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Ridge and Runnel Beach Morphodynamics: An Example from the Central East Coast of Ireland

Monica E. Mulrennan

Department of Geography
University College Dublin
Dublin, Ireland

ABSTRACT

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Variations in the morphodynamic response of a ridge and runnel beach system, on the central east coast of Ireland, were measured over twelve months. The ridge and runnel system complies with the general criteria of 'true' ridge and runnel forms, as defined by KING and WILLIAMS (1949), in that it occurs under conditions of limited fetch, low beach gradient, large tidal range and medium to fine sediment size. The ridges represent semi-permanent mid- to low-energy equilibrium forms which are destroyed under high energy conditions. Relatively minor changes in the morphological expression of the ridge and runnel beach were superimposed upon large scale volumetric changes to the beach. The beach surface aggraded during a year characterised by a significantly higher incidence of storm conditions than average. This response is largely dependent on the availability of sediment and the prevailing wind direction. The changes in the morphology of the ridges and runnels were also controlled by the mesotidal conditions which operate along the study area but showed no relation to spring/neap tidal movements. The findings suggest that definitions of 'ridge and runnel' may have been too rigorous with regard to conditions of permanency, mobility and sediment availability.

ADDITIONAL INDEX WORDS: *Morphodynamic response, equilibrium swash bars, ebb-tidal delta.*

INTRODUCTION

The terminology 'ridge and runnel' is applied here *sensu stricto* to describe the morphological highs and intervening lows across the intertidal zone of certain low-gradient sandy foreshores (KING and WILLIAMS, 1949). The development of this type of beach morphology is limited geographically due to its association with very specific conditions of fetch (and hence wave spectra), beach slope, tidal range and sediment size. The importance of fetch lies in the average wavelength experienced on the beach. Under limited fetch conditions the predominant waves are short and tend to build a steeper swash slope (*i.e.* a ridge) than long waves. Mean beach slope is important as the response of a low beach slope to these short waves is manifest in the creation of swash bars (ridges) which represent an attempt to form an equilibrium gradient on a beach which is naturally much less steep. This process of gradient adjustment takes place between high and low tide. The development of a series of ridges across the intertidal zone is, therefore, dependent upon the width of tidal translation zone which is in turn controlled by the combination of a low beach slope and high tidal range conditions. The significance of sediment size is closely related to beach gradient so that the development of ridge and runnel topography is invariably limited to the flat dissipative slopes of sandy beaches.

The purpose of this paper is twofold: (1) to describe the short-term (one year) morphodynamics of a ridge and runnel system along the central east coast of Ireland; and (2) to compare the findings of this study with the results of previous work on ridges and runnels in order to clarify the range of conditions and controls under which they develop.

STUDY AREA

The Portmarnock barrier is the southernmost of a series of Holocene barrier-beach complexes found on the east coast of North County Dublin, Ireland. It extends in a south-easterly direction from a Carboniferous limestone headland to the Baldoyle Estuary at its distal or southern end (Figure 1). Extensive progradation of beach ridges has occurred around the southern end of the barrier over the last two hundred years. This has resulted from a redistribution of sediments within

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Present address: Australian National University, North Australia Research Unit, P.O. Box 41321, Casuarina, NT 0811 (Australia).

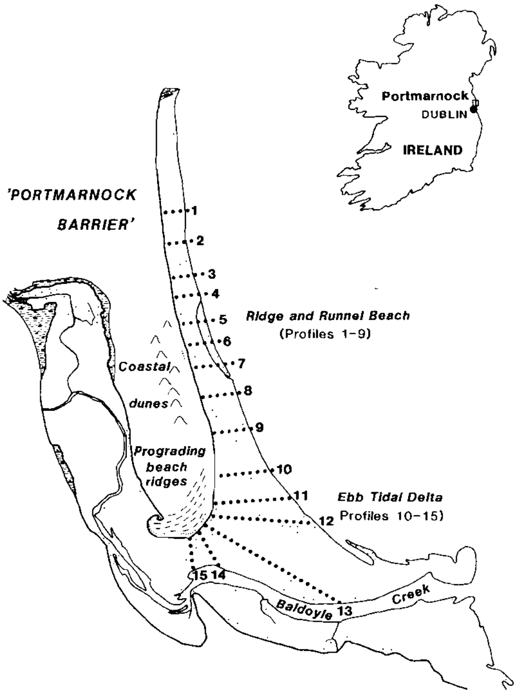

Figure 1. Location of the study area at Portmarnock Barrier, North County Dublin, showing beach survey plan along the ridge and runnel system and ebb-tidal delta of the intertidal zone.

the estuary/barrier/ebb-tidal delta system. Subsequent feedback effects from this have resulted in a diminution in the offshore sediment supply to the northern end of the beach, thereby inhibiting beach recovery after storm events and initiating long-term beach erosion (MULRENNAN, 1990).

The beach at Portmarnock is 3.6 km in length and varies in width from 240 m at its northern end to almost 1 km across the ebb-tidal delta to the south. The intertidal ridge and runnel system is the most prominent feature of the beach and is aligned parallel or sub-parallel to the shore (Figure 1). The ridges, usually three or four in number, are asymmetrical in cross-section with the steeper slope facing landward and increase in size towards the low-tide level. In general, the ridges are more than 1.25 m in height, with wavelengths of 40 to 110 m and ridge face gradients of 0.04. They are laterally continuous for several 100's of metres except where they have been broken through by cross-beach channels. The ridge and runnel system merges with an ebb-tidal delta at the distal end of the barrier where the ridges trend away from the coastline. The delta is a lobate sediment accumulation (1.98×10^6 m^2), deposited seaward of the Baldoyle Inlet, by ebb-tidal currents and local wave energy which in the absence of regional longshore drift are intimately connected.

The coastline experiences moderate wave conditions as a result of the restricted fetch (less than 200 km) of the Irish Sea. The most common wave condition recorded at the Kish Bank Light Vessel (10 km offshore) over a twelve month period (Nov 1968–Oct 1969) had a wave height of just under 0.65 m, a wave period of 4.0 sec and a wave steepness value of 1:15 (MARTIN, 1971; M.I.A.S., 1986). This condition prevailed for 89% of the time. Wave heights were generally highest in the winter months and a maximum deep water wave height of 10 m was recorded. The significant wave height exceeded 2 m for 19% of the time then, but did so for only 4% of the time during the summer, 6% during the spring and 9% of the time during the autumn. There was little seasonal variation in the wave period, although shorter period waves (3–4 sec) were more common in summer than in winter. The longest wave period of 18.5–19.0 sec was recorded during the spring, but the wave periods were usually less than 8.0 sec. Tides are semi-diurnal with a mean spring range of 3.9 m, although the coincidence of a storm surge coupled to a high spring tide may add as much as 2 m to predicted tidal values (CARTER, 1983).

METHODS

In order to describe the changing shape of the beach, fifteen levelled profiles normal to the coast were selected for survey (Figure 1). Profiles 1 to 9 were located along the ridge and runnel beach and profiles 10 to 15 were across the ebb-tidal delta. The exact location of the profiles was determined on the basis of sites which were representative of the perceived morphological variation of the beach.

The height of the beach was levelled (relative to Irish O.D.) at 10 m intervals along each profile. The upper limit or landward "closeout" was delimited by the driftline of the highest spring tide, while the position of the seaward "closeout" was dictated by tidal conditions. The beach profiles were surveyed on a monthly basis between September 1985 and September 1986 as determined by the coincidence of daylight hours and low tidal conditions.

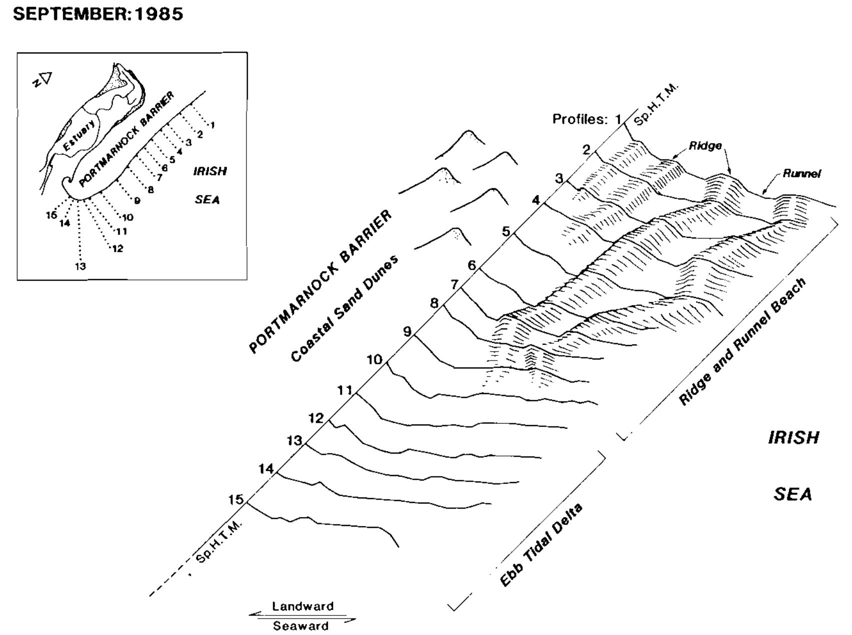

Figure 2. Alongshore variations in the height of the 15 beach profiles as measured in September, 1985. (Inset shows location of profiles relative to Figure 1.)

Each beach profile was plotted to show changes in morphological shape over both space and time. Alongshore and up-beach variations in the fifteen profiles were plotted for each of the twelve monthly surveys. The beach profiles for September 1985 are shown in Figure 2. Changes to the beach profiles over time were illustrated by superimposing each of the fifteen profiles with the corresponding profile for the twelve monthly surveys. Temporal variations to Profile 1, the most northerly profile, are shown in Figure 3. A curve joining the lowest and highest points of the profiles indicated the level below and above which the foreshore did not extend (*i.e.* the sweep zone). Changes in beach dimensions over space and time were determined by comparison of one profile with another and provided an index to the assessment of patterns of beach changes.

Foreshore gradient is given as the vertical interval divided by the ground distance (*i.e.* the *sine* of the slope). Ridge gradient was calculated as the vertical over the horizontal interval of the steepest 10 m section of the seaward ridge face. Ridge height was calculated as the vertical interval between the crest of the ridge and the lowest point of the runnel seaward of the ridge, while the ridge wavelength was determined by measuring the horizontal distance between two parallel ridge crests.

The beach profile data were also analysed graphically using digital terrain modelling which created a continuous surface of beach height values at a selected contour interval of 0.5 m (range of 4.0–8.5 m). This surface consists of a regular distribution of points, the heights of which were interpolated from the surveyed beach data set and provides a useful representation of both spatial and temporal variations in the height of the foreshore. A schematic plan of the beach is included in Figure 4 to show the relative position and orientation of the terrain model.

Sediment sampling coincided with the beach profile surveys of September, December, February, April and August. Samples were collected from the backshore, high-tide, mid-tide and low-tide position of each profile so that both spatial (alongshore and up-beach) and temporal variations in grain size properties were examined. Particle size analysis was carried out in accordance with standard laboratory procedures (British Standards Institution, 1975: BS 1377, Test 7(B)).

The emphasis of this study was on morpholog-

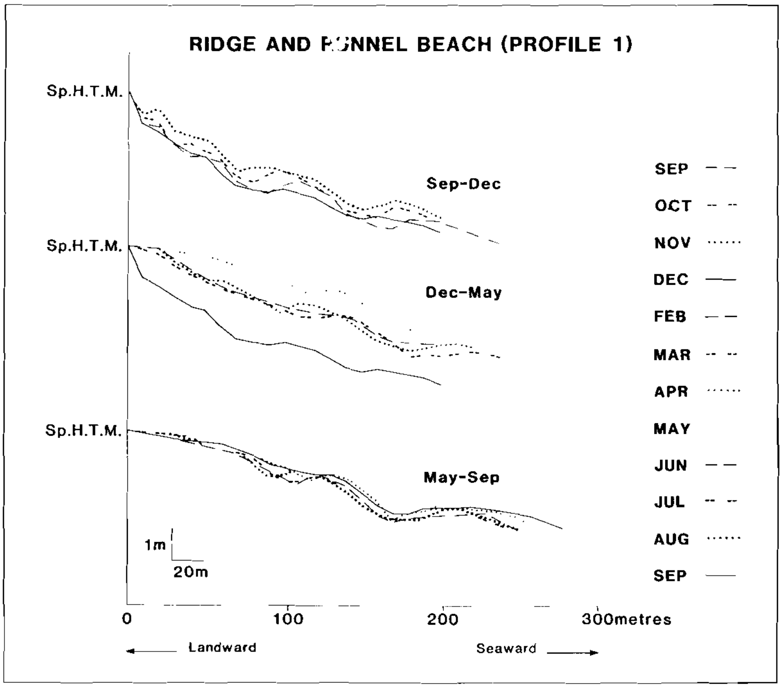

Figure 3. Temporal variations between September 1985 and September 1986 in the height of Profile 1 across the ridge and runnel beach.

ical and sedimentological measurements rather than process monitoring. Local process conditions (wave, wind and tidal) were derived from secondary data sources (wave records, seastate observations, wind based surrogates, tide tables, *etc.*) and are summarised below.

RESULTS

The morphodynamic response of the ridge and runnel system is described in terms of spatial and temporal variations in: (i) the two-dimensional response of the beach surface (*i.e.* gradient adjustments and changes in the dimensions and positions of the ridges); and (ii) three-dimensional volumetric changes to the beach (*i.e.* sweep zone dimensions). This distinction is useful and valid because the behaviour of the ridge forms displayed almost total independence of volumetric changes to the beach.

The sedimentary and process dynamics of the foreshore are also described and an attempt is made in the final subsection to relate the spatial and temporal variations in the morphodynamic and sedimentological response of the foreshore to the processes which prevailed over the study period.

Morphological Response

The mean gradient of the ridge and runnel beach was 0.015 but each profile exhibited a wide range and variety of slopes (0.010–0.024 on Profile 1). In general, it was possible to recognise 2 to 3 ridges along each of Profiles 1 to 9. An inner ridge was sometimes present near the neap tide HWM during the late autumn and early winter months. This ridge was small and ephemeral, with a steep ridge face (0.07) frequently merging with a prograding backshore berm. The low-tide ridge, in contrast, was extremely stable in form with a flat ridge face of 0.02 and a wavelength of over 90 m. Ridge development was greatest at the mid-tide position (100–150 m seaward of Spring HWM). In general, these ridges were greater than 1.27 m in height, with a ridge face gradient of 0.04 and a wavelength of 60 m.

The foreshore had a mean overall gradient of 0.013 but profile gradients decreased alongshore from a maximum of 0.016 on Profile 1 to a min-

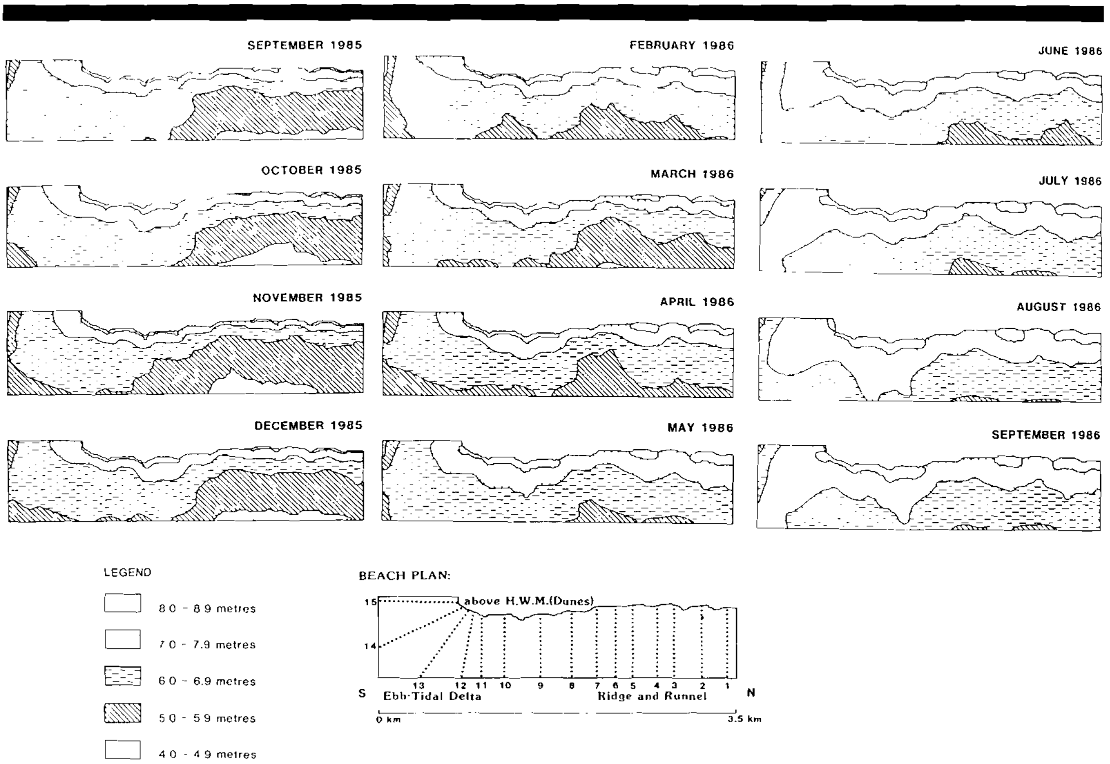

Figure 4. Digital terrain models showing spatial and temporal variations in the height of the Portmarnock beach (metres, Irish O.D.). (Insets show legend and schematic beach plan relative to Figure 1.)

imum of 0.007 on Profile 13. Similarly, a distinct alongshore variation was displayed in terms of ridge gradient, height and amplitude so that the ridge and runnel system merged imperceptibly with the ebb delta between Profiles 9 and 10. The morphodynamics of the ebb-tidal delta are not described here but the contrast between the ridge and runnel and the ebb delta system was clearly reflected in the low gradients across the delta.

The ridge and runnel system also displayed marked variations over time (Table 2, Figure 3). The beach surveys from September to November were characterised by well-developed ridge sets which maintained a coherent form and were associated with only minor oscillations in gradient and form as a result of ridge migration. Ridge migration rates were of the order of 10 m per month and migration was generally landwards. A reduction in the dimensions and number of ridge forms was observed in December and was followed by a combing down of the ridges in February. This period was associated with a marked gradient change from 0.016 to 0.013. The initial stages of ridge recovery and re-establishment were detected during both the March and April surveys and the development of these ridges continued throughout the late spring and summer months. Ridge migration occurred at a rate of 0.5 m per month and mean gradients of less than 0.010 were characteristic at this time.

This pattern is very clearly illustrated in Figure 3 which shows the temporal variations to Profile 1 over the twelve month survey period. In general, the ridges preserved their form well as they migrated slowly landwards. However, two major shifts offset this pattern so that an abrupt change in the morphological expression of the ridge and runnel system occurred between December 1985 and February 1986 and between April and May 1986.

Volumetric Response

Changes in the level of the ridge and runnel beach (*i.e.* sweep zone) over the year were in the order of 1.8 m, reaching a maximum of 2.97 m on Profile 4 and were nowhere less than 1.3 m sea-

Table 1. *Temporal variations in foreshore response (profiles 1-15 from September 1985 to September 1986).*

Survey Period	Mean Gradient		Vol. Change (m^3 day^{-1})	
	R&R	Delta	R&R	Delta
September	0.018	0.008	—	
October	0.017	0.011	+3,213	+584
November	0.017	0.011	−721	−1,558
December	0.020	0.011	7,867	−3
February	0.015	0.010	+9,172	−8
March	0.014	0.010	−4,363	+1,050
April	0.014	0.011	+2,658	+71
May	0.012	0.010	+7,101	+2,755
June	0.012	0.009	−745	+415
July	0.011	0.009	+958	+710
August	0.012	0.009	+1,130	+1,069
September	0.011	0.009	+1,090	−1,622
Mean Annual	0.014	0.009	+1,057	+314

Table 2. *Spatial variations alongshore (profiles 1-9 = ridge and runnel; profiles 10-15 = ebb-tidal delta).*

Profile Nos.	Foreshore Gradient			Sweep Zone (1 yr)	
	Min	Mean	Max	m	Net m m^{-1}
01	0.010	0.016	0.024	2.60	+0.170
02	0.011	0.016	0.013	2.43	+0.160
03	0.011	0.016	0.023	2.29	+0.130
04	0.010	0.015	0.021	2.97	+0.140
05	0.011	0.014	0.019	2.60	+0.170
06	0.011	0.015	0.020	2.43	+0.130
07	0.010	0.013	0.017	1.42	+0.120
08	0.010	0.013	0.017	1.60	+0.140
09	0.009	0.013	0.016	1.20	+0.060
10	0.009	0.011	0.014	0.90	+0.050
11	0.007	0.009	0.011	0.73	+0.020
12	0.006	0.008	0.010	0.88	+0.050
13	0.005	0.007	0.009	1.47	+0.090
14	0.007	0.010	0.012	1.71	+0.070
15	0.012	0.013	0.015	1.56	+0.060

ward of the neap tide HWM. These changes are significantly greater than those recorded in most other studies of ridge and runnel systems (see discussion). Maximum vertical change occurred at the mid-tide position and the largest sweep zones were characteristic of the more northern profiles of the beach. Above the mean HWM of neap tides, changes were small, although values of 0.35 m were not uncommon. The beach surveys monitored the gradual progradation of the backshore berm which was reflected in vertical and gradient changes to the backshore environment. In contrast, the ebb-tidal delta (Profiles 10–15) displayed a marked stability over time. There, vertical changes were in the order of 0.32 m and were more the result of seasonal stages in incipient dune development than a significant net change in the vertical expression of the delta.

There were two periods of abrupt change. A vertical rise of 1.86 m was recorded in the level of the ridge and runnel beach between December and February and a second period of aggradation (1.28 m) occurred along this part of the foreshore (Profiles 1–9) prior to the May survey. The pattern and extent of these changes is illustrated by the sweep zone dimensions of Profile 1 (Figure 3).

Comparison between the monthly digital terrain models illustrates the very substantial net aggradation in the level of the beach over the year (Figure 4). The proportion of the foreshore higher than 7.0 m increased from 15.34% in September 1985 and 21.13% in February 1986 to 49.43% in September 1986. Similarly, the proportion of the foreshore lower than 6.0 m decreased from 34.91% in September 1985 and 20.10% in February 1986 to 2.83% in September 1986.

Estimates of volumetric changes to the beach were derived from the vertical changes measured along the profiles. An estimated net sediment increment of 756,435 m^3 over an area of 972 m^2 (1,455 m^3 day^{-1}) occurred across the intertidal zone over the twelve months; 80% of this net aggradation was concentrated along the ridge and runnel beach (601,700 m^3 over an area of 677 m^2), while a net addition of only 154,730 m^3 (area of 302 m^2) accumulated on the ebb-tidal delta, accounting for only 20% of the annual net change to the volume of the beach (Table 1, Figure 2). Contrasts were also apparent in the direction of volumetric changes with periods of net erosion across the delta coincident with phases of net deposition along the ridge and runnel beach, and vice versa. For example, the major aggradation phase in February, estimated to have raised the level of the ridge and runnel beach by more than 1.8 m between December and February, was paralleled by a minor net lowering of the ebb-tidal delta.

These disparities are clearly illustrated by the monthly terrain models (Figure 4). While both the ridge and runnel system and the ebb-tidal delta accreted over the year, the relative height of the delta gradually decreased so that after December 1985 it becomes increasingly difficult to distinguish the ridge and runnel system from the delta solely in terms of their respective elevations. The delta was exceptionally stable, ranging in height from 5.5–8.4 m between September 1985 and September 1986. However, the ridge and runnel beach was more than 2.0 m lower in elevation than the delta between September and December 1985 compared to a difference of only 0.5 m from June to September 1986.

The morphodynamic response of the ridge and runnel beach, as outlined above, was manifest in the development and destruction of ridge forms superimposed upon a net aggradation of the beach surface. The observations of this study did not show a direct relationship between ridge development and variations in beach volume or gradient. The relationship between the beach surface (*i.e.* ridge development) and beach volume is more analogous to a corrugated or rubber sheet acting independently of changes to its substratum. For example, ridge and runnel development throughout the months of September to November (autumn) 1985 was paralleled by a significant net loss of sediment and a consequent lowering of beach gradient, while the persistence of distinct ridge forms throughout the summer months of 1986 occurred under conditions of net sediment deposition. Similarly, the absence of ridge formation in February 1986 was not simply a response to a specific beach gradient requirement (KING and WILLIAMS, 1949; WRIGHT, 1976) since the development of ridges was associated with both a steeper beach gradient in the autumn of 1985 and a significantly flatter beach gradient throughout the summer of 1986. This suggests that short-term changes to the volume of the beach, inducing changes in beach gradient, did not exceed the critical beach slope requirements for ridge and runnel development (HALE and McCANN, 1982).

Sediment Dynamics

The sedimentary properties of the ridge and runnel beach did not exhibit any significant alongshore variation but were significantly different from those of the ebb-tidal delta at the southern end of the foreshore. The backshore zone emerged as a distinct morpho-sedimentary environment, characterised by significantly finer, better sorted and more positively skewed properties than the foreshore sediments. The mid-tide sediments were generally the finest and best sorted of the wave-lain sediments as well as being clearly discriminated by their negatively skewed and leptokurtic size distributions.

The sedimentary properties of the Portmarnock beach deposits were found to relate to temporal variations more than the generally acknowledged spatial controls (FOLK and WARD, 1957; FRIEDMAN, 1961; GREENWOOD, 1969). The sediments collected in September 1985, December, 1985 and August 1986 were characterised by significantly finer and better sorted grain size properties and more positively skewed and leptokurtic distributions than those collected in February and April 1986.

Process Dynamics

The annual wind conditions for the period between September 1985 and September 1986 were characterised by higher wind speeds than average and associated with a higher percentage occurrence of winds from both a west-southwesterly (offshore) and north-easterly (onshore) direction (Table 3). Offshore winds of less than 10 knots generally prevailed throughout the autumn/early winter months of 1985. These winds persisted into early 1986 and were replaced by a strong shift to storm force onshore winds at the end of January. Strong onshore winds continued to dominate during the month of February and into March. The winds shifted to an offshore vector prior to the April survey and high wind velocities remained characteristic. These winds moderated significantly prior to the May survey and became more variable in direction. The winds over the summer months were generally offshore in direction and associated with wind speeds of less than 9 knots.

Seastate observations for the study period found that calm/slight conditions prevailed during the months of July to September; moderate seastates were typical from October to December, while the months of January to April were characterised by rough seas. Conditions gradually improved again over the spring and into the summer months (Table 3).

Process-Response

The behaviour of the ridge and runnel system at Portmarnock conformed closely to the basic model, proposed by KING and WILLIAMS (1949), relating ridge development to an equilibrium beach state which forms in response to normal wave energy conditions. Ridge forms were very well developed throughout the period from September to November 1985 when relatively low energy, normal wave conditions prevailed. However, storm events prior to February 1986 were of sufficient magnitude and duration to result in the suppression of ridge form, indicating that ridge development is a mid- to low-energy equilibrium form

Table 3. *Temporal variations in beach process and response.*

	Mean Vert. Change m m^{1}		Most Common Process Conditions		
Survey Period	R&R	Delta	Seastate	Vel. (knots)	Direction
Sep/Oct	+0.033	+0.007	moderate	07.8	SE (offsh)
Oct/Nov	−0.009	−0.014	moderate	08.6	W (offsh)
Nov/Dec	−0.044	+0.004	moderate	10.7	SW (offsh)
Dec/Feb	+0.103	−0.001	rough	15.4	W (offsh)
Feb/Mar	−0.028	+0.004	rough	12.6	E (onsh)
Mar/Apr	+0.019	−0.003	rough	13.3	SW (offsh)
Apr/May	+0.074	+0.029	slight	10.9	NE (onsh)
May/Jun	−0.008	+0.013	moderate	12.6	Sw (offsh)
Jun/Jul	+0.009	+0.013	slight	07.4	E (onsh)
Jul/Aug	−0.010	+0.009	slight	08.3	W (offsh)
Aug/Sep	+0.008	−0.003	slight	09.2	NW (offsh)

which can be destroyed by high energy conditions. The re-establishment of the ridge and runnel system in the post-storm period (March 1986) provides further confirmation that this type of beach topography is not a product of storms, but the equilibrium response of the foreshore to average wave conditions. An increasing development of these ridges was observed throughout the late spring and the response of the foreshore to the relatively calm conditions of the summer months was again manifest in the persistence of well established ridge forms and progradation of the backshore berm.

Attempts to relate volumetric changes along the foreshore to the prevailing processes are less clear. For example, a substantial net addition of sediment to the volume of the ridge and runnel beach occurred during a year which was characterised by a significantly higher incidence of storm conditions than average. Similarly, aggradation of the beach surface in February was preceded by storm wave conditions, while the net aggradation recorded in May was associated with low wave energy. Such changes in the direction of the onshore/offshore sediment transport seem to have been more closely controlled by variations in wind direction than the level of wave energy operating at the time. For example, periods of beach aggradation in February and April were both characterised by a predominance of strong winds from an offshore (south-westerly) direction, whereas winds from a markedly onshore direction preceded degradation of the beach in March. The effect of such an onshore wind would have produced a landward movement of the surface water which was compensated by a seaward movement in the lower layers, carrying sand offshore and resulting in beach degradation. A reverse mechanism (King and Williams, 1949), in response to strong offshore winds, may account for the net aggradation to the beach in February and April.

Differential sediment transport in the nearshore zone may also be related to factors such as sediment heterogeneity and the morphological stage of the beach (Carter, 1988). Despite their limited range, the textural characteristics of the Portmarnock beach sediment displayed significant variations across the foreshore and over time in relation to the energy conditions responsible for their deposition. In particular the grain size properties seem to reflect local spatial variations in the process operations alongshore and confirm the spatial contrasts between the morphodynamic response of the ridge and runnel system and the ebb-tidal delta.

The morphological stage of the beach provides a vital control over short-term fluctuations in the availability of beach sediment and hence over the morphodynamics of the beach system. Under mid- to low-energy conditions, the volume of sediment available for onshore-offshore exchange is generally limited, with nearshore bars providing an important sediment store. These bars also exert a significant control over the amount of wave energy available on the foreshore so that beach and dune erosion during storms is reduced when waves initially break on a nearshore bar. The low elevation and relative stability of the beach between September and November 1985, compared with the subsequent survey months, suggests that a large volume of sediment may have been stored in the offshore bars and shoreline wave energy was significantly reduced as a result. The storm events (onshore winds) of early 1986 resulted in a transfer of sediment from the nearshore zone to the beach so that the key to the new adjustment phase in February was inextricably linked to the availability of sediment; the suppression of ridge forms at this time representing a lag in the response of the beach to a temporary excess in sediment supply.

In summary, the development of ridges and runnels along the study beach represents a mid- to low-energy equilibrium form which is destroyed under high-energy conditions. The semi-permanent nature of the ridges is related to storm frequency/magnitude relations and the reaction and relaxation times of the ridges. Observations over a twelve month period found that relatively small scale changes to the morphological expression of this ridge and runnel beach were superimposed upon much larger scale volumetric changes to the beach. Unexpectedly, the beach surface aggraded during a year characterised by a significantly higher incidence of storm conditions than average. The interpretation of this response is largely dependent on the availability of sediment and the prevailing wind direction that controls the flow circulation and movement of sediment in the nearshore zone.

DISCUSSION

The seminal work of KING and WILLIAMS (1949) established 'ridge and runnel' beach morphology as a form of swash bar development related to an *in-situ* process of beach slope adjustment. An important factor in this genetic connotation was that the development of 'true' ridge and runnel was only associated with very specific conditions of tidal range (macro), fetch (limited), sediment size (fine to medium sand) and beach slope (low). Since then the application of 'ridge and runnel' terminology to a range of morphologically similar, although genetically different, features found on intertidal and subtidal beach zones has led to confusion surrounding the formation and development of this type of morphology.

This change in the usage of the term was introduced by HAYES (1967) and later elaborated by HAYES and BOOTHROYD (1969). Several North American investigators have since adopted the term for the morphological description of onshore migrating sandbodies which are products of a nearshore adjustment of excess sediment to wave conditions (DAVIS *et al.*, 1972; FOX and DAVIS, 1974; OWENS and FROBEL, 1977). In this context ridges and runnels are considered ephemeral features of the swash zone which can occur on both tidal and non-tidal beaches (HINE, 1979). Several European workers reflect the influence of these North American studies (BERG, 1977; DABRIO and POLO, 1981). BERG (1977) recognises two types of ridge and runnel beaches: (i) semi-permanent features which are destroyed by storm waves; and (ii) permanent ridge and runnel beaches, akin to those described by KING and WILLIAMS (1949), that are sheltered from the destructive effects of storm waves.

ORFORD and WRIGHT (1978) have been critical of this *ad hoc* application of the nomenclature. They believe that a nomenclature which has established genetic connotations should not be used purely in a descriptive sense. ORME and ORME (1988, p. 169) acknowledge the existence of what they refer to as "some transatlantic miscommunication" on this issue. However, they propose a third mechanism of ridge and runnel formation, associated with the episodic development of ridges by runnel erosion rather than ridge accretion, and suggest that "the ridge and runnel enigma is best resolved by recognising genetic diversity amid generic similarity" (1988, p. 169).

It is not the purpose of this discussion to add to the growing semantic debate about 'ridge and runnel' terminology. However, the striking paucity of studies on 'true' ridge and runnel features compounded by their limited geographical distribution has been responsible for a considerable degree of confusion even within the existing literature. Many previous studies (KING and WILLIAMS, 1949; PARKER, 1975; WRIGHT, 1976) were conducted along the prominent ridge and runnel topography of the coastline of northwest England. The findings and observations of such work reflect the response of ridge and runnel systems to the set of process, topographic and sedimentary conditions specific to that area and cannot be considered representative of all such features.

It seems that in an attempt to assert the integrity of 'true' ridge and runnel beaches, many studies have presented rigorous definitive statements of their behaviour based on a very limited number and range of field observations. The result of this tendency has led to further confusion rather than clarification. Several discrepancies, discussed below, have arisen in relation to issues such as the spatial variability of ridge development, the permanency/semi-permanency of ridge forms, tidal control over ridge migration and the relationship between sediment availability and ridge and runnel development.

Spatial Variability

The significance of temporal changes in beach morphology has long been acknowledged while spatial variations in macroscale beach morphology have been largely neglected. Previous studies of ridge and runnel topography have generally concentrated on a single beach profile and attempted to monitor profile changes over time. For example, the findings of KING and WILLIAMS (1949) were based on the observation and measurement of a single profile, while WRIGHT (1976, p. 49) argued that "one traverse across a ridge and runnel beach is as representative as another, especially when considered over a short time period of one to two years." The present study incorporated measurements of fifteen profiles along a 3.5 km beach and found significant alongshore variations in the gradient, ridge dimensions and volumetric changes of the profiles.

Permanency

The ridges of 'true' ridge and runnel beaches have been described as semi-permanent features of the intertidal zone (KING and WILLIAMS, 1949). WRIGHT (1976) considered the ridges at Ainsdale in northwest England to be permanent features and the development of a completely different storm profile was not observed. The rhythmic topography investigated by HALE and McCANN (1982) on Vancouver Island, British Colubmia, provides a further example of permanent ridge development but there the ridges developed under storm wave conditions whereas the observations at Portmarnock suggest that storm conditions were responsible for the destruction/suppression of ridge forms. Furthermore, BERG'S (1977) classification of ridge and runnel beaches, on the basis of their permanency, implies that the ridges of the Portmarnock foreshore have closer affinities to semi-permanent ridge and runnel beaches, having ridges during calm weather that are destroyed by storm waves, than the permanent ridge and runnel beaches akin to those investigated by KING and WILLIAMS (1949).

This rigid classification of ridge and runnel systems as permanent or semi-permanent features leads to confusion because the question of permanency is not genetically determined and, therefore, fails to discriminate the semi-permanent ridges and runnels of the present study from those ephemeral features of the North American literature (HAYES, 1967; HAYES and BOOTHROYD, 1969; FOX and DAVIS, 1974; HINE, 1979). The findings of Portmarnock study suggest that the semi-permanent nature of ridge forms is directly related to storm frequency and magnitude relations and the reaction and relaxation times of the ridge forms. It is, therefore, more appropriate that the definition of 'true' ridge and runnel features should incorporate both the permanent and semi-permanent nature of ridge forms rather than "limit the application of the term to situations in which the number of ridges, and their respective positions, remain constant through time" (HALE and McCANN, 1982, p. 428).

Ridge Migration

The original criteria, proposed by KING and WILLIAMS (1949), associated ridges with sediment transport but there was no systematic migration shorewards. The ridges maintained their positions, probably in relation to mean tide levels, and there was no macro-profile adjustment in ridge form resulting from rapid sediment transport. Other workers found no such correspondence between ridge position and the stand of low and high tides. For example, because of the high tidal range (macrotidal) and low foreshore gradient at Ainsdale (WRIGHT, 1976), the mean values of high and low spring and neap tides did not represent positions of particularly long still-stand over any bi-monthly tidal cycle.

The temporal framework of the Portmarnock study, involving field monitoring at monthly intervals, resulted in a nearly repetitive tidal sequence between successive surveys so that the possible control of spring-neap scale tidal movement could be established. The location of the most persistent ridges displayed no apparent relation to mean tide levels. Ridge migration was associated with minor changes to the volume of the foreshore and occurred under conditions of relatively low wind and wave energy. The persistence of these conditions allowed maintenance of a striking coherence of ridge form throughout the autumn months of 1985 and summer of 1986.

Notwithstanding the absence of an apparent control by mean tidal levels, the development of a series of ridges and runnels along Portmarnock beach is closely controlled by the general mesotidal conditions which operate off the North County Dublin coastline. Comparison with the findings of other studies (KING, 1972; PARKER, 1975; WRIGHT, 1976), all of which were carried out on macrotidal beaches, suggests that the mesotidal conditions of the present study are responsible for the more limited number of ridges (2–4), the closer horizontal spacing (wavelength, 40–70 m) and the absence of an intertidal sandflat area along the Portmarnock foreshore.

Sediment Availability

There is general agreement in the scientific literature that ridged profiles are prominent only where the foreshore gradient is less than the equilibrium gradient. Most workers view an abundance of fine sand as an essential prerequisite in this regard (KING and WILLIAMS, 1949; KING, 1972; MCCAVE and GEISER, 1979). Others, such as HALE and MCCANN (1982, p. 417), suggest that ridge and runnel development can occur either under sediment surplus conditions or in situations where there is a gently sloping erosive platform and limited sediment supply. The issue is difficult to reconcile because observations of 'true' ridge and runnel beach systems (KING and WILLIAMS, 1949; KING, 1972; PARKER, 1975; WRIGHT, 1976) have invariably been carried out under conditions of limited net foreshore aggradation or degradation (at least in the short-term of 1 to 2 years) so that the sediment budget was arguably in a state of dynamic equilibrium. Wright remarks on the response of his study beach at Ainsdale that "changes there are reflected solely in the development and destruction of ridges and runnels within a broad envelope delimited by the sweep zone, involving little net change in the amount of sediment present on the profile" (1976, p. 71).

The context of such studies differs substantially from that of Portmarnock where minor fluctuations in the morphological expression of the beach surface (*i.e.* ridge forms) were superimposed upon large scale volumetric adjustments of the beach (Table 1). Ridge development was observed under conditions of both limited (autumn 1985) and abundant sediment availability (summer 1986). The absence of ridges along the beach profiles in February coincided with the period of maximum volumetric change which suggests that ridge development is closely controlled by the reaction and relaxation times involved in the adjustment of the beach surface (ridges) to changes in the availability of sediment.

It is apparent from the above that while a general appreciation exists of the controls on ridge and runnel development, there has been a tendency in the literature to underestimate the range of possible conditions under which ridges and runnels will develop. In particular, the behaviour of ridge and runnel topography has been poorly understood in relation to their spatial and temporal variability.

CONCLUSION

The ridge and runnel topography described here is a distinct morphogenetic feature associated with certain conditions of fetch, beach slope, tidal range and sediment size and complies with the original criteria of 'true' ridge and runnel forms, as defined by KING and WILLIAMS (1949). The ridges are semi-permanent features of the intertidal zone and represent a mid- to low-energy equilibrium form which is destroyed under high energy storm conditions. The dimensions of the ridge and runnel system reflect the mesotidal conditions which operate along this particular shoreline. Regular surveys of the northern ridge and runnel system and the southern ebb-tidal delta have demonstrated the mobility of the former and the relative stability of the latter. The changing morphological expression (*i.e.* height, wavelength and gradient adjustments) of the ridge forms displays almost total independence of, and is overshadowed by, volumetric (*i.e.* sweep zone) changes to the foreshore.

While the observations described generally concur with those of KING and WILLIAMS (1949) for 'true' ridge and runnel beaches, significant differences are also revealed in relation to the spatial variability of foreshore morphology, the permanency/semi-permanency of ridge forms, the mobility of ridges in response to local tidal movements, and the significance of sediment availability in ridge formation. The findings of this study suggest a greater range of conditions under which 'true' ridge and runnel topography develop than has been acknowledged in the literature. It is concluded that previous definitions, in an attempt to assert the integrity of these beach forms, may have been too rigorous with regard to many of these factors.

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□ RESUMEN □

Durante doce meses se midieron, en la costa este central de Irlanda, las variaciones de las respuestas morfodinámicas de un sistema banco y valle de playa. El sistema banco y valle cumplían con el criterio general de formas 'verdaderas' de bancos y valles, tal cual fueron definidas por King y Williams (1949), es decir que ocurren bajo condiciones limitadas del campo de acción del viento (fetch), con un bajo gradiente de playa, con gran amplitud de marea y dimensión del sedimento de mediano a fino. Los bancos representan formas de equilibrio semipermanentes y con condiciones de energía (de media a baja), las cuales son destruídas en situaciones de alta energía. Cambios relativamente menores en la expresión morfológica de los bancos y los valles de la playa eran superpuestos a cambios volumétricos, a gran escala, en la playa. La superficie de la playa durante un año se hallaba caracterizada por una notable alta incidencia de las condiciones de las tormentas promedio. Estas respuestas dependen, en gran medida, de la disponibilidad de sedimento y de la dirección del viento prevaleciente. Los cambios en la morfología de los bancos y los valles eran también controlados por las condiciones de mesomarea, las cuales operan a lo largo del área del estudio, pero no mostraron relación con los movimiento de las mareas de sicigias y cuadraturas. Los hallazgos sugieren que las definiciones de 'bancos y valles' pueden haber sido demasiado rigurosas respecto a las condiciones de permanencia, mobilidad y disponibilidad de sedimentos.—*Néstor W. Lanfredi, CIC-UNLP, La Plata, Argentina.*

□ RÉSUMÉ □

Les variations des réponses morphodynamiques d'un système à crêtes et sillons prélittoraux ont été mesurées pendant douze mois sur le centre est de la côte d'Irlande. Ce système repond aux critères généraux de vrais crêtes et sillons prélittoraux, tels que définis par King et Williams (1949), parce qu'il se produit lorsque le fetch est limité, que le gradient de plage est faible, le marnage important et la taille du sédiment moyenne à fine. Les crêtes constituent des formes d'équilibre semi-permanentes par énergies moyennes ou faibles; elles sont détruites lorsque se produisent des conditions de forte énergie. Des modifications relativement mineures de la géomorphologie de la plage à crêtes et sillons prélittoraux se superposent à des modifications du volume à grande échelle de la plage. Durant l'année, caractérisée par une plus forte incidence des conditions de tempête que de conditions moyennes, il y a eu accrétion de la surface de la plage. Ce type de réponse est surtout liée à la disponibilité en sédiments et à la direction des vents dominants. Les modifications de la morphologie des crêtes et sillons prélittoraux dépendent aussi du caractère mésoltidal qui n'était pourtant pas en relation avec les mouvements vives eaux/mortes eaux. Les observations suggèrent que la définition de "crêtes et sillons" est peut-être trop rigoureuse pour les conditions de permanence, de mobilité et de disponibilité en sédiments.—*Catherine Bousquet-Bressolier, Géomorphologie E.P.H.E., Montrouge, France.*

□ ZUSAMMENFASSUNG □

Veränderungen der Morphodynamik eines Komplexes aus Strandriff und Strandpriel im zentralen Bereich der Ostküste Irlands wurden über einen Zeitraum von zwölf Monaten erfaßt. Mit begrenzter Fetch, geringem Strandgefälle, großem Tidenhub und mittleren bis feinen Korngrößen entspricht der hier untersuchte Komplex den von King und Williams (1949) definierten Formen eines typischen Strandriff-Strandpriel-Systems. Die Strandwälle stellen unter schwach- bis mittelenergetischen Bedingungen geschaffene, relativ beständige Gleichgewichtsformen dar; unter hochenergetischen Bedingungen werden sie zerstört. Relativ geringe morphologische Veränderungen des Komplexes aus Strandriff und Strandpriel überlagerten großräumige Veränderungen des gesamten Strandvolumens. Innerhalb eines Jahres, das durch überdurchschnittlich häufig auftretende Stürme gekennzeichnet war, kam es zu einer Erhöhung der Strandoberfläche. Sie ist vor allem durch die Bereitstellung entsprechender Sedimente und durch die vorherrschenden Windrichtung bedingt. Die morphologischen Veränderungen des Strandriff-Strandpriel-Systems wurden auch durch mesotidale Bedingungen im Untersuchungsgebiet verursacht. Sie lassen aber keinen Zusammenhang mit Spring- bzw. Nipptiden erkennen. Die Ergebnisse zeigen, daß die Definitionen von Strandriff und Strandpriel in bezug auf deren Beständigkeit und Mobilität sowie die Verfügbarkeit von Sedimenten offenbar zu eng gefaßt waren.—*Jürgen Wunderlich, Department of Geography, University of Marburg, Germany.*