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Ecology of sandy beaches in Oman

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Abstract. The benthic macrofauna and physical features of 10 sandy beaches along the coast of Oman were surveyed quantitatively. This is a mesotidal regime mostly subject to low to moderate wave energy but more exposed in the south. Five northern beaches are tide-dominated, with low wave energy, and their profiles consist of a berm, a steep, swash-dominated upper shore and a broad tide-dominated terrace from mid-shore downwards. They are composed of moderately sorted fine to medium sands. Southern beaches experience greater wave energy, particularly during the summer southwest monsoon, and exhibit smoother, concave profiles with fine, fairly well sorted carbonate sand. 58 species and species groups were recorded, with crustaceans, polychaetes and molluscs dominant. In general species richness was high, at least 19 - 25 species per beach, but dry biomass moderate to low at 26 - 90 g/m shoreline, with one high value of 450 g/m. Total abundance was moderate at 3 - 73 $\times 10^3$ organisms/m of beach. Some zonation was evident with ocypodid crabs and *Tylos* in the supralittoral, cirolanid isopods on the upper shore and a variety of species on the lower shore. The coast of Oman appears to constitute a single zoogeographic region, but with some regional differentiation between north and south due to varying physical conditions. Thus, OmanÕs beaches are characterized by tide-dominated morphodynamics and exceptionally high species richness.

Keywords: Arabia; Biogeography; Macrofauna; Morphodynamics; Species richness; Wave energy.

Abbreviation: BSI = Beach State Index.

Introduction

Sandy shores, including beaches, dominate the coast in most temperate and tropical regions and can be classified on the basis of morphodynamic type and tide range (Short 1997). Microtidal beaches can be reflective, intermediate or dissipative in response to increasing wave energy and finer sands. As tide range increases, all beaches tend towards flatter, more dissipative profiles. These changes have a major influence on beach fauna. In general, faunal diversity and abundance increase from microtidal reflective to macrotidal dissipative types. However, most surveys have covered microtidal areas and there is limited information on mesotidal regimes and little quantitative data from beaches in the tropics (McLachlan 1990,1991; Jaramillo et al. 1993).

The Sultanate of Oman has a coastline of 1700 km, of which ca. 1200 km is tropical sandy beach. Ansell (1980) described the fauna of the beach at Qurm, McLain (1984) examined the beach fauna of the northern Gulf coast of Saudia Arabia and Clayton (1996) studied ghost crabs in Oman. Beyond these papers there are no published accounts of beach ecology in Oman or on the Arabian Peninsula in general; the ecology of the beaches is largely unknown.

The beaches of Oman are scenic and have great tourism potential. They are widely used by artisanal fishermen and to a limited extent for recreation. Along the Batinah coast in the north the beaches are eroding. Other management problems relating to beaches include protection of turtle breeding areas (Salm et al. 1993), increasing development close to the shore and reduction in sediment supply. Furthermore, these shores are highly susceptible to chronic oil pollution (Coles & Al-Riyami 1996) and there is potential for acute impacts from the considerable oil shipping traffic. Although a coastal zone conservation and management plan, which includes beaches, has been drawn up for Oman (Anon. 1986-1991), there is little background ecological information on which to base conservation and management programs.

The aims of this study are to provide a first account of the morphology and macrofaunal ecology of the sandy beaches of Oman and to contrast this to beaches in other regions, to document biodiversity patterns, and to identify any invertebrate populations sufficiently large for commercial exploitation. This will contribute both to knowledge of beaches in general and the information base on OmanÕs soft coasts in particular.

Study area

The coast of Oman is exposed to a mesotidal regime with a maximum spring tide range of 3 m. The north coast from RasÕ Al-Hadd (Fig. 1) to the border with the United Arab Emirates is mostly subjected to low wave

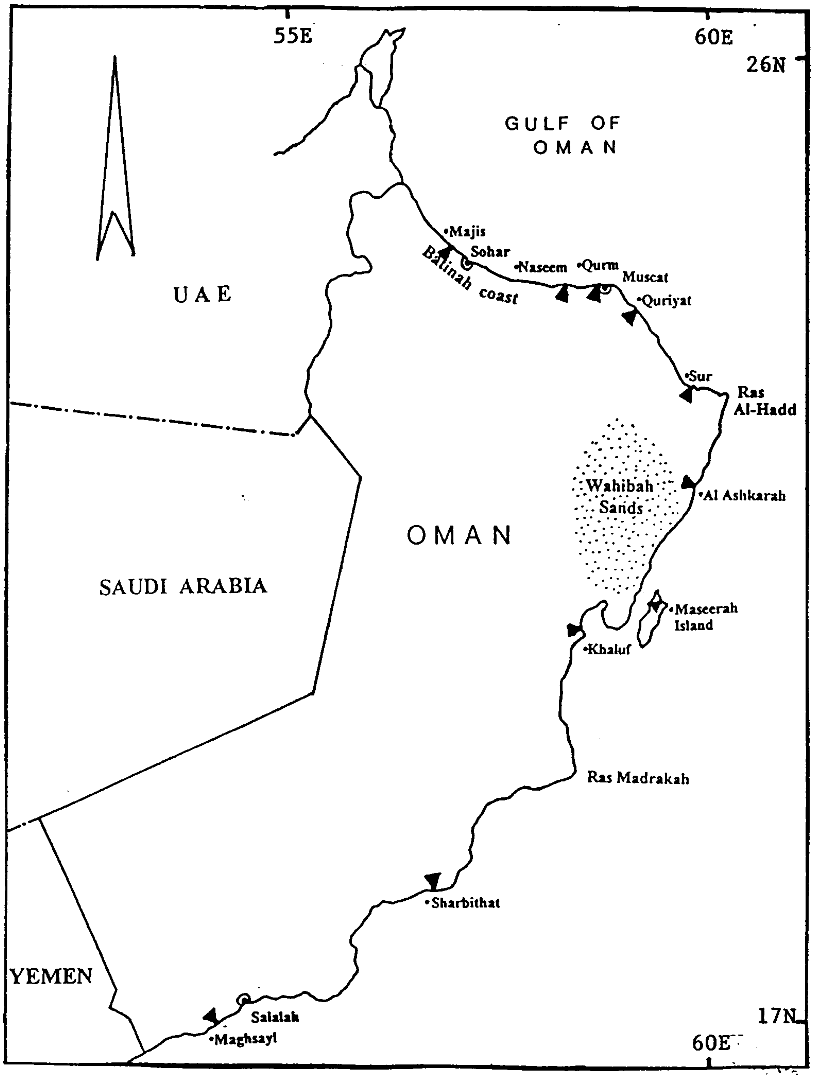

Fig. 1. Coastline of Oman showing location of the 10 beaches sampled and places mentioned in the text.

energy, whereas wave conditions become more energetic south of Ras Al-Hadd, especially during the southwest monsoon (June - August). The climate is warm to hot and sea temperatures range from 20 - 35 ¡C.

The nature of the beach material is strongly influenced by local geology. The northern coast is fed by wadis draining ophiolite outcrops and the dark mineral fragments of ophiolite mix with lighter biogenic carbonates to form a range of medium to dark beach sands with areas of lighter carbonate sands in areas with outcrops of tertiary carbonate rocks. The remainder of the coast is devoid of ophiolite outcrops and the dominant rock types are carbonates of various ages. There is also an input of quartz sand from the Wahiba sands and other inland sand bodies. Sands along the eastern and southern coasts are therefore predominantly carbonate with a little quartz and other materials, and are consequently light in color.

Methods

10 beaches were surveyed between August and December 1995 during spring low tides using a standard quantitative procedure. These were once-off surveys designed to examine broad patterns and not to address seasonal changes. The nature of the shore was observed, sea water temperature and salinity taken with a mercury thermometer and hand refrectometer respectively and a transect line was laid out from above the high water mark to the low tide swash zone. 10 stations were demarcated along this line, at equal horizontal intervals: station 2 was on the drift line and station 10 in the swash zone. The profile was then surveyed using a tape measure and ranging poles. A 50 ml sample of the top 5 cm of sand was collected at each station for grain size determination and the positions of the swash zone, effluent line (water table outcrop) and drift line noted.

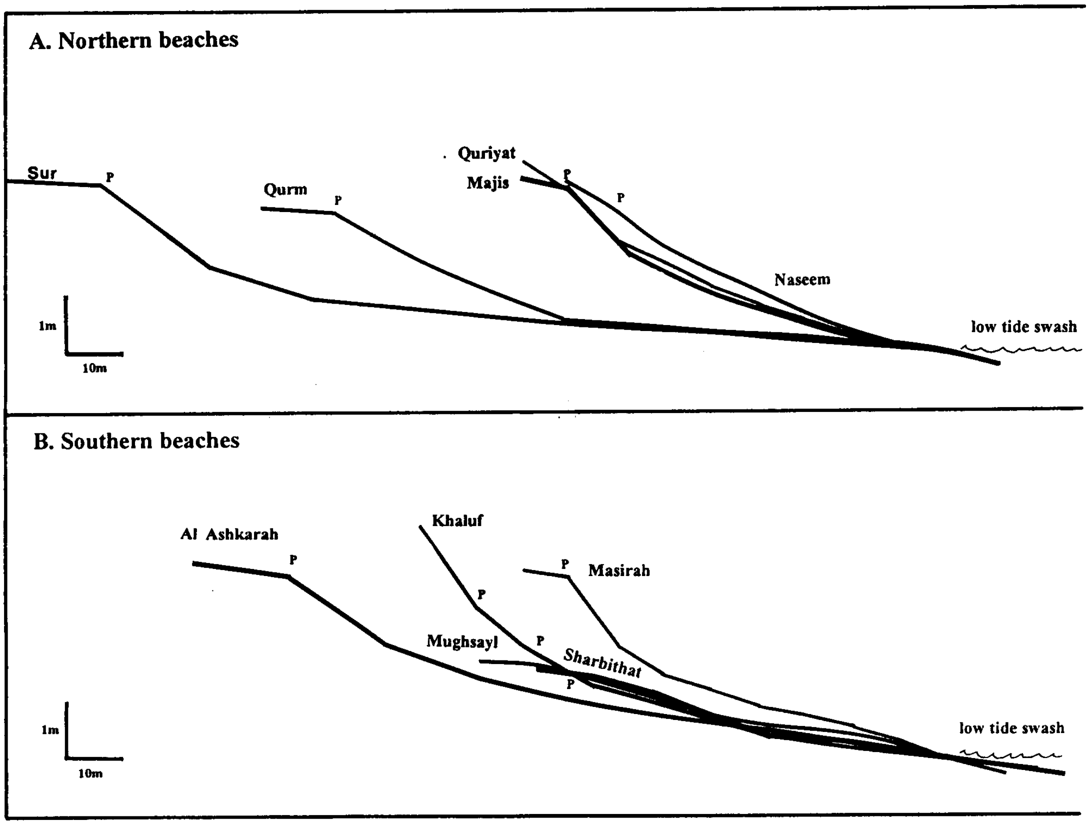

Fig. 2. Profiles of the 10 beaches sampled showing positions of drift line (P), water table outcrop (horizontal lines), and low tide swash region.

Supralittoral fauna at station 1 was not sampled. Rather, the number of burrows along 10 m of shoreline were counted, and ocypodid species composition taken from Clayton (1997) and TŸrkay et al. (1996). Quadrat sampling ran from station 2 to station 10. At each station five quadrats of 1/15 m^2 (0.067 m^2) were excavated to 25 cm and the sand passed through a 1-mm mesh sieve bag. All specimens were stored in 5 - 10 % formalin in sea water. Total sampled area was thus 3 m^2 per beach.

Sand samples were analysed by wet sieving through a nest of sieves at 1.0 phi intervals. Results were plotted as cumulative curves and graphic parameters calculated (Folk 1974). The fauna was sorted, identified as far as possible, and counted. Polychaetes were identified to genus, molluscs to species using Bosch et al. (1996), and crustaceans were despatched to various taxonomists.

For approximations of biomass 10 - 30 specimens of all common species were oven dried at 60¡C for 48h after removal of shells. For rare species where there were insufficient specimens for analysis, values were estimated from similar sized common species. Abundance and biomass were calculated per m^2 at each station and then per running m of transect for each species at each beach.

Relationships between the 10 beaches and zonation patterns within each were explored using established multivariate analysis techniques. For the between-beach analysis all samples for each beach were pooled, and the data standardised to 100 % within each beach, and for the within-beach analyses the data at each sampling station were standardized to 100 %.

Zonation within each of the 10 beaches was explored by superimposing the results of a TWINSPAN (Two-Way Indicator Species Analysis, Hill 1979a) clustering technique on the diagram of a Detrended Correspondence Analysis, (Hill 1979b) for each beach. The delimitation of relationships between beaches was explored in the same manner. In addition, in order to explore any potential influence of the measured environmental parameters on the relationships between beaches in the Ôordination spaceÕ, a second ordination was carried out in which the relationships between beaches were constrained on the measured environmental parameters (mean grain size, overall beach slope, particle sorting and the position of the water table outcrop) Ð this is the technique of Canonical Correspondence Analysis (CANOCO, ter Braak 1986; Jongman et al. 1995).

Results

Physical features of the beaches are summarised in Table 1 and sand analysis results in Table 2. At the time of sampling, all beaches were wide, concave, mesotidal and with fine to medium sand. Morphodynamically they divide into five northern beaches and five southern beaches. The northern beaches experience low wave energy and consist of wide, flat, tide-dominated lower shores and narrow, steeper, swash-dominated upper shores with a berm above the drift line. The water table outcrop usually corresponds to the break in slope on the beach face (Fig. 2). Sediments were mixed, moderately sorted dark ophiolite sands in the fine to medium range. Southern beaches (especially in the extreme south) were more wave dominated with smoother convex profiles and with the water table lower on the shore. The sediment was fairly well sorted fine white carbonate sand.

Wave energy was indicated by Hb/T where Hb =breaker height, T =period. This index was lower in the north: during the survey, values were 5-12 cm/s for the north as opposed to 9-13 cm/s for the south. Values will be higher during the southwest monsoon. Dividing these values by the sand fall velocity (Gibbs et al. 1971) gives dimensionless fall velocity (Ω) values of 2-5, typical of intermediate beaches.

Faunal species composition, abundance and biomass values for the 10 beaches are summarised in Table 3. A total of 58 species and species groups were recorded, some new to science and many not identified to species level. Polychaetes (at least 13 species), crustaceans (at least 25 species) and molluscs (14 species) were dominant. Minimum number of species per beach ranged from 19 (Quriyat) to 25 (Khaluf), with four beaches recording at least 23 species. Species richness was therefore relatively uniform across the beaches. It should be noted that actual species numbers will be higher than listed; ocypodids for example are known to occur as four species (Clayton 1996; TŸrkay et al. 1997) but are listed only as a single species here.

Abundance values were more variable than species richness and ranged from 3216 organisms/m transect (= 72 m^2) at Quriyat to 73326 organisms/m transect at Sur (162 m^2). Other than for this high value at Sur, and 31278 at Qurm, all beaches had total abund ances in the range 3-16 $\times 10^3$ organisms/m. Overall, crustaceans made up 52%, molluscs 31% and polychaetes 16% of total numbers.

Biomass values were relatively uniform, all falling in the range 28-90 g/m (shell-free dry biomass) except at Sur, where exceptional abundance of *Umbonium vestiarium* contributed 442 g/m (85% of biomass). Other cases where single species contributed significantly to total biomass were Qurm, where *Matuta victor* contributed 22 g/m (25% of biomass) and Mughsayl where *Emerita* spec. totalled 56 g/m (63% of biomass). Overall, molluscs made up 55% of biomass, crustaceans 24% and polychaetes 17%. Biomass values listed do not include supralittoral ocypodids, but do include their juveniles collected intertidally in the quadrat samples.

For all beaches except Masirah (also spelt Maseerah) and Mughsayl, the first TWINSPAN grouping identifies a clear zonation, with the top one (Naseem, Quriyat, Qurm and Sur), two (Al-Ashkarah, Majis and Sharbitat) or four (Khaluf) sampling stations being separated from those lower down, and with the two zones clearly separating on the first axis of the Detrended Correspondence Analysis (Fig. 3). The ordination and clustering analyses identify two zones within the lower beach zone on a few of the beaches, notably Qurm, Al-Ashkarah and Sharbitat, but in general the separations are much less marked than that between the upper and lower zones. It must be noted that, in addition to these two zones embracing stations 2 to 10 on each beach, supralittoral fauna occurred at station 1 which was not included in the zonation analysis.

Ocypodids were present on all upper shores, and juveniles often occurred in the intertidal zone. In the north, *Tylos* spec. nov. occurred in low abundance around the drift line. Below this, *Eurydice peracitis* inhabited the upper shore and then *Umbonium vestiarium* occured slightly lower, on sheltered shores. The lower shore was

Table 1. Physical features of 10 beaches in Oman Ð arranged from north to south as recorded on the sampling days.

Beach	Coordinates	Date	Sea water Temp. (°C)	Sea water Salinity %	Tide range predicted (m)	Beach width (stns 1-10) (m)	Station intervals (m)	Overall beach slope	Vertical drop stns 1-10 (m)	Water table outcrop (Stn)	Wave height (m)	Wave period (s)
Majis	24° 30' N; 56° 40'E	95.09.27	33	33	2.4	81	9	$^1/_{24}$	3,31	4,5	0,4	4
Naseem	23° 40'N; 58 ° 10'E	95.09.11	32	35	2,1	72	8	$^1/_{23}$	3,17	6,0	0,4	3
Qurm	23° 30'N;58 ° 30'E	95.09.10	32	34	2,2	117	13	$^1/_{46}$	2,52	5,0	0,3	4
Quriyat	23° 10'N;59 ° 00'E	95.11.21	28	36	2,4	72	8	$^1/_{21}$	3,35	6,0	0,2	4
Sur	22° 35'N;59 ° 30'E	95.10.26	31	32	2,6	162	18	$^1/_{53}$	3,08	3,5	0,3	4
Al-Ashkarah	21° 40'N;59 ° 30'E	95.10.25	29	31	2,6	144	16	$^1/_{39}$	3,73	3,7	0,9	10
Masirah	20° 35'N;59 ° 00'E	95.11.07	28	31	2,2	72	8	$^1/_{23}$	3,21	8,6	0,5	4
Khaluf	20° 25'N: 58 ° 00'E	95.11.06	29	31	2,1	90	10	$^1/_{22}$	4,08	6,2	0,5	4
Sharbitat	17° 55'N;56 ° 20'E	95.12.03	27	35	1,8	90	10	$^1/_{47}$	1,92	7,6	0,8	9
Mughsayl	16° 30'N;53 ° 45'E	95.12.05	30	35	1,9	90	10	$^1/_{45}$	1,98	8,9	1,0	8

inhabited by *Donax* spp., *Urothoe* sp., *Periculoides* sp. and *Gastrosaccus* sp. nov. and, near the swash zone, *Bullia* spp. and *Oliva bulbosa*. In the south, *Tylos* sp. nov. was abundant around the drift line, as were oligochaetes in most cases. Below this was *Excirolana* sp. nov., then *Eurydice longipes* and finally *Emerita* sp.; *Donax scalpellum* and *Gastrosaccus* sp. nov. occurred on the lower shore.

Classification of the 10 beaches resulted in a split into two broad groups, the four southern beaches being distinct from the five northern beaches and Al-Ashkarah (Fig. 4). The first level grouping of the TWINSPAN clustering identified two groups of beaches (Khaluf, Masirah, Mughsayl and Sharbitat, and Al-Ashkarah, Majis, Naseem, Quriyat, Qurm and Sur, Fig. 4a), with Sur being separated out from the other five beaches in the second level grouping. The two groups are also ordered in a similar fashion on the first axis of the Detrended Correspondence Analysis (Fig. 4a). Although the same two groups persist in the Canonical Correspondence Analysis (Fig. 4b), they are more clearly separated, with the four southern beaches being strongly constrained by the water table outcrop. Khaluf, Masirah and Mughsayl cluster together in the biplot, with Sharbitat additionally constrained by the overall beach slope. The relative length of the arrows for the four environmental parameters is an indication of the relative importance of their influence in the ordination, with water table outcrop being the most important followed, in order, by overall beach slope, particle sorting and mean grain size. Five of the six northern beaches cluster together in the biplot, largely characterised by a low water table outcrop and relatively steeper beach slopes. Sur is separated from the other northern beaches, being a beach with a relatively shallow overall slope.

Beaches of different morphodynamic types from different geographic localities have previously been compared using a simple index (Beach State Index, BSI) which is based on tide range, wave energy and particle size (McLachlan et al. 1997). High values (> 1.5) indicate ultradissipative beaches, whereas lower values (< 0.7)

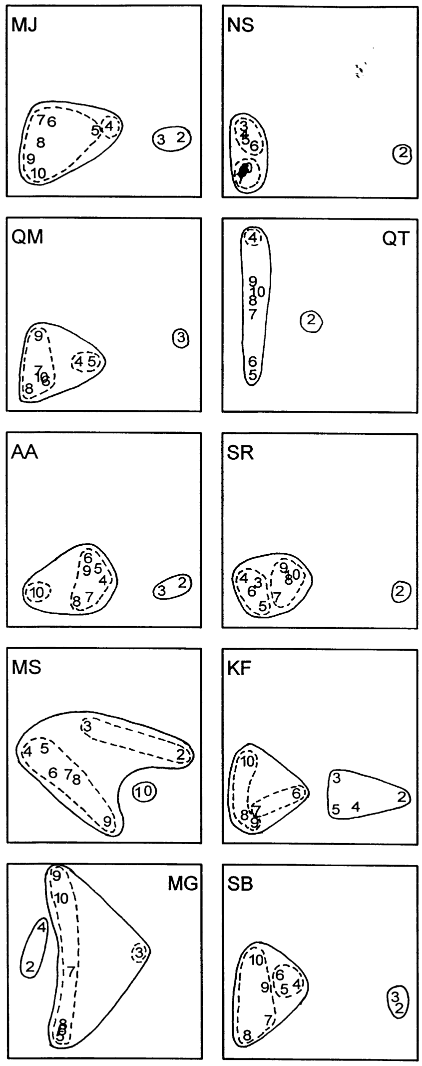

Fig. 3. Beach zonation: Detrended Correspondence Analysis, axes 1 and 2, with the first and second grouping of a TWINSPAN clustering superimposed (solid and dashed lines respectively) for each of the beaches. AA =Al-Ashkarah; KF = Khaluf; MG =Mughsayl; MJ =Majis; MS =Masirah; NS =Naseem; QM =Qurm; QT =Quriyat; SB, Sharbitat; SR = Sur. Top to bottom ordering is on an approximate N-S axis.

Table 2. Mean sand particle sizes at 10 stations across 10 beaches in Oman. Beaches listed from north to south.

Beach	Mean particle size (Mz) in µm stations 1	2	3	4	5	6	7	8	9	10	Overall mean µm (ϕ)	Graphic standard deviation σ_i Overall Mean (ϕ)	Highest (stn)	Lowest (stn)	Graphic skewness SK_i Overall mean (ϕ)	Highest (stn)	Lowest (stn)	Remarks (on sand)
Majis	500	220	150	180	260	190	190	175	135	140	200 (2.34)	0.96	1.21 (5)	0.70 (2)	Ð0.15	0.16 (1)	Ð0.49(10)	1*
Naseem	300	240	190	210	390	450	270	240	220	430	294 (1.83)	0.87	1.43 (10)	0.45 (3)	Ð0.08	+ 0.73 (1)	Ð0.47 (2)	2
Qurm	205	215	155	156	162	145	150	144	149	136	162 (2.64)	0.53	0.73 (5)	0.46 (3)	0.22	+0.29 (10)	Ð0.05 (5)	3
Quriyat	225	225	200	365	275	420	270	210	170	175	253 (2.04)	0.89	1.24 (4)	0.68 (2)	Ð1.10	Ð0.22 (8)	0.02 (7)	4
Sur	190	170	150	155	150	145	150	145	140	130	150 (2.72)	0.62	0.74 (4)	0.47 (2)	0.13	0.24 (3)	Ð0.10 (1)	1
Al-Ashkarah	420	200	160	160	145	160	115	150	120	220	170 (2.54)	0.81	1.31 (10)	0.50 (3)	Ð0.08	0.21 (3)	Ð0.32 10)	1
Maseerah	280	235	176	165	155	160	150	145	135	150	175 (2.50)	0.69	0.84 (10)	0.56 (3)	0.02	0.18 (7)	Ð0.11 (2)	1
Khaluf	540	240	190	145	145	150	125	140	165	180	202 (2.30)	0.90	1.83 (1)	0.65 (7)	0.01	0.16 (1)	Ð1.54(10)	1
Sharbitat	180	170	175	185	180	160	170	160	160	210	175 (2.48)	0.56	0.87 (10)	0.42 (2)	0.01	0.21 (6)	Ð0.29(10)	3
Mughsayl	175	175	175	175	175	75	175	175	170	180	175 (2.51)	0.37	0.42 (10)	0.32 (3)	0.02	0.13 (9)	Ð0.15(10)	5

* 1 =moderately sorted fine;2 =moderately sorted medium; 3 =fairly well sorted fine; 4 =moderately sorted medium/fine; 5 =well sorted fine.

Table 3. Summary of abundance and biomass of 58 species groups recorded on 10 sandy beaches in Oman. P = Polychaete; O = Olichaete; C = Crustacean and M = Mollusc.

	Majis	*Naseem*	*Qurm*	*Quiryat*	*Sur*	*Al-Ash*	*Masira*	*Khaluf*	*Sharbit*	*Mughs*
P. Glycera spp.	459	936	351	288	108	1488	768	750	1920	990
P. Magelona spp.	162	72	2847	360	4590	96	288	0	240	0
P. Orbinia sp.	54	0	78	72	162	0	0	150	0	180
P. Rhamphobracium sp.	108	0	39	96	810	0	24	390	0	30
P. Scoloplos sp.	1458	0	0	24	0	0	0	30	0	450
P. Lumbrineris sp.	0	0	0	0	54	0	0	60	30	60
P. Goniadopsis sp.	0	0	0	48	0	144	0	300	330	0
P. Neanthes sp.	0	0	0	0	108	0	0	120	0	0
P. Nephtys sp.	54	0	117	72	810	0	0	0	0	90
P. Polyophthalmus sp.	0	0	0	24	0	48	1656	1530	0	0
P. Sabellidae	0	0	0	0	162	0	0	0	0	0
P. Spionidae sp.	0	0	0	72	972	2352	0	0	0	0
P. Maldanidae	0	0	0	0	0	0	0	0	0	270
O. Oligochaete sp	0	0	0	0	0	0	0	0	570	120
C. Urothoe sp.	5265	1728	17511	1344	11070	336	0	390	0	0
C. Periculoides sp.	1701	384	2964	168	486	1344	672	360	0	30
C. Microprotopus sp.	513	336	3198	0	0	0	0	570	0	0
C. Ampelisca sp.	81	48	0	48	378	48	216	2010	0	1290
C. Indoischnopus sp.	54	0	0	0	0	0	0	60	0	0
C. Tylos sp. nov.	0	24	0	72	108	144	408	3090	870	120
C. Eurydice longipes	0	0	0	0	0	0	80	0	2400	40
C. Eurydice ?peracitis	297	800	0	0	0	0	0	0	0	0
C. Eurydice chelifer	0	184	0	0	0	0	0	0	0	0
C. Excirolana sp. nov.	0	0	0	0	0	0	80	300	2400	40
C. Sphaeromopsis sp.	0	0	0	0	0	0	80	0	2400	40
C. Cyathura sp.1	0	192	858	0	162	240	0	300	0	180
C. Cyathura sp. 2	0	192	156	0	0	0	0	60	0	0
C. Gastrosaccus sp. nov.	1674	936	1872	360	54	4128	1344	1320	3540	1500
C. Eocuma n. sp.	702	72	0	0	54	1296	192	27	0	0
C. Iphinoe n. sp.	216	0	0	0	0	0	0	0	0	0
C. Emerita sp.	0	0	0	0	54	48	336	0	60	1110
C. Hippa sp.	27	0	0	0	0	0	0	0	0	0
C. Pagurus sp.	0	0	0	24	0	96	168	0	0	0
C. Dotilla sulcata	0	48	39	0	0	0	0	0	0	0
C. Leucosid sp.	27	480	468	24	0	0	0	30	150	0
C. Matuta victor	0	0	78	0	0	0	0	0	0	0
C. Ocypode spp.	<1	24	<1	<1	<1	1	<1	30	7	10
C. Callianassa sp.	756	24	156	0	0	0	0	0	0	0
C. Acetes erythraensis	0	0	78	0	0	672	24	0	0	0
M .Bullia mauritiana	0	0	0	72	0	48	24	0	30	0
M. Bullia semiplicata	0	0	0	0	0	48	0	0	0	0
M. Nassarius persicus	0	0	10	0	0	0	0	0	0	0
M. Umbonium vestiarium	0	0	117	0	52596	0	0	0	0	0
M. Polinices mammila	0	0	10	0	0	0	0	0	0	0
M. Oliva bulbosa	0	144	39	0	54	144	0	0	0	0
M. Niso venosa	0	0	78	0	0	0	0	0	0	0
M. Impages hectica	0	0	0	0	0	0	0	0	0	150
M. Donax scalpellum	567	48	117	0	0	336	48	540	60	60
M. Tivela ponderosa	0	24	117	24	0	0	96	0	210	0
M. Donax clathratus	0	0	0	0	54	0	0	300	0	0
M. Donax nitidus	0	0	0	0	54	0	0	0	0	0
M. Donax townsendii	0	408	0	0	0	0	0	330	210	90
M. Dosinia alta	0	0	0	24	378	0	0	60	0	0
Nemertea sp.	135	192	0	0	0	48	24	0	90	180
Insect larvae	27	48	0	0	0	48	0	0	90	0
Coleoptera	108	0	0	0	0	0	0	0	90	0
Juvenile crabs	27	0	0	0	0	0	0	0	30	0
Hemichordates	0	0	0	0	48	0	54	0	0	0
Number of species	23	23	23	19	23	21	20	25	20	21
TOTAL (numbers per metre)	14472	7344	31298	3216	73326	13153	6582	13107	15727	7030
BIOMASS (grams per metre)	54.3	48.2	89.9	28.6	523.1	77.2	44.2	42.1	51.2	88.5

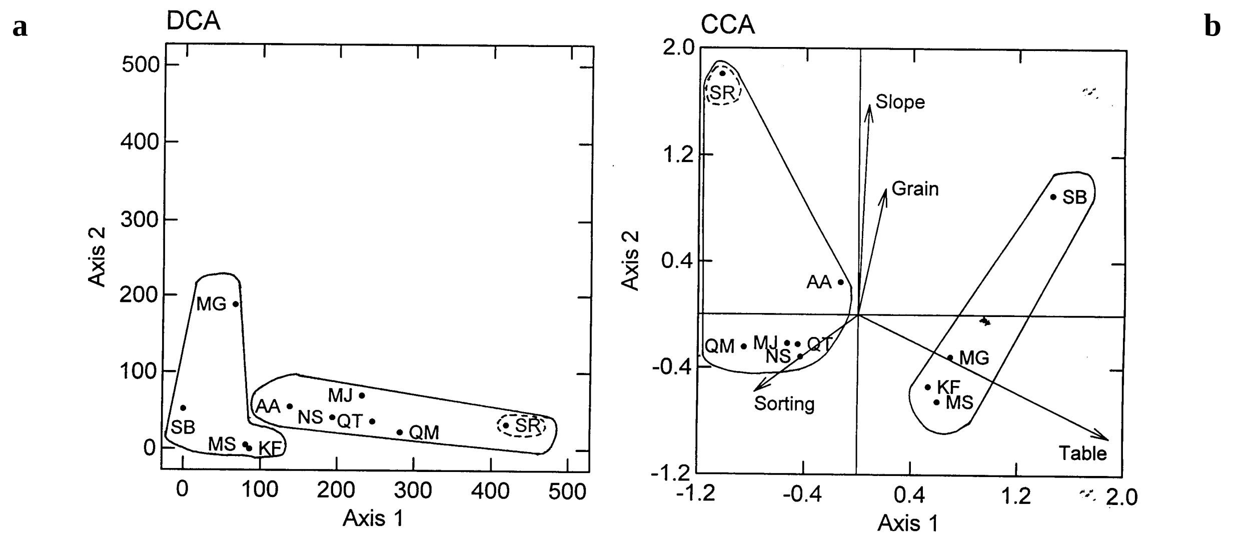

Fig. 4. Relationships between beaches. **a.** Ordination diagram of a Detrended Correspondence Analysis, axes 1 and 2, with the first and second grouping of a TWINSPAN clustering superimposed (solid and dashed lines respectively); **b.** Biplot of a Canonical Correspondence Analysis, axes 1 and 2, also with the first and second grouping of the TWINSPAN clustering superimposed and with arrows indicating the direction of influence of the four physical parameters (overall beach slope, mean grain size, particle sorting and position of water table outcrop). The relative length of the arrows for the environmental parameters indicates the relative strength of their influence in ordering the data, and the direction of the arrows the direction of their influence in the ordination space. Site abbreviations as in Fig. 3.

generally indicate microtidal reflective beaches. To calculate this for the Omani beaches, a maximum tide range of 3.0 m was assumed in all cases and sand particle size was converted to fall velocity using Gibbs et al. (1971). Comparison of OmanÕs beaches with 70 other beaches from a variety of regions around the world (McLachlan et al. 1997) (Figs. 5 - 7) indicates that these beaches fall in the upper mid-range of beach types (BSI 1 - 1.3) and are intermediate between microtidal and macrotidal systems. Species richness (Fig 5) is notably high on these Omani beaches which form a cluster well above the global trend. Abundance (Fig. 6) matches the global trend but tends to be slightly above average for beach state. Biomass, on the other hand (Fig. 7), while clustering amongst global values, tends in most cases to be slightly below average.

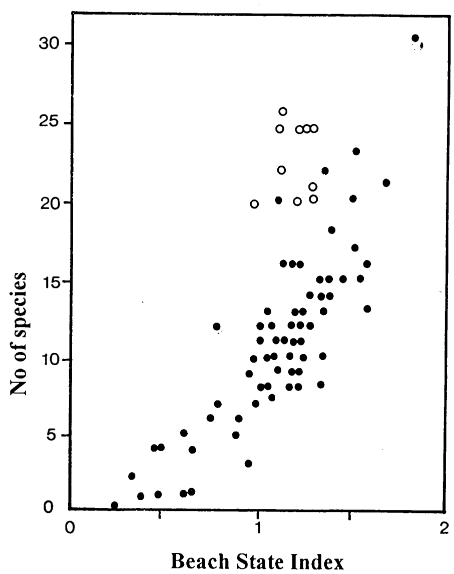

Fig. 5. Species richness as a function of beach state after McLachlan et al. (1997) with 70 ÔglobalÕ values (filled circles) and 10 Omani beaches (open circles).

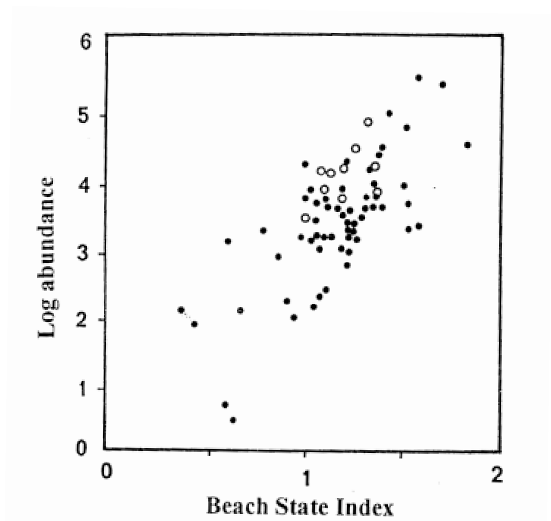

Fig. 6. Total faunal abundance over a range of beaches, after McLachlan et al. (1997), (filled circles) and for 10 Omani beaches (open circles).

Discussion

The sandy beaches of the Oman coastline are subjected to low to medium wave energy, mesotidal and subject to tropical temperatures, although in the extreme south they may become subjected to high wave energy during the summer southwest monsoon, at which time they experience lower sea-surface temperatures due to upwelling. This is the first report of the ecology of such systems, most previous work having been confined to microtidal wave-dominated beaches.

The prevalent conditions of tide and wave energy, interacting with mostly fine sand, result in broad flat beaches, tide-dominated on the lower shores but tending towards swash control in the upper intertidal. Based on the dimensionless fall velocity or DeanÕs parameter ($\Omega = 2$ - 5) the beaches may be classified as intermediate, i.e. neither dissipative nor reflective. Based on relative tide range (RTR = tide range/breaker height) they are intermediate to tide-dominated (RTR = 3 - 15), never wave-dominated, except during the monsoon in the south. Following a gradient of decreasing wave energy from south to north, OmanÕs beaches thus become increasingly tide-dominated.

The number of species (and species groups) recorded is high at 58, and includes several new species, reflecting the limited knowledge of intertidal ecology in this area. A few species are typical of the north west Indian Ocean and also occur on the coasts of Africa and India. TŸrkay et al. (1996) considered the East African assemblage of ocypodids to be distinct from those of Oman which in turn are distinct from those of India and Pakistan, although both *O. cordimanus* and *O. rotundata* have wide distributions. Clayton (1996) also considered the Omani ocypodid assemblage to be distinct from that of East Africa and India.

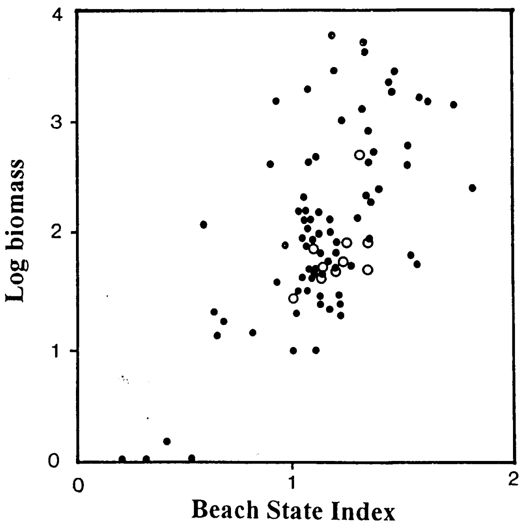

Fig. 7. Biomass over a range of beaches, after McLachlan et al. (1997) (filled circles) as well as for 10 Omani beaches (open circles).

On six of the 10 beaches zonation appears to be associated with the position of the water table outcrop, which lies close to the separation of the upper from the lower shore zone at Al-Ashkarah and Sur and close to the separation of the lower shore into two zones at Khaluf, Majis, Naseem, Qurm and Sharbitat. There does not appear to be any obvious influence of the position of the water table outcrop at Masirah, Quriyat or Mughsayl. Overall, these zonation patterns conform to the typical pattern of three zones described for many other shores (McLachlan & Jaramillo 1995): air breathing crustaceans (*Ocypode, Tylos*) characterise the supralittoral, cirolanid isopods the mid-shore and a variety of species the lower shore.

The supralittoral fauna has been covered only superficially in this study as it was not included in the quantitative samples and has been described elsewhere. Four species of ghost crabs occur on Arabian shores, *Ocypode cordimanus, O. joisseaumei, O. rotundata,* and *O. saratan* (TŸrkay et al. 1996), *O. rotundata* being commonest on open beaches (Clayton 1996). The supralittoral *Tylos* is a new species currently under description, as are two of the cirolanids.

The separation of the beaches into two groups by the ordination and clustering analyses (Fig. 4a) is a N-S split, suggesting two zoogeographical divisions. However, the beachesÕ physical characteristics provide a relatively clearer separation (Fig. 4b). The four southern beaches appear to be largely separated from those of the north by the influence of the position of the water table outcrop, and there is therefore no clear evidence for a zoogeographical split. Rather, physical beach parameters appear to play an overriding role in the overall composition of the beach fauna.

Since many species (e.g. *Gastrosaccus* sp. nov., *Donax scalpellum*) were common to all 10 beaches (Table 3), this reinforces our conclusion that we are not dealing with two distinct zoogeographic provinces. Rather, this implies that the coast of Oman constitutes a single province with subregions in the north and south determined by physical factors, particularly exposure. Species most characteristic of the north were the amphipolds *Urothoe* sp., *Periculoides* sp., *Microprotopus* sp. and the cirolanid *Eurydice peracitis*, the sand shrimp *Callianassa* sp. and the gastropods *Oliva bulbosa* and *Umbonium vestiarium*. These are all species characteristic of lower energy situations. In the south *Ampelisca* sp., *Tylos* sp. nov., *Excirolana* sp. nov., *Sphaeromopsis* sp. and *Emerita* sp., all species favouring exposed situations, were more common.

Plotting the species richness, abundance and biomass of the Omani beach macrofauna against a beach state index (BSI) allows a crude comparison with a wide range of beaches from different latitudes and conditions. These plots (Figs. 5 - 7) show that OmanÕs beaches are distinguished by high species richness, whereas abundance and biomass fall well within the range recorded on other beaches. The high species richness is even more remarkable when it is considered that not all specimens were identified to species level: ocypodids are known to occur as four species, but are listed as one, and insects associated with the drift line were not included. Further, Jaramillo et al. (1995) have shown that a total sample area of 3.0 m^2, as used here, recovers about 90% of the species on a beach. Bearing this in mind we suggest that true species richness for Oman may lie around 30 species per beach survey, considerably above the normal range recorded on beaches with similar BSI values.

Why are these beaches so species rich? The answer may lie in a combination of:
(1) the location in a tropical region marked by generally high diversity (Sheppard et al. 1992);
(2) sands of variable mineralogy and a spread of particle sizes providing more niches than the very well sorted sands typical of exposed beaches; and
(3) the creation of a relatively benign environment by the low energy conditions, thus enabling delicate forms that are often excluded from more exposed beaches to survive, especially on the flat lower shore.

Relevance for conservation and management

This study has provided a first account of sandy beach ecology on the Indian Ocean coast of the Arabian peninsula. In view of the considerable shipping traffic and high potential for oil spills in this area, baseline information is clearly needed. We have presented quantitative information which will serve as a baseline for further work on coastal conservation and pollution monitoring in the region. This has shown that OmanÕs sandy beaches are characterised by tide-dominated morphology and increasing wave exposure southwards. They constitute a single zoogeographic province and harbour a fauna distinguished by exceptionally high species richness. However, despite the many species present, none attain sufficient abundance to support commercial exploitation. This information should be expanded in the future with studies on seasonal patterns and human impacts.

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