BROULEE: AN ISLAND NO MORE?

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Abstract

Broulee Island is located at the southern end of Broulee Beach on the south coast of NSW and has now been connected to the mainland by a tombolo for almost 30 years. Historically, this tombolo has been severed during large swell events on at least six occasions since 1828, resulting in a salient. During subsequent calmer periods, sand transported from the adjacent Bengello Beach has accumulated in the lee of the island to reform the tombolo.

Building on earlier work by Ballard (1982), this paper presents a history of the salient/tombolo at Broulee Island from various sources. While significant gaps in the dataset are acknowledged, on average, the tombolo has been severed approximately every 15-25 years since 1828. Following the most extensive breach on record during the May-June 1974 storms, it took approximately 6.5 years for the tombolo to reform.

This analysis considers both the secondary and tertiary sediment compartments containing Broulee Beach. Intertidal sand samples throughout the secondary sediment compartment confirm earlier observations that a major change in sediment texture and source abruptly occurs at Broulee Island. However, when the tombolo is severed, quartz-rich sediment from the adjacent Bengello Beach can “leak” into the Broulee Beach embayment which has carbonate-rich sand.

At present, the narrowest point of the tombolo appears to have more sand volume than existed prior to May-June 1974. Also, the tombolo is now in its most heavily vegetated state since aerial photographs began in 1961. On its present trajectory, will this ever truly be an island again? The possibility of future severing of the tombolo is discussed, along with its implications for management of coastal hazards in the area.

Introduction

Broulee Island is located at the southern end of Broulee Beach on the south coast of NSW and has now been connected to the mainland by a tombolo for almost 30 years (see example of the present connected state in Figure 1). Historically, this tombolo has been severed during large swell events on at least six occasions since 1828, resulting in a salient (see example of disconnected state in 1966 in Figure 2). During subsequent calmer periods, sand transported from the adjacent Bengello Beach has accumulated in the lee of the island to reform the tombolo. This paper presents a history of the salient/tombolo at Broulee Island, examines the secondary and tertiary sediment compartments containing Broulee Beach (including collection and analysis of sediment samples) and considers the future connectivity of the island.

Figure 1: Present View to Broulee Island from Broulee Head – 23/02/2017

Figure 2: 1966 View to Broulee Island from Broulee Head (Credit: Plumb Family)

Background Information

Broulee Beach is a 1.74 km long, east-north-east facing (70°) curving embayed beach located between the northern Mossy Point and the large Broulee Island, which is tied by a tombolo to Broulee Head at the southern end of the beach (Figure 3). This basalt island has been connected to the mainland (also basalt) since the beginning of 1989. Both Broulee Head and Island are fringed by well-developed basalt rock platforms.

Figure 3: Broulee Beach and Bengello Beach Tertiary Sediment Compartments. Red dots indicate sediment sampling sites (Aerial Photo 2/3/2015)

A tombolo is a salient (foreshore widening) which extends sufficiently to connect dry sand (i.e. above mean sea level) to an offshore feature (such as an island). Where a feature is located sufficiently close to shore, sand will accumulate in the lee to form a tombolo during periods of low wave energy (Figure 4). During high wave energy, tombolos may be severed from the feature, resulting in a salient. A salient is essentially an unstable beach form between a straight beach and a tombolo (Kamphuis, 2000). Once connected, a tombolo will starve downdrift beaches of normal longshore sediment supply. The effect of periodic tombolos is the temporary storage and release of a "pulse" of sediment to the downdrift region (Chasten et al., 1993). The Broulee Island tombolo is classified as asymmetrical as it is supplied with sediment from only one direction; the southern side (Ballard, 1982).

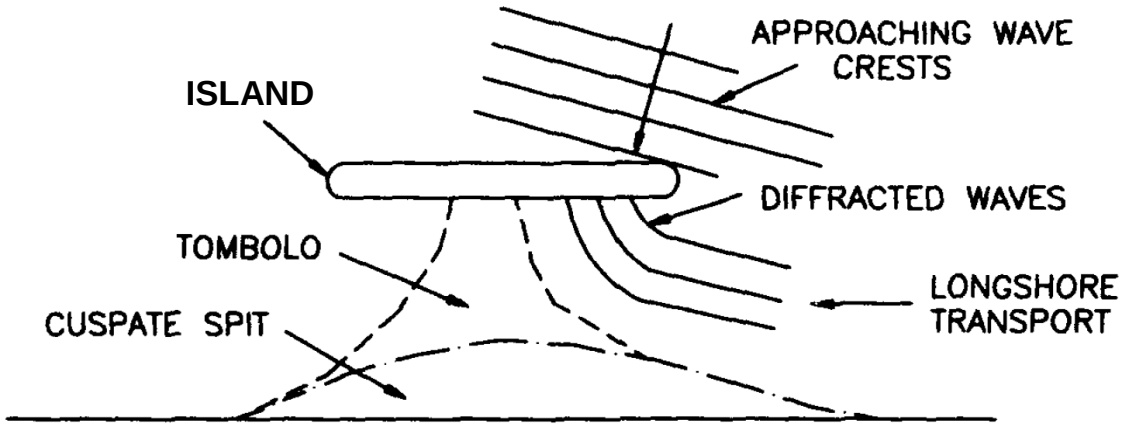


Figure 4: Shoreline response (tombolo growth) due to low energy wave crests approaching obliquely to the shoreline (Adapted from Chasten et al., 1993)

Broulee Beach is moderately embayed (embayment ratio = 0.6; straight line distance between controlling headlands divided by curved shoreline length), with the southern end very sheltered by the island, with median significant wave height increasing up the beach from 0.4 m in the south to 0.9 m in the north (Coghlan et al, 2017). The low waves maintain a reflective beach in the southern corner, grading northwards as waves increase, to a low tide terrace, then tranverse bar and rip with several beach rips usually present from about 1 km up the beach, extending to the northern end where a permanent boundary rip flows out across a rock platform against the base of Mossy Point, assisted by flow from Candlagan Creek. During high southerly wave events, the rips increase in size and spacing, combining to form a mega-rip against the northern rocks of Mossy Point, with large rips also possibly operating down the beach.

The low wave energy conditions at the southern end create a wide, flat beach. On the southern side of Broulee Spit, the beach is reflective with a steep gradient. A healthy, vegetated dune exists along the entire beach.

Coastal Geomorphology

Sediment Compartments

The NSW Coastal Management Act (2016) identified 47 secondary coastal sediment compartments along the NSW coast as developed by the National Climate Change Adaption Research Facility (NCCARF, McPherson et al., 2015; Thom et al., 2018). Broulee Beach is located in:

- the south coast region (NSW02);
- the Durras-Cape Howe primary compartment (PC 02);
- the Broulee secondary compartment (NSW02.06.03) which extends from Mosquito Bay head to Bingie Bingie Point (Figure 5); and
- a tertiary compartment comprising the Broulee Bay embayment.

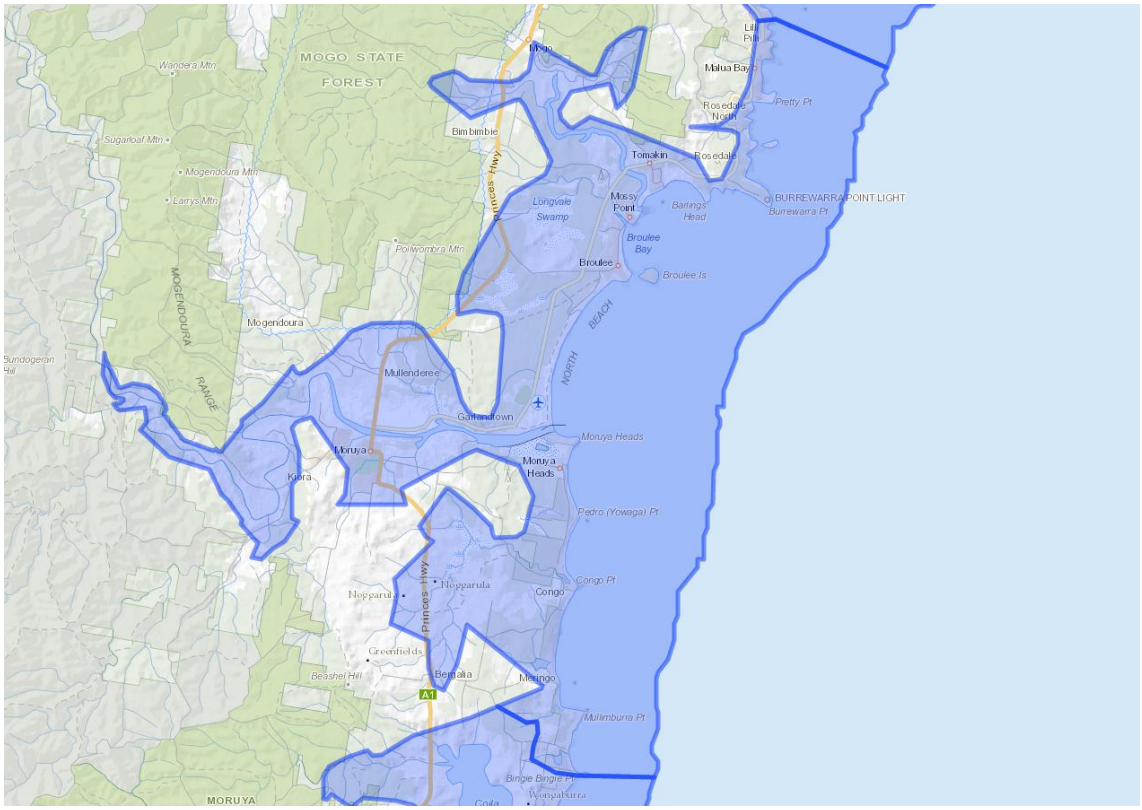


Figure 5: Broulee Secondary Sediment Compartment (Source: CoastAdapt, 2018)

Prominent headlands break the Broulee secondary compartment into a series of smaller tertiary sediment compartments (comprising embayed beaches), with no linkages between the small compartments north of Burrewarra Point and possible linkages in the south between Congo-Pedro-Moruya Beaches and Bengello Beach via Congo Point, Pedro Point, and Moruya Heads (Figure 5) (Oliver et al., 2018). Broulee Beach has periodic connection to Bengello Beach to the south when the tombolo to Broulee Island is severed. Figure 3 shows the dramatic change in the nature of the shoreline between the northern rocky shore with small embayed beaches with very small separate tertiary sediment compartments and the large regressive barriers of Barlings Beach-Tomakin Cove and Beach and Broulee Beach-Bengello Beach and their larger and linked sediment compartments. This morphology is a reflection of the larger accommodation space available in each of the central bays and the abundant source of lithic quartz sediment from the Moruya River via the inner shelf, and north of Broulee Island, supplemented by local carbonate production.

Holocene Evolution

The NSW south coast was drowned by the Holocene sea level transgression, reaching its present level about 6,500 years ago and forming the present coast of rocky headlands, embayed beaches and estuaries. The Broulee secondary compartment had a positive sediment supply in the mid-Holocene leading to the deposition of the beach systems and in some cases their accretion up to 2 km seaward, as occurred at Bengello Beach (Thom, et al., 1978, 1981; Oliver et al., 2015) and Moruya-Pedro Beaches (Oliver et al., 2018). At Bengello Beach, Oliver et al. found the barrier commenced accretion at the sea level stillstand approximately 6,500 years ago and accreted seaward at a rate of 0.27 m/year, or one foredune ridge every 110 years, until about 400 years ago when it appears to have stabilised and built the large outer foredune. A similar barrier evolution was recorded at Pedro Beach located 4 km to the south. Its 1.3 km wide regressive foredune ridge plain built seaward at a rate between 0.49-0.75 m/year. It filled its accommodation space and ceased prograding about 4,000 years ago, followed by the accumulation of a large seaward foredune (Oliver et al., 2018), with excess sand possibly moving around Pedro Point to Moruya Beach.

Most other beach systems in the compartment also underwent some degree of barrier accretion and sediment accumulation with sediment largely derived from the inner shelf, while the estuaries have been infilling with both fluvial, marine and in situ carbonate sediments. Due to available accommodation space within the coastal valley and a suitable supply of sand, Broulee Beach underwent substantial accretion of several hundred metres since the sea level highstand, with some of the Broulee sand very likely to be Moruya River sand deposited in the inner shelf. The beach is backed by the northern part of the Broulee-Bengello barrier system, a large regressive beach to foredune ridge plain that is 1 km wide behind Broulee Beach with a volume of approximately 5.6 M m^3.

Sediment Carbonate Content

The beaches within the secondary compartment received varying supplies of carbonate sand derived from the adjacent rocks and sea floor. The considerable variation in tertiary sediment compartment behaviour is typical of the southern NSW coast with the coastal geology (headland, rocks and reefs) influencing the transport of sediment into each compartment. The sources of sand for the beach can also be gauged from the texture, that is, their size, sorting and composition. The sand sources for the beaches in the Broulee secondary compartment are a combination of fluvially derived quartz (lithic) sand deposited on the shelf at lower sea levels and reworked onshore during the sea level transgression and locally produced carbonate material (generally shell fragments derived from the rocks and sea floor immediately adjacent to each beach).

Through preliminary surveys of offshore seabed sediments between Barlings Beach and Tuross Head, Hall (1981) first observed that there is a distinct change in sediment between Bengello Beach and Broulee Beach. Hall found that the Bengello Beach sediments are fine, well-sorted quartz with low carbonate, extending up to 25 m depth, whereas the Broulee Beach to Barlings Beach nearshore sediments are medium grained, moderately to poorly-sorted carbonate-rich sands (Figure 6).

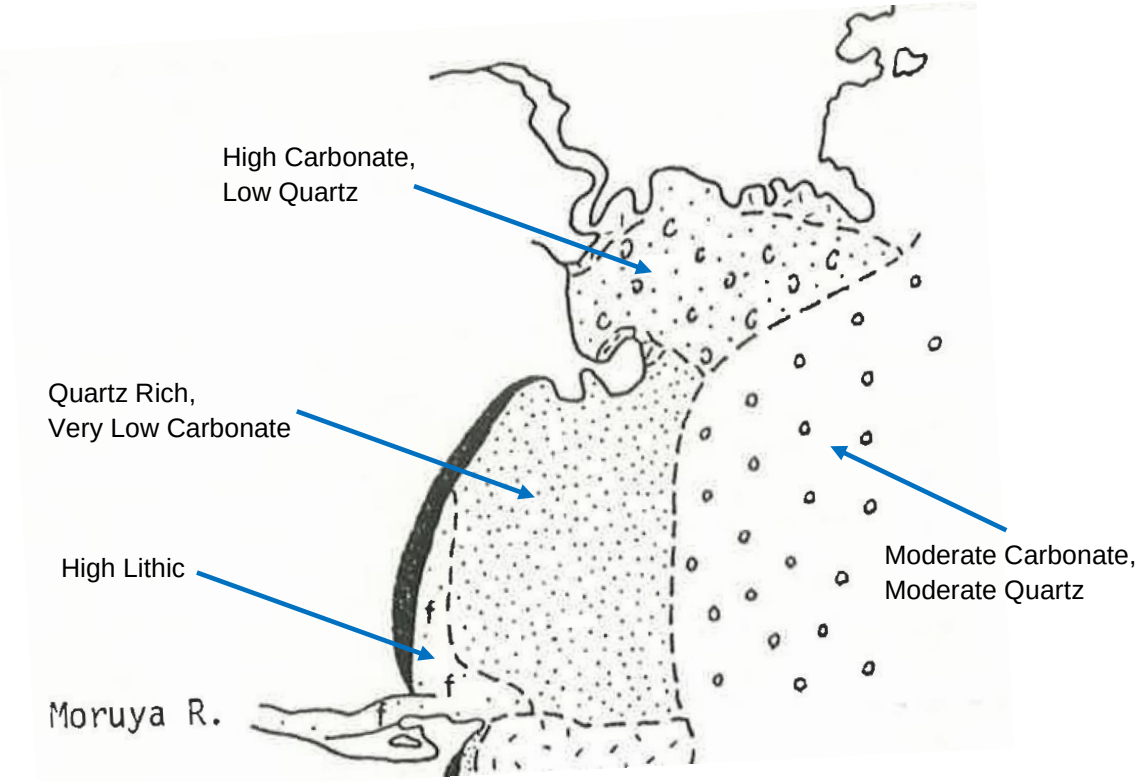


Figure 6: Nearshore Sediments at Broulee-Bengello (Adapted from Hall, 1981)

Sediment samples have previously been collected from the intertidal zone of many of the beaches in the Broulee secondary compartment as part of the development of the Australian Beach Safety and Management Program database (ABSAMP, 2009). However, samples were not collected in the areas of interest at Broulee and Bengello Beaches (Table 1), although sediment samples from adjacent beaches showed a marked change in carbonate content between Barlings Beach (north of Broulee Beach) and south of the Moruya River. To identify the exact location of significant sediment change between Bengello Beach (marine quartz) and Broulee Beach (carbonate sand), WRL collected sand samples from the intertidal zone (see locations on Figure 3) to test for carbonate content. The dried sediment samples were treated with hydrochloric acid to determine the percentage carbonate content (Table 1). At beaches where analysis was conducted by both ABSAMP and WRL (Coghlan et al, 2017), the values generally compared well.

Table 1: Carbonate Content of Sand Samples

Beach	Section/Comment	Carbonate Content (%)	
		ABSAMP (2009)	WRL (2017)
Malua Bay	Central	77.2	78.4
Guerilla Bay	Central	45.4	44.8
Barlings Beach	Western end	60.4	74.0
Tomakin Cove	Central		71.4
Broulee Beach	Northern end		84.0
Broulee Island Tombolo	Southern side		47.9
Bengello Beach	Northern end		5.4
	Central (windsock)		4.6
	Southern end (north of training wall)		4.3
Moruya Heads 2		0	
Moruya (Heads)		3.2	
Pedro Beach		5.0	
Congo Beach		4.1	

In the areas of interest, the three medium sand samples along Bengello Beach all had a low carbonate content (approximately 5%). However, immediately north of Bengello Beach (on the southern side of Broulee Island tombolo) the carbonate increases to 48% and in the adjoining Broulee Beach it increases to 84% at its northern end (both samples fine sand). All the remaining beaches to the north remain high in carbonate (45-78%). This implies that there is a major change in sediment texture and source between Bengello Beach and Broulee Beach, and beaches to the north. While Bengello Beach is composed of quartz-lithic sand ultimately derived from the Moruya River, the beaches to the north have a substantial amount of their sediment derived from the local marine biota. The beach material therefore confirms the findings about the nearshore material by Hall (1981), with Broulee Island separating the two tertiary sediment compartments. However, as the tombolo to the island is breached during major storms, there is periodic leakage of the quartz-rich sand into the Broulee tertiary compartment, which explains the lower carbonate content on the southern side of the tombolo.

Sediment Transport Between Bengello Beach and Broulee Beach

Broulee Beach is temporarily linked to Bengello Beach when the tombolo at Broulee Island is breached during major wave events and sand is washed into the Broulee Beach compartment (Ballard, 1982; see Figure 7, Thom, et al., 1986). In this mode, the two tertiary sediment compartments form a single sediment compartment, which has a tenuous connection and periodic northward transport of quartz-rich sand via the spit.

The photogrammetry data for Broulee Beach (Coghlan et al., 2017) indicates overall beach accretion between 0.55-0.70 m/year since 1962, which decreases to the north, with slight recession at the northern end, which could be related to instability at the mouth of Candlagan Creek. The recent accretion could be related to the three (3) breaches of the tombolo (between 1965 and 1987), which would have supplied pulses of sand to the southern end of the beach, which may have been reworked along the beach. The fact that the outer foredune is in the order of 400 years old (Oliver et al., 2015) suggests there has been no substantial accretion since that time.

Further Geomorphology Work

While the preceding sections provided a review about what we do know about the Broulee Beach and Bengello Beach compartments, considerable unknowns remain. These include:

- the nature and scale of the on-offshore exchange of sand within each beach, and between the beaches;
- the potential permanent loss of sand offshore via mega-rips;
- the rate of carbonate production and its transport to the shore;
- the rate of carbonate abrasion and removal as fines (mud-silt);
- the supply of fluvial sediment from the Moruya River into the southern end of the Bengello Beach compartment; and
- the impact of the training walls at the Moruya River mouth which commenced construction in 1890 (Patterson Britton and Partners, 2009).

Exploring these unknowns would require detailed field investigations to address them.

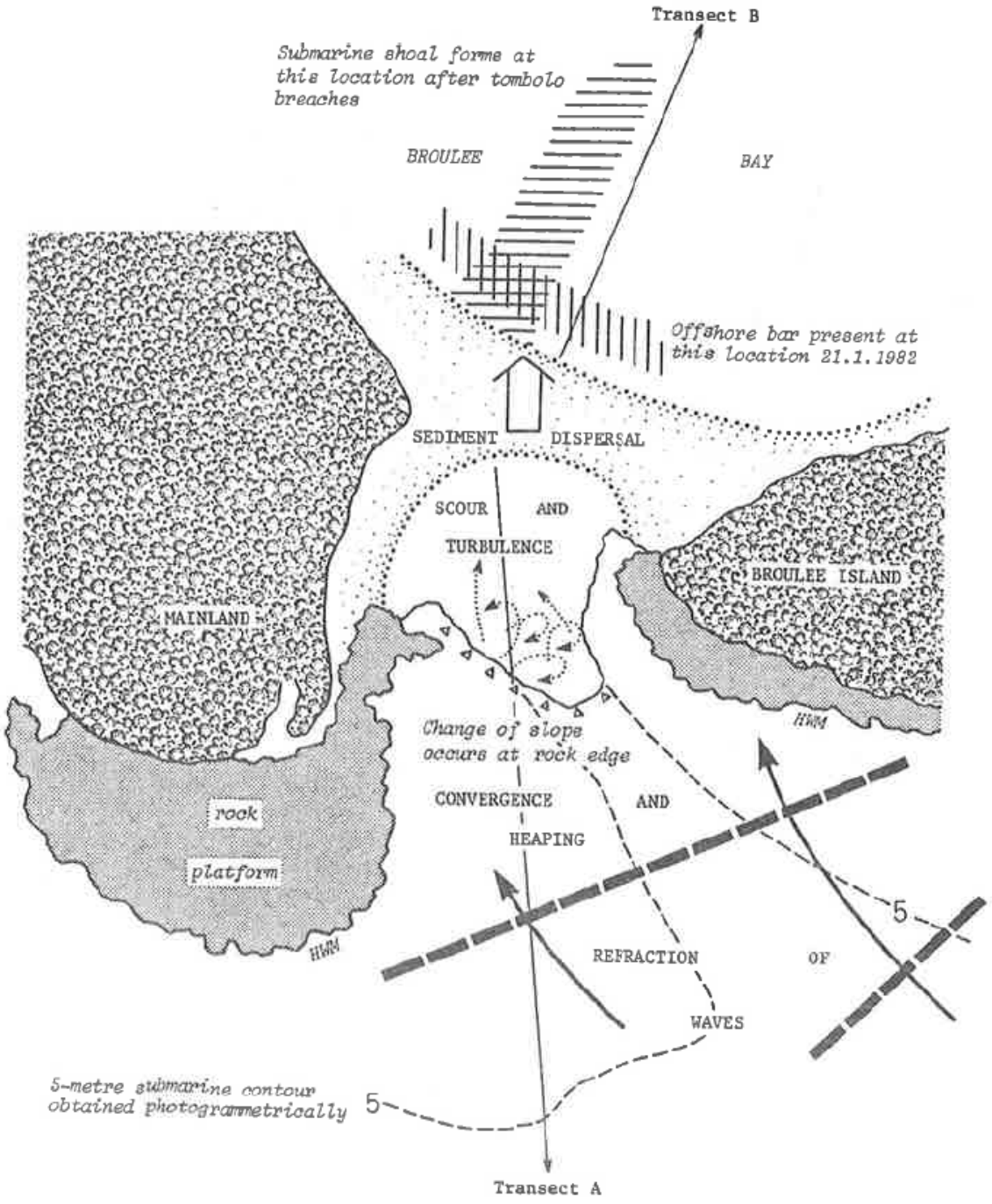


Figure 7: Shoreline response (tombolo severance) due to high energy waves originating on the southern side of Broulee Island (Source: Ballard, 1982)

Historical Connectivity of Broulee Island

The periodic or ephemeral tombolo at Broulee Island has been historically breached during large swells, separating the island from the mainland temporarily, although the most recently recorded breach occurred sometime between May 1984 and May 1987.

Ballard (1982) provides an extensive history of the salient/tombolo at Broulee Island between 1828 and 1981. A variety of data sources were used including maps, photographs, illustrations, documented observations and NSW legislative assembly proceedings. Ballard found that the tombolo is severed rapidly from waves originating on its southern side (Bengello Beach) but then takes a longer period of time to re-connect to the island. Analysis of a series of aerial photographs between 1961 and 1981 clearly showed the transport of sediment from the tombolo to the north into Broulee Bay when it was breached, resulting in a relatively deep channel separating the island from the salient.

The status of the Broulee Island tombolo between 1828 and 1901 has been tabulated by WRL in Table 2, based on findings by Ballard (1982). In 1873, shortly before it was severed, vegetation (including root systems) on the tombolo was removed to widen a track which existed between Broulee Island and the mainland. From 1920 to 1930, shell-grit was mined from within Broulee Bay which may have resulted in a depleted supply of sediment to maintain the tombolo (Ballard, 1982). Unfortunately, there are large gaps in the record when the tombolo may have been severed which have gone unrecorded, particularly between 1901 and the first aerial photograph in 1961.

Table 2: History of Broulee Island Salient/Tombolo Condition (1828-1901)

Date	Salient/Tombolo Condition	Reference
1828	Connected	Ballard (1982)
1837	Connected	Ballard (1982)
1839	Connected	Ballard (1982)
1841	Disconnected (Possible)	Ballard (1982)
1843	Disconnected	Ballard (1982)
1845	Connected	Ballard (1982)
1869	Disconnected	Ballard (1982)
1873	Disconnected	Ballard (1982)
1891	Connected	Ballard (1982)
1892	Connected	Ballard (1982)
1901	Disconnected (Possible)	Ballard (1982)

Ballard's aerial photography analysis has been extended by WRL through examination of historical aerial images provided by the Office of Environment and Heritage (OEH) between 1961 and 2011 (reproduced in Figure 8). Landsat 5 satellite imagery (30 m resolution courtesy of USGS/NASA) were also extracted for a 20-month period between May 1987 and January 1989 (see Figure 9) to show the process by which Broulee Island was last reconnected to the mainland. Additional photographs from other sources were also collected and included in the analysis, with the status of the Broulee Island salient/tombolo between 1961 and 2018 tabulated in Table 3.

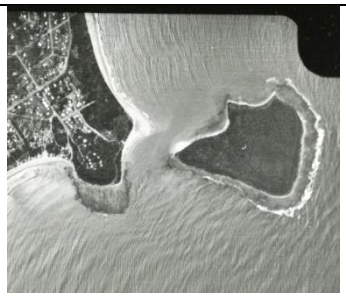
A. 1/8/1961

B.??/2/1964

C. 7/1/1969

D. 6/4/1972

E. 10/9/1975



F. 11/3/1977

G. 28/7/1977

H. 26/11/1977

I. 21/12/1980

J. 27/8/1981

K. 12/4/1984

L. 25/10/1988

M. 22/11/1991

N. 15/4/1993

O. 6/2/1999

P. 7/3/2005

Q. 28/3/2007

R. 15/5/2011

Figure 8: OEH Aerial Photographs

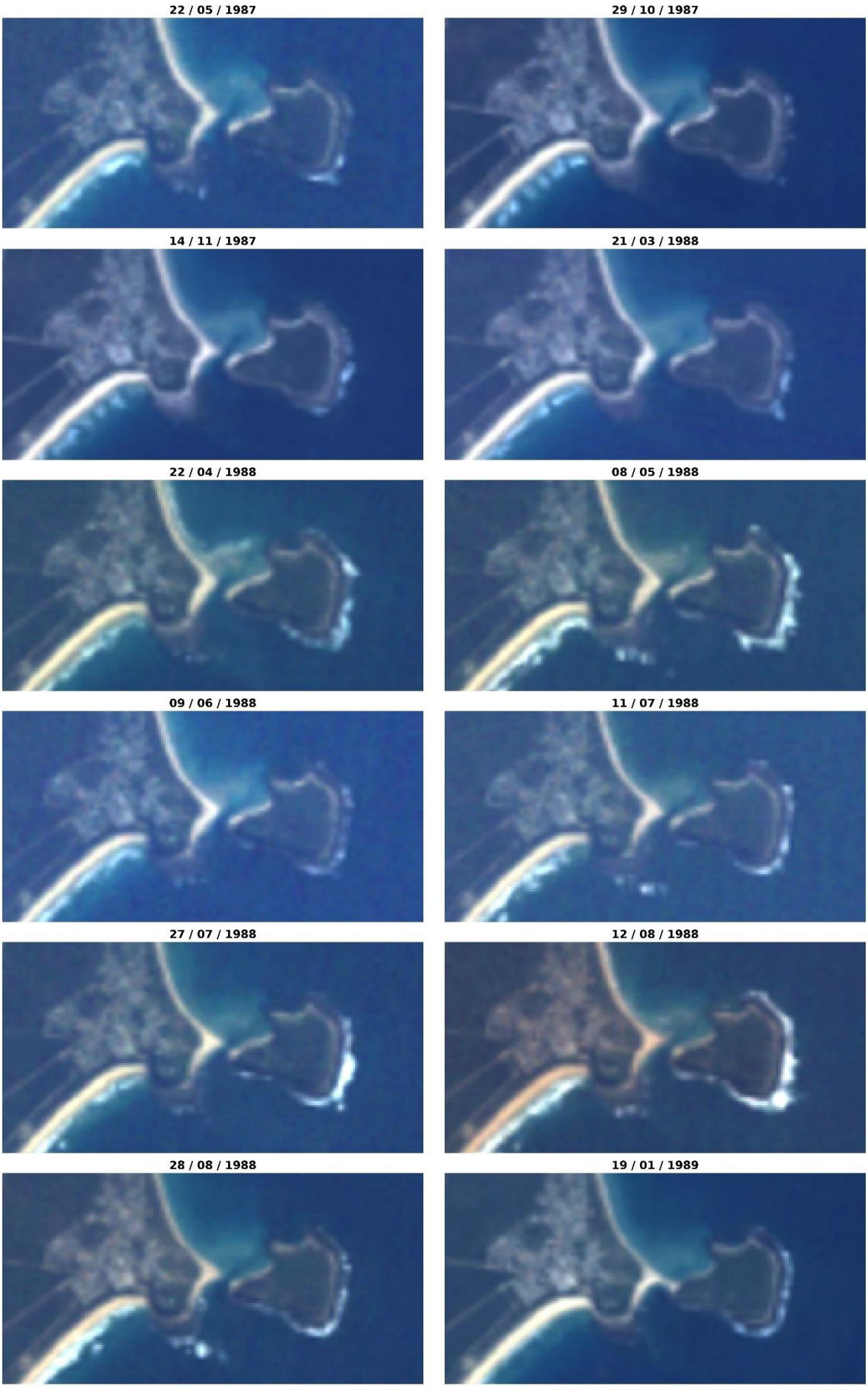


Figure 9: Broulee Island Connection (Landsat 5 Satellite Imagery 1987-89)

Table 3: History of Broulee Island Salient/Tombolo Condition (1961-2018)

Date	Salient/ Tombolo Condition	Vegetation Status	Reference
1/08/1961	Connected	No vegetation	OEH Aerial Photograph
??/03/1963	Connected	No vegetation	Oblique Photograph
??/02/1694	Connected	No vegetation	OEH Aerial Photograph
3/02/1965	Connected	?	Ballard (1982)
15/05/1966	Disconnected	N/A	Ballard (1982)
??/??/1967	Disconnected	N/A	Moruya & District Historical Society Observation
7/01/1969	Disconnected	N/A	OEH Aerial Photograph
9/05/1971	*Connecting*	?	Ballard (1982)
4/06/1972	Connected	No vegetation	OEH Aerial Photograph
??/06/1974	Disconnected	N/A	Ballard (1982)
10/09/1975	Disconnected	N/A	OEH Aerial Photograph
11/03/1977	Disconnected	N/A	OEH Aerial Photograph
28/07/1977	Disconnected	N/A	Ballard (1982)
26/11/1977	Disconnected	N/A	OEH Aerial Photograph
28/11/1977	Disconnected	N/A	OEH Aerial Photograph
??/12/1979	Disconnected	N/A	WRL Site Inspection
21/12/1980	*Connecting*	No vegetation	OEH Aerial Photograph
27/06/1981	Connected	No vegetation	OEH Aerial Photograph
11/04/1984	Connected	Thinly vegetated	OEH Aerial Photograph
29/05/1984	Connected	Thinly vegetated	WRL Site Inspection
22/05/1987	Disconnected	N/A	Landsat Satellite Image
25/10/1988	Disconnected	N/A	OEH Aerial Photograph
19/01/1989	Connected	No vegetation	Landsat Satellite Image
22/11/1991	Connected	No vegetation	OEH Aerial Photograph
15/04/1993	Connected	Thinly vegetated	OEH Aerial Photograph
6/03/1996	Connected	Vegetated	DLWC Oblique Aerial Photograph
6/02/1999	Connected	Vegetated	OEH Aerial Photograph
7/03/2005	Connected	Vegetated	OEH Aerial Photograph
28/03/2007	Connected	Vegetated	OEH Aerial Photograph
15/05/2011	Connected	Vegetated	OEH Aerial Photograph
8/12/2012	Connected	Vegetated	WRL Site Inspection
24/02/2017	Connected	Vegetated	WRL Site Inspection
15/07/2018	Connected	Vegetated	NearMap Aerial Photograph

Based on the histories presented in Tables 2 and 3, Broulee Island has been disconnected three to five (3-5) times between 1828 and 1901 (73 years) and three (3) times between 1961 and 2018 (57 years). While significant gaps in the dataset are acknowledged, on average, the tombolo has been severed approximately every 15-25 years. At the time of writing, the island has remained connected for at least 29 years. There is not enough evidence to confidently comment on the varying length of time that the island may be disconnected following a breach, but it is noted that, following the breach in May/June 1974, a tombolo did not reform until late 1980/mid 1981; a six to seven year duration. Similarly, on adjacent Bengello Beach surveys, McLean et al. (2010) found that it took eight years for the beach to fully recover from the 1974 storms.

Assuming an eroded bed level of -1 m AHD between Broulee Head and Broulee Island (based on James Carley's personal observations of wading/swimming in 1979 and 1986-1987), a cross-sectional volume of 245 m^3/m above -1 m AHD (inferred from the 2017 transect described in the next section) and an eroded length of 150 m (based on the aerial photograph following the May/June 1974 storm sequence; Figure 8E), it is estimated that approximately 40,000 m^3 of sand was released into Broulee Bay when the tombolo was severed in May/June 1974. Note that the volumes of sand released into Broulee Bay upon severing of the tombolo at other times have not been estimated.

Future Connectivity of Broulee Island

On 24 February 2017, WRL undertook a cross-sectional survey at the approximate narrowest point of the tombolo. Ground surface elevations were measured using a Trimble R10 RTK-GPS and offset using the NSW CorsNET network. The transect had a volume of 159 m^3/m above 0 m AHD and is shown in Figure 10. The crest of the dune along the tombolo was approximately 3 m wide at the time of the site inspection.

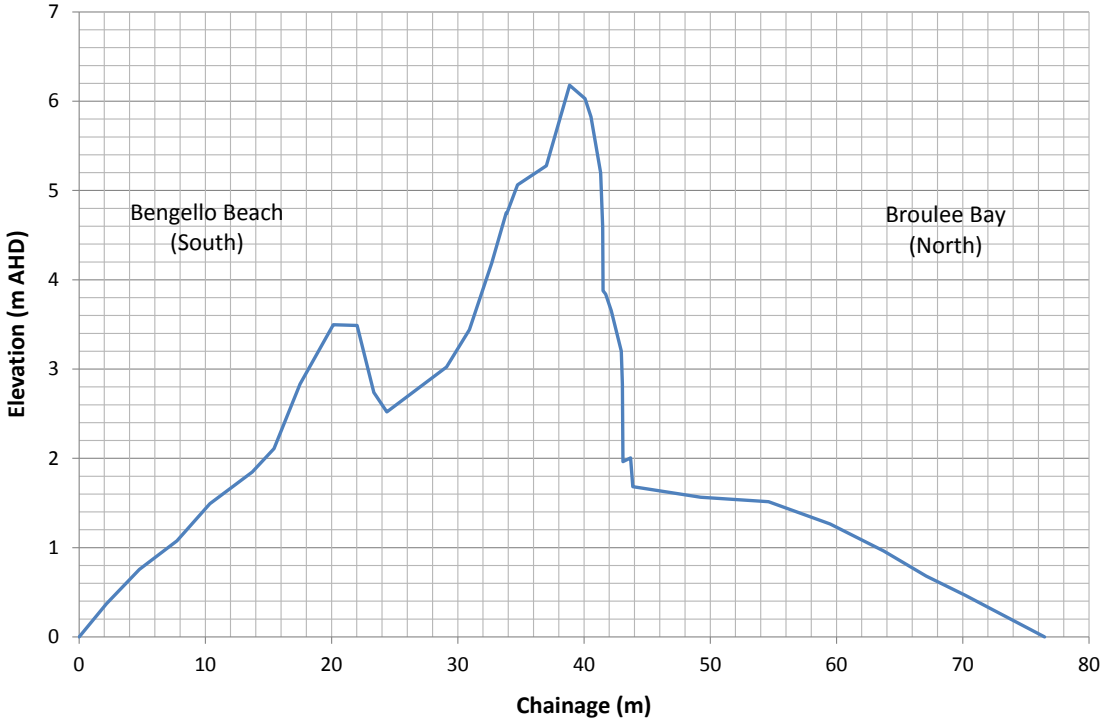


Figure 10: WRL Survey of Broulee Island Tombolo (Facing West) – 24/02/2017

It is noted that the nominal design storm demand for the centre of Bengello Beach (170 m^3/m above 0 m AHD, based on erosion measured during May/June 1974; see Coghlan et al., 2017) is slightly larger than the volume currently in the tombolo transect. However, the present profile appears to have more volume and is heavily vegetated in contrast to the un-vegetated state of the tombolo prior to the May/June 1974 storm sequence (Figure 8D). Indeed, the tombolo is now in its most heavily vegetated state (see Figure 11) since aerial photograph records began in 1961, which may contribute to the lack of breaches in the last 29 years.

Figure 11: Heavily Vegetated State of the Tombolo – 24/02/2017 (Approximate Narrowest Point, Facing North)

The tombolo connecting Broulee Island with the mainland is now jointly managed by Eurobodalla Shire Council and the NSW National Parks and Wildlife Service. Present management practices include protection of native vegetation, weeding of noxious and invasive exotic species (particularly Bitou bush; *Chrysanthemoides monilifera subsp. rotundata*) and control of feral animals. Each of these activities is anticipated to reduce the susceptibility of the tombolo to erosion initiated from the southern side (Bengello Beach). Also, the following historical activities, which are no longer permitted, would have increased the vulnerability of the tombolo:

- clearing of vegetation on the tombolo;
- mining of shell-grit from within Broulee Bay;
- vehicle traffic across the tombolo;
- campfires on Broulee Island; and
- grazing of cattle.

While the present condition and trajectory of the tombolo indicates that it has become less vulnerable to erosion, upon reflection of the weight of historical evidence, our opinion is that it is likely that the tombolo will be severed again at some stage in the future. As such, it is prudent to allow for this possibility in planning for management of future coastal hazards in the area. In particular, the central and southern sections of the Broulee Beach shoreline are expected to temporarily recede in the event that Broulee Island is disconnected.

Note that we have not undertaken an assessment of the potential for a breach to occur on the present profile. Detailed modelling of the potential for a breach would be complex as it involves interactions between wave runup, wave overtopping, cross shore erosion, longshore processes and vegetation.

Summary

While Broulee Island has now been connected to the mainland by a tombolo for almost 30 years, it has previously been severed during large swell events on at least six occasions since 1828. While there are significant gaps in the historical dataset, from the available information, on average, the tombolo has been severed approximately every 15-25 years over this time. Following the most extensive breach on record during the May-June 1974 storms, which was estimated to deposit approximately 40,000 m^3 of sand from the tombolo northward into Broulee Bay, it took approximately 6.5 years for the tombolo to reform.

Intertidal sand samples throughout the Broulee secondary sediment compartment confirm earlier observations that a major change in sediment texture and source abruptly occurs at Broulee Island. To the north of the island, Broulee Beach is composed of carbonate-rich sand, which is generally fragments of shell material, derived from the rocks and sea floor immediately adjacent to the beach and supplied onto it in an ongoing fashion. To the south of the island, Bengello Beach comprises lithic-quartz sand ultimately derived from Moruya River fluvial sands, as well as inner shelf sands transported landwards during the sea level transgression and a small carbonate fraction (approximately 5%). However, when Broulee Island is disconnected from the mainland, it has been shown that Broulee Beach and Bengello Beach temporarily form a single, tenuous sediment compartment. In this mode, quartz-rich sediment from Bengello Beach can “leak” into the carbonate-rich Broulee Beach embayment. During subsequent calmer periods, sand transported from Bengello Beach accumulates in the lee of the island to reform the tombolo which then prevents sediment exchange between the two beaches.

At present, the narrowest point of the tombolo appears to have more sand volume than existed prior to May-June 1974. Also, the tombolo is now in its most heavily vegetated state since aerial photographs began in 1961. While the present condition and trajectory of the tombolo indicate that it has become less vulnerable to erosion, it is considered likely that the tombolo will be severed again at some point in the future. This possibility should continue to be planned for in future management of coastal hazards in the area.

The authors recommend that detailed field investigations be undertaken to address the considerable unknowns remaining about the Broulee Beach and Bengello Beach tertiary sediment compartments.

Acknowledgments

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