Journal of Coastal Research | 8 | 2 | 398–407 | Fort Lauderdale, Florida | Spring 1992

Sand Beach Ecology: Swash Features Relevant to the Macrofauna

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ABSTRACT

McARDLE, S.B. and McLACHLAN, A., 1992. Sand beach ecology: Swash features relevant to the macrofauna. *Journal of Coastal Research*, 8(2), 398–407. Fort Lauderdale (Florida), ISSN 0749-0208.

Aspects of swash climate of significance to benthic macrofauna were studied over 19 tidal cycles on 10 beaches representing a range from reflective to ultra-dissipative extremes. Dissipative beaches typically had slopes of 1:50–1:80, swash periods of 40–60 sec and wave period/swash period ratios about 0.2. Reflective beaches had slopes steeper than 1:15, swash periods of 11–13 sec and wave period/swash period ratios about 0.80. Intermediate beaches typically displayed slopes of 1:25–1:45, swash periods of 15–30 sec and wave period/swash period ratios of 0.4–0.65. Most beaches displayed more reflective characteristics at high tide and more dissipative characteristics at low tide. Control of swash climate was primarily by beach slope and wave height, the former being more important towards the reflective extreme, the latter towards the dissipative extreme and both being critical in intermediate beaches. The implications of different swash climates for beach fauna are discussed.

ADDITIONAL INDEX WORDS: *Beach fauna, benthic macrofauna, dissipative beach, reflective beach, tidal cycle, swash climate.*

INTRODUCTION

Exposed sandy beaches represent one of the harshest marine environments for macrobenthic animals. They are devoid of biological structures, even permanent burrows are absent, and communities are entirely controlled by physical processes. Yet the physical environment is elementary in that sandy beaches require only waves and sand for formation. Therefore, wave height, wave period and sand fall velocity may be used to represent the range of environmental variables that produce beaches (SHORT, 1987). The major beach morphodynamic types and their classification relative to environmental variables have been described by SHORT (1979), WRIGHT and SHORT (1984), SHORT and HESP (1982) and SHORT (1987). Grain size varies relatively little for any beach and therefore temporal variability in beach type is primarily a function of variation in wave height and to a lesser degree wave period (WRIGHT *et al.*, 1985).

Despite the limited number of parameters necessary to define a beach, ecologists have had minimal success demonstrating factors controlling the benthic macrofauna on exposed beaches. Many workers have implicated sand grain size but have not been able to demonstrate cause and effect relationships (SALVAT, 1964; JARAMILLO, 1987) and it has been concluded that grain size alone does not characterise a beach (BALLY, 1983). While most sandy beach organisms can tolerate a wide range of sand particle sizes and beach slopes (McLACHLAN, 1983), it has been shown that major changes in macrobenthic diversity and abundance occur in response to changes in beach type, even where small changes in particle size are concerned and different beach types are primarily the result of different wave energy levels (McLACHLAN, 1990). Since breaking waves occur far from the intertidal in many beaches, it has been argued that these changes in benthic communities must be in response to changes in swash climate rather than wave climate directly (McLACHLAN, 1990).

We argue that swash climate on the beach face is the most important aspect of the environment experienced by animals inhabiting exposed sandy beaches. Specializations characteristic of animals living in this environment include the ability to burrow rapidly and repeatedly, and the ability to move up and down the beach with the tides or to regulate behaviour to match the tidal rhythm (ANSELL and TREVALLION, 1969). A number of crustaceans, gastropods and bivalves use the upwash or backwash to move up and down the beach and have been referred to as "swash-riders" (EL-

91030 received 25 March 1991; accepted in revision 23 September 1991.

Table 1. *General information on study areas.*

Beach	Code	Number of Studies	Position	Aspect	Maximum Tidal Range	Tidal Regime	Exposure	Beach Type	Mean Grain Size (μm)
*Whisky Run	WR	3	43°10'N 124°25'W	West	3.6	Mixed	Exp	Diss	183
*Three Mile	TM	2	43°45'N 124°12'W	West	3.6	Mixed	Very exp	Diss	250
†Sundays River	SR	5	33°43'S 25°50'E	South	2.1	Semi-diurnal	Exp	Int	247
†Kings	KB	2	33°58'S 25°38'E	Northeast	2.1	Semi-diurnal	Int	Int	207
†Plettenburg	PB	1	34°05'S 23°22'E	East	2.1	Semi-diurnal	Int	Int	228
†Maitlands	MB	1	33°05'S 25°16'E	South	2.1	Semi-diurnal	Very exp	Diss/int	302
†Buffalo	BF1	1	34°04'S 22°59'E	South	1.75	Semi-diurnal	Exp	Int	217
†Buffalo	BF2	1	34°04'S 22°59'E	Southeast	1.75	Semi-diurnal	Int	Int	227
†Oubos	OB	1	34°04'S 24°13'E	South	1.6	Semi-diurnal	Shelt	Ref	268
†Stompneus	ST	2	17°59'S 32°44'E	Northeast	2.1	Semi-diurnal	Shelt	Ref	338

Under beach types: diss = dissipative, int = intermediate, ref = reflective. Exposure: exp = exposed, int = intermediate, shelt = sheltered. * = USA; and † = South Africa

LERS, *personal communication*). This ability to 'surf' is especially obvious in *Donax* sp. which orientate during migration (ANSELL and TREVALLION, 1969; TIFFANY, 1972; WADE, 1967) and in *Bullia* sp. (ANSELL and TREVALLION, 1969; MCLACHLAN and YOUNG, 1982). These behaviour patterns must clearly be affected by and respond to swash periods, speeds, *etc.*

The swash climate associated with different beach types has not been examined by ecologists. Swash climate has also not received the same attention as has beach and surf zone morphology and dynamics, although a few references have been made to changes in swash period and its relationship to beach slope (ERICKSEN, 1970; EMERY, 1960; DUNCAN, 1964). GUZA and THORNTON (1982) investigated the effects of changing offshore wave heights on swash height (runup) but for a single beach only. A basic analysis of swash climates, needed by biologists, has not been provided in the sophisticated literature on beach processes.

On the assumption that swash climate is the key variable affecting intertidal beach communities, we aim (1) to examine the relationship between swash climate and basic physical variables defining different beach types and (2) to quantify key swash variables considered important to the fauna, such as swash period and speed, and their variability over different beach types.

STUDY SITES AND SWASH FEATURES

Beaches

Field data were collected from two geographical areas, southern Africa and the west coast of the USA. South African tides are semidiurnal with a mean spring range of 1.6 m and a maximum of 2.1 m. Much of the southern coast of South Africa takes the form of south-east facing log-spiral bays which experience increased wave action towards their eastern extremities. Seven study sites were situated here (Table 1).

The Oregon coast in the north-west USA includes exposed beaches facing directly into the North Pacific and experiencing heavy storm surf throughout the extended winter. Tides are mixed, with a maximum daily excursion of 3.6 m and a mean excursion of about 2 m (KOMAR *et al.*, 1976). The period of incident waves ranges 6–13 sec and

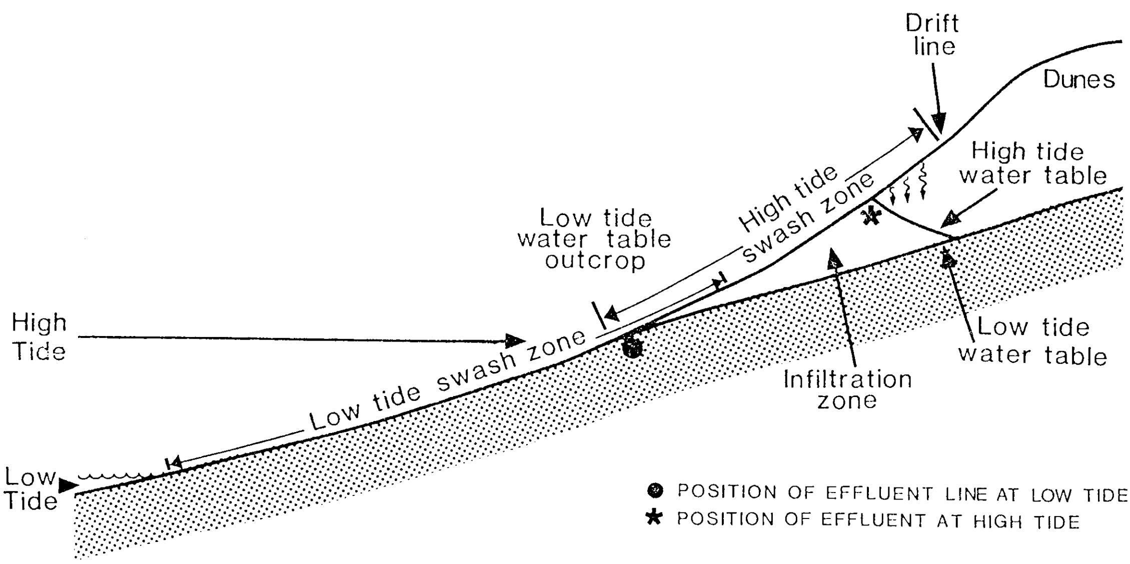

Figure 1. Terminology pertaining to the swash zone on an intermediate beach (after McLachlan, 1990).

breaker height 1–8 m, the latter averaging 3–4 m for 8 months of the year and 1–2 m for 4 months (Komar *et al.*, 1976). Two series of readings were taken on these beaches during relatively calm weather and one during a storm (Table 1).

Swash Zone

Sandy beaches may be divided into reflective, intermediate and dissipative types. Reflective beaches have coarse sand, lower incident waves and small tides, no surf zone and waves breaking directly on the beach face. Dissipative beaches have fine sand, large waves, with a very broad surf zone where much of the incident wave energy is dissipated before reaching the beach. Intermediate beaches have bars and channels. Using wave and sediment characteristics each type may be quantified to generate a Ω value (Dean, 1973), a dimensionless fall velocity:

$$\Omega = \text{wave height/settling velocity} \times \text{wave period.}$$

Wright *et al.* (1982) have defined beaches in southern Australia as dissipative when, $\Omega > 6$, as intermediate when $1 < \Omega < 6$ and as reflective when $\Omega < 1$.

The swash zone may be defined as that part of the intertidal zone which is periodically covered by water (Figure 1) in response to tide excursions and wave runup (Komar, 1976; Packwood, 1983). Typically, beaches of low slope have wide swash zones and those with steep slopes, narrow swash zones (Duncan, 1964). The swash zone is located above the tide level, and its position on the beach varies with the tide, shifting landward during a flood tide and seaward during an ebb tide. The lower limit of upwash is characterised by bore collapse and the upper limit demarcated by the point where the leading edge of swash reaches a maximum runup and begins backwash (Waddel, 1976). The leading edge of the swash is usually marked by a line of foam making it easier to determine when the upwash ends and the backwash begins (Emery and Gale, 1951). The intersection of the beach face and the water table usually occurs within the swash zone, at a point referred to as the effluent line (McLachlan *et al.*, 1985). The beach face surface below the effluent line is saturated, giving the 'glassy layer' effect common to sandy beaches.

METHODS

At each study site a transect was set up perpendicular to the shoreline from the previous high water mark to below low water. Numbered 2 m and 1 m high poles were deployed along the transect at 5 m and 1 m intervals respectively. The swash climate was measured for 15 min per hour over a tidal cycle (12 hr) by recording the time

Table 2. *Mean values (and standard errors) for physical beach and swash variables.*

Site	1/Slope	Sett. Vel. cm·sec⁻¹	Wave Height (m)	Deans (Ω)	Swash Period (sec)	Wave Period (sec)	Upwash Time (sec)	Upwash Dist. (m)	Upwash Speed m·sec⁻¹	Back Speed m·sec⁻¹	Wave/ Swash Ratio	No. of Efflu. Cross.
ST1	11.58	4.43	0.42	0.97	12.37	9.77	4.80	6.24	1.34	0.85	0.79	50.75
	(0.32)		(0.02)	(0.13)	(0.23)	(0.43)	(0.14)	(0.19)	(0.03)	(0.03)	(0.02)	(1.94)
ST2	11.49	4.57	0.50	1.06	12.61	10.32	5.02	6.73	1.36	0.92	0.82	51.27
	(0.46)		(0.07)	(0.25)	(0.16)	(0.44)	(0.14)	(0.20)	(0.04)	(0.20)	(0.03)	(1.63)
OB1	12.50	3.57	0.83	2.73	11.98	8.52	3.95	5.06	1.28	0.78	0.71	41.08
	(0.30)		(0.06)	(0.26)	(0.32)	(0.54)	(0.19)	(0.56)	(0.09)	(0.10)	(0.02)	(1.58)
BF1	41.18	2.62	2.46	7.65	28.72	12.27	14.15	18.94	1.30	1.31	0.43	10.50
	(6.62)		(0.11)	(0.70)	(2.76)	(0.35)	(1.39)	(1.63)	(0.03)	(0.05)	(0.04)	(2.12)
BF2	34.41	2.89	1.01	3.70	23.74	9.45	12.30	13.94	1.13	1.22	0.40	10.83
	(3.92)		(0.06)	(0.38)	(1.71)	(0.35)	(1.00)	(0.67)	(0.04)	(0.04)	(0.03)	(2.11)
KB1	25.73	2.44	1.62	7.31	19.16	9.08	9.67	11.97	1.30	1.23	0.47	13.62
	(1.02)		(0.08)	(0.50)	(0.56)	(0.38)	(0.34)	(0.29)	(0.04)	(0.02)	(0.02)	(1.78)
KB2	37.02	2.44	1.41	5.62	16.95	10.28	9.10	9.73	1.17	1.00	0.61	10.42
	(4.32)		(0.12)	(0.65)	(1.60)	(0.30)	(0.81)	(0.59)	(0.08)	(0.03)	(0.04)	(2.78)
MB1	30.69	4.11	2.42	4.29	21.91	13.73	10.92	13.00	1.14	1.14	0.63	11.75
	(0.29)		(0.10)	(0.18)	(0.41)	(0.24)	(0.19)	(0.51)	(0.03)	(0.04)	(0.02)	(0.66)
PB1	27.82	2.82	2.40	6.29	24.31	13.53	11.08	15.54	1.36	1.19	0.56	13.67
	(2.46)		(0.10)	(0.36)	(1.97)	(0.11)	(0.83)	(1.13)	(0.03)	(0.04)	(0.05)	(2.35)
SR1	31.12	3.25	2.05	5.71	18.17	11.05	9.97	10.68	1.02	1.32	0.61	18.58
	(1.41)		(0.07)	(0.27)	(0.80)	(0.40)	(0.51)	(0.57)	(0.02)	(0.04)	(0.04)	(1.78)
SR2	33.09	3.16	2.24	5.00	23.31	14.18	11.20	11.99	1.04	1.01	0.61	7.62
	(2.36)		(0.04)	(0.25)	(1.39)	(0.64)	(0.64)	(0.60)	(0.01)	(0.04)	(0.05)	(1.44)
SR3	29.37	3.20	2.60	6.40	20.21	12.70	9.25	10.95	1.15	1.00	0.63	11.58
	(0.97)		(0.10)	(0.34)	(0.60)	(0.24)	(0.20)	(0.32)	(0.02)	(0.03)	(0.02)	(0.43)
SR4	27.20	3.25	2.99	7.30	26.08	12.60	10.66	14.91	1.35	0.97	0.48	8.17
	(0.54)		(0.08)	(0.33)	(0.34)	(0.21)	(0.32)	(0.30)	(0.03)	(0.03)	(0.01)	(0.68)
SR5	43.00	3.20	2.02	5.55	27.52	11.37	11.96	13.46	1.12	0.88	0.41	6.92
	(2.47)		(0.08)	(0.20)	(1.14)	(0.39)	(0.59)	(0.57)	(0.04)	(0.02)	(0.01)	(1.77)
TM1	44.96	3.19	>5.00	12.27	59.42	12.77	29.67	49.09	1.57	1.65	0.22	3.08
	(2.49)		(0.00)	(0.28)	(2.60)	(0.00)	(1.65)	(3.04)	(0.06)	(0.08)	(0.01)	(0.40)
TM2	63.66	3.31	2.20	5.98	45.03	11.12	22.58	20.66	0.93	1.04	0.25	2.67
	(7.24)		(0.08)	(0.25)	(3.05)	(0.34)	(1.71)	(1.26)	(0.03)	(0.05)	(0.02)	(0.87)
WR1	76.00	2.03	1.34	9.37	37.32	7.05	18.08	12.14	0.71	0.74	0.19	3.50
	(6.23)		(0.05)	(0.76)	(2.17)	(0.17)	(1.31)	(1.02)	(0.04)	(0.07)	(0.01)	(0.68)
WR2	56.21	2.17	1.75	11.03	41.40	7.31	17.25	10.08	0.64	0.53	0.18	4.81
	(3.41)		(0.05)	(0.83)	(2.61)	(0.11)	(1.13)	(0.57)	(0.02)	(0.03)	(0.01)	(1.44)
WR3	64.06	2.03	2.65	15.02	51.74	8.69	24.55	22.30	0.93	0.93	0.17	1.95
	(1.62)		(0.13)	(1.40)	(1.64)	(0.00)	(1.18)	(1.50)	(0.04)	(0.07)	(0.01)	(0.57)

No. of Efflu. Cross. = Number of effluent crossings per 15 min. Sett. Vel. = Settling velocity

and position of the beginning and end of each swash on the transect. On all occasions swash length was recorded to the nearest 1 m and time to the nearest second (RIEDL, 1971). If a swash crossed the effluent line the position and time of crossings was recorded. The lower limit of a swash was taken as the point where the following wave or bore overran it.

Concurrent with the swash measurements, visual breaker height and period (stop watch) and wind speed (hand held anemometer) and direction (compass) were recorded at hourly intervals. Visual estimates of breaker height and period were compared with values from a seismograph at Oregon State University's Hatfield laboratory for the three Oregon data sets and found to be within 10%, an accuracy considered adequate for the purposes of this study.

At the time of low tide the beach profile was surveyed from high water to below low water using a dumpy level and sediment samples were collected at low, mid and high tide positions for grain size analysis. Grain size was estimated graphically following wet sieving through a set of sieves at 0.5 ϕ intervals. Settling velocity was then calculated from this using the values produced for glass spheres (GIBBS *et al.*, 1971). Swash zone slope was calculated for each hour of the tidal cycle from the beach profile as well as the minimum and maximum swash limits for each period.

Swash speed was estimated from swash distance and time. At each hourly sample, mean values were calculated for swash distance, time and speed. This contributed to a data set of 12 hourly samples for 19 studies at 10 study sites. A wave/swash ratio was calculated (Table 2) by dividing wave period by swash period, resulting in a value between 0.18 and 0.82. The state of the tide was represented using an arbitrary scale from 0 (low tide) to 6.5 (high tide).

Statistical Analysis

The mean values for each swash variable for each 15 min recording period were used in an ANOVA to examine the effect of site on each variable. Multiple range analysis (STATGRAPHICS, 1986) was applied for each variable to indicate 'threshold levels' between groups, *i.e.* to attempt to separate beaches into reflective, intermediate and dissipative categories on the basis of swash climate. A stepwise multiple regression was employed to determine the relative importance of the independent variables (wave height, period, beach slope, grain size) in controlling swash climate features (period, length, speed, *etc.*). For this analysis the data was grouped into the different beach types as identified by multiple range tests.

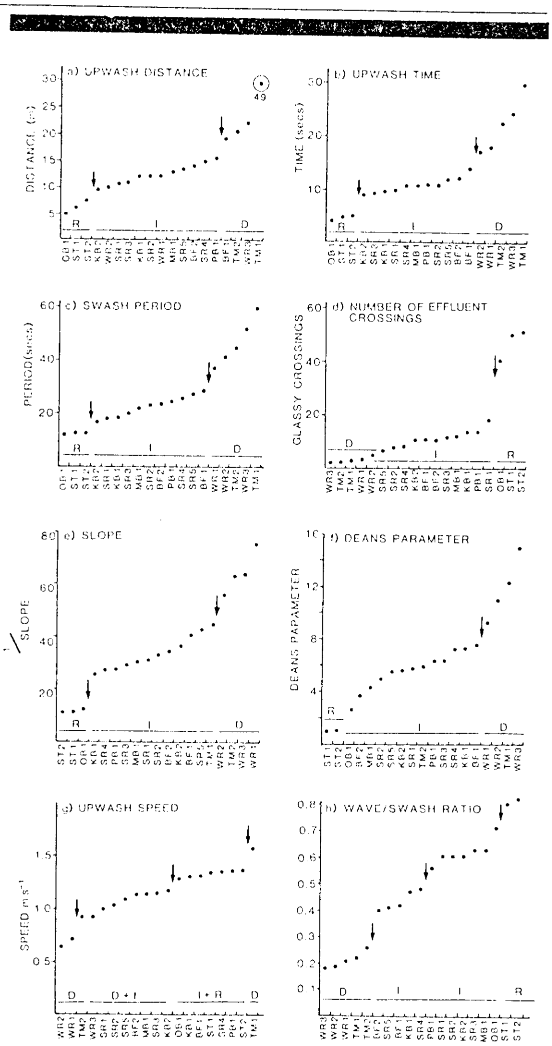

Figure 2. Plots of mean values of physical and swash climate variables, indicating limits of grouping by multiple range tests. R = reflective, I = intermediate and D = dissipative. Note the changes in the order of the beaches on the x axis.

RESULTS

The mean values and standard errors for all variables from each data set (*i.e.* each complete series of readings taken over 12 hr on one beach) are listed in Table 2. All dependent variables (and independent variables of wave height and slope) are significantly different for these beaches (ANOVA, $p < 0.00001$).

The groupings produced by multiple range analysis for each variable indicate possible "threshold levels" between the three main beach types as well as the range of values likely to be characteristic of each type (Figure 2). Important features of these parameters are discussed in what follows.

UPWASH DISTANCE (distance from bore collapse to point of maximum runup; Figure 2a). TM1 is distinct probably because of the 'ultradissipative' condition of the beach during a very high energy event (mean wave height > 5 m). The threshold level between intermediate and dissipative beaches occurs at 17 m and between reflective and intermediate beaches at 8 m mean upwash distance.

UPWASH TIME (time from beginning to end of upwash distance; Figure 2b). The separation between intermediate and dissipative beaches occurs at 16 sec with a further delimitation at 20 sec which probably isolates those beaches tending

Table 3. *Results of stepwise multiple regression for (a) dissipative, (b) intermediate, (c) reflective, (d) dissipative and reflective, and (e) all beaches F to enter model = 4 (*F to enter = 3).*

	Dependent Variable							
	Upwash Distance		Upwash Time		Upwash Speed		Swash Period	
	Independent	r^2	Independent	r^2	Independent	r^2	Independent	r^2
a	Wave height	0.80	Wave period	0.37	Wave height	0.82	Wave height	0.39
	Tide	0.83	Slope	0.48			Slope	0.62
			Wave height	0.60				
b	Slope	0.40	Slope	0.60	Tide	0.16	Slope	0.48
	Wave height	0.49	Wave height	0.63	Wave height	0.19	Wave height	0.55
			Tide	0.63			Tide	0.56
c	Slope	0.19	Slope	0.33	Wave height	0.90	Slope	0.21*
					Tide	0.23	Wave period	0.32*
							Tide	0.49*
d	Wave height	0.83	Wave height	0.64	Wave period	0.48	Wave height	0.64
	Wave period	0.85	Slope	0.87	Slope	0.70	Slope	0.89
	Tide	0.87			Wave height	0.73		
					Tide	0.76		
e	Wave height	0.55	Slope	0.58	Slope	0.32	Slope	0.58
	Slope	0.62	Wave height	0.76	Wave height	0.44	Wave height	0.76
	Wave period	0.62	Wave period	0.77			Wave period	0.77
	Tide	0.63						

Note that r^2 values in each set are cumulative

towards an ultradissipative state. Reflective beaches are clearly separate from the intermediate group at 6–8 sec, the range of the former being 3.5–5 sec.

SWASH PERIOD (time interval between swashes; Figure 2c). The threshold level between reflective and intermediate beaches occurred at about 15 sec and between reflective and dissipative beaches at 32 sec. The upper range for swash period in the dissipative group was 60 sec for TM1, *i.e.* ultradissipative conditions during a storm.

NUMBER OF EFFLUENT LINE CROSSINGS (the mean number of swashes that either reach or cross the effluent line during a 15 min period; Figure 2d). There is a marked separation of reflective beaches, which show a range of 41–52 crossings per 15 min, in contrast to the upper range for the intermediate and dissipative beaches of below 20. Although there is no definite break between intermediate and dissipative states, the five beaches representative of dissipative states display the lowest values and in each case record less than 5 effluent line crossings per 15 min.

SLOPE (mean beach face slope within the upper and lower limits of the swash for each hour of the tidal cycle; Figure 2e). With the exception of TM1, the threshold between intermediate and dissipative states occurs at a slope of 1/50. The lower end of the intermediate group is 1/25, whereas the three reflective beaches range 1/11–1/12.

DEANS PARAMETER (Ω) (Figure 2f). Values are slightly higher than reported by WRIGHT *et al.* (1982). A group of dissipative beaches exists above 8.5 and a group of the two most reflective beaches (ST1 & ST2) below 1.06. OB1 has been grouped with the intermediate beaches, recording the lowest Ω value in that group. TM2 here is grouped with the intermediate beaches.

UPWASH SPEED (calculated from upwash distance and upwash time as mean speed; Figure 2g). No clear grouping of different beach types is evident. Dissipative beaches displayed the highest and lowest speeds, intermediate beaches were less variable and reflective beaches displayed the most uniform speeds.

WAVE/SWASH RATIO (wave period/swash period; Figure 2h). There was a clear grouping of dissipative beaches with values of 0.18–0.25 representing the lower range of wave/swash ratios. Reflective beaches displayed the highest values, about 0.8.

Stepwise multiple regression (Tables 3 and 4) indicated that slope and wave height account for most of the variation in swash climate, especially upwash time, upwash distance and swash period. For the dissipative beaches (Tables 3a, 4a) wave height was the most important independent variable in most cases, explaining up to 82% of the variance in the data; for the intermediate beaches slope and wave height (Tables 3b, 4b) explained most of the variance in swash climate whereas in the case of reflective beaches (Tables 3c, 4c) slope was most important. Combining reflective and dissipative beaches (Tables 3d, 4d) resulted in wave height and slope explaining most (up to 87%) of the variance; the same held when all beaches were combined (Tables 3e, 4e).

DISCUSSION

In this study, a wide range of beach morphodynamic types was selected to investigate features of swash climate important to benthic macrofauna. We have shown reflective, intermediate and dissipative beaches to display characteristic swash climates. Wave and beach characteristics explain much of the variation in swash climate over this range. From the variables examined, beach slope and wave height emerge as the most important factors controlling swash climate. When dissipative beaches are analysed separately, wave height emerges as the most important variable whereas for reflective or intermediate beaches slope is the most important variable.

Emery and Gale (1951), recorded a close relationship between swash period and beach slope and suggested that swash period could be used as an indicator of beach slope as it tends to increase as beach slope decreases. The results for swash period and beach slope from the present study agree with those of Emery and Gale (1951) (Figure 3). A similar relationship was noted by Ericksen (1970) who found that swash period decreased towards high tide due to an increase in the slope of the foreshore. We also recorded wave/

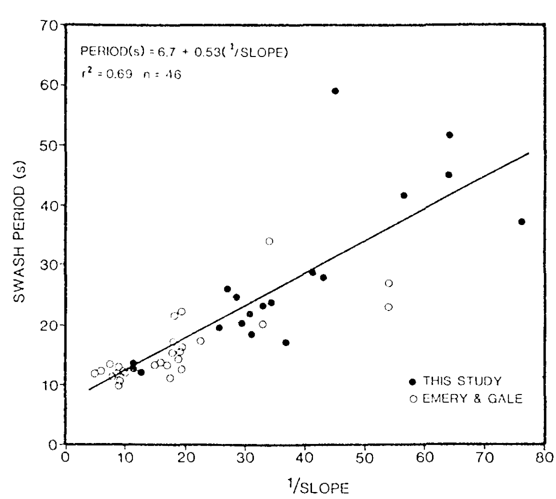

Figure 3. Relationship between swash period and beach slope.

Table 4. *Final model produced from stepwise variable selection for swash distance, time, speed and period for (a) dissipative, (b) intermediate, (c) reflective, (d) dissipative and reflective and (e) all beaches.*

	Dependent Variable	Equation	r^2
a	Dist.	= 1.19 + 10.5(wave height) − 1.62(tide)	0.83
	Time	= −3.61 + 0.66(wave period) + 1.78(slope) + 3.35(wave height)	0.60
	Speed	= 0.32 + 0.25(wave height)	0.82
	Swash period	= 6.95 + 7.64(wave height) + 0.33(slope)	0.62
b	Dist.	= 1.13 + 0.26(slope) + 2.09(wave height)	0.49
	Time	= 2.96 + 0.20(slope) − 0.20(tide) + 0.87(wave height)	0.63
	Speed	= 0.96 + 0.05(wave height) + 0.04(tide)	0.19
	Swash period	= 6.08 + 3.07(wave height) + 0.35(slope) − 0.65(tide)	0.56
c	Dist.	= 3.52 + 0.26(slope)	0.19
	Time	= 2.30 + 0.23(slope)	0.33
	Speed	= 1.02 + 0.05(wave height) + 0.03(tide)	0.23
	Swash period	= 5.08 − 0.21(tide) + 0.29(slope) + (0.46)wave period	0.49
d	Dist.	= 9.42 + 1.52(wave period) + 8.21(wave height) − 1.10(tide)	0.87
	Time	= 0.85 + 0.18(slope) + 4.17(wave height)	0.87
	Speed	= 0.71 + 0.06(wave height) − 0.01(slope) − 0.04(tide)	0.76
	Swash period	= 5.06 + 7.86(wave height) + 0.35(slope)	0.89
e	Dist.	= 3.70 − 0.51(wave period) + 7.51(wave height) + 0.09(slope) − 0.57(tide)	0.63
	Time	= 2.09 + 3.49(wave height) + 0.22(slope) − 0.39(wave period)	0.77
	Speed	= 1.25 + 0.10(wave height) − 0.01(slope)	0.44
	Swash period	= 6.41 − 0.79(wave period) + 6.95(wave height) + 0.43(slope)	0.77

swash ratios increasing towards high tide as beaches became more reflective. This was even the case for our 'reflective' beaches which were only truly reflective at high tide.

The effect of beach slope on swash period is *via* interference between successive swashes (KEMP, 1975): as beaches become flatter, collisions between swashes increase in frequency (WADDELL, 1976). Maximum interference therefore occurs on flat dissipative beaches where every swash is overrun by the next, resulting in a longer (infragravity) swash period and a longer upwash time (*i.e.* swash period greatly exceeds wave period). On steep reflective beaches each backwash is completed before the next upwash begins and there is a tendency for one swash to occur for every breaking wave.

On dissipative beaches most incident wave energy is dissipated in the surf zone and incident wave period is converted to infragravity periods. These beaches filter the lowest volumes of sea water (by swash filtration through their interstices) because of their long swash periods, high water tables and fine sands (MCLACHLAN, 1989). Furthermore, this filtration is driven mainly by tides or infragravity set up and set down because so much of the incident wave energy is dissipated in the surf zones. Reflective beaches have larger grain sizes resulting in an increase in infiltration during the upwash; backwash therefore does not interfere with the upwash to the same extent. Indeed, reflective beaches filter 100 times the volumes filtered by dissipative beaches and this filtration is effected entirely by waves, tides playing a negligible role (MCLACHLAN, 1989).

As a result of the relationship between beach slope and wave height (BASCOM, 1951; DAVIES, 1972), these two factors may exert a coupled effect on swash climate. To observe the influence of either variable in isolation it is necessary to maintain the other at a constant level. This is what happened when the data for the dissipative beaches were analyzed separately. Slope is more constant for a beach than wave height since it responds to changes in wave climate. Wave height, however, changes rapidly depending on the time of the study. This results in short and medium term (hours to days) changes in swash climate being explained by wave height. The influence of beach slope on swash climate is more obvious when the full range of beaches is examined as this is the only way of providing a complete range of beach slopes.

There has been little attempt to relate distribution of intertidal beach fauna to morphology and dynamic features of beaches, particularly swash. MCLACHLAN *et al.* (1981) found a relationship between macrofaunal diversity and abundance and beach slope, the tendency being for flat dissipative beaches to have the richest macrofauna. MCLACHLAN and HESP (1984), attributed a concentration of two *Donax* sp. in cusp bays on reflective beaches to net swash flow, dependence on swash for transport and/or an active preference for bays where there was maximum feeding time and slower swash speeds. This explanation was supported by DONN *et al.* (1986), who recorded a higher abundance of *Donax serra* where beach slope was flattest and speculated that *Donax* might be able to detect beach slope.

From the results of the present study it is proposed that *Donax* sp. may select parts of a beach with flatter slopes *via* swash climate variables, *i.e.* an indirect response to slope *via* direct response to swash climate. Swash period may be a reliable method of estimating beach slope due to the good correlation between swash period and beach slope (Figure 3).

CONCLUSIONS

Not inhabiting permanent burrows, all macrofauna on exposed beaches must enter the swash at times. Most species move, feed, burrow and reproduce in the swash, these activities being controlled by complex rhythms and orientation responses. It is inconceivable that these species are not directly affected by, and adapted to, swash climate. We have not demonstrated this, however, but we have provided a conceptual model of swash climate from which experimental tests could be designed.

Using simple techniques readily available to biologists we have been able to divide our 10 study beaches into three types and to show that each type, reflective, intermediate and dissipative, is characterised by a distinctive swash climate. Changes in swash climate correlate well with changes in beach type: swash periods lengthen, swash lengths increase and effluent line crossings decrease from reflective to dissipative beaches. Parallel trends occur in the fauna: there is a linear increase in intertidal macrobenthic species richness and a logarithmic increase in total abundance from reflective to dissipative beaches as well as a decrease in mean individual body size (MCLACHLAN, 1990).

Are the changes in swash climate directly responsible for the community changes over this range of beaches? We believe they are. However, simple correlation does not resolve this since we need to demonstrate cause-and-effect relationships. This can only be done experimentally by subjecting animals to controlled conditions where one variable is manipulated at a time. Flume tank studies where animals of different body size and taxonomic affinity are evaluated in terms of their ability to orientate, move, surf, or burrow under conditions of different swash speeds, periods, *etc.* will elucidate this further.

ACKNOWLEDGEMENTS

We thank the FRD for a grant to A. McLachlan. Members of the sandy beach group provided much needed assistance; special thanks goes to Trevor Molloy and Ted Donn for help in the field and to Maggie Hawkins for preparing the figures.

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□ RESUMEN □

Algunos aspectos sobre el significado del régimen de lavado de la playa por acción de las olas, sobre la macrofauna bentónica, fueron estudiados en 10 playas durante 19 ciclos de marea, con características, aquéllas, que iban desde reflectivas a ultra disipativas extremas. Las playas disipativas presentaban pendientes típicas, entre 1:50 y 1:80, los períodos de los lavados eran de 40–60 s, y la relación período de la ola/período del lavado era del orden de 0.2. Las playas reflectivas tenían pendientes superiores a 1:15, con períodos de lavado de 11–13 s, y con una relación de período de las olas/períodos de lavado de aproximadamente 0.80. Las playas intermedias presentaban pendientes típicas que se hallaban entre 1:25–1:45, con períodos de lavado de 15–30 s, y la relación período de la ola/período de lavado entre 0.40 a 0.65.

La mayor parte de las playas estudiadas presentaban características de mayor reflectividad durante las pleamares, y más disipativas en los períodos de las bajamares.

El régimen de lavado se hallaba controlado, primariamente, por la pendiente de la playa y la altura de la ola, siendo la primera de mayor importancia en las playas reflectivas extremas, y las olas en las disipativas extremas, siendo ambas críticas para las playas intermedias.

En este trabajo, también se ha discutido, las implicancias de los diferentes regímenes de lavado para la fauna de la playa.—*Néstor W. Lanfredi, CIC-UNLP, La Plata, Argentina.*