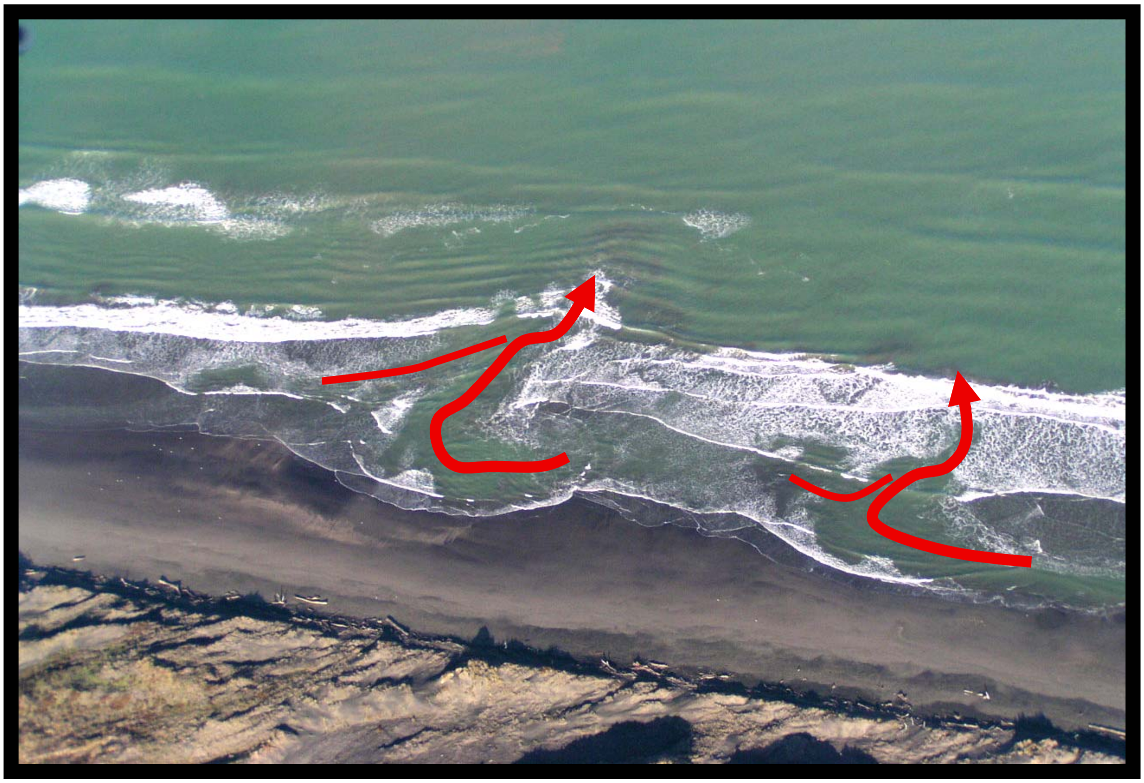
Rip-associated bathing hazards on beaches characterised by net offshore bar migration



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Cover: Example of transverse inner bar configurations on the Wanganui coast. The rips, depicted by the red arrows, are asymmetric with oblique orientation, typical of those which occur along coasts characterised by strong longshore currents with alternating approach directions.

INTRODUCTION

While recreational bathing is a major pastime throughout the world, oceanic sandy beaches can be particularly hazardous. Such beaches often have sand-bars, longshore troughs and rip-channels, all of which result in varying water depth; breaking waves and bores which generate turbulence and multi-directional surf zone currents; tides which continually change water depth and current velocities; wind-driven currents, and rip currents. The level of risk to which bathers are subjected is a product of both the hazards and the characteristics of the beach-user (e.g. height and swimming ability). The risk may be mitigated, and hence bather safety increased, by surf lifeguards patrolling the beach and by public education programmes.

Rip currents pose the greatest threat to swimmers because they are the least obvious hazard (Short, 1999). Furthermore, rip currents may occur close to the shoreline, vary in strength with changing tide, wave and wind conditions, and may be fast-flowing even when waves are relatively small (0.5 to 1.0 m).

During the 1990s, coastal researchers observed a new type of morphological behaviour in which subtidal sand-bars formed near the shoreline, systematically migrated seaward across surf zone, then flattened out and disappeared within the outer surf zone. This process may take several years to complete and is referred to as net offshore bar migration or NOM. Such bar behaviour has been studied using longer-term data-sets from coastal sites in the USA (Lippmann et al., 1993), the Netherlands (Wijnberg and Terwindt ,1995; Ruessink and Kroon 1994), Japan (Kuriyama and Lee, 2001) and New Zealand (Shand et al., 1999). NOM also occurs on the southern shores of the Great Lakes during ice-free years (Howser, 2004). Recent results from the New Zealand site at Wanganui suggest that a systematic change in morphological (plan-view) configuration accompanies a bar undergoing NOM and often these configurations incorporate rip-channels (Shand et al., 2004). The present paper will focus on the relationship between NOM and those configurations which present the greatest risk to bathers.

The paper will firstly describe the Wanganui field site, its environmental conditions, and the methods used to acquire data. The process of net offshore bar migration will then be illustrated, its salient characteristics described, and an estimate made of the extent to which it occurs on the New Zealand coast. Systematic variation in configuration during NOM will then be identified, with particular attention given to rip-dominated configurations. Finally, the results are summarized and consideration given to their application.

STUDY SITE

The Wanganui field site covers some 6 km of coast to the northwest of the Wanganui Rivermouth on the southwestern coast of the New Zealand North Island (Fig 1). The nearshore is characterised by fine sand (~0.2 mm), has a cross-shore slope of 1 in 110 and width of ~550 m. Two subtidal sand-bars are usually present; these bars undergo net offshore migration, i.e. NOM, with the mean life-cycle of a bar being ~3 yrs. The foreshore is characterised by medium sand (~0.3 mm), has an average cross-shore slope of 1 in 20 and an average width of ~85 m. About 30% of the time a small amplitude (swash) bar is present on the lower foreshore.

The mean neap tide range is 0.8 m and the mean spring tide range is 2.4 m. The mean deepwater significant wave height is 1.3 m and the 5% excedence value is 2.5 m. The mean time interval between successive waves (wave period) is 10.1 s (range 3.5 s to19 s) with sea wave conditions (periods <10 secs) occurring for ~75% of the time and swell wave conditions (periods >10 secs) for the remaining time. Approximately 42% of waves approach from the west, ~24% from the south and ~34% lie within one degree of shore-normal. The prevailing WNW wind approaches the coast at ~35 deg from the shoreline, and the 5% excedence value of the wind speeds is 12.4 m/s. The mean value for longshore currents within the inner surf zone is 0.42 m/s and the 5% excedence value is 1.01 m/s. Wave height, wind strength and the magnitude of longshore currents are all positively correlated, as are their approach directions.

DATA ACQUISITION

Inter-tidal beach characteristics were identified from morphological maps (e.g. see Fig 2). These maps were produced using ground surveys carried out at fortnightly intervals between August 1991 and March 1995. Beach (inter-tidal) width was derived from the location of the low tide step, this being used as a proxy for the seaward boundary of the foreshore. In addition, plan-view morphological configurations of the beach and inner bar system were obtained using a classification scheme.

Surf-zone morphology was identified from time-lapse photographs. The photographs were exposed for ~5 minutes and field sampled at monthly intervals from on top of a 42 m high cliff located some 3200 m northwest of the rivermouth (see asterisk Fig 1). The long-exposure results in a statistically stable intensity pattern in which higher intensity areas represent shallower depth as wave-breaking is depth-dependent (see Figs 3A and 3B). Each photo was digitised, rectified (perspective distortion removed) to ground co-ordinates and the coastline straightened to facilitate subsequent analysis. The methodology has been described in detail by Bailey and Shand (1993, 1996). The rectified image corresponding to the time-lapse image in Fig 3B, is shown in 3C.

It is noted that photo or video imaging has huge potential for increasing scientific understanding of surf zone processes, and offers real hope for morphodynamic modelling and providing real-time hydrodynamic data. For example, providing wave heights and current velocities for a grid of locations (say every 10 m^2) within a predetermined study area.

For the present exercise, a 300 m long section of coast within the Wanganui study area was used; this section was located between 1400 m to 1700 m from the rivermouth, hereafter referred to as ‘site 1550’. Cross-shore distances to the step and bar-crests were longshore-averaged over the 300 m to derive representative values for each sample.

NET OFFSHORE BAR MIGRATION

Net seaward movement of the low tide step, the inner bar and the seaward bar are all suggested in the 3 time-lapse photos (Fig 4) which span an 18 month period.

How these bar-crest locations fit within longer-term data sampled at 4 weekly intervals over 6.5 yrs can be ascertained from Fig 5. Several repetitions of NOM occurred in which bars systematically migrate seaward then disappear in the outer surf zone. It is also evident that the formation of a new bar occurs about the same time as the disappearance of the existing outer bar.

How the low tide step locations in Fig 4 fit within longer-term data sampled at 2 weekly intervals is evident in Fig 6. These data show a systematic widening and narrowing of the beach. New bars form upon a widened inter-tidal beach. The beach then narrows and remains like this for several months before widening prior to the generation of the next bar.

While NOM is repetitious, there is significant temporal and spatial variation. For example, Fig 7 shows the bar generation history for both the 1550 m site and also for a site ~5 km from the rivermouth (site 5050). While the mean generation periods are similar (1.17 yrs at site 1550 c.f. 1.13 yrs at site 5050) the ranges show substantial variation (0.25 to 1.8 yrs for site 1500 c.f. 0.3 to 3.2 yrs for site 5050). It is also evident that bar generation is non-contemporaneous between these two sites. At Wanganui, variation in NOM behaviour has been found to occur every 1-2 km in the longshore direction. Temporal variation is also evident in the rate at which the bars systematically migrate across the surf zone, with Wanganui values ranging between 75 to 320 m/yr. In addition, NOM behaviour varies on a regional basis with mean return periods at the global sites ranging between 1 yr for the Japanese Pacific coast, to 14.4 yrs for the northern coast of Holland, and NOM rates ranging between 35 m/yr for the northern coast of Holland and 164 m/yr for Wanganui.

Analysis of environmental conditions at the global NOM sites shows that such coasts are characterised by multiple sand-bars, lower cross-shore gradients, regular storm-waves and winds and micro-meso tidal range (see Tables 1 and 2). Approx 25% of the NZ oceanic coast meets these conditions and hence the potential for NOM.

Rip-associated bathing hazards and NOM

CONFIGURATIONS

Because surf zone morphologies are typically complex, a classification approach was used in the present exercise. All (plan-view) configurations were assigned to one of the following four categories:

1. linear (elsewhere, e.g. Wright and Short (1984), such configuration has been referred to as a longshore bar and trough),
2. undulating (elsewhere referred to as (a)rhythmic or crescentic topography),
3. transverse (elsewhere referred to as transverse bar and rip, or simply as ripped topography) and
4. subdued (elsewhere referred to as low tide terrace; such morphology may include minor irregularities including mini-rips).

Fig 8 shows examples of each type of configuration on the series of time-lapse photos displayed earlier (Fig 4) to illustrate offshore bar and step migration.

It is noted that rips may occur in any of the 4 classes; however, they are most prevalent under transverse configurations. Rips within this class also present the greatest bathing hazard because transverse bars facilitate seaward positioning of bathers, and current strength may be relatively high even under lower energy conditions.

The images in Fig 8 suggest that undulating configurations occur following bar generation with transverse configurations predominating during the central portion of the inter-generation period, and linear configurations being characteristic prior to generation of a new bar. The associated time-series of fortnightly data (Fig 9) confirms such configuration tendencies, with the filtered 'dimensionality-based' (see below) curve more clearly illustrating the fluctuation between transverse (3D) configurations during the mid-generation period and linear (2D) configurations later in the inter-generation period.

Subdued configurations were rarely observed in these data, although they were more prevalent in another Wanganui study (Shand et al., 2003) which used higher resolution data with a closer sampling interval from a site located further (3 km) from the rivermouth. In that study subdued configurations were found to form as a result of rip channel infill which occurred at times of higher tidal range and lower wave conditions.

Configuration ‘dimension’ relates to the level of morphological variation in the longshore direction. In particular, morphologies which are non-changing in the longshore direction, e.g. linear configurations, are fully definable with a single (two-dimensional or 2D) cross-shore profile because the third (longshore) dimension is constant. By contrast, descriptions of morphologies which vary in the longshore direction require several cross-shore profiles because the third dimension is not constant. The number of profiles depends on the particular morphology, with ‘stronger’ 3D configurations requiring a greater number of profiles than ‘weaker’ 3D configurations. Subdued configurations are considered to be dimensionless and as such were excluded from the filtering process referred to earlier.

On average, the duration of the transverse (ripped) configurations, hereafter referred to as the ‘transverse of ripped-phase’, is approximately one third of the inter-generation period.

The nature of the ripped configurations was further investigated by analysing the cross-shore rip channel length. Examples of ripped configurations and associated rip-lengths are depicted in the two time-lapse photos shown in Fig 10. These samples occurred during the same inter-generation period as the time-lapse photos used in Figs 4 and 8. These results suggest that rips increase in size during the inter-generation cycle and this is confirmed in the fortnightly time-series of rip-lengths depicted in Fig 11. The rips have been grouped to show how they relate to the inter-generation cycles, and temporal trend lines have been fitted to each group. These results confirm that rip-size, and hence bathing hazard, increases during the transverse morphology phase of the inter-generation cycle.

It is noted that during the longest inter-generation period (1993-94), the rips increased in length then decreased somewhat prior to the end of the phase. This resulted from infill within the landward part of the channel, as indicated by the seaward displacement of the step (see Fig10). Wanganui image-data (not shown) suggest that such behaviour is driven by a positive feedback processes which causes constriction within the rip channel and the eventual truncation of the landward portion of the channel.

DISCUSSION and CONCLUSIONS

Rips associated with transverse morphologies create the greatest hazard for bathers and such configurations occur systematically on NOM coasts such as that at Wanganui. In particular, they occur during the central portion of the bar generation cycle. On average this rip-phase lasts for ~5 months which is one third of the inter-generation period.

Transverse configurations evolve during the rip-phase. In particular, rip channels tend to increase in size and hence their potential as a bathing hazard also increases. However, the level of hazard for any rip channel varies according to the overall morphology, wave conditions, currents and tide.

NOM-associated rip-phases and bathing hazard affect New Zealand recreational beaches. As noted earlier, 25% of New Zealand's oceanic coast has environmental conditions conducive to NOM. In particular, these areas comprise sand-dominated surf zones of the west coast on the North and South Islands, together with exposed sandy surf zones around the base of the South Island, the east coast of the South Island, and the east coast of the North Island south of East Cape.

From a resource planning perspective, it would be useful for surf lifesavers to recognise where a bar is within the NOM cycle, or more particularly where a beach is in the bar-generation cycle. This would enable a basic prediction to be made as to how configurations are likely to (systematically) change in the foreseeable future.

To determine where sections of beach/inner-bar are within the bar generation cycle/NOM cycle, it is necessary to carry out morphological monitoring at 2 to 4 weekly intervals. Such a sampling regime is required because of the quasi-regular nature of NOM. Ideally, monitoring should consist of surf zone imaging and ground surveys for the inter-tidal beach. As changes affecting the beach are preceded by changes in the seaward bar(s), this approach provides the greatest warning time of systematic configuration changes which influence bathing hazard. Alternatively, monitoring of the inter-tidal beach width alone should enable observers to "keep in touch" with where the coast is with respect to the NOM-associated bar generation cycle and associated configuration phases. Of particular interest is any major narrowing of the inter-tidal beach as this is likely to precede a period of hazardous rips.

ACKNOWLEDGEMENTS

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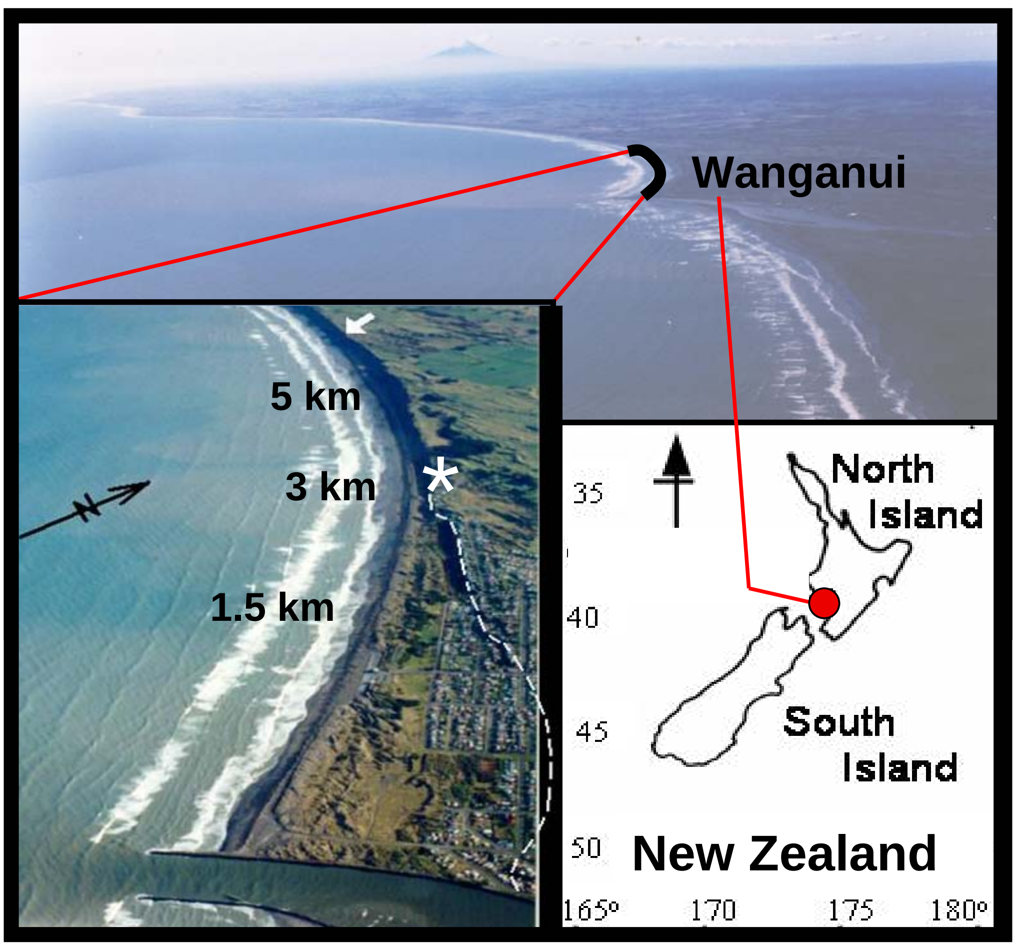

Figure 1 Location maps of the Wanganui study site. The asterisk in lower left figure marks the camera position (see text), while the dashed white line depicts the shoreline prior to construction of rivermouth jetties in the late 19th and early 20th centuries.

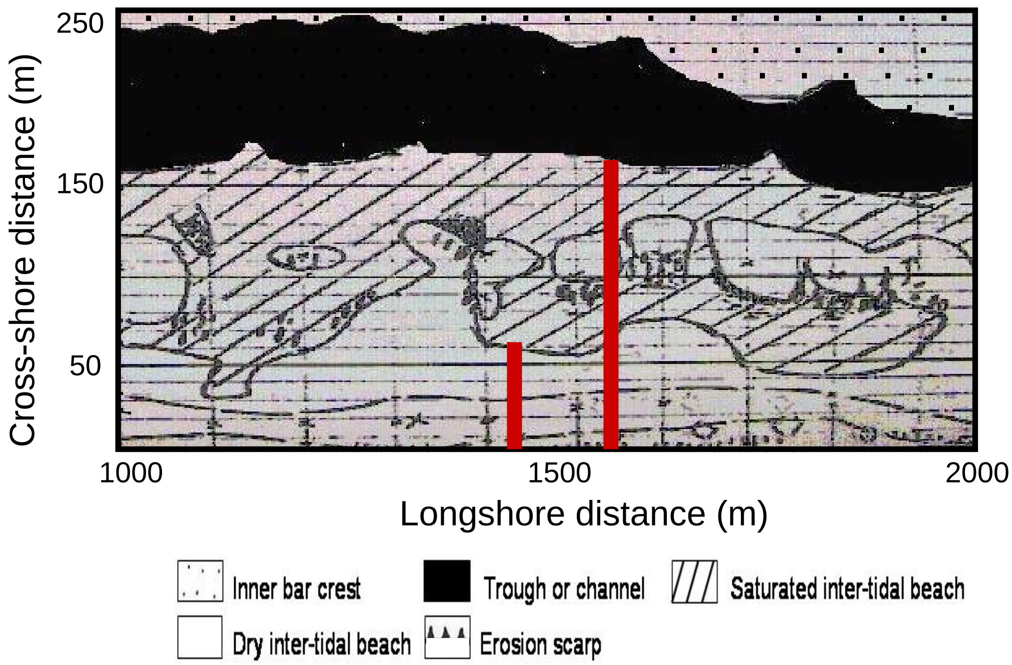

Figure 2 Example of morphological map constructed from ground surveys. The longer vertical bold line depicts inter-tidal beach width, whilst the shorter line depicts beach width at mean sea level.

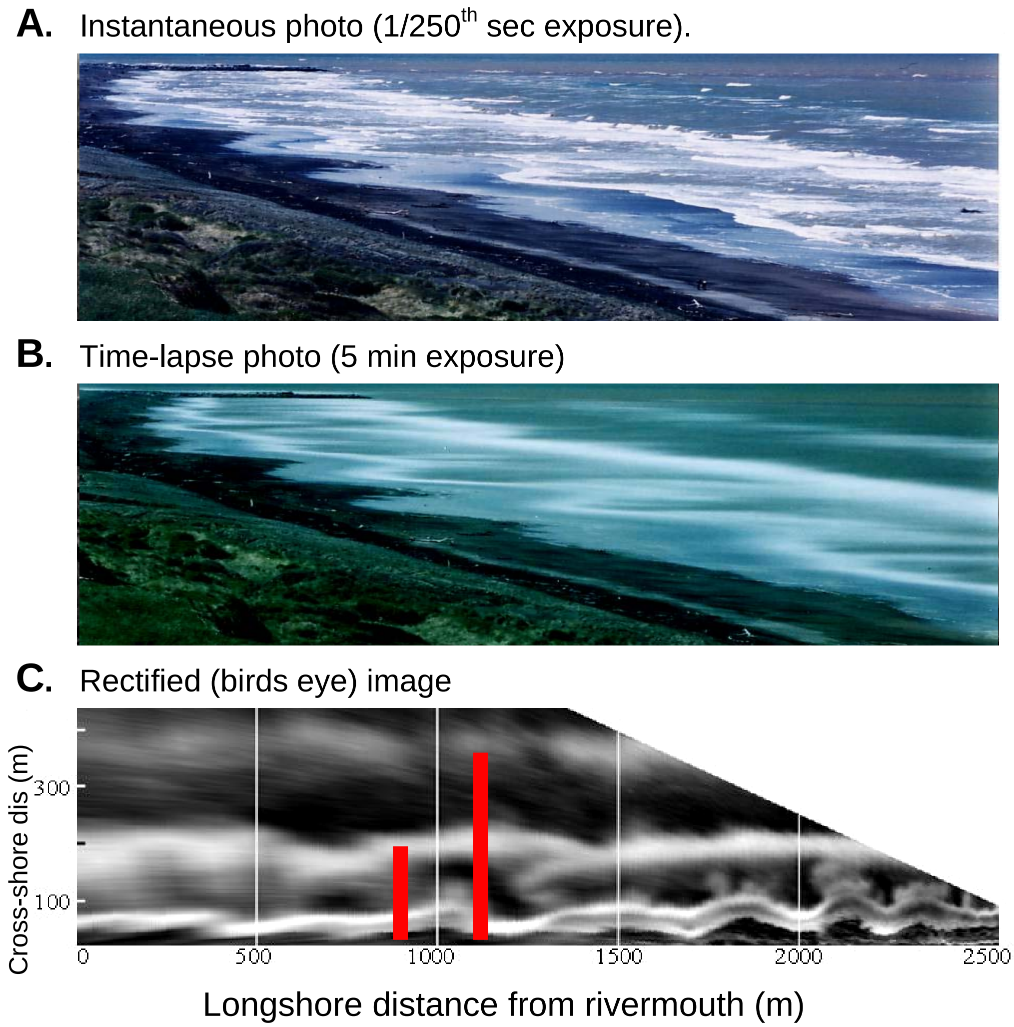

Figure 3 Instantaneous photo (A) shows the eastern portion of study area with the Wanganui River's northern jetty (North Mole) evident at top of picture. The corresponding 5 min time-lapse photo (B) more clearly depicts (relative) topographic variation, with higher intensities corresponding to shallower areas. The rectified image (C) has had the perspective distortion, associated with the oblique viewing angle, removed by digital image processing. The coastline has also been straightened in C to further facilitate analysis. The longer vertical bold line in C depicts cross-shore distance from the dune-toe to the outer bar, while the shorter line depicts distance to the inner bar-crest.

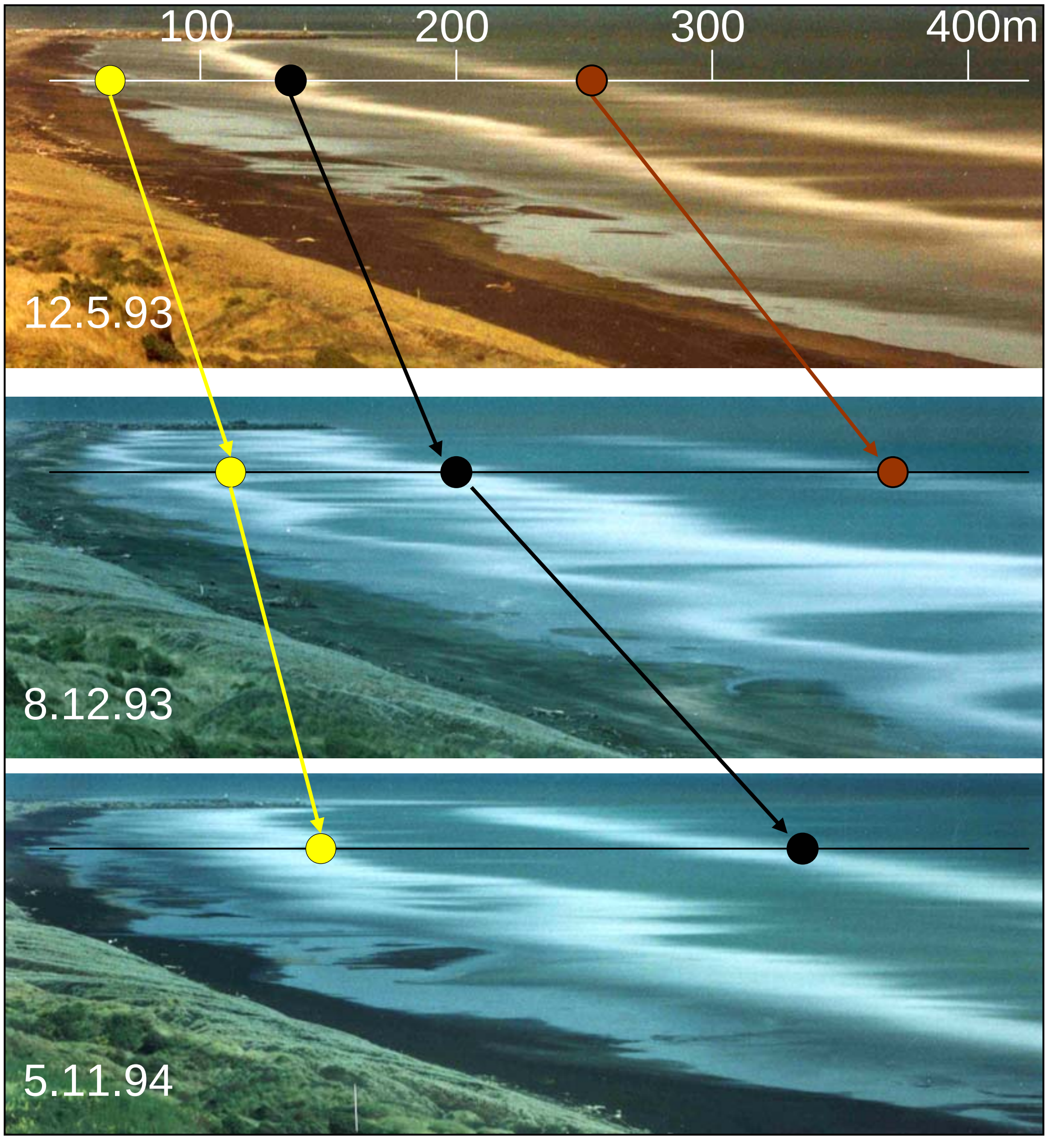

Figure 4 Time-lapse depiction of the seaward trend in bar migration and beach width at a cross-shore transect located 1550 m alongshore from the northwestern rivermouth jetty. Note how the seawardmost bar has disappeared in the final photograph.

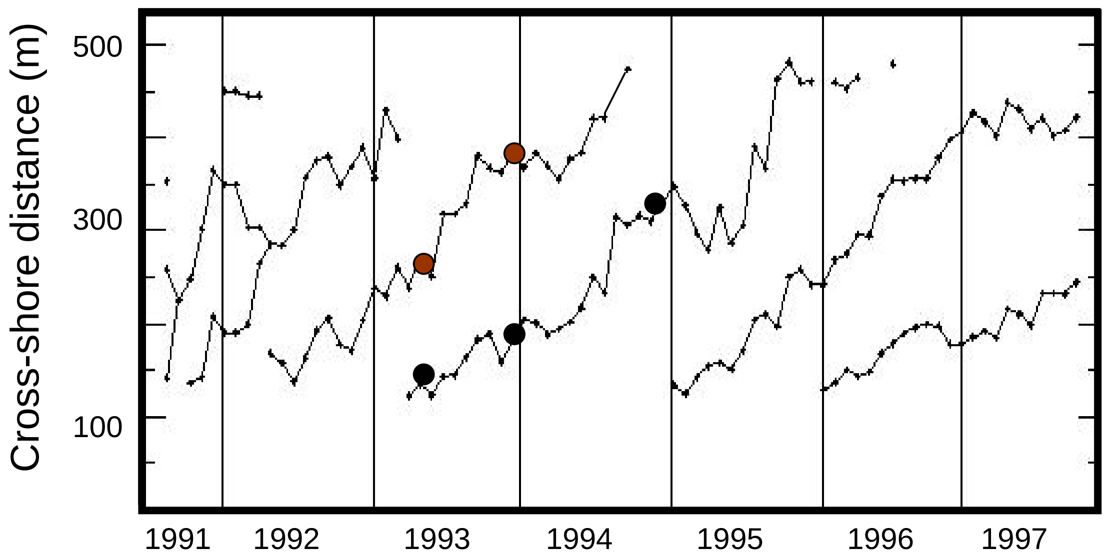

Figure 5 Time-series of sub-tidal bar-crest locations for a 300 m wide transect centered 1550 m (from the rivermouth) during the period August 1991 to November 1997. The five dots locate the bar-crests depicted in the set of three time-lapse photos shown in Figure 4.

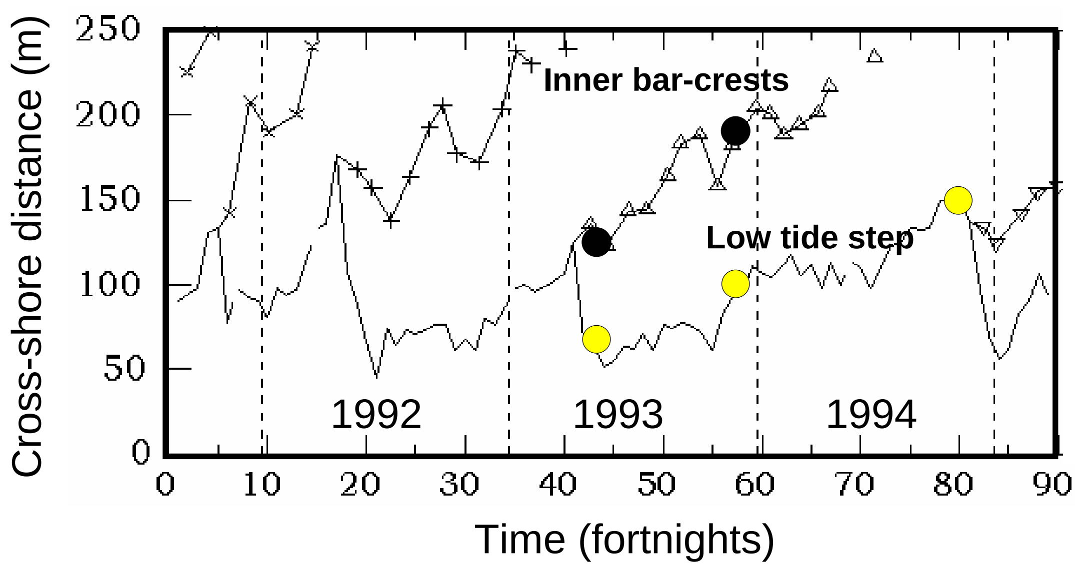

Figure 6 Time-series of low tide step and inner bar-crests for 300 m wide transect centered 1550 m during the period August 1991 to March 1995. The five dots locate the step and bar-crests as depicted in the set of time-lapse photos shown in Figure 4.

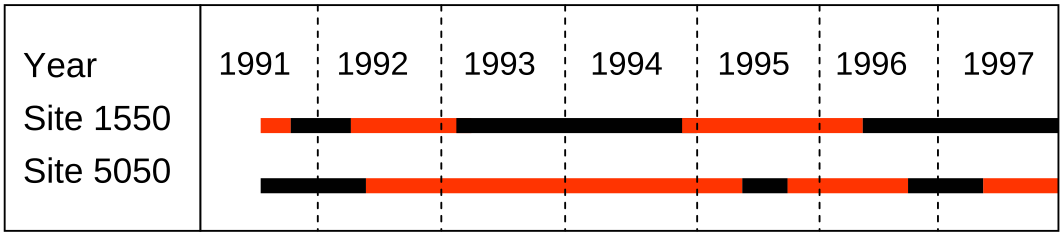

Figure 7 Bar generation periods for transects at 1550 m and 5050 m from the rivermouth.

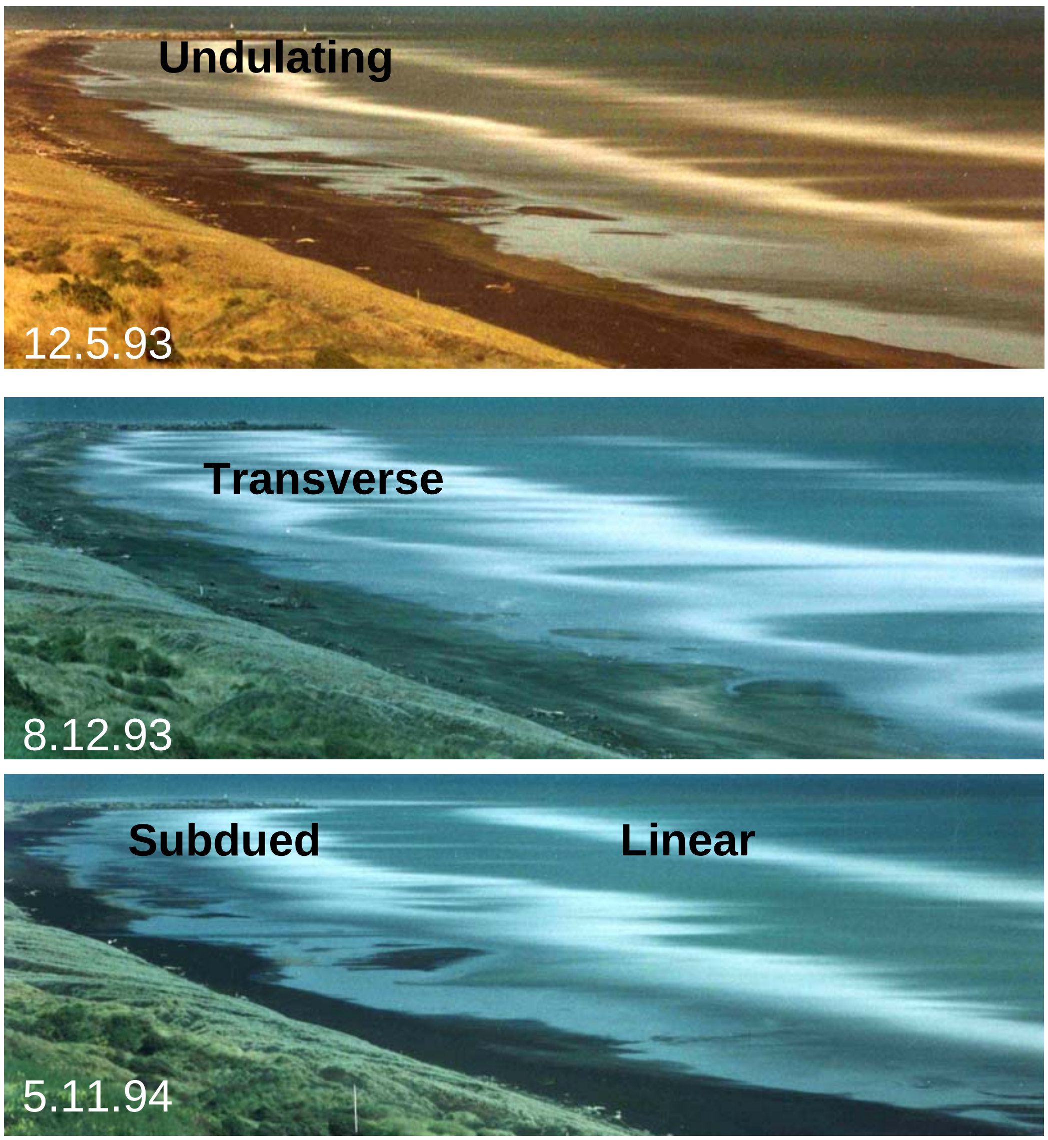

Figure 8
Examples of sections of coast exhibiting the four configuration classes used in this study. The three time-lapse photographs are the same as those used to illustrate NOM in Fig 4.

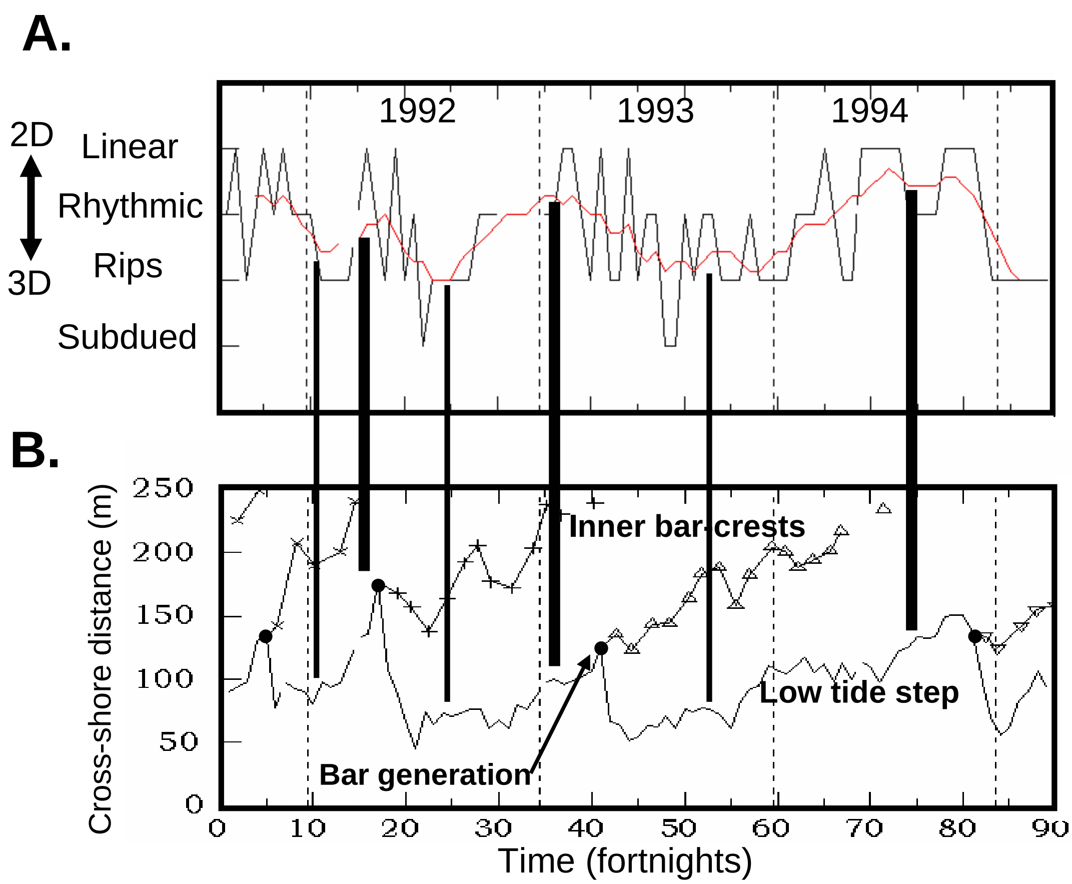

Figure 9 Time-series for configuration classes (A) and corresponding low tide step and inner bar-crest distances (B) for site 1550. The smooth line is A denotes the filtered dimensionality (see text). The vertical lines linking A and B, illustrate the nature of the correlation between configuration dimension and beach width, with the bold lines corresponding to lower dimensions and the thin lines corresponding to higher dimensions.

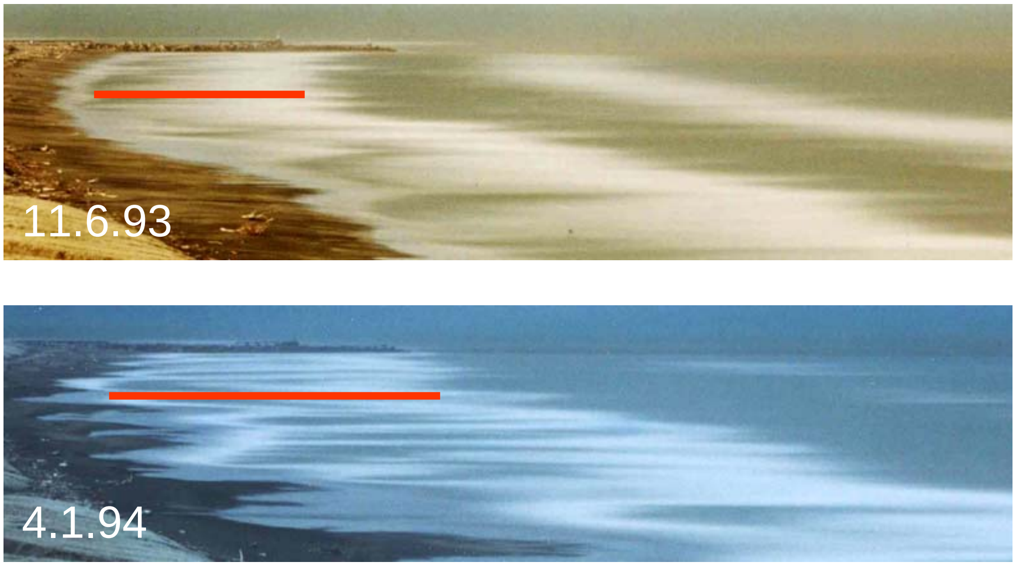

Figure 10 Examples of changing cross-shore length of rips during the ripped-phase of the same inter-generation cycle spanned by the time-lapse series in Figs 4 and 8.

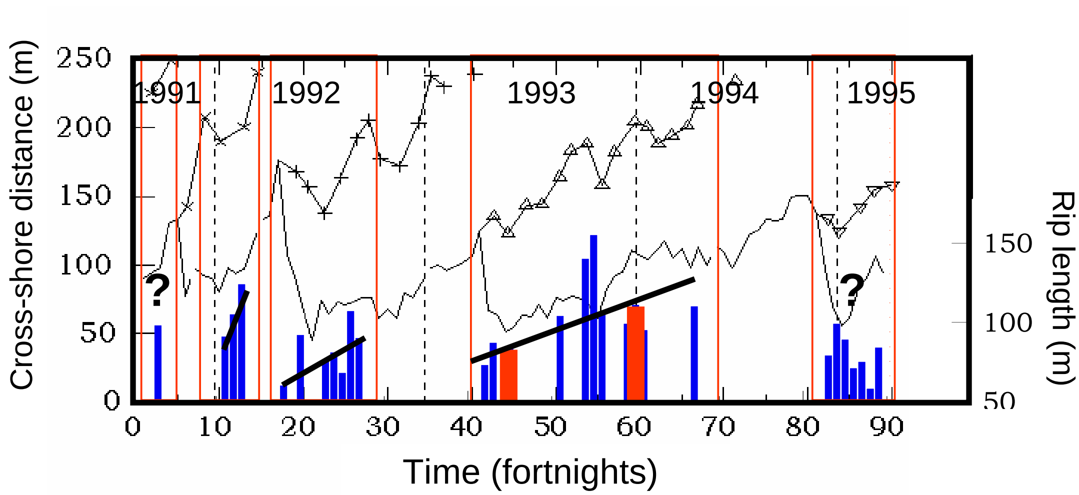

Figure 11 Time-series of rip-length for site 1550 during the period August 1992 to March 1995. The shaded areas define rip-phases and fitted linear models define the underlying change in length during each phase. There are not enough data-points in both the initial and final rip-phases to identify a trend. The two bold bars are those depicted in Fig 10.

Table 1 Physical environmental conditions on NOM coasts

Parameter	Mean	Minimum - maximum
Width (m) of sub-tidal bar zone	550	120 - 1075
Slope of nearshore	1:140 0.007	1:90 – 1:260 0.011-0.004
Bar number in cross-shore direction	2.5	2-4
Bar volume (m^3) prior to degeneration	302	10-575

Table 2 Energy condition on NOM coasts

Parameter	Mean	Minimum-maximum
H_{sig} (m) (daily average)	1.28	1.1-1.37
$H_{0.01}$(m) (extreme storm)	3.9	3.1-4.4
Wave-based seasons	2	1-4
T_{sig} (s)	7.6	6.3-11.4
Wind speed$_{0.1}$ (m/s)	13.5	12.3-14.8
Wind approach from shoreline (deg)	47	17-82
Spring tide range (m)	1.9	1.2-2.5

Hsig = mean daily significant wave height, where ‘significant’ refers to the mean of the upper 1/3 of values; $H_{0.001}$ = 1% exceedence wave height value; Tsig = mean daily significant wave period.