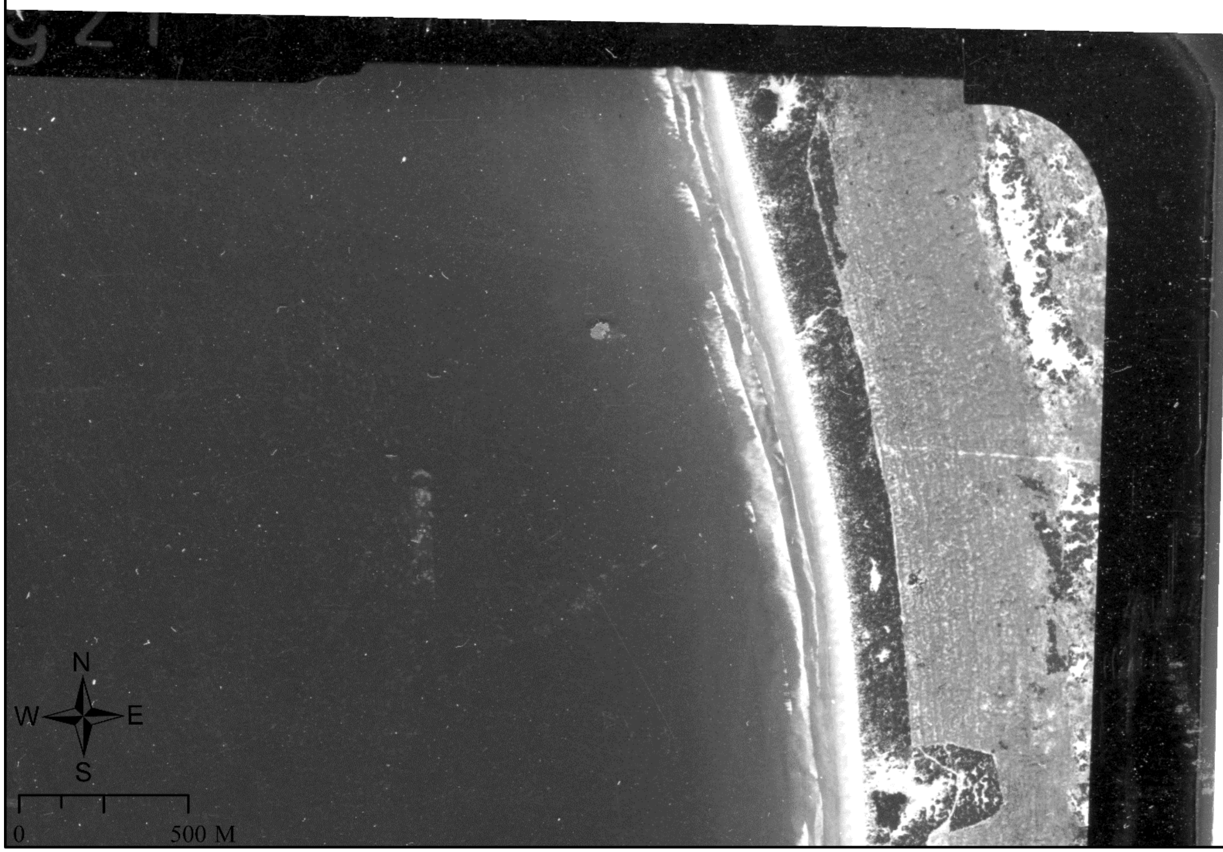
Guichen 2 – 1969



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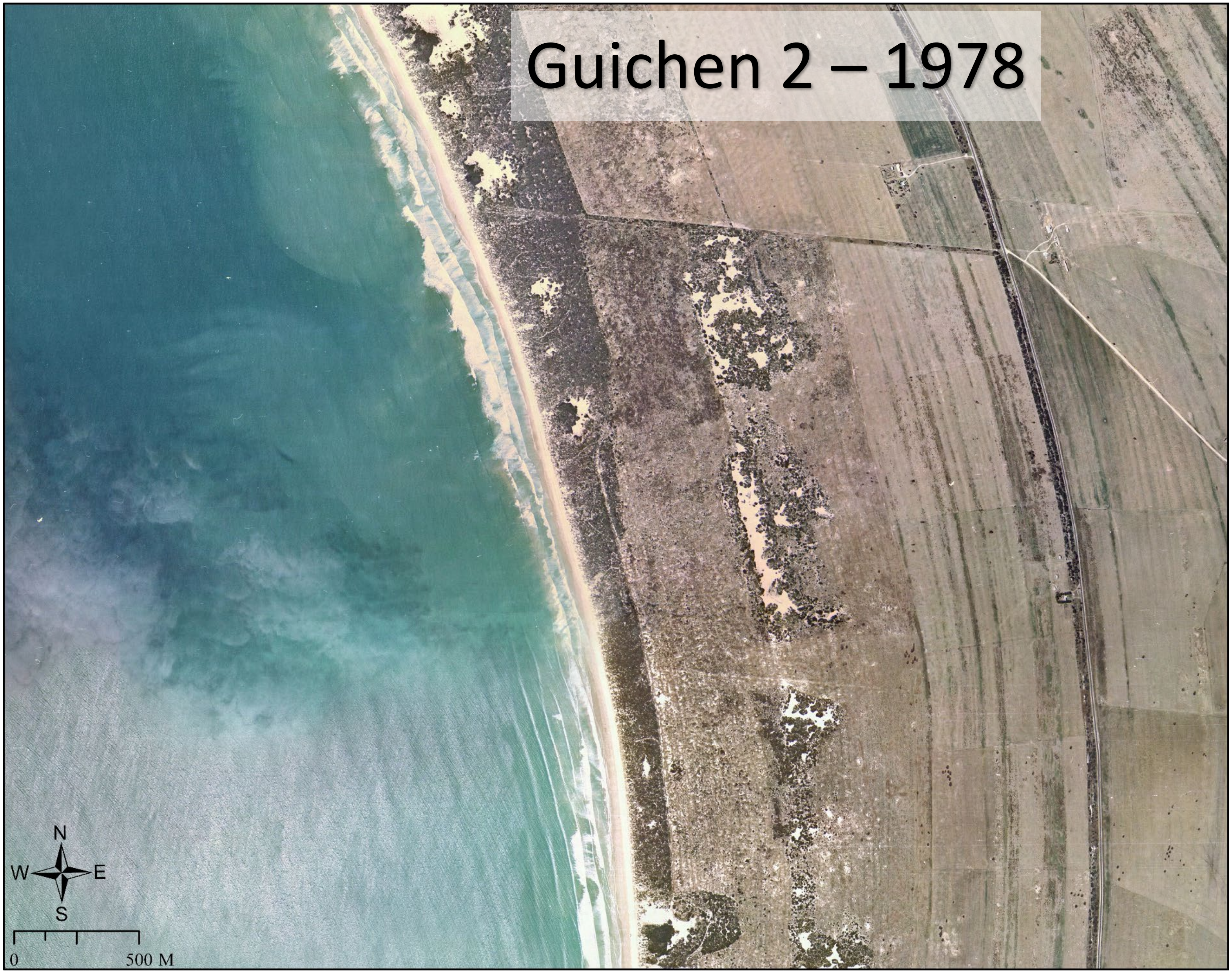

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Guichen 2 – 1982

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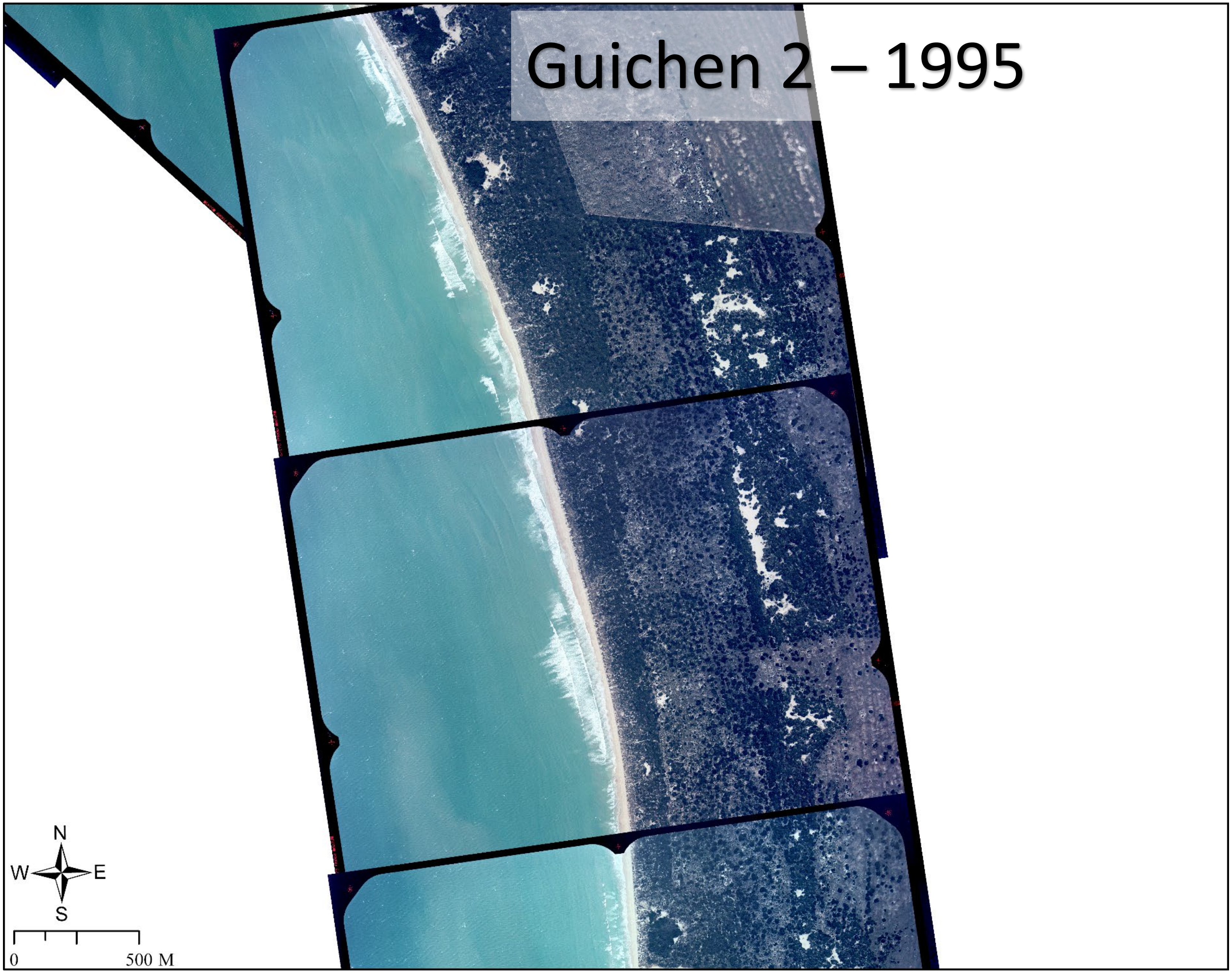

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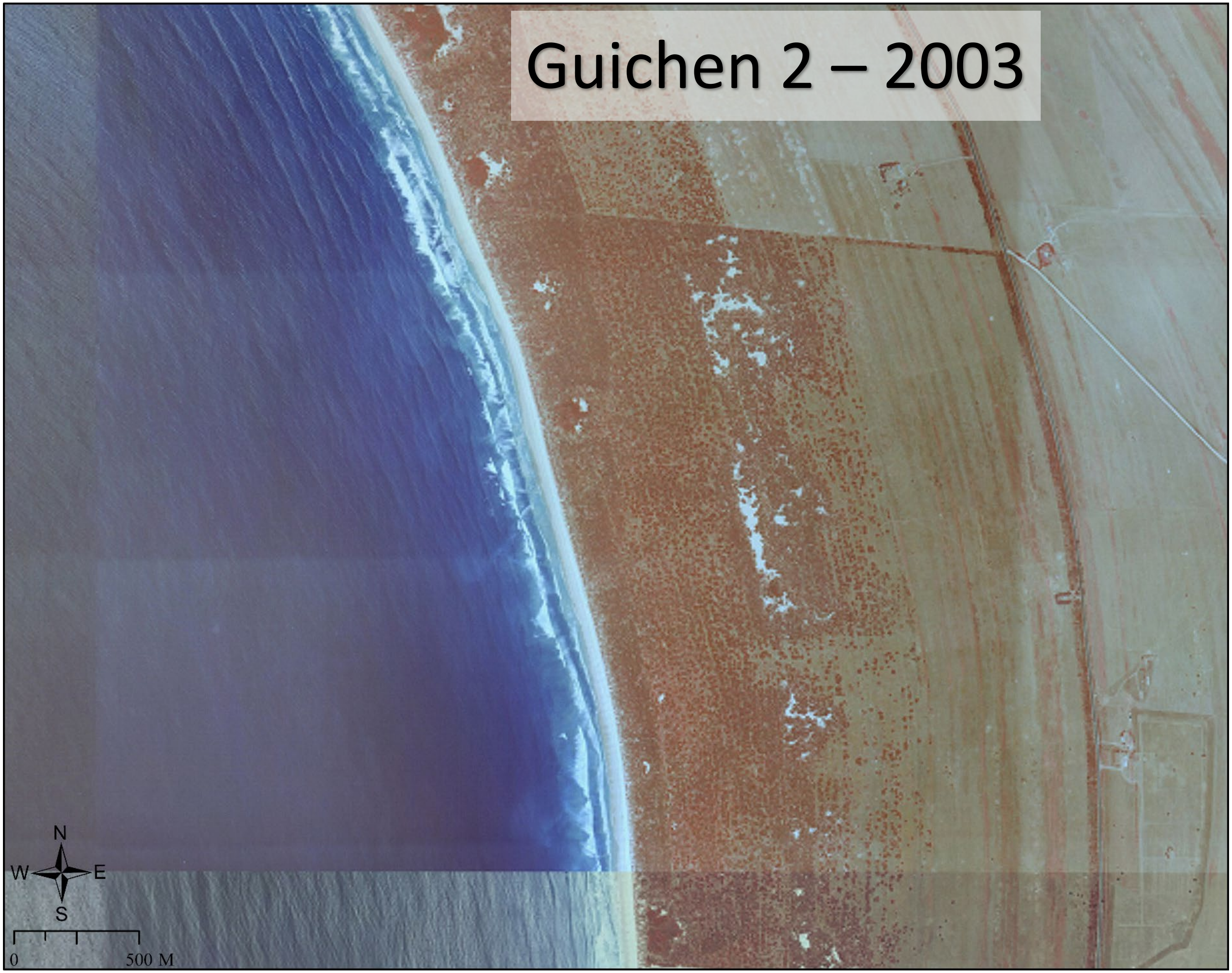

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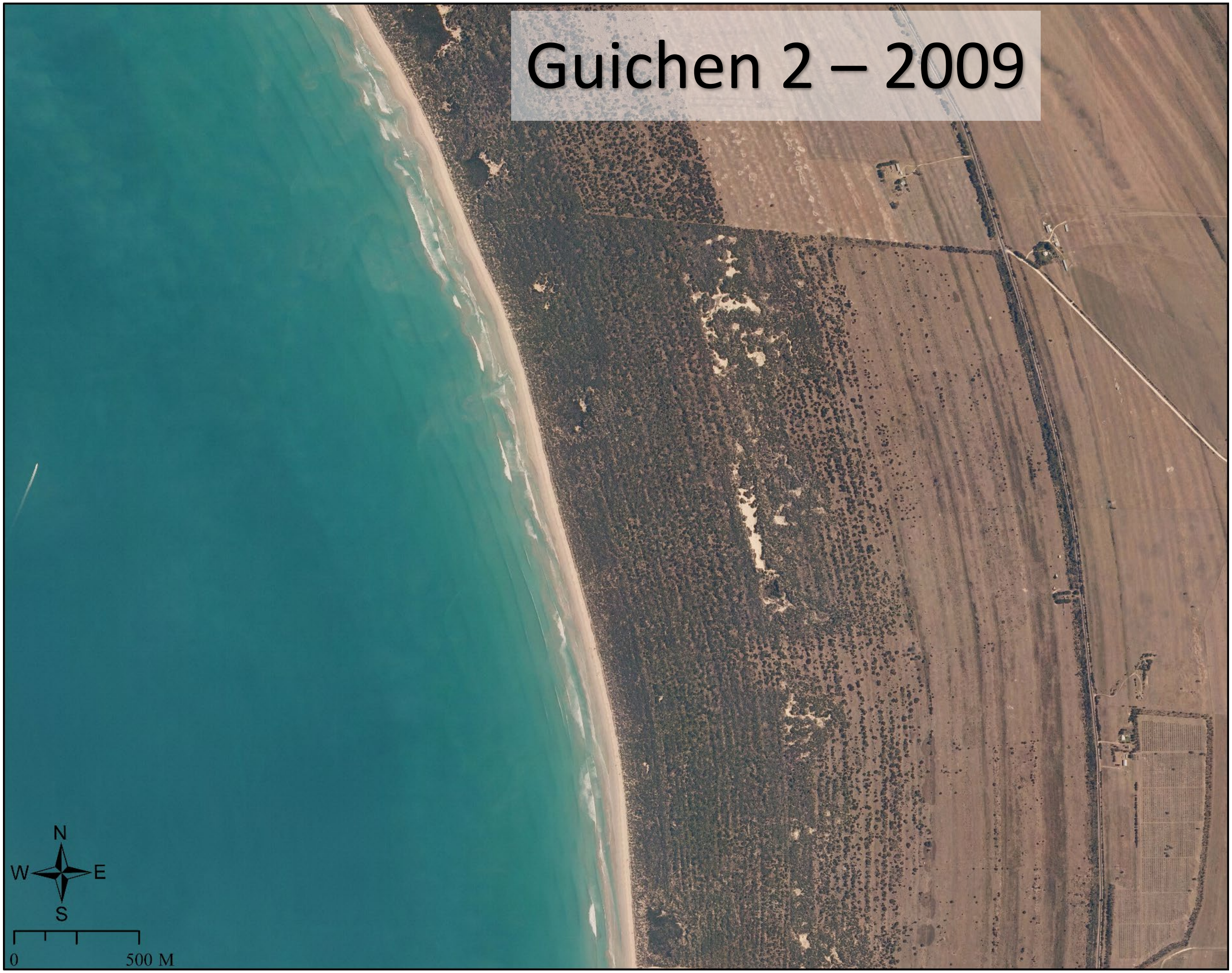

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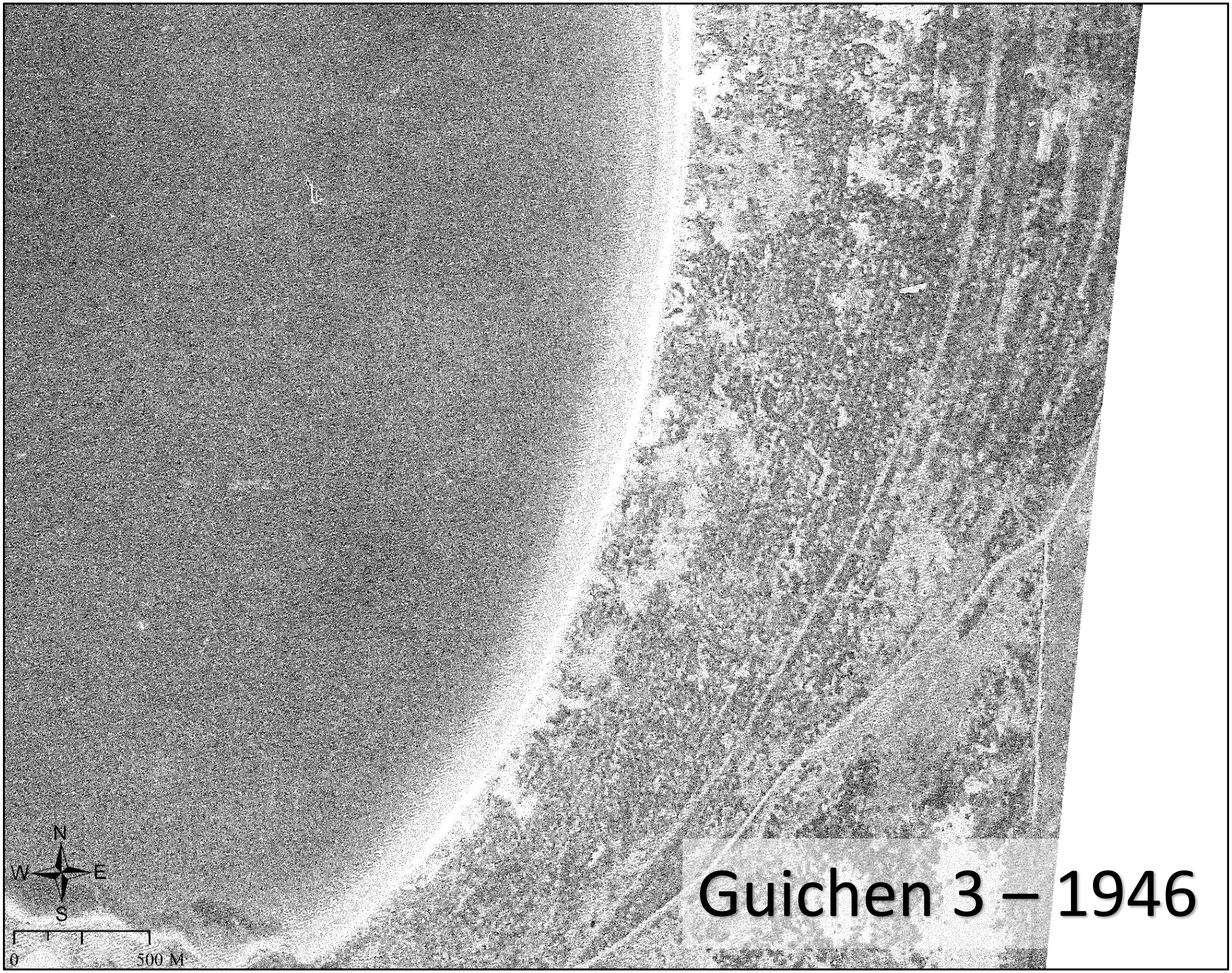

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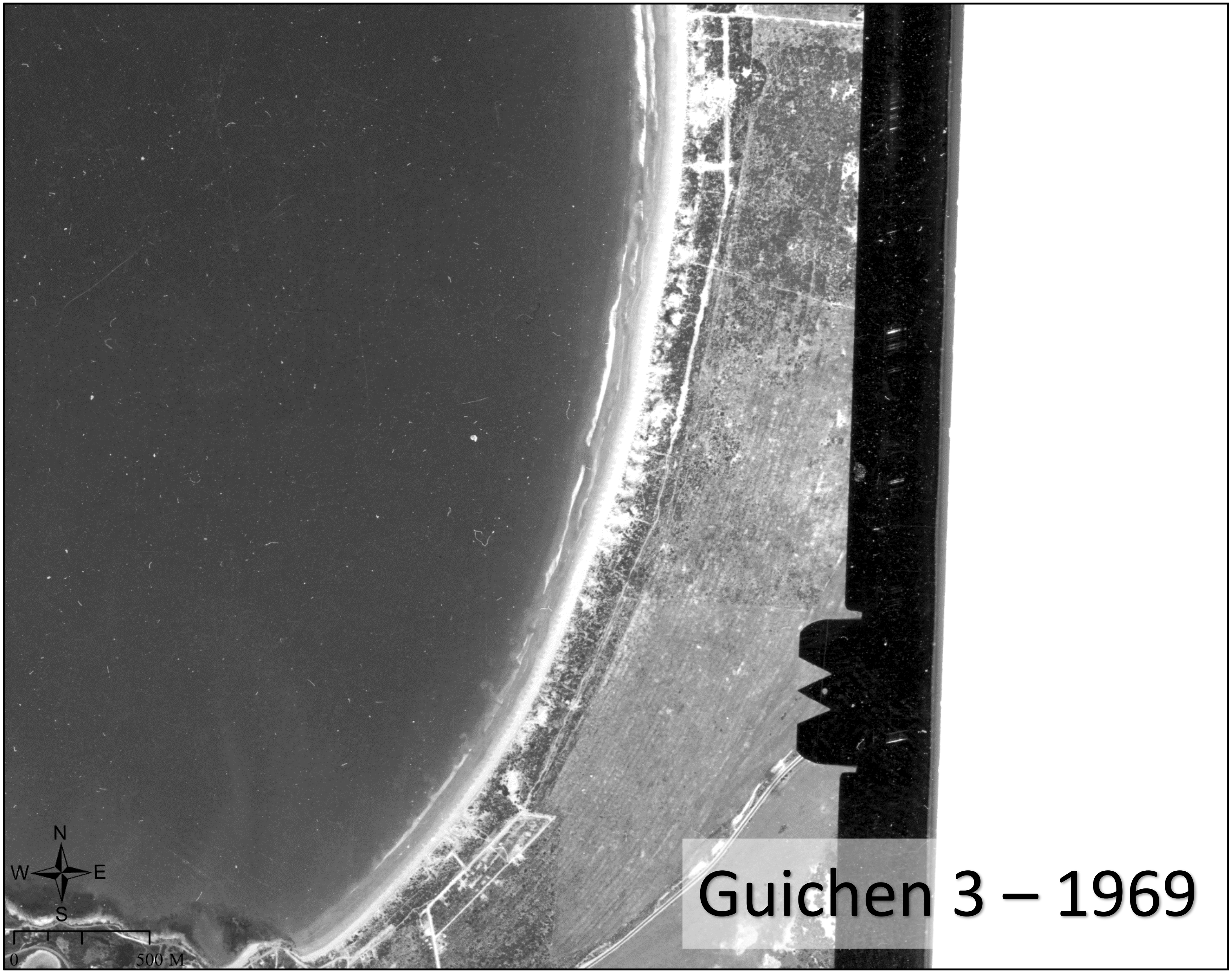

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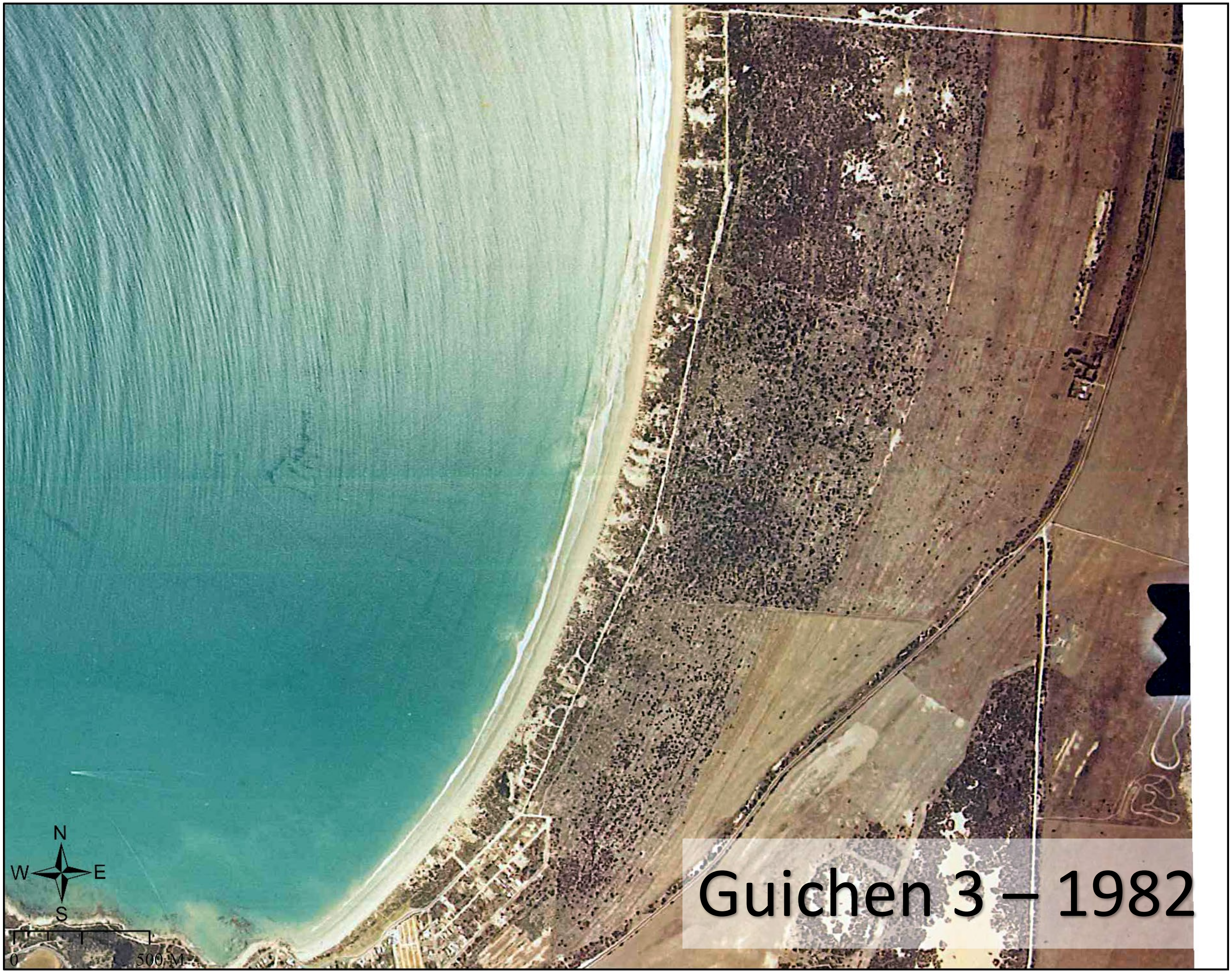

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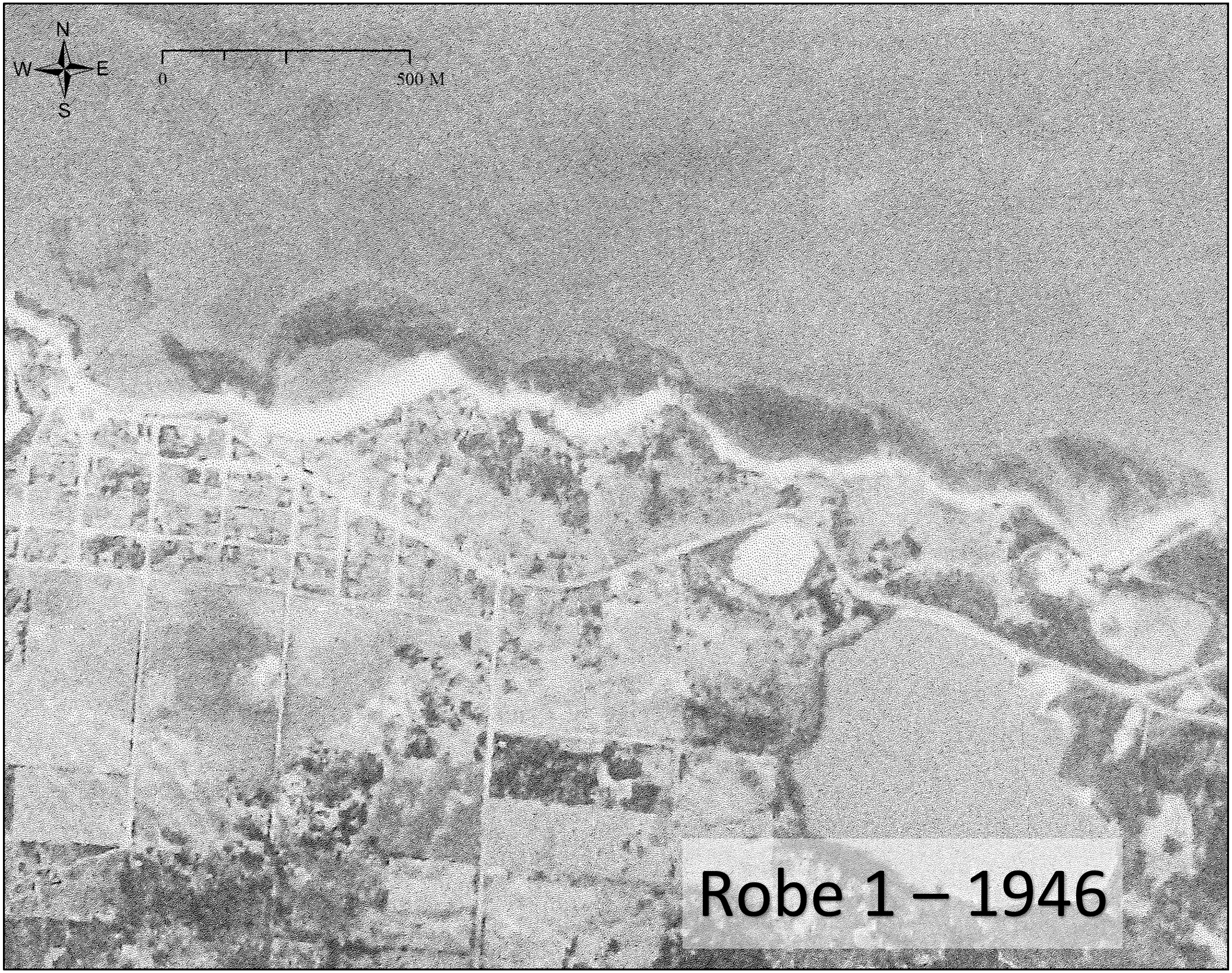

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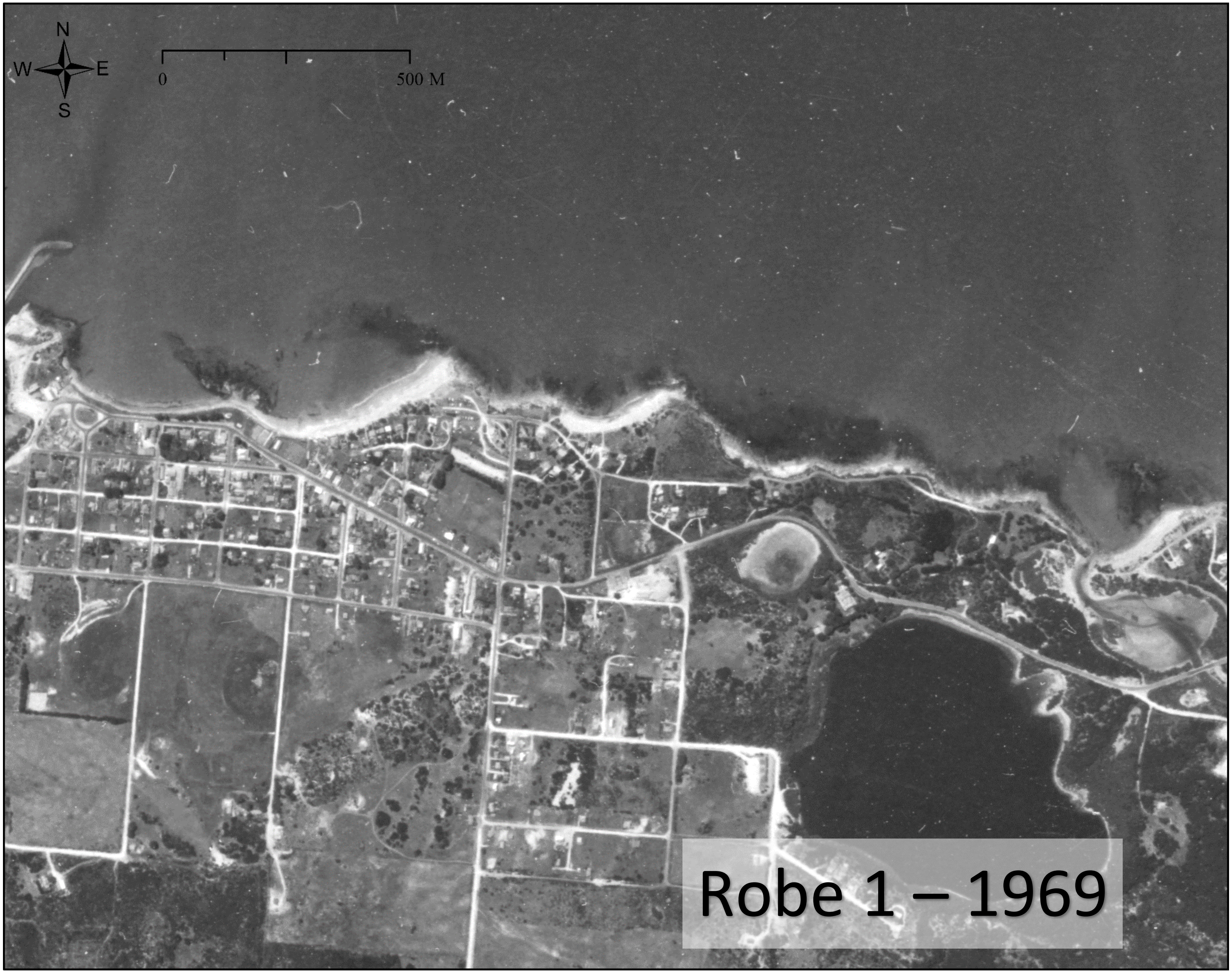

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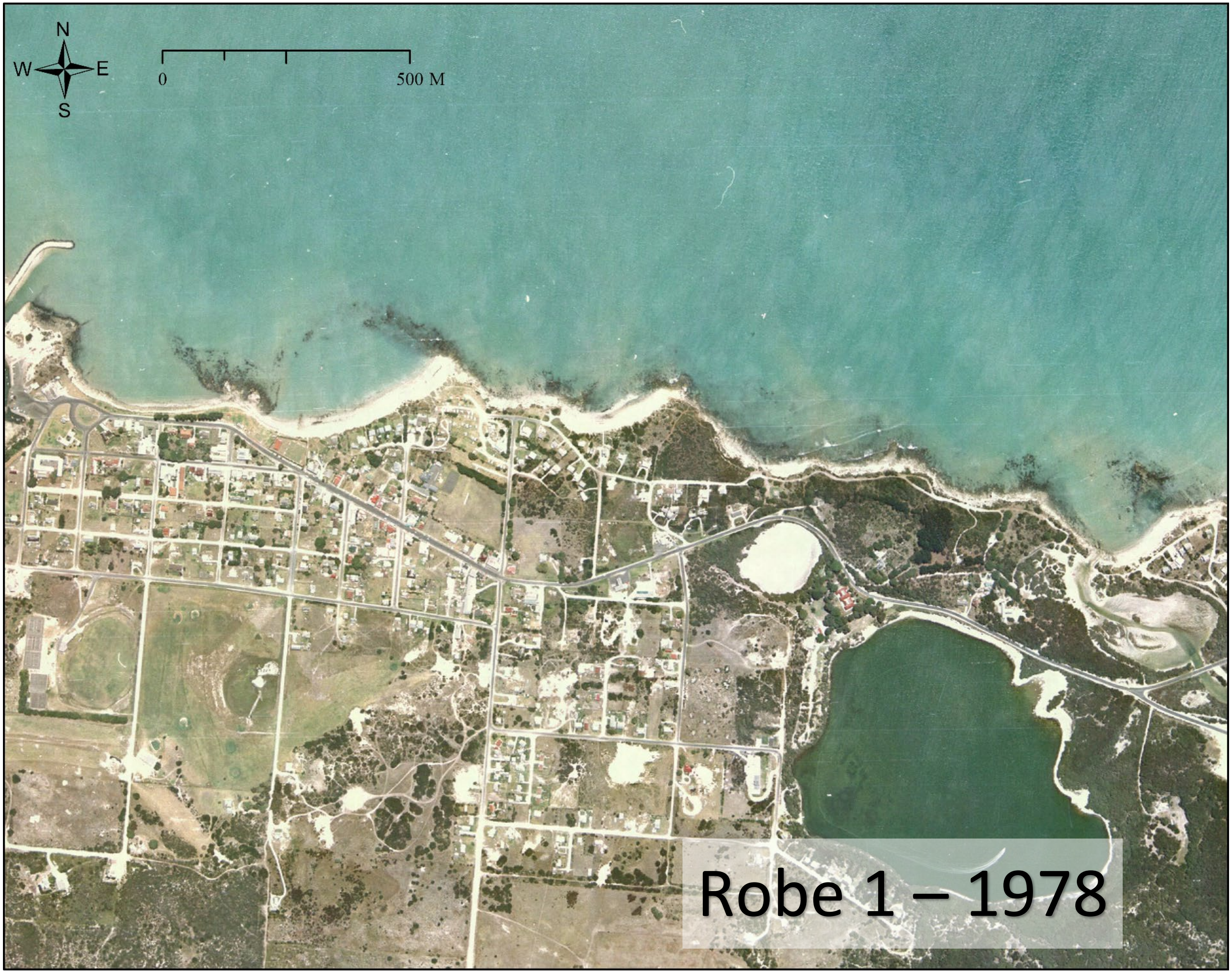

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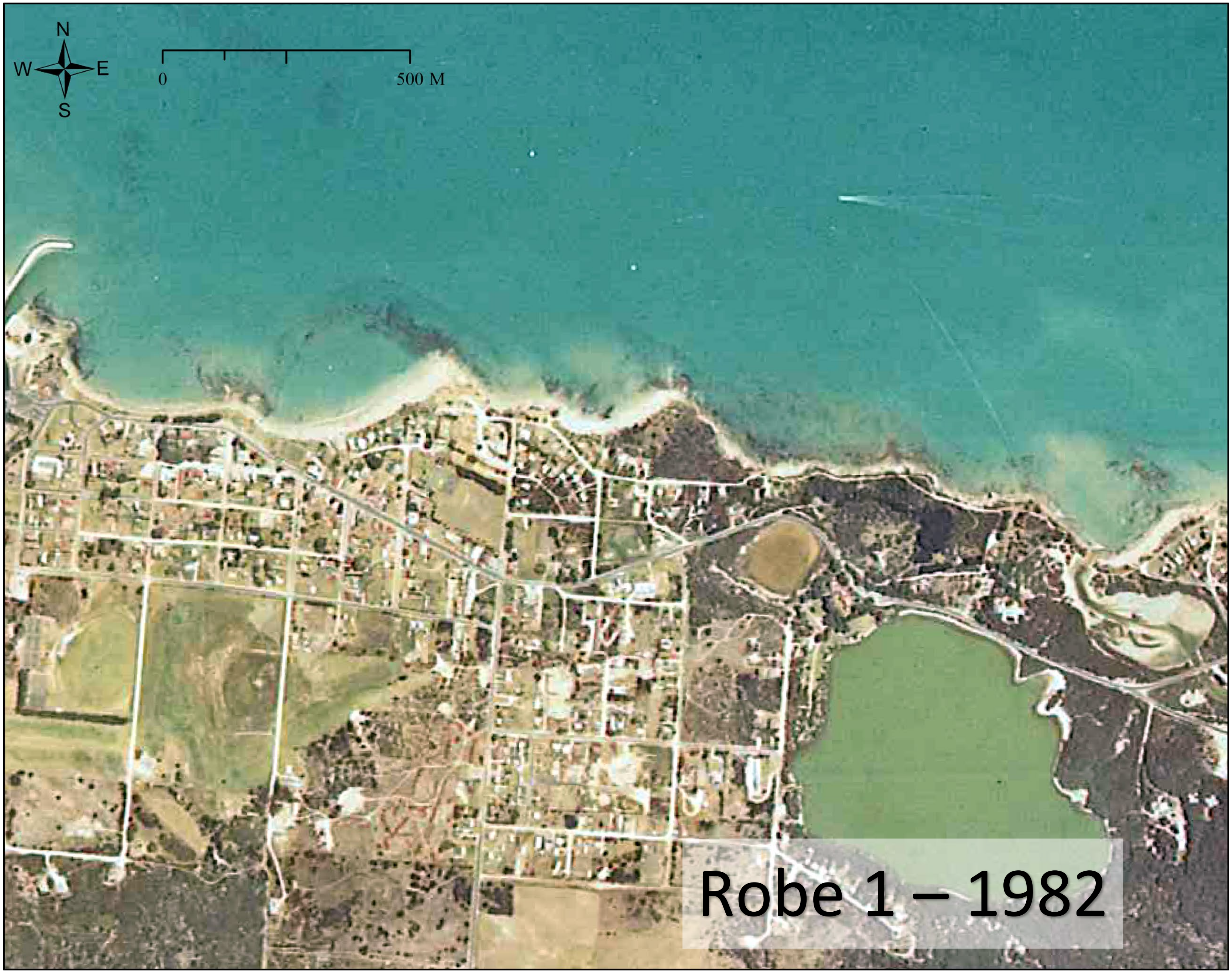

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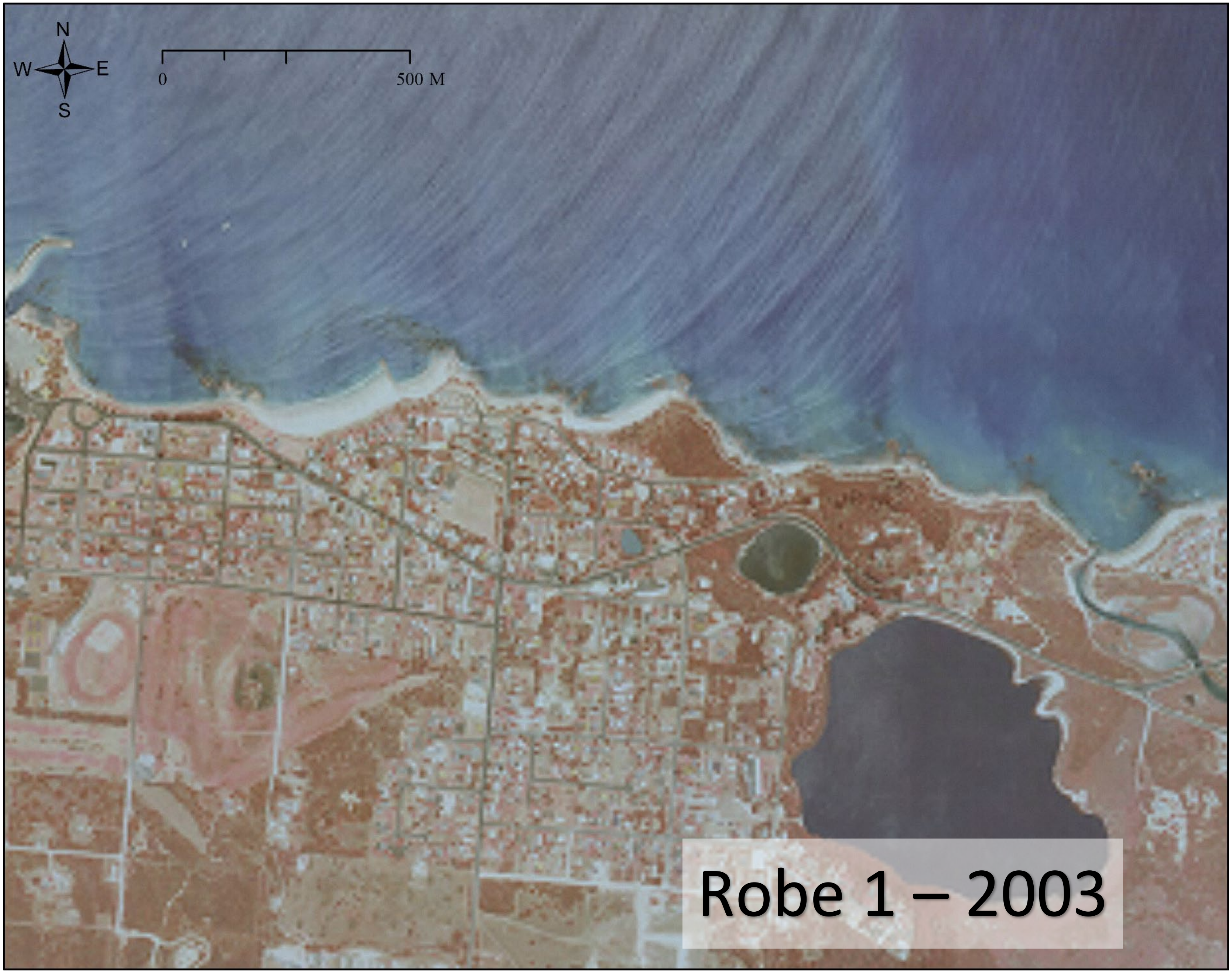

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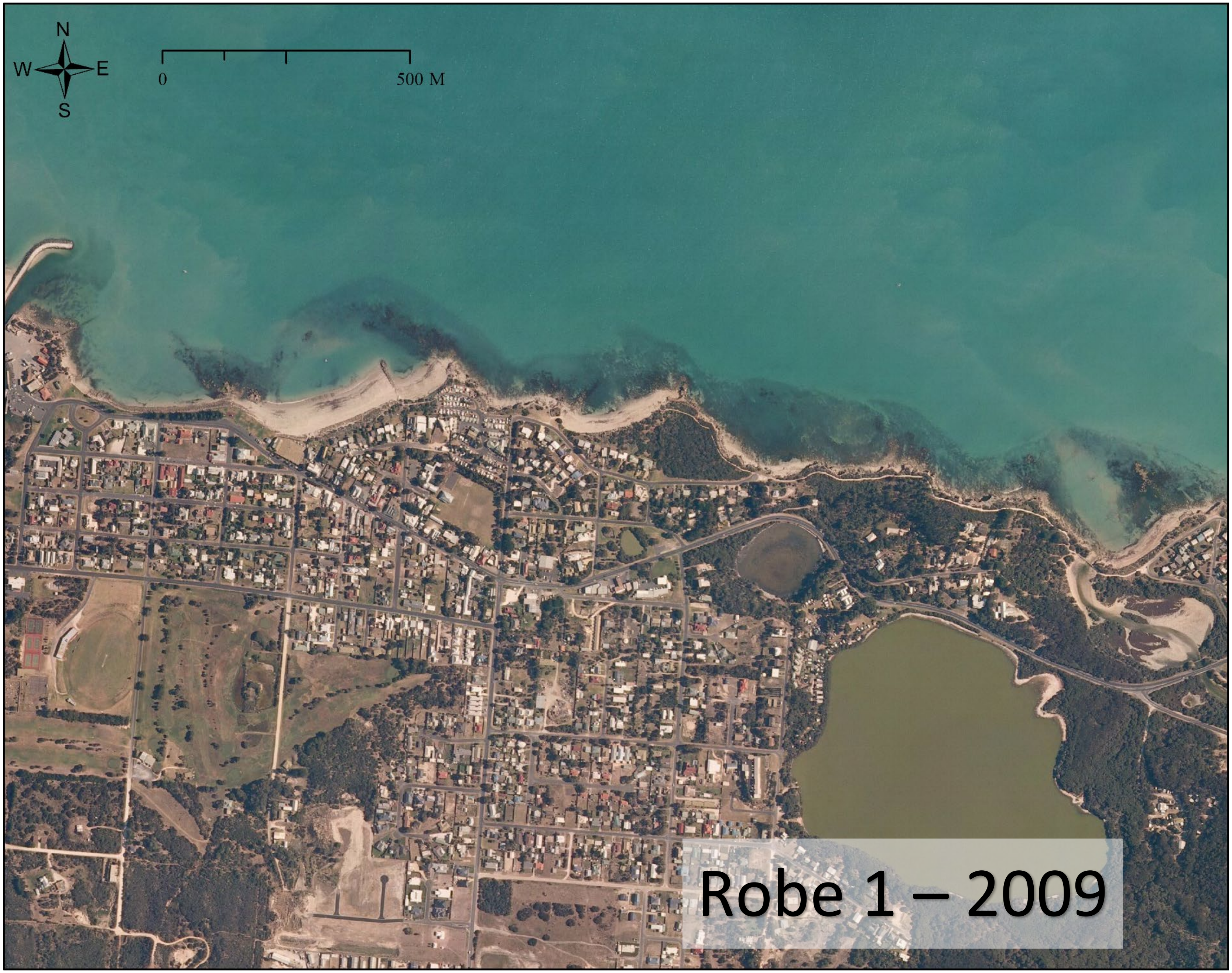

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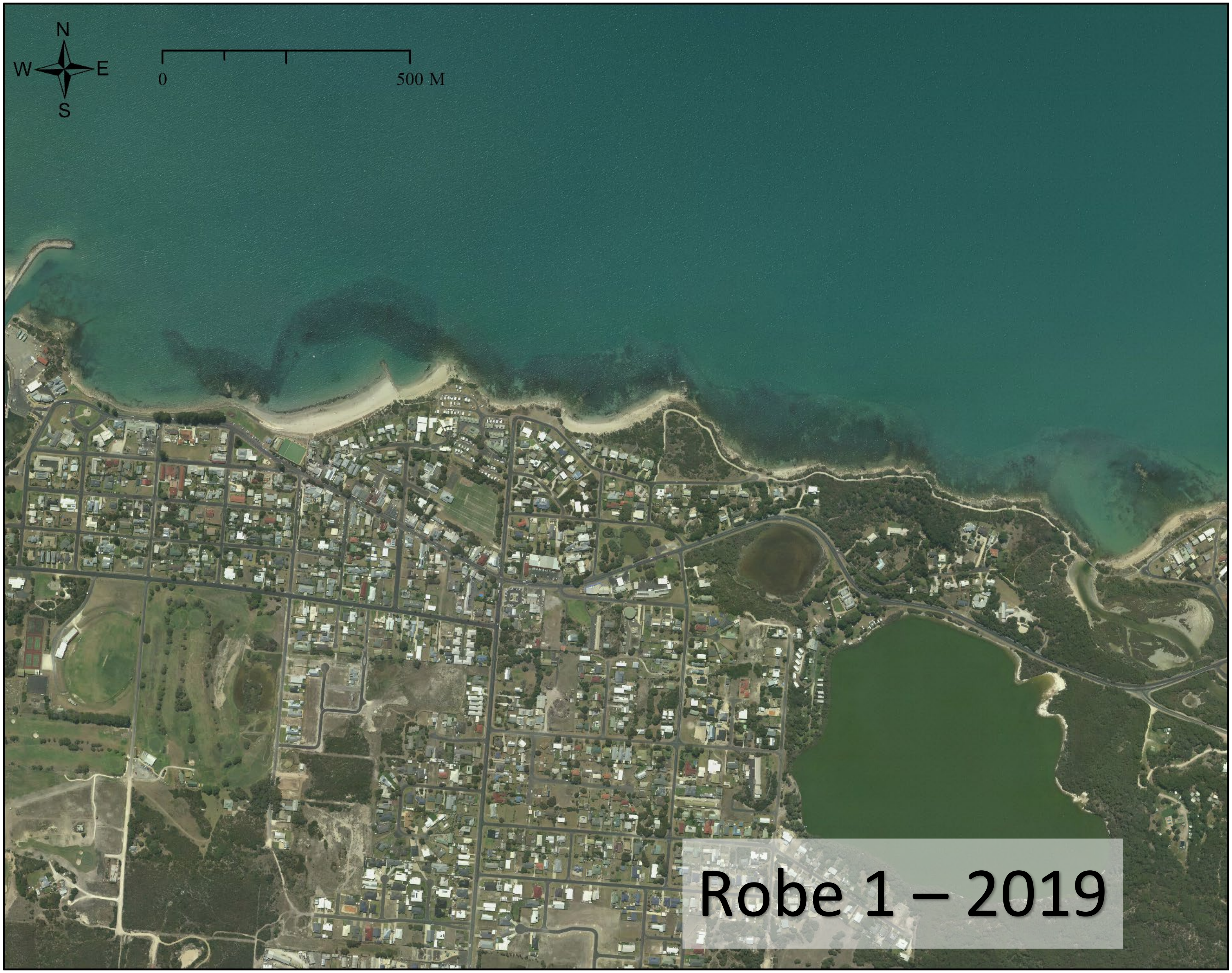

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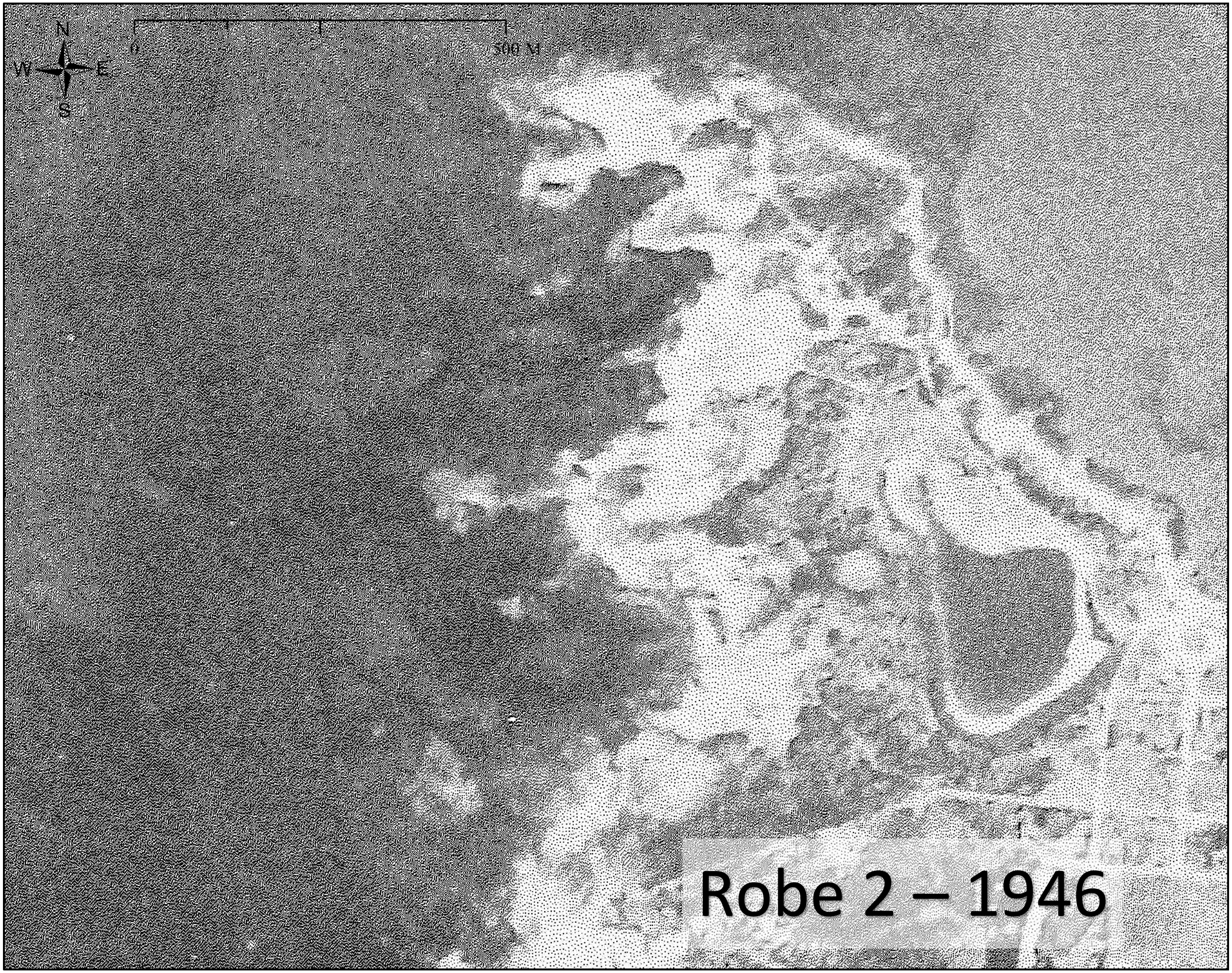

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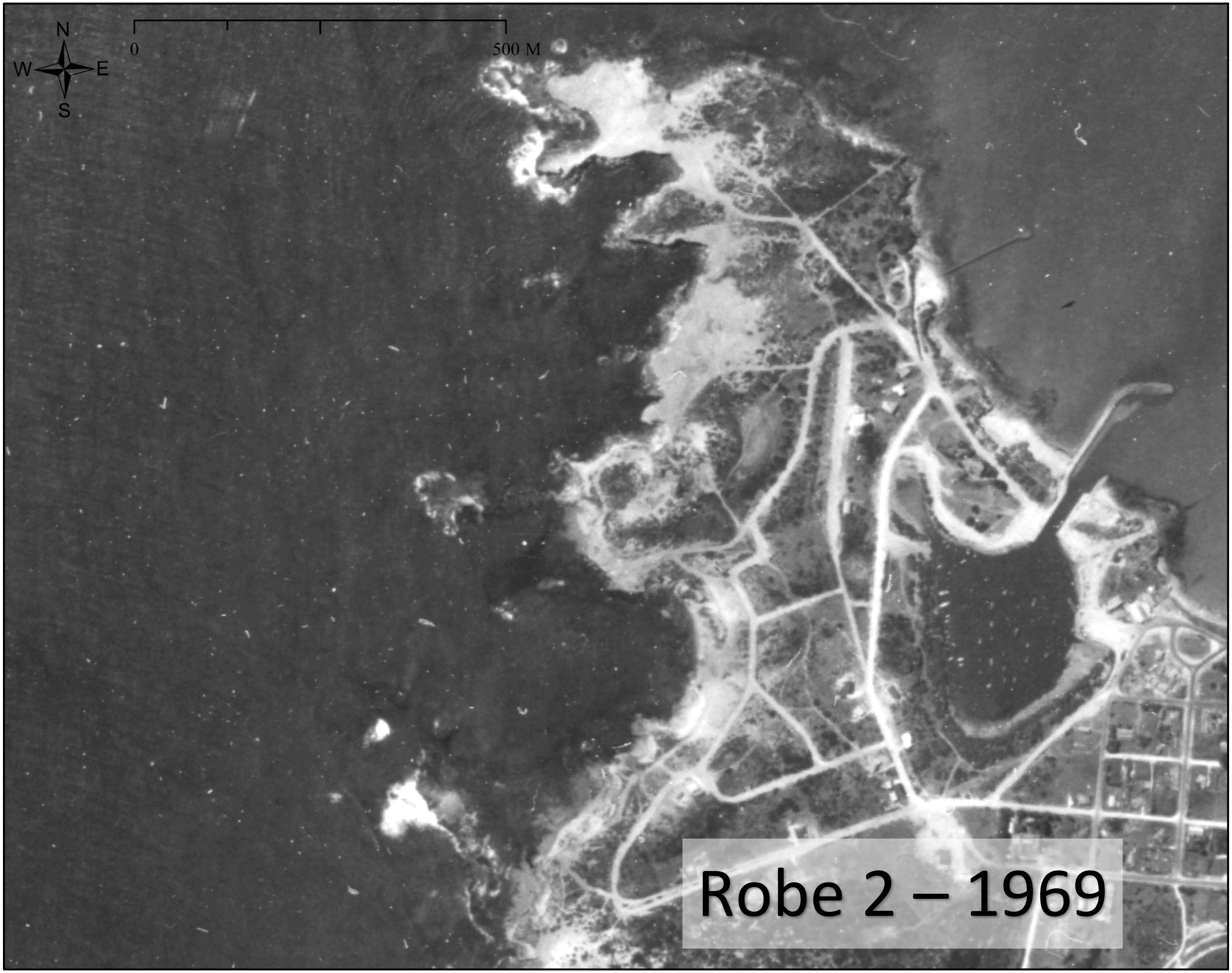

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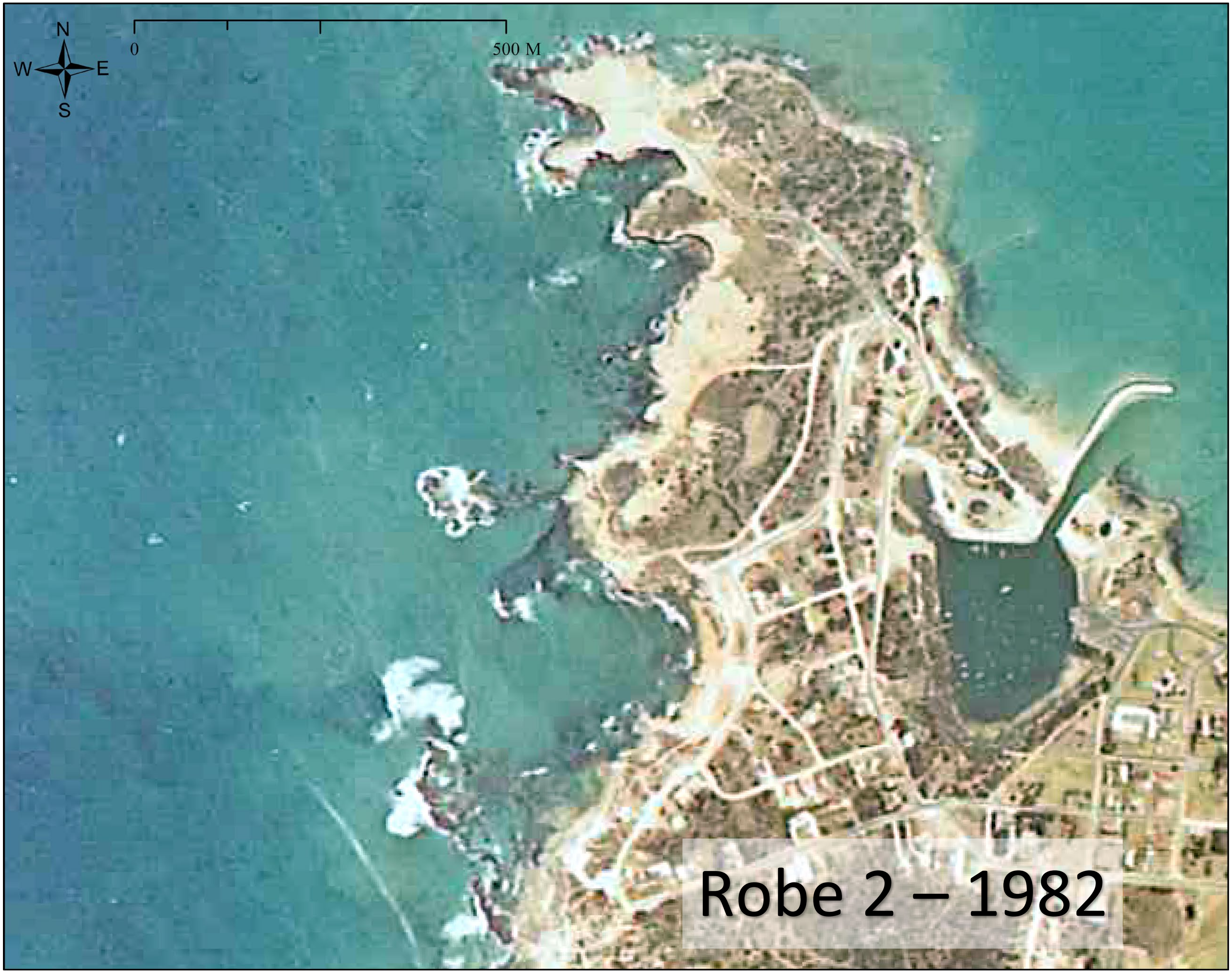

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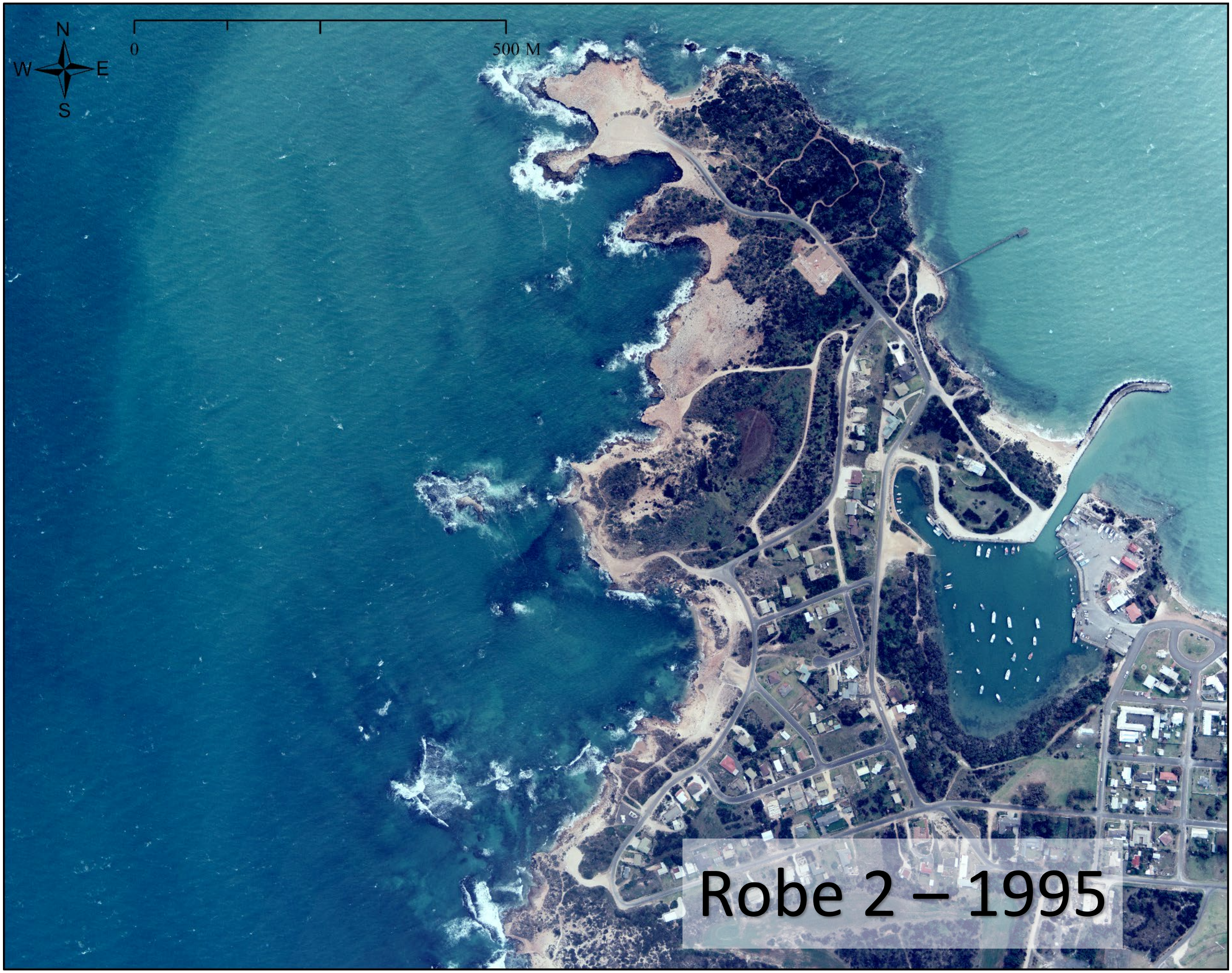

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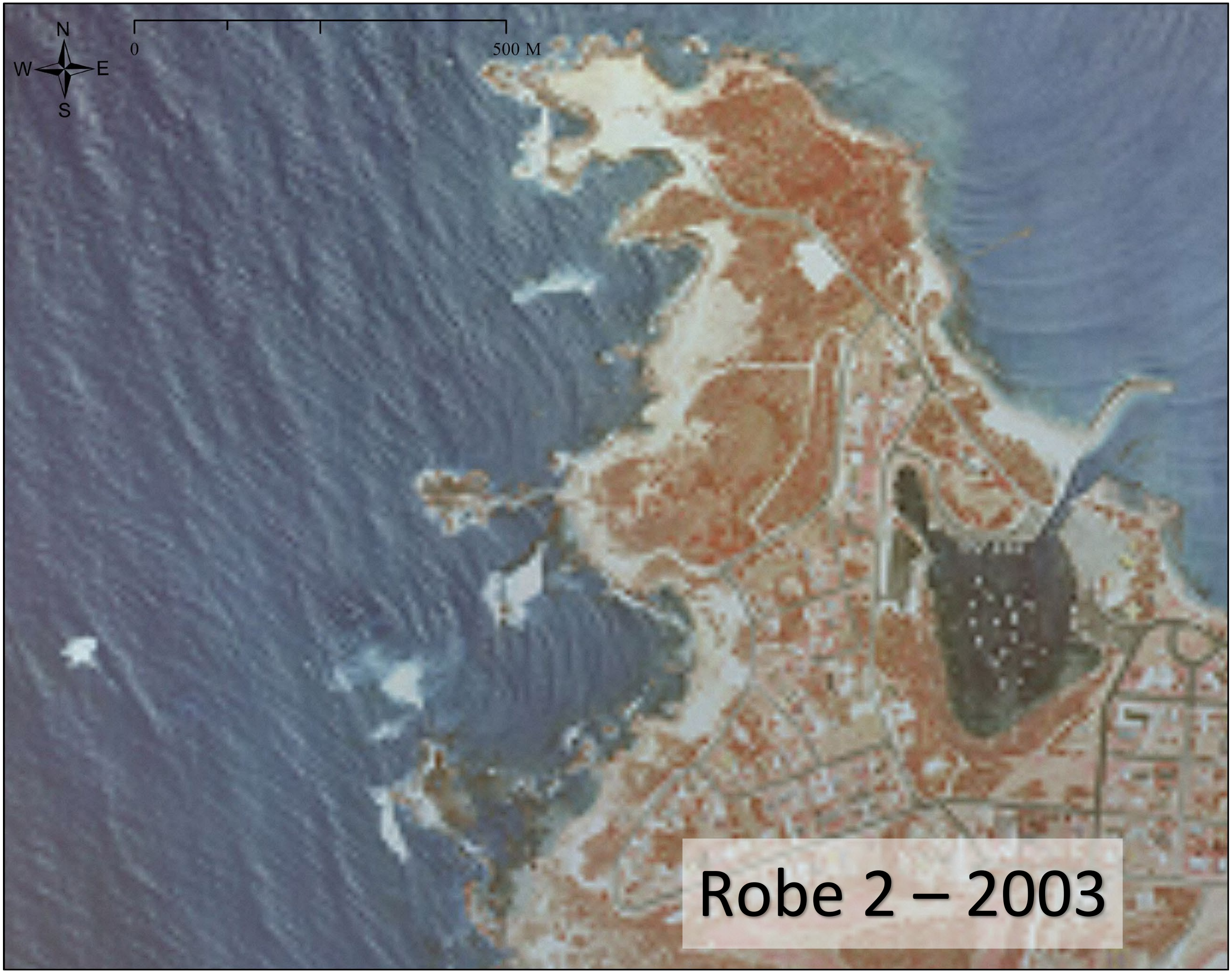

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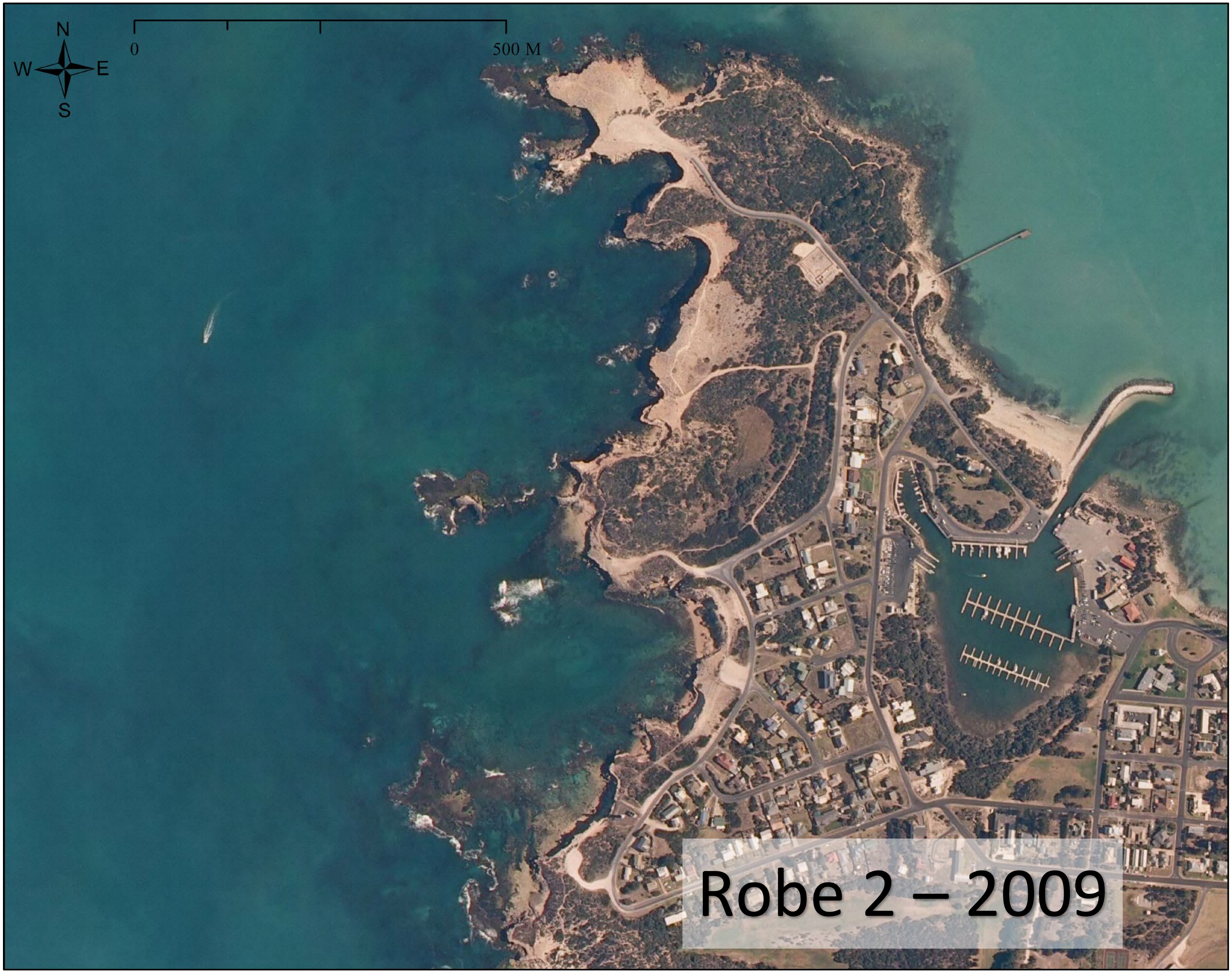

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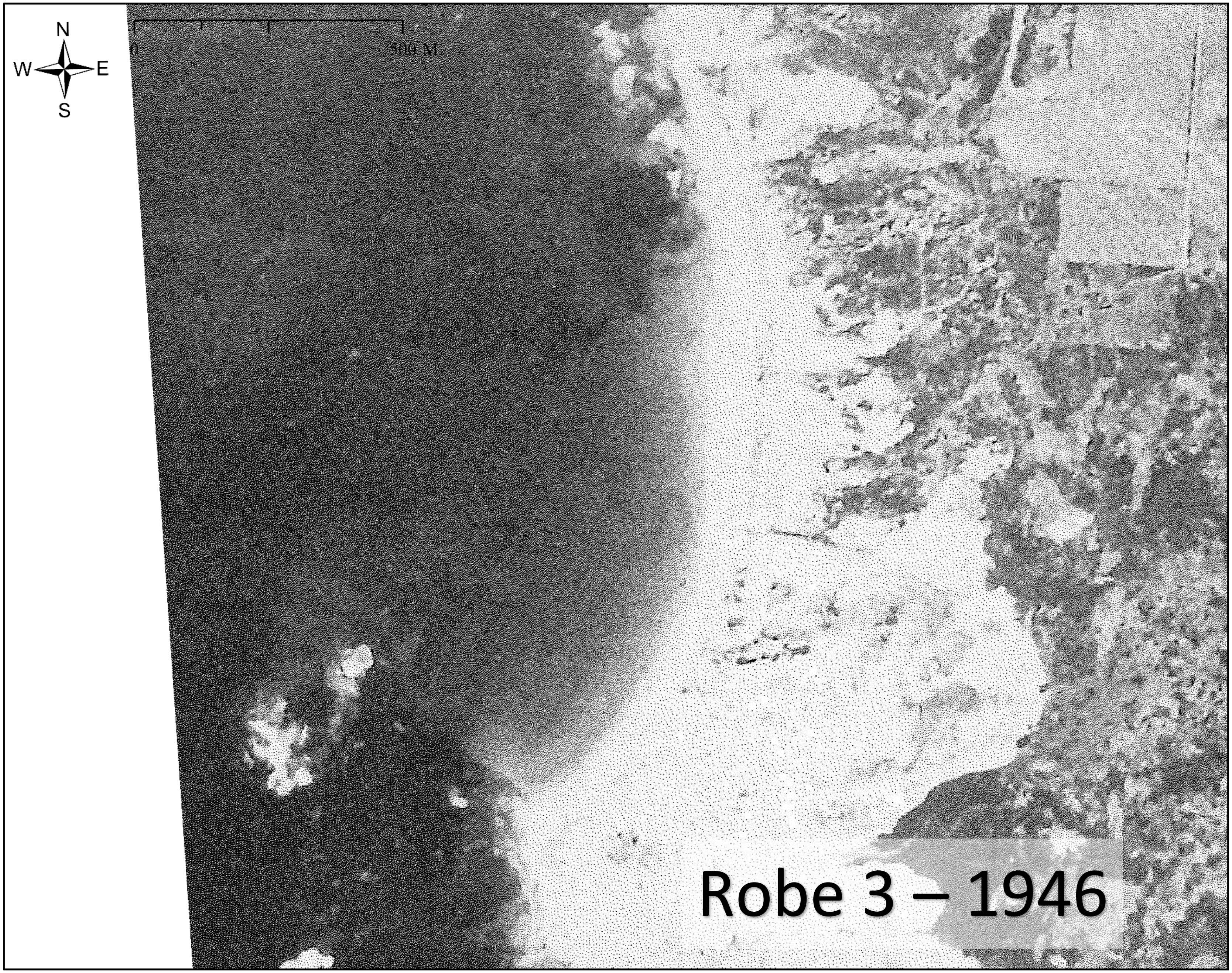

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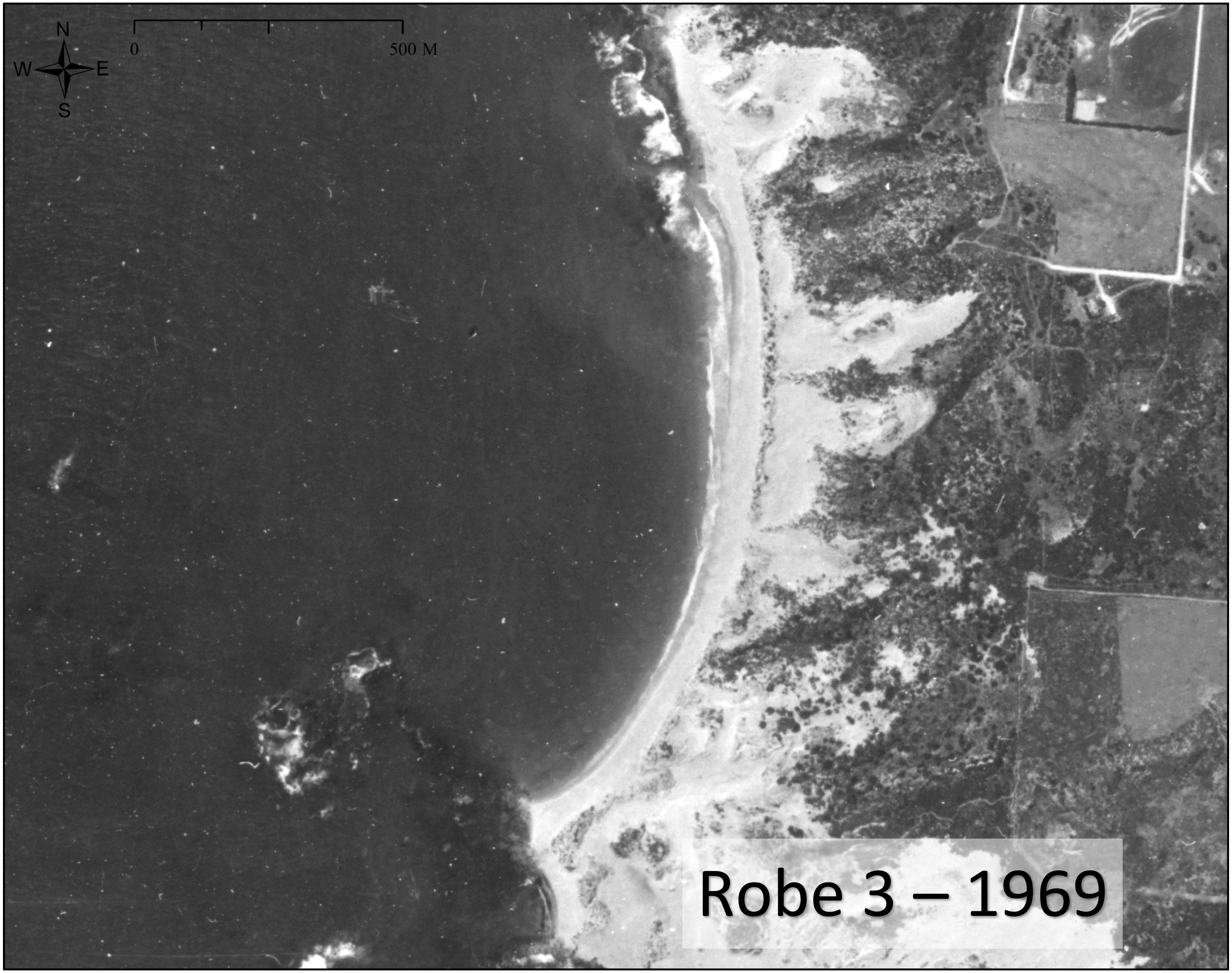

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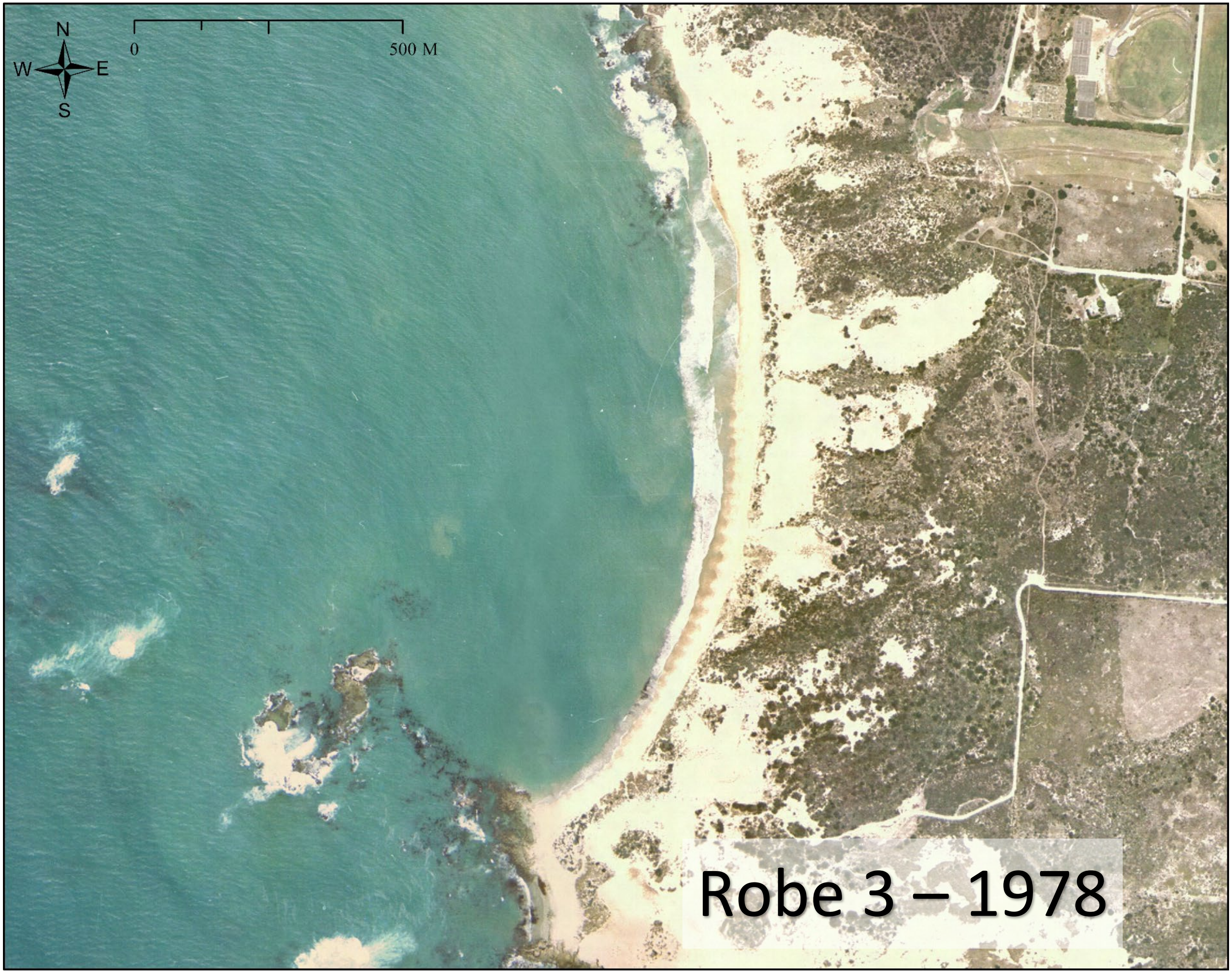

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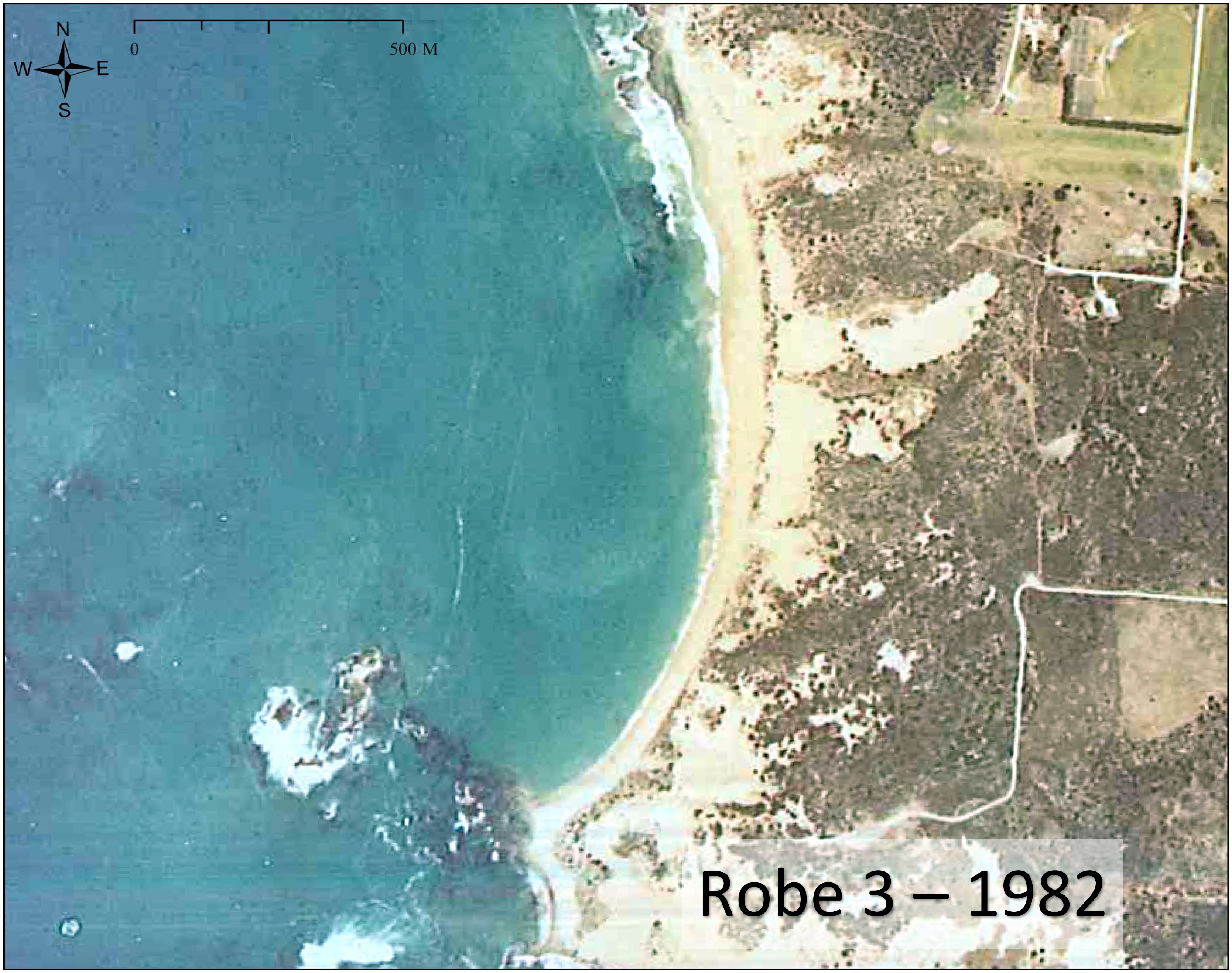

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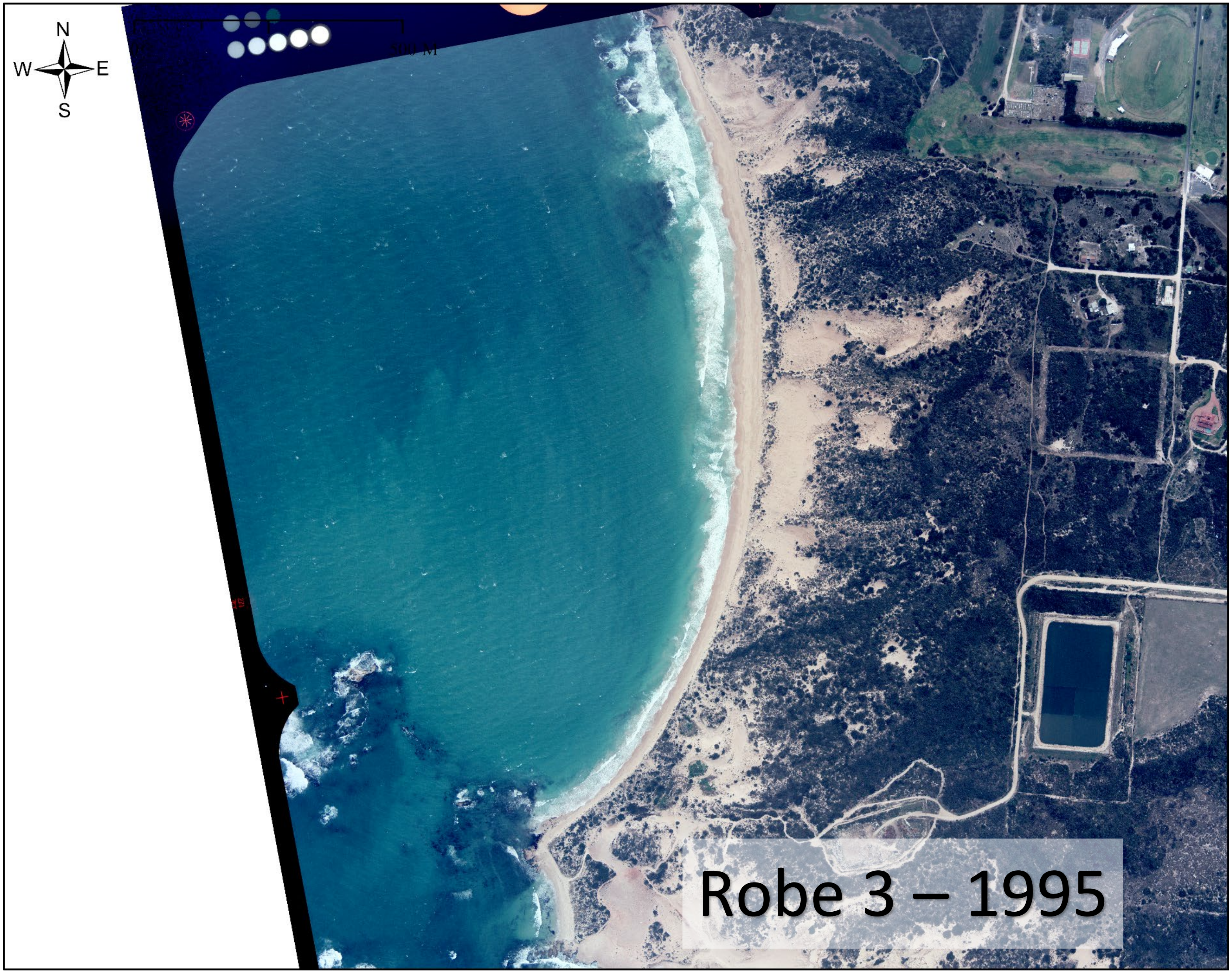

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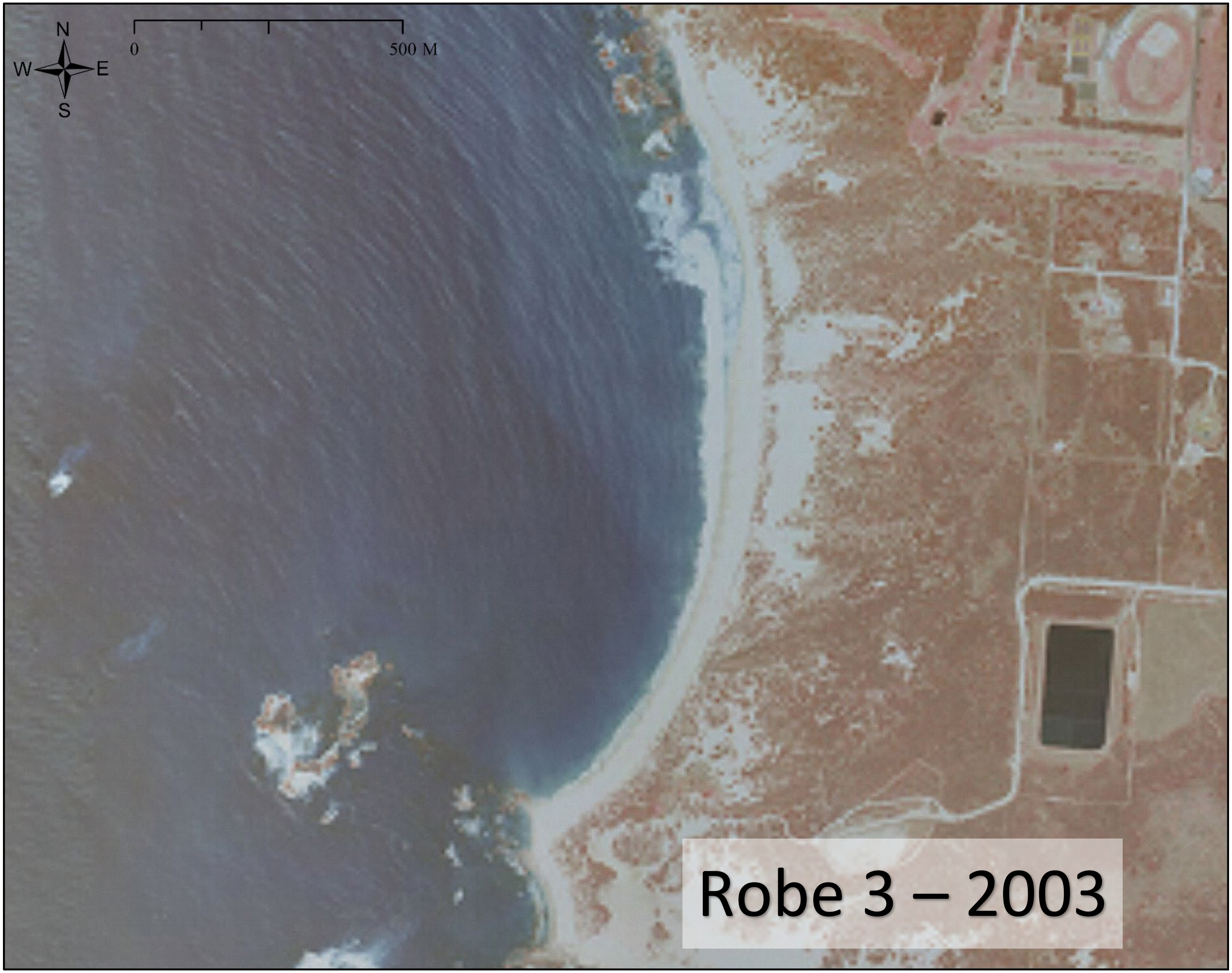

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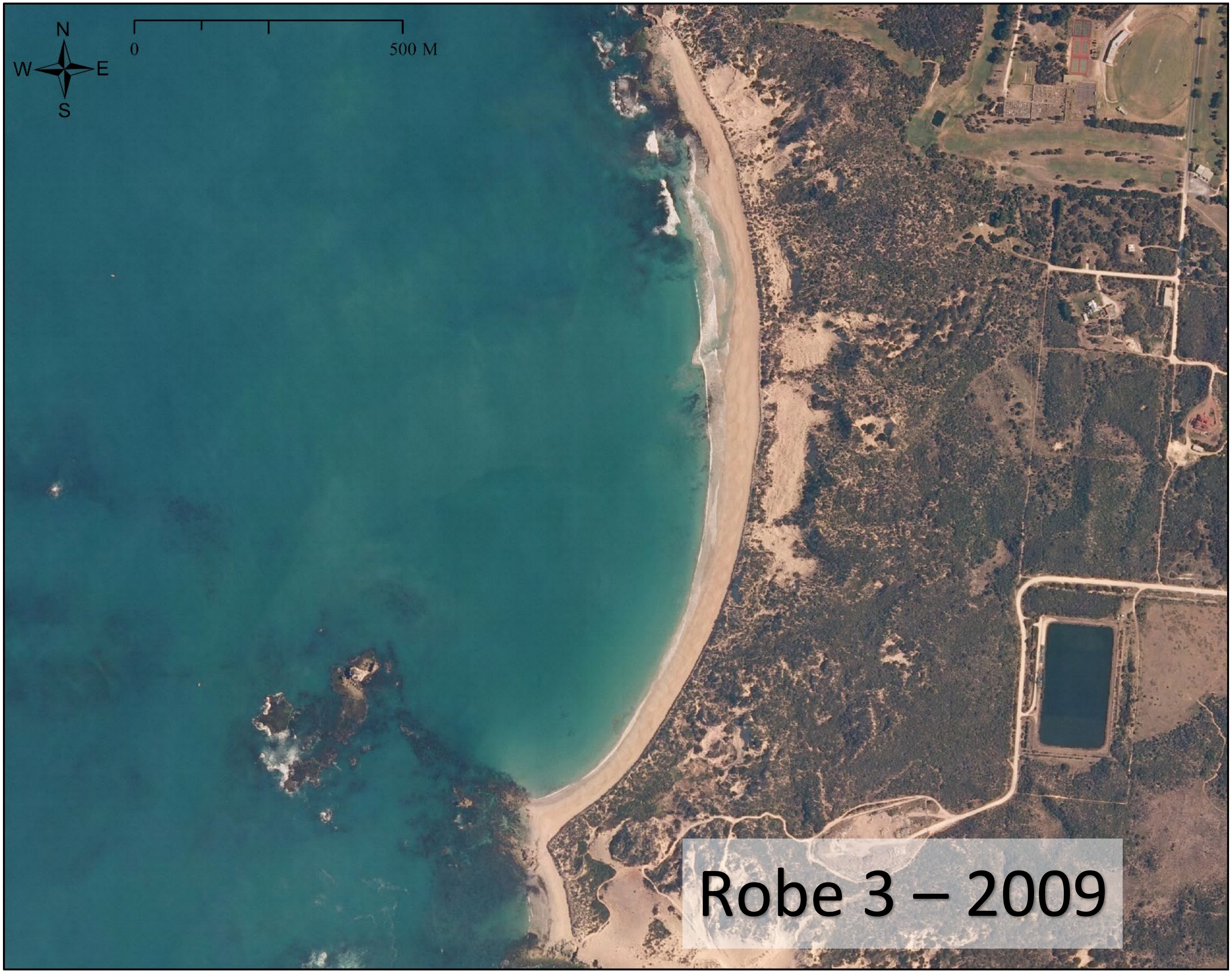

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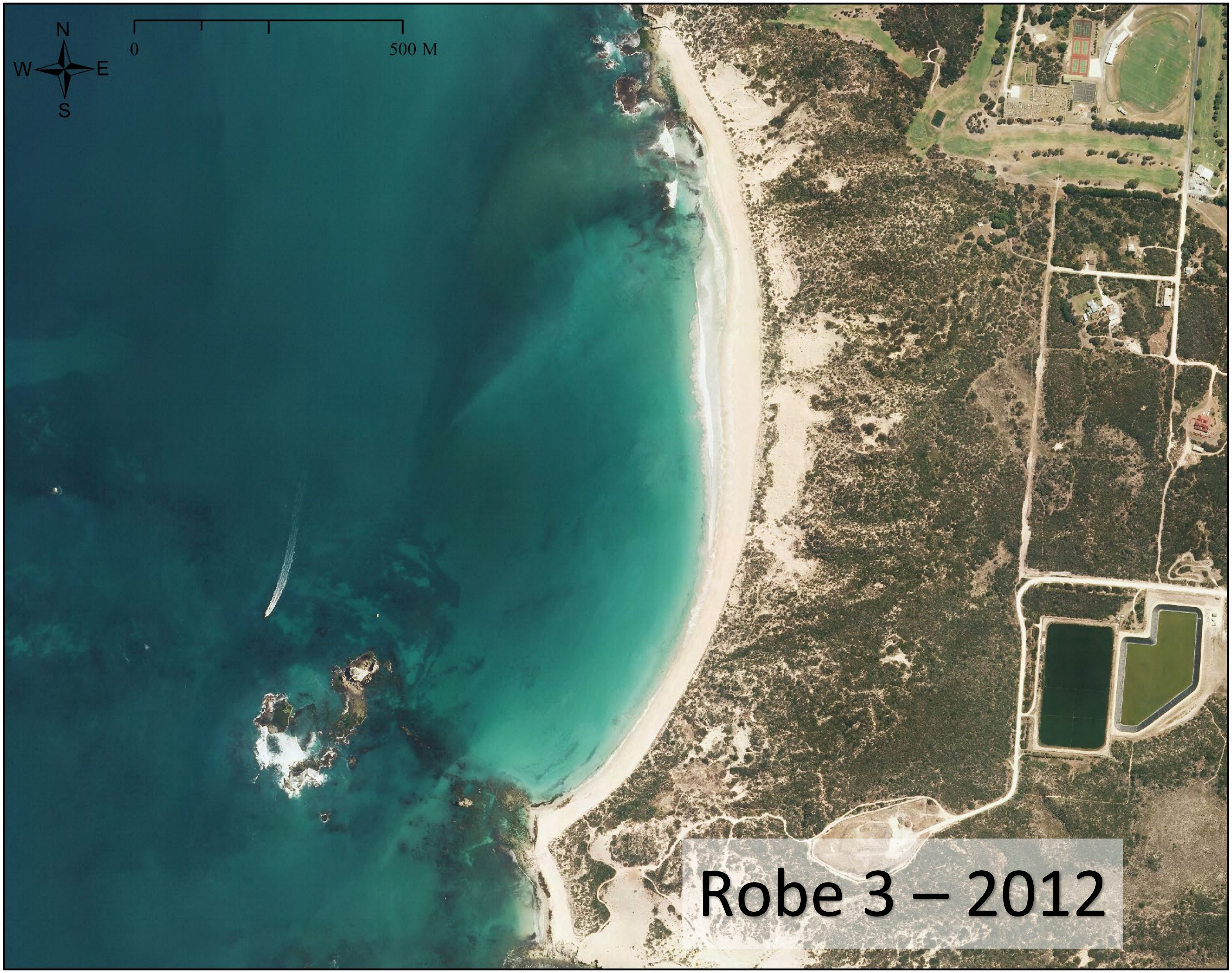

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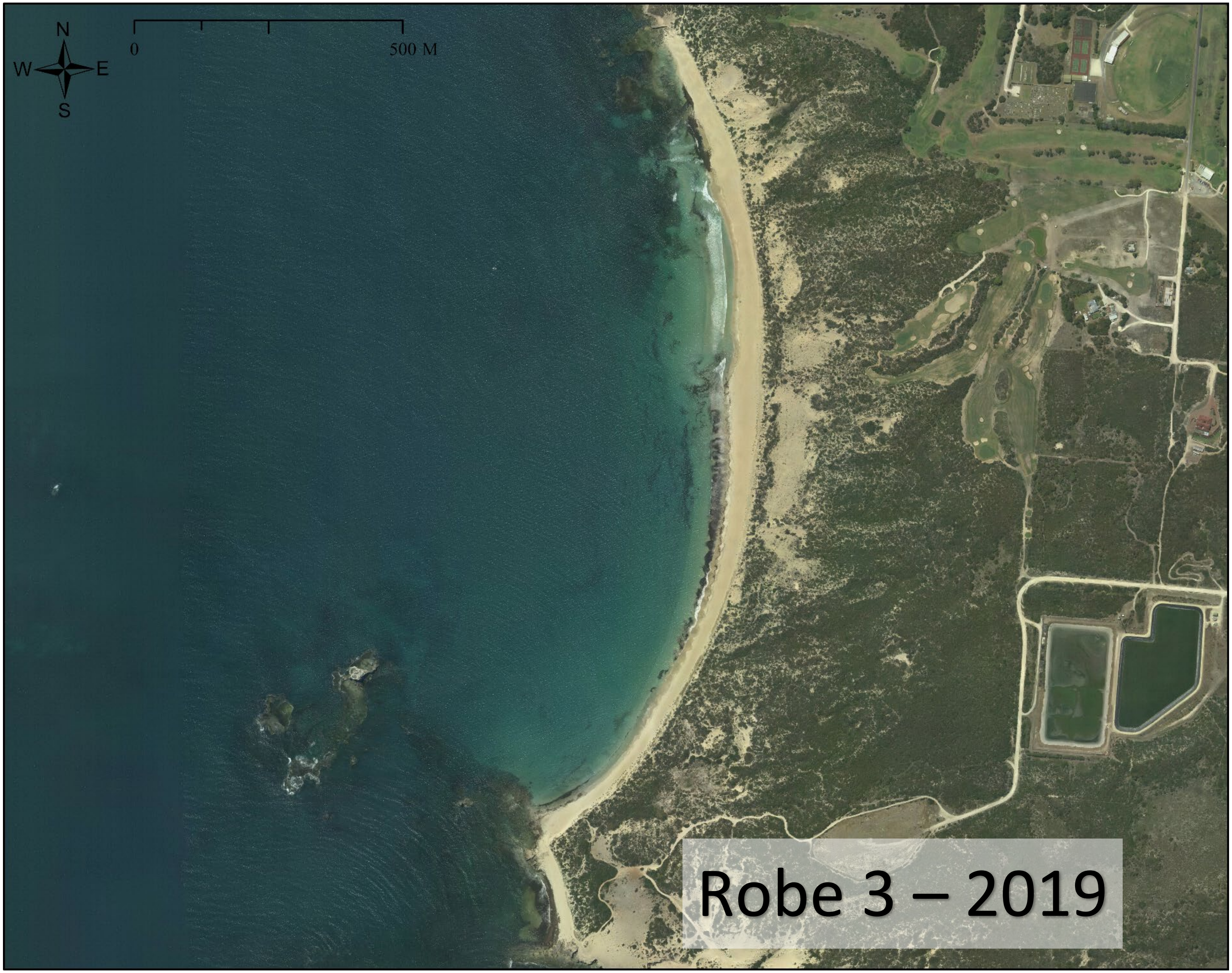

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