ASSOCIATIONS BETWEEN NET OFFSHORE BAR MIGRATION AND BACKSHORE EROSION

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Abstract: This paper investigates the relationship between wave-induced backshore erosion and the cycle of net offshore bar migration (NOM) using a 3.4 yr morphological data-set collected at Wanganui, New Zealand. Four episodes of *laterally extensive* erosion, and 3 episodes of *localised* erosion were identified. Each type of erosion was associated with different aspects of NOM. Laterally extensive episodes coincide with higher levels of outer bar degeneration, a single subtidal bar and 2D (longshore bar/trough) or weak 3D (arrhythmic bar/trough) inner bar configurations; these configurations occur later in the inter-generation period. By contrast, isolated episodes coincide with lower levels of outer bar degeneration, double submarine bars and 3D (transverse bar/rip) inner bar configurations; these configurations occur earlier in the inter-generation period. Mechanisms explaining these associations are discussed, together with implications for coastal research and management.

Keywords: Backshore erosion, net offshore bar migration, NOM, surf zone, bar generation, bar degeneration, inner bar configurations, Wanganui, New Zealand

INTRODUCTION

Wave-induced erosion of the upper (subtidal) beach may extend into the backshore and adjacent foredune. This type of morphological behaviour has relevance for coastal management in terms of, for example, dune instability or property loss.

Net offshore bar migration (NOM) describes the systematic seaward migration of coastal sand-bars across a multi-bar surf zone. Such subtidal bars form within the inner surf zone and disappear several years later in the outer surf zone. Since the mid 1980s, NOM has been recognised on the North Carolina coast, the Dutch coasts, at Hasaki, Japan and at Wanganui, New Zealand. These oceanic coasts are characterised by moderate wave energy at predominantly sea wave frequencies.

Recently, Guillen et al. (1999) identified alternating periods of accretion and erosion affecting the foredune-toe along the coast of Holland, which correlate with the recurrence frequency of the offshore bar migration cycle. The purpose of the present paper is to identify the nature of backshore erosion at Wanganui, New Zealand, and to determine its relationship with the NOM cycle. Only erosion in which the escarpment was at least 1 m high is considered, as less severe cut was observed to recover and stabilize relatively quickly. The timing and nature of episodes of erosion will be related to a range of systematic morphological behaviours associated with the NOM cycle including degeneration of the outermost bar, number of subtidal bars in the cross-shore direction, and morphological (plan-view) configuration of the inner bar. The analysis utilises a 3.4 yr record of morphological data sampled at 2-4 weekly intervals. Before detailing the data acquisition techniques, the environmental conditions at the Wanganui study site will be described.

FIELD SITE

The field site is ~1.5 km from the Wanganui Rivermouth on the southwestern coast of the New Zealand North Island (Fig 1). The nearshore is characterised by fine sand (2 to 3 phi), has a cross-shore slope of ~0.0092 and width of ~530 m. Two subtidal sand-bars are usually

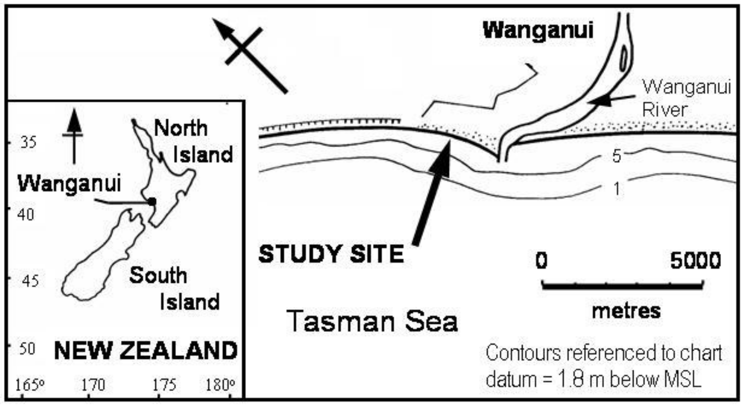


Figure 1 Location map of the Wanganui study site

present; these bars undergo net offshore migration with the mean life-cycle of a bar being ~3 yrs (Shand et al., 1999). The foreshore is characterised by medium sand (1.7 phi), has an average cross-shore slope of ~0.055 and an average width of ~85 m. About 30% of the time a small amplitude (swash) bar is present on the lower foreshore. Morphological plan-view configurations of the inner bar and lower beach are described later in the results section. The foredune is characterised by fine sand (2.2 phi), is ~5 m high, has a seaward slope of ~10^0 and the vegetation-front is encroaching seaward at ~1 m/yr. The backshore area, i.e. that area between the foreshore and the foredune, is ~10 m wide.

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 wave period is 10.1 s (range 3.5 s to19 s) with sea wave conditions occurring for ~75% of the time and swell waves for the remaining time. Approximately forty two percent 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 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.

MORPHOLOGICAL DATA

Episodes of backshore erosion were identified on morphological maps which cover several hundred metres of coast; examples are shown in Fig 2. The maps were produced from high resolution ground surveys carried out at fortnightly intervals between August 1991 and March 1995. The fortnightly sampling detected all episodes of backshore erosion, as such erosion was only observed to occur under higher (spring) tidal range. Errors, based on 95% confidence intervals, are estimated to be 5 m in the cross-shore direction and 10 m in the longshore direction. To detect morphological variation, a 300 m long study area was used. The morphological maps were also used to determine the (average) cross-shore location for the low tide step; this location was used as a proxy for the seaward boundary of the foreshore. In addition, plan-view morphological configurations of the inner bar system were derived from the maps.

To identify cycles of NOM, the cross-shore position of sand-bars were defined by intensity maxima on a sequence of time-lapse (4 min exposure) photographs. These *time-exposure* photographs were taken at monthly intervals from on top of a 42 m high cliff located ~1600 m northwest of the study site. Examples of an instantaneous photo (1/125th sec), together with the corresponding time-exposure and rectified images, are depicted in Figs 3A-C.

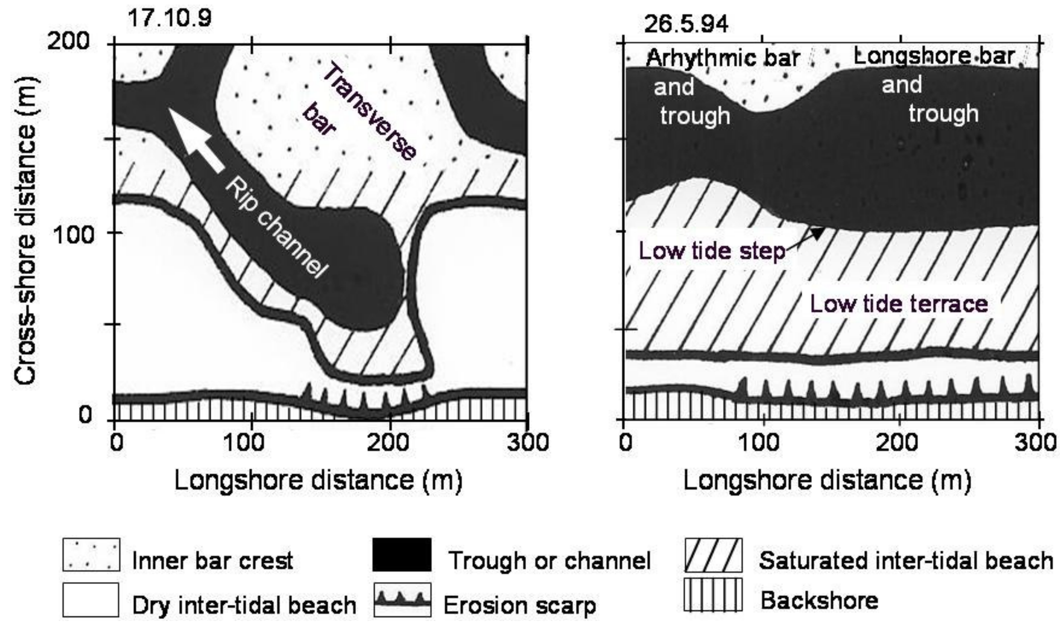


Figure 2 Examples of low tide morphological maps used to identify backshore erosion, the low tide step, and inner bar configuration.

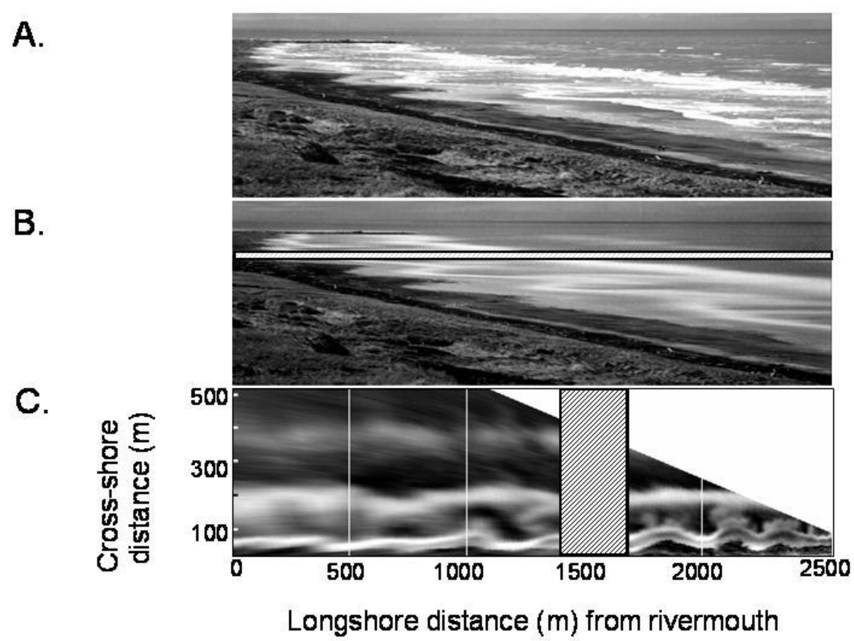


Figure 3 Examples of instantaneous (1/125th sec) photo (A), corresponding 4 min time-exposure photo (B), and rectified image with straightened coastline (C). Photo is the first in an 8 shot panorama. The 300 m wide study area is depicted by the shaded areas in B and C.

Intensity values were averaged over the 300 m long study area, and time-series of the cross-shore distances for each bar were then constructed and analysed. These techniques are described in Bailey and Shand (1996). Different levels of outer bar degeneration were determined from intensity patterns on rectified time-exposure images. Errors are estimated to be ~15 to 20 m in the cross-shore direction and ~75 m in the longshore direction. The somewhat large longshore value reflects the distance from the camera. It is acceptable for the present study, however, given the typical spatial similarity of surf zone morphology in any particular sample, together with the need to determine longer term systematic cross-shore bar migration rather than the analysis of inter-survey bar migrations.

RESULTS

Time-series for each subtidal sand-bar that existed during the study period are shown in Fig 4. While only bar 3 underwent a full NOM cycle during the 3.4 yr study, an underlying seaward migration trend still characterised the other 4 partially completed bar cycles. The merging of bars 2A and 2B early in the study is the result of bar switching, a morphological behaviour in which bars realign in the long-shore direction (see Shand et al., 2001; Shand, 2003). It is also noted that each new bar was generated after the seawardmost bar had disappeared. Bar generation was defined to occur at the time pronounced bar/trough relief first developed. The low tide step is also plotted in Fig 4, and these data show the inter-tidal beach abruptly narrows following generation of a subtidal bar, and then systematically widens until the next bar is generated. During the study period there were 4 instances of bar formation within the inner surf zone, and 4 cases of bar degeneration within the outer surf zone.

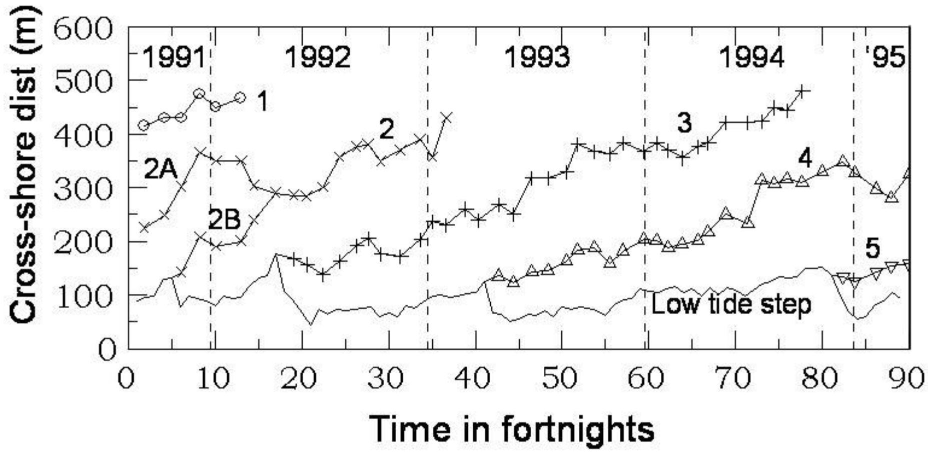


Figure 4 Cross-shore migration of subtidal bars (marked 1-5) during the study period. The low tide step between successive bar generations, is also shown.

Seven episodes of backshore erosion occurred during the study period, with scarp heights ranging up to 2 m. The timing and longshore length of each episode is depicted in Figs 5 – 7. In three instances, the eroded length extended beyond the 300 m long study area; in these cases, the total length was recorded. The longshore extent of the seven erosion episodes was bimodally distributed, with *laterally extensive* episodes having lengths of 300 to 650 m, and the more *localised* episodes having lengths between 100 and 160 m. The laterally extensive erosion also remained evident for longer with a mean value of 95 days compared with 38 days for localised episodes.

The changing degeneration status of each outer bar during its final months, are depicted in Fig 5. Outer bars were classified as being either *pronounced* or *subdued*. Pronounced bars occurred where a distinct trough was present to landward. By contrast, subdued bars lacked a distinct landward trough. This approach was used to separate relatively low and high levels of bar degeneration because it could be assessed from intensity patterns on the time-exposure images used in this study. The technique is described in Shand (2003). The results in Fig 5 show that laterally extensive episodes correspond with subdued outer bars, while localised erosion corresponds with pronounced outer bars, i.e. with higher and lower levels of outer bar degeneration respectively.

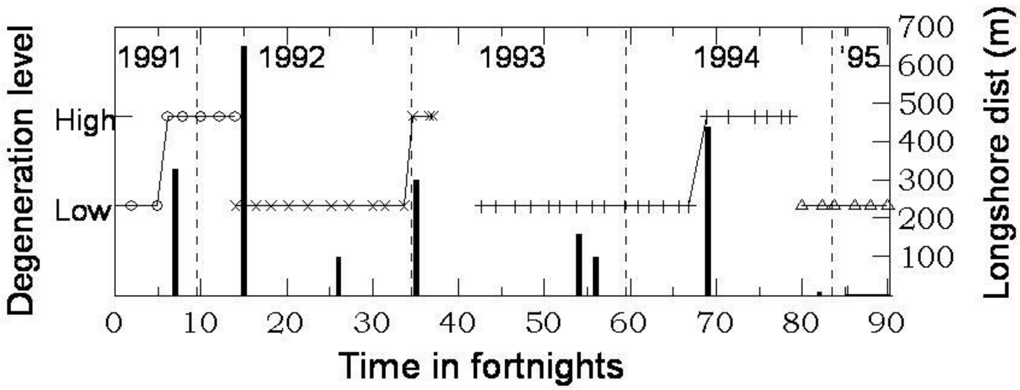


Figure 5 Relative level of outer bar degeneration, where *high* refers to a subdued profile and *low* to a pronounced profile (see text for further explanation). The overlain bar graph depicts the longshore extent of the 7 episodes of backshore erosion.

The number of bars in the cross-shore direction (bar number) are depicted in Fig 6. Only those outer bars with a low level of degeneration were included in the bar number calculation, as these bars are most likely to behave like more landward bars and, under storm conditions, significantly dissipate wave energy. The results show that two well developed subtidal bars occurred for 75% of the study period, while for the remaining 25% of the time only a single bar existed. Furthermore, double bars occurred during four separate periods, with the single bars occurring during the three intervening periods. When bar number was compared with the erosion episodes, all three cases of localised erosion corresponded with double bars, and three of the four laterally extensive episodes corresponded with single bars. While the remaining laterally extensive episode occurred with double bars, the landward bar was particularly small, having just been generated, and therefore relatively ineffective at dissipating incoming wave energy.

Morphological configurations for the innermost subtidal bar, are depicted in Fig 7. The assignment of configurations was based on the mutually exclusive classification scheme described in Shand et al. (2003). This method was developed to uniquely categorise the typically complex non-linear configurations which occur at Wanganui, into one of the following categories: linear bar and continuous trough; non-linear bar and continuous trough; non-linear bar and discontinuous trough; and subdued topography. The predominant type of morphology within each class was: *longshore bar and trough; arrhythmic bar and trough; transverse bar and rip; and wide low tide terrace* (extending to the inner bar) respectively. Examples of the first three types of morphology, together with an inter-tidal low tide terrace, are depicted in Fig 2.

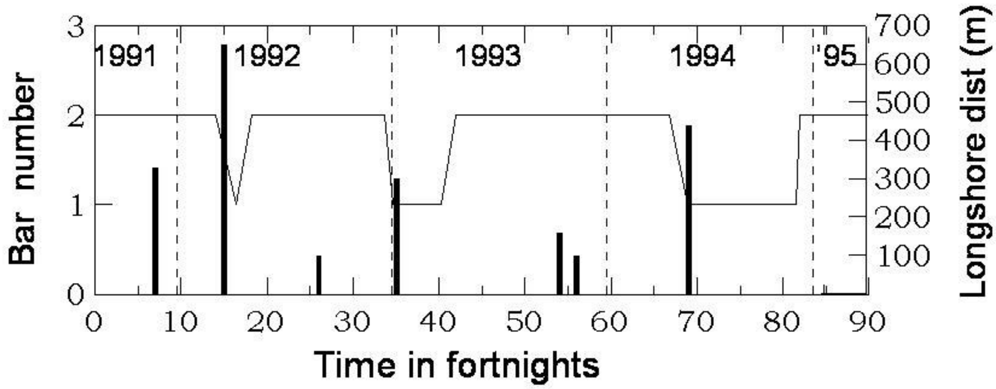
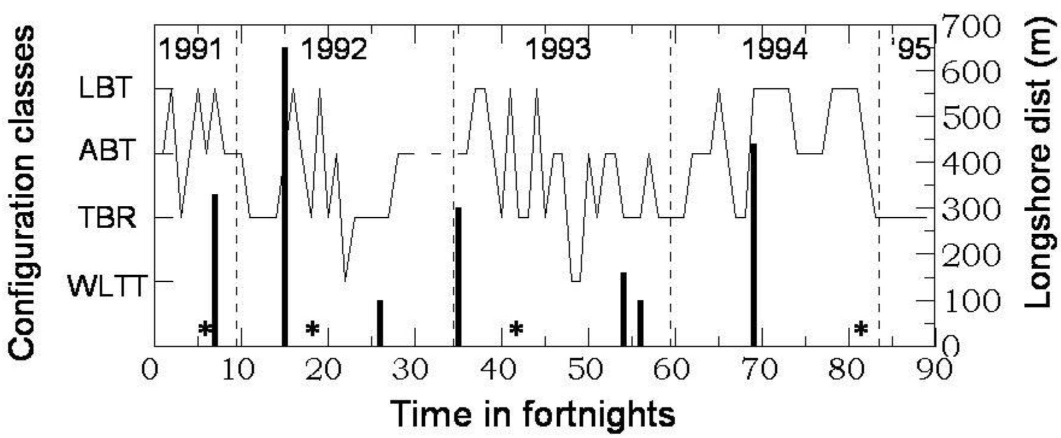


Figure 6 Number of sub-tidal bars in the cross-shore direction. Outer bars were only included where they had a *low level* of degeneration, as shown in Fig 5. The overlain bar graph depicts the longshore extent of the 7 episodes of backshore erosion.



LBT=longshore bar/trough ABT=arrhythmic bar/trough TBR=transverse bar/rip WLTT=wide low tide terrace

Figure 7 Inner bar configurations represented by the predominant types of morphology in each class (see text). Vertical bars depict the longshore extent of backshore erosion episodes. Asterisks denote times of bar generation.

While the fortnightly survey interval would necessarily not detect all successive configuration changes, an underlying systematic variation is evident. In particular, the configuration time-series depicted in Fig 7, shows the predominance of transverse/rip, together with arrhythmic morphologies during the early/mid inter-generation period. Low tide terraces also occurred during this time. Later in the inter-generation period, and in conjunction with beach widening, the predominant configuration changed to longshore bar/trough, together with arrhythmic morphologies. However, it is noteworthy that these more linear morphologies often occur, albeit briefly, when a new bar is generated.

A comparison of the timing of erosion episodes with inner bar configurations indicates that the laterally extensive episodes coincide with longshore bar/trough and arrhythmic configurations, which tend to occur later in the inter-generational period. By contrast, the localised episodes coincide with transverse bar/rip configurations, which occur earlier in the inter-generation period.

DISCUSSION

Laterally extensive episodes of backshore erosion coincide with a change in the cross-shore profile of the seawardmost bar from pronounced relief to subdued relief, and the number of subtidal bars reducing from two to one. With such morphology, a higher proportion of incident wave energy would reach the shoreline and be available for backshore erosion, as storm wave energy can be effectively dissipated when breaking occurs over an outer bar, e.g. see Keady and Coleman (1980). By contrast, at times of higher bar number and more pronounced relief, a lower portion of incident wave energy would reach the shoreline, thereby resulting in less extensive erosion. Energy conditions associated with different types of backshore and upper beach erosion are considered in a separate paper (Shand et al, in prep).

Systematic variation of configurations within the inner bar system, appears to influence the nature of backshore erosion in the following manner. Strongly 3D inner bar morphologies (transverse bar and rip) result in varying beach width in the longshore direction. This limits areas likely to undergo backshore wave attack to the rip-associated embayments, and this situation would facilitate the occurrence of episodes of localised erosion. By contrast, 2D configurations (longshore bar/trough) and weakly 3D morphologies (arrhythmic bar/trough) result in more uniform beach width, and this would facilitate the occurrence of more widespread backshore erosion. Such laterally extensive erosion appears to be consistent with *mode 2* beach cut as described by Wright (1980), while localised erosion is consistent with *mode 3* beach cut.

While both laterally extensive and localised types of backshore erosion correlate with several (contrasting) aspects of the NOM cycle, the regular erosion episodes observed along the coast of Holland (Guillen et al., 1999) are probably laterally extensive for the following reasons. Laterally extensive episodes at Wanganui occurred during each of the three inter-generation periods, while localised episodes occurred during only two inter-generation periods. In addition, laterally extensive erosion episodes had greater longshore extent and were more persistent than localised episodes.

NOM-associated backshore erosion has several implications for coastal management. Firstly, wave-induced foredune scarping is a major cause of dune instability, i.e. blowout and subsequent parabolic development (e.g. see Carter et al., 1990). Such processes have been observed at Wanganui. However, the quasi-regular nature of NOM-induced dune erosion could enable management authorities to broadly predict these events and have resources available to enable re-contouring and planting.

NOM-associated backshore erosion also has significance in identifying shoreline change, as used in, for example, the delineation of Coastal Hazard Zones. This is because commonly used coastal reference features such as the foredune-toe, the dune vegetation front, the debris line or the saturation zone boundary, are likely to systematically fluctuate in their cross-shore locations. Such variation, however, can be minimised by averaging over greater longshore reaches when calculating cross-shore distances to the shoreline indicator.

CONCLUSION

Four episodes of laterally extensive backshore erosion occurred during the 3.4 yr study period. Their longshore distances ranged between 330 and 640 m, scarp height between 1 and 2 m, and persistence between 7 and 280 days. Three episodes of localised erosion occurred, with longshore distance ranging between 100 and 160 m, scarp height between 1 and 2 m, and persistence between 7 and 42 days. Each type of erosion coincided with different aspects of the NOM cycle. Laterally extensive episodes coincided with higher levels of outer bar degeneration, a single subtidal bar, and either the 2D (longshore bar/trough) or weakly 3D (arrhythmic bar/trough) inner bar configurations which tend to occur later in the inter-generational period. With such morphology, greater amounts of storm wave energy can reach the backshore and erode a considerable longshore reach. By contrast, localised episodes coincide with lower levels of outer bar degeneration, double subtidal bars and strongly 3D (transverse bar and rip) inner bar configurations which tend to occur earlier in the inter-generational period. With this type of morphology, backshore erosion will be confined to the embayments of well-developed rip channels, thereby limiting the lateral extent of such erosion. NOM-associated backshore erosion is likely to result in quasi-regular periods of dune instablility, and also in systematic variation in the location of coastal reference features used to determine shoreline change.

ACKNOWLEDGEMENTS

This study was supported by a Research Fellowship (contract MAUX0104) from the New Zealand Foundation for Science and Technology (FRST).

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