

Macrofaunal community structure of beaches in northern New South Wales, Australia

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Abstract. Macrofaunal community composition of ten exposed sandy beaches in northern New South Wales, Australia, appeared to correlate with beach morphodynamic state even though the data represented sampling at only a single time. Better results were obtained by using the Beach State Index (BSI) rather than the dimensionless fall velocity (Ω). Species number and abundance significantly increased as the BSI value increased, whereas biomass was not correlated with BSI. The New South Wales beaches had a higher species number and abundance relative to BSI than did beaches in a published review of beaches around the world.

Introduction

Macrofaunal communities of Australian beaches have been studied by Dexter (1983, 1984, 1985), McLachlan and Hesp (1984), McLachlan (1985, 1990), Haynes and Quinn (1995), Hacking (1996), James and Fairweather (1996) and McLachlan *et al.* (1996); however, information on sandy-beach ecology in Australia remains scant (reviews: Fairweather and Quinn 1994; Fairweather 1990).

There has, however, been significant research in Australia in regard to the physical nature of beaches (Wright *et al.* 1979; Short and Wright 1981, 1983, 1984; Short and Hesp 1982; Wright and Short 1984; Wright *et al.* 1985), and results concerning the dynamics of beach morphology have produced a scheme for categorizing physical beach states. The concept of beach morphodynamic states refers to the depositional forms of sandy beaches and their hydrodynamic processes (Short and Wright 1984).

Beaches are fairly simple physical systems, in that only sand and waves are inherently required for their development (McArdle and McLachlan 1992). The dimensionless fall velocity, Ω , incorporates both wave and sediment data and can be used to index beaches according to their physical characteristics or morphodynamic state (Short and Wright 1984). It is expressed by the formula

$$\Omega = H_b/W_s T \quad (1)$$

where H_b is wave breaker height (cm), W_s is the sediment fall velocity based on Stoke's law (Gibbs *et al.* 1971) (cm s^{-1}) and T is the wave period or average time (s) between waves.

Six common beach states have been identified. There are two extreme and opposite beach states. Dissipative beaches, formed in conditions of high waves and fine sand, have a wide, gently sloping beach face and broad surf zone containing sandbars. They have high Ω values of 7^+ and are considered a high-energy beach state because of the energy

contained in the surf zone. In contrast, reflective beaches, displaying coarse sediment and low waves, are considered low-energy beaches. The waves do not break in lines but rather crash on and surge up the steep beach face and Ω values are small (<1). The four intermediate beach states, with Ω values of 1–6, are longshore bar-trough, rhythmic bar and beach, transverse bar and rip, and low-tide terrace. They are the most mobile in terms of sediment exchange and may move from one intermediate state to another depending on conditions (Short and Wright 1983). Intermediate beaches are usually expressed in terms of their most recurring state (as related to prevailing sediment characteristics and modal breaker conditions).

On the basis of earlier studies (reviews: McLachlan 1983; Brown and McLachlan 1990) much sandy-beach research has recently concentrated on the changes in the structure of intertidal macrofaunal communities across the different beach morphodynamic states. This research, mainly in southern Africa and Chile (e.g. McLachlan *et al.* 1993; Jaramillo and McLachlan 1993) with one study in Australia (McLachlan *et al.* 1996), has revealed that dissipative beaches have a higher species number, abundance and biomass than beaches of a more reflective nature. This suggests that sandy-beach macrofaunal communities are greatly regulated by physical conditions.

The trend of macrofaunal increase with increasing Ω has held over a wide range of geographical and climatic conditions. However, the use of Ω as a universal measure of beach state has not proved completely adequate as it does not take into account the effect of tidal range (McLachlan *et al.* 1993). The relative tidal range determines the importance of swash and surf zone processes as opposed to wave shoaling processes over the beach profile (Masselink and Short 1993). So, to facilitate more apt comparisons of beaches over wide areas, Ω has recently been modified to produce another dimensionless beach-state parameter known as the Beach State Index or BSI (McLachlan *et al.*

1993) and expressed by

$$[BSI] = \log([H_b M / W_s T E] + 1) \quad (2)$$

where M is the maximum tide range (m) and E is a constant representing the maximum theoretical equilibrium tide for the earth covered in water [$E = 0.8$]. The formula can be translated to

$$[BSI] = \log([\Omega M / 0.8] + 1). \quad (3)$$

In terms of BSI, beaches can be categorized as follows (McLachlan *et al.* 1993): < 0.5, reflective; 0.5–1.0, low-to-medium-energy intermediate; 1.0–1.5, high-energy intermediate to dissipative; 1.5–2.0, fully dissipative; and > 2.0, ultra-dissipative macrotidal.

Use of the BSI in contrast to Ω has shown an improved fit of the data on the regression line for species number, abundance and biomass over a range of beaches and locations (McLachlan *et al.* 1993). Hence, participants at an international symposium ('Sandy Beaches '94, Valdivia, Chile, 1994) agreed to use this parameter when comparing beaches on anything other than a local scale. The apparent lack of effect of latitude implies that geography is secondary to shore morphology in affecting beach macrofaunal communities.

There has been little research in Australia to test these ideas (Fairweather and Quinn 1994). The scope of this paper is thus to build on the data already compiled from overseas research through investigations of eastern Australian beaches. The specific aim is to relate macrofaunal community structure of beaches in warm temperate northern New South Wales (NSW) to beach morphodynamic state (using both Ω and BSI) and to compare the results to those of a similar study by McLachlan (1990).

Methods

Study area

The warm-temperate coastline of northern NSW, Australia, experiences a highly variable wind-wave climate and a persistent south-easterly swell. The semi-diurnal tides have a mean spring range of 1.6 m and a maximum range of 2 m. A morphodynamic variety of ten exposed sandy beaches was selected for study within this region: Cudgen, Cabarita, North Corindi, Arrawarra, Ocean View, Hearns Lake, Shelley, Moonee, Korora and Boambee (Fig. 1). They were, as far as known, free from pollution and stranded kelp.

Sampling procedure

Each beach was investigated once at low tide on consecutive days from 5 to 15 January 1994. The sampling method was akin to that used by McLachlan *et al.* (1993) to permit comparisons.

At each beach, a transect was drawn perpendicular to the horizon from above the high-tide drift line to the low-tide swash. The transect was divided into 10 equally spaced tidal levels; Level 1 was above the drift line, Level 2 was on the driftline, and the lowest, Level 10, was in the low-tide swash. At each of the beach levels, three replicate 0.1 m² samples were

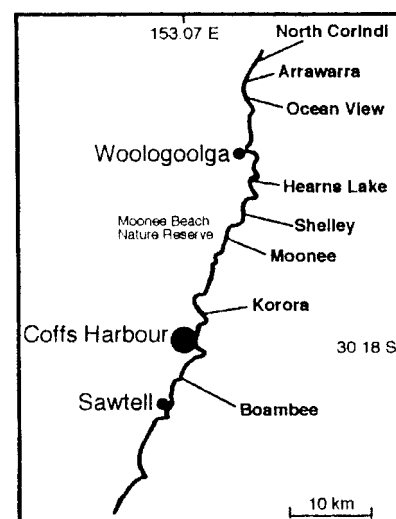
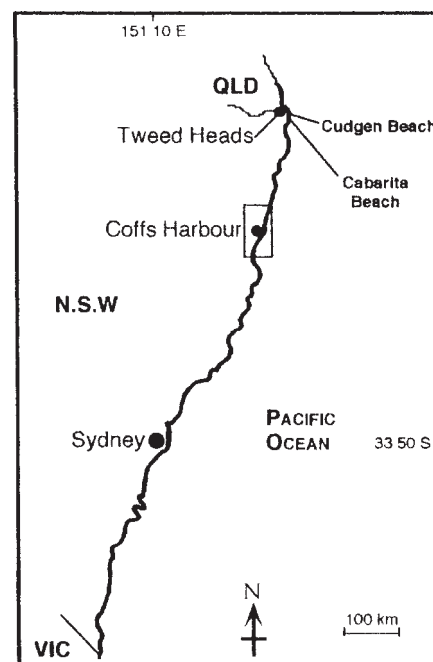
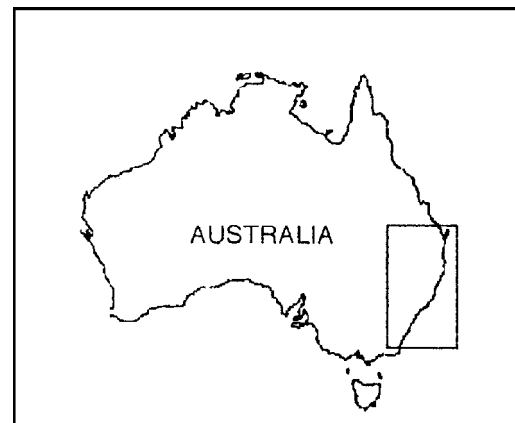


Fig. 1. Location of study sites, northern NSW, Australia.

taken approximately 1 m apart to a depth of 35 cm. The samples were regulated by using a metal box frame (33 × 33 × 35 cm) which could be pushed into the sediment, the sample being removed from within. Each sample was sieved on site through a 1-mm mesh; this has been shown to have an adequate retention efficiency for sandy beach macrofauna (Hacking 1998). A decantation method was employed in cases where massive sediment was retained, the end point being defined as the time when no animals occurred for three consecutive decantations.

The beach profile at each site was surveyed with the aid of a theodolite and staff, and the wave height and period were estimated. At each beach site and level, a sediment sample was taken to 35 cm. Sediment size was analysed by the use of a series of graded sieves corresponding to the Wentworth scale (Buchanan 1971) and the results were calculated in terms of sediment fall velocity (Gibbs *et al.* 1971). Ω and BSI were calculated from Eqns 1 and 3 for each beach.

Fauna collected were preserved and stored in 4% buffered formaldehyde in seawater and later sorted, identified, counted and weighed (shell-free biomass determined by drying at 60°C for 48 h). Insects and any other 'terrestrial' fauna are as characteristic of beach sediment as are intertidal marine species and these were included in the data. McLachlan (1990) also included them.

Because most macrofaunal populations on beaches are highly mobile and undergo many migrations, population distributions and associated densities can vary greatly. For this reason, abundance and biomass of macrofaunal communities are commonly considered by beach ecologists in strips of beach 1 m wide and not in areas of metres squared. In this way, abundance and biomass data allow the estimation of whole populations and may be compared with information collected during different seasonal and lunar cycles (Brown and McLachlan 1990). In the present study, abundance and biomass values per metre of beach were obtained by linear interpolation using distances between sampling points after obtaining abundances per metre squared at each level by averaging the replicates.

The transects sampled in this study are intended to reflect only the morphodynamic characteristics of a particular section of beach and not the beach in its entirety.

Analysis

Data were checked for non-constancy of variances and outliers by using residual plots, and the assumption of data normality and linearity was confirmed with normal probability plots of residuals. Abundance and biomass data were subsequently log transformed.

The results for species number, abundance and biomass for the ten NSW beaches were regressed with Ω and BSI. Regression slopes for the present data and the data of McLachlan (1990) were compared and tested against the null hypothesis that the slopes and intercepts were equal (i.e. that the data come from the same statistical population) by analysis of covariance.

Results

In total, 38 species were detected (Table 1). Calculations of Ω and BSI for the ten beaches showed the sites to represent a range of almost-reflective to high-energy-intermediate states (Table 2). There are no fully dissipative beaches in northern NSW (Short 1993).

On the basis of Ω , only species number formed a significant regression ($t_8 = 4.81$, $P = 0.001$, $R^2 = 74.1\%$). There was no significant relationship with Ω for log abundance ($t_8 = 2.25$, $P = 0.054$, $R^2 = 38.8\%$) or log biomass ($t_8 = 1.45$, $P = 0.186$, $R^2 = 20.7\%$). The BSI provided more significant results overall, with both species number and log abundance forming significant regressions (Figs 2 and 3).

Biomass remained unrelated to beach index (Fig. 4).

As expected from results of previous studies, macrofaunal species number and abundance increased significantly from low to high BSI for the NSW beaches. However, comparisons of slopes with the worldwide data of McLachlan (1990) showed significant differences between the sets of species number and abundance data. Species number was generally higher for the NSW beaches, for which the steeper slope of the line (Fig. 2) suggests a more rapid increase with beach state energy. The two regression lines for abundance (Fig. 3) are parallel, NSW beaches exhibiting a similar increase in abundance (slope), though at a higher count. Biomass data were not significantly different from those published by McLachlan (1990) (Fig. 4).

Discussion

In contrast to past studies (e.g. McLachlan *et al.* 1993), use of BSI in place of Ω in the present study resulted in a slight decrease in the fit of the data for species number across the range of beach types (as indicated by a small fall in R^2 values). However, use of the BSI increased the fit of the abundance regression to make it significantly different from zero; this indicates that tidal effects influence animal abundance and that tidal range should be included when beach morphodynamics and macrofauna are investigated on even a small geographic scale. Improved data fit means improved predictability of the composition of the macrofaunal community over the range of beaches; this, along with demonstrating trends, is a major consideration in this type of research. Therefore, the beaches will be discussed in terms solely of the BSI.

The results of this study suggest that more dissipative beaches harbour richer fauna. Species number and abundance consistently increased from low to high BSI, species number being the most predictable in this regard. This has also been demonstrated in previous work (e.g. McLachlan *et al.* 1993).

The results also support the premise that the physical aspects of beaches are of major importance in determining the composition of macrofaunal communities. Rather than respond to changes in any single physical parameter, variations in beach communities result from different combinations of sand particle size and wave regime (McLachlan 1990). This may be explained in terms of the intertidal swash climate.

'Swash' is the term given to the water that runs up and down the beach face as waves break. Most beach species move, feed, burrow and reproduce in the swash (McArdle and McLachlan 1992) and must be affected by it. The swash climate of a beach is determined by the physical parameters that are used in the beach morphodynamics formulae to classify beaches (principally wave height and sediment size, which together influence beach slope); the impact of swash

Table 2. Raw data for warm-temperate beaches of northern NSW

BSI, Beach State Index; Ω , dimensionless fall velocity; Abundance, total number of macro-invertebrates per metre of beach; Biomass, total shell-free biomass of macroinvertebrates per metre of beach; W_s , sediment fall velocity; Wave height, average wave height; Wave period, average time between breaking waves

Beach	BSI	Ω	Slope	No. species	Abundance (m ⁻¹)	Biomass (g m ⁻¹)	W_s (cm s ⁻¹)	Wave height (cm)	Wave period (s)
Korora	0.701	1.61	0.074	5	315.12	26.24	0.062	100	10
N. Corindi	0.860	2.50	0.027	10	2766.63	15.95	0.032	80	10
Arararra	0.933	3.03	0.041	8	7666.65	141.95	0.033	100	10
Shelley	0.944	3.12	0.035	11	6625.28	36.45	0.032	100	10
Ocean View	1.011	3.71	0.032	12	3075.70	42.36	0.035	130	10
Cabarita	1.025	3.84	0.045	17	22933.90	243.54	0.039	150	10
Hearns Lake	1.068	4.28	0.042	13	4533.31	16.07	0.035	150	10
Cudgen	1.072	4.32	0.042	13	8533.30	240.70	0.037	160	10
Boambee	1.083	4.44	0.022	18	3672.69	54.65	0.036	160	10
Moonee	1.083	4.44	0.029	19	4214.80	206.45	0.036	160	10

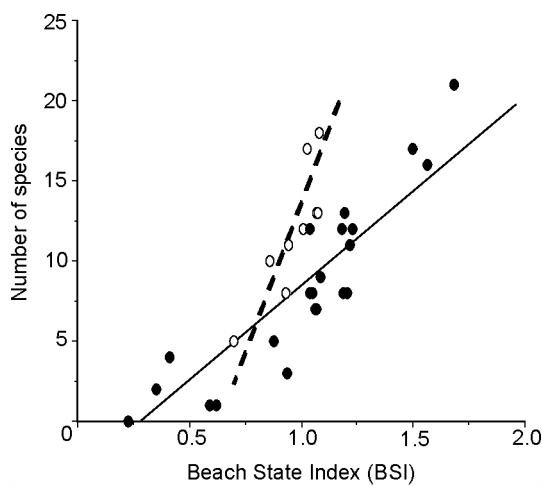


Fig. 2. Number of species of macro-invertebrates on temperate beaches. (○) Northern NSW (present study): significant regression $t_8 = 4.50$; $P < 0.001$; No. NSW species = $30.7 [\text{BSI}] - 17.4$; $R^2 = 71.7\%$. (●) Beaches from McLachlan (1990): No. McLachlan (1990) species = $13.3 [\text{BSI}] - 5.07$; $R^2 = 82.1\%$. Slopes of lines significantly different ($t_{29} = 2.63$; $P = 0.014$).

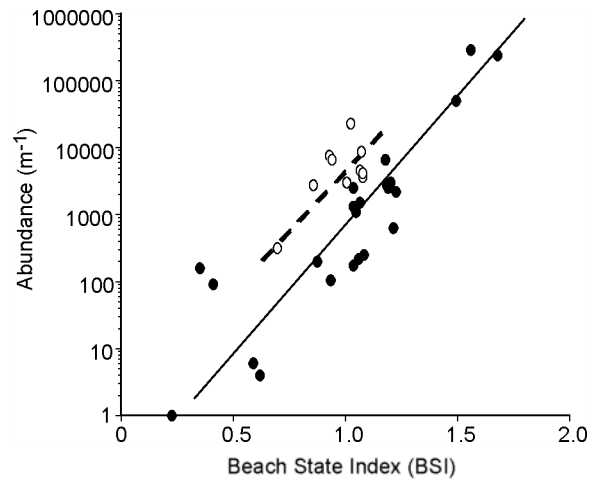


Fig. 3. Abundance of macro-invertebrates (m⁻¹) on temperate beaches. (○) Northern NSW (present study): significant regression $t_8 = 2.76$; $P < 0.025$; log NSW abundance = $2.72 [\text{BSI}] + 0.96$; $R^2 = 48.8\%$. (●) Beaches from McLachlan (1990): log McLachlan (1990) abundance = $3.26 [\text{BSI}] - 0.48$; $R^2 = 78.2\%$. Slopes of lines significantly different ($t_{29} = 0.03$; $P = 0.742$); intercepts of lines significantly different ($t_{30} = 4.18$; $P < 0.001$).

on the intertidal area is more intense on reflective beaches than on dissipative beaches. It is likely that the lower species numbers and abundance of reflective beaches result from strong swash, because the swash would hinder feeding and movement, and would present an increased risk of stranding (McLachlan *et al.* 1993); hence, only the most specialized macrofaunal species probably survive. In this study, the most reflective beaches lacked mysid shrimps, nemerteans and small polychaetes (Table 1). Two of these beaches (Korora and Arararra) also lacked amphipod communities. The large sediment size and strength of the swash probably did not allow for the persistence of these fine-bodied animals.

Conversely, more dissipative beaches exhibit a longer, gentler, more 'hospitable' swash which may be tolerated and

used by a wider range of animals. As a result of the swash climate, dissipative beaches also display more varied processes on the beach face, and this potentially allows for greater habitat complexity which may be exploited by a larger diversity of species. In equating BSI with harshness of the swash environment, the present results support the 'swash exclusion hypothesis' of McArdle and McLachlan (1992).

The strength of correlation with biomass of the present beaches was not significant when BSI was used as an index. This may be due to a greater effect of nutrient availability as opposed to control by combinations of physical factors. Wave energy alone plays a large role in generating nutrients in the surf zone and flushing dissolved or particulate organic

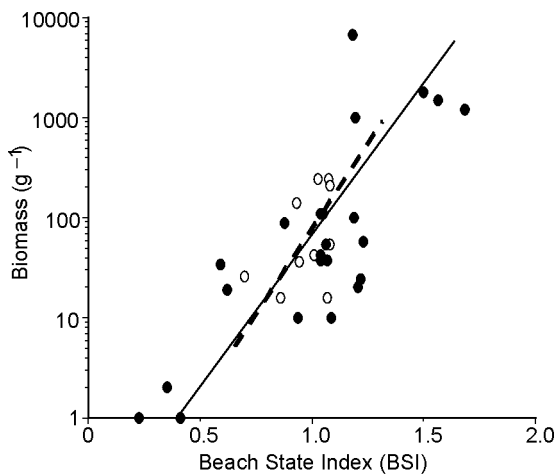


Fig. 4. Biomass of macro-invertebrates (g^{-1}) on temperate beaches. (○) Northern NSW (present study): Non-significant regression $t_8 = 1.45$; $P < 0.185$; $\log \text{NSW biomass} = 1.75 [\text{BSI}] + 0.08$; $R^2 = 20.8\%$. (●) Beaches from McLachlan (1990): $\log \text{McLachlan (1990) biomass} = 2.15 [\text{BSI}] - 0.43$; $R^2 = 59.8\%$. Slopes of lines significantly different ($t_{20} = 0.30$; $P = 0.767$); intercepts of lines not significantly different ($t_{30} = 0.68$; $P = 0.501$).

compounds through the sand habitat, and this may influence the biomass of the macrofauna, especially filter-feeding organisms (McLachlan 1990).

Although trends in the present species number and abundance data are similar to those of past studies, t -tests revealed that the regression curves for species number and abundance differed significantly from those in McLachlan (1990). It seems that the northern NSW beaches harbour more species and a larger number of individuals relative to beach type, whereas biomass is more consistent with other data.

It is possible that these results are real and that beaches on the east coast of Australia have evolved a higher number of species that can inhabit beach sand. However, sampling in the present study was conducted entirely during mid summer (a recruitment time for many macrofaunal species (Leber 1982)), and this may have led to a higher abundance and hence to detection of rarer animals and a higher species count. Nevertheless, the work of McLachlan (1990) was executed at various times of year and so there can be no certainty as to a seasonal effect in this comparison.

The most likely explanation for the differences in the two sets of species numbers is that it is an artefact caused by the inability to sample a full morphodynamic range of beaches for warm temperate Australia. If more dissipative beaches could have been sampled, the results from the morphodynamic extremes might have altered the fitted lines making them less significantly different from those of other studies.

Whatever the case, and despite the problems associated with 'snapshot' surveys of such a variable environment

(James and Fairweather 1996), there is a remarkably consistent increase in number of beach macrofaunal species and individuals with BSI across similar beach surveys. There is much scope to investigate this trend further as our understanding of beach communities and how to measure and describe them matures.

Acknowledgments

Thanks are extended to Graeme and Anne Trethewey, and Denise Gosper and friend, for assistance with fieldwork. Thanks also to Professor Anton McLachlan (University of Port Elizabeth, South Africa) and Dr Andrew Short (Sydney University) for technical advice. I also gratefully acknowledge Drs Steve Smith and Stuart Cairns for assistance with statistical interpretation and Associate Professor Rod Simpson for continuous support and comments on the manuscript. Assistance with species identifications was graciously given by Dr Anna Murray (Australian Museum) and Dr Mary Notestine (University of New England).

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Manuscript received 16 December 1996; revised 19 May and 30 September 1997; accepted 30 September 1997