

**Faunistic diversity of
Maltese pocket sandy and
shingle beaches: are these
of conservation value?***

OCEANOLOGIA, 47 (2), 2005.
pp. 219–241.

© 2005, by Institute of
Oceanology PAS.

KEYWORDS

Shingle
Sandy beaches
Fauna
Coastal conservation
Malta

MARIKA J. GAUCI
ALAN DEIDUN
PATRICK J. SCHEMBRI

Department of Biology,
University of Malta,
Msida MSD06, Malta;
e-mail: asmgauci@maltanet.net

Received 19 January 2005, revised 21 April 2005, accepted 10 May 2005.

Abstract

The littoral fauna of Maltese sandy and shingle beaches is generally regarded as impoverished and consequently of little conservation interest. The fauna of three sandy and three shingle beaches was systematically sampled by coring, standardised searching and pitfall traps. Diversity and population density were highest at the surface for sandy beaches, but were highest below the surface for shingle. The two beach types had distinct suites of species and individual beaches were faunistically distinct. Maltese sandy and shingle beaches are of conservation importance for their habitat-restricted species, some of which have limited local and regional distributions, and are internationally protected.

* The work on sandy beaches was carried out as part of the MECO project (Bases for the Integrated Sustainable Management of Mediterranean Sensitive Coastal Ecosystems) funded by the European Commission under its 'Co-operation with the Third Mediterranean Countries and International Organizations' (Contract No ERBIC 18-C198-0270).

The complete text of the paper is available at <http://www.iopan.gda.pl/oceanologia/>

1. Introduction

Despite their small size (316 km²), the Maltese Islands have a relatively long coastline of 272 km (Axiak et al. 1999). Rocky shores are the predominant shore type, constituting c. 90.5% of the entire coastline; sandy and shingle shores collectively constitute 2.4% of the coastline and the remaining 7% is built-up. Some 60% of the Maltese coastline is inaccessible, which means that anthropogenic pressures on the non-developed accessible coastline of the Maltese Islands are intense as a result of the high population density (1194 km⁻²) and the large number of tourists who visit the islands (c. 1.2 million annually in recent years – Mallia et al. 2002).

Sand and shingle are mobile sediments that differ mainly in their particle size distribution (0.063–2 mm for sand and 2–256 mm for shingle, on the Udden-Wentworth scale). Pérès & Picard (1964) distinguish two types of biocoenosis on soft substratum Mediterranean shores: rapidly-drying sediments, including sand, in which invertebrates can burrow, and slow-drying sediment where the sediment is covered by plant debris or by cobbles or boulders and where desiccation is slow. Both types of shore occur in the Maltese Islands and all gradations exist, from sand, to sand covered with pebbles, cobbles and boulders, or mixtures of all three. In general, however, c. 6 km (2.2%) of the coastline is sandy, while c. 0.6 km (0.2%) can be described as shingle. Both shingle and sandy beaches receive periodic inputs of seagrass wrack (mainly *Posidonia oceanica*).

Maltese beaches are microtidal (maximum tidal range c. 20 cm; Drago & Xuereb 1993) and zonation patterns and community dynamics are primarily dictated by wave action; thus, Maltese beaches exhibit rather extensive supralittoral zones. However, because of their small size, the swash often runs up over all or almost all of the supralittoral when winds blow onshore, and the beaches may be completely immersed during severe storms, which may result in erosion or accretion, depending on circumstances, but which certainly has a profound effect on both terrestrial and marine beach biota.

Globally, sandy beaches have been well studied, but the few studies on the ecology of shingle beaches that have been carried out have dealt mostly with the terrestrial vegetation. While some studies on single species or related groups of species exist (for example, Furato & Ito (1999) on the isopod *Ligia cinerascens*, Morse (1997) on the lycosid spider *Pardosa lapidicina*, Martins (2001) on five species of Elobiidae, and Moore et al. (1995) on the amphipod *Orchestia scutigerula*), the faunal assemblages of shingle have rarely been studied as a whole.

In the Maltese Islands, sandy beaches with backing sand dunes are of high conservation value owing to the rarity of this habitat type, and therefore that of its associated biota, which includes endemic species, and

the threat that such habitats will disappear altogether (Cassar & Stevens 2002). A study by Deidun et al. (2003) is the only one on the ecology of Maltese sandy beaches published to date, while there are no published ecological studies on Maltese shingle beaches apart from a few casual records of species collected from such habitats. Maltese sandy beaches harbour an impoverished fauna compared to other Mediterranean beaches and are compartmentalised, that is, each beach appears to be ecologically isolated and supports a more or less unique assemblage of species (Deidun et al. 2003).

The popular perception of sandy and shingle beaches as 'ecological deserts' in faunistic terms, and the economic importance of such shores, especially sandy beaches, are the main hurdles to their conservation in the Mediterranean region. This is hardly surprising given that the Mediterranean receives 135 million tourists annually (EEA 1999), mainly for its coastal amenities, and that almost 40% of the resident population of 380 million people lives in the coastal area (King 1997).

The present study investigates the fauna of Maltese shingle beaches with the aim of providing basic ecological information on these habitats, compares Maltese shingle and sandy beaches especially with regards to the observed compartmentalisation and faunal impoverishment of the latter shore type (Deidun et al. 2003), and assesses their conservation value.

2. Material and Methods

The location of the beaches studied is shown in Fig. 1. All the beaches are located on open coasts, except for the Qawra 'Inland Sea', which is an enclosed body of water surrounded by vertical rock faces and connected to the open sea by a narrow, c. 80 m-long semi-submerged tunnel in the cliffs, in which the water depth is about 20 m.

Depending on the size of the beach, two or three shore-normal transects were laid out from mean sea level upshore, to the point where the vegetation-free sediment gave way to dunes, terrestrial vegetation or a road. Transects were divided into wet and dry zones, using the strandline as the boundary between the two.

On the shingle beaches, a standardised search was made separately in the dry and wet zones of each transect to collect motile fauna; the superficial shingle within a band 0.5 m on either side of the transect line was searched intensely for 10 minutes. All motile organisms encountered during each search were collected and fixed in 70% ethanol and the exact area covered was recorded. On sandy beaches, where motile fauna are much more easily spotted, 10 minute standardised searches were made within 5 m × 3 m rectangles, one each in the wet and dry zones of each transect.

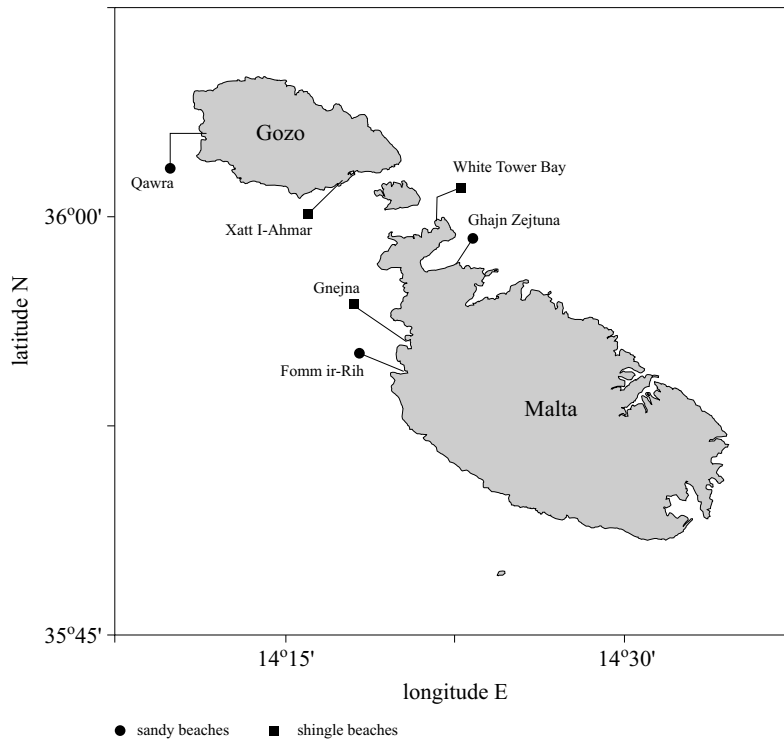


Fig. 1. Map of the Maltese Islands showing the location of the beaches studied

On both the sandy and shingle beaches, known volumes of sediment were wet-sieved and sorted to collect interstitial (among the shingle) and burrowing (in the sand) macrofauna. On the sandy beaches, the samples were collected with a 24 cm-diameter circular corer. The corer was pushed into the sand and the top 10 cm of sand were transferred to a 0.5 mm-mesh sieve and wet-sieved. The organisms retained on the sieve were collected. The same procedure was then repeated for the sand fractions between 10 cm and 20 cm and between 20 cm and 30 cm below the beach surface. On shingle beaches, a corer was carefully pushed into the shingle in each of the two zones along each transect. Individual pebbles and cobbles that obstructed the corer were removed to allow the corer to achieve full penetration into the substratum. Depending on the grain size at each sampling station, one of two cylindrical corers of different diameter was used. The smaller corer (internal diameter 15.5 cm) was used when the substratum consisted of small pebbles that allowed rapid penetration of the corer. For coarser sediment, a larger corer (internal diameter 25.5 cm) was used, since (i) too few pebbles and cobbles would be sampled with a small corer, and (ii) it would be harder

to drive a small corer into the substratum especially if cobbles of the same size as the corer are present. Samples from different depth strata within the sediment – 0–10 cm, 10–20 cm, and where possible, 20–30 cm – were collected and processed using one of two procedures depending on the size of grains. Layers predominantly containing large grains (very coarse pebbles and cobbles) were processed by inspecting each grain individually for both fauna and algae. Grains with algae were washed in water to release any fauna associated with the algae. Samples containing predominantly small grains (sand, and pebbles smaller than 32 mm) were wet-sieved and sorted. For both the sandy and shingle beaches, three replicate samples were collected from each wet and dry zone of every transect.

Pitfall traps were used to collect nocturnal fauna visiting sandy beaches (on shingle beaches, pitfall traps were found not to work efficiently and were not used). Constellations of five plastic cups (7.5 cm diameter), one at the centre and the other four in a cross pattern separated from the central cup by a distance of 1 m (Fig. 2), were set up in the wet and dry zones. 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 wood resting on the sand, which served as walk-ways; the use of such walk-ways greatly enhances sampling efficiency (L. Chelazzi, personal communication). Traps were left overnight and emptied in the morning. In the laboratory, fauna were sorted, identified and counted.

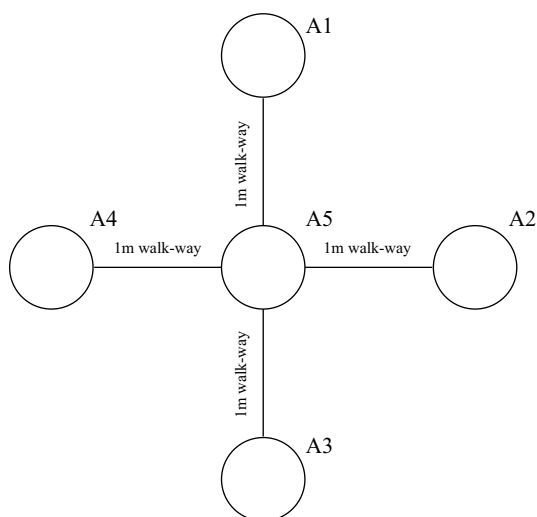


Fig. 2. Schematic plan view of the constellation of pitfall traps used in the current study. A1–A5 represent plastic cups buried with their rims flush with the sediment surface. Thin wooden strips laid on the surface of the sand act as walk-ways

The grain-size distribution of sandy beach sediment was determined using the method described by Buchanan (1984). For shingle beaches, this method could only be applied to the sediment fraction < 8 mm. Dried

samples from shingle beaches were divided into two fractions by sieving through an 8 mm sieve. The shingle retained by the 8 mm sieve was analysed manually using a gravel-sizing template (Hydro Scientific Ltd.).

Exposure for each beach was calculated using the method devised by Thomas (1986). The exposure was calculated for all the beaches except for the Qawra 'Inland Sea', since the Thomas exposure index is designed for use on open coasts. The beach slope was measured by the 'rules and spirit-level' method described by Eifion Jones (1980). The organic content of the sediment was determined using the Walkley and Black titration method following wet-oxidation by potassium dichromate, as described in Morgans (1956) and Buchanan (1984). For shingle beaches, the organic content was only determined for the sand fraction in the wet zone of Qawra and Ghajn Zejtuna; in the dry zone of these beaches and at Fomm ir-Rih, organic content could not be determined due to the absence of sand.

Data were analysed by non-metric multidimensional scaling (NMDS) and agglomerative, group-average linkage, hierarchical clustering on a similarity matrix generated with the Bray-Curtis similarity measure, using the PRIMER 5 statistical package (Clarke & Warwick 1994). Other statistical analyses were made using SPSS v. 9 (Statistical Package for Social Sciences; SPSS Inc.). For NMDS overlays, the mean grain size and sorting parameters were averaged for the three depth strata for each beach zone. Before calculation of community parameters, the faunal data were log transformed to reduce the size of large species densities relative to small values whilst conserving their rates of change. Species contributing less than 1% to the total abundance were excluded from the statistical analyses.

3. Results

Table 1 gives some physical characteristics of the beaches studied.

On the Udden-Wentworth system, as extended for coarse sediments by Blair & McPherson (1999), the sand at White Tower Bay was classified as fine, while that at Gnejna and Ix-Xatt l-Ahmar was classified as medium. In all three sandy beaches, both wet and dry zones had sediment of the same grade. The shingle beaches had a median grain size mostly in the pebble range and grain size increased from the wet to the dry zone. The shingle at Qawra varied from fine pebbles in the wet to medium pebbles in the dry zone, that at Fomm ir-Rih varied from medium pebbles in the wet to coarse pebbles in the dry zone, while that at Ghajn Zejtuna varied between granules in the wet and coarse pebbles in the dry zone. Slope varied from 0.09° to 0.38° for the sandy beaches but was significantly higher (one-way ANOVA; $p < 0.05$) on the shingle beaches where it varied from 6.80° to 13.11°. Exposure to wave action was similar for both beach types varying

Table 1. Physical characteristics of the six beaches studied. Where applicable, the standard error of the mean is given in square brackets. For those beaches where parameters were determined separately for the wet and dry zone, these are indicated by W and D, respectively

Beach	Physical parameter						
	Median grain size	Sorting coefficient	Beach slope	Thomas exposure index	Length of beach	% Organic content	Depth of anoxic layer (cm below beach surface)
	$[\phi]$	$[\phi]$	$[\circ]$		[km]	[SE]	[SE]
Xatt l-Ahmar	W 1.23 D 1.50	W 1.04 D 1.24	0.248	2.76	0.08	W 0.092 [27.99×10^{-3}] D 0.079 [25.94×10^{-3}]	W 6.0 [1.24] D 13.0 [2.25]
White Tower Bay	W 2.56 D 2.36	W 0.78 D 0.80	0.207	4.86	0.15	W 0.046 [14.29×10^{-3}] D 0.039 [16.46×10^{-3}]	W 13.0 [2.30] D 20.0 [3.40]
Gnejna	W 1.05 D 1.43	W 0.97 D 0.68	0.222	2.17	0.25	W 0.063 [1.67×10^{-3}] D 0.043 [2.34×10^{-3}]	W 8.3 [2.10] D > 30
Qawra	W -2.23 D -3.98	W 1.82 D 1.90	10.48	not measured	0.12	W 0.155 [0.008]	not measured
Ghajn Zejtuna	W -1.75 D -4.30	W 0.98 D 0.85	7.71	3.99	0.10	W 0.135 [0.025]	not measured
Fomm ir-Rih	W -3.51 D -4.26	W 1.40 D 1.00	7.00	4.79	0.08	not measured	not measured

Table 2. Species collected by coring and 'standard search' from the two types of beach studied. Species constituting less than 1% of the total number of individuals in all the beaches of a particular sediment type were not used for statistical analyses and are indicated by the symbol x. Species listed in the Maltese *Red Data Book* are indicated by RDB

Species	Shingle beaches		Sandy beaches	
	Coring [indiv. m ⁻³]	Standard search [indiv. m ⁻² min ⁻¹]	Coring [indiv. m ⁻³]	Standard search [indiv. m ⁻² min ⁻¹]
Polychaeta				
Cirratulidae sp.	247.1			
Nereidae sp.	15.0			
Gastropoda				
<i>Truncatella subcylindrica</i>	322.0			
Pseudoscorpiones				
<i>Chthonius halberti</i> ^x	7.5			
Araneae				
Gnaphosidae sp.	15.0			
<i>Heliophanus</i> sp. ^x				0.7
Theridiidae sp. ^x	7.5			
Lycosidae sp.			3.6	
Isopoda				
<i>Armadilloniscus littoralis</i> ^x	7.5			
<i>Halophiloscia couchi</i>	22.5			
<i>Stenophiloscia zosteræ</i>	44.9			
<i>Jaera</i> sp.	22.5			
<i>Ligia italica</i>		3.7	3.6	4.0
<i>Sphaeroma serratum</i>	44.9			
Amphipoda				
<i>Hyale</i> cf. <i>crassipes</i>	29.9			
<i>Melita hergensis</i>	194.7			
<i>Orchestia stephenseni</i>	15.0			4.7
<i>Talorchestia deshaysii</i>				16.0
Decapoda				
<i>Pachygrapsus marmoratus</i>		1.9		
Chilopoda				
<i>Henia bicarinata</i> ^x	7.5			

Table 2. (continued)

Species	Shingle beaches		Sandy beaches	
	Coring [indiv. m ⁻³]	Standard search [indiv. m ⁻² min ⁻¹]	Coring [indiv. m ⁻³]	Standard search [indiv. m ⁻² min ⁻¹]
Orthoptera				
<i>Aiolopus strepens</i>				4.0
<i>Mogoplistes squamiger</i> ^{RDB}	22.5			
Dermaptera				
<i>Anisolabis maritima</i> ^{RDB}	22.5	5.6		
<i>Labidura riparia</i>			1.8	
Hymenoptera				
<i>Anthophora</i> sp.				0.7
<i>Bembix oculata</i>			7.2	16.7
<i>Camponotus barbaricus</i>				54.0
<i>Pheidole pallidula</i>	67.4	5.6		
<i>Polistes omissus</i>				23.3
Spechidae sp. ^x				0.7
<i>Tapinoma simrothii</i>				2.0
Diptera				
<i>Craticulina</i> sp.				15.3
<i>Fucellia tergina</i> ^x				1.3
<i>Tethina ochracea</i> ^x			1.8	1.3
Coleoptera				
<i>Allophylax picipes</i>			1.8	
<i>melitensis</i> ^{RDB}				
<i>Ammobius rufus</i> ^{RDB}			3.6	12.7
<i>Anthicus</i> sp. ^x			3.6	0.7
<i>Berosus</i> sp.			5.4	
Histeridae sp. ^x				0.7
<i>Phaleria acuminata</i> ^{RDB}			9.0	2.0
Staphylinidae sp. ^x	7.5			
<i>Trachyscelis aphodioides</i> ^{RDB}			19.7	8.7
Hemiptera, Heteroptera				
<i>Brachynema cinctum</i> ^x				0.7

between 2.17 and 4.86, which is considered low (Thomas exposure index < 6.5; Thomas 1986).

The organic carbon content in the dry zone of the sandy beaches varied between 0.007% and 0.128%. In the wet zone, the organic carbon content ranged from 0.026% to 0.140% for the sandy beaches and from 0.117% to 0.161% for the shingle beaches. ANOVA showed that there was no significant difference between beach types for wet zone organic carbon content, but only just ($p = 0.05$).

Table 2 shows the abundance of individual species collected by coring and standardised searches for the two beach types. A total of 11 species were collected from sandy beaches by coring and 19 from shingle beaches. No species were common to both types of sedimentary beaches. For the shingle beaches, the species collected by coring were recorded in greater densities (range: 15.9 to 1106.8 individuals m^{-3}) than those collected by the same technique on sandy beaches (range: 3.9 to 60.0 individuals m^{-3}). The individual abundances of species collected by coring were more even on the sandy beaches than on shingle, where the fauna was dominated by a few species (Fig. 3). For example, two species, *Truncatella subcylindrica* and *Melita hergensis*, constituted 78% of all the individuals collected by coring at Fomm ir-Rih.

While species richness and abundance were always higher on the shingle beaches, these differences were not always statistically significant. ANOVA showed that both species richness and abundance in the wet zone of shingle beaches were significantly higher ($p < 0.05$) than on the sandy beaches; however, there was no significant difference for the dry zone, even if only just ($p = 0.05$).

The highest density of individuals (10 175.4 individuals m^{-3}) on shingle beaches was recorded for the 10–20 cm depth stratum of the wet zone. The highest density of individuals (214.3 individuals m^{-3}) on sandy beaches was recorded for the 10–20 cm depth stratum of the dry zone. Within the two depth strata 0–10 cm and 10–20 cm, species richness and abundance were usually higher on shingle beaches. However, this difference was only significant ($p < 0.05$) for the 0–10 cm depth stratum, particularly in the wet zone.

Fig. 4 shows the abundance of the major taxonomic groups collected by coring from the two beach types. On sandy beaches, Coleoptera had the largest representation in terms of number of individuals (72.2% of all individuals), but on shingle beaches it was the Mollusca (28.7%) followed by Polychaeta (23.3%) and Amphipoda (21.3%) that had the highest densities.

A total of 20 species were collected from sandy beaches by standardised searches, while only four were collected from shingle beaches (Table 2).

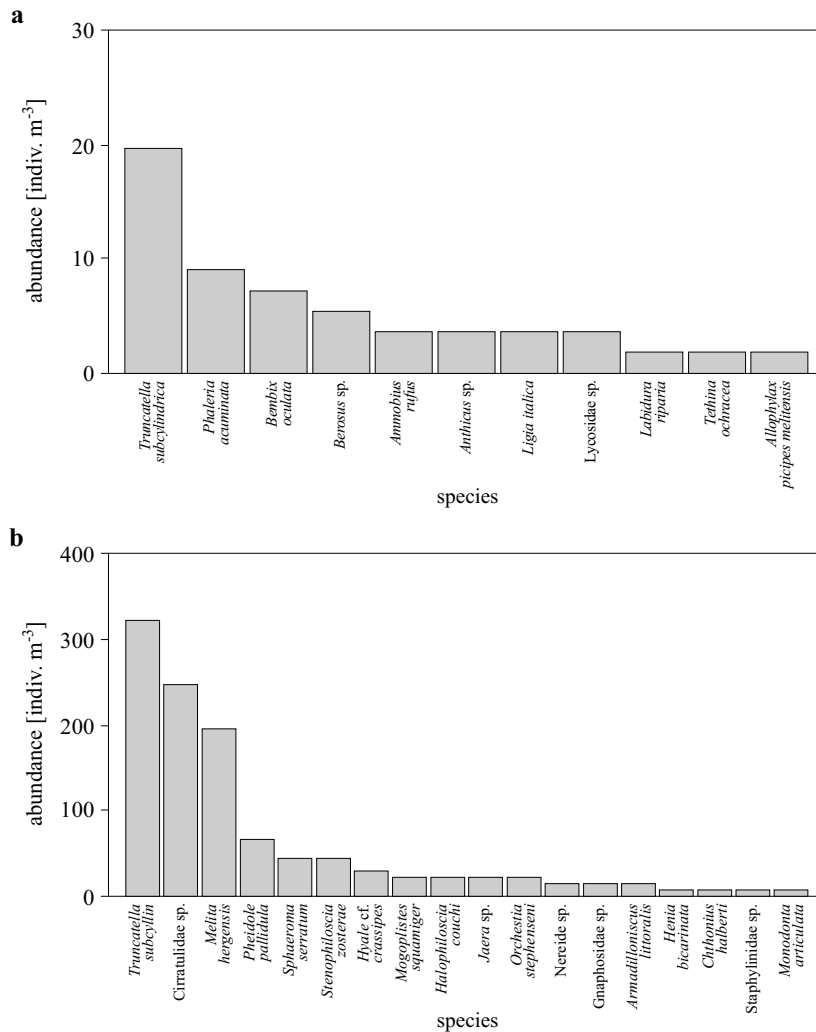


Fig. 3. Species-abundance plots for fauna collected by coring for sandy beaches (a) and shingle beaches (b)

The isopod *Ligia italica* was the only species collected from both beach types. Table 2 shows that on the shingle beaches, species collected by standardised search were recorded in lower densities (range: 1.7 to 5.6 individuals m⁻² min⁻¹) than those collected using the same technique on sandy beaches (range: 0.7 to 54.0 individuals m⁻² min⁻¹). The individual abundances of species recorded by standardised search were more even on shingle beaches than on sandy beaches (Fig. 5).

Fig. 6 shows the abundance of the major taxonomic groups recorded by standardised searches. On sandy beaches, Hymenoptera (ants) had

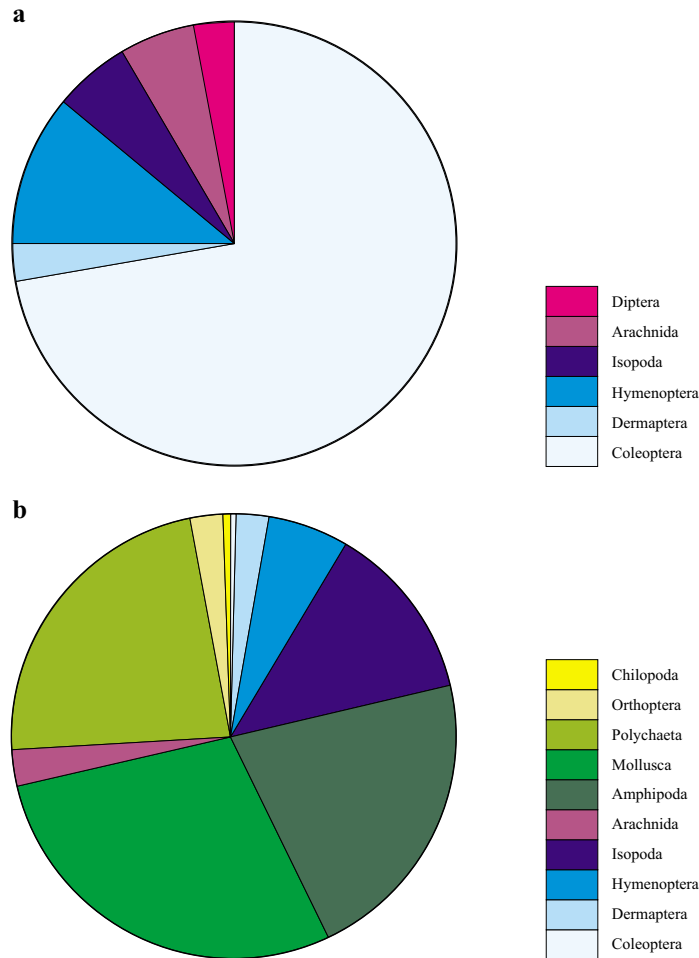


Fig. 4. The percentage abundance of major taxonomic groups collected by coring for sandy beaches (a) and shingle beaches (b)

the largest representation in terms of number of individuals (57.8% of all individuals recorded). On shingle beaches, the most abundant groups were Hymenoptera (ants) and Dermaptera (33.4% each).

Cluster analysis of the abundance data obtained from the core samples (Fig. 7a) clearly separated shingle and sandy beaches into distinct groups. However, within each beach type, the three beaches sampled are quite dissimilar from each other. Cluster analysis on abundance data obtained by standardised searches gave similar results (Fig. 7b). NMDS plots for the abundance data (Fig. 8) confirmed the results of the cluster analyses for both sampling techniques. The relationship of the NMDS plot with various physical parameters of the beaches was studied by plotting these parameters

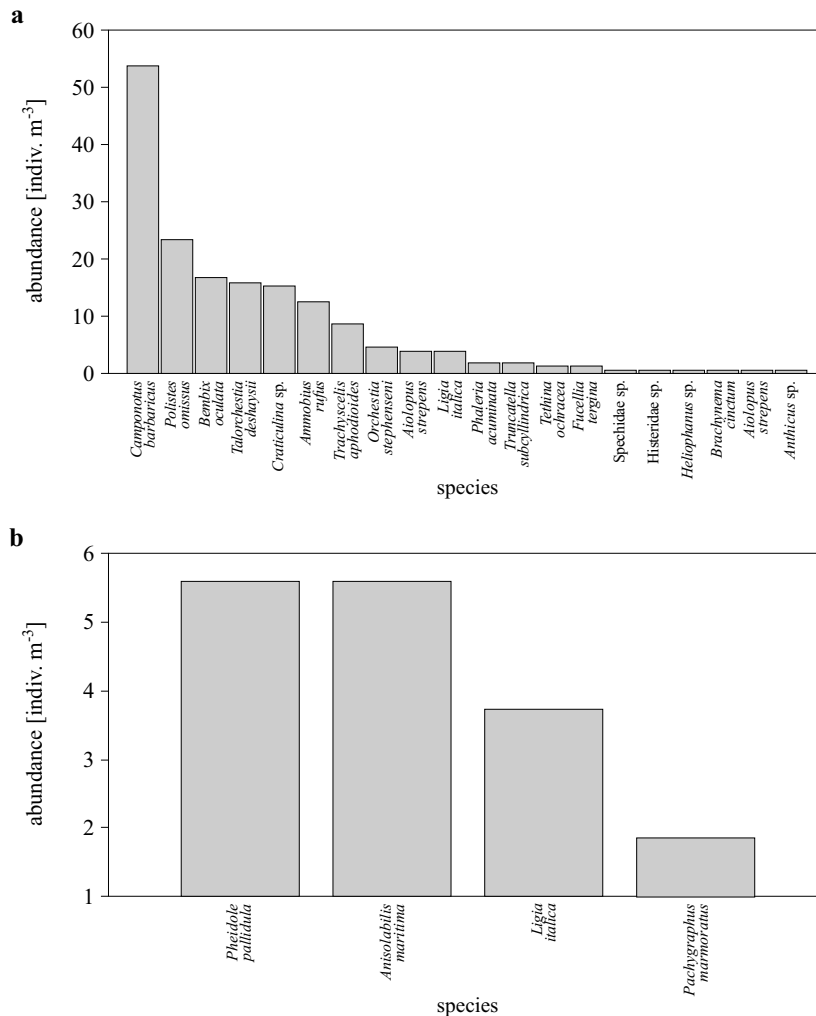


Fig. 5. Species-abundance plots for fauna recorded by 'standardised searching' for sandy beaches (a) and shingle beaches (b)

as overlays on the NMDS map. Of the various physical parameters tested, grain size and to a lesser extent, beach length, best correlated with the observed patterns.

Table 3 gives data on fauna collected by pitfall traps; a total of 15 species were collected with an abundance varying between 0.01 and 0.92 individuals/trap/hour. *Phaleria acuminata* was the most abundant species recorded (52.3% of all individuals collected in the traps). Some 40% of the species that were collected by pitfall traps were not recorded by either coring or by standardised searching. Moreover, the pitfall traps captured much higher numbers of individuals than did the other techniques; thus,

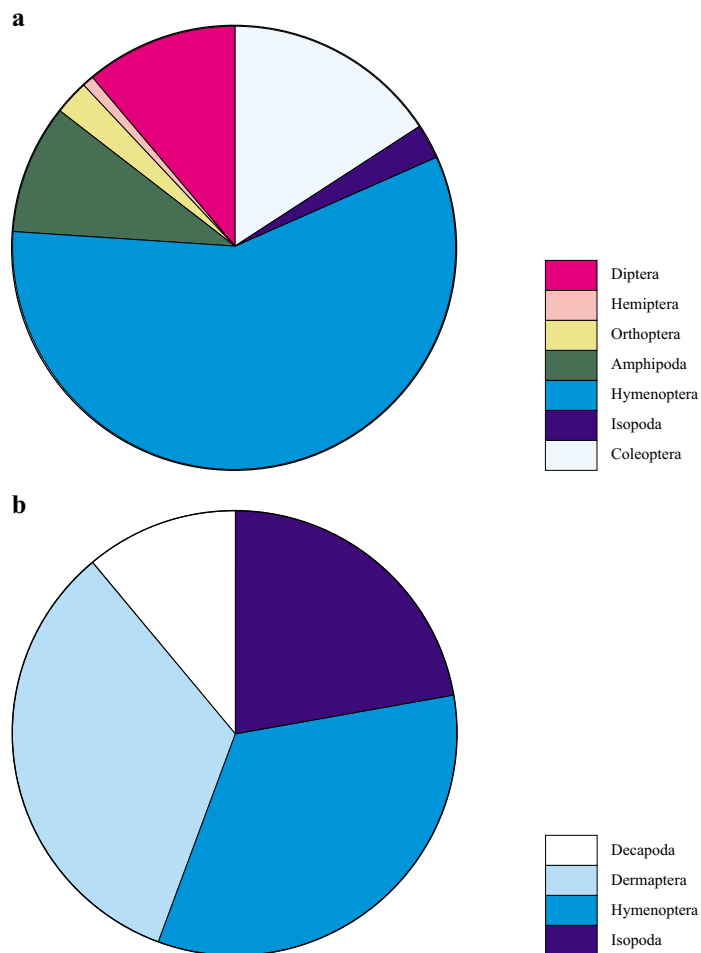


Fig. 6. The percentage abundance of major taxonomic groups recorded by ‘standardised searching’ for sandy beaches (a) and shingle beaches (b)

86.0% of all individuals collected from Gnejna, 72.7% of those from White Tower Bay, and 84.7% of those from Xatt l-Ahmar were collected by pitfall traps.

4. Discussion

Comparative studies of sedimentary shores are lacking, especially those comparing shingle with sandy beaches (see for example Reise 2001). In the case of the Maltese Islands, both sandy and shingle beaches consist of sediment that accumulates at the head of embayments and are of small size (0.075–0.25 km in length). All Maltese beaches are therefore pocket beaches and are to a greater or lesser extent isolated from each other.

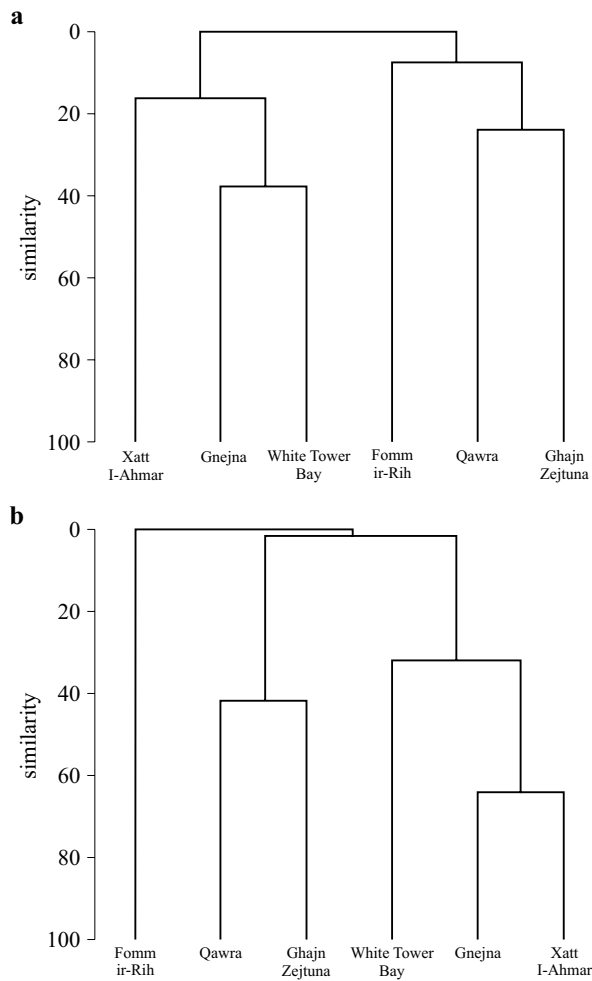


Fig. 7. Dendrograms resulting from cluster analysis (Bray-Curtis similarity index and agglomerative group-average linkage) of faunal abundance data obtained by coring (a) and standardised searches (b)

Because of the large grain size and high porosity, shingle beaches are expected to have poor organic carbon retention capacities in their surface layers. Compared to sandy beaches, organic material strands more abundantly on shingle, since a greater proportion of the swash percolates through the sediment; however, the coarse surface layers of shingle beaches retain very little organic content, and it is the sandy matrix in the subsurface layers that becomes rich in organic material percolating downwards. This might explain the higher organic carbon content obtained for the fine sediment of the shingle beaches studied, compared to the values for the sandy beaches, even if these higher values were not statistically significantly different.



Fig. 8. NMDS plots of species abundance data obtained by coring (a, b) and by 'standardised searching' (c, d) with overlays of selected physical parameters: (a), (c) – mean grain size; (b), (d) – beach length

The exposure between the sandy and shingle beaches studied was not very different. There is disagreement between authors on the relationship between exposure and the particle size distribution of sedimentary beaches. For example, Little (2000) claims that particle size decreases with increase in exposure, whereas Brown & McLachlan (1990) state that it is only under sheltered conditions that very fine sand can remain on a beach, and cobble shores are at least exposed to moderate wave action. Our results show that embayments with practically the same exposure can have either shingle or sandy pocket beaches, whereas some sandy beaches in the Maltese Islands have exposure values of up to 12.9 on the Thomas scale (Deidun et al. 2003). In contrast, the maximum exposure for the shingle beaches studied was 4.8 for Fomm ir-Rih.

On the shingle beaches, slope was significantly higher than for the sandy beaches, while the difference in the mean particle diameter between the two beach types is obvious. The swash exclusion hypothesis (see for example Defeo et al. 2000) predicts a constant increase in species richness, abundance and biomass from reflective to dissipative conditions on beaches (see for

Table 3. Species collected using pitfall traps (this technique was used on sandy beaches only)

Species	Pitfall traps [indiv.(trap hour ⁻¹) ⁻¹]
Araneae	
<i>Lycosidae</i> sp.	0.01
Isopoda	
<i>Armadillium vulgare</i> *	0.01
<i>Ligia italica</i>	0.01
Amphipoda	
<i>Orchestia stephensi</i>	0.01
<i>Talorchestia deshaysii</i>	0.10
Zygentoma	
<i>Ctenolepisma longicaudata</i> *	0.02
Dermaptera	
<i>Labidura riparia</i>	0.15
Hymenoptera	
<i>Camponotus barbaricus</i>	0.12
Formicidae sp.*	0.21
<i>Messor structor</i> *	0.04
Coleoptera	
Alleculidae sp.*	0.01
<i>Allophylax picipes melitensis</i> ^{RDB}	0.01
<i>Anthicus</i> sp.	
<i>Phaleria acuminata</i> ^{RDB}	0.92
<i>Phaleria bimaculata</i> *	0.13

* indicates species that were not also collected by coring or by 'standard search'. Species listed in the Maltese *Red Data Book* are indicated by RDB.

example McLachlan 1990). Thus, sandy beaches with their smaller sediment grain size and shore slope (dissipative) should promote a higher abundance and diversity of benthic macrofauna (McLachlan 1996; Denadai & Amaral 1999) while shingle beaches with steep slopes and coarser grains are expected to exhibit a lower species richness and abundance.

However, in the present study, a larger number of species (19) and individuals (mean density = 1269.2 individuals m⁻³) were collected by coring in the wet and dry zones of the shingle beaches than in the sandy beaches (11 species and mean density of 69.8 individuals m⁻³). On the other hand, a higher number of species (20) and individuals (172 individuals m⁻² min⁻¹) were collected from sandy beaches by standardised searching in contrast to shingle beaches (4 species and 18.6 individuals m⁻² min⁻¹) (Table 2).

Therefore, Maltese sandy beaches have a higher species diversity and higher densities of fauna at the surface in contrast to shingle beaches, where most diversity and the highest densities are found below the surface layers.

The paucity of surface fauna on shingle beaches agrees with the usual description of such beaches as being visibly bare of animal life. Although both sand and shingle beaches are unstable habitats in which wave action continuously reworks the sediment, on shingle beaches this instability is coupled with a grinding effect caused by grains impacting against each other. Moreover, sand can hold more water in its interstices than shingle, the latter being highly permeable and susceptible to rapid drying up at the surface. Shingle fauna are therefore more subject to desiccation, high temperatures and mechanical damage at the surface than fauna inhabiting sand.

The oxygen content of the interstitial water is known to be an important factor in determining faunal distribution on sandy beaches (Brown 1969). Below the surface stratum (0–10 cm) of the wet zone, the sediment on the sandy beaches studied was anoxic, resulting in low faunal diversity and abundance in the deeper strata. This may be due to compaction of the sand in the wet zone rendering oxygenation of deeper sediment layers difficult. The anoxic layer occurred at much deeper levels in the sediment of the shingle beaches due to the large interstitial spaces between grains. Thus, oxygen content is hardly limiting on shingle beaches and abundances remain high with depth.

Carbon content, species richness, and abundance were lower on sandy beaches compared to shingle beaches. Natural sources of organic material are plankton that are filtered out of the water, and deposited wrack. However, Maltese coastal waters are oligotrophic and therefore the latter source is probably more important. Large quantities of leaves of the seagrass *Posidonia oceanica* are deposited on most Maltese sandy and shingle beaches during the autumn and winter months. Wrack can be a direct food source for scavengers, whereas wrack breakdown results in the interstitial spaces between the coarser grains of shingle beaches becoming progressively clogged by finer sediment with a substantial organic content. Consequently, faunal species richness and abundance on the Maltese shingle shores studied were higher than those of sandy beaches. It must also be noted, however, that on the heavily frequented shores of the Maltese Islands, anthropogenic input of organic material into the sediment may be significant, obfuscating the relationship between natural sources of organic carbon and biotic characteristics of the beach, whether sandy or shingle.

Species abundances as estimated by standardised searches were more even on shingle beaches than on sandy beaches (Fig. 5), but the reverse was the case for abundances estimated by coring (Fig. 3). For both

sandy and shingle beaches, the dominant faunal group on the surface was Hymenoptera, specifically the two ant species *Camponotus barbaricus* on the sandy beaches and *Pheidole pallidula* on shingle; however, on shingle beaches, the dermapteran *Anisolabis maritima* was equally abundant (Fig. 6). While the two ants are ubiquitous in the Maltese Islands, *A. maritima* is limited to particular coastal habitats and is considered rare (Schembri 1989). On the shingle beaches, the isopod *Ligia italica* was common (third in abundance rank) while it occurred much less frequently on sandy beaches (tenth in abundance rank). *L. italica* is characteristic of supralittoral rock (Pérès & Picard 1964; Schembri et al. 2005), a habitat type approximated by shingle but not by sand. Thus, the surface-dwelling fauna on shingle beaches consists of fast moving species that can forage on the surface but which are able to rapidly seek shelter among the grains when threatened or during adverse environmental conditions.

Below the surface, sandy beaches were dominated by Coleoptera (72.2% of individuals collected by coring) mainly tenebrionids, whilst shingle beaches were dominated by Mollusca (28.7% of individuals collected by coring) mainly the gastropod *Truncatella subcylindrica*, followed by Polychaeta (23.3%) and Amphipoda (21.3%) (Fig. 4). Tenebrionid beetles are characteristic of Mediterranean sandy habitats, particularly of the dry zone and higher regions of sandy beaches, and exhibit particular adaptations (see for example Chelazzi & Colombini 1989); among such adaptations are (i) the ability to forage on the surface of the sand, mostly at night, and (ii) rapid burrowing in the sediment to avoid dislodgment by waves and swash, to escape from predators, and to seek refuge from high surface temperatures during the day (Little 2000).

The dominant sub-surface species on shingle was the gastropod *T. subcylindrica*. At the level where this species is abundant, the sediment consisted of coarse grains from the lower end of the shingle range intermixed with finer sediment. This snail is well adapted to living in this type of sediment, having a small size and exhibiting autotomy of the first few whorls of the shell to ensure that the adult conserves a small size (Seaward 2001) as otherwise it would be constrained to inhabit the larger interstitial spaces in the upper, more hostile layers of shingle. Polychaetes and amphipods were subdominant on shingle beaches. The former, an unidentified cirratulid, is fossorial and occurred in the 10–20 cm depth stratum of the wet zone, where grain size was smallest, thus allowing the animals to burrow. On the other hand, the amphipod *Orchestia stephensi* is very fast moving when disturbed, as are the isopods *Halophiloscia couchi* and *Stenophiloscia zosteriae*, which occurred in low abundances on the shingle beaches studied; fast movement is an adaptation to escape predators and pebble dashing.

It is significant that 40% of species collected by pitfall traps on sandy beaches were not collected by either coring or standardised searching. This suggests that on these beaches, a large number of species forage on the surface of the sand at night but seek refuge during the day by burrowing in the sediment in areas of the beach further upshore than those investigated here, for example, the dune region. One such species is the tenebrionid beetle *Phalaris bimaculata*, an exclusively nocturnal, dunal species (Chelazzi & Colombini 1989).

Maltese shingle and sandy beaches have different suites of animals with no species common to the two beach types; moreover, the similarity between beaches of the same type is also low (Fig. 7). This confirms the compartmentalisation discussed by Deidun et al. (2003) for Maltese sandy beaches, and shows that the same phenomenon is shown by Maltese shingle beaches. Thus, not only is each beach type unique, but each individual beach has its own particular biological characteristics. This leads to the question of conservation.

Whereas the conservation value of Maltese sand dunes has often been highlighted (see review in Cassar & Stevens 2002), and most Maltese dunes are now protected (Schembri et al. 2002), other sandy beach habitats and shingle beaches have not been considered.

Although the six beaches studied had low species richness and abundances compared to coastal dunes and other shore types, the species that occur are nonetheless of importance. Whilst some species recorded in the present study are also found in adjacent habitats (e.g. *L. italica*) or are ubiquitous (e.g. *Henia bicarinata*), other species are restricted to the beach habitat (e.g. *Phalaris acuminata* and *Ammobius rufus*). Sandy beaches, and to a greater extent, shingle beaches, are rare in the Maltese Islands, and thus species that are locally abundant in such habitats (e.g. *Phalaris* spp. on sand and *T. subcylindrica* on shingle) are still of conservation importance since their habitat has a restricted distribution. Moreover, some of these stenotopic species occur in low abundances (e.g. *Stenophiloscia zosterae* on shingle and *Labidura riparia* on sand), making them of even greater conservation concern. Even more important are those species that either have a restricted regional distribution or are endemic. Although not recorded in the present study, the tenebrionid, *Clitobius ovatus* occurring in Malta and Tunisia is an example of the former, while *Stenosis melitana*, *Stenosis schembrii* and *Pseudoseriscius cameroni* (also tenebrionids) are examples of the latter (unpublished data from an ongoing study that extends the present results to include seasonal variation). Because of their restricted regional distribution, some of these species are internationally protected (for example, the endemic tenebrionid *P. cameroni* and the cricket *Brachytrupes*

megacephalus are both listed in the European Union's 'Habitats Directive' as recently amended by the Treaty of Athens, the former in Annex II, which includes species of Community interest whose conservation requires the designation of Special Areas of Conservation, and the latter in Annex IV that lists species of Community interest in need of strict protection).

Within the Maltese Islands, some species are restricted to a single beach, at least as far as is presently known. Thus the pseudoscorpion *Chthonius halberti* was only found at Qawra, while the tenebrionid *Phaleria bimaculata* was only recorded from White Tower Bay. In another study, Deidun (2001) recorded the isopod *Tylos europaeus* only from Ramla. This compartmentalisation implies that each beach is ecologically isolated and supports a more or less unique assemblage of species (Deidun et al. 2003); therefore, no beach can be considered as expendable – all Maltese beaches deserve protection.

Acknowledgements

We thank Professor Felicita Scapini (CoNISMa, Italy), coordinator of MECO, and Louis F. Cassar (Foundation for International Studies, University of Malta), the Malta coordinator of the project, for financial and other help received. We are also grateful for research grants from the University of Malta to PJS. We thank Dr Joseph A. Borg, Dr Stephen Schembri, Mr David Dandria (all at the University of Malta), Dr Lorenzo Chelazzi, Dr Isabella Colombini, Dr Mario Fallaci, Dr D. Benvenuti and Dr G. Messana (all at the Centro di Studio per la Faunistica ed Ecologia Tropicali del C.N.R., Firenze) for the identification of specimens and much other help. We also thank Joseph Debono, Miraine Rizzo and Marthese Azzopardi for their assistance. We are indebted to two anonymous referees for their helpful comments on an earlier draft of this paper.

References

- Axiak V., Gauci V., Mallia A., Mallia E. A., Schembri P. J., Vella A. J., 1999, *State of the environment summary report for Malta 1998*, Environ. Prot. Dept., Min. for the Environment, Floriana (Malta), 130 pp.
- Blair T. C., McPherson J. G., 1999, *Grain-size and textural classification of coarse sedimentary particles*, J. Sediment. Res., 69 (1), 6–19.
- Brown A. C., 1969, *The ecology of the sandy beaches of the Cape Peninsula, South Africa*, T. Roy. Soc. S. Afr., 3, 247–279.

- Brown A. C., McLachlan A., 1990, *Ecology of sandy shores*, Elsevier, Amsterdam, 328 pp.
- Buchanan J. B., 1984, *Sediment analysis*, [in:] *Methods for the study of marine benthos*, N. A. Holme & A. D. McIntyre (eds.), Blackwell Sci. Publ., Oxford, 41–63.
- Cassar L. F., Stevens D. T., 2002, *Coastal sand dunes under siege: a guide to conservation for environmental managers*, Int. Environ. Inst., Found. Int. Stud., Valletta (Malta), x + 194 pp.
- Chelazzi L., Colombini I., 1989, *Zonation and activity patterns of two species of the genus Phaleria Latreille (Coleoptera Tenebrionidae) inhabiting an equatorial and a Mediterranean sandy beach*, Ethol. Ecol. Evol., 1, 313–321.
- Clarke K. R., Warwick R. M., 1994, *Change in marine communities: an approach to statistical analysis and interpretation*, Nat. Environ. Res. Council, Plymouth, 144 pp.
- Defeo O., Gomez J., Lercari D., 2000, *Testing the swash exclusion hypothesis in sandy beach populations: the mole crab Emerita brasiliensis in Uruguay*, Mar. Ecol. Prog. Ser., 30, 1–19.
- Deidun A., 2001, *A study of the distribution and abundance of the supralittoral macrofauna of four Maltese sandy beaches*, Unpubl. B.Sc. diss., Dept. Biol., Malta Univ., Malta.
- Deidun A., Azzopardi M., Saliba S., Schembri P. J., 2003, *Low faunal diversity on Maltese sandy beaches: fact or artefact?*, Estuar. Coast. Shelf Sci., 58, 83–92.
- Denadai M. R., Amaral A. C. Z., 1999, *A comparative study of intertidal molluscan communities in sandy beaches, São Sebastião channel, São Paulo state, Brazil*, Bull. Mar. Sci., 65 (1), 91–103.
- Drago A. F., Xuereb A., 1993, *Tide tables 1993, Grand Harbour, Malta*, Malta Maritime Authority (MMA) & Malta Counc. Sci. Technol. (MCST), Malta, 43 pp.
- EEA (European Environment Agency), 1999, *State and pressure of the marine and coastal Mediterranean environment*, (Environ. assess. Rep. No 5), OPOCE (Office for Official Publications of the European Communities), Luxembourg, 137 pp.
- Furato T., Ito T., 1999, *Life cycle and environmentally induced semelparity in the shore isopod Ligia cinerascens (Ligiidae) on a cobble shore along Tokyo bay, central Japan*, J. Crustacean Biol., 19 (4), 752–761.
- Jones Eifion W., 1980, *Field teaching methods in shore ecology*, [in:] *The shore environment, Vol. 1: Methods*, W. F. Farnham, D. E. G. Irvine & J. H. Price (eds.), Acad. Press, London, 19–44.
- King R., 1997, *Population growth: an unavoidable crisis?*, [in:] pp. 164–180, *The Mediterranean: environment and society*, R. King, L. Proudfoot & B. Smith (eds.), Arnold, London, xv + 315 pp.
- Little C., 2000, *The biology of soft shores and estuaries*, Oxford Univ. Press, Oxford, 252 pp.

- Mallia A., Briguglio M., Ellul A.E., Formosa S., 2002, *Physical background, demography, tourism, mineral resources and land-use*, [in:] *State of the environment report for Malta, 2002*, Min. for Home Affairs and the Environment, Santa Venera (Malta), p. 120.
- Martins A. M. F., 2001, *Ellobiidae – lost between land and sea*, J. Shellfish Res., 20 (1), 441–446.
- McLachlan A., 1990, *Dissipative beaches and macrofauna communities on exposed intertidal sands*, J. Coast. Res., 6, 57–71.
- McLachlan A., 1996, *Physical factors in benthic ecology: effects of changing sand particle size on beach fauna*, Mar. Ecol. Prog. Ser., 131 (3), 205–217.
- Morgans J. F. C., 1956, *Notes on the analysis of shallow-water soft substrata*, J. Anim. Ecol., 25, 367–387.
- Moore P. G., MacAlister H. E., Taylor A. C., 1995, *The environmental tolerances and behavioural ecology of the sub-Antarctic beach-hopper ‘Orchestia’ scutigera Dana (Crustacea: Amphipoda) from Husvik, South Georgia*, J. Exp. Mar. Biol. Ecol., 189 (1)–(2), 159–182.
- Morse D. H., 1997, *Distribution, movement, and activity patterns of an intertidal wolf spider Pardosa lapidicina population (Araneae, Lycosidae)*, J. Arachnol., 25, 1–10.
- Pères J. M., Picard J., 1964, *Nouveau manuel de bionomie benthique de la mer Méditerranée*, Rec. Trav. St. Mar. Endoume, 31 (47), 5–137.
- Reise K. (ed.), 2001, *Ecological comparisons of sedimentary shores*, Springer-Verl., Berlin, 384 pp.
- Schembri P. J., Baldacchino A. E., Mallia A., Schembri T., Sant M. J., Stevens D. T., Vella S. J., 2002, *State of the environment report for Malta 2002: Living resources, fisheries and agriculture*, [in:] *State of the environment report for Malta, 2002*, Min. for Home Affairs and the Environment, Santa Venera (Malta), 162–346.
- Schembri P. J., Deidun A., Mallia A., Mercieca L., 2005, *Rocky shore biotic assemblages of the Maltese Islands (Central Mediterranean): a conservation perspective*, J. Coast. Res., 21 (1), 157–166.
- Schembri S., 1989, *Insects excluding Coleoptera and Lepidoptera*, [in:] *Red data book for the Maltese Islands*, P. J. Schembri & J. Sultana (eds.), Information Dept., Valletta (Malta), 90–96.
- Seaward D. R., 2001, *The spaces in between: interstitial molluscs in Chesil shingle*, [in:] *Ecology and geomorphology of coastal shingle*, J. R. Packham, R. E. Randall, R. S. K. Barnes & A. Neal (eds.), Westbury Acad. Sci. Publ., Yorkshire, 377–378.
- Thomas M. L. H., 1986, *A physically derived exposure index for marine shorelines*, Ophelia, 25 (1), 1–13.