Research Article

Turk J Zool
2012; 36(3): 291-306
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doi:10.3906/zoo-1004-26

Spatial and temporal variations in the species composition and abundance of benthic molluscs along 4 rocky shores of Karachi

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Received: 27.04.2010

Abstract: A total of 97 species of macromolluscs were collected from 4 rocky beaches (Manora, Buleji, Nathiagali, and Cape Monze) along the Karachi coast from December 1993 to December 1995. More species were recorded from Buleji (68) and Manora (63) than from Nathiagali (55) and Cape Monze (57). Gastropods dominated at all 4 of the sites studied. Four species were commonly abundant at all 4 sites: *Turbo coronatus, Nerita albicilla, Morula granulata,* and *Cerithium rubus*. The average number of species decreased with an increase in the tidal heights at Manora, Buleji, and Nathiagali, whereas this was greater in the high tidal zone at Cape Monze's rocky shore. The average number of individuals of molluscs was greater in the midtidal zone at the Manora and Buleji rocky shores, whereas it was greater in the low tidal zone at Nathiagali and Cape Monze. Two-way nested analysis of variance showed that the number of individual molluscs was significantly different among zones and among sites in most of the samples. Species richness, diversity, and evenness, however, were not found to be significantly different among zones and sites. Cluster analyses, derived from Bray-Curtis measures of similarity based on abundance data, showed the discrimination between carnivore gastropods and an increase in the abundance of herbivore gastropod molluscs. Differences in community structure amongst sites appeared to be due to habitat structure, substrate instability, human disturbances, and degree of exposure.

Key words: Spatial, abundance, tidal level, rocky shores

Introduction

The ecological importance of the littoral zone in marine ecosystems is widely recognised. Intertidal zones reflect the sessile or sluggish nature of the common species. Their populations and communities can be easily estimated and experimentally manipulated (Paine, 1977). The intertidal zone is typified by a greater range of environmental conditions than any species can permanently withstand and still reproduce successfully (Trait and DeSanto, 1972).

The spatial and temporal variations in populations and communities are analysed qualitatively as well as quantitatively to characterise the spectrum of intertidal ecosystems. These analyses have been widely used to determine the pattern of distribution, abundance, maintenance of species diversity, and stability of communities (Legendre and Legendre, 1998; Koenig, 1999).

Rocky shores are rich in invertebrate fauna and provide a range of habitats for a variety of organisms belonging to almost all invertebrate phyla. The littoral benthic organisms as a whole and molluscs in particular play an important role in the local marine food chain. Molluscs serve as food for a number of other animals, particularly as veliger larvae and newly settled young. The principal predators of aquatic

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molluscs are fish, aquatic birds, and mammals, many of which are adapted to a diet of molluscs (Barnes, 1974). Marine molluscs constitute an important group and are 1 of the 2 dominant phyla of the rocky intertidal coast of Pakistan.

The literature on the ecology of rocky shores and intertidal organisms has been comprehensively summarised by Lewis (1964), Stephenson and Stephenson (1972), Valiela (1995), and Raffaelli and Hawkins (1996). The composition, distribution, and diversity of molluscs were studied by Jiang and Zhou (1982), Ruwa (1984), Asakura and Suzuki (1987), and Chapman and Underwood (2008), among others. Very few studies on the aforementioned aspects have been undertaken in Pakistan, however. Ahmed et al. (1982) documented the distribution and abundance of intertidal organisms on some beaches of the Makran coast. In that study, molluscs were observed to dominate on all of the beaches. A few species were found to be abundant or fairly abundant, although most of the species were only occasionally or rarely present. The biomass and species composition of a littoral rocky shore of the Karachi coast were examined by Barkati and Burney (1995) and Burney and Barkati (1995). According to Barkati and Burney (1995), some species were available in large numbers more regularly than others, and molluscs were among the most abundant species. Ahmed and Hameed (1999) studied seasonal variations in the biomass of intertidal macroorganisms from the rocky shore of Buleji. Rahman and Barkati (2004) analysed the effect of pollution and disturbance in molluscan communities on 4 beaches of Karachi by using abundance/biomass curves. Abundance/biomass comparison plots showed undisturbed or unpolluted conditions throughout the investigation period at Cape Monze. Nathiagali was also revealed to be unpolluted in most of the samples. However, Manora and Buleji showed moderately disturbed or moderately polluted conditions throughout the study period. Species composition and faunal diversity at 3 sites of Sindh mangroves were further documented by Barkati and Rahman (2005). The index of disturbance of benthic molluscs at 4 rocky shores of Karachi was investigated by Rahman and Barkati (2009). A relatively high index of disturbance based on the dry biomass abundance ratio (B:A) reflects the undisturbed nature of Cape Monze, followed by the Nathiagali rocky shore. On the other hand, Manora and Buleji appeared to be more disturbed, as indicated by a low B:A ratio.

The present study attempts to analyse the molluscan species composition and abundance in reference to tidal height (i.e., high, middle, and low tidal zones) on 4 rocky beaches of Karachi, Sindh.

Materials and methods

Four rocky ledges, namely Manora, Buleji, Nathiagali, and Cape Monze, were selected along the coast of Karachi. Nathiagali (24°51′N, 66°45′E) and Cape Monze (24°49′N, 66°40′E) are located in a naval restricted area far from the city, at a distance of 30 and 35 km, respectively, and are thus relatively undisturbed. Conversely, Manora (24°46′N, 66°57′E) and Buleji (24°50′N, 66°48′E) are located about 3 km southwest and 18 km northwest of Karachi, respectively. The intertidal shores of Manora, Buleji, and Cape Monze are open to direct surf action, while Nathiagali is protected from the direct surf action of the sea due to the presence of a rocky cliff of considerable height, allowing the water to reach the flat intertidal portion only after reducing its force.

The rocks of Manora are composed of Manchar sandstone and arenaceous clay, capped by hard conglomerates (Siddiqui, 1959). The substratum of the shore is of a hard, rocky type with plain surfaces of extremely low slopes occupied by boulders. The middle and the lower regions consist of continuous rocky platforms. Some parts of the ledge appear to form low-profiled rocky overhangs and cave-like shelters.

The rocks of Buleji are rough and hard. The coast receives drainage from a few small, temporary streams. The ledge is a gradually sloping, more or less triangular platform, with a slightly uneven profile consisting of slightly elevated and depressed areas. Boulders of various sizes can be seen scattered near the high water mark. The middle and lower reaches of the ledge are made up of rather flat rocks and small boulders.

The geological structure of Nathiagali's rocky ledge is simple. It is a semisheltered coast and there are large boulders present on the high and low littoral zones. At several places, the area is sandy between the rocks, which have crevices. The middle littoral zone is muddy as it remains under water.

Cape Monze proper is entirely composed of nummulitic rocks, chiefly limestone (Siddiqui, 1959). It is a relatively stable beach with a sharply steep vertical cliff. The bottom is flat but rough and uneven. Various sizes of boulders and stones are present throughout the littoral zone.

The rocky shores along the Karachi coast provide a wide variety of habitats for marine flora and fauna. Ninety species of green, 62 species of brown, and 103 species of red seaweeds have been reported (Shameel, 1996). Other than molluscs, the marine fauna commonly present on these shores include hydroids, tubiculous polychaetes, amphipods, isopods, pistol shrimps, alpheid shrimps, barnacles, crabs, brittle stars, star fishes, and sea urchins (Ahmed, 1980; Tahera and Naushaba, 1995; Ghalib and Hasnain, 1997; Ahmed and Hameed, 1999).

Karachi is the biggest coastal city, with a human population of about 10 million (Beg, 1993). Various stresses have had adverse effects on coastal species and their habitats. Among these are overexploitation, the conversion of natural areas, pollution, the urbanisation of coastal areas, industrialisation, and the development of public facilities (Ahmed, 1997). The inshore waters are characterised by high turbidity due to extensive beach erosion.

Sampling and laboratory techniques

Visits were made on a quarterly basis for a period of 2 years, from December 1993 to December 1995, resulting in a total of 9 visits to each site. The physical parameters of each study site, including date, time, tidal level, air and water temperatures, pH level, and salinity were recorded at each visit (details given in Rahman and Barkati, 2004).

Considering the type of shore, variable substratum, and limited available time for sampling during the low tide, the beaches were arbitrarily divided into 3 zones on the basis of tidal height. These divisions were high tidal zone (HTZ), (b) mid-tidal zone (MTZ), and low tidal zone (LTZ). The quadrat samples were spaced in a random fashion over an area parallel with the shoreline. At each of the 4 sites, 3 quadrat samples of 1 m^2 were taken from each tidal level. In total, 9 quadrat samples were obtained from each site. All samples were returned to the laboratory and frozen until they could be further analysed in the laboratory. The molluscs were sorted, identified, counted, blotted to remove excess water, and weighed (with shells). Molluscan species were identified using the following literature: Subrahmanyam et al. (1952), Kundu (1965), and Dance (1977).

In the present study, abundance is defined as the total number of individuals of a taxon or taxa per surface unit area. The average values of these quadrats were used to determine the total abundance for each tidal zone. The values of the 3 tidal zones were averaged to determine the abundance per average square meter of each study site.

The following diversity indices were used as measures of the community structure of a sample. Margalef's index (D') was used for richness (D' = (S – 1) / log N, where S = total number of species and N = total number of individuals observed). The Hill diversity number, N1, was used to calculate both richness and evenness combined ($N1 = e^{H'}$, where H′ = Shannon-Wiener index) and the modified Hill ratio, E5, was used for evenness (E5 = N2 – 1 / N1 – 1). In our 2-way nested analysis of variance, the subordinate classification was nested within the higher level of classification. The 2-way nested analysis of variance of abundance measure permits the partitioning of spatial variance into a treatment component. The expected mean squares generated in these analyses were used to estimate the percentage of total variation attributed to differences among sites and treatments (Sokal and Rohlf, 1981). Cluster analysis was based on a data matrix containing estimates of the number of individuals of each molluscan species found in each of the 36 quadrat samples. The matrix was subject to root-root transformation (Field et al., 1982) for measuring the similarity between each pair of samples based on Bray-Curtis similarity measures. Diversity indices and cluster analysis were calculated using the statistical software PRIMER v. 6 (Clarke and Gorley, 2006) from the Plymouth Marine Laboratory, UK.

Observations

The molluscan species may be broadly divided into 4 categories: Category 1, species present in all samples and in large numbers; category 2, species present in almost all samples but in low numbers; category 3, species found in only a few samples; and category 4, species collected only once or twice during the study and in low numbers.

Details are given below about the seasonal change in the molluscan abundance, percentage cover, average number of species, and average number of individuals on the 4 rocky shores of the Karachi coast, Manora, Buleji, Nathiagali, and Cape Monze.

Manora

A total of 63 molluscan species were recorded (Table 1): Gastropods (49 spp.) dominated the ledge, followed by bivalves (12 spp.), amphineurans (1 sp.), and cephalopods (1 sp.). Only 10 species provided more than 1% mean cover (average percentage composition). Less than 1% mean cover was shown by each of the 53 species (Table 1). Details of molluscan species included in the 4 categories are given in Table 1.

The average number of species was highest at Manora (33.33; Figure 1). The average number of species decreased with an increase in the tidal heights, corresponding to 22.6 species during low tide, 19.6 during mid-tide, and 16.0 during high

Table 1. A list of the molluscan species at 4 localities along the Karachi coast. Percentage cover and categories are also mentioned. Category 1, ++++; 2, +++; 3, ++; 4, +.

Species	Manora		Buleji		Nathiagali		Cape Monze	
	%	Category	%	Category	%	Category	%	Category
Gastropoda								
Acmea sp.	-	-	0.10	++	0.15	++	0.03	+
Acmea saccharina	-	-	-	-	-	-	0.03	+
Astele sp.	0.01	+	0.02	+	0.01		0.05	+
Astrea stellata	-	-	0.01	+	0.01	+	-	-
Bursa subgranosa	0.01	+	0.01	+	-	-	0.08	++
Calliostoma scobinatum	0.76	+++	0.10	++	0.05	++	1.07	+++
Cantharus rubiginiosus	2.32	+++	0.28	+++	0.37	+++	0.78	+++
Cantharus spiralis	0.73	++	0.09	++	0.11	++	0.51	++
Cantharus undosus	0.08	+	0.03	++	0.27	+++	3.78	++++
Cellana ornata	-	-	-	-	-	-	0.01	+
Cellana radiata	-	-	0.22	++	1.61	+++	0.46	++
Cellana sp.	-	-	0.02	+	0.30	++	0.01	+
Cerithedia cingulatus	7.61	++++	6.20	++++	3.95	+++	0.56	++
Cerithium hanleyi	0.17	++	1.09	++	9.95	++++	0.01	+
Cerithium morus	27.11	++++	20.43	++++	0.71	+++	0.13	++
Cerithium rubus	19.74	++++	19.58	++++	16.28	++++	8.10	++
Cerithium sinensis	0.65	+++	0.35	+++	0.86	+++	0.03	+
Cerithium sp.	17.83	++++	15.29	++++	3.06	+++	0.08	++
Clanculus ceylanicus	0.51	+++	0.24	+++	0.22	+++	0.24	+++
Clanculus pharaonius	0.06	++	0.09	++	0.26	+++	0.05	+
Clypidina notata	-	-	0.07	+	-	-	-	-
Conus biliosus	0.20	+++	0.06	+++	0.08	++	0.94	+++
Conus coronatus	0.02	+	-	-	-	-	0.08	+
Cypraea arabica	-	-	-	-	-	-	0.19	++
Cypraea chinensis	-	-	0.01	+	-	-	-	-
Cypraea depressa	-	-	-	-	-	-	0.03	+
Cypraea gracilis	0.01	+	-	-	-	-	-	-
Cypraea ocellata	-	-	0.02	+	-	-	0.03	+
Cypraea turdus	-	-	0.01	+	0.10	++	-	-
Diodora bombayana	0.04	++	0.03	++	-	-	0.21	++
Drupa subnodulosa	0.01	+	-	-	0.01	+	-	-
Drupa tuberculata	0.07	++	0.05	++	0.01	+	0.19	+++
Engina mendicaria	-	-	-	-	-	-	0.11	+
Epitonium scalare	0.01	+	0.01	+	-	-	-	-
Euchelus asper	0.08	++	0.69	+++	4.71	++++	1.58	++
Glossodoris	0.04	+	0.04	++	0.02	+	0.11	+
Heliacus stramineus	-	-	0.01	+	-	-	-	-
Heliacus variegatus	0.01	+	0.09	+	-	-	-	-
Latirus sp.	0.01	+	-	-	-	-	-	-

Table 1. (Continued).

Species	Manora		Buleji		Nathiagali		Cape Monze	
	%	Category	%	Category	%	Category	%	Category
Littorina sp.	0.01	+	-	-	-	-	-	-
Mitra ambigua	0.07	+++	0.06	++	0.02	+	0.11	++
Morula uva	1.10	+++	0.15	+++	0.16	+	2.58	+++
Morula granulata	4.06	++++	0.97	+++	1.48	+++	20.82	++++
Nassarius thersites	0.26	++	0.11	++	0.19	+++	0.03	+
Nassarius livescens	-	-	-	-	0.02	+	-	-
Nassarius sp.	0.21	+++	0.04	++	-	-	-	-
Natica onca	0.04	++	-	-	-	-	-	-
Nerita albicilla	1.42	+++	2.26	+++	9.94	++++	4.61	++++
Nerita textilis	-	-	-	-	0.10	++	0.16	+
Nodilittorina picta	-	-	0.07	++	3.93	+	-	-
Nodilittorina sp.	-	-	0.01	+	0.06	+	-	-
Oliva tremulina	-	-	-	-	-	-	0.21	++
Onchidium daemelli	0.04	++	0.06	++	0.07	++	-	-
Patella sp.	-	-	0.03	+	0.01	+	-	-
Pisania tritonoides	-	-	0.01	+	-	-	-	-
Pisania sp.	-	-	-	-	0.01	+	-	-
Planaxis sulcatus	0.75	+	13.25	++++	2.96	+++	-	-
Pterygia sp.	0.01	+	0.02	+	-	-	-	-
Pyrene flava	-	-	0.02	++	0.28	+++	0.24	++
Pyrene misera	0.95	+++	0.77	+++	0.17	+++	0.21	++
Pyrene punctata	-	-	-	-	-	-	0.11	++
Pyrene terpsichore	0.09	+	-	-	-	-	-	-
Rissoina sp.	0.01	+	-	-	-	-	-	-
Sinum sp.	-	-	0.05	+	0.17	+	-	-
Tectus crenulatus	0.03	+	-	-	-	-	-	-
Thais carinifera	0.03	+	0.01	+	0.01	+	0.08	++
Thais echinulata	0.41	++	0.01	+	-	-	0.11	++
Thais hippocastanum	0.07	++	0.03	++	0.12	++	0.62	+++
Thais rudolphi	0.15	++	0.01	+	0.62	+++	1.45	+++
Thais rugosa	0.35	+++	0.14	+++	0.06	+	0.43	+++
Thais undata	0.10	+	-	-	-	-	-	-
Trochus stellatus	0.21	+	0.33	+++	14.82	++++	21.49	++++
Turbo coronatus	7.55	++++	13.34	++++	16.92	++++	4.51	++++
Turbo intercostalis	0.21	++	1.68	+++	3.13	++++	17.41	++++
Vexillum sp.	-	-	-	-	0.07	++	0.03	+
Bivalvia								
Arca bistrigata	-	-	-	-	-	-	0.05	+
Arca complanata	-	-	0.01	+	-	-	0.03	+
Arca symmetrica	-	-	-	-	-	-	0.05	+
Barbatia obliquata	0.07	+++	0.02	+	-	-	0.11	++
Bassina sp.	0.17	+++	0.02	+	-	-	-	-
Cardium sp.	0.02	++	0.01	+	-	-	-	-
Circe scripta	-	-	-	-	0.01	+	-	-
Crassostrea tuberculata	0.03	+	0.06	++	0.07	+	-	-
Chylamys pallium	0.01	+	-	-	-	-	-	-
Lithophaga nigra	0.24	+++	0.26	++	0.20	+	0.16	+
Lithophaga sp.	0.37	+++	0.04	+	-	-	-	-
Martesia striata	0.20	++	0.07	+	-	-	-	-
Ostrea folium	0.01	+	-	-	-	-	-	-
Pecten sp.	-	-	0.02	+	-	-	-	-
Perna viridis	2.34	+++	0.02	+	-	-	-	-
Sunetta scripta	0.01	+	0.07	++	0.01	+	0.08	+
Sunetta sp.	0.05	++	0.05	++	0.27	++	0.24	++
Tapes literatus	-	-	-	-	0.05	+	-	-
Amphineura								
Chiton sp.	0.31	+++	0.71	+++	0.96	++	3.35	+++
Cephalopoda								
Octopus vulgaris	0.01	+	0.02	+	0.02	+	0.03	+

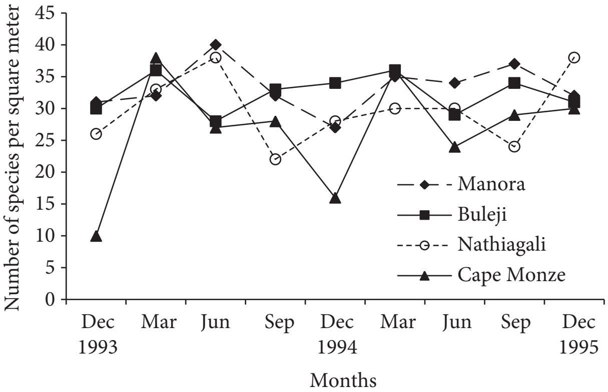

Figure 1. Seasonal variation in the number of molluscan species per square meter from the 4 study sites: Manora, Buleji, Nathiagali, and Cape Monze.

tide. In the LTZ, the number of species was low in winter (December) and highest in the summer. In the MTZ and HTZ, changes in the number of species were not consistent with the season (Table 2). The average number of individual molluscs was highest in the MTZ (275/m^2), followed by HTZ (234/m^2) and LTZ (94/m^2). The number of individuals in the LTZ and MTZ changed seasonally, from high in winter (December) to low the following spring (March) during 1994 (Table 3). However, in 1995, low values were recorded in summer in all tidal zones, whereas high values occurred in different seasons. The number of individual molluscs in the total area was low in summer and high in autumn during both years of the study (Figure 2). The Manora molluscan fauna had the highest Hill diversity index (N1 = 3.63) of all sites studied (Figure 3).

Buleji

A total of 68 species of molluscs were sampled, consisting of gastropods (54 spp.), bivalves (12 spp.), amphineurans (1 sp.), and cephalopods (1 sp.). The total number of species per sample varied from 28 (June 1994) to 36 (March 1995). Nine species made up 93% of the molluscan fauna and the remaining 7% corresponded to 60 species (Table 1). Details of the species included in all 4 categories are given in Table 1.

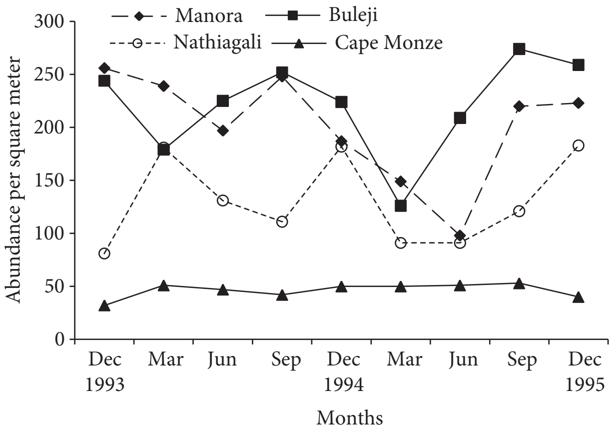

Figure 2. Seasonal variation in the number of molluscan individuals per square meter from the 4 rocky shores: Manora, Buleji, Nathiagali, and Cape Monze.

Table 2. Seasonal variation in the number of molluscan species in low, middle, and high tidal zones of the Karachi coast: Manora, Buleji, Nathiagali, and Cape Monze.

Month	Manora			**Buleji**			Nathiagali			Cape Monze		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
Dec 1993	21	21	16	25	13	7	18	12	11	6	4	6
Mar 1994	23	14	15	23	19	9	18	18	14	21	13	25
Jun 1994	28	22	17	19	13	10	21	26	19	11	14	15
Sep 1994	25	21	13	25	6	12	15	11	13	14	13	13
Dec 1994	15	20	15	25	21	11	19	14	14	6	8	8
Mar 1995	25	11	16	28	18	6	19	19	9	20	13	23
Jun 1995	21	22	18	21	14	13	19	19	20	11	15	15
Sep 1995	24	24	18	23	18	15	12	13	19	17	17	16
Dec 1995	22	22	23	27	15	11	19	22	21	15	17	21

Table 3. Seasonal variation in the number of individual molluscs per square meter in low, middle, and high tidal zones of the Karachi coast: Manora, Buleji, Nathiagali, and Cape Monze.

Month	Manora			Buleji			Nathiagali			Cape Monze		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
Dec 1993	142	390	236	195	394	144	104	78	063	26	29	40
Mar 1994	85	282	351	74	324	140	184	206	156	56	43	55
Jun 1994	118	326	146	149	363	163	109	193	91	48	45	49
Sep 1994	112	354	278	96	459	203	116	133	86	27	39	59
Dec 1994	77	247	236	62	368	242	231	121	194	49	52	47
Mar 1995	103	166	180	89	139	150	90	97	86	54	43	54
Jun 1995	55	132	108	114	283	230	78	100	94	53	47	51
Sep 1995	93	288	279	108	346	369	72	90	200	31	56	73
Dec 1995	81	296	291	114	322	340	271	81	197	26	57	38

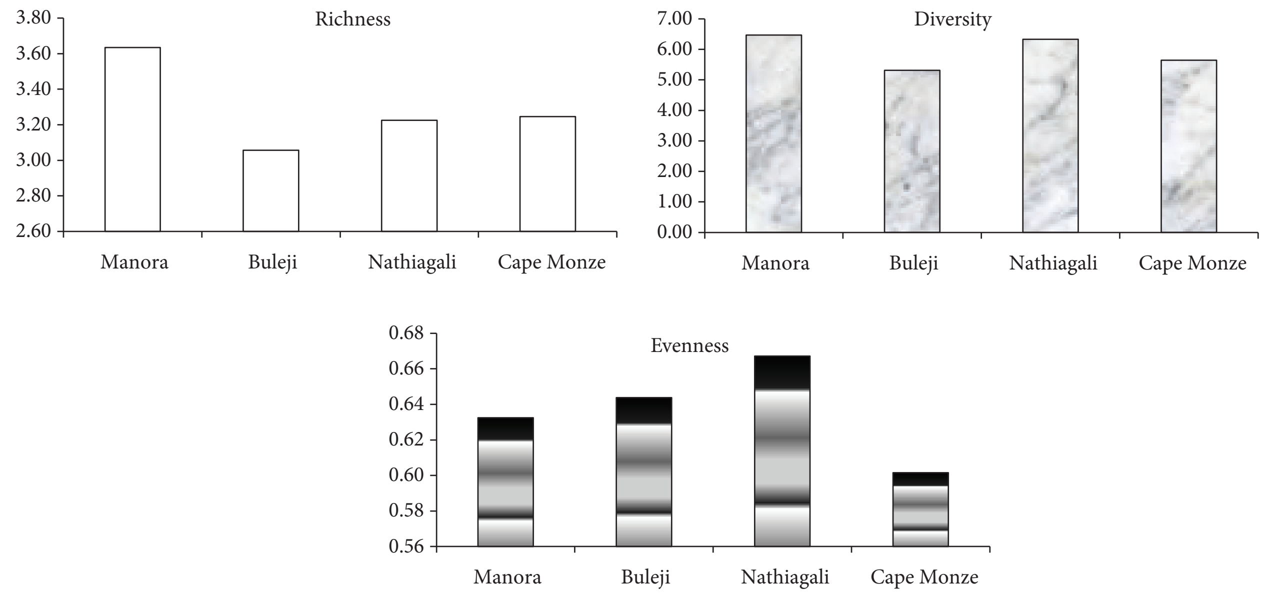

Figure 3. Mean annual richness, diversity (N1), and evenness (E5) for each study area using molluscan density data.

The average number of species decreased with an increase in tidal heights, with 24 species present during low tide, 15 during middle, and 10 during high. There was no definite pattern of change with change in season (Figure 1). The number of species, for instance, in the LTZ was at a minimum in the summer (June) during both years, and at its highest in winter (December) during the first year and in spring (March) during the second year of study (Table 2). The average number of individuals was highest in the MTZ (333.11/m^2), followed by the HTZ (220.11/m^2) and LTZ (111.22/m^2). Molluscan individuals of the LTZ and MTZ showed different seasonal patterns during the 2 years of study (Table 3). The mean yearly Hill diversity (N1) was 5.31, richness (D') was 3.06, and evenness (E5) was 0.64 (Figure 3).

Nathiagali

There were 55 species in the area belonging to the following classes of phylum Mollusca: gastropods (47 spp.), bivalves (6 spp.), amphineurans (1 sp.), and cephalopods (1 sp.). The total number of species per sample ranged from 22 in September 1994 to 38 in both June 1994 and December 1995. Only 12 species had an average percentage cover of more than 1% (Table 1). A mean cover of less than 1% was contributed by each of the 43 species in different collections. Details of the species included in the 4 categories are given in Table 1.

The average number of species was highest in the LTZ (17.77), followed by the MTZ (17.11) and HTZ (15.5). Molluscan species in the LTZ changed seasonally; the lowest values were recorded in autumn (September) during both of the study years, while the greatest numbers were observed in summer during the first year and remained constantly high throughout winter, spring, and summer of the second year. The number of species in the MTZ varied from high in summer (June) to low in autumn (September) during 1994, but was high in spring and summer and low in September during 1995. In the HTZ, the species number was low in winter and high in summer during the first year, whereas low values were recorded in spring and high values in summer during the second year of study (Table 2).

The average number of individual molluscs was highest in the LTZ (139.44/m^2), followed by the HTZ (129.67/m^2) and MTZ (122.11/m^2). The number of individual molluscs from all 3 tidal zones fluctuated seasonally, from low in winter (December) to high in spring (March) during the first year (Table 3). During the second year, however, the values were high in winter (December) and low in autumn (September) in the LTZ and MTZ. The values in the HTZ varied from low in spring (March) to high in autumn (September). Although the June and December samples contained the most species, there was no marked seasonality in Hill diversity N1 (6.33 yearly mean).

Cape Monze

A total of 57 species were recorded during the study period. Gastropods were represented by 45 species, bivalves by 7, and amphineurans and cephalopods by 1 species each. The number of species per sample varied from 10 in January 1994 to 38 in March 1994.

Twelve species of molluscs provided 90% of average percentage cover, while 45 species provided the remaining 10% (Table 1). Details on the species included in each of the 4 categories are given in Table 1.

The average number of species was higher in the HTZ (15.77) as compared to the other 2 zones, with the LTZ and MTZ having an average of 13.44 and 12.66 species, respectively. The number of species in all 3 tidal zones was at a minimum during the winter season (December), while the species in the LTZ and HTZ were found to be at a maximum in spring (March) during both years. Molluscan species numbers in the MTZ, however, were high in summer (June) during 1994 and in autumn (September) during 1995 (Table 2).

The average number of individuals increased with an increase in tidal height, with 41.14/m^2 observed in the LTZ, 45.51/m^2 in the MTZ, and 51.81/m^2 in the HTZ. Individual molluscs in the LTZ were at their highest numbers in the spring and their lowest in the autumn during both years. In the MTZ, the individuals fluctuated seasonally from low in winter to high in summer during 1994, whereas they varied from low in spring to high in autumn during 1995. The number of individual molluscs in the HTZ changed from low in winter (December) to high in autumn (September) during both years of study (Table 3).

The total number of individuals at Cape Monze was high in spring and winter, with low values in summer and autumn during 1994. However, consistently high values were recorded in the spring, summer, and autumn, with relatively low values in the winter, during 1995. Richness was highest in spring, evenness in winter, and the Hill diversity N1 in autumn.

Comparison between sites

Over the course of our study, 97 species of molluscs were collected from the 4 sites. A greater number of mollusc species were sampled from Buleji (68) and Manora (63) compared to the Nathiagali (55) and Cape Monze (57) rocky shores. The average number of molluscs per square meter was also higher at

Buleji (221.70/m^2) and Manora (201.92/m^2) than at Nathiagali (130.37/m^2) and Cape Monze (46.01/m^2).

Five species of molluscs were abundant at all 4 of the sites: *Turbo coronatus*, *Nerita albicilla*, *Morula granulata*, *Cerithium rubus*, and *Chiton* sp. At Manora and Buleji, 3 species of the family Cerithidae (*Cerithium morus*, *Cerithium* sp., and *Cerithidea cingulatus*) were abundantly present but were seen in few numbers at Nathiagali and Cape Monze (Table 1). The molluscs abundantly present only on the beaches of Nathiagali and Cape Monze were *Euchelus asper*, *Cantharus undosus*, *Trochus stellatus*, *Thais rudolphi*, *Turbo intercostalis*, *Nerita textilis*, and *Cellana radiata*.

The bivalve *Perna viridis* was abundantly present only on the rocky shore of Manora, while the gastropod *Planaxis sulcatus* was abundantly present on Buleji and Nathiagali's rocky shores. *Conus biliosus* was regularly found only at Cape Monze. Some species of molluscs, such as *Onchidium damellai*, *Glossodoris*, *Cypraea* sp., *Thais* sp., *Bursa subgranosa*, *Barbatia obliquata*, and *Cantharus rubiginiosus*, were found occasionally on all shores (Table 1).

The average number of species was highest at Manora (33.33), followed by the Buleji (32.33) and Nathiagali (29.88) rocky shores. Cape Monze had the lowest average number of species (26.44). A pronounced seasonal variation in the number of species present was observed at the 4 sites (Table 2). In most of the samples, the number of species was highest at the Buleji and Manora rocky shores (Figure 1).

The mean number of individual molluscs was considerably higher at Buleji (221.44/m^2) and Manora (201.88/m^2) as compared to the Nathiagali (130.22/m^2) and Cape Monze (46.22/m^2) rocky shores (Table 3). In most of the samples, the number of individuals was higher on Buleji's rocky shore (6 out of 9) and, in the rest of the samples, values were highest on Manora's rocky shore. Cape Monze had the lowest number of individuals as compared to the other 3 sites throughout the study period (Figure 2).

The species richness of the macromolluscan community at Manora was significantly higher than at the other 3 sites. Furthermore, the species richness of the low-tide community was higher than that of the mid- and high-tide communities. Species diversity was high at Manora and more or less indifferent at Nathiagali, but significantly lower at Cape Monze and Buleji. Equitability was high at Nathiagali and Buleji, somewhat low at Manora, and significantly lower at Cape Monze. Equitability was higher in HTZ communities and gradually decreased in the MTZ and LTZ.

Two-way nested analysis of variance showed that the numbers of individual molluscs at all 4 sites were significantly different at a level of 5% in December 1993, March 1995, and June 1995 (Table 4), whereas samples from September and December 1995 were significantly different at a level of 10%. The samples in which the numbers of individuals were different at the 25% significance level included March 1994, June 1994, September 1994, and December 1994. The number of individuals among zones within sites was significantly different in all samples at the 5% level except in December 1994, which was significantly different at 10%. Species richness, diversity, and evenness were not significantly different between zones and sites, however.

The cluster analysis showed a clear separation between the quadrat samples from Cape Monze (cluster 1) and the quadrat samples from Nathiagali, Manora, and Buleji (cluster 2). In cluster 2, the samples from Nathiagali are dissimilar to those from other sites, whereas the samples from Manora and Buleji are inseparable (Figure 4). The samples from the 3 distinct tidal zones in each of the 4 sites are similar to one another, but at different similarity levels.

Discussion

Discussing the rocky shore communities of Pakistan, Ahmed (1997) stated that the rocky beaches are dominated by gastropod molluscs and decapod crustaceans. Based on the published information about the species composition of molluscan populations from various parts of the world, 3 categories can be identified: those featuring more gastropods than bivalves, those with more bivalves than gastropods, and those containing equal or almost equal numbers of bivalves and gastropods (Table 5). Working on 3 coastal sites in Baluchistan,

Table 4. Seasonal variation in the values of 2-way nested analysis of variance based on estimates of molluscan abundance from 4 rocky sites.

Month	Source of variation	Degrees of freedom (df)	Sum of squares (SS)	Mean squares (MS)	F ratio	Probability
	Among sites	3	349,497.10	116,499.03	4.61	<0.05
Dec 1993	Among zones within site	8	201,987.10	25,248.39	2.41	<0.05
	Within zone	24	251,104.70	10,462.70		
	Among sites	3	170,501.44	56,833.81	2.08	<0.25
Mar 1994	Among zones within site	8	218,673.11	27,334.14	2.44	<0.05
	Within zone	24	269,327.33	11,221.97		
	Among sites	3	168,150.22	56,050.07	2.48	<0.25
Jun 1994	Among zones within site	8	180,649.33	22,581.17	2.90	<0.05
	Within zone	24	186,834.00	7784.75		
	Among sites	3	293,654.44	97,884.81	2.57	<0.25
Sep 1994	Among zones within site	8	305,206.44	38,150.81	4.90	<0.05
	Within zone	24	186,726.00	7780.25		
	Among sites	3	157,347.86	52,449.29	1.96	<0.25
Dec 1994	Among zones within site	8	214,002.44	26,750.31	2.34	<0.10
	Within zone	24	273,976.67	11,415.69		
	Among sites	3	50,430.53	16,810.18	8.00	<0.05
Mar 1994	Among zones within site	8	16,800.89	2100.11	1.49	<0.05
	Within zone	24	33,785.33	1407.72		
	Among sites	3	124,162.44	41,387.48	6.08	<0.05
Jun 1994	Among zones within site	8	54,495.78	6811.97	2.61	<0.05
	Within zone	24	62,757.33	2614.89		
	Among sites	3	264,688.53	88,229.51	3.08	<0.10
Sep 1994	Among zones within site	8	228,950.44	28,618.81	8.62	<0.05
	Within zone	24	79,644.00	3318.50		
	Among sites	3	248,512.33	82,837.44	2.74	<0.10
Dec 1995	Among zones within site	8	241,716.22	30,214.53	3.23	<0.05
	Within zone	24	224,316.67	9346.53		

Ahmed et al. (1982) reported more gastropod species as compared to bivalves. In the present study, 97 species of molluscs were recorded from 4 rocky beaches on the Karachi coast. The gastropod-to-bivalve ratio for these locations was determined to be 49:12 at Manora, 54:12 at Buleji, 47:6 at Nathiagali, and 48:7 at Cape Monze.

Relative abundance

Ahmed et al. (1982) categorised the molluscan species of the Makran coast in Pakistan, into 4 types: abundantly present, fairly abundant, occasionally present, and rarely present. In the present study, few species were categorised as abundantly present, more were fairly abundant, and a number of species were either rarely or occasionally present on the 4 rocky shores of Karachi. The same inference has been drawn by a number of other authors (Fuxue et al., 1994; Barkati and Burney, 1995; Dye, 1998; Ahmed and Hameed, 1999; Hameed et al., 2001).

The presence of some molluscan species on more than one type of shore and the discontinuity in distribution has been the subject of many studies (Atapattu, 1972; McQuaid and Branch, 1984; Litaay, 1994). During the present study, 5 species of molluscs were shown to be commonly abundant at all 4 sites. A further 3 species were present abundantly at Manora and Buleji but were seen in few numbers at Nathiagali and Cape Monze. Eight gastropod molluscs were abundantly present on the beaches of Nathiagali and Cape Monze.

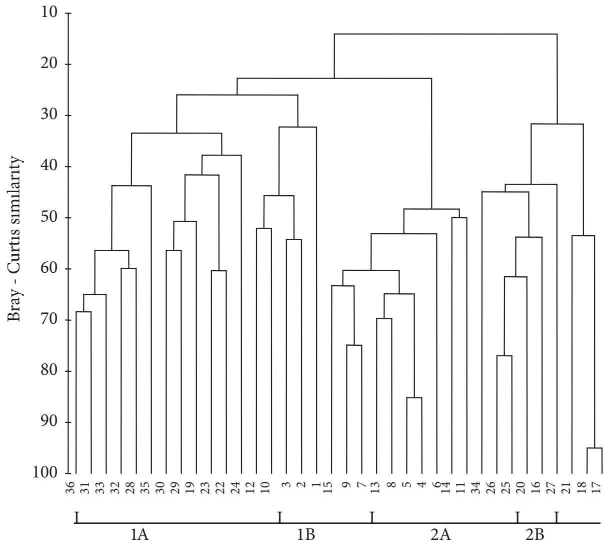

Figure 4. Dendrogram showing the group average clustering of Bray-Curtis similarity indices based on root-root transformed molluscan abundance at the 4 study sites. Numbers refer to replicate quadrat samples 1-9, 10-18, 19-27, and 28-36 representing sites Manora, Buleji, Nathiagali, and Cape Monze, respectively; letters indicate clustering of quadrat samples.

Abundance of molluscs at different sites

The mean abundance of macroorganisms varied from site to site depending on a number of factors. Macroinvertebrate abundance was previously determined at 167.4/m^2 on sea stack, 102.5/m^2 on a boulder beach in California (Seapy and Littler, 1978), and at 3609/m^2 at Coal Oil Point and 583/m^2 at Corona del Mar in California (Littler, 1980).

The abundance of intertidal organisms at exposed sites ranged from 75.0 to 118.4 individuals/20 cm^2 and from 6.7 to 147.6 individuals/20 cm^2 on the sheltered shores of Keppel Bay, Australia (Coates, 1998). The abundance of macrobenthos ranged from 55.5 to 2333.5 individuals/m^2 with an average of 716.24 individuals/m^2 in the vicinity of Carson Submarine canyon in the north-western Atlantic Ocean (Houstan and Haedrich, 1984). Barkati and Burney (1995) found that the number of macromolluscs ranged from 83.0 to 6394.0 individuals/m^2 on Buleji's rocky shore.

Table 5. Ratio of gastropod and bivalve species among benthic molluscs.

Number of species			Locality	Reference
Molluscs	Gastropods	Bivalves		
31	13	18	West Bay, Gwader, Pakistan	Ahmed et al., 1982
21	13	08	East Bay, Gwadar, Pakistan	Ahmed et al., 1982
24	16	08	Jiwani, Pakistan	Ahmed et al., 1982
62	44	-	Buleji, Pakistan	Ahmed and Hameed, 1999
68	-	-	Pacha, Pakistan	Hameed et al., 2001
57	27	05	West coast, Sri Lanka	Atapattu, 1972
	29	02	South coast, Sri Lanka	
	19	02	East coast, Sri Lanka	
39-120	-	-	Japan	Asakura and Suzuki, 1987
113	-	-	Venezuela	Carvajal and Capelo, 1993
91	70	19	Somalia	Chelazzi and Vannini, 1980
125	97	15	California, USA	Littler, 1980
298	199	99	Mexico	Gonzalez et al., 1991
54	33	15	China	Fuxue et al., 1994
73	45	24	Spain	Troncosa and Urgorri, 1991
55	-	-	Indonesia	Kaligis, 1995
-	40	24	Egypt	El-Komi, 1996
63	49	12	Manora, Karachi, Pakistan	Present study
68	54	12	Buleji, Karachi, Pakistan	Present study
55	47	06	Nathiagali, Karachi, Pakistan	Present study
57	48	07	Cape Monze, Karachi, Pakistan	Present study

The mean number of molluscs was considerably higher at Buleji (221.4/m^2) and Manora (201.8/m^2) as compared to the Nathiagali (130.2/m^2) and Cape Monze (46.2/m^2) rocky shores (Figure 2).

Abundance and tidal level

A decrease in the number of species and individuals present on rocky shores in an upshore direction has been noted by Loi (1981) and McQuaid et al. (1985). Littler (1980) observed variation in the distribution and abundance of organisms in 3 tidal zones at 10 sites within the Southern California Bight. Li et al. (1993) recorded the highest vertical distribution of species from MTZs at Daya Bay in China. On various shores in Pakistan, the MTZs have been shown to be the most productive in terms of the total number of species and individuals by Barkati and Burney (1995), Ahmed and Hameed (1999), and Nasreen et al. (2000).

During the present study, the number of species decreased with an increase in the tidal height, whereas the average number of individual molluscs was highest in the MTZ on the rocky shores of Manora and Buleji. The average number of species and individuals was highest in the LTZ of Nathiagali's rocky shore. On the Cape Monze shore, the average number of species was higher in the HTZ and the average number of individuals increased with an increase in tidal height.

The abundance of macroinvertebrates and macrophytes on rocky shores often varies with the seasons (Littler, 1980; Horn et al., 1983; Barkati and Burney, 1995; Dye, 1998; Fatima and Barkati, 1999; Nasreen et al., 2000). The abundance varied with the seasons at the 4 sites studied during the present investigation. Generally, local or site-specific conditions tended to predominate and obscure any broad climatic effects.

According to Barkati and Burney (1995), it was hard to distinguish a clear seasonal trend in the variation of the number of individual macroinvertebrates at the Buleji rocky shore on the coast of Karachi. Fatima and Barkati (1999) noted that during the summer months (April to August, the monsoon period), both algal and invertebrate species were less abundant at Paradise Point, Karachi. Nasreen et al. (2000) mentioned an increase in the number of individuals from May to August (beginning of southwest monsoon) on the Manora rocky shore.

A general lack of any widespread or consistent patterns in the abundance of rocky intertidal macrophytes and macroinvertebrates was noted at 10 sites within the Southern California Bight (Littler, 1980). Dwivedi et al. (1973) observed variations in the benthic fauna of 2 sites in Goa, India, from month to month; the density of macrobenthos declined in August and increased in October.

A number of factors are believed to influence the distribution of communities in the littoral area. The species composition and quantitative horizontal distribution of communities in the littoral area may be related to salinity and wave exposure (Cai et al., 1991). The vertical distribution is in relation to tides (McQuaid et al., 1985; Li et al., 1993), water current (Cruz-Abrego et al., 1994), and disturbances (Littler, 1980; Lasiak and Field, 1995). The distribution of species has also been revealed to depend upon the type of substrate and the habitat heterogeneity (McQuaid et al., 1985; Fuxue et al., 1994; El-Komi, 1996). The number of species and their distribution were also correlated to the presence of suspension and filter feeders on rocky shores (Atapattu, 1972; McQuaid et al., 1985).

According to Grubelic (1992), steep, well-washed rocky shores are inhabited by a larger number of plant and animal species compared to vertical and exposed localities or those that are sloping and sheltered. Banse (1968) pointed out that in addition to the effect of tidal position, low oxygen values near the bottom of the shelf between Bombay and Karachi would sometimes affect the distribution of benthic animals, demersal fish, and shrimp.

The results of the present investigation suggest that the distribution and abundance of molluscan communities are related to a number of the factors mentioned above; the vertical distribution of species is mostly related to the daily tidal cycle of submersion at the study sites. Cape Monze, having less emersion time, possessed more evenly distributed species of molluscs. Exposure to wave action, however, is one of the key factors in the distribution of molluscan species on Nathiagali's rocky shore. The distribution and abundance of molluscan species are positively correlated with the presence of mussels at the

Manora rocky shore, confirming the observations of Loi (1981), McQuaid et al. (1985), and Azevedo (1992). With a variety of habitats, the gradually sloping rocky shores of Manora and Buleji show a high abundance of molluscan species as compared to Nathiagali, a site that features vertical sloping. The species are comparatively less evenly distributed on the Manora and Buleji rocky shores, probably due to stress, desiccation, and sand inundation, as well as disturbance. The undisturbed sites of Nathiagali and Cape Monze possess more stable and evenly distributed molluscan communities.

Molluscan diversity

According to Littler (1980), the richness at Coal Oil Point, a community stressed by both oil and sand inundation, was much lower than that of other sites. Sites high in richness and number of taxa were often low in evenness. Wu and Richards (1981) observed an increase in species diversity with increasing salinity and decreasing silt-clay fraction of sediment in a subtropical estuary in Hong Kong. According to McQuaid and Branch (1984), richness was low and evenness was high on an unstable substratum. However, no significant differences in richness or evenness were found between exposed and sheltered rocky beaches around the Cape of Good Hope in South Africa. Contreras et al. (1991) stated that the species diversity in littoral molluscs was high on rocky shores with heterogeneous substrate and low in partially protected areas with smooth rocks in the Chamela Bay in Mexico. The results of the present study showed that species richness and diversity were slightly higher on a heterogeneous and stable substrate (Cape Monze). According to Warwick et al. (1990), macrofaunal diversity was lowest in disturbed and polluted areas and highest in undisturbed areas of Hamilton Harbour, Bermuda.

However, Warwick and Clarke (1993) pointed out that diversity behaves neither consistently nor predictably in response to environmental stress. Furthermore, Lasiak and Field (1995) indicated that exploitation had no significant effect on species richness or diversity on the Transkei coast of South Africa.

The results of the present investigation are in accordance with the observations of Warwick and Clarke (1993) and Lasiak and Field (1995) in showing that the trends in species richness, diversity, and evenness are not significantly different among sites. The richness was only slightly higher at the most stable and undisturbed community (Cape Monze) than at the relatively more unstable and disturbed sites (Manora, Nathiagali, and Buleji). Species were more evenly distributed at Buleji and less evenly at the Nathiagali, Manora, and Cape Monze rocky shores, confirming the results of Littler (1980) and McQuaid and Branch (1984). The diversity values correspond to those of species richness, whereas the evenness values are negatively correlated to the values of species richness at the 4 sites during the study period.

Cluster analysis

Numerical classification based on the species composition of communities is an effective means of illustrating the dynamic patterns observed in the long-term benthic biological data (Stull et al., 1986). The results of cluster analysis undertaken in the present study showed that the grouping of sites appeared to be due to habitat structure, substrate instability, human disturbances, and degree of exposure. The close grouping of the 2 gently sloping sites, Manora and Buleji, which are subjected to high levels of stress, is due to substrate instability and human disturbances. The semisheltered site, Nathiagali, was the next most similar to this group, while the most stable rocky ledge, Cape Monze, had less exposure time and was thus least correlated with the first 2 sites mentioned. The same inference was drawn by other researchers. According to Seapy and Littler (1978), who studied 2 rocky intertidal habitats in central California, the major differences between the sites appeared to be to the result of differences in the shearing forces of waves and the relative degree of habitat structure.

A detailed ecological study of the 10 sites along the Southern Californian Bight was carried out by Littler (1980). He mentioned that a dendrogram based on the combined overall mean abundance produced groupings of the island sites having mixtures of cold-water and warm-water biota clustered together with the ocean beach habitat. The 2 leeward warm-water sites were found to be the next most similar to the first locations, while the 2 disturbed sites were correlated with the aforementioned sites to a lesser extent. The 2 cold-water sites formed a second cluster group, while the oil-polluted site was not closely correlated with any of the other sites. Lasiak and Field (1995) mentioned that their cluster analysis, based on abundance data, provided the most clear-cut discrimination between the exploited and nonexploited rocky sites of South Africa.

In the present investigation, the dendrogram showed that the quadrat samples in zones were distinct on the Manora, Buleji, and Nathiagali rocky shores. The quadrat samples from one tidal zone of Manora were more similar to the quadrat samples from the same tidal zone of Buleji than to the other tidal zones of the same site. Similarly, the quadrat samples from the vertical LTZ and HTZ of Nathiagali were more similar to each other than to the quadrat samples from the horizontal MTZ. The present observation is in conformity with those of Seapy and Littler (1978), Loi (1981), Seapy and Littler (1982), and Kaandorp (1986).

In Loi's study of the Port of Long Beach, California, the dendrogram resulted in 3 groupings comprising the shoreline, inner breakwater, and outer breakwater stations on intertidal assemblages on hard substrates (1981). The relatively low similarity of species composition between stations in the shoreline group seems to be because of possible variations in the environmental factors, including silt and oil. Seapy and Littler (1978) recognised 12 cluster groups in the boulder beach of central California's rocky intertidal habitats. These fell into 2 large groups, the first containing a series of upper beach quadrats and the other comprising a series of lower beach quadrats. According to Kaandorp (1986), 2 groups were evident in the division of communities, the first group from shaded habitats and the other group from horizontal and vertical surfaces on the rocky substrate communities of the Boulannais coast of northwestern France. According to Seapy and Littler (1982), the macrobiota on Santa Cruz Island revealed the presence of 5 distinct zones in the dendrogram. Asakura and Suzuki (1987) studied the distribution patterns of intertidal molluscan fauna on the exposed rocky shores of the Pacific coasts of Japan. Commonness indices showed that the molluscan fauna of the study sites situated within the wide area between the Kanto and Kyushu were closely related with each other, and they can be regarded as a single province. The Tohoku district was less related with this region and the Okinawa district was found to be the least related. The present results are in accordance with those of Asakura and Suzuki (1987).

Acknowledgements

The first author is extremely grateful to Dr K.R. Clarke, Mrs Linda Horsfield, Prof R.F.C. Mantoura, Ray Gorley, and Martin Carr of Plymouth Marine Laboratory, UK, for sending the PRIMER software used for data analysis, as well as for many helpful comments and suggestions.

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