The Geomorphology of the Ocean Beach Dune System – Implications for Future Management of Ocean Beach Domain

A Report to the Dunedin City Council

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Executive Summary

(1) This report examines the natural character of the Ocean Beach dune system prior to human intervention and addresses the following questions:

(i) What was the natural state of the dune system?
(ii) What geomorphic processes were important?
(iii) What changes have occurred due to the introduction of marram grass and infrastructure development?
(iv) What are the implications of the findings for the future management of the Domain?

(2) Ocean Beach is a high energy coast with a high sand transport potential. Prevailing winds are from the southwest, which occur relatively frequently compared with other exposed coasts.

(3) The dune system of Ocean Beach Domain is similar to other southeast coast dune systems: (i) the dune system has developed in a well-defined embayment; (ii) sediment transport within the dune system is primarily alongshore, driven by the prevailing southwest winds; and (iii) there is a gradation in energy within the embayment, from the relatively sheltered western end of the system to the exposed eastern end.

(4) The seaward and landward boundaries of the dune system do not appear to have changed much since 1890. The high tide lines in 1890 and 2007 are more or less in the same location. The Ocean Beach Railway, Victoria Road and Tahuna Road mark the western boundary of the system

(5) The pre-modified dune system comprised three major elements: (i) a line of dunes running from the Esplanade to Queens Drive, alongside Victoria Road; (ii) a broad, flat, deflation surface, seawards of these dunes; and (iii) a transgressive (moving) dunefield that rose towards and over the ridge that separates Ocean Beach and Tomohawk Beach.

(6) It is unlikely that either Ocean Beach or Tomohawk Beach dune systems contained a foredune, except for the features in the lee of Forbury and Lawyer's Heads, respectively. Similarly, it is doubtful whether a foredune developed in association with pikao could ever be established along the Ocean Beach shoreline.

(7) The modern Ocean Beach Domain forms a significant barrier between the Pacific Ocean and the south Dunedin suburbs and this function must be retained and enhanced in any development of the Domain. Future development of the Domain must accommodate a worst case extreme event that would produce water levels 3 m above present mean sea level.

(8) Future development of the Ocean Beach Domain must also consider the impact of rising sea levels on groundwater and plan to accommodate drainage infrastructure should redevelopment of Ocean Beach Domain proceed.

(9) The Ocean Beach Domain was planted, stabilised and in-filled to form land within the dynamic coastal zone; that is, within the zone previously inundated by storm surge or affected by waves. This process could not be controlled once marram grass was introduced, since marram grass encourages both progradation and accretion.

(10) The fundamental problem with the Ocean Beach coastline is that the land-sea interface has been forced seawards and this line is being contested by the sea. This problem is likely to get worse with eustatic sea-level rise, with increasing loss of amenity values and increasing maintenance costs.

(11) The Council faces the choice of either protecting the current coastline (by either hard structures or beach nourishment); maintaining the status quo; or accommodating coastal processes by retreating. The last option would entail sacrificing land to establish a wider back-beach and more gently-sloping hinterland.

(12) There is relatively little risk of uncontrolled sand dune development and migration should the Council decide to widen the beach and create a storm surge zone. Wind-blown sand transport is primarily to the north, rather than towards the housing development adjacent to Victoria Road.

1.0 Background & scope of study

This report (Report A) is a contribution to a program of coastal management by the Dunedin City Council, along and within the Ocean Beach Domain. It examines the natural character of the Ocean Beach dune system prior to human intervention and addresses the following questions:

(v) What was the natural state of the dune system?
(vi) What geomorphic processes were important?
(vii) What changes have occurred due to the introduction of marram grass and infrastructure development?
(viii) What are the implications of the findings for the future management of the Domain?

Report B will examine costs and benefits associated with the status quo and the risk to infrastructure and amenities posed by single or multiple (closely-spaced) storm events. The implications of future climate change are also considered. Over the past few years storm events have caused erosion that has been costly to mitigate, has limited public access and which has reduced the amenity value of the Domain. Is the status quo the best option for the future. What alternative foredune and hinterland topographies, amenities and facilities, are feasible (Report C)? Is it possible to maintain an effective barrier to storm surge / tsunami inundation, while improving public access, recreational and amenity values?

2.0 Wind regime

The geomorphology of the Ocean Beach dune system is primarily a function of eolian (wind-driven) processes. The direction, strength and variability of winds affecting the Ocean Beach Domain dune system have been investigated by Pattanapol *et al.* (2010). They used data gathered from both Lawyers Head (2005-2008) and Taiaroa Head (1972-2010) to characterise the wind regime (the variation in wind speed, duration and direction) at Ocean Beach. We used Taiaroa Head data to examine these processes, once we had established there was a strong correlation between the two data sets (Appendix A). The Lawyers Head data, though derived adjacent to the study area, was not used because the record is relatively brief and because of problems with missing data. There is a strong correlation between wind speed at the two sites and a weaker correlation with wind direction.

The south coast of the Otago Peninsula is a high-energy coastline, exposed to winds from the northeast to the southwest (Figure 1). Strong onshore winds originate from the south and southwest. Winds from other onshore directions occur much less frequently and are relatively weak. Considering onshore winds (between 73-250^{o}), winds in excess of 10ms^{-1}

accounted for 34.6% of the record in the period 1996-2010 (Figure 2). Sand is likely to be entrained by winds in excess of $10ms^{-1}$ blowing over unconsolidated dry sand, which on the Beaufort Scale equates to a 'strong breeze'. Winds above $20ms^{-1}$ equate to a 'strong gale'.

Onshore winds (73-250^{o}) in excess of $10ms^{-1}$ (over a 3-hour period) typically occur 400-600 times a year (Figure 3). The period 2002-2009 has been relatively calm, with typically 200-400 events.

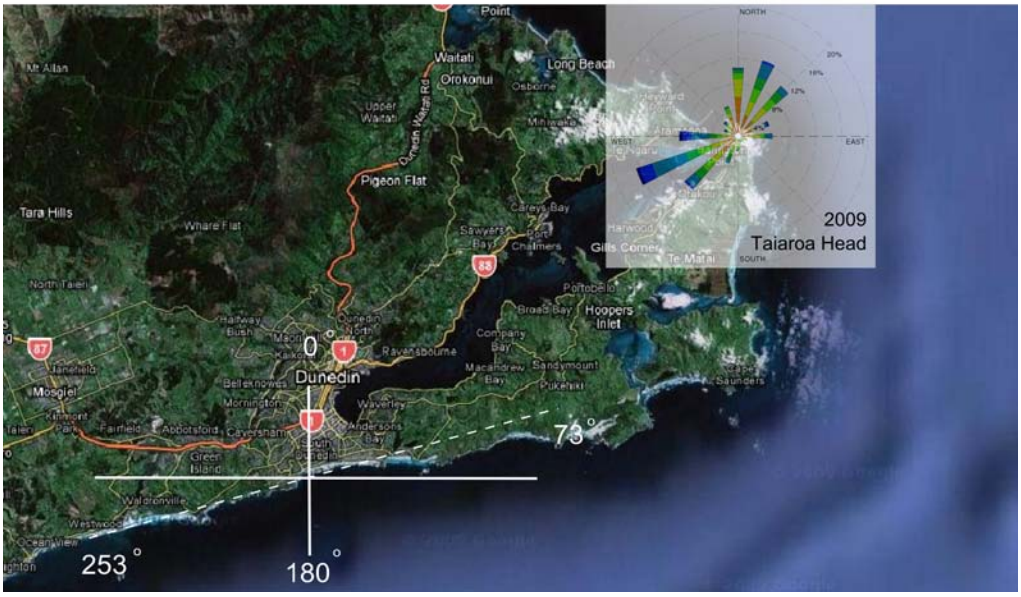

Figure 1: The Ocean Beach dune system is exposed to winds from the northeast to southwest (from 73-250^{o}). The wind rose is for Taiaroa Head – all winds from all directions.

3.0 The Ocean Beach Domain dune system

Ocean Beach Domain is a highly modified dune system on the south coast of Dunedin City. When Dunedin City was established this dune system was probably largely intact and largely unmodified. This was an active dune system that comprised a distinctive array and arrangement of landforms, typical of embayed dune systems of the southeast and south coasts of the South Island. Section 3.1 examines the characteristics that distinguish this type of dune system. The pre-modified dunes of Ocean Beach Domain had some distinctive qualities, but in other respects were comparable with other dune systems of southeast South Island.

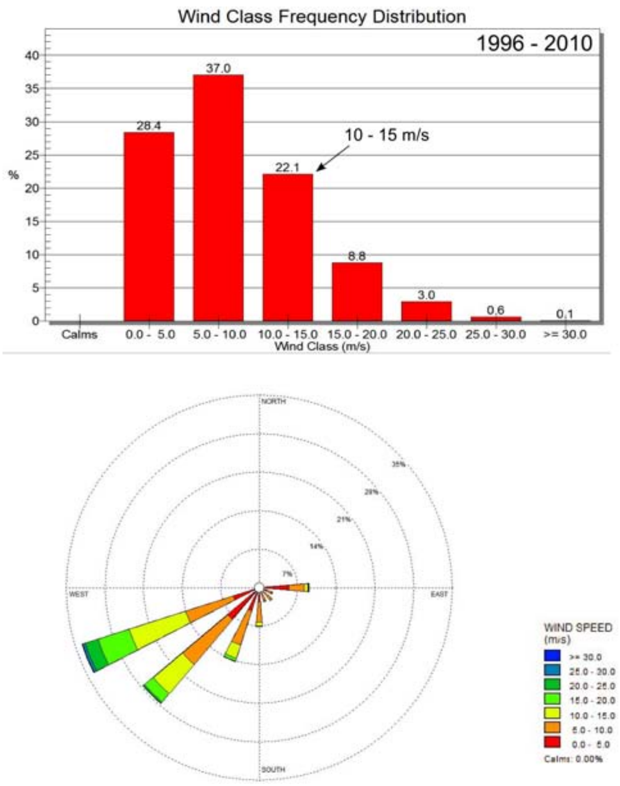

Figure 2: Onshore wind class frequency distribution (Taiaroa Head, 1996-2010). Winds in excess of 10ms^{-1} occurred 34.6% of the record.

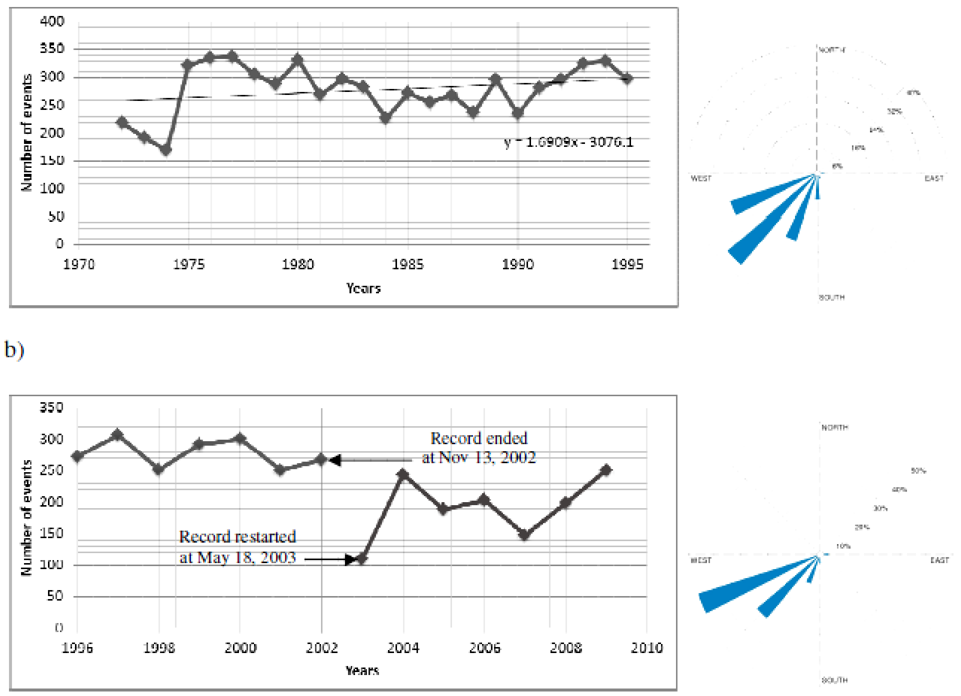

Figure 3: Time series of onshore wind events (73-250^{o}) exceeding 10ms^{-1} for the period 1996-2009.

Section 3.2 describes the major landform elements of the study area and the associated physical processes. These processes are relevant to the future management of the Ocean Beach Domain, whichever redevelopment option is pursued. These processes also reveal significant problems associated with the status quo.

Dune landscapes result from the interaction of sediment, wind and plants in a particular accommodation space (usually an embayment between adjacent headlands). We know very little about the flora of the pre-settlement dune system, except that pikao (*Desmoschoenus spiralis*, recently re-named *Ficinia spiralis*) was common prior to the introduction of marram grass. The pattern of dune forms in the pre-modified dune system is in large part due to the variable sand-trapping capabilities of pikao (Section 3.3). The final part of this section briefly examines the importance and effectiveness of the Ocean Beach Domain dunes as a barrier to storm inundation of the low-lying hinterland, which was referred to as 'the flat' following settlement (Section 3.4). Future redevelopment of the Domain must protect the suburbs from future inundation, taking account of projected eustatic sea-level rise. Consideration must also be given to the future impact of groundwater fluctuations.

3.1 Context

We typically associate dunes with windward (exposed) coasts, whereby sand is blown inland, from the back-beach to the foredune or beyond, more or less perpendicular to the shoreline. Around much of the New Zealand coast the prevailing winds actually strike the line of the coast at an acute angle, so that the resultant net sand transport vector is at a significant angle to the coast. This phenomenon is very pronounced on the coasts bordering Foveaux Strait (north coast of Stewart Island and the coast of mainland Southland) and the coastline between Invercargill and the Otago Peninsula. Both coasts are sheltered from the northwest winds, and the prevailing southwest winds transport sand alongshore; in the case of Waipapa Point parallel to the shoreline!

The nature of particular dune systems depends, therefore, on the interaction of several factors, particularly the orientation of the coast relative to the prevailing winds, the degree of exposure of sections of coast to the prevailing southwest winds (and episodes of extreme southerly winds), an adequate sand supply, and the nature of the embayment in which sand is deposited and dune systems evolve. The vegetation cover is also important – the following section discusses the characteristics of the Ocean Beach Domain prior to the introduction of marram grass. Dune forms and dune processes associated with marram are discussed in Section 3.1.

On prograding coasts - coasts that are building seawards by the addition of foredunes (for example) - the transport of sand from beach to foredune at an acute angle may have little effect on foredune morphology. Sand is trapped by foredune plant species (pikao in southern New Zealand), regardless of the angle it is blown from the beach. For example, Victory Beach and Allans Beach, on the Otago Peninsula, have prograded by the addition of shore-parallel foredune ridges over the last 6,000 years or so, despite the acute angle of the prevailing winds along the beach. In contrast, Sandfly Bay, which is significantly more exposed to the prevailing winds, may not have contained foredunes prior to the introduction of marram grass.

The exposure of the coast to the prevailing winds is an important control on dune system evolution. Exposure is related to the orientation of the coastline and the morphology of the embayment (or, the configuration of the accommodation space). Deeply indented embayments defined by prominent headlands, may result in relatively sheltered beaches and tend to favour foredune formation. Progradation has occurred in a deeply indented embayment, which is afforded some shelter from the southwest winds by Sandymount in the case of Allans Beach and Mt Charles in the case of Victory Beach. These sites are still exposed to southerly and westerly winds and regular foredunes have formed despite the acute angle formed between the shoreline and prevailing winds.

Rates of sedimentation may exceed the sand trapping efficacy of pikao within more exposed embayments. A range of foredune types may form in such cases, from irregular mounds with a patchy vegetation cover (Type 4, Short and Hesp, 1982), through which sand may pass easily, to continuous linear foredunes (Type 1). The contemporary (marram) foredune that lies in front of John Wilson Drive is an example of a Type 1 foredune. Sand passing through a Type 4 or 5 foredune may accumulate in the immediate hinterland, in association with pikao, or it may be transported well downwind.

Dune systems on the southeast coast of the South Island commonly form ‘headland-bypassing’ dune systems within well-defined embayments (Figure 4). Foredunes may develop in the section of the coast afforded shelter by headlands to the west (Foveaux Strait) or south (Waipapa Pt to Otago Peninsula headland). The eastern or northerly sections of the coast are relatively exposed to winds and rates of sand transport may exceed the sand-trapping or sand-holding capacity of the indigenous vegetation. A range of dune Transgressive dune landscapes may result, in which part, or the entire dune surface, is mobile during high wind events. Sandsheets, parabolic dunes and transverse dunes are characteristics of such landscapes. Where the prevailing winds strike the coastline at a acute angle sand may be blown alongshore, within these transgressive dune systems, across the downwind headland and into the next embayment. This process occurs at several sites in Southland and east Otago, namely Sandhill Point, Waipapa Beach, Haldane Bay (Figure 5), Ocean Beach, Tomohawk Beach and Sandfly Bay.

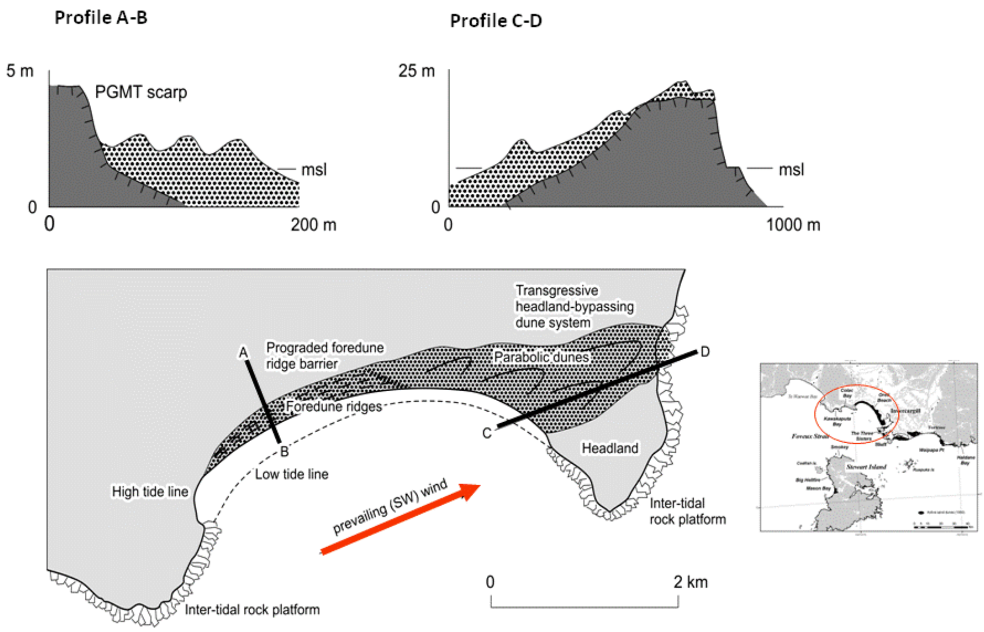

Figure 4: Interpretation of dune system development in southeast New Zealand. Sedimentation is driven by winds that flow alongshore. In some cases sand is transport across headlands by the prevailing wind. Primary dune forms such as foredune ridges may form and be preserved in the lee of headlands.

The dune system of Ocean Beach Domain, therefore, shares characteristics with other southeast coast dune systems: (i) the dune system has developed in a well-defined embayment; (ii) sediment transport within the dune system is primarily alongshore, driven by the prevailing southwest winds; and (iii) there is a gradation in energy within the embayment, from the relatively sheltered western end of the system to the exposed eastern end. Other characteristics are unique to the Ocean Beach Domain dune system and these are discussed below.

3.2 Geomorphology

Historic information:

Early descriptions, paintings and photographs of Ocean Beach consistently portray the major features of the dune system. These include the exceptional plan and profile survey of August 1890; paintings; postcards; and oblique photographs. All of the images are obtained from the hills to the south of St Clair or from the city looking across the Flat. Sufficient information is available to describe the dune system adjacent to St Kilda, but such information is poor compared with St Clair. The 1890 survey plan is an exceptional resource, since it includes three profiles across the dune system, presumably derived by the chain survey method.

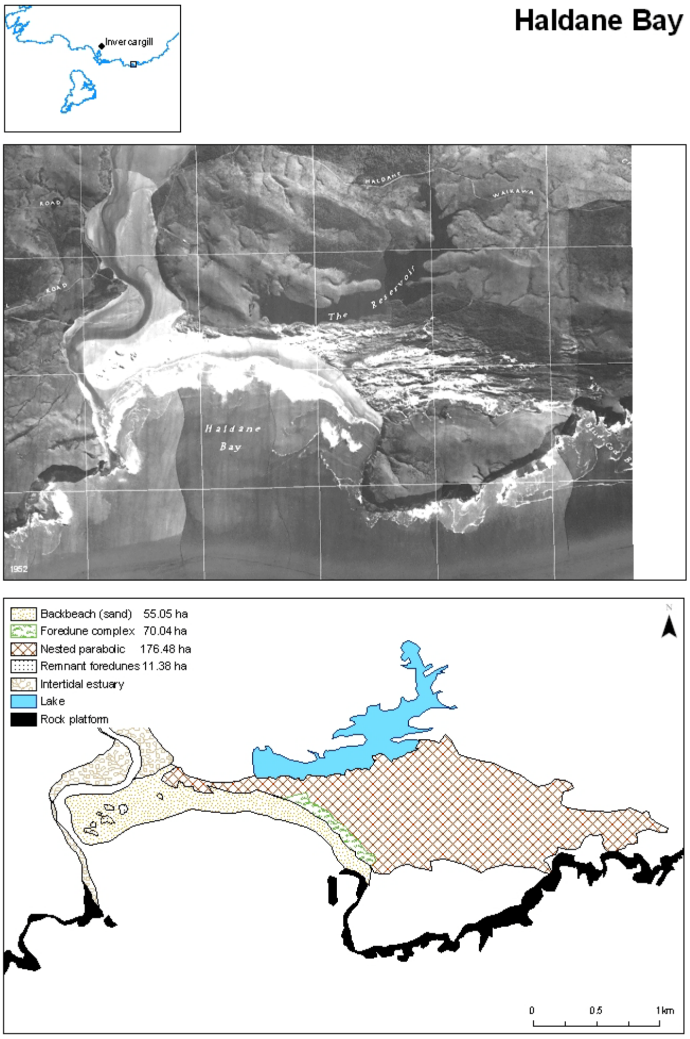

Figure 5: Aerial photograph and interpretation of Haldane Bay dune system. Sand is transported upslope and across the headland separating Haldane Bay and Curio Bay.

We cannot assume that the dune system depicted in historic documents had not been affected by human activity, prior to or during the early years of settlement. Maori has occupied the district for several hundred years prior to colonisation and may well have occupied the dunes and disturbed foredune vegetation. However, there is no direct evidence of this process. It is also important to note that dune system development is cyclic, usually over time scales of decades to hundreds of years. The early images of the dune system provide a snapshot of the landscape; we do not know whether the system was tending towards an increased plant cover and stability, or was still responding to one or a series of disturbance events.

Dune system boundaries:

The boundaries of the Ocean Beach Domain dune system have been defined by, and contained within, roads and railway lines since the earliest survey plans were available. The Ocean Beach Railway was opened in 1876. The line ran along modern day Andersons Bay Road and Queen's Drive, then along the landward edge of the dunes, along the line of cotemporary Victoria Road, before culminating at Forbury Racecourse. The railway appears to have been constructed within the dunes system, but only on the landward margin. The location of the railway line, at the very base of the dunes, is shown clearly in the 1880s photograph of the 'poor man's grandstand' (L&R New Zealand Ltd 2009, p.11). It is likely that Tahuna Road and some adjacent housing is constructed on the former dune system. The Dunedin City Council cemetery lies entirely within the dunes.

There is some indication that the seaward margins of the dune system have not changed significantly since the first reliable survey in 1890. The roads of St Clair and St Kilda have not changed in the period 1890 to 2010, allowing the coastal features portrayed in the 1890 plan to be superimposed on recent aerial photographs. It appears that the position of the line of high tides along the St Clair section of coastline has changed little since 1890 (Figure 6). The distance from fixed points to the high water line, in 1890 and 2010, appear to be comparable (Table 1).

Figure 6: The 1890 high tide line approximates the position of the contemporary high tide line. The location of dunes bordering Victoria Road and the lagoon (to become Hancock Park) is indicated as they were mapped in 1890.

Table 1: Distances from fixed points (street intersections) to high water in 1890 and 2009. Distances (m) derived from chain survey (1890) and aerial photography (2009).

1890 profile	1890	2010
Profile AB	502	500
Profile CD	370	380
Profile EF	160	155

Major geomorphic features of the dune system:

The pre-modified dune system comprised three major elements: (i) a line of dunes running from the Esplanade to Queens Drive, alongside Victoria Road; (ii) a broad, flat, deflation surface, seawards of these dunes; and (iii) a transgressive (moving) dunefield that rose towards and over the ridge that separates Ocean Beach and Tomohawk Beach (Figure 7). The deflation area and sand sheet can be seen as functionally related, as can the deflation surface and the line of dunes. There is little direct connection between the dunes bordering Victoria Rd and the transgressive dunefield.

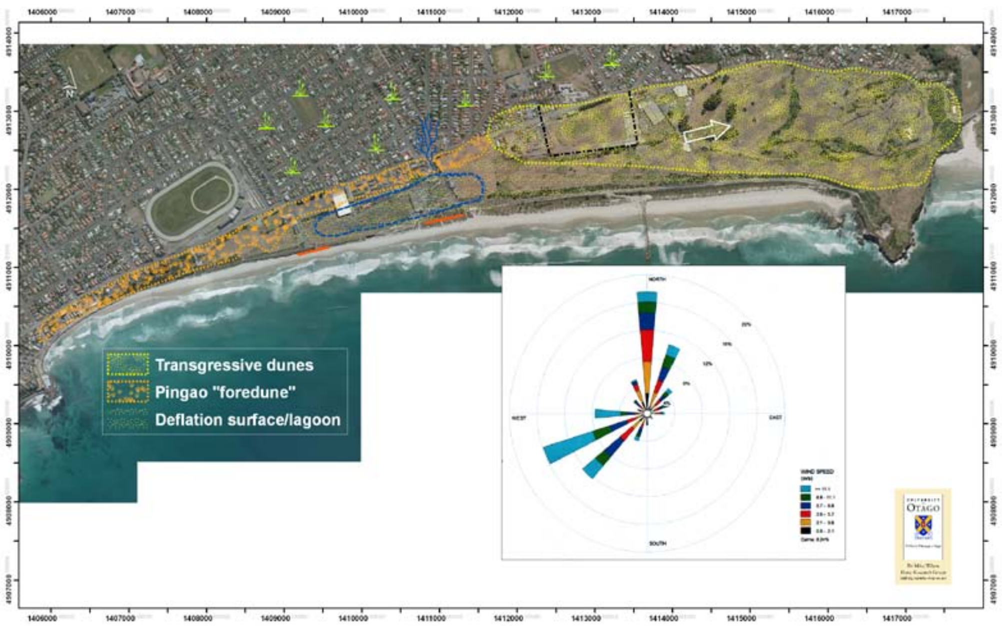

Figure 7: The major geomorphic elements of the pre-modified Ocean Beach dune system.

Deflation surface

The deflation surface occupies most of the central areas of the dune system and extends from high water to Victoria Road in the vicinity of Queens Drive, and between the dunes bordering Victoria Road, and the trangressive dunefield to the north. These elements are clearly evident in Guy Morris's postcard, taken around 1905 (Figure 8). This postcard provides the clearest image and an almost complete view of the early dune system, although some changes to dune form and plant cover had already occurred. The deflation surface is very low, with no evidence of a vegetated foredune. Nor is there any sign of the lagoon, mapped in the 1890 survey, although this feature may have been a seasonal, ephemeral or tidal feature.

Figure 8: Coloured photograph of the Ocean Beach dune system (Guy Morris, ca. 1905)

Sand would have been exchanged between the beach and deflation surface at low tide, driven ashore by either southwest or northeast winds. The actual volume of sand stored in this environment was probably low, since dry, unvegetated sand is readily transported down-wind. Sand would have been incorporated into the dunes to the southwest or to the northeast relatively rapidly.

The 1890 profiles show the deflation surface has two elements (Figure 9 & Figure 10). A low ridge, 50-75m wide, about 0.5m above high water, occurs in the usual foredune location. However, there is no evidence this ridge was vegetated. Much of the rest of the deflation surface towards St Clair is occupied by a 'lagoon', which was once a popular swimming location for children (Aitken, 1975). This lagoon is indicated in Figure 6 (as mapped in 1890) and is more or less centred on the modern Hancock Park. The lagoon, and the stream that drained through the dunes to the lagoon, are just evident left of centre in Figure 11.

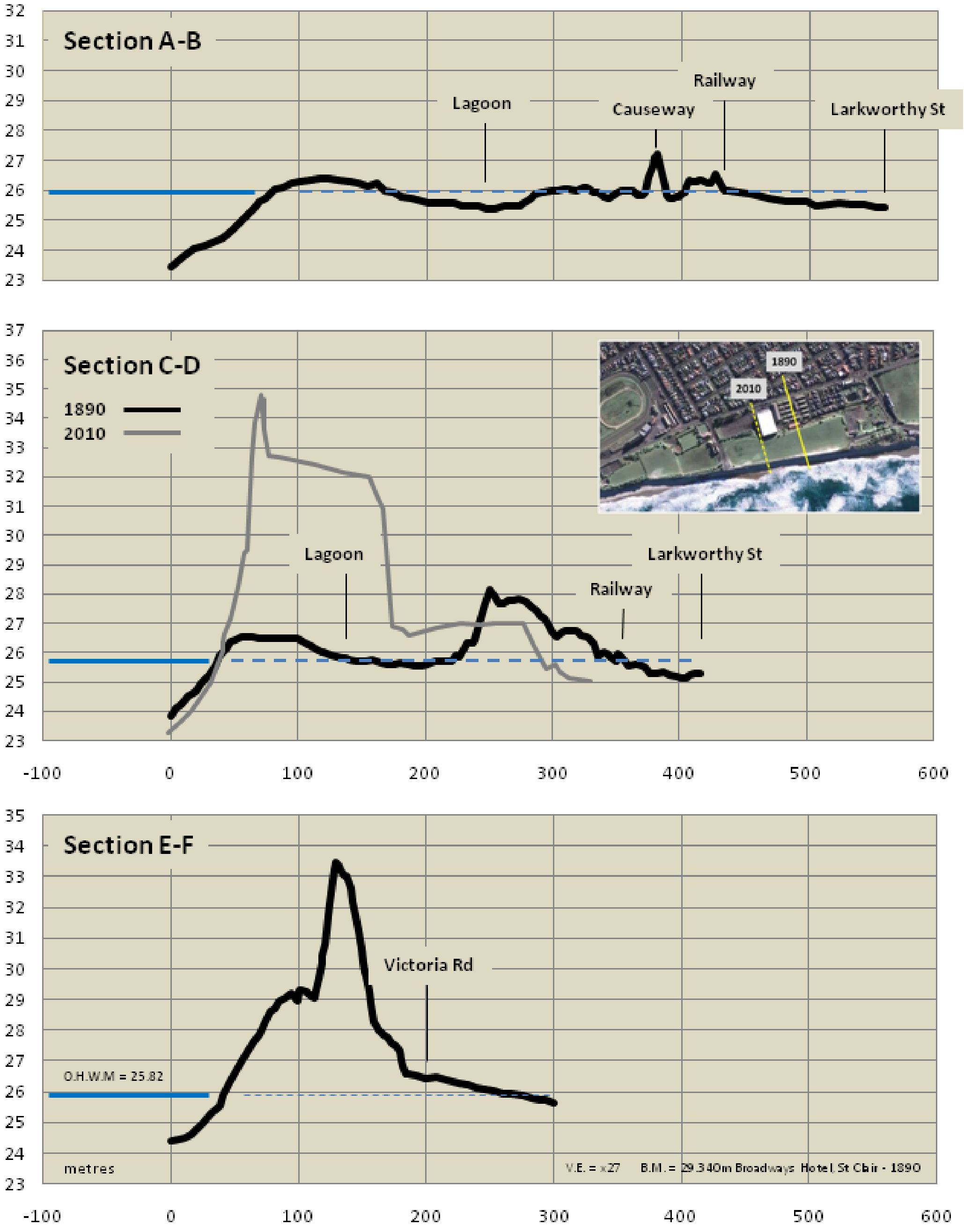

Figure 9: Profiles AB, CD and EF, surveyed in 1890. A modern profile is included in Profile CD, to provide an indication (only) of the reclamation and land development that has occurred since 1890. The line and elevation of the high tide line is used as a common datum.

Figure 10: Location of 1890 and 2010 profiles.

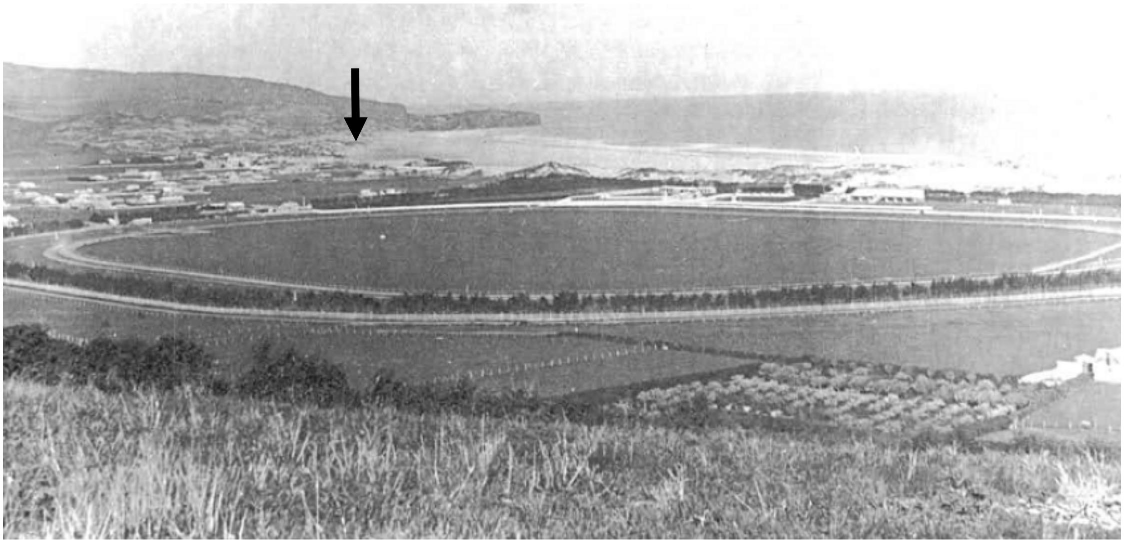

Figure 11: An oblique view across Forbury Racecourse and the dune system to the northeast (ca. 1880) (Alexander Turbull Library). The approximate position of the stream that passes through the dunes is marked with an arrow.

Dunes

The dunes that ran from the Esplanade to Queens Drive, alongside Victoria Road, are unusual features (possibly unique) and are not easily classified. They form a line of dunes, but they are not linear (or longitudinal/seif) dunes in the classic sense – such forms are not coastal dunes. They have the form of a foredune or foredune complex, but they are generally set back from high water. Early photographs and paintings show that they are primarily colonised by and formed in conjunction with pikao, although other species were doubtless present. A similar set of dunes formed at Tomohawk Beach, in the lee of Lawyers Head.

They are essentially a series of aligned 'coppice dunes' developed in the lee of Forbury Head and the section of (true) foredune at St Clair. Coppice dunes develop in conjunction with sand-trapping and sand-binding dune plants, in conditions of low to moderate sand supply and bidirectional wind direction. At Ocean Beach the sand-binding capacity of pikao was not adequate to form dunes at the rear of the beach or across the deflation surface. The dunes bordering Victoria Road developed where the hill country afforded some shelter from the south-westerlies. A second level of shelter was then afforded by the large foredune, which was a true foredune lying adjacent to the beach, which remains largely intact adjacent to the ST Clair Surf Life Saving Club.

The genesis of these dunes may be quite complex. Sand may have been transported onshore, across the deflation surface, by winds from the northeast, but then redistributed by winds from the southwest. At the time Dunedin was established these dunes formed a distinct barrier between the Pacific Ocean and 'the Flat' further inland (Figure 12). They appear almost continuous in this 1864 photograph, although they become progressively lower towards Queens Drive. By the time Morris Guy produced the St Clair postcard in 1905 these dunes had already been partially mined and plantings of marram and lupin had commenced.

Figure 12: View of the St Clair sand dunes from the Dunedin business district (1864) (Alexander Turnbull Library).

There is no suggestion in the historical data that sand was a nuisance for the adjacent houses along Victoria Road, although reference is made to sand blowing from dunes into Tahuna Park in 1876. This is because the dunes bordering Victoria Road were relatively sheltered from southwest winds and because these winds, when they did occur, would tend to blow sand alongshore (to the north). Presumably winds from the northeast would, on occasion, be able to transport sand in quantity, but this sand was trapped by pikao and dune building commenced.

Transgressive dunes

The dune system north of the lagoon and the deflation surface was probably dotted with small pikao shadow and coppice dunes, dune types characteristic of moderate to high rates of sand transport. This section of the dune system conveyed sand to the north and northeast, towards Tomohawk Beach. Sedimentation would have been episodic, during periods of high southwest and southerly winds, and highly variable, but occasionally dramatic.

Potential rates of sand transport across the rising topography from the modern Hancock Park to the ridge currently containing the crematorium are high. Future management of this section of Ocean Beach Domain should ensure an effective cover of vegetation is maintained.

3.3 Dune flora

The past dune flora of the Ocean Beach Domain is of interest in two respects. Firstly, future management might include plantings of indigenous dune species. It would be appropriate to plant species that existed in the Domain, preferably derived from remnant local populations. Secondly, future management may wish to utilise both indigenous and exotic species to vegetate areas within the range, including landforms and surfaces have been engineered. We will need to understand the sand-holding capacity of different species, and the resilience of different species to pedestrian traffic, if hazard management, amenity and landscape imperatives are to be achieved. The current report addresses the first of these interests – the nature of the dune system flora prior to extensive dune system modification. The efficacy of different combinations of plants, slopes, exposures and use profiles is addressed in a separate report.

Comparatively little is known about the flora of the Ocean Beach dune system, prior to the introduction of marram grass (*Ammophila arenaria*) and tree lupin (*Lupinus arboreus*). Leonard Cochane reported on the dune flora of New Zealand in the late 1890s, but did not comment on Ocean Beach. The early paintings and photographs indicate that pikao was widespread in the two dune fields described, but was absent from the deflation surface. We would expect, based on surviving floras at comparable Otago and Southland sites, that a set of other dune-specific species would be present. These would include *Pimelia arenaria* (Sand Daphne); C*oprosma acerosa* (Sand Coprosma); and *Euphorbia glauca* (Shore Spurge) in areas of low to moderate sedimentation. A range of herbs usually associated with deflation surfaces may also have been present (e.g. Raoulia spp.), however, the low level of the deflation surface and evidence of frequent inundation, would have prevented the establishment of such species.

The Ocean Beach and adjacent Tomohawk Beach dune systems are exposed to strong onshore winds from the south and southwest on occasion, as described above. It is unlikely that either system contained a foredune, except for a feature in the lee of Forbury and Lawyer's Heads, respectively. Observations of wind flow over the modern marram foredune in Tomohawk Beach demonstrate extreme flow acceleration. Marram grass is barely able to sustain a foredune and this beach may be one of the most exposed (to extreme winds) in New Zealand. Similarly, it is doubtful whether a foredune developed in association with pikao could ever be established along the Ocean Beach shoreline.

3.4 The Flat

The modern Ocean Beach Domain forms a significant barrier between the Pacific Ocean and the south Dunedin suburbs and this function must be retained and enhanced in any development of the Domain. In the 1860s 'The Flat' was an area of low-lying land and wetlands between Dunedin City, the head of Otago Harbour and the Ocean Beach dunes. On several occasions in the late 1800s and early 1900s the sea passed through the dune system and inundated the adjacent housing. A storm surge of less than 0.6m would have inundated the deflation surface and the neighbouring suburbs in 1890.

The contemporary suburbs of St Kilda and St Clair remain well below the level of high tides and the risk of inundation remains and will worsen. Future development must accommodate a worst case extreme event that combines higher global sea levels, a large storm surge, El Niño conditions during a negative inter-decadal Pacific oscillation and a king tide. Such conditions, if combined, would produce water levels 3 m above present mean sea level (Fitzharris, 2010); or about 2.0m above high tide.

3.5 Groundwater

Future development of the Ocean Beach Domain must also consider the impact of rising sea levels on groundwater. Bores indicate that the level of the ground water in South Dunedin is only 0.60m below ground level, and that the level fluctuates with tide level. This problem will pose a serious challenge to the Council should mid-range sea-level estimates eventuate. It would require significant engineering works or the abandonment of low lying areas should sea-level rise above 0.6m. This problem will eventuate gradually, but consideration should be given to the design of such works should redevelopment of Ocean Beach Domain proceed.

4.0 Dune system modification, 1900 - 2010

The history of the Ocean Beach Domain is summarised in the L&R New Zealand Ltd report of May 2009. The Council, individuals and the Ocean Beach Domain Board employed every available technology towards increasing the mass, height and stability of the former dune system. Leonard Cockayne had published on the subject of sand stabilisation and promoted the use of brush fencing, marram grass and tree lupin. Between 1900 and 1920 much of the deflation surface was divided by a network of brush fences and systematically planted in marram grass and tree lupin and by the 1940s the dune system was vegetated and stable. Most of the line of dunes beside Victoria Road were levelled or removed. The section between the Esplanade and the racecourse remains.

A semi-continuous foredune had formed alongshore, between Lawyers Head and the racecourse, by the 1950s. Photographs of this feature suggest it was 4-5m high at this time. At St Clair, the hinterland was raised by dumping of refuge and fill, and the new surface developed for recreation. The land was now 4-5m above high water and safe from inundation. The construction of John Wilson Ocean Drive afforded the same protection to the northern half of the embayment.

These developments destroyed the geomorphology and ecology of the former dune system – matters that were understandably overlooked by the authorities. The management goal for most of the last century was to safeguard the low-lying housing of South Dunedin. This was achieved, but at a cost. That cost is the ongoing contest between the sea and the Council for the seaward margins of the Ocean Beach Domain. Bob Kirk (1996) concluded:

> *This problem is an excellent example of the intrusion of development into a coastal buffer zone within which entirely normal and expected fluctuations in beach and foredune form occur from time to time around a long-term stable configuration (Kirk, 1979, p.26).*

Put another way, land was created where it should not be. The Ocean Beach Domain was planted, stabilised and in-filled to form land within the dynamic zone; within the zone previously inundated by storm surge or affected by large waves. To a large degree this process could not be controlled once marram grass was introduced. Marram grass encourages both progradation and accretion and is inclined to forced the land seawards.

At Mason Bay, on the exposed west coast of Stewart Island, we determined the coast had build seawards by about 60m since the introduction of marram grass.

Marram grass and progradation

Marram grass will trap and hold sand in most conditions, but is also readily eroded by waves eroding the base of the foredune during episodes of storm surge. Thus, near vertical scarps may be cut during storm events as the face of the foredune is undermined, collapses and is then washed away. In time the face of the eroded foredune is re-colonised by marram and re-established. This process is driven by the deposition of viable rhizome washed alongshore (which can produce shoots and vigorous growth; by *in situ* rhizome also producing shoots; and by the collapse of the face of the foredune, resulting in blocks of sand sliding down the face of the foredune. Such blocks may contain culms of marram. Marram survives and usually thrives under conditions of episodic erosion and recovery.

One negative outcome, however, is that public access to the coast can be hindered following scarping events. In addition, the back-beach, the section of the beach above the high tide line, usually becomes steeper and narrower following the development of marram foredunes. For some people the beach may be too narrow and too steep to navigate at high tide. Scarps make access difficult for all but the most athletic pedestrian.

Beach profiles surveyed between 1989 and 2009 demonstrate these processes. The example cited is ‘section 17’ located approximately 100m south of Lawyers Head (Figure 13). The linear foredune in front of John Wilson Ocean Drive has accreted and prograded during this time, with the occasional scarping event associated with elevated sea levels during storms. During the same period the back-beach has become considerably steeper.

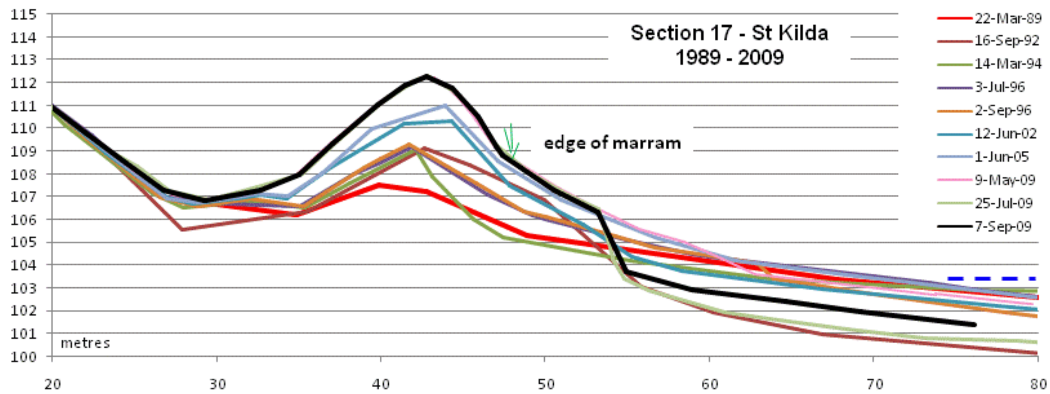

Figure 13: Beach-foredune profile record – Section 17, John Wilson Ocean Drive – 1989 – 2009.

The Ocean Beach Domain sand budget

The development of Ocean Beach Domain has resulted in the redistribution and removal of large quantities of sand from the beach-dune system. The pre-modified dune system may well have been a one-way sediment sink – sand blown from the beach into the dunes may have been either incorporated in the Victoria Road dunes or transported northwards through the transgressive dune field. Still, the mining, vegetation or burial of most of these dunes represents a net loss to the sand system. This includes sand that was contained in back-beach deposits, which were eventually buried as the land was pushed seawards and then capped with clay and soil.

There is no evidence that new sand is being delivered to the St Clair – St Kilda embayment, from offshore deposits or elsewhere. The comparison of the 1890 and 2007 aerial photograph indicates that the approximate position of the line of high tides had not changed in almost 120 years. What has changed is the relationship between the beach and the hinterland, from a wide, gentle- sloping back shore to an abrupt scarp or steep backshore. Whereas energy was once dissipated across a wide surface it is now focused on the edge of the land.

Finally, while marram grass is an effective sand binder, some of the sand trapped and contained in foredunes is largely lost from the beach-nearshore system, at least at certain temporal and spatial scales. For example, over the last twenty years the foredune fronting John Wilson Ocean Drive has accreted and prograded, while the foredune bordering Kettle Park has disappeared. The exceptional efficiency of marram grass may interrupt the circulation of sand, resulting in areas of persistent sand deficit and erosion.

Export of sand along Kettle Park

Marram foredunes will prograde and accrete so long as sand is available, however, it will not thrive in conditions of sand scarcity or sand erosion. These conditions occur where the back-beach ends abruptly at the base of a scarp. Such conditions have persisted for some years along St Clair Beach, in front of Kettle Park. In this case the foredune, which may never have been substantial, or may have been buried beneath fill, has been eroded, resulting in a steep face at the rear of the beach. Sand that accumulates in front of the scarp during low to moderate sand transport conditions (or is dumped during beach nourishment operations), may be blown across the face of the scarp and onto the adjacent sports fields during high flow conditions. This process also results in a net loss of sand to the beach system.

5.0 Management implications

The Ocean Beach Domain dune system has been converted into a series of stable terraces and bunds to maintain a barrier to storm inundation and to establish recreational facilities. The main problem is that the land-sea interface is in the wrong location and is increasingly being contested by the sea. This problem is likely to get worse, with increasing loss of amenity values and increasing maintenance costs.

The pre-modified dune system including a line of dunes that offered some protection to storm surge inundation. These did not develop in the usual 'foredune' position because of the high exposure of this stretch of coast and the relative inefficiency of pikao. The effectiveness of these dunes was reduced over time and new dunes established with marram.

The Council faces the choice of either protecting the current coastline (by either hard structures or beach nourishment); maintaining the status quo; or accommodating coastal processes by retreating. The last option would entail sacrificing land to establish a wider back-beach and more gently-sloping hinterland. The Council is examining and assessing the costs and benefits of all options. The retreat option might result in unacceptable disruption to the recreational facilities in the Domain – depending on how much is required and how the new space might be utilised. It is entirely feasible that the amenity of the Domain could be significantly enhanced, while exercising the retreat option.

The Council can celebrate two conditions. Firstly, the seaward margins of the Domain are not intensively developed and the Council is the landowner. Pressure to hold the current coastline would be significantly greater had the coast been intensively urbanised. Secondly, there is relatively little risk of uncontrolled sand dune development and migration should the Council decide to widen the beach and create a storm surge zone. Wind-blown sand transport is primarily to the north, rather than towards the housing development adjacent to Victoria Road.

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Appendix A: Analysis of Lawyers Head and Taiaroa Head wind records (from Pattanapol et al., 2000).

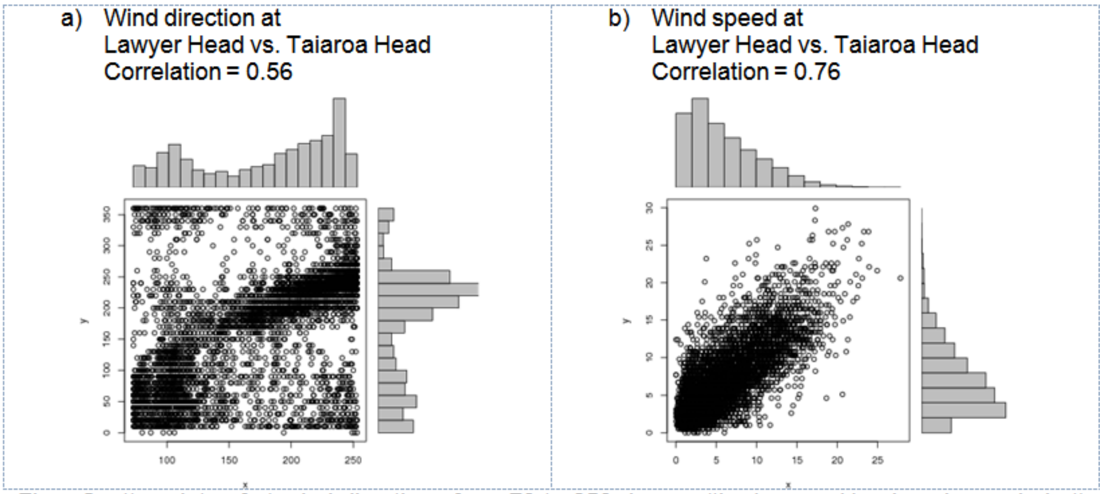

Fig.a Scatter plots of a) wind directions from 73 to 253 degree (the Lawyer Head onshore wind at) and b) corresponding wind speeds, recorded at the Lawyer Head and theTaiaroa Head with marginal histograms during 2005-2008. The wind data recorded at the Lawyer Head and at the Taiaroa Hear were represented in the horizontal (x) and vertical (y) directions respectively.