Long or short? Investigating the effect of beach length and other environmental parameters on macrofaunal assemblages of Maltese pocket beaches

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**A B S T R A C T**

Despite numerous published studies that have evaluated the influence of different physical parameters, including beach slope, sediment organic content and grain size, on beach macrofaunal assemblages, very few studies have investigated the influence of beach length on biotic attributes of the same assemblages. Four beaches on the Maltese Islands were sampled using pitfall traps at night for eight consecutive seasons during 2001–2003. Macrofaunal collections were dominated by arthropods, mostly isopods (especially *Tylos europaeus*) and tenebrionid beetles (especially *Phaleria* spp.). The environmental variables of beach slope, exposure to wave action, sediment organic content, mean particle diameter, log beach length, beach width and the beach deposit index (BDI) were regressed against a number of biotic parameters, including log individual abundance, total species, Shannon–Wiener (*H*₀) diversity index value and the psammophilic fraction of the total species collected, whilst BIO-ENV and NMDS were used to identify the physical parameter which could best explain observed biotic patterns. RELATE was used to assess the long-term persistence of macrofaunal assemblages on beaches of different lengths. Results from this study suggest that, whilst the influence of beach length and beach width on individual abundance and total species number is unimportant, these ‘beach-area’ parameters may affect the taxonomic composition of a beach assemblage, mainly in terms of the psammophilic fraction of assemblages, as well as the permanence of macrofaunal assemblages on a beach. Shorter and narrower beaches were found to be more prone to sporadic and random events of colonisation by euryoecious species. In the absence of human disturbance and mass mortality events, beaches of limited dimensions can still maintain stable macrofaunal assemblages. Individual abundance and total species number could not be related to a single or small suite of physical parameters. The study further highlights the need to include biological interactions, the degree of human disturbance and other variables such as environmental heterogeneity and the connectivity of the individual beaches when assessing inter-beach differences in macrofaunal assemblages.

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1. Introduction

Total species number and individual abundances of beach macrofauna have been shown to decrease with increasing beach slope and grain size, and with decreasing beach width (e.g. Degraer et al., 2003). The effects of beach length (i.e. distance between headlands) on these biotic parameters have, however, hardly been addressed, with the exception of the studies by Rodil et al. (2006) and Brazeiro (1999). The latter postulates that the total number of species may increase with beach length, with short and ‘pocket’ beaches supporting fewer species than longer ones, although the relationship between beach length and total species number is not obvious and may be non-linear and scale-dependent. According to McLachlan and Dorvlo (2005), however, the effects of beach length on total species number are not clearly understood.

Rodil et al. (2006) list beach length, along with slope and wave height, as the main environmental variables affecting the total species number, individual abundance and biomass of macrofaunal communities on intermediate-sized beaches. These authors, however, suggest that different macrofaunal species exhibit different responses to increasing beach length. While most species (e.g. the amphipod *Bathyperote pelagica*, the bivalve *Donax trunculus* and the cumacean *Cumopsis fagei*) found in the lower beach levels showed higher densities on longer beaches, species of the upper beach (e.g. the polychaete *Ophelia bicornis* and the amphipod *Talorchestia brito*) showed an opposite trend, whilst the density of other species...
Communities, while Colombini et al. (2005) studied the influence of plant cover on tenebrionid species. Carpaneto and Fattorini (2001) looked at the influence of humidity, water level and light intensity on the surface activity of the carabid Eurynebria complanata and moisture, sand temperature and salinity on the distribution of selected beach arthropods, and Fallaci et al. (1997) examined the influence of air temperature, relative humidity, pH, sand moisture and organic matter, sediment granulometry and sand temperature within continuous patches of habitat with respect to fragmented habitat patches. By using Maltese beaches as a test, this study aims to investigate whether increasing beach length (defined as the distance between the headlands of a beach) results in higher total species number and individual abundance within psammophilic (i.e. beach-specific) arthropod communities, and whether beaches of limited length can sustain long-term populations of these species.

2. Materials and methods

2.1. Macrofaunal sampling

Four Maltese beaches of different length, varying from 80 m (Xatt I-Ahmar) to 500 m (Ramla I-Hamra) were sampled (Fig. 1). Table 1 gives selected characteristics of the beaches sampled.

Due to beach length considerations, one transect was used on the beach at Xatt I-Ahmar, two transects were used on the beach of White Tower Bay and three transects were used on the beaches of Ramla I-Hamra and Golden Bay. Transects were divided into a wet and dry zone, using the strandline as the boundary between the two zones. This was possible since the maximum tidal range on the Maltese Islands is only 20 cm. Samples were collected in eight consecutive seasons, from autumn 2001 to summer 2003. Constellations of pitfall traps, each consisting of five plastic cups (7.5 cm diameter and a height of 10 cm) arranged one at the centre and the other four in a cross pattern separated from the central cup by a distance of 1 m, were used to collect nocturnal, surface active fauna. Each cup was inserted into the sand such that the rim was flush with the sediment surface. The peripheral traps were connected to the central one by thin strips of ‘Flexiglas’ resting on the sand, which served as walk-ways. Traps were left overnight and emptied in the morning. A pitfall trap constellation was placed in the wet and dry zone of each transect. The number of transects and pitfall trap constellations per beach resulted in little variability in sampling effort, which ranged from 1 constellation 2000 m$^{-2}$ of beach area to 1 constellation 3000 m$^{-2}$ of beach area. Macrofauna collected were identified and counted, and collections were standardized to individuals per trap per hour.

2.2. Monitoring of environmental parameters

Beach environmental parameters monitored were the mean grain size of the sediment, the percentage organic content of the sediment, beach slope and exposure to wave action, whilst the length and width of each of the beaches sampled were also measured. Exposure to wave action was determined using the method described by Thomas (1986). The parameter ‘beach length’ was log transformed to reduce the large differences in values obtained for the different beaches (range 0.08–0.50 km). A difficulty encountered in the present study when assessing the effect of beach width on macrofaunal communities was the definition of beach width itself, which is not always clear in the literature. For the purpose of the present study, beach width was taken to be the maximum extent of the ‘bare-sand, unvegetated width’ of the beach (i.e. excluding even dunal remnants). Under such a definition, Ramla I-Hamra exhibited the largest beach width (maximum 100 m), whilst Xatt I-Ahmar exhibited the smallest beach width (maximum 18 m). Beach width maxima were used in the statistical analyses.

2.3. Statistical analyses

For each beach, the total individual abundance ($N$) was calculated; values were then log transformed to down weight the importance of the very abundant species in order to allow rare species to play some role in determining similarity between samples (Clarke and Warwick, 1994). Total species ($S$) as well as values for the Shannon–Wiener ($H'$) diversity index log$_2$ were calculated for each beach.

The number of species recorded exclusively on just one beach was expressed as a percentage of the total number of species recorded from the same beach, whilst the psammophilic fraction of the total number of species was also estimated (Table 1).
Psammophiles are sand-specific species, which were separated from coastal (i.e. present in different coastal habitats, including on rocky shores) and euryoecious/ubiquitous species on the bases of their habitat preferences in Malta as reported in the literature (e.g. Caruso and Lombardo, 1982; Mifsud and Scopula, 1998; Mifsud, 1999; Nardi and Mifsud, 2003) or following consultation with relevant taxonomists (see Acknowledgements). Species which were collected in less than 1.5% of all pitfall trap samples (considered arbitrarily as an adequate truncation point to eliminate rare species contributing to data noise), or during one season only, were excluded from the analyses.

A number of studies (e.g. Rodil and Lastra, 2004) highlight the usefulness of composite variables/measures, rather than individual variables, in explaining observed biotic patterns. McLachlan et al. (1993) found that Dean’s parameter is a good predictor of the total number of species, abundance and biomass for microtidal beaches from different geographic regions; however, since wave-related data were not recorded in the present study, another biotic classification index, BDI, was calculated. BDI is commonly used for microtidal beaches under a wide range of conditions and has been applied by McLachlan and Dorvlo (2005) in identifying global patterns in sandy beach macro-benthic communities. The index is calculated as follows:

$$BDI = \left(\frac{1}{\tan B}\right) \left(\frac{a}{Mz}\right)$$

where tan B is the beach slope, a is 1.03125 (mm) and Mz is the mean sand particle size (mm). Despite the biotic variables monitored being probably dependent on more than one environmental variable, possible correlations between environmental variables (including BDI) and the various biotic parameters were investigated using simple linear regression, as multiple regression analyses are reproduced in Fig. 2A–D. The psammophilic fraction was recorded from the longest beach (Ramla l-Hamra) and the shortest from the shortest beach (Xatt l-Ahmar), whilst the highest percentage of single-beach species was recorded from the shortest (Xatt l-Ahmar) and the longest (Ramla l-Hamra) beaches sampled. This was done in order to assess the long-term persistence of macrofaunal assemblages on beaches of different lengths.

In order to gauge the adequacy of sampling efficiency, the Chao and Lee Type II species estimator was computed to estimate the seasonal values of species richness for the various beaches sampled. This non-parametric estimator appears to be one of the most robust species richness estimators (Henderson and Seaby, 2002) and has been recommended by Walther and Moore (2005) as the most suitable (in terms of reduced bias and high precision) species estimators for beetles and invertebrates.

Multivariate statistical analyses were made using the PRIMER 6 (Clarke and Gorley, 2006) and the SPSS v. 13 (Norussis, 1993) statistical packages.

3. Results

3.1. Biotic and abiotic data

A total of 16,260 individuals belonging to 141 species and 14,556 individuals belonging to 129 species were collected respectively during the first and second year of sampling. All species collected were arthropods. Fauna collected from all the beaches considered together belonged to 17 broad taxonomic groups, with Coleopterans being the most represented in terms of species and Isopoda being the most represented in terms of individual abundance. The most common species in the samples (in terms of individual abundance) were Tylus europaeeus, Phaleria acuminata, Phaleria bimaculata, Tallitrus saltator and Orchestia stephensi.

Table 1 gives the values of selected physical parameters for the beaches sampled, together with the total number of species of the psammophilic fraction of the fauna collected, the total individual abundance for each beach, and the percentage (over the total number of species for the beach) of species restricted to single beaches only.

The highest percentage of single-beach species was recorded from the shortest beach (Xatt l-Ahmar), whilst the highest psammophilic fraction was recorded from the longest beach (Ramla l-Hamra) and the lowest from the shortest beach.

Values obtained for the Chao non-parametric estimate for species richness (S) coincide very closely with the recorded values of species richness, with the exception of White Tower Bay dry zone values, indicating the ‘expected’ number of species was indeed recorded for every beach through the trapping technique.

3.2. Biotic–abiotic relationships

No conclusive correlations between the biotic variables measured (logN, S, and H’ and the psammophilic fraction) and the environmental variables emerged from the simple linear regression analyses. Just four of the 28 regressions carried out were significant ($p = 0.05$; d.f. = 3). The relevant plots for the significant biotic–abiotic regressions are reproduced in Fig. 2A–D. The psammophilic fraction (of the total number of species) was positively correlated

<table>
<thead>
<tr>
<th>Beach</th>
<th>Beach length (km)</th>
<th>Beach width (m)</th>
<th>BDI index value</th>
<th>Mean percentage of sediment organic content (% (SD))</th>
<th>Exposure to wave action value</th>
<th>Mean grain size (phi (SD))</th>
<th>Mean beach slope (degrees (SD))</th>
<th>Mean H’ values (SD)</th>
<th>Percentage of single-beach species</th>
<th>Psammophilic fraction (based on species) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Tower Bay</td>
<td>0.12</td>
<td>85</td>
<td>4.87</td>
<td>0.075 (0.019)</td>
<td>6.19</td>
<td>2.83 (0.90)</td>
<td>1.45 (0.88)</td>
<td>0.97 (0.54)</td>
<td>32.1</td>
<td>17.9</td>
</tr>
<tr>
<td>Golden Bay</td>
<td>0.22</td>
<td>75</td>
<td>2.00</td>
<td>0.075 (0.020)</td>
<td>6.80</td>
<td>1.66 (0.45)</td>
<td>1.54 (1.20)</td>
<td>1.13 (0.58)</td>
<td>30.8</td>
<td>25.5</td>
</tr>
<tr>
<td>Ramla l-Hamra</td>
<td>0.50</td>
<td>100</td>
<td>0.045</td>
<td>0.045 (0.010)</td>
<td>8.72</td>
<td>2.20 (0.35)</td>
<td>2.42 (1.10)</td>
<td>0.59 (0.36)</td>
<td>41.8</td>
<td>29.1</td>
</tr>
<tr>
<td>Xatt l-Ahmar</td>
<td>0.08</td>
<td>18</td>
<td>2.36</td>
<td>1.21 (0.37)</td>
<td>2.21</td>
<td>1.29 (0.22)</td>
<td>1.02 (0.44)</td>
<td>0.74 (0.24)</td>
<td>55.6</td>
<td>16.7</td>
</tr>
</tbody>
</table>
with log beach length and beach width, whilst the total species number \((S)\) was positively correlated with beach width and sediment organic content.

The abiotic-factor combination which gave the highest, albeit still low, correlation factor (rho value 0.370) in the BIO-ENV analysis was the beach slope/sediment organic content. The abiotic factor combination involving beach length that had the highest correlation factor was exposure to wave action/beach length/beach width, with a rho value of 0.333, indicating that beach length is not an important abiotic factor in explaining the observed biotic separation patterns.

Fig. 3 gives the NMDS plot for pitfall trap samples collected during both years of sampling. Of the different physical parameters used as overlays in the NMDS analyses, beach slope and sediment organic content were the most useful in explaining the observed ordination patterns, although they could not fully explain them; the NMDS ordinations overlaid with beach slope and sediment organic content are shown in Fig. 3.

A comparison of cyclical model similarity matrices generated using biotic data from the shortest (Xatt l-Ahmar) and the longest (Ramla l-Hamra) Maltese beaches sampled, together with an analysis of the single-season collections, was done in order to assess the long-term stability of macrofaunal communities on short beaches. Table 2 gives the results of the RELATE analysis; none of the values obtained were significantly different from the generated cyclic pattern at \(p = 0.05\).

Table 3 gives the percentage number of times that species were collected from the beaches over the total sampling period. No clear pattern emerges from this table, although the longest Maltese beach (Ramla l-Hamra) gave the lowest percentage of ‘single-season species’ and the shortest Maltese beach (Xatt l-Ahmar) had the highest such percentage. Considering the combined percentages of species collected in four sessions or more (and hence exhibiting inter-annual persistence on a beach), Xatt l-Ahmar had the second highest value (8.7%), whilst Ramla l-Hamra had the second lowest value (7.2%).

4. Discussion

In the analysis of different Chilean beach assemblages by Brazeiro (1999), simple and multiple linear regression analyses (forward stepwise method) did not show any significant correlation between the total number of species and beach length; however, when the analysis was carried out for the 0.2–2.0 km range of beach lengths, the total number of species residuals increased with beach length, suggesting that the two are related, although not in an obvious way.

In the present study, beach length did not emerge as an important discriminatory factor when regressed against various biotic factors (with the exception of the psammophilic fraction measure) and was not identified as an important structuring variable in the
multivariate analyses. No single environmental variable was useful in explaining the observed biotic separation patterns. On the other hand, the longest and shortest Maltese beaches sampled (Ramla l-Hamra and Xatt l-Ahmar respectively) had the largest and smallest psammophilic component of the total number of species recorded from all Maltese beaches, respectively, while the psammophilic fraction was positively correlated ($p < 0.05$) with both log beach length and beach width.

Taxonomic composition is also influenced to an extent by human disturbance (e.g. Scapini et al., 1992; Weslawski et al., 2000; Colombini et al. (1996) and Fallaci et al. (1996) as regulating the extent of dunal vegetation in the back-beach areas or the degree of human disturbance, rather than environmental factors, structure the macrofaunal assemblage on the sandy beaches studied. In fact, some authors, including, Dugan et al. (2004), believe that biological interactions, including competitive ones, not only affect the distributions and zonation of intertidal macro-infauna but potentially also community structure. Studies by Veloso and Cardoso (2001) show that the abundance of the communities was also not related to any physical parameter and these authors suggested that certain biotic factors, such as food source, recruitment, predation and competition, are responsible for the differences in macrofaunal densities between beaches. In addition, Nucci et al. (2001) have demonstrated a relationship between environmental heterogeneity and species richness.

Since the macrofaunal species collected in the present study were predominantly terrestrial, marine connectivity factors, including the degree of long shore current diffraction by headland obstruction, are not expected to play such an important role in the structuring of the beach macrofaunal assemblages.

The discordance between biotic and abiotic data might also be due to the restricted number of sandy beaches sampled in the present study and perhaps also due to insufficient characterisation of the physical environment. Additional physical parameters which were not monitored in this study and which are considered by Colombini et al. (1996) and Fallaci et al. (1996) as regulating the zonation of at least some of the sandy beach macrofauna, include air and sand temperatures, sand water content (especially important for burrowing activity of isopods), the relative humidity of the air and even the sea–land direction of the wind. The inability of the present study to relate beach community parameters (the total number of species and individual abundance) with physical variables is at variance with the observation by Braziero (2001) and Rodil and Lastra (2004) that no single physical factor actually accounts for changes in the total number of species, individual abundance and biomass. The relative lack of biotic–abiotic correspondence might suggest that biological interactions and other site-specific factors, including the extent of dunal vegetation in the back-beach areas or the degree of human disturbance, rather than environmental factors, structure the macrofaunal assemblage on the sandy beaches studied. In fact, some authors, including, Dugan et al. (2004), believe that biological interactions, including competitive ones, not only affect the distributions and zonation of intertidal macro-infauna but potentially also community structure. Studies by Veloso and Cardoso (2001) show that the abundance of the communities was also not related to any physical parameter and these authors suggested that certain biotic factors, such as food source, recruitment, predation and competition, are responsible for the differences in macrofaunal densities between beaches. In addition, Nucci et al. (2001) have demonstrated a relationship between environmental heterogeneity and species richness.

The general species-deficient nature of the beaches sampled can be attributed to their micro-tidal, reflective conditions, which have been associated with low total species counts (the Habitat Harshness Hypothesis; Deido et al., 2001). Pocket beaches of reduced length might be considered as ecological islands in their own merit, in view of the lack of long shore currents between them, and due to the paucity of sandy coastlines on the Maltese Islands, which results in the few sandy beaches being separated by long stretches of...
non-sandy coastline (Deidun and Schembri, in press); this is presumed to hinder inter-beach biotic recruitment. Such a lack of recruitment to beaches of reduced length is especially significant when considering the effect of stochastic events, including severe storms, and of human disturbance, which might extinguish particular species from a beach. Beaches from where such species have been extirpated may remain without these species for long periods of time due to the reduced inter-dune dispersal as a result of their isolated nature. Jaramillo et al. (1996) are of the opinion that naturally occurring disturbances are far more disruptive events than mechanical disturbance by human activity.

McLachlan and Dorvlo (2005) state that small beaches cannot sustain stable macrofaunal communities; the present study gave conflicting results with respect to this claim. The RELATE analysis indicated that the whole beach macrofaunal assemblage as well as selected macrofaunal taxa did follow a cyclical pattern of variation over the two sampling years, hinting at a possible inter-annual community persistence. This might suggest one of two things: (1) if a critical beach length, below which long-term biotic community stability and permanence are not possible, does exist then this length must be below 80 m (the length of the beach at Xatt l-Ahmar), at least for Maltese beaches; or (2) that effective inter-beach recruitment is occurring.

A large fraction of the species collected in this study (77 species, 40.3%) was collected from single beaches only. This suggests that there is little inter-beach connectivity. This is not surprising given that Maltese shores are predominantly rocky with just 2.4% of the 210-km long coastline consisting of sand or shingle (Axiak et al., 1999) and that most Maltese beaches are isolated by headlands and by long stretches of rocky coastline.

For all the beaches sampled and irrespective of their length, the majority of species collected were recorded during one sampling season only (percentage of ‘single-season’ species ranging from 52.7 to 67.6%). The percentage of species collected in less than 4 out of the total 8 seasons sampled (hence, not showing inter-annual persistence) ranged from 87.6 to 92.0% on the same beaches. Besides the instability of macrofaunal communities on small pocket beaches, stochastic events, which contribute to the variability in species composition on a beach, may explain these observations. Post-storm recolonisation of the beaches studied may result from recruitment from back-beach dunal areas, rather than from adjacent beaches—three of the four beaches sampled in the present study were backed by small pockets of degraded dune remnants (the exception was Xatt l-Ahmar which was too narrow for a dune to develop but was backed by vegetated clay slopes). This emphasises the ecological importance of dune remnants as potential refugia for psammophilic species, even when such remnants are degraded, although further studies on the degree of overlap between dunal and beach faunal populations are necessary to assess this.

### 5. Conclusion

In conclusion, the results of this study suggest that ‘beach area’ considerations, including beach length and width, whilst not immediately important in structuring beach macrofaunal communities, might impinge on the taxonomic composition of such assemblages, with shorter and narrower beaches being more prone to sporadic and random events of colonisation by euryecious species. The same results further emphasise the need to factor in biotic interactions in studies on community descriptors and to employ composite environmental variables rather than single variables in testing for their putative influence on beach macrofaunal assemblages. This study also suggests that extremely short beaches can still sustain stable macrofaunal communities and, in the absence of human disturbance and extreme stochastic events, these can act as refuges for otherwise rare psammophilic species.

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