New Zealand Geographer (2008) **64**, 117–128 doi: 10.1111/j.1745-7939.2008.00135.x

Research Article

Multi-decadal coastal change in New Zealand: Evidence, mechanisms and implications

Karin R. Bryan,[1] Paul S. Kench[2] and Deirdre E. Hart[3]
[1]*Department of Earth and Ocean Sciences, University of Waikato, Hamilton, New Zealand,* [2]*School of Geography, Geology and Environmental Science, The University of Auckland, Auckland, New Zealand* [3]*Department of Geography, University of Canterbury, Christchurch, New Zealand*

Abstract: Coastal research and monitoring on New Zealand beaches have typically examined seasonal and event-driven (storms) changes in the coast. However, historical records are now of sufficient length to indicate that change occurs at longer timescales. This paper presents examples of multi-decadal change at three case-study locations around New Zealand. Results show that morphological adjustment of the coast occurs at multi-decadal scales and is much larger than short-term dynamics. Physical mechanisms driving changes are ill defined but may be associated with El Niños and La Niña episodes which modulate waves and sea level, as well as changes in sediment supply.

Key words: coastal change, coastal hazards, sand spits, Mokau spit, New Brighton, Ohiwa spit.

Sandy beach systems along the New Zealand coastline are sites of high population pressure. Over the past 40 years the 'rush to the coast' has seen intensification of development, tourism and economic activities that place a premium on the natural and physical values of sandy coastlines. Indeed New Zealand's national psyche is partly founded on perceptions of the amenity value of our beaches.

Beaches may be generically defined as aggregates of wave-deposited sediments forming pocket or drift aligned beach systems and sand spits (Woodroffe 2003). Beach systems, in particular those associated with sand spits, are extremely dynamic, changing their position in response to changes in waves and tides and exacerbated by episodic storm and coastal inundation events. Numerous case studies have documented the physical response of sand systems to high energy storm and cyclone events (Dally & Dean 1984; Gallagher *et al.* 1998; Black *et al.* 2002). However, the mechanisms causing shoreline change also exhibit significant variation at longer timescales. A number of studies have identified climate-induced changes in wind and wave processes that produce inter-annual and decadal variability in sea levels and wave regimes around New Zealand (e.g. Bell & Goring 1998; Goring & Bell 1999; Gorman *et al.* 2003; Goodwin 2005). However, the implications of such adjustments for the physical stability of dynamic coastal environments such as spits are less well understood. The few international studies that do exist suggest that beach change is considerably more complex than simple cross-shore event-driven sediment exchange. For example, climate-associated changes in the orientation of beaches have been observed from longer monitoring datasets (Ranasinghe *et al.* 2004; Short & Trembanis 2004). However, simple models show that in principle the feedbacks

---

Note about authors: Karin Bryan is Senior Lecturer in the Department of Earth and Ocean Sciences at the University of Waikato. She specializes in beach processes and teaches coastal oceanography; Paul Kench is Associate Professor and coastal geomorphologist with research and teaching interests in coastal processes and coastal management at The University of Auckland; Deirdre E. Hart is Senior Lecturer in the Department of Geography at the University of Canterbury, where she researches and teaches coastal studies.

E-mail: k.bryan@waikato.ac.nz

between coastal morphology and wave climate can also lead to longer time scale patterns (Cowell & Thom 1994; Plant *et al.* 1999; McLean & Shen 2006).

To date few studies have examined the types and magnitudes of medium-term shoreline change in New Zealand and coupled them with possible driving mechanisms. Such assessments are critical since much of the human development of our sandy coasts has occurred with a limited, or complete lack, of knowledge of the true extent of these decadal scale changes. One consequence has been large scale infrastructural retreats necessitated by significant erosion episodes that are often considered unprecedented. Yet critical examination of historical charts and aerial photographs (> 50 years) often show large-scale shoreline movements which suggest that the record of erosion episodes in many cases is based on the collective memory of communities that date back a mere 20–30 years. Over the past 30 years, regional councils have established long-term beach monitoring sites along the New Zealand coast to document coastal change. These records have been used widely to define the short-term (event scale) dimensions of coastal change but in only a few cases have longer term analyses been undertaken (e.g. Oldman *et al.* 2003). Some of these coastal monitoring records are now of sufficient length to allow reinterpretation of coastal dynamics spanning several decades.

This article outlines the evidence for decadal to centennial coastal change at three spit sites around New Zealand: Ohiwa on the east coast of the North Island; Mokau on the west coast of the North Island and New Brighton on the east coast of the South Island (Fig. 1). Importantly, the article highlights major differences in the magnitude and morphological change between the event and multi-decadal timescales and identifies gaps in our understanding of coastal change at this timescale, which is critical for supporting coastal planning and management.

Multi-decadal to centennial scale change of the Ohiwa–Waiotahi spit system, Bay of Plenty

The Ohiwa–Waiotahi spit complex is located in the Bay of Plenty (Fig. 1 and 37°59′S, 177°10′E). The system is approximately 5 km in length and consists of sandy spits that impound Ohiwa Harbour (to the west) and the Waiotahi Estuary (to the east, Fig. 2a). Typical of many inlet systems in the upper east coast of the North Island, Ohiwa spit and neighbouring Ohope spit have been the sites of human settlement characterized by holiday homes that encroach on the coastal dune system. Ohiwa spit, and adjacent inlet, is also an example of a dynamic coastal system that has directly interacted with human occupation of the coastal zone, with dramatic consequences (Fig. 2d). As such it has become a classic example of cyclical coastal change to inform future coastal management and planning in New Zealand.

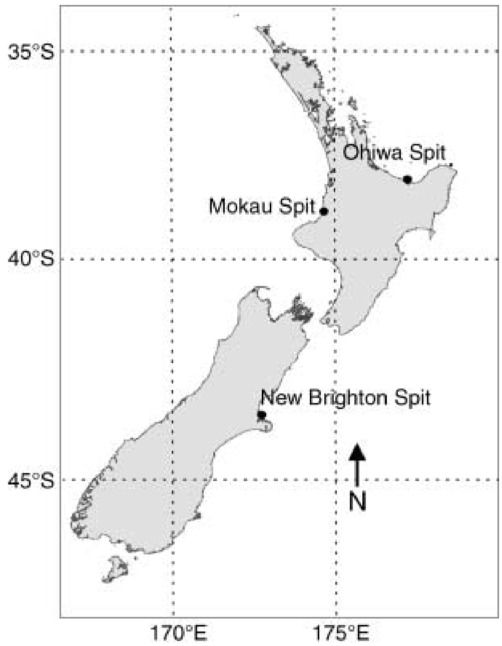

Figure 1 Map showing the location of Ohiwa Spit, Mokau spit and New Brighton Spit.

Understanding the nature of shoreline change at Ohiwa spit is compounded by the dual processes of the open coast, but also the dynamics of the Ohiwa inlet system. Ohiwa spit forms the eastern boundary of the entrance to Ohiwa harbour. At the centennial scale, analysis of historical records between 1867 and 1976 showed the Ohiwa Harbour entrance slowly migrated eastwards, causing the lengthening of Ohope spit and shortening of Ohiwa

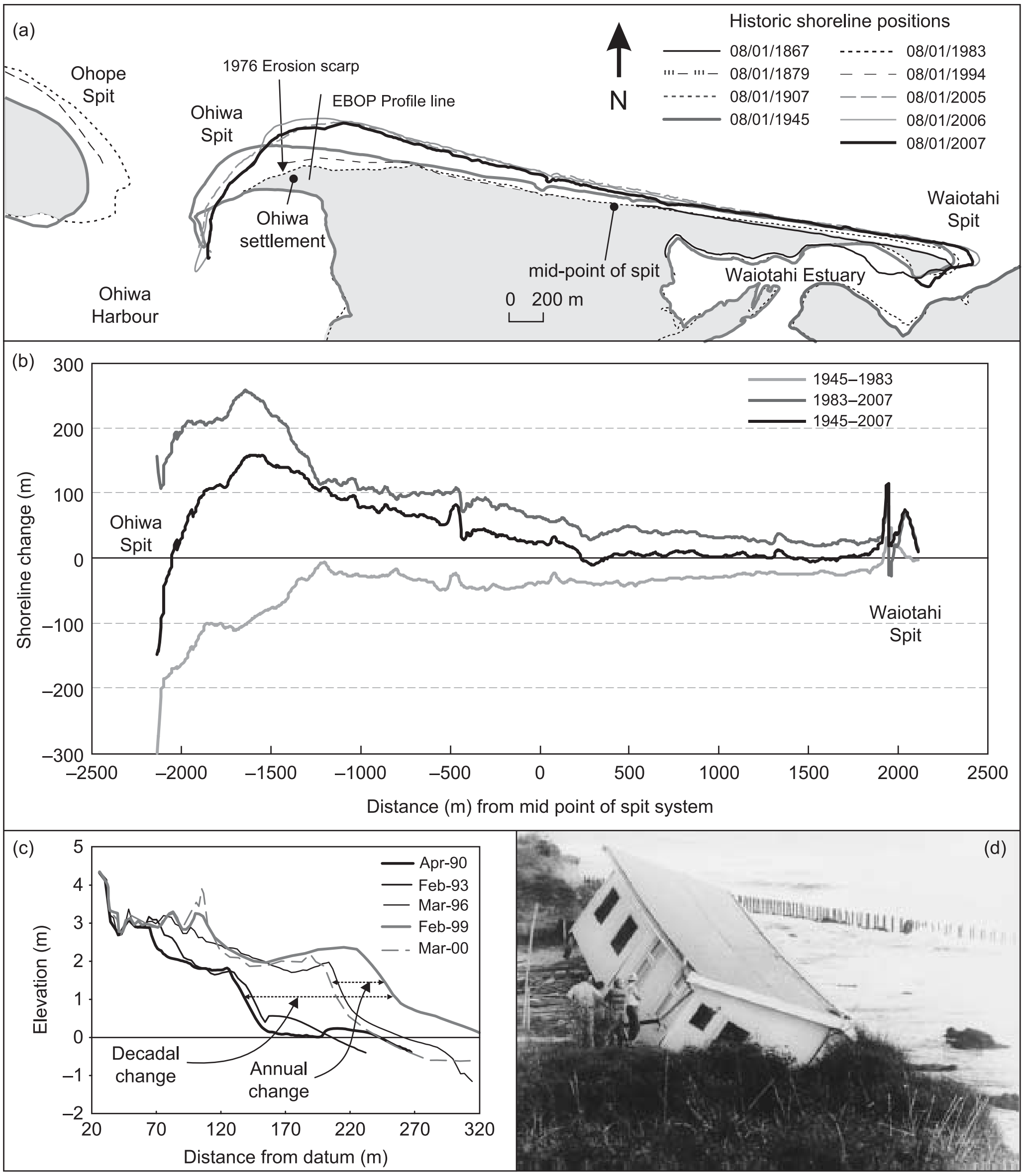

Figure 2 Shoreline positions at Ohiwa to Waitoahi spit 1867–2007. (a) Geo-referenced historic shorelines. Data is compilation of historic shoreline sourced from the Environment Bay of Plenty Coastal Resource Sheets and annual GPS surveys 2004–07 undertaken by the School of Geography, Geology and Environmental Science, The University of Auckland. (b) Analysis of shoreline change at 1-m intervals along the spit system using the Digital Shoreline Analysis System (DSAS) (c) Summary coastal profile data at Ohiwa spit (Source: Environment Bay of Plenty), and (d) Photograph of home toppling over dune scarp at Ohiwa settlement in 1976 (Source: Whakatane Museum).

spit (Gibb 1977; Healy *et al.* 1977; Richmond *et al.* 1984, Fig. 2(a)). This lateral migration of the spit resulted in erosion and loss of the hotel and wharf facility on Ohiwa spit. Based on this analysis Gibb (1977, 1984) estimated the future life span of the Owiha spit at 60–200 years.

A summary of shoreline positions for Ohiwa spit that span the past 140 years (1867–2007, Fig. 2a) shows: (i) Ohiwa spit did extend

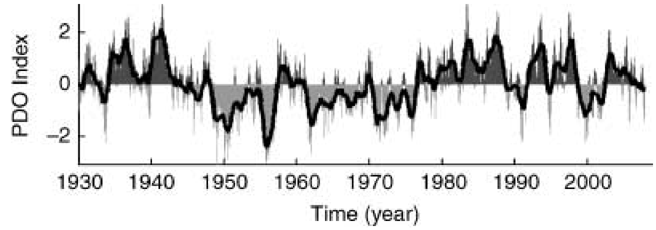

Figure 3 The Pacific Decadal Oscillation Index (shaded areas) with a 12-month running mean superimposed (black, thick line). The index is calculated using the leading principal components of the sea surface temperature anomalies in the North Pacific Ocean. The darker grey shading corresponds to positive or warm periods (when more El Niño events tend to occur) and the lighter shading corresponds to negative or cooler periods (when more La Niña events tend to occur). Data provided by Nathan Mantua, http://jisao.washington.edu/pdo/PDO.latest.

considerably further westward in the late 19th century; (ii) Ohiwa spit underwent substantial eastward migration by 1983, and; over the past 24 years both Ohope and Ohiwa spits have migrated back to the west by up to 400 m. This updated evidence indicates that lateral displacement of the entrance is substantial and that change may not necessarily be unidirectional toward the east, but oscillate within a broader section of coast at centennial timescales.

The ocean shoreline of the Ohiwa–Waiotahi system has also exhibited significant shoreline mobility. For instance, the period between 1945 and 1983 was characterized by substantial erosion, in excess of 200 m close to the entrance and gradually decreasing eastwards to about 75 m (1 km from the entrance) and 20–30 m in the centre of the beach system (Fig. 2a,b). Anecdotal evidence indicates this erosion occurred in the mid-to-late 1970s. This period is widely believed to have been characterized by multiple storm episodes (particularly a severe storm in 1976), possibly associated with the sustained period of La Niñas which occurred during the negative phase of the Pacific Decadal Oscillation (PDO) (Fig. 3), that depleted sediment supplies stored in dunes causing erosion, which has left an erosional scar observed on sand systems along much of the north-east coast of New Zealand (e.g. author's field observations at Bream Bay, Omaha and Coromandel).

In contrast, the period between 1983 and 2007 is characterized by substantial progradation in excess of 250 m at Ohiwa spit and reducing to 30–50 m by the mid-point of the spit system (Fig. 2b). This latter phase of accretion is clearly shown in a summary plot of coastal profile monitoring established by Environment Bay of Plenty at Ohiwa spit (Fig. 2c). This plot also highlights the large short-term variability that occurs in response to storms and seasonal variations in wave climate, but which are an order of magnitude less than the larger multi-decadal shifts in the shoreline. Of note, there has been net progradation at Ohiwa spit between 1945 and 2007 (Fig. 2b).

In summary, large (±200 m) fluctuations of the shoreline appear to be characteristic of the Ohiwa spit inlet and open ocean coastline. There is also evidence that such fluctuations are cyclic. Gibb (1977) showed that the shoreline position between 1867 and early 1907 showed extensive progradation, followed by erosion from 1908 to 1945 and further progradation from 1945 to 1959. Figure 2 clearly shows the ensuing erosion and accretion episode spanning the last 60 years. Consequently, over the last 140 years there appear to be at least three periods of significant shoreline advance and two periods of erosion. This strongly suggests a pattern of 50–60 years cycles within which periods of erosion and progradation dominate for periods of 25–30 years. Such cycles are expressed as: lateral displacement of the spit; cross-shore displacement of the shoreline, and; re-alignment of the shoreline to the north-east in progradational phases and to the north in erosional phases (Fig. 2a).

Like other examples of coastal change around New Zealand, the detailed process mechanism forcing such long-term change is poorly resolved. Although not proof, the periods of erosion and accretion identified at Ohiwa correspond loosely with the sustained La Niña (higher sea level and stormier conditions producing east-coast erosion) and El Niño (depressed sea level and sustained westerlies producing east-coast accretion) phases proposed by de Lange (2000). However, the precise alterations in wave climate that may have influenced littoral drift patterns on the coast are not clear.

The Ohiwa case study also underscores the relevance of establishing long-term as well as short-term dynamics of coastal systems for the purposes of coastal hazard planning. The erosion period of the 1970s directly threatened settlement on Ohiwa Spit. At least one house was destroyed (in the storm of April 1976) and several others were forced to relocate (Fig. 2d). In this case settlement had encroached on the area of coast that is within the dynamic envelope of coastal change at multi-decadal timescales. Construction of centennial scale chronologies of coastal change along our developed coastlines is imperative for sound coastal hazard assessment. However, the temporal scale of human understanding of coastal dynamics is also short. In 2007 Opotiki District Council received an application for building consent to establish structures in the now-accreted foredune in front of the 1976 erosion scarp (Fig. 2a). Such an activity represents re-occupation of the coastal margin that was in the sea in the 1970s and poses a threat to infrastructure and human safety.

Detecting the processes responsible for short-term spit evolution: The Mokau river mouth

The town of Mokau lies on the north-west coast of the North Island, some 60 km north of New Plymouth (Fig. 1 and 38°43′S, 174°38′E). The town has expanded onto an adjacent sand spit in the 1950s, which extends southward toward the mouth of the Mokau River, and a headland (Fig. 4a). The headland anchors the river mouth on its southern shore. The north-west coast of the North Island is characterized by very energetic wave conditions, often originating from the Southern Ocean (Gorman *et al.* 2003), which drive a northward littoral drift carrying large volumes of sand northward. The Mokau sand spit forms part of this system, with its main source of sediment arriving from the rivers draining off Mount Taranaki along with the local Mokau River supply. As with all spits, it is a strongly dynamic feature and has experienced significant erosion since it was first developed in the 1950s (Needham 2004). By 2004, 11 properties were lost, with another succumbing to a storm in June 2006. Despite efforts of the local community to protect the receding shoreline with sand-bags, boulders and timber sea-walls, erosion continues to be a problem.

Maps of the shoreline over the last century from Environment Waikato (EW) (presented in Needham 2004) show that the current shoreline is close to its 1884 configuration. The development occurred when the spit was at its maximal extent (some 170 m longer) in 1956. It is interesting to qualitatively compare these configurations to the state of the PDO index (Fig. 3), which was in a positive phase in the early part of this century (1920s) in which case El Niño events were more likely to occur (de Lange 2000). El Niño events are associated with increased westerly winds and erosion on the west coast (although the link to erosion has not been substantiated). Development in the late 1950s coincided with a switch to a negative PDO along with an increase in the likelihood of La Niñas and a decrease in the likelihood of westerly winds (and thus less erosion). The period from 1980 to the early 2000s was a time of intense erosion and also corresponded to a switch back to a positive PDO index as characterized by a dominance of El Niño patterns. The timing of these patterns of erosion and accretion should mirror patterns on the east coast which benefits from an increased incidence of westerly winds. Although it is difficult due to lack of monitoring data to extend this by making a quantitative link with decadal scale climate variations such as the PDO index, it is very clear that a very long time scale (20–30 years) cyclic patterns of spit development are a characteristic of Mokau, as with Ohiwa Spit.

One of the goals of a coastal scientist is to develop models that are capable of predicting fluctuations in shoreline positions. At the base of such a model is a clear understanding of

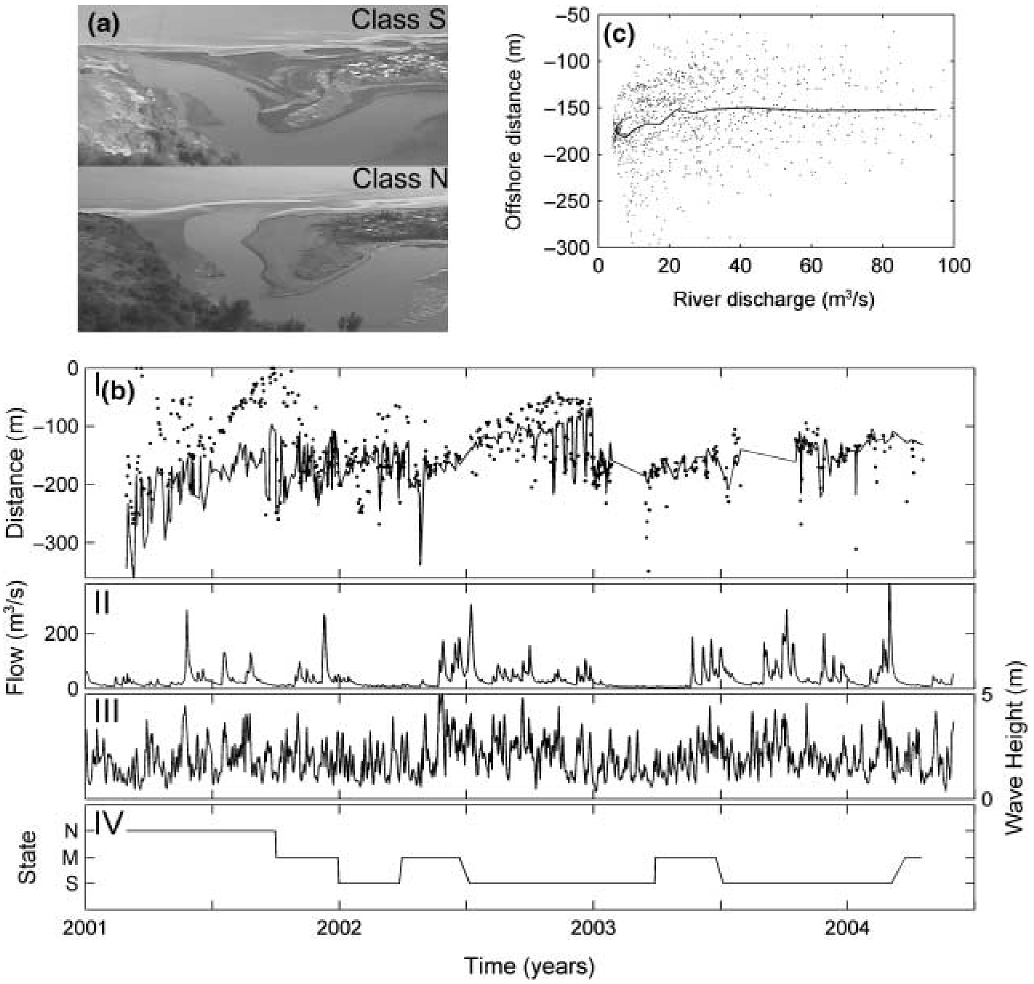

Figure 4 (a) View of the Mokau Sand spit in two of its classes of states (S and N) from the NIWA-Environment Waikato video camera which is located on the headland looking northward (after Needham 2004). (b) Time series of (I) shoreline location at two sites on the seaward side of the spit (dots: close to the river mouth, line: 150 m northward) (II) Mokau River discharge (III) Offshore significant wave height and (IV) spit classification. (Figure redrafted from Needham 2004 and used with permission from Environment Waikato. NIWA provided river discharge and wave data). The classifications mean N: northward trending river mouth, S: southward trending river mouth and M: mid-way between the northern and southern extremes. (c) Relationship between shoreline position at the northern-most site and river discharge. A similar relationship existed between the shoreline position at the more southern site and the discharge.

the processes driving such changes. Shoreline surveys undertaken every decade or so are only useful to underpin a broad scale qualitative understanding (such as the possible association with El Niño-La Niña and PDO patterns). Moreover, these surveys are often only undertaken after storm events or during phases of development, and therefore can alias the natural erosion-accretion signal. To provide higher frequency measurements of shoreline change, the National Institute of Water and Atmospheric Research (NIWA) and Environment Waikato (EW) installed a video camera mounted on the headland south of the Mokau Spit. Figure 4a shows the view from the camera. Needham (2004) digitized and classified the spit over a four-year period when the camera was in operation (2001–2004) and used this to track shoreline variations at two alongshore locations, one at the eroded scarp at the river end of the spit, and the other some 150 m northward (Fig. 4bI). The shoreline that he digitized varied by up to 300 m over the four-year period, with some obvious cyclic behaviour (Fig. 4bI). However, there was no significant statistical relationship with the processes that might cause the shoreline variability (offshore significant wave height, river discharge and tidal variations) (Fig 4bII,III). (The dataset is insufficiently long to attempt correlation with the Southern Oscillation Index.) There also seemed be little association with the spit classification, where Class S corresponds essentially to the river mouth tending southward (Fig. 4a, top panel), Class N corresponds to a northward tendency (Fig. 4a, bottom panel) and Class M corresponds to a channel midway between the northern and southern extremes.

These data represent some of the most detailed and extensive measurements of spit geometry available in New Zealand. Some qualitative pattern can be observed in these data, for example the shoreline appeared to erode in the winter-spring months after a period of increased discharge and wave energy. This did not appear to occur in late 2003. It could be that superimposed on this pattern was the general localized switch toward El Niño conditions at the end of 2002 (year 1) that may have enhanced erosion. However, despite these qualitative observations, no obvious quantitative proof could be found (e.g. correlations) of the relationship between shoreline change and the process variables using simple linear techniques (Needham 2004). Some very weak relationships could be detected between river flow and shoreline variations (Fig. 4c). This result is discouraging because with no ability to clearly demonstrate a link with processes, it is not clear which processes should be included in a shoreline change model and how these processes should be modelled. It is clear that, given the number of competing drivers, a much longer dataset is needed to develop a model.

Human occupation of a dynamic spit, New Brighton, Christchurch

This case study examines New Brighton spit (43°32′S, 172°44′E, Fig. 1), a dynamic feature of Christchurch city and home to an estimated 8 000 people. Evidence suggests that the enclosing spit and estuary system comprises one of the most recent pre-human additions to the southern Pegasus Bay coastal environment. It started to form well after sea level stabilized at the mid-Holocene highstand 6 000 years ago, growing southward in several phases to finally enclose the estuary over the last 1 000 years (Blake 1964; Brown & Weeber 1992). These phases were interrupted by periods of erosion and breaching and fed by major pulses of Waimakariri River sediments, possibly driven by Southern Alps tectonic activity (McFadgen & Goff 2005). However, as in many of New Zealand's modern urban settings, overlying patterns of coastal occupation do not reflect the physically dynamic and youthful nature of this shoreline.

Based on the Port of Lyttelton tide gauge, sea levels are presently rising by 2.1 mm per year (Hannah 2004). This increases the demand for sediment so that the shoreline morphology can adjust in line with the new level of the sea at the shore. This is compounded with a decrease in continental shelf contributions to Pegasus Bay to around 5% of coastal sediment inputs. The remaining 95% of sediment supplies are sourced from rivers, 77% comprising sands and silts from the Waimakariri River (Griffiths & Glasby 1985). Our understanding of the current behaviour of this shoreline comes from a range of primary and secondary studies, including shoreline and sediment budget modelling, aerial photographs, beach profiles, historical and contemporary records, maps and photographs (Table 1).

Several Pegasus Bay sediment budgets have been produced over the last three decades with variable results. Hicks (1998) review of these estimates the New Brighton spit and Christchurch City sections of coast are supplied with a surplus 549 000 and 463 000 m^3 per year, respectively. Information sources used to construct the reviewed budgets include river discharge and shoreline modelling, beach profiles and aerial photographs.

As part of the Environment Canterbury (ECan) coastal monitoring network, the 53 km Pegasus Bay shoreline has been monitored since 1977 at a growing number of sites, and since 1990 at 60 sites with annual to

Table 1 Sources of information on the state of the Christchurch coast

Type	Spatial scale and resolution	Temporal scale and resolution
Geological evidence	Regional coverage, some sub-regional resolution	Holocene
Shoreline and sediment budget modelling	Regional coverage, 1 000 m resolution	Historical calibration and prediction
Aerial photographs	Low to high-resolution regional coverage	1940-present at sub-decadal intervals
Beach profiles	60 local profile sites	1977/1990 to present
Maps, photographs and reports	Variable coverage and resolution	Historical

six monthly surveys (Cope *et al.* 1998; Gabites 2005). Initial analysis of these records suggests that Christchurch's beaches are generally characterized by a slight tendency to accrete punctuated by substantial cycles of storm erosion and subsequent recovery, with more pronounced cycles towards the southern spit (Fig. 5).

Since 1977, severe sea storms have struck Canterbury during 11 out of 30 years (Gabites 2005), with the 1978 storm, and to a lesser extent, storms in 1992 and 2001–2002 having the greatest impacts on the New Brighton spit coast (Hart *et al.* 2008). Profile records since 1990 show that most beaches along the spit experienced substantial erosion in 1992 and partial recovery during 1993, with pre-storm excursion distances reached years later at sites towards the southern end of the spit. The storms of 2000–2001 again stripped the beaches along the Brighton spit of large volumes of sediment, profile records indicating that some have yet to fully recover (Fig. 5).

The observed pattern since 1990, of gradual accretion overlain by storm–recovery cycles, is similar to that reported for other sites, for example Moruya in south-eastern New South Wales, Australia. The 32 years Moruya record indicates that the last two decades of accretion are the recovery and dynamic-equilibrium phases of a much larger cycle, including a period of severe erosion in response to the early 1970s storms-in-series (McLean & Shen 2006). The Ohiwa and Mokau Sand spits also appear to exhibit very long erosion cycles. In this context, it can be concluded that the changes shown in the New Brighton profile record represent only part of the dynamics of this system over historical time. Moreover the slight positive trend typified in Figure 5 is likely an artefact of record length. This shows that while the short-term information on beach state provided by profile records may be crucial for effective management practices, these generally short records need to be used in conjunction with other forms of information to inform planning decisions.

Aerial photograph analysis reveals that the distal end of New Brighton spit has been very mobile over the last century (Fig. 6). Up to 20 houses along the open-coast and estuary shores of the spit tip now occupy areas that were foreshore in the 1940s and, to a lesser extent, in the 1960s. This mismatch between spit dynamics and patterns of habitation is acknowledged in the Canterbury Regional Coastal Environment Plan in the form of hazard set-back lines, which limit further development of these areas (ECan 2005).

Few areas of New Brighton coast today retain substantial tracts of the natural landscape. The dunes are second generation, having reformed with introduced vegetation after sheep grazing during the 19th century removed the original native cover causing the demise of the dunes. Walkway, solid-wall and sand fence structures are widespread along the foreshores and backshores of the beach while re-contouring, pedestrian and vehicle traffic has modified many areas without structures (Hart & Knight 2008). These management and development interventions indicate that over historical timescales future spit shorelines will be a function, not only of the physical beach system behaviour reflected in profile and aerial photograph records, but also of human interventions to protect infrastructure and resource use values.

Given the geological record of spit change and predictions of future climate changes, it is

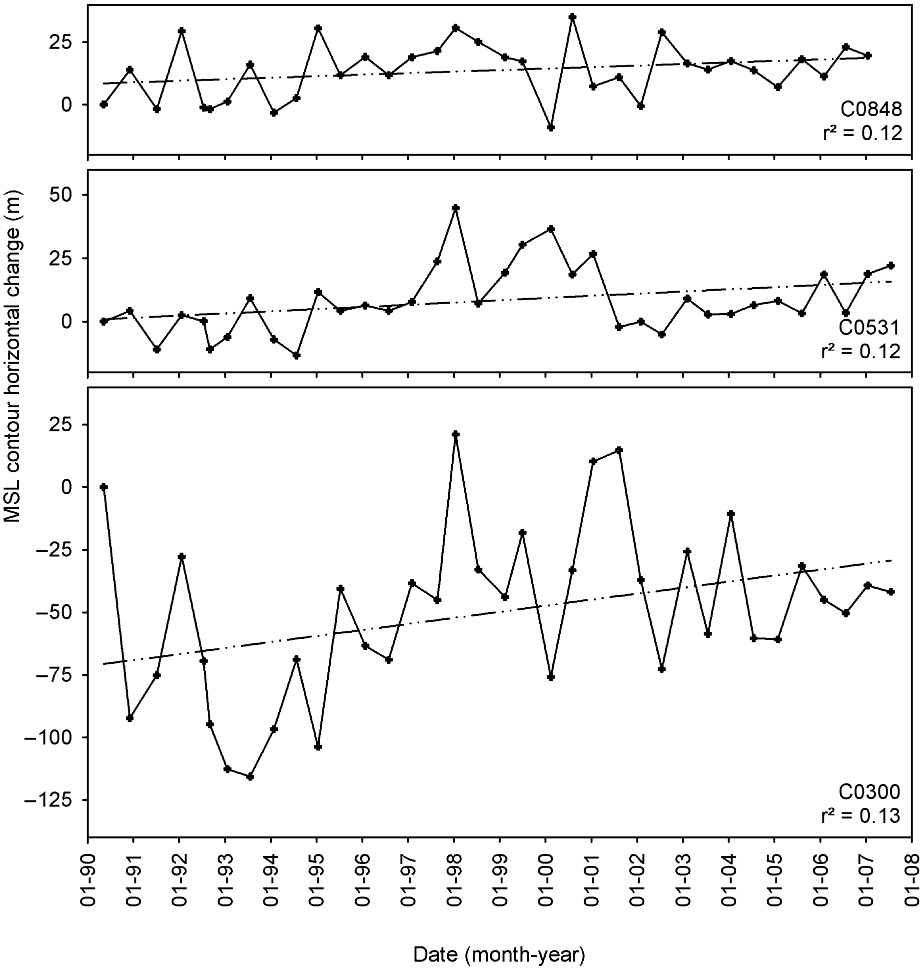

Figure 5 Changes in foreshore width since 1990 along New Brighton spit as indicated by the horizontal excursion of the mean sea level (MSL) contour from its 1990 position (0 m). Solid lines show change in ECAN profiles C0848 (northern spit), C0531 (centre of spit) and C0300 (southern spit) while the dotted lines and r^2 correlation values indicate their linear trends. The MSL excursion is a crude but effective proxy for beach volume, indicating whether the beach is in an eroded (negative excursion) or accreted (positive excursion) state relative to the first survey.

questionable as to how long these interventions can dampen large-scale shifts in the stability of the spit. Together the geological, historical, sediment budget, profile and aerial photograph evidence highlight that New Brighton spit is a dynamic coastal system responsive to changes in sediment and energy conditions. The dominant sediment supply to this feature has changed from offshore to catchment-related sources over geological time and will likely continue to vary over historical timescales in response to the episodic delivery of river sediments and climate variability, both year-to-year and multi-decadal.

Discussion

There are very distinct similarities between the three sand-spit systems that are examined here. First, they were all developed extensively during periods in which the spits were in a healthy, accreted state, indicating a general lack of knowledge at the time of the spatial and temporal extent of changes. Second, the behaviour of the spits appear to exhibit some very long-scale cyclic behaviour at 30–50 years timescales. However, the limited data presented suggests that the erosion and accretion episodes may be out of phase between the east and west

Figure 6 Shoreline changes along the distal end of New Brighton spit 1940–2005 (modified from Hart *et al.* 2008).

coast. The two east coast sites are currently in an accretionary period (recovering from a storm period in the 1970s), whereas the west coast site is currently in an erosional phase. However, evidence from west coast beaches north of Auckland (see review in Hart & Bryan paper in this issue) suggest that large sand slugs are liberated from deltas (such as at the entrance to the Manukau Harbour) and move northward along the coast causing local erosion and accretion. This alongshore-connectivity between beaches makes it far more difficult to detect trends and associate them with climatic variability.

The results presented here also show that multi-decadal coastal change along sand spits is an order of magnitude greater (10^2 m) than changes driven by storms (10^1 m). This difference highlights the fact that multi-decadal coastal change has far greater management implications than the shorter focus on storm hazards. The danger lies when only very recent knowledge of wave climate is used to underpin current definitions of coastal hazard set-back zones which occurs throughout many areas in New Zealand, and is the main planning instrument used to control coastal development. It is encouraging to see some of the very recent hazard-set back zones (e.g. for beaches along the Coromandel Peninsula) incorporating both long and short-term shoreline fluctuations and recognizing the influence of sediment budget changes, sequences of storms and sea-level rise.

The driving mechanisms of the observed coastal change at the case study sites remain largely speculative. Conventional theory suggests that changes in sea level, wave direction, wave height and sediment supply are the primary drivers of medium-term coastal change (Cowell & Thom 1994; Woodroffe 2003). In this regard, the PDO oscillation has been implicated as a likely mechanism promoting such modifications to sea level and wave climate around the New Zealand coast (de Lange 2000). The contrasting behaviour between the east and west coast sites may be an indication of the erosional influence that sustained La Niña phases have on east coast beaches. These occur during negative PDO periods, such as dominated the late 1970s (culminating in the extreme storms-in-series of 1978). Conversely, sustained El Niño phases may be associated with erosion on west coast beaches (associated with a positive PDO index) such as occurred during the late 1990s and early 2000s (Fig. 3). El Niño conditions are characterized by an increase in westerly winds, in contrast to La Niña conditions which are associated with a predominance of north-easterly winds and an increase in sea storm events on the east coast. These results are certainly consistent with the association of shoreline erosion with the PDO index noted at Bayview Beach north of Napier (Oldman *et al.* 2003). However, the detailed causative mechanisms linking PDO cycles with specific changes in wave climate and sediment transport responses have yet to be resolved (although the link between El Niño-La Niña cycles has been shown in Gorman *et al.* (2003)). There are simply not the records or number of case studies to test this hypothesis. The aerial photographs and shoreline surveys span very long time scales, but are usually only collected every decade or so. Conversely, video camera data provides daily information on shoreline change on many New Zealand beaches but lacks sufficient duration (e.g. the Mokau camera system ran from 2001 to 2006).

The lack of correlation of sand spit behaviour with the external forcing at the Mokau site indicates that even if much better datasets were available, the processes are not simple to define. Such lack of correlation with external forcing in other geomorphic features such as sand bar shape, rip-current dynamics and sand ripple behaviour might indicate that such systems have such strong internal feedbacks that their behaviour and resulting shape is largely controlled by the feedbacks rather than the forcing. For example, spit orientation affects wave shoaling patterns and river mouth channel geometry, which in turn feed back into controlling sand transport and, ultimately, spit shape. Such feedbacks cannot be studied using simple tools such as linear correlations. Moreover, inertial lags arising from movement of large sediment slugs along the coast or peeling off ebb-tidal deltas confound the signal. In this light, and given the obvious inability to link past behaviour to wave climate or river conditions, and the very sketchy understanding of the impact on wave climate and river conditions of climate change (e.g. MFE 2004), the task of making quantitative predictions on shoreline response for the future remains a challenging one.

Conclusions

Much of New Zealand's intensively inhabited sandy coastal environment is in a continual state of morphological adjustment to wave processes, sea level, sediment supply and sediment transport. These processes are known to vary at short (daily to seasonal), inter-annual and multi-decadal timescales. The three case studies presented in this paper clearly show that the magnitude of morphological adjustment of sand systems exhibits marked difference between the temporal scales of interest. In particular, multi-decadal changes at sand-spits on the coast were found to be an order of magnitude larger (10^2 m) than event driven changes (10^1 m). Consequently, pre-occupation with short-term morphological behaviour in the identification of coastal hazard assessments to support coastal planning and management must be reconsidered in light of the more substantial changes in the coast at longer multi-decadal timescales. While coastal monitoring records are growing in extent and value over time, more weight needs to be placed in the planning process on obtaining the longer datasets and information at larger timescales, despite their reduced quality and coverage, while continuing ongoing fundamental research on understanding processes drivers and feedbacks in these intensely dynamic systems.

Acknowledgements

The National Institute of Water and Atmospheric Research and Environment Waikato provided funding for and Mokau video, wave predictions and river data for B. Needham's thesis. Environment Canterbury provided the data used to construct Figures 5 and 6.

References

Bell RG, Goring DG (1998). Seasonal variability of sea level and sea-surface temperature on the north-east coast of New Zealand. *Estuarine, Coastal and Shelf Science* **46**, 307–18.

Black PK, Gorman RM, Bryan KB (2002). Bars formed by horizontal diffusion of sediment. *Coastal Engineering* **47**, 53–75.

Blake GJ (1964). *Coastal Progradation in Pegasus Bay*. Unpublished MSc Thesis (Geography), University of Canterbury.

Brown LJ, Weeber JH (1992). *Geology of the Christchurch Urban Area*, IGNS Geological Map 1, 1 : 25 000.

Cope J, Flatman M, Howes A, Young B (1998). *A Summary of Monitoring and Investigations on the Pegasus Bay Coastline 1993–97*. Environment Canterbury Report No. U98/30.

Cowell PJ, Thom BG (1994). Morphodynamics of coastal evolution. In: Carter RWG, Woodroffe CD, eds. *Coastal Evolution, Late Quaternary Shoreline Morphodynamics*. Cambridge University Press, Cambridge, pp. 33–86.

Dally WR, Dean RG (1984). Suspended sediment transport and beach profile evolution. *Journal of Waterway, Port, Coastal and Ocean Engineering* **110**, 15–33.

ECan (2005). *Regional Coastal Environment Plan for the Canterbury Region*. Environment Canterbury Report No. R04/13/1.

Gabites B (2005). *A Summary of Monitoring and Investigations on the Canterbury Bight Coastline*. Environment Canterbury Report No. U05/77.

Gallagher EL, Elgar E, Guza RT (1998). Observations of sand bar evolution on a natural beach. *Journal of Geophysical Research* **103**, 3203–15.

Gibb JG (1977). Late Quaternary sedimentary processes at Ohiwa Harbour eastern Bay of Plenty with special reference to property loss on Ohiwa Spit. *Water and Soil Technical Publication* National Water and Soil Conservation Organisation 5.

Gibb JG (1984). Coastal erosion. In: Spenden I, Crozier MJ, eds. *Natural Hazards in New Zealand*. New Zealand Commission for UNESCO, pp. 134–58.

Goodwin ID (2005). A mid-shelf, mean wave direction climatology for Southeastern Australia and its relationship to the El Niño-Southern Oscillation since 1878 A.D. *International Journal of Climatology* **25**, 1715–29.

Goring DG, Bell RG (1999). El Niño and decadal effects on sea-level variability in northern New Zealand: a wavelet analysis. *New Zealand Journal of Marine and Freshwater Research* **33**, 587–98.

Gorman RM, Bryan KB, Laing AK (2003). Wave hindcast for the New Zealand region: deep-water wave climate. *New Zealand Journal of Marine and Freshwater Research* **37**, 589–612.

Griffiths GA, Glasby GP (1985). Input of river-derived sediment to the New Zealand continental shelf. I. Mass. *Estuarine, Coastal and Shelf Sciences* **21**, 773–87.

Hannah J (2004). An updated analysis of long-term sea level change in New Zealand. *Geophysical Research Letters* **31**, L03307, doi: 10.1029/2003GL019166.

Hart DE, Knight GA (2008). Geographic information system assessment of tsunami vulnerability on a dune coast. *Journal of Coastal Research* (forthcoming).

Hart DE, Marsden I, Francis M (2008). Coastal systems. In: Winterbourne M, Knox GA, Marsden ID, Burrows C, eds. *Natural History of Canterbury*, 3rd edn. Chapter 20, Canterbury University Press, Christchurch (forthcoming).

Healy TR, Harray KG, Richmond B (1977). *The Bay of Plenty Coastal Erosion Survey*. Department of Earth Sciences, University of Waikato. Occasional Report 3.

Hicks DM (1998). *Sediment Budgets for the Canterbury coast: A Review, with Particular Reference to the Importance of River Sediment*. Unpublished Consultancy Report to the Canterbury. Regional Council CRC80506, NIWA, Christchurch.

de Lange WP (2000). Interdecadal Pacific Oscillation (IPO): a mechanism for forcing decadal scale coastal change on the northeast coast of New Zealand? *Journal of Coastal Research SI* **34**, 657–64.

McFadgen BG, Goff JR (2005). An earth systems approach to understanding the tectonic and cultural landscapes of linked marine embayments: Avon-Heathcote Estuary (Ihutai) and Lake Ellesmere (Waihora), New Zealand. *Journal of Quaternary Science* **20**, 227–37.

McLean R, Shen J-S (2006). From foreshore to foredune: Foredune development over the last 30 years at Moruya Beach, New South Wales, Australia. *Journal of Coastal Research* **22**, 28–36.

MFE (2004). *Coastal Hazards and Climate Change: A Guidance Manual for Local Government in New Zealand* ME512, Ministry for the Environment, Wellington.

Needham B (2004). *The Variation in River Mouth Dynamics, Spit and Shoreline Morphology at Mokau*, Unpublished MSc Thesis, University of Waikato.

Oldman JW, Smith K, Ovenden R (2003). Coastal Erosion hazard assessment of the Foreworld sites between Gill Rd and Franklin Rd, Bayview, Hawke Bay. *NIWA client report*, FWL03202.

Plant NG, Holman RA, Freilich MH, Birkemeier WA (1999). A simple model of interannual sandbar behaviour. *Journal of Geophysical Research* **104**, 15755–76.

Ranasinghe R, McLoughlin R, Short A, Symonds G (2004). The Southern Oscillation Index, wave climate and beach rotation. *Marine Geology* **204**, 273–87.

Richmond BR, Nelson CS, Healy TR (1984). Sedimentology and evolution of Ohiwa harbour, a barrier-impounded estuarine lagoon in Bay of Plenty. *New Zealand Journal of Marine and Freshwater Research* **18**, 461–78.

Short AD, Trembanis AC (2004). Decadal scale patterns in beach oscillation and rotation Narrabeen Beach, Australia – time Series, PCA and wavelet analysis. *Journal of Coastal Research* **20**, 523–32.

Woodroffe CD (2003). *Coasts: Form, Process and Evolution*. Cambridge University Press, Cambridge, p. 638.