Long-term shoreline change analysis, Otago Harbour entrance to Karitane

Prepared for

Port Otago Ltd

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Executive Summary

This report presents an assessment of long-term shoreline change for the beaches between the Otago Harbour entrance and Karitane. The time period examined covers from about 1863 to 2013. Source information includes studies by Gibb (1978), Nicholson (1979) and Goldsmith (1995), plus aerial photographs from 1980, 1997, 1999, 2005 and 2013.

It was found that all of the shores except Karitane have prograded (built out seaward) in the past. In recent times the beaches were subject to erosion and accretion of sediment, resulting in periods of retreat and progradation of the shoreline respectively.

The shorelines of Warrington, Purakanui and Long Beach continue to prograde in the long-term, while Kaikai shows persistent retreat of the shoreline. Karitane, Whareakeake and Aramoana appear to be in a state of dynamic equilibrium over the long-term. The beaches in the vicinity of Doctors' Point have accreted, but exhibit little shoreline change due to the sand being stored in the nearshore resulting in relatively large fluctuations in depth of the nearshore shoals and bars around the entrance to Blueskin Estuary. Shelly Beach has eroded in the past, but due to human intervention the beach is relatively stable in position and form.

1. Introduction

1.1 Background

This report accompanies reports on changes to the ocean beaches between Otago Harbour and Karitane (Single 2014a, 2014c), as part of studies carried out in accordance with the conditions of ORC Consent No RM11.153. In particular, this report and the beach change reports fulfil condition 11. (d), with this report covering long-term shoreline change analysis from aerial photographs:

> <u>*Surf, Current and Sediment Transport*</u>
>
> 11. Within 3 months of the commencement of this consent, the consent holder shall commission a wave, hydrodynamic and sediment dynamics study by a person or organisation recognised by the consent authority as having the requisite qualifications and experience. The study will involve numerical modelling and empirical analysis of the coastal and sediment dynamics, including the transport pathways, for the coastal region between Taiaroa Head and Karitane Peninsula.
>
> This purpose of the study will be to identify the optimum location and extent of disposal grounds for the long-term deposition of dredge spoil from the harbour maintenance programme. The study will consider the equilibrium sediment supply requirements for the beaches west of the harbour entrance and the effects of disposal on surfing wave corridors, and wave quality at surf breaks of national significance identified in NZCPS (2010). The study shall be completed within 2 years from the date of commencement of this consent in accordance with s.116 of the Resource Management Act 1991, and shall include as a minimum:
>
> (a) a program of wave and current measurement for the purpose of calibration and validation of numerical coastal process models; and
>
> (b) establishment of numerical models of the wave, hydrodynamic, tidal and sediment transport parameters; and
>
> (c) remote photographic and video capable monitoring of the Aramoana and Whareakeake surf breaks and the establishment of a web site to allow surfers to record their personal observations of surf quality; and
>
> (d) beach profile analysis and the completion of long-term shoreline change analysis from aerial photographs.

Beaches and shorelines change at various spatial and temporal scales. There are different time-scales of change that can be used to assess the character of the variability of the shore. For example:

- Short-term changes (up to a year) include periods of storminess (or relatively quiescent periods), tidal effects and annual climate and sea-level changes.
- Historical changes (from one year to 100 years) include periods of longer storm cycles (2 to 20 years) such as El Nino and Southern Pacific Oscillation, while also encapsulating sea level changes (historically sea level for the Otago region has risen at a rate of about 0.15 m per 100yrs). Historical changes will also reflect changes to the sediment budget inputs and possible onshore/offshore exchanges of sediment.
- Long-term changes (from 100 to about 6,500 years ago) include changes since the Holocene transgression (end of relatively rapid post-glacial sea level rise), eustatic climate variability (storminess and changes in predominant wind/wave directions) and sediment budget changes, especially in supply of sediment from the seafloor to the coast.

Beach profiles are used to assess the change of a beach at specific locations over the period between surveys. The time-scale of change can be as short as between tides, over a period of a storm or during a season. A general picture of the changes to a greater stretch of shore, such as a bay, can be attained from a profile when accompanied by descriptions of the character of the surrounding shore and photographs of the beach.

Eight beach profiles from Karitane to Aramoana, established by Otago Regional Council (ORC) in 1990, were re-surveyed along with a further fourteen profiles at Shelly Beach in June 2013 and May 2014. The profile data has been assessed with earlier re-surveys (May 1998, March 2008, March 2011), and gives an indication of snapshots in time of the beach form and extent, and the changes between surveys. Single (2014a) presents a description of the survey network and monitoring carried out since it was established. Single (2014c) presents results of changes between June 2013 and May 2014.

Nicholson (1979) describes long-term (as defined above) changes to the shore from Aramoana to Purakanui from a geomorphological analysis of beach and backshore morphology and sediments. He found that for the 5,000 to 6,000 years of near-present sea levels, boulder beaches and progradational beach ridges with associated lagoons and swamps near, or at the base of the hinterland slopes dominated the shoreline within the bays. He concluded that the beaches had prograded relatively recently and quite rapidly. Based on archaeological data and extrapolating historical progradation rates, he suggests that the progradation phase of beach change may be a phenomenon of the last 200 to 500 years. Nicholson considered that the accretion and progradation of sand was a result of a variation in the supply of sediment from offshore.

Nicholson also presents an assessment of shore change over an historical time period from analysis of old survey plans, maps and aerial photographs. His timeframe encompasses the period since European colonisation and the first cadastral maps (1863) through to March 1979. His findings are presented in conjunction with analysis of more recent maps and photographs for the beaches from Karitane south to the Otago Harbour entrance in Section 2.

For the purposes of this study, the following usage of the term “long-term shoreline change” as used in the ORC Consent No RM11.153 11 (d) is considered to be synonymous with the “historical changes” definition as described above, relating to the last 100 years.

1.2 Methodology

Previous studies regarding the shores of the wider Blueskin Bay area have been reviewed for Port Otago Ltd by the author (Single and Benn 2007), and a discussion of the coastal environment and coastal processes is included in Single (2011a, 2011b). The findings of Nicholson (1979) were included in that work. This report builds on the work by Nicholson to update those findings and to include additional beaches in the area.

<u>Methods to determine shoreline change</u>

Table 1.1 shows the data sources for the historical coverage of shoreline change used by Nicholson (1979) and for this report. Land Information New Zealand (LINZ) maps, ortho-rectified and geo-referenced vertical aerial photographs have been used to locate the position of the shoreline at various dates. Aerial photographs from earlier than 1997 were not available due to the closure of the New Zealand Aerial Mapping (Ltd) archive, and loss of holdings in the University of Canterbury, Geography Department post the 2011 Christchurch earthquake and subsequent rationalisation of resource material. Nicholson’s maps of shoreline positions and shoreline change data were used to determine the shore change for the period 1863 to 1979.

Table 1.1 Data sources for historical analysis of shoreline change (* scales for recent photographs varied but were adjusted for analysis using GIS)

Data type	Date	Scale	Source
Cadastral Map	1863	1:7920	Lands and Survey
Topgraphic Map	1922	1:31680	Hocken Library
Topgraphic Map	1942	1:25000	Hocken Library
Aerial Photograph	1951	1:15980	Lands and Survey
Aerial Photograph	1957	1:18160	Lands and Survey
Aerial Photograph	1967	1:66630	Lands and Survey
Aerial Photograph	1972	1:25430	Lands and Survey
Aerial Photograph	1975	1:50640	Lands and Survey
Aerial Photograph	1979	1:12715	N&ES Patterson Ltd
Aerial Photograph	1980	*	Dunedin City Council
Aerial Photograph	1997	*	Otago Regional Council
Aerial Photograph	1999	*	LINZ
Aerial Photograph	2005	*	Dunedin City Council
Aerial Photograph	2013	*	Dunedin City Council

Aerial photographs from 1980, the 1990s, and since 2000 were available as digital images. These images were geo-referenced to the New Zealand Map Grid, and scaled so that the shoreline could be mapped and changes in shoreline position could be measured using Geographical Information Systems (GIS) software.

The reference shoreline referred to in the analysis was the seaward vegetation line. This relates to the most stable part of the upper beach in most cases due to either being the limit of erosion of the vegetated dunes, or the seaward extent of vegetation encroachment that will occur during periods of beach stability or progradation.

Nicholson measured the position of the shoreline from fixed points on the land. These points were close to sea level and near photograph centres so as to minimise measurement errors resulting from relief and radial distortion in the image. This method was repeated for the later photographs, although radial distortion was removed by ortho-rectification of the images to align with the NZMG base map.

Estimates of error

Errors in measurement of shoreline positions and changes from maps and aerial photographs can result from three main sources. The first is in defining the shoreline that is to be mapped or measured. In this case, the vegetation line at the landward extent of the sandy beach was used as the shoreline. This removes interpretations of cadastral definitions such as MHWS, HAS (highest astronomical tide), and how those definitions or usages may change over time and by different mapmakers. It also removes difficulties or ambiguity in determining the position on the shore from photographs that show only an expanse of sand with no colour differentiation of the limit of tidal elevation, and loss of definition of beach features due to the highly reflective sand surface.

Aerial photograph interpretation can include an inherent error due to displacement and distortion of the image with distance away from the centre of the photograph. Error can also arise due to the photograph scale as this affects the definition and resolution of beach features. This type of error has been minimised for this study by using ortho-rectified photographs or geo-rectification of photographs to the NZMG base map. Some error will still result due to imperfect ortho-rectification. However this has also been minimised by using, where possible, photographs centred on the beach.

Plotting and measurement error can also occur due to scale and measurement from the images due to potential human error in the accuracy of mapping the shoreline position and subsequent measurements of successive shoreline positions. Nicholson identifies measurement errors in his work of about ± 15 m. For example, the smallest useful measurement from maps and photographs at a scale of about 1:16000 is 0.5 mm. This represents a ground measurement of 8 m.

Zooming in on the beach can vary the scale of digital images used in the GIS package. However useful measurement is constrained by image clarity at the pixel level. This can vary from 0.5 to 4.5 m depending on the image resolution. Therefore the accuracy of the plotted shoreline could be ± 4.5 m. The GIS package measures the distance between selected points to accuracy of 0.01 m, but measurements were rounded to 0.1 m.

As data for this study were being compared to Nicholson's work, it should be considered that measurements and the results discussed could have a value of ± 15 m. However measurements from photographs for the period since 1980 are likely to be within ± 5 m accuracy.

2. Long-term shoreline change

This section presents results of the analysis of shoreline position change from the work of Nicholson (up to 1979) for Purakanui, Long Beach, Whareakeake and Kaikai Bays, and interpretation of recent aerial photographs for the period 1980 to 2013 for those bays plus Karitane, Warrington, Aramoana and Shelly Beaches. In addition, data from beach profile surveys since 1990 have been compared with the aerial photograph analysis. The attached figures show plotted shoreline positions from Nicholson (1979) and from work for this study. The base photograph is the 2013 mosaic photograph, ortho-rectified to NZMG. Locations of the detailed figures are shown in Appendix 1.

2.1.1 Karitane

Figure 2.1 shows plotted shorelines at Karitane for 1980, 1997, 1999, 2005 and 2013, while Table 2.1 shows the measurements of change in shoreline position in the vicinity of surveyed beach profiles assessed in Single (2014a, 2014c).

Steep clay banks back the beach north of the Karitane Peninsula. It has been subject to erosion mitigation work through deposition of hard fill at some time prior to 1990. Although the clay bank shows evidence of failure and slumping, there is also field evidence that small dunes can develop seaward of the backshore. These dunes are low in amplitude and are likely to be short-term features on the shore.

The aerial photograph interpretation shows that although changes in vegetation position, and hence the plotted shoreline, can occur over time, there is no consistent trend in the shoreline change over the study period. This is consistent with the findings of the beach profile surveys. Episodes of accretion are countered by periods of erosion, with the longer-term result being minor progradation or stability.

The beach does display a long-term erosional aspect in that the backshore is steep and at times undercut by wave action. There is also an indication from the aerial photographs that erosion was prevalent between 1980 and 1997. Erosion of the high banks has resulted in slumping of the backshore onto the beach. At a very local scale, these slumps show as progradation of the shoreline, and do provide temporary protection to the hinterland from further erosion. However the sediment deposited to the beach is gradually removed to offshore or spread along the shore and there is no sustained supply of sediment from the backshore to the beach.

Table 2.1 Rates of shoreline change at Karitane. See Appendix 1 for profile locations.

From aerial photographs

Time Interval	Progradation (+) or Retreat (-) (m) Location E03	E04	Average (m)	Rate ($m.yr^{-1}$)
1980 – 1997	0	0	0.0	0.0
1997 - 1999	20.1	16.5	18.3	9.2
1999 - 2005	0.5	-2.6	-1.1	-0.2
2005 - 2013	0	-3.4	-1.7	-0.2
1980 - 2013	20.6	10.5	15.6	**0.5**

From beach profile surveys

Time Interval	Progradation (+) or Retreat (-) (m) Location E03	E04	Average (m)	Rate ($m.yr^{-1}$)
1990 - 1998	0.8	1.0	0.9	0.1
1998 - 2006	-0.3	2.3	1.0	0.1
2006 - 2008	-0.8	7.8	3.5	1.8
2008 - 2011	0.5	-10.9	-5.2	-1.7
2011 - 2013	-0.3	0.3	0.0	0.0
2013 - 2014	-0.1	0.3	0.1	0.1
1990 - 2013	-0.1	0.9	0.4	**0.02**

Figure 2.1 Shoreline changes at Karitane 1980 to 2013. Base photo is 2013 imagery.

2.1.2 Warrington

Figure 2.2 shows plotted shorelines at Warrington for 1980, 1997, 1999, 2005 and 2013, while Table 2.2 shows the measurements of change in shoreline position in the vicinity of surveyed beach profiles assessed in Single (2014a, 2014c).

Table 2.2 Rates of shoreline change at Warrington. See Appendix 1 for profile locations.

From Gibb (1978)

Time Interval	Progradation (+) or Retreat (-) (m) Location S155/232906		Rate ($m.yr^{-1}$)
1862 - 1968	30.0		**0.28**

From aerial photographs

Time Interval	Progradation (+) or Retreat (-) (m) Location E01	E02	Average (m)	Rate ($m.yr^{-1}$)
1980 – 1997	85.0	72.6	78.8	4.6
1997 - 1999	-4.3	-1.3	-2.8	-1.4
1999 - 2005	-21.0	0.0	-10.5	-1.8
2005 - 2013	90.8	51.1	71.0	8.9
1980 - 2013	150.5	122.4	136.5	**4.10**

From beach profile surveys

Time Interval	Progradation (+) or Retreat (-) (m) Location E01	E02	Average (m)	Rate ($m.yr^{-1}$)
1990 - 1998	20.5	33.3	26.9	3.4
1998 - 2006	23.3	21.0	22.1	2.8
2006 - 2008	62.8	23.2	43.0	21.5
2008 - 2011	-3.4	8.4	2.5	0.8
2011 - 2013	1.0	5.1	3.1	1.5
2013 - 2014	1.6	4.4	3.0	3.0
1990 - 2013	105.8	95.4	100.6	**4.37**

The wide sandy beach is backed by a well-vegetated dune system with stable back-dunes and dynamic foredunes. Gibb (1978) presents an estimate of long-term shoreline change from analysis of map positions of the MHWM in 1862 and 1968 for a beach position near the northern ORC beach profile site (E02). The measured beach change was +30 m over this time period, giving a long-term rate of change of +0.28 $m.yr^{-1}$.

The aerial photograph interpretation shows beach change for the period 1980 to 2013 of +4.1 $m.yr^{-1}$ (progradation). Within this period there was progradation between 1980 and 1997, and erosion between 1997 and 2005. During this period, it is likely that the dunes grew in bulk and height without foreshore progradation. The greatest rate of change resulted from the development of low vegetated dunes between 2005 and 2013.

These findings are consistent with the surveyed beach profile changes between 1990 and 2014, where the average rate of change was +4.4$m.yr^{-1}$. The beach is susceptible to storm erosion resulting in overwash of the low dunes along the southern end of the beach, but appears to be accreting in the long-term. It is likely that changes to the shoreline will not be at a constant rate as the beach erodes rapidly during storm events but recovers more slowly. Dune development also occurs through initial building out of the dune extent then growth in height and volume of the dunes. This means that even with a constant sediment supply, the beach will prograde rapidly for a short period before stabilising in shoreline position while the dunes get higher.

Figure 2.2 Shoreline changes at Warrington 1980 to 2013. Base photo is 2013 imagery.

2.1.3 Doctors' Point

Figures 2.2 and 2.3 show plotted shorelines at Doctors' Point for 1980, 1999, 2005 and 2013. There have been localised areas of accretion of the shoreline and progradation of some of the beaches within embayments along the shore. However in general there has been little shoreline change since 1980. There is evidence of significant volumes of sand stored in the nearshore, and there are likely to be relatively large fluctuations in depth of the nearshore shoals and bars with changes to the channel around the entrance to Blueskin Estuary.

2.1.4 Purakanui

Figure 2.3 shows plotted shorelines at Purakanui for 1980, 1997, 1999, 2005 and 2013. In addition, the shorelines plotted by Nicholson (1979) are also included. Table 2.3 shows measurements of change in shoreline position for different parts of the beach.

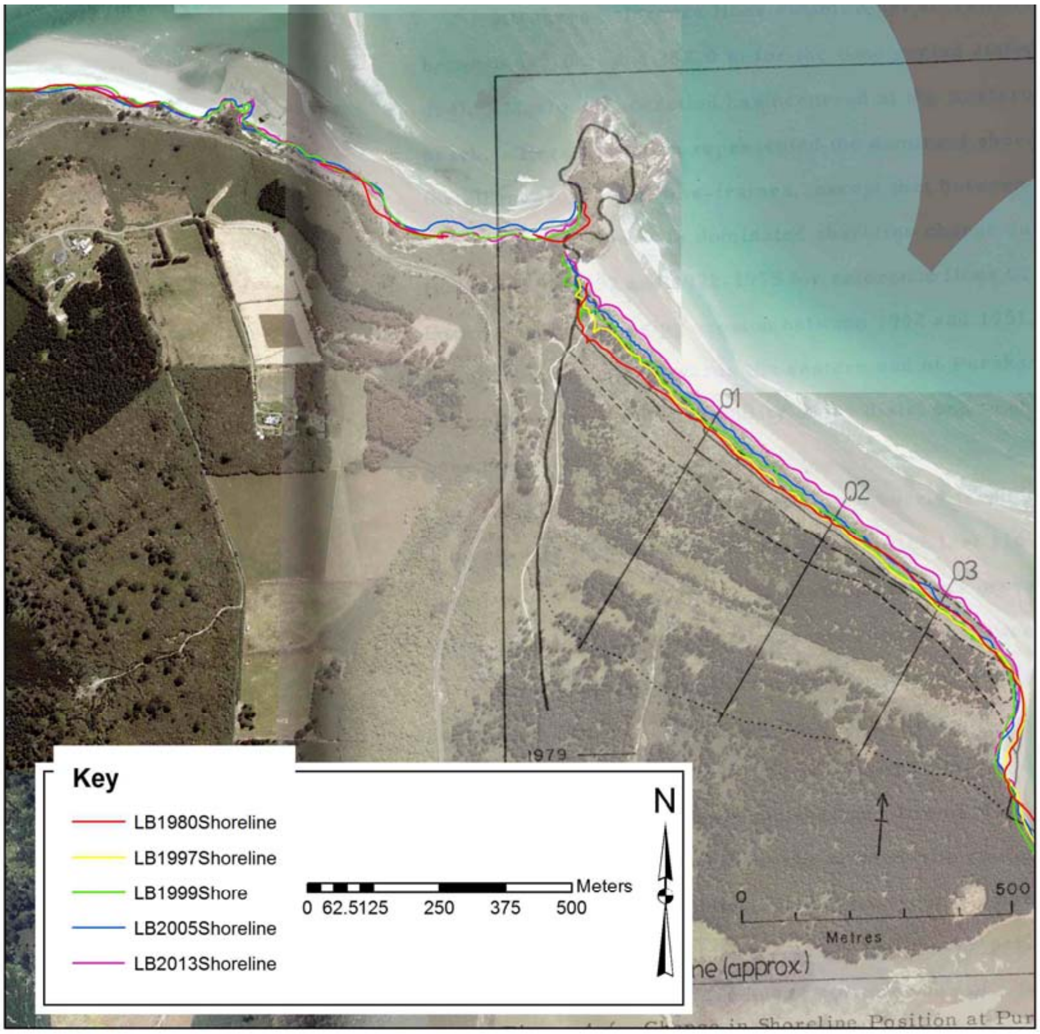

Figure 2.3 Shoreline changes at Purakanui including plotted shorelines from Nicholson (1979) and those plotted from aerial photographs from 1980 to 2013. Base photo is 2013 imagery.

Purakanui Bay contains a progradational spit north of the inlet to Purakanui Inlet. Gibb (1978) proposed a rate of long-term change for the period 1891 to 1975 of +5.18 $m.yr^{-1}$. Nicholson (1979) also investigated this shoreline. He calculated net progradation of 370.4 m between 1863 and 1979 at a mean rate of +3.2 $m.yr^{-1}$. Nicholson considered his rate more accurate than that of Gibb as it represented the whole beach, whereas it was thought Gibb's rate was for one part of the beach. Nicholson found differences in the rate of change over time, with erosion occurring between 1972 and 1975. The progradation is a result of landward movement of sand from the nearshore, deposited on the beach and forming sub-parallel dunes and ridges.

The aerial photograph analysis shows continued progradation of the shore but at a slower rate than prior to 1979. The mean rate of change between 1979 and 2013 is +1.4 $m.yr^{-1}$. The changes include variable change along the beach most likely as a direct response to the direction of wave approach and to possible changes near the distal end of the spit as a result of instability of the inlet entrance. There is also a temporal variability in the change, with field evidence indicating erosion of the seaward face of the dunes and subsequent rebuilding of dunes. It is likely that the infilling of the bay between the Mapoutahi headland and the inlet channel will continue to slow as the shallow bay gets narrower in offshore width and the beach gets closer to deep water.

Overall the long-term shoreline change at Purakanui is progradation at about +2.9 $m.yr^{-1}$, with progradation of +1.4 $m.yr^{-1}$ since 1979 and +1.1 $m.yr^{-1}$ since 1997.

Table 2.3 Rates of shoreline change at Purakanui.

From Gibb (1978)

Time Interval	Progradation (+) or Retreat (-) (m) Location S164/252878		Rate ($m.yr^{-1}$)
1891 - 1975	435.0		**5.18**

Nicholson (1979) measurements

Time Interval	Progradation (+) or Retreat (-) (m) Location P01	P02	P03	Average (m)	Rate ($m.yr^{-1}$)
1863 - 1942	357.9	304.9	249.5	304.1	3.8
1942 - 1951	15.8	4.0	-11.9	2.6	0.3
1951 - 1957	22.2	-4.0	-7.9	3.4	0.6
1957 - 1967	30.1	59.4	30.1	39.9	4.0
1967 - 1972	52.3	39.6	47.5	46.5	9.3
1972 - 1975	-52.3	-39.6	-30.1	-40.7	-13.6
1975 - 1979	19	19.8	4.8	14.5	3.6
1863 - 1979	445	384.1	282	370.4	**3.19**

From Nicholson plotted shorelines (ortho-rectified and geo-referenced)

Time Interval	Progradation (+) or Retreat (-) (m) Location P01	P02	P03	Average (m)	Rate ($m.yr^{-1}$)
1863 - 1951	381.5	328.4	248.6	319.5	3.6
1951 - 1967	46.2	52.6	33.1	44.0	2.7
1967 - 1972	52.1	44.5	46.9	47.8	9.6
1972 - 1979	-19.1	-18.5	-29.8	-22.5	-3.2
1863 - 1979	460.7	407	298.8	388.8	**3.35**

From aerial photographs

Time Interval	Progradation (+) or Retreat (-) (m) Location P01	P02	P03	Average (m)	Rate (m.yr^{-1})
1979 - 1980	10.3	12.8	12.1	11.7	11.7
1980 - 1997	1.1	2.9	-8.9	-1.6	-0.1
1997 - 1999	7.6	7.1	3	5.9	3.0
1999 - 2005	18.9	3.8	10	10.9	1.8
2005 - 2013	14.4	25.6	23.2	21.1	2.6
1979 - 2013	52.3	52.2	39.4	48.0	**1.4**

2.1.5 Long Beach

Figure 2.4 shows plotted shorelines at Long Beach for 1980, 1997, 1999, 2005 and 2013. In addition, the shorelines plotted by Nicholson (1979) are also included. Table 2.4 shows measurements of change in shoreline position for different parts of the beach, mainly in the vicinity of beach profiles as assessed by Single (2014a, 2014c).

Long Beach contains a sandy foreshore backed by well-vegetated dunes. The bay extends between Potato Point in the north and Pilot Point in the south. However in the past, a rock outcrop has separated a small pocket beach at the north end of the bay from the main beach. With progradation of the bay, these two beaches have joined to form one continuous shoreline, albeit broken by two stream channels, at some time between 1980 and 1997.

Nicholson (1979) considered long-term shoreline change for the two beach compartments separately. He found that both compartments prograded between 1863 and 1979, with the northern section at a net rate of +1.04 m.yr^{-1}, and the southern beach at a net rate of +1.83 m.yr^{-1}. Both beaches showed episodes of erosion during the late 1970s, with greater fluctuation in shoreline change at the northern and southern ends of the beach.

Goldsmith (1995a) also investigated long-term change at Long Beach in his study of beaches at the entrance to Otago Harbour. He found an average rate of change between 1871 and 1942 of +2.96 m.yr^{-1}, and +1.08 m.yr^{-1} for the period 1942 to 1985.

Analysis of shoreline change from the aerial photographs taken since 1979, show similar patterns of variability and overall progradation. The shoreline shows accretion since an initial erosional phase between 1979 and 1980. The net rate of shoreline change between 1979 and 2013 was +1.5 m.yr^{-1} for the northern section of the beach and + 1.0 m.yr^{-1} for the southern section. The magnitude of shoreline change is consistent with that shown by the beach profile surveys, where a net rate of +1.5 m.yr^{-1} was recorded for the two beach profiles. This latter rate includes the effects of the 1979 to 1980 erosion and recent erosion episodes since 2008 along the southern part of the beach.

Overall, Long Beach exhibits recent long-term progradation of between +1.0 and +1.6 m.yr^{-1}. However erosion episodes can result in retreat of the dunes in localised areas, leading to a net negative (erosion) annual shoreline change. It is also likely that progradation at this beach will slow as the shoreline gets closer to the seaward extent, and out of the sheltering effect of the headlands.

Table 2.4 Rates of shoreline change at Long Beach. (nc and 0 indicate no change in position)

Nicholson (1979) measurements

Time Interval	(+) or (-) Location P04	Rate (m.yr^{-1})	Progradation (+) or Retreat (-) (m) Location P05	P06	P07	Average (m)	Rate (m.yr^{-1})
Pre-1863	nc	-	286.6	452.8	408.8	376.8	
1863 – 1942	89.3	1.1	60.1	84.2	72.2	72.2	0.9
1942 – 1951	55.3	6.1	75.3	72.2	48.1	65.2	7.2
1951 – 1957	0.0	0.0	0.0	0.0	16.0	5.3	0.9
1957 – 1967	0.0	0.0	20.8	72.2	1.1	31.4	3.1
1967 – 1972	0.0	0.0	28.8	42.5	41.7	37.7	7.5
1972 – 1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1975 – 1979	-24.0	-6.0	0.0	0.0	0.0	0.0	0.0
1863 – 1979	120.6	1.04	185.0	271.1	179.1	211.7	**1.83**

From Nicholson plotted shorelines (ortho-rectified and geo- referenced)

Time Interval	(+) or (-) Location P04	Rate (m.yr^{-1})	Progradation (+) or Retreat (-) (m) Location P05	P06	P07	Average (m)	Rate (m.yr^{-1})
1863 – 1942	89.5	1.1	60.0	88.5	73.7	74.1	0.9
1942 – 1951	52.0	5.8	90.2	49.5	49.0	62.9	7.0
1951 – 1957	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1957 – 1967	0.0	0.0	11.6	18.7	25.8	18.7	1.9
1967 – 1972	0.0	0.0	15.4	40.5	32.9	29.6	5.9
1972 – 1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1975 – 1979	-19.2	-4.8	0.0	0.0	0.0	0.0	0.0
1863 – 1979	122.3	1.05	177.2	197.2	181.4	185.3	**1.60**

From aerial photographs

Time Interval	(+) or (-) Location P04	Rate (m.yr^{-1})	Progradation (+) or Retreat (-) (m) Location P05	P06	P07	Average (m)	Rate (m.yr^{-1})
1979 - 1980	-10.8	-10.8	-16.4	-35.0	-29.7	-27.0	-27.0
1980 – 1997	35.9	2.1	36.6	59.6	46.6	47.6	2.8
1997 – 1999	17.5	8.8	-2.3	-6.0	13.8	1.8	0.9
1999 – 2005	4.5	0.8	8.5	16.3	11.6	12.1	2.0
2005 – 2013	5.0	0.6	3.1	-8.7	3.3	-0.8	-0.1
1979 – 2013	52.5	1.51	29.5	26.2	45.6	33.8	**0.99**

From beach profile surveys (Locations of profiles are shown in Appendix 1)

Time Interval	Progradation (+) or Retreat (-) (m) Location E20	E21	Average (m)	Rate (m.yr^{-1})
1990 - 1998	8.8	14.4	11.6	1.5
1998 - 2006	-5.8	1.6	-2.1	-0.3
2006 - 2008	4.0	11.7	7.9	3.9
2008 - 2011	-3.3	0.6	-1.4	-0.5
2011 - 2013	0.3	-1.1	-0.4	-0.2
2013 - 2014	0.0	-6.5	-3.3	-3.3
1990 - 2013	3.9	20.7	12.3	**0.53**

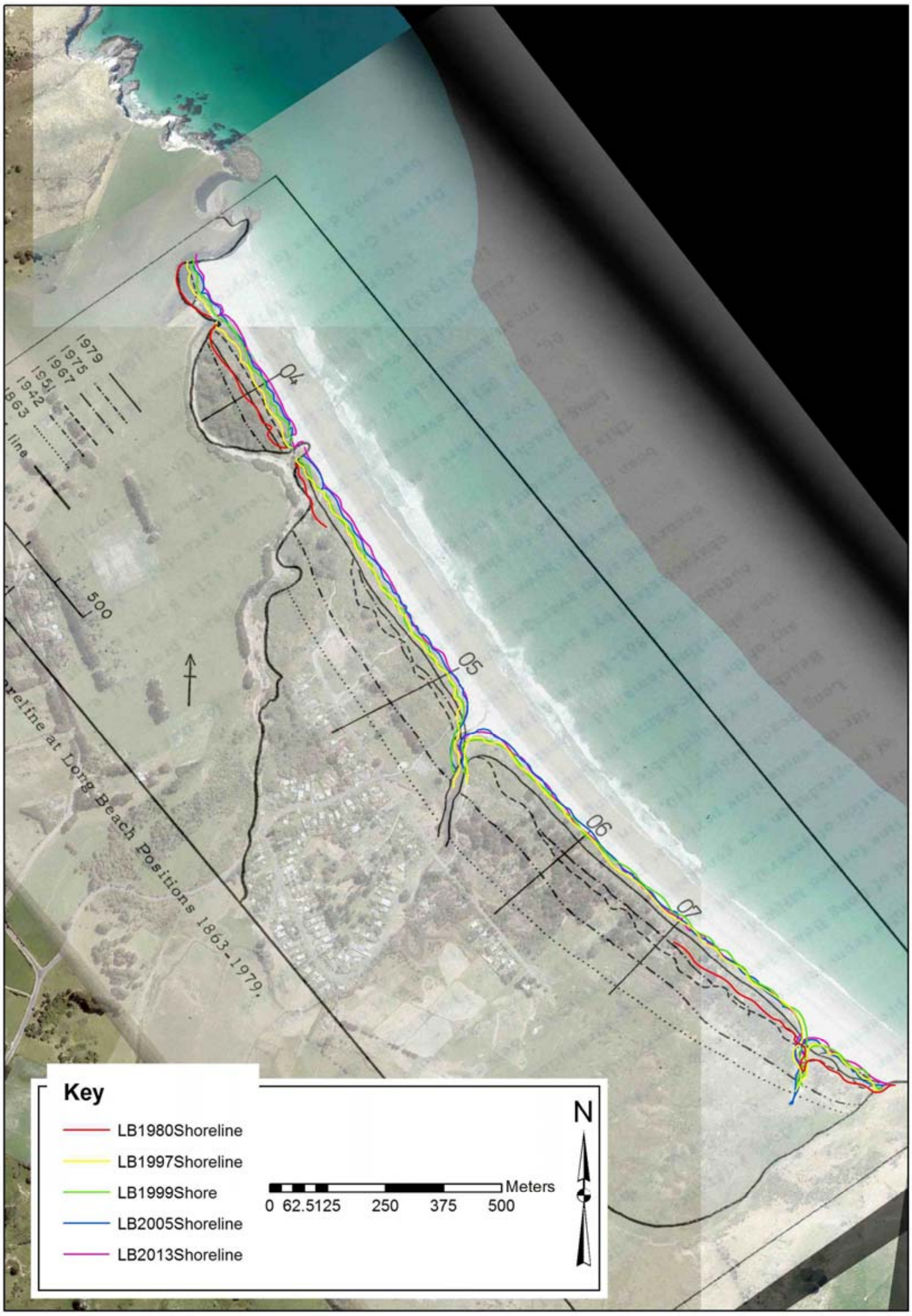

Figure 2.4 Shoreline changes at Long Beach, including plotted shorelines from Nicholson (1979) and those plotted from aerial photographs from 1980 to 2013. Base photo is 2013 imagery.

2.1.6 Whareakeake

Figure 2.5 shows plotted shorelines at Whareakeake for 1980, 1997, 1999, 2005 and 2013. In addition, the shorelines plotted by Nicholson (1979) are also included. Table 2.5 shows measurements of change in shoreline position for different parts of the beach.

Whareakeake (also known as Murdering Beach) is a relatively small bay-head beach between Pilot Point and Purehurehu Point. The beach is generally sandy with vegetated dunes on the backshore. A stream crosses the dune field and the beach at the southern end. From analysis of the substrate and dune development within the bay, Nicholson identified Holocene progradation of the beach of over +350 m until 1863.

Nicholson (1979) found net retreat of the shoreline at Whareakeake between 1863 and 1979. The rate of retreat varied over time from -0.42 $m.yr^{-1}$ between 1863 and 1951, to -6.72 $m.yr^{-1}$ between 1975 and 1979. The mean net rate of retreat was -0.89 $m.yr^{-1}$. He found that retreat of the frontal dunes had been fairly even along the shore, although the influence of fluctuation in the position of the stream channel was also evident.

Table 2.5 Rates of shoreline change at Whareakeake.

Nicholson (1979) measurements

Time Interval	Progradation (+) or Retreat (-) (m) Location P08	P09	Average (m)	Rate ($m.yr^{-1}$)
Pre-1863	254.4	449.0	347.2	
1863 - 1951	-28.1	-45.7	-36.9	-0.4
1951 - 1957	-22.5	-20.0	-21.3	-3.5
1957 - 1975	-20.0	-16.0	-18.0	-1.0
1975 - 1979	-32.1	-21.6	-26.9	-6.7
1863 - 1979	-102.7	-103.3	-103.0	**-0.89**

From Nicholson plotted shorelines (ortho-rectified and geo-referenced)

Time Interval	Progradation (+) or Retreat (-) (m) Location P08	P09	Average (m)	Rate ($m.yr^{-1}$)
1863 - 1951	-19.9	-40.1	-30.0	-0.3
1951 - 1975	-28.8	-22.6	-25.7	-1.1
1975 - 1979	-29.3	-18.9	-24.1	-6.0
1863 - 1979	-78.0	-81.6	-79.8	**-0.69**

From aerial photographs

Time Interval	Progradation (+) or Retreat (-) (m) Location P08	P09	Average (m)	Rate ($m.yr^{-1}$)
1979 - 1980	32.1	29.4	30.8	30.8
1980 - 1997	13.6	1.6	7.6	0.4
1997 - 1999	-13.6	-20.1	-16.9	-8.4
1999 - 2005	13.0	11.2	12.1	2.0
2005 - 2013	6.9	14.4	10.7	1.3
1979 - 2013	52.0	36.5	44.3	**1.30**

The analysis of aerial photographs since 1979 shows progradation for the period up until 1997, retreat between 1997 and 1999, and progradation from 1999 to 2013. The mean net rate of change was +1.3 $m.yr^{-1}$.

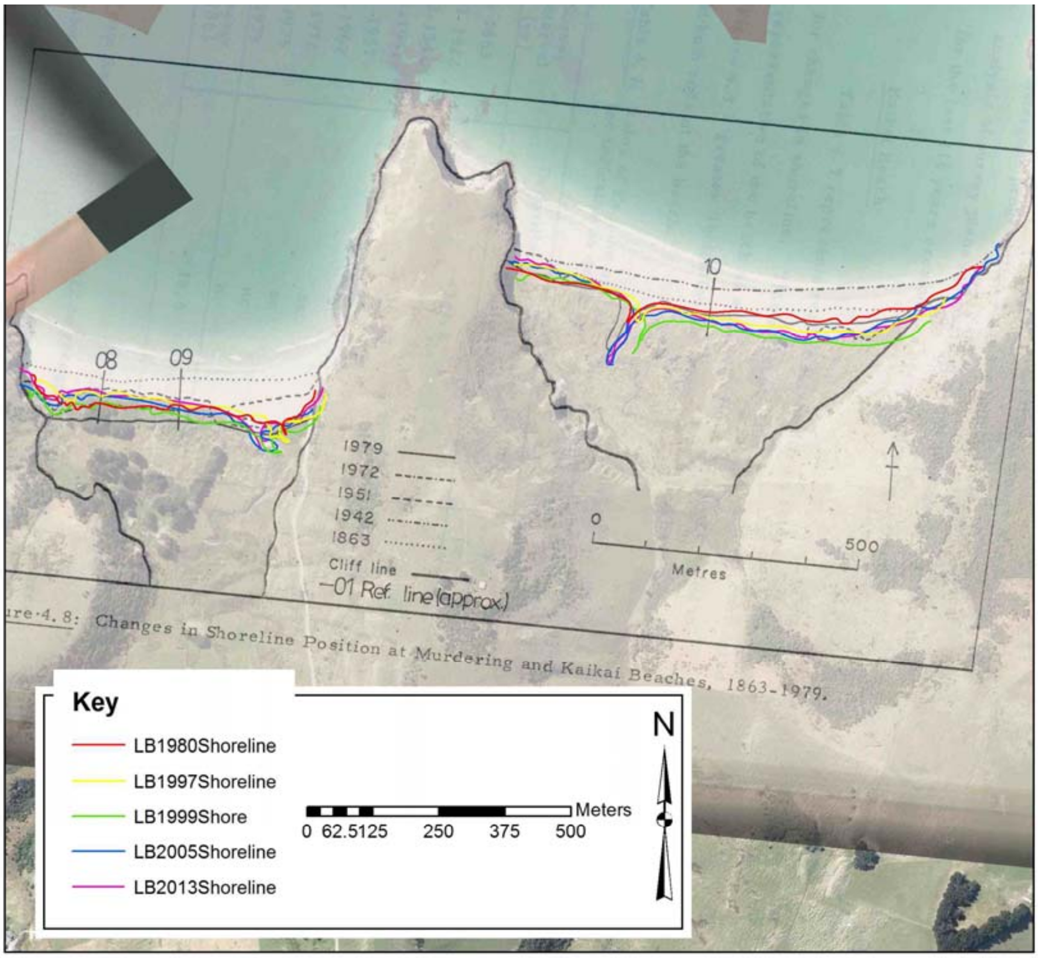

Figure 2.5 Shoreline changes at Whareakeake and Kaikai, including plotted shorelines from Nicholson (1979) and those plotted from aerial photographs from 1980 to 2013. Base photo is 2013 imagery.

Erosion of the dunes in response to storm wave action can result in retreat of the shoreline in the order of 10 to 20 m. Recovery of the dunes and seaward advance of vegetation is slow in comparison to storm retreat. The antecedent wave environment prior to the aerial photograph being taken affects the determination of a long-term rate of change. It is likely that the bay is relatively stable although prograding slowly in the long-term. Although there is greater potential for this beach to infill between the headlands than the neighbouring Long Beach and Kaikai Beach, it is likely that the local wave environment for this bay and leakage of sediment from the bay to the north during erosion events will inhibit the progradation of the beach.

Overall, the long-term rate of shoreline change for Whareakeake since 1979 is +1.3 $m.yr^{-1}$. However the beach is subject to periods of prolonged erosion. It is likely that the long-term state of the beach is a dynamic equilibrium, with a nearly stable long-term shoreline position.

2.1.7 Kaikai Beach

Figure 2.5 also shows plotted shorelines at Kaikai beach for 1980, 1997, 1999, 2005 and 2013. In addition, the shorelines plotted by Nicholson (1979) are also included. Table 2.6 shows measurements of change in shoreline position for different parts of the beach.

Kaikai Beach is a bay-head beach between Purehurehu Point and Heyward Point. The beach is sandy with vegetated dunes on the backshore, with one stream channel crossing through the dunes and onto the beach just west of the middle of the bay. The 1863 map shows that Holocene progradation of the beach extended about +380 m seaward from a fossil boulder beach ridge at the head of the embayment.

Table 2.6 Rates of shoreline change at Kaikai.

Nicholson (1979) measurements

Time Interval	(+) or (-) Location P10	Rate ($m.yr^{-1}$)
Pre-1863	321.2	
1863 - 1942	36.0	0.5
1942 - 1951	-54.5	-6.1
1951 - 1957	0.0	0.0
1957 - 1967	0.0	0.0
1967 - 1972	0.0	0.0
1972 - 1975	0.0	0.0
1975 - 1979	0.0	0.0
1863 - 1979	-18.5	**-0.16**

From Nicholson plotted shorelines (ortho-rectified and geo-referenced)

Time Interval	(+) or (-) Location P10	Rate ($m.yr^{-1}$)
1863 - 1942	30.0	0.4
1942 - 1951	-51.0	-5.7
1951 - 1957	0.0	0.0
1957 - 1967	0.0	0.0
1967 - 1972	0.0	0.0
1972 - 1975	0.0	0.0
1975 - 1979	0.0	0.0
1863 - 1979	-21.0	**-0.18**

From aerial photographs

Time Interval	(+) or (-) Location P10	Rate ($m.yr^{-1}$)
1879 - 1980	6.4	6.4
1980 - 1997	-12.1	-0.7
1997 - 1999	-16.0	-8.0
1999 - 2005	11.4	1.9
2005 - 2013	0.0	0.0
1979 - 2013	-10.3	**-0.30**

Nicholson (1979) found that the shoreline position was stable for long periods of time, with no change in shoreline position recorded between 1863 and 1922, and between 1951 and 1979. A progradational phase between 1922 and 1942 was reversed between 1942 and 1951, with the retreat positioning the shoreline approximately aligned with the 1863 shoreline. Nicholson calculated the mean net rate of change at -0.15 $m.yr^{-1}$. Within the relative stability in position, erosion and accretion of the dunes occurred at the ends of the beach, with the shoreline position varying by up to 30 m at the western end (closest to Purehurehu Point).

Although significant erosion near the middle of the bay between 1980 and 1999 has resulted in net retreat of the shore over the period 1979 to 2013, accretional phases from 1979 to 1980, and 1999 to 2005 have resulted in a relatively stable shoreline position, with overall change in the order of -0.3 $m.yr^{-1}$. The shoreline position has remained nearly unchanged since 2005.

Overall, Kaikai Beach is relatively stable in form, although the ends of the beach exhibit potential to retreat and prograde in response to changes in the wave environment. At low tide, the beach extends to the seaward limit of the headland at Purehurehu Point, indicating that the bay is essentially infilled and in dynamic equilibrium in relation to the predominant direction of wave approach, the supply of sediment to the beach from the nearshore, and changes in wave energy (storms and swell conditions).

2.1.8 Aramoana

Figure 2.6 shows plotted shorelines at Aramoana and Shelly (Spit) Beach for 1980, 1997, 1999, 2005 and 2013. Table 2.7 shows measurements of change in shoreline position for different parts of the beach in the vicinity of the beach profiles assessed by Single (2014a, 2014c).

Table 2.7 Rates of shoreline change at Aramoana. See Appendix 1 for profile locations.

From aerial photographs

Time Interval	Progradation (+) or Retreat (-) (m) Location E18	E19	Average (m)	Rate ($m.yr^{-1}$)
1980 - 1997	-19.2	-7.2	-13.2	-0.8
1997 - 1999	20.4	14.6	17.5	8.8
1999 - 2005	-5.7	-2.7	-4.2	-0.7
2005 - 2013	-4.3	5.0	0.4	0.0
1980 - 2013	-8.8	9.7	0.4	**0.01**

From beach profile surveys

Time Interval	Progradation (+) or Retreat (-) (m) Location E18	E19	Average (m)	Rate ($m.yr^{-1}$)
1990 - 1996	-0.1	9.0	4.4	0.7
1996 - 2002	-0.1	4.9	2.4	0.4
2002 - 2005	0.4	8.1	4.3	1.4
2005 - 2006	-4.8	-15.3	-10.0	-10.0
2006 - 2011	15.0	20.4	17.7	3.5
2011 - 2013	-4.4	-2.4	-3.4	-1.7
2013 - 2014	1.9	-1.2	0.3	0.3
1990 - 2013	8.0	23.5	15.8	**0.68**

There are effectively two sections to Aramoana Beach. The southern section extends from the Mole north to Lion Rock, at the northern end of the vegetated dune area. The backshore in this area consists of well-vegetated dunes that have become stable and prograded rapidly after the construction of the Mole in 1885. Goldsmith (1995a) notes that the beach in this area prograded at a rate of +3.64 $m.yr^{-1}$ between 1884 and 1909, but the average rate of change was only +0.88 $m.yr^{-1}$ between 1909 and 1985.

North of Lion Rock, to Heyward Point, the backshore development of the beach is constrained by the cliff, and by the presence of a number of small rock outcrops. The low tide extent of sand reaches beyond the seaward limit of the rock outcrops, but the beach at high tide is very narrow.

The northern section of the beach shows little net change since 1980, except for vegetation and consolidation of the dunes directly north of Lion Rock. There was also minor progradation between 1997 and 1999, erosion between 1999 and 2005 and a mixture of erosion and progradation between 2005 and 2013. The most consistent progradation has occurred over the 500 m of beach north of Lion Rock, where there is some dune development in the backshore.

The southern section of Aramoana Beach has also undergone erosion and progradation since 1980. Initial erosion between 1980 and 1997 was followed by accretion, at times with an annual rate of up to +15 $m.yr^{-1}$, was followed by erosion and retreat of the dunes between 1999 and 2005, with a mixture of retreat and progradation (to the eastern and western end of this section of shore respectively) between 2005 and 2013. The net result is minor progradation since 1980 at a net rate of +0.1 $m.yr^{-1}$.

This pattern of change is consistent with that shown from analysis of the beach profile surveys as shown in Table 2.7. The net shoreline change between 1990 and 2014, if extrapolated from the beach profiles, is +0.7 $m.yr^{-1}$.

Overall, Aramoana Beach appears to be in a state of dynamic stability, with the shoreline retreating as a result of storm erosion and slowly prograding in recovery during more quiescent periods.

Figure 2.6 Shoreline changes at Aramoana and Shelly Beach plotted from aerial photographs from 1980 to 2013. Base photo is 2013 imagery.

2.1.9 Shelly Beach (The Spit)

Plotted shorelines for Shelly (Spit) Beach for 1980, 1997, 1999, 2005 and 2013 are shown in Figure 2.6. The historical context of change to the Aramoana and Shelly Beach area is shown in Figure 2.7, while detail of Goldsmith's shoreline plots are shown in Figure 2.8. Recent rates of shoreline change have not been presented for Shelly Beach, as the margin of error due to uncertainty of determining the vegetation line on the aerial photographs is too great.

Historically, the shoreline of Shelly Beach eroded rapidly following the construction of the Mole. Goldsmith (1995a) estimates an average annual rate of retreat of -5.7 m.yr-1 between 1884 and 1909, and a retreat of -0.9 m.yr-1 between 1909 and 1985. Changes between 1951 and 1990 are shown in Figure 2.8.

A comparison of Figure 2.8 and Figure 2.6 shows that the general shape of the spit landform between the Mole and the harbour channel has remained unchanged since 1951. However the central area of Shelly Beach and the central section of the spit adjacent to the Training wall have become narrower while the northwest end and the southern tip of the spit have increased in bulk (width, height of dunes and denser vegetation).

There is no definite trend in shoreline change over the long-term due to the variable nature of the shoreline position in response to storm wave erosion and subsequent beach recovery, dune blowouts and past dune management measures, and inshore sediment nourishment by Port Otago Limited. Reports by Goldsmith (1995a), Johnston (1997), Single and Stephenson (1998), Bunting et al. (2003b), Leon (2005) and Single (2014b) consider changes to Shelly Beach in relation to Port Otago Limited activities in more detail.

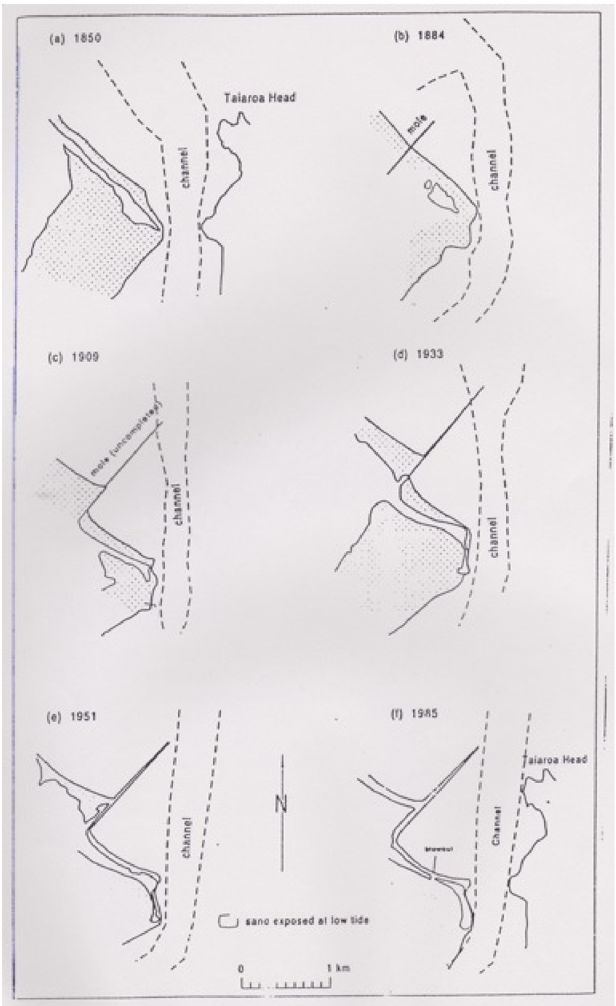

Figure 2.7 Historical morphological development of the Otago Harbour entrance (source: Goldsmith, 1995b).

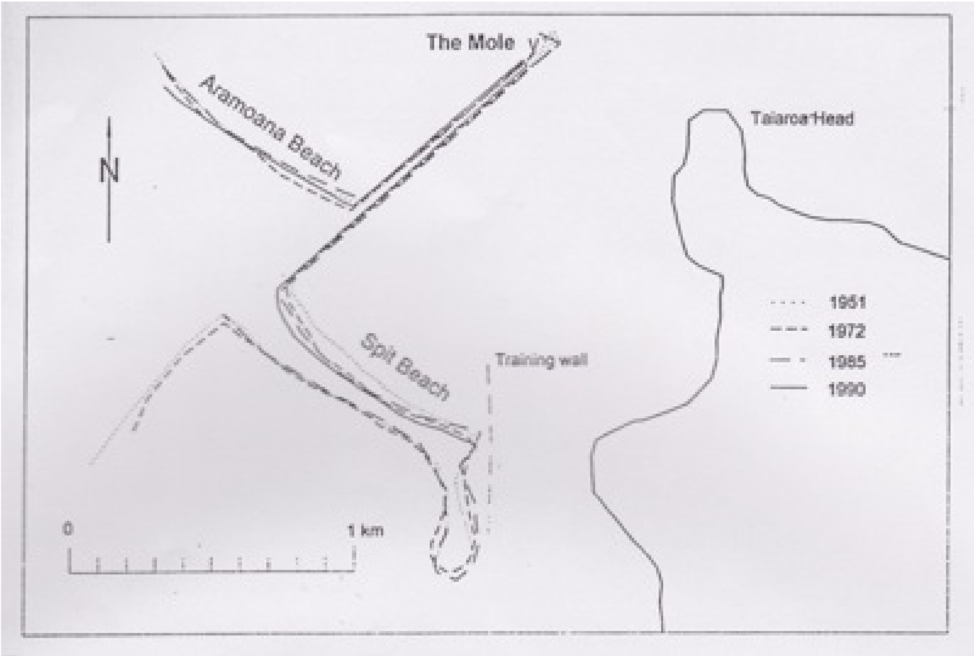

Figure 2.8 Detailed morphological changes to Aramoana and Shelly (Spit) beaches between 1951 and 1990 (source: Goldsmith 1995a).

3. Discussion of overall findings

The investigation of long-term shoreline change of the beaches between Otago Harbour and Karitane has included analysis of previous studies (Gibb 1978, Nicholson 1979, Goldsmith 1995) that have plotted shorelines and/or measured shore change from maps and aerial photographs. Due to unavailability of photographs, a full re-examination of aerial photographs older than 1980 has not been possible. However by combining the data from the different studies, a description of the trends in long-term shoreline change and the order of magnitude changes recorded historically has been possible.

Karitane

The shoreline at Karitane fluctuates at the northern end in response to supply of sediment from offshore and at the southern end from slumping of the steep backshore slope. Since 1980, the beach overall has been relatively stable but does exhibit a small net progradation of the shoreline.

Warrington

The beach at Warrington has accreted in volume and the shoreline has prograded over historical times. Although subject to episodes of erosion and shore retreat, there is a recent net rate of progradation of around +4.0 $m.yr^{-1}$ since 1980. This is greater than estimated for the period between 1862 and 1968, and may reflect an increase in the supply of sediment to the shore, or increased stability of the dune system and the ability of the dunes to buffer the shore against storm erosion.

Purakanui

Historically, the shore at Purakanui has prograded rapidly, developing a well-vegetated dune field. At the north-western end of the beach, the shoreline is near the seaward limit of the headland. However at the southern end, fluctuation to the seaward end of the channel to Purakanui Inlet results in erosion along this section of shore. The beach is subject to episodes of erosion that can result in periods of net retreat of the shoreline. However since 1979, the shore has continued to prograde, although at a slower rate than from 1863 to 1979 (+1.4 $m.yr^{-1}$ in comparison to more than +3.0 $m.yr^{-1}$).

Long Beach

Long Beach has infilled the bay between Potato and Pilot Points to the extent that the intermediary headland separating the northern and southern sections of the beach is now inland of the foreshore. The rate of progradation since 1979 is slower than the historical rate to 1979 (+1.0 $m.yr^{-1}$ in comparison to +1.6 $m.yr^{-1}$), and the beach is subject to episodes of erosion in response to storm events. Alongshore movement of two stream channels that cross the dunes and foreshore also result in erosion of the foredune near the stream outlets.

Whareakeake

Historical retreat of the shore in the order of about -1.0 $m.yr^{-1}$ and subsequent erosion of the dune system followed progradation of Whareakeake beach prior to 1863. Although there have been episodes of erosion since 1979, the shoreline has prograded at a net rate of +1.3 $m.yr^{-1}$.

Kaikai

Kaikai is the only beach that shows persistent retreat since 1863. Prior to 1863, the bay had infilled with sand, with a well-vegetated dune field developed. Erosive events cause rapid retreat of the dunes and slow recovery. This results in historical net shoreline change of less than -0.3 $m.yr^{-1}$. Essentially the beach could be considered to be dynamically stable in the long-term.

Aramoana

North of Lion Rock, the beach at Aramoana can be considered as relatively stable, subject to episodes of erosion and accretion as a response to changes in the wave environment. A near-vertical cliff backs the narrow sand beach, while steep dunes have formed at the base of the cliff.

South of Lion Rock the beach has undergone changes as a result of the construction of the Mole and stabilisation of the entrance to Otago Harbour. Rapid progradation between 1884 and 1909 has been followed by periods of net erosion and shoreline retreat, and net progradation. Recent shoreline change has resulted in small net progradation..

Shelly Beach

Shelly Beach is a narrow strip of steep dunes backing a shallow foreshore. The beach has a history of erosion and loss of the dune barrier in response to storm wave attack. Dune management and nearshore sand replenishment has resulted in dynamic stability of the beach and dunes since the mid 1990s, whereby the shoreline effectively pivots about the mid-point of it’s length with erosion at one end and accretion at the other depending on the direction of wave approach. Pockets of local erosion along the eastern end of the spit have resulted in net retreat of the shoreline over short distances, while the southern tip of the spit has prograded.

Overall

Over the long-term, or historically, the beaches of Otago between Otago Harbour and Karitane have prograded to a position where further seaward progression of the shore is limited by loss of the sheltering effect against the wave environment provided by the headlands of each bay. The beaches generally prograded until the mid 1940s to 1970s, but show a slower rate of progradation since then due to episodes of beach retreat in response to storm events or prolonged periods of storm waves, and slow recovery. It appears that the dune systems have grown in height and in sand volume, so it is likely that sand is still supplied to the beaches from offshore. However it is also likely that sand moved offshore during storms is lost from individual bay systems, and transported either further offshore or alongshore, eventually recirculating through other beaches in the Blueskin Bay area.

Warrington, Purakanui and Long Beach show persistent progradation (seaward advance) of the shoreline in the long-term, while Kaikai shows persistent retreat of the shoreline. Karitane, Whareakeake and Aramoana appear to be in a state of dynamic equilibrium over the long-term. Shelly Beach has eroded in the past, but due to human intervention the beach is relatively stable in position and form.

4. References

Bunting K, Single MB, Kirk RM (2003): *Effects of dredge spoil at Shelly Beach, Otago Harbour*. Report for Port Otago Ltd. Land and Water International Ltd. 31p.

Gibb JG (1978): Rates of coastal erosion and accretion in New Zealand. New Zealand *Journal of Marine and Freshwater Research*, 12 (4): p429-456.

Goldsmith MJ (1995a): *Morphological change of sandy beaches at the entrance to Otago Harbour* MSc thesis (Geography, Otago University). 165p.

Goldsmith MJ (1995b): *Shoreline changes at the entrance to Otago Harbour* Unpublished report prepared for the Beach-haven Earth Trust. 15p.

Johnstone N (1997): *Consequences of breaching of the Aramoana Spit Sand Dunes.* Unpublished Memorandum presented to Otago Regional Council, RC250. 4p excluding figures and appendix.

Leon JP (2005): *Coastal evolution of Shelly Beach, Otago Harbour: A composite approach to examining the morphodynamic behaviour of a human-modified sand spit* MSc Thesis (Geography, Canterbury University). 216p.

Nicholson DC (1979): *Sand beaches in southern Blueskin Bay*. MA thesis (Geography, Canterbury University). 185p.

Single MB, Benn J (2007): *Port Otago project next generation summary of existing physical coastal environment information and scoping for further studies*. Port Otago Ltd. 65 p

Single MB (2011a): *Port Otago maintenance dredging consents – Physical coastal environment*. Report for Port Otago Ltd. Shore Processes and Management Ltd April 2011.

Single MB (2011b): *Port Otago maintenance dredging consents – Beach morphology, Otago Harbour entrance to Karitane*. Report for Port Otago Ltd. Shore Processes and Management Ltd April 2011.

Single MB (2014a): *Beach profile surveys and morphological change, Otago Harbour entrance to Karitane*. Report for Port Otago Ltd. Shore Processes and Management Ltd January 2014.

Single MB (2014b): *Long Mac groyne and Shelly Beach geomorphological processes*. Report for Port Otago Ltd. Shore Processes and Management Ltd January 2014.

Single MB (2014c): *Beach profile surveys and morphological change, Otago Harbour entrance to Karitane, May 2013 to May 2014*. Report for Port Otago Ltd. Shore Processes and Management Ltd August 2014.

Single MB; Stephenson WJ (1998): *South Spit Beach assessment of erosion mitigation.* Report for Port Otago Ltd Land and Water Studies International Ltd. 10p.

5. Appendix 1

Location of detailed figures from Section 2 and surveyed profiles. Spit Beach is more commonly known as Aramoana Beach