CENTRO, Vol. 1, No. 5, 1990, pp. 13 - 32

Ecology of the Għadira Pool Macrofauna (Għadira Nature Reserve, Maltese Islands, Central Mediterranean)

MARK J. BORG, PATRICK J. SCHEMBRI and VICTOR AXIAK

Department of Biology, University of Malta, Msida, Malta.

ABSTRACT

Sediment and water samples were collected quantitatively from three stations in the pool within the Għadira Nature Reserve at monthly intervals over a period of 12 months (May 1985-April 1986). The macrofauna within these samples was sorted into species and counted to provide estimates of population density and abundance, and of their fluctuation with season.

Five species dominated the samples: *Ventrosia ventrosa* (Gastropoda), *Cerastoderma glaucum* (Bivalvia), *Orchestia gammarellus* (Amphipoda), *Lekanesphaera hookeri mediterranea* (Isopoda) and the larvae of an unidentified species of Chironomidae (Diptera). Other species present in lower numbers included: *Truncatella subcylindrica* (Gastropoda), *Ovatella myosotis* (Gastropoda), *Gammarus aequicauda* (Amphipoda), larvae of *Sratiomys longicornis* and an unidentified species of Syrphidae (Diptera), four different species of Hydrophilidae (Coleoptera), and the fish *Liza ramada* and *Aphanius fasciatus.*

Overall species richness was low but individual species reached very high population levels: the most abundant species were *Ventrosia ventrosa* and *Cerastoderma glaucum* with average population densities of 15,000-52,000 individuals/m^2 and 4000-4600 individuals/m^2, respectively, over the study period. Benthic diversity was higher than diversity in the water column. Population density of most species fluctuated with season. Three patterns were observed: strongly unimodal (as shown by *Orchestia gammarellus,* strongly bimodal (as shown by the chironomid larvae), and populations which were maintained throughout the year with occasional peaks (as shown by *Ventrosia ventrosa, Cerastoderma glaucum* and *Lekanesphaera hookeri*). Populations of different species peaked at different times and for a given species, populations in different stations peaked at slightly different times and reached different levels. In many cases, the timing and amplitude of the population peaks could be correlated with changes in the physico-

chemical parameters affecting the pool; however, different species were affected by different factors or combinations of factors. In some cases, low population densities could also be correlated with changes in pool chemistry, mainly low dissolved oxygen concentrations.

Spatial variation in the pattern and/or amplitude of population fluctuations was noted for certain species. In general, this seemed to be correlated primarily with the varying nature of the substratum, the degree of water level fluctuations and the blooming of micro- and macroalgae in the different parts of the pool.

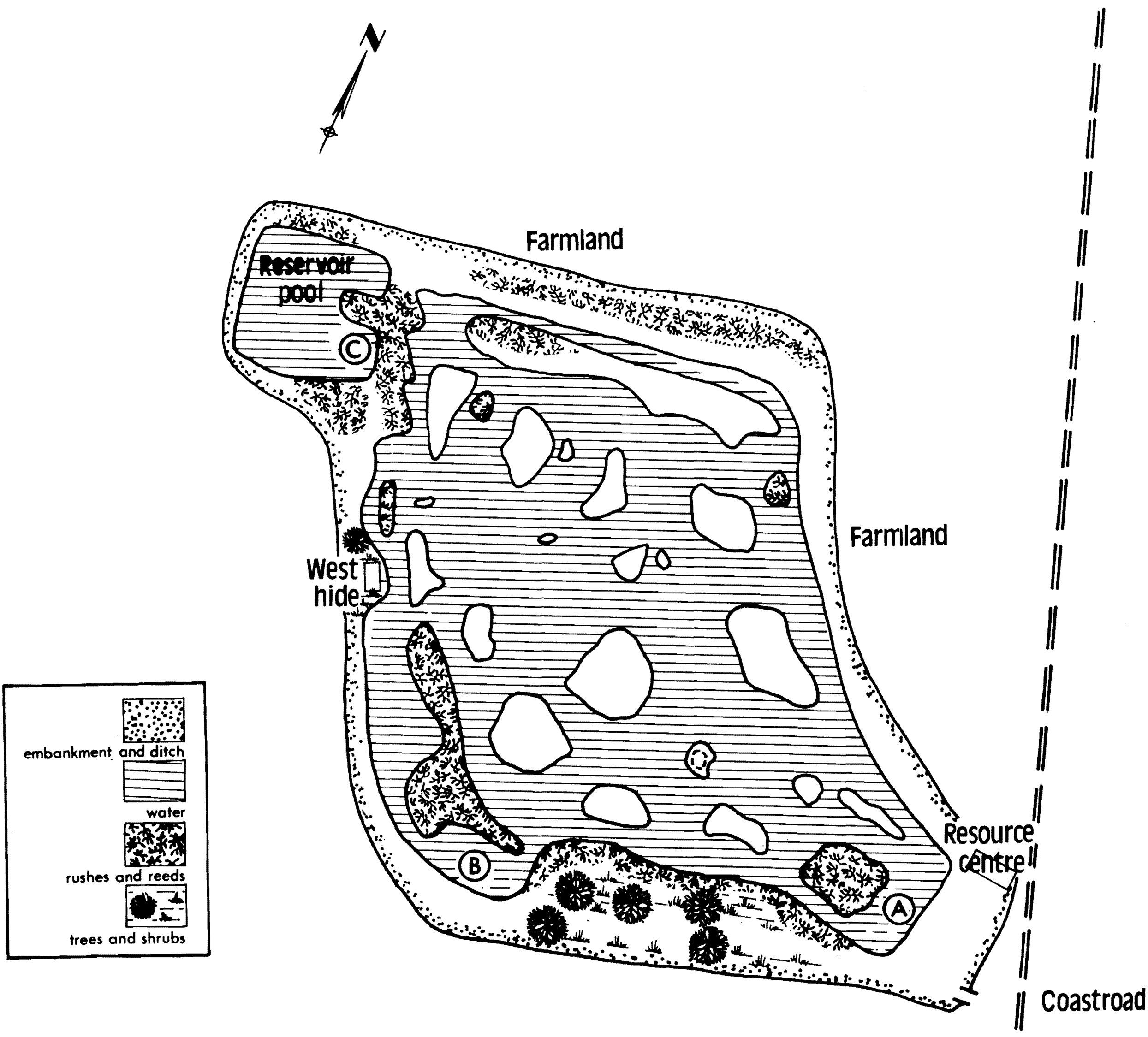

Fig. 1: Map of the Għadira Nature Reserve showing location of the three sampling stations.

Introduction

Saline marshland occupies less than 0.5% of the 190km coastline of the Maltese Islands. The Għadira marsh, situated on the northeastern coast of Malta at Mellieħa Bay, and covering an area of c.6 hectares, is the largest such habitat in the islands.

On the microtidal Maltese shores (mean tidal range 0.06m, spring range 0.15m; U.S. Dept. of Commerce, 1985), saline marshlands are maintained by seasonal changes in water level rather than by tidal fluctuations. These changes are controlled by the annual cycles of temperature and precipitation which define two ecological seasons: a wet season (October to March) during which falls c.70% of the total annual rainfall (which averages c.530mm) and with a mean temperature range of 11.0-18.0°C; a dry season (April to September) during which falls c.30% of the total annual rainfall and with a mean temperature range of 18.1-26.3°C (Mitchell, 1961).

The Għadira marsh is situated on the northeastern tip of a downthrown block of limestone between two SE to NW running parallel normal faults, which define Marfa Ridge to the north and Mellieħa Ridge to the south. The Għadira graben is tilted downwards to the northeast (Pedley *et al.*, 1976). The northeast shore of the graben is therefore surrounded by higher land on three sides and this has resulted in alluvial and colluvial deposits accumulating at Għadira. The saline marshland known as the Għadira marsh develops on these deposits. On the seawards side, this marsh is bounded by the sandy shore of Mellieħa Bay. A system of sand dunes develops at the back of the beach, forming a boundary between the marshland at Għadira and the beach. The marsh substratum consists of beach sand towards the northeast. The substratum becomes predominantly alluvial deposit towards the southwest.

Previous to 1980, a pool of water formed in the centre of the Għadira marsh during the wet season and then gradually dried up until by mid-summer, it was completely dry. Thake (1981) has discussed the dynamics of this process. According to his model, the pool formed partly by accumulation of rainwater, directly, and from surface runoff from the surrounding high ground, and partly by incursion of seawater directly from Mellieħa Bay during heavy seas and indirectly through seepage through permeable strata. During the dry season this water evaporated, the pool becoming progressively more saline until it dried up completely leaving a deposit of salt in the soil. The greater part of this salt was washed back to the sea by overflow from the pool during the following wet season.

In 1980 habitat engineering work was started in the Għadira area as part of a plan to turn the Għadira marsh and part of the surrounding land into a bird sanctuary with restricted access (Axell, 1980; see also Malta Ornithological Society, 1979, 1981, 1982, 1983a, b; Sultana, 1990) The main aim of the work was to deepen the central pool such that it would retain some water all the year round. Additionally, a ditch and embankment were constructed round the perimeter of the protected area, a reservoir was excavated to the west of the pool and several artificial islands were created within the pool itself. This work was completed by 1984. Although the protected area is legally a bird sanctuary (Government of Malta, 1980), it has functioned as a nature reserve since its inception (Sultana, 1990). The reserve was officially opened on 10 May 1988.

Few studies on the pool biota were made prior to the habitat engineering work in 1980 and in the main these consisted of non-quantitative species lists and habitat descriptions. These works have been summarised by Lanfranco (1967), Savona Ventura *et al.* (1980) and Schembri (1981).

The present work gives the results of a study of the pool macrofauna carried out after completion of the habitat engineering works as part of a larger study on the ecology of the Għadira Nature Reserve and is a companion paper to the study of Hili *et al.* (1990) on the physico-chemical characteristics of the pool.

Material and Methods

Samples were collected from the three stations indicated in Fig. 1. These stations were chosen as being representative of the different substratum types in the pool. Station A, the closest to the coast, had a bottom predominantly of sand, while the bottom at station C, which was situated in the 'reservoir' (originally designed to dilute the main saline pool with freshwater; Axell, 1980), was of hard, compact, clayey soil. Station B had a substratum intermediate between that of stations A and C.

Quantitative samples of the benthic and pelagic macrofauna were collected from each station at monthly intervals over the period May 1985 to April 1986. Benthic forms were sampled using a hand-operated corer of circular cross-section. The cores, which were take at randomly selected locations within a given station, had a surface area of $0.038m^2$ and variable depth depending on the compactness of the bottom sediment, but since all infauna was found to penetrate no deeper than 3cm, only the top 5cm of each core were processed. Cores were sieved through 2.0mm mesh and all animals retained were sorted by hand under a stereomicroscope, preserved in 70% ethanol, identified and counted.

Pelagic samples were taken using a 50cm diameter plankton net (mesh size 1.0mm) with an attached float in order to keep it just below the water surface. The net was transported a measured distance into the pool and towed to land by hand. When the water was too shallow to allow towing of the net without contact with the bottom, a known volume of water collected from the pool using a bucket was strained through the plankton net. Pelagic samples obtained in this way are indicated by an asterisk in Tables 2-4. All animals retained by the net were preserved in 70% ethanol, identified and counted.

No samples were taken from station C in December 1985 because of the presence of birds in the reserve, since the sampling procedure would have disturbed them.

Community parameters were calculated as described in Brower and Zar (1977). Data on the physico-chemical parameters of the pool were obtained from Hili *et al.* (1990).

Results

Species Survey

Table 1 lists the 13 macrofaunal species which occurred in our samples.

The Għadira hydrobiids belong to the *Ventrosa ventrosia* species complex as defined by Giusti and Pezzoli (1984). These gastropods occurred in both benthic and pelagic samples since although found mainly on the bottom sediment, they also crawled on strands of floating algae or beneath the waters' surface film. Although predominantly herbivores and deposit feeders, *V. ventrosa* were observed gathering on dead fish, presumably to scavenge. Both *Truncatella subcylindrica* and *Ovatella myosotis* occurred only in benthic samples, the latter however was absent from the reservoir. Although predominantly infaunal, some *Cerastoderma glaucum* were found in pelagic samples, as individuals occasionally attached themselves to strands of floating algae, mainly *Cladophora*.

Individuals of *Orchestia gammarellus* aggregated close to the pool edges especially in cracks and irregularities on the bottom but also on floating strands of *Enteromorpha intestinalis* during blooms of this alga. *Orchestia gammarellus* were thus present in both benthic and pelagic samples. This species was observed to mate in May. *Gammarus aequicauda* occurred only in the vicinity of station A where it was found just at the edges of the pool and under stones bordering the pool edge. This species was not present in the quantitative samples. Apparently, *Gammarus aequicauda* only invaded Għadira after the habitat modifications were made, presumably because of the year-round supply of saline water now available (Moore and Schembri, 1986).

Lekanesphaera hookeri mediterranea is better known under its older generic name of *Sphaeroma;* it has been recently transferred following a revision of this genus by Jacobs (1987). Individuals were observed either swimming in the water column or foraging on the bottom sediment, however, they were occasionally also found under stones in shallow water. Not unexpectedly, they occurred in both benthic and pelagic samples. *L. hookeri* were observed to feed on bottom detritus and to scavenge. Mating occurred in June.

The larvae and pupae of an unidentified species of chironomid were found in all three stations. All efforts to breed the larvae into adults failed so the species could not be determined. Just before eclosion the pupae floated to the surface, following which the adults emerged; empty pupae were collected from station C in July. A behaviour for which we have no explanation at present is the carrying of chironomid larvae by the amphipod *Orchestia gammarellus. Stratiomys longicornis* were represented in our samples by their aquatic larvae. A single stratiomyid pupa was collected in August in station C which perhaps suggests that emergence may take place at about this time. Four different species of hydrophilid beetles occurred in our samples. Although a number of beetles of the family Hydrophilidae have been recorded from the Maltese Islands (e.g. Cameron and Caruana Gatto, 1907), these records need confirmation and revision in the light of modern taxonomic knowledge of the group (S. Schembri, personal communication) hence no attempt has been made to identify the Għadira species pending such a review. The only other insect encountered in the pool at Għadira was a single pupa of a syrphid fly which was found at station A in October 1986; no specimens occurred in our samples, however.

Two species of fish occurred at Għadira, *Aphanius fasciatus* and *Liza ramada.* The former was deliberately introduced into Għadira (Cilia, 1986) following deepening of the pool. The other invaded the pool from Mellieħa Bay during heavy weather when waves crossed the 100m or so of beach separating the pool at Għaidra from the sea. *Aphanius fasciatus* occurred in pelagic samples from all three stations but *Liza ramada* did not occur in our quantitative samples, possibly because it is too fast and too large to be caught by our sampling gear. It is reported that an unspecified species of eel has also invaded Għadira in the same way as *Liza ramada* (C. Gauci, personal communication); we cannot however confirm this record from our present work.

Quantitative samples

The results of the pelagic and benthic quantitative sampling are presented in Tables 2, 3 and 4. Inspection of these tables shows that *Ventrosia ventrosa* is by far the most abundant species in the pool; at times population densities reached values as high as 280,000 individuals m^{-2} (e.g. August 1985 station A benthic sample, Table 2). This species occurred at all times of the year in all three stations. The next most abundant species were *Cerastoderma glaucum* and *Orchestia gammarellus,* however, while *C.glaucum* occurred in nearly all samples, *O.gammarellus* occurred at particular times of the year only, and occasionally at very high population densities (e.g. April and March 1986 benthic samples at stations A and B respectively, Tables 2 and 3). *Lekanesphaera hookeri* and the chironomid larvae were also fairly regularly represented in our samples, although at much lower population densities than the foregoing species. An additional two species, the gastropods *Truncatella subcylindrica* and *Ovatella myosotis,* were present throughout the year, at least in some stations, but always in low densities. The remaining species were only sporadically represented in our samples and also at very low densities.

Table 5 gives the mean monthly population density of the five most abundant pool species for each station. It is evident that station A supported higher population densities than the other two stations, both for each species individually (excepting *Cerastoderma glaucum*), and for all species considered together. *C.glaucum* reached its highest average density in station B although

Table 1

Classified list of the macrofaunal species collected from the pool at the Għadira Nature Reserve during the period May 1985-April 1986. Species marked with a dagger did not occur in the quantitative benthic and pelagic samples.

Mollusca: Gastropoda
Hydrobiidae
Ventrosia ventrosa (Montagu) (complex?)
Truncatellidae
Truncatella subcylindrica (Linnaeus)
Melampidae
Ovatella (Myosotella) myosotis (Drapamaud)
Mollusca: Bivalvia
Cardiidae
Cerastoderma glaucum (Poiret)
Crustacea: Amphipoda
Gammaridae
†*Gammarus aequicauda* (Martynov)
Talitridae
Orchestia gammarellus (Pallas)
Crustacea: Isopoda
Sphaeromatidae
Lekanesphaera hookeri mediterranea (Lejuez)
Insecta: Coleoptera
Hydrophilidae
Hydrophilidae sp. I
Hydrophilidae sp. II
Hydrophilidae sp. III
Hydrophilidae sp. IV
Insecta: Diptera
Chironomidae
Chironomidae sp.
Stratiomyidae
Stratiomys longicornis (Scopoli)
Syrphidae
†Syrphidae sp.
Chordata: Actinopterygii
Cyprinodontidae
Aphanius fasciatus Nardo
Mugilidae
†*Liza ramada* (Risso)

---

average population densities at all three stations are hardly different. Apart from its overall lower macrofaunal population densities relative to station A and B, station C was characterised by a complete absence of *Ovatella myosotis* and by a very reduced density of *Orchestia gammarellus*.

The following community parameters were calculated separately for the pelagic (Table 6) and benthic (Table 7) samples: species richness *(s)*, the total number of macrofaunal species in the sample; Simpson dominance *(λ)*, as a measure of the distribution of individuals amongst species; the inverse of λ (d_s) as a measure of diversity (*sensu* Hurlbert, 1971); and e_s, the associated evenness measure.

For all three stations, pelagic macrofaunal species richness was overall low, the highest mean value, that for station A, being only 2.92. Mean pelagic species richness was comparable for stations A and B (Mann-Whitney U-test, $0.20<P<0.30$), however, station C had a significantly lower value than either (Mann-Whitney U-test; A and C, $P<0.001$; B and C, $0.001<P<0.002$). For stations A and B, where pelagic species richness was high ($s = 4$ or 5, e.g. May, June and December at station A, June and December at station B; Table 6), the corresponding dominance values were also high while both diversity and evenness were low indicating that one very abundant species dominated the samples. Pelagic diversity and dominance showed very little variation from month to month in stations A and B as shown by the low standard deviations

Table 2

The number of individuals of each macrofaunal species collected from station A in the Għadira pool (see Fig. 1) during 12 monthly sampling trips between May 1985 and April 1986. Each cell entry gives the number of individuals collected in pelagic samples (upper figure; expressed per m^3 of water) and the number collected in benthic samples (lower figure, expressed per m^2 of bottom). The asterisk marks those pelagic samples not collected by hauling (See Material and Methods section).

	May	Jun	*Jul	*Aug	*Sep	*Oct	*Nov	*Dec	*Jan	*Feb	Mar	Apr
	3,077	1,368	0	4,712	2,299	2,482	140	1	194	69	1,491	13
V. ventrosa	41,132	35,895	11,473	280,000	151,579	24,053	6,605	11,842	7,316	26,184	9,789	23,421
	72	14	0	80	34	0	0	0	0	0	0	0
C. glaucum	9,579	6,026	289	12,868	7,421	1,053	263	421	7,421	237	447	2,342
	0	0	0	0	0	0	0	0	0	0	0	0
T. subcylindrica	53	0	26	132	132	0	53	79	26	53	26	53
	0	0	0	0	0	0	0	0	0	0	0	0
O. myosotis	0	26	132	0	0	0	0	26	0	26	0	0
	74	0	0	0	0	0	1	33	252	194	346	0
O. gammarellus	8,053	0	0	0	26	26	26	5,026	4,632	6,211	1,316	22,395
	6	2	0	0	0	0	0	1	0	11	26	0
L.hookeri	79	79	0	0	0	0	26	26	53	0	0	4,605
	5	1	0	0	0	0	0	0	0	0	0	0
Chironomidae sp.	842	132	0	0	473	26	26	0	0	0	0	3,421
	0	0	0	0	0	11	0	0	0	0	0	0
Hydrophilidae sp. I	0	0	0	0	0	26	0	0	0	0	0	0
	0	0	0	0	11	0	0	1	0	0	0	0
Hydrophilidae sp. II	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	11	0	0	0	0	0	0	0	0	0
Hydrophilidae sp. III	0	0	0	0	0	0	0	0	0	0	0	0
	0	2	57	23	0	0	0	0	0	0	0	0
A. fasciatus	0	0	0	0	0	0	0	0	0	0	0	0

Table 3

The number of individuals of each macrofaunal species collected from station B in the Għadira pool (see Fig. 1) during 12 monthly sampling trips between May 1985 and April 1986. Each cell entry gives the number of individuals collected in pelagic samples (upper figure; expressed per m^3 of water) and the number collected in benthic samples (lower figure, expressed per m^2 of bottom). The asterisk marks those pelagic samples not collected by hauling (See Material and Methods section).

	May	Jun	*July	*Aug	*Sep	*Oct	*Nov	*Dec	*Jan	*Feb	Mar	Apr
	97	3,468	412	538	1,979	206	0	4,312	435	0	60	26
V. ventrosa	5,105	19,657	37,789	147,947	82,000	5,105	8,105	7,921	3,237	2,237	13,789	14,895
	0	287	69	23	0	0	11	11	0	0	0	0
C. glaucum	9,895	12,447	7,527	5,105	4,710	3,368	3,842	2,421	1,000	0	53	4,632
	0	0	0	0	0	0	0	0	0	0	0	0
T. subcylindrica	0	0	26	0	53	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
O. myosotis	0	0	79	53	26	0	0	0	0	0	0	0
	18	0	0	0	0	0	0	1,910	217	23	0	0
O. gammarellus	1,342	0	0	0	0	0	0	79	26	342	29,579	263
	0	0	0	0	0	0	0	11	0	11	0	0
L. hookeri	26	0	53	0	26	0	0	158	0	0	0	105
	0	7	0	0	0	0	0	0	0	0	0	0
Chironomidae sp.	53	0	0	395	184	0	26	0	0	0	0	53
	0	0	0	0	0	0	0	0	0	0	0	0
S. longicornis	0	0	0	0	53	0	0	26	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0	0
Hydrophilidae sp. I	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	2	0
Hydrophilidae sp. II	0	0	0	26	0	0	0	0	0	0	0	0
	0	1	0	0	0	0	0	0	0	0	0	0
Hydrophilidae sp. III	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	2
Hydrophilidae sp. IV	0	0	0	0	0	0	0	0	0	0	0	0
	0	1	0	0	11	0	11	0	0	0	0	0
A. fasciatus	0	0	0	0	0	0	0	0	0	0	0	0

Table 4

The number of individuals of each macrofaunal species collected from station C in the Għadira pool (see Fig. 1) during 12 monthly sampling trips between May 1985 and April 1986. Each cell entry gives the number of individuals collected in pelagic samples (upper figure; expressed per m^3 of water) and the number collected in benthic samples (lower figure, expressed per m^2 of bottom). The asterisk marks those pelagic samples not collected by hauling (See Material and Methods section). No samples were collected during December 1985. Chironomidae collected in the July 1985 pelagic sample were all empty pupae (marked by dagger).

	May	Jun	*July	*Aug	*Sep	*Oct	*Nov	*Dec	*Jan	*Feb	Mar	Apr
	4	0	126	343	366	34	0	-	69	0	0	0
V. ventrosa	6,789	1,210	22,184	62,316	15,526	12,125	17,186	-	8,452	7,325	5,431	8,546
	0	0	0	0	0	0	0	-	0	0	0	0
C. glaucum	4,894	5,684	6,737	5,684	789	1,210	948	-	3,786	4,546	6,782	5,483
	0	0	0	0	0	0	0	-	0	0	0	0
T. subcylindrica	0	0	26	0	0	26	0	-	0	52	0	0
	0	0	0	0	0	0	0	-	0	0	0	0
O. myosotis	0	0	0	0	0	0	0	-	0	0	0	0
	4	0	0	0	0	0	0	-	0	0	1	0
O. gammarellus	1,737	0	0	0	0	0	0	-	0	0	120	877
	0	0	0	0	0	0	0	-	0	0	0	0
L. hookeri	105	0	0	26	26	0	26	-	0	0	215	418
	0	0	†69	0	0	0	0	-	0	0	0	0
Chironomidae sp.	79	0	0	500	26	26	0	-	0	0	79	26
	0	0	0	0	0	0	0	-	0	0	0.4	0.2
A. fasciatus	0	0	0	0	0	0	0	-	0	0	0	0

calculated (Table 6). Large monthly variations in these community parameters were however noted for station C. This was due to the large number of samples with *s* values of 1 or 0.

For the benthic macrofauna (Table 7), station A had the highest mean species richness whereas station C had the lowest value, although there was no significant difference between mean *s* for stations B and C (Mann-Whitney U-test, $0.50<P<0.60$). Variation in benthic species richness from month to month was also larger at these two stations than at station A (coefficients of variation: A=19.0%, B=41.3%, C=30.8%). Mean benthic diversity and dominance were very similar for all three stations (Table 7). Overall, diversity was low, dominance was high and evenness was low irrespective of the species richness, indicating that at all three stations one, perhaps two, species which were numerically much more abundant than all others, dominated the samples. For all three stations, there was considerable month to month variation in benthic community parameters (Table 7). In station A the January and April samples stood out because of their comparatively high diversity and evenness. In this station, during most months, one benthic macrofaunal species far outnumbered all others present, however, in the January and April sample, the benthos was codominated by two species, both of which reached comparably high population levels. The same explanation applies also to the high diversities measured for the January benthic sample at station B and for the January, March and April samples at station C.

As expected, fluctuations in population numbers occurred for most species. Three different patterns was observed: (i) strongly unimodal, as for *Orchestia gammarellus* (Fig. 2); (ii) strongly bimodal, as for the chironomid larvae (Fig. 3); and (iii) a population which was maintained throughout the sampling period and which showed occasional highs, as for *Ventrosia ventrosa*, *Cerastoderma glaucum* and *Lekanesphaera hookeri* (Figs 4-6). Due to their low frequency of occurrence in our samples, no definite trends could be discerned for the other pool species.

Orchestia gammarellus reached its single peak in the period March to May, the population becoming reduced in numbers, occasionally to zero levels, at other times (Tables 2-4). The population peaked in April in station A, in March in station B and in May in station C, in each case during that month when the water level is highest (Fig. 2).

The two population peaks shown by the chironomid larvae (Fig. 3) probably correspond to two periods of emergence. In station A the largest peak occurred in the spring months, with a smaller peak in autumn. In stations B and C, the largest peak occurred in late summer-early autumn, the spring peak being much lower.

Ventrosia ventrosa populations maintained fairly constant levels throughout the sampling period, except in the summer months when they peaked (Tables 2-4). These peaks probably originated from a concentration effect. As the pool dried during the hot summer months, motile benthic animals migrated away from the edges towards the deeper central regions of the pool which always held some water and consequently large numbers of *V. ventrosa* came to occupy a small area of bottom; the reverse process occurred as the pool filled up again following the first rains in September-October (Fig. 4). The same phenomenon was observed for *Cerastoderma glaucum* (Tables 2-4). In this case, however, a significant proportion of the population was not able to migrate fast enough to move with the receding water and perished. Large numbers of the dead shells of this species are uncovered each year as the waterline retreats.

Over and above the concentration effect, the populations of *C. glaucum* also peaked at those times when the levels of nitrates and phosphates in the ambient water were high (Fig. 5 and Hili *et al.*, 1990). In station A both the *C. glaucum* population and that of *V. ventrosa* experienced a large drop in numbers in July. This correlated with a massive drop in dissolved oxygen concentration (Fig. 4).

Lekanesphaera hookeri occurred practically all the year round in all three stations (Tables 2-4). Population levels were fairly constant throughout the sampling period with the exception of station A where the population showed a massive peak in April 1986 (Fig. 6) which had no

Table 5

The mean monthly population density of the five most abundant macrofaunal species in pelagic and benthic samples collected from three stations in the Għadira pool (see Fig. 1) over the period May 1985 to April 1986. Pelagic population densities are expressed per m^3 of water and benthic densities per m^2 of bottom.

Station	A		B		C	
	pelagic	benthic	pelagic	benthic	pelagic	benthic
V. ventrosa	1321	52441	961	28982	86	15190
C. glaucum	21	4031	32	4583	0	4231
O. gammarellus	75	3976	181	2636	0.45	249
L. hookeri	4	406	2	31	0	74
Chironomidae sp.	0.5	410	0.6	59	0	67

Table 6

Community parameters for the monthly pelagic samples collected from three stations in the Għadira pool (See Fig. 1) during the period May 1985 to April 1986. No samples were taken from station C in December 1985.

Station	A				B				C			
	s	d_s	λ	e_s	s	d_s	λ	e_s	s	d_s	λ	e_s
May	5	1.10	0.91	0.22	3	1.39	0.72	0.45	2	2.33	0.43	1
June	5	1.03	0.97	0.20	5	1.17	0.85	0.23	0	0	0	0
July	2	1.38	0.72	0.68	2	1.33	0.75	0.66	1	1.00	1.00	1.00
August	3	1.04	0.96	0.35	2	1.09	0.92	0.54	1	1.00	1.00	1.00
September	3	1.04	0.96	0.35	2	1.01	0.99	0.51	1	1.00	1.00	1.00
October	2	1.01	0.99	0.50	1	1.00	1.00	1.00	1	1.00	1.00	1.00
November	2	1.01	0.99	0.50	2	2.10	0.48	1.00	0	0	0	0
December	4	1.19	0.84	0.27	4	1.75	0.57	0.44	-	-	-	-
January	2	1.97	0.51	0.98	2	1.80	0.56	0.90	1	1.00	1.00	1.00
February	3	1.77	0.56	0.59	2	1.82	0.55	0.88	0	0	0	0
March	3	1.48	0.68	0.49	2	1.07	0.94	0.53	2			
April	1	1.00	1.00	1.00	2	1.16	0.86	0.56	2	1.13	0.88	0.39
Mean	2.92	1.25	0.84	0.51	2.42	1.39	0.77	0.64	1	0.56	0.53	0.74
s.d.	1.24	0.33	0.18	0.27	1.08	0.38	0.19	0.25	0.77	1.17	0.55	0.56

Table 7

Community parameters for the monthly pelagic samples collected from three stations in the Għadira pool (See Fig. 1) during the period May 1985 to April 1986. No samples were taken from station C in December 1985.

Station	A				B				C			
	s	d_s	λ	e_s	s	d_s	λ	e_s	s	d_s	λ	e_s
May	6	1.93	0.52	0.32	5	2.14	0.47	0.43	5	2.53	0.39	0.51
June	5	1.34	0.75	0.27	2	1.90	0.53	0.95	2	1.41	0.71	0.70
July	4	1.07	0.93	0.27	5	1.39	0.72	0.28	3	1.56	0.64	0.52
August	3	1.09	0.92	0.36	5	1.07	0.93	0.22	4	1.20	0.83	0.30
September	5	1.11	0.90	0.22	7	1.12	0.89	0.16	4	1.11	0.90	0.28
October	5	1.09	0.91	0.22	2	1.92	0.52	0.96	4	1.21	0.83	0.30
November	6	1.12	0.89	0.19	3	1.78	0.56	0.59	3	1.11	0.90	0.37
December	6	1.83	0.55	0.31	5	1.64	0.61	0.33	-	-	-	-
January	5	2.91	0.34	0.58	3	1.58	0.63	0.53	2	1.75	0.57	0.87
February	5	1.48	0.68	0.30	2	1.30	0.77	0.65	3	1.91	0.52	0.64
March	4	1.37	0.73	0.34	3	1.77	0.56	0.59	5	2.11	0.47	0.42
April	6	2.91	0.34	0.48	5	1.63	0.61	0.33	5	2.26	0.44	0.45
Mean	5.00	1.60	0.71	0.32	3.92	1.60	0.65	0.50	3.64	1.65	0.65	0.49
s.d.	0.95	0.67	0.22	0.11	1.62	0.33	0.15	0.26	1.12	0.50	0.19	0.19

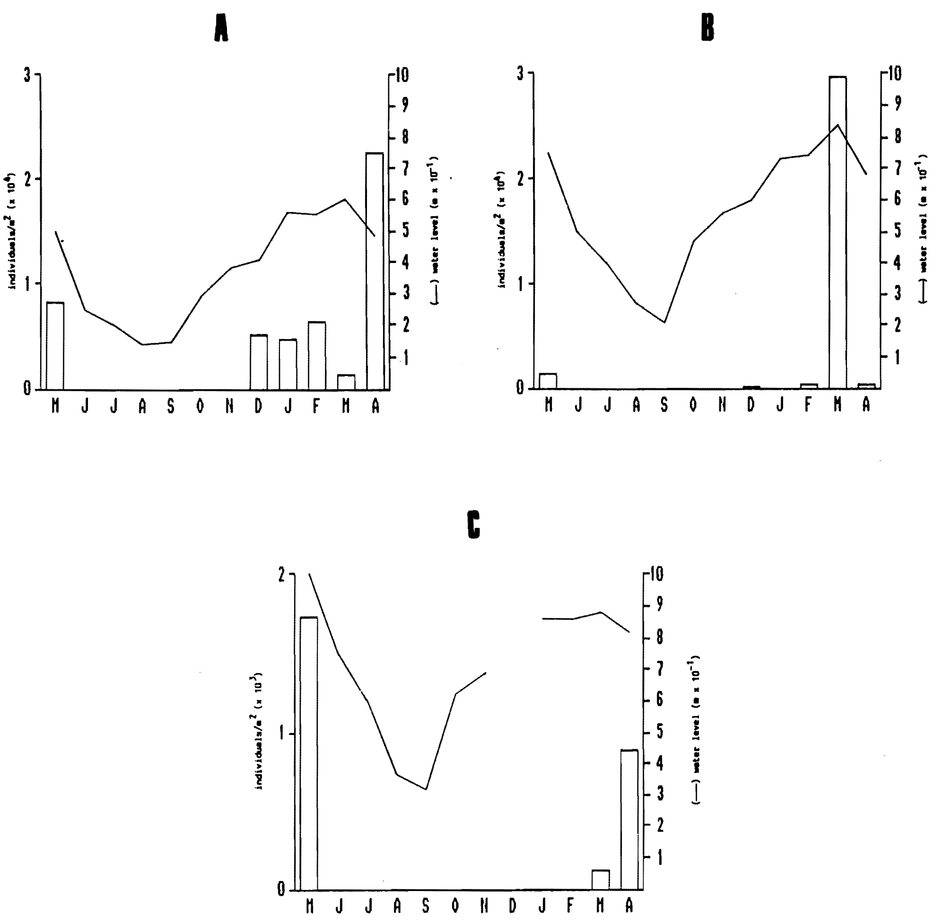

*Fig. 2: Variation in population density of the amphipod **Orchestia gammarellus** in each Għadira pool station (histograms) and variation in water level at each station (line graphs) during the study period.*

equivalent in the other two stations (Tables 2-4).

Discussion

European saltmarshes, including those of the European Mediterranean lands, have been recently surveyed by Dijkema (1984). Although miniscule, the Għadira marsh nonetheless exhibited vegetational communities and zonation patters typical of Mediterranean saline marshlands (as described by Beeftink, 1984 and Géhu and Rivas-Martinez, 1984) prior to the engineering works (Lanfranco, 1967; Savona Ventura *et al.*, 1980; Schembri, 1981). These halophilic communities were maintained by the seasonal fluctuations in soil inundation and water salinity, and what little data is available, points to the Għadira marsh as functioning as a saline marshland ecosystem (Schembri, 1981; Lanfranco, 1990). Following the habitat engineering works, the Għadira pool became a permanent rather than a transient feature and the saline marshland communities retreated to come to occupy that area of the pool edge and of the shores of the artificial islands affected by the inundation and desiccation cycle as the pool dries partially during the dry season and refills during the wet season; additionally, many non-saltmarsh

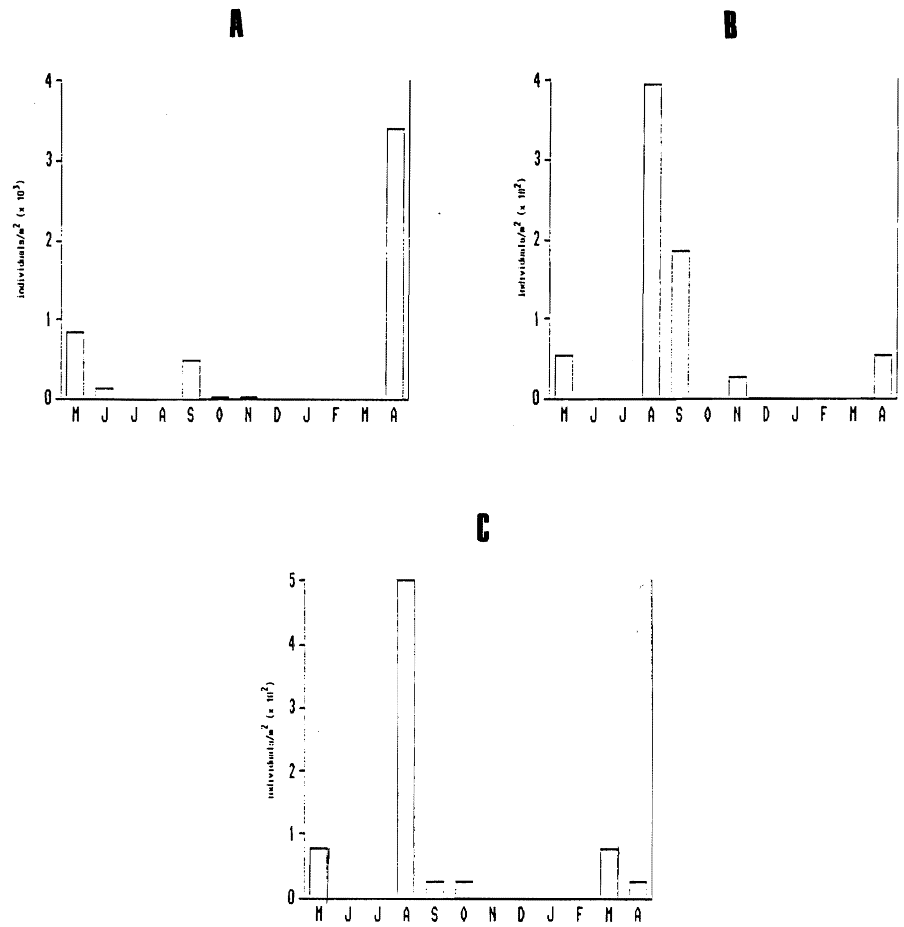

Fig. 3: Variation in chironomid population density in each Għadira pool station during the study period.

floristic elements were introduced into these communities as part of the habitat engineering works (Lanfranco, 1990). The pool as it now functions is more similar in character to a coastal lagoon such as those found on the southern Mediterranean coast (see survey by Kerambrun, 1986) than to the temporary pools which form in Mediterranean saltmarshes.

The general features of coastal lagoons have been reviewed by Phleger (1981) and Krumbein *et al.* (1981). In common with such environments, the Għadira pool has a lower macrofaunal species richness than either freshwater pools or the coastal marine environment in the same geographical area, and the species present are predominantly euryecious and able to tolerate large changes in ambient salinity, temperature and oxygen concentration. As for lagoonal environments elsewhere (Krumbein *et al.*, 1981), some individual species attain very high population densities. However, species richness at Għadira is much lower than is found in other Mediterranean coastal lagoons and salinas for which data exists (Halim and Guarguess, 1981; Kerambrun, 1986; Britton and Johnson, 1987). Three main factors probably contribute to this: (i) the Għadira pool is very small and has a low diversity of habitats; (ii) it receives no freshwater input other than from rain, therefore, salinity varies more or less homogeneously throughout the pool. In contrast, Mediterranean lagoons and salinas with higher species richness than Għadira

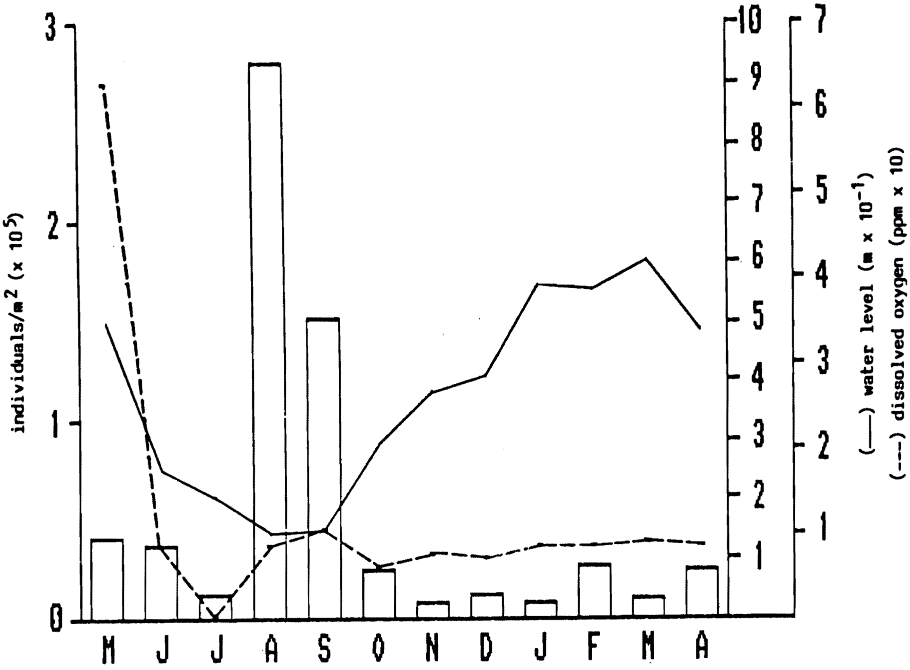

*Fig. 4: Variation in population density of the hydrobiid gastropod **Ventrosia ventrosa** in Għadira pool station A (histogram) and variation in water level (solid line) and in dissolved oxygen concentration (dashed line) during the study period.*

have a range of salinities present at all times of the year (Halim and Guarguess, 1981; Kerambrun, 1986; Britton and Johnson, 1987); (iii) the Għadira pool is completely cut off from the sea except for a drainage pipe which is mostly kept shut. Guelorget and Perthuisot (1983) have observed that the more a lagoon is isolated from the sea and the less the exchange of water with the marine environment, the poorer the biota of the lagoon, irrespective of salinity.

While some species have invaded the pool only after the habitat engineering works were completed (e.g. *Gammarus aequicauda;* Moore and Schembri, 1986), evidence exists that pool macrofaunal species richness has declined overall since the habitat modifications at Għadira were made. Pre-1980 records of marcrofauna from the Għadira pool include a number of species, amongst them dytiscid and hydrophilid coleopterans and tabanid and other dipterans (S. Schembri, personal communication; see also Savona Ventura *et al.*, 1980), which have not been encountered in our survey. It should be pointed out however, that since samples were taken only from a limited area of the pool, the possibility that species other than those listed in Table 1 also occur cannot be excluded.

The Għadira pool species are either detrivores, herbivores or scavengers, or else unspecialised omnivores. This probably correlates with the large amounts of detritic organic material accumulating in the pool and the rich microbial flora it must support and also with the seasonal blooming of both micro- and macro- algae. In particular, specialised predators are almost totally absent from the pool, however birds are important predators on the pool macrofauna (Gauci, 1990).

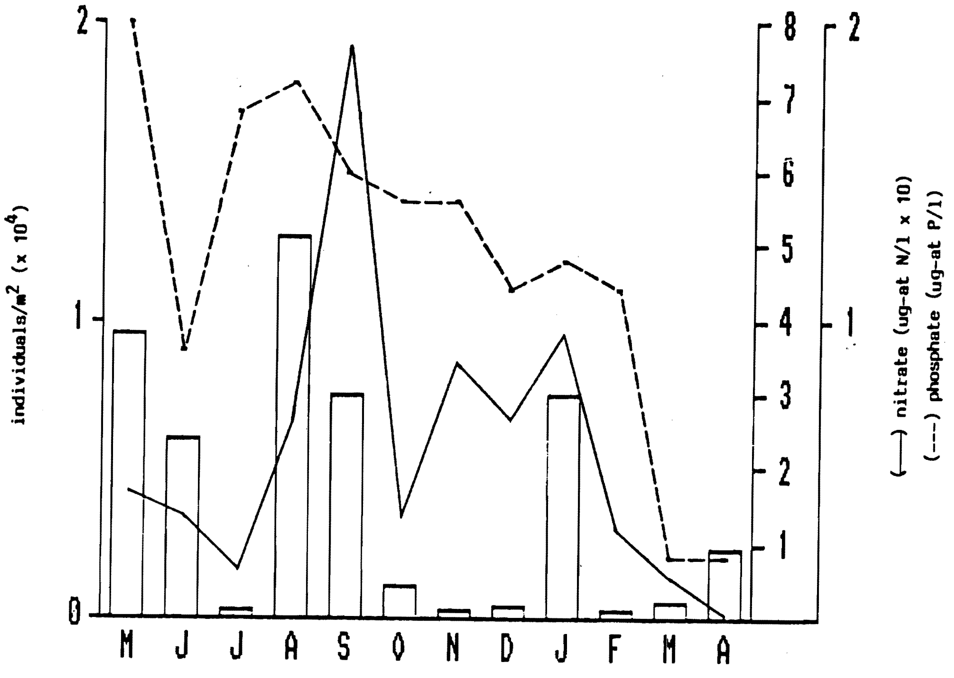

Fig. 5: Variation in population density of the cardiid bivalve Cerastoderma glaucum in Għadira pool station A (histogram) and variation in the concentration of dissolved nitrates (solid line) and phosphates (dashed line) during the study period.

In spite of the relative homogeneity of the pool habitat, interstation variation in overall species richness and in the average abundance of particular species was noted. Both parameters decline along a NE to SW gradient. This is probably correlated with the increase in the fine particulate content of the substratum and the decrease in amplitude of water level, and hence salinity, fluctuations along this gradient (Hili *et al.*, 1990). For example, the complete absence of *Ovatella myosotis* at station C is probably related to the different nature of the substratum at this station from that at stations A and B. It is not likely to be due to differences in the physico-chemical parameters of the reservoir water since fluctuations in these were well within the range of those observed in stations A and B where *O.myosotis* occurs (Hili *et al.*, 1990). The low numbers of *O. gammarellus* on the other hand are most probably due to the fact that in station C there were no blooms of the algae *Cladophora* sp. and *Enteromorpha intestinalis* on which the amphipods aggregated in the other stations; algal blooming in turn being related to the seasonal pattern of salinity changes.

Within each station, pelagic macrofaunal abundance was always much less than benthic macrofaunal abundance. This is to be expected as all species which occurred in our samples are strictly speaking benthonic, even if they do occasionally occur in the water column. This is true also for the killifish *Aphanius fasciatus* which, although never collected in our benthic samples, is still benthonic and when undisturbed spends much of its time foraging on the bottom sediment (Grech, 1989).

The community parameters calculated confirm that for all three stations and for both the pelagic and benthic macrofauna, the bulk of individuals collected belong to one, occasionally two, species, all others being very much less frequent.

The population fluctuations of most pool species are probably controlled mainly by extrinsic factors. Evidence for this comes from the observations that populations of the same species at different stations reached their peaks and troughs at slightly different times, while in some cases the timing and amplitude of these fluctuations could be correlated with changes in the abiotic and biotic factors affecting the pool. For example the population peaks of *Orchestia gammarellus* at all three stations occurred at times when the water level was at its highest (Fig. 2) and are probably related to the availability of water. Again, it is tempting to speculate that the observed population highs and lows of the filter-feeding *Cerastoderma glaucum* are related to the massive blooms and crashes of the pool microalgae and those of the macroalgae and their thycoplankton (see Lanfranco, 1990). Algal blooming may be an important factor controlling the populations of the Għadira pool fauna. Summertime eutrophication events which bring about deoxygenation of the water column with subsequent elimination of aquatic fauna are a common feature of Mediterranean brackish water bodies with a poor connection to the sea (Kelly and Naguib, 1984; Britton and Johnson, 1987).

On the other hand, some of the observed fluctuations were probably due to the concentration effect and may not represent real changes in population levels (e.g. *Ventrosia ventrosa* and *Cerastoderma glaucum*). As is predicted by the concentration hypothesis, the populations of both these species at station C did not experience such pronounced summer peaks as at stations A and B (Tables 2-4), seasonal fluctuations in the Għadira pool water level being least evident in the reservoir (Hili *et al.*, 1990).

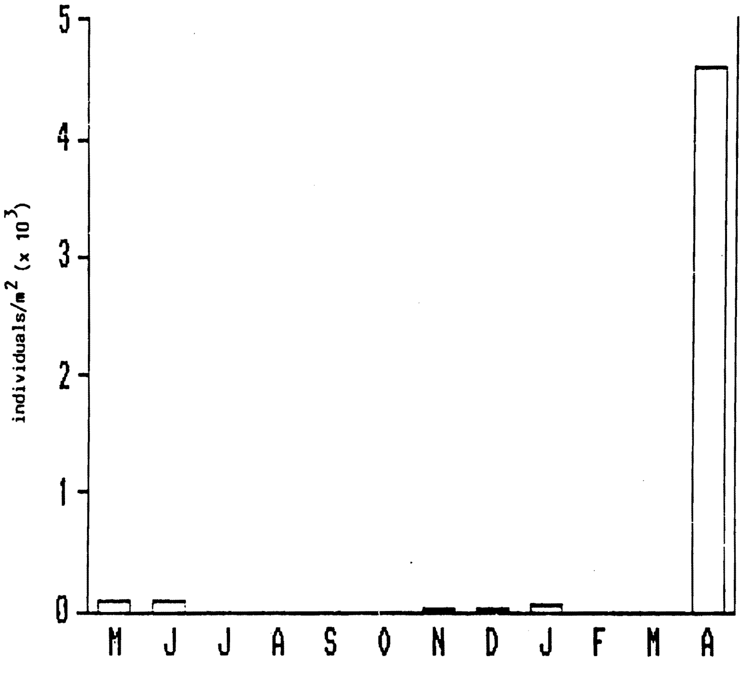

Fig. 6: Variation in population density of the sphaeromatid isopod Lekanesphaera hookeri mediterranea in Għadira pool station A during the study period.

For certain species, population fluctuations did not appear to be related to any obvious environmental change, for example, the massive population explosion of *Lekanesphaera hookeri* in April 1986 at station A. It is possible however that it was perhaps associated with the much larger populations of the alga *Enteromorpha intestinalis* found at this station.

Aknowledgements

We are grateful to the Environment Division of the Ministry of Education for permission to study the Għadira pool and to Mr Charles Gauci, officer in charge of the Għadira Nature Reserve for his cooperation and for information about the Reserve. We are grateful also to the technicians of the Biology Department of the University of Malta for assistance, particularly Mr Charles Galea for his help in the sampling. We thank Mr Carmel Hili for information on the pool environment; Mr Stephen Schembri for identification and information about the insects at Għadira; Dr B.J.M. Jacobs (Rijksmuseum van Natuurlijke Historie, The Netherlands) for identification of aquatic isopods; Professor Folco Giusti (Università di Siena, Italy) and Dr Paolo Cesari (Museo Civico di Storia Naturale, Venezia, Italy) for identification of aquatic gastropods; Dr Fernando Ghisotti (Milano, Italy) for identification of bivalves; Dr P.G. Moore (University Marine Biological Station Millport, Scotland) for identification of amphipods; Mr Edwin Lanfranco (University of Malta) for botanical information; Mr M.A. Azzopardi for computer programs, Ms M.R. Pirotta for typing part of the manuscript, and Ms Sandra Copperstone for drawing Fig. 1.

REFERENCES

Axell, H.E. (1980) Għadira Malta: development as a national nature reserve. Paper presented at the *12th International Council for Bird Preservation European Section Conference, Malta 2-9 Nov. 1980*; 4pp. (mimeographed)

Beeftink, W.G. (1984) Geography of European halophytes. In: Dijkema, K.S. (ed.) *Salt marshes in Europe*. pp. 15-33; Strasbourg: European Committee for the Conservation of Nature and Natural Resources, Council of Europe.

Britton, R.H. and Johnson, A.R. (1987) An ecological account of a Mediterranean salina: the Salin de Giraud, Camargue (S. France). *Biological Conservation* 42: 185-230.

Brower, J.E. and Zar, J.H. (1977) *Field and laboratory methods for general ecology*. Iowa: W.C. Brown.

Cameron, M. and Caruana Gatto, A. (1907) A list of the Coleoptera of the Maltese Islands. *Transactions of the Entomological Society, London* 59: 383-403.

Cilia, J.L. (1986) Il-Buzaqq *(Aphanius fasiatus)*. *Potamon* No. 15: 131-136.

Dijkema, K.S. (ed.) (1984) *Salt marshes in Europe*. Strasbourg: European Committee for the Conservation of Nature and Natural Resources, Council of Europe; 178pp + map.

Gauci, C. (1990) The avifauna of the Għadira Nature Reserve. *Centro* 1 (5): 33 - 45

Géhu, J.M. and Rivas-Martinez, S. (1984) Classification of European salt plant communities. In: Dijkema, K.S. (ed.) *Salt marshes in Europe*. pp. 34-40; Strasbourg: European Committee for the Conservation of Nature and Natural Resources, Council of Europe.

Giusti, F. and Pezzoli, E. (1984) Gli Hydrobiidae salmastri delle acque costeriere Italiane: primi cenni sulla sistematica del gruppo e sui caratteri distintivi delle singole morphospecie. *Lavori delle Società Italiana di Malacologia* 21: 117-148.

Government of Malta (1980) Legal notice Nº 68 of 1980. *Malta Government Gazette* No. 13756, 8 Aug. 1980

Grech, M. (1989) Behaviour of the local Killifish, *Aphianus fasciatus*. Unpublished B. Ed. (Hons) dissertation, Faculty of Education, University of Malta. vi + 142 pp.

Guelorget, O. and Perthuisot, J.P. (1983) Le domaine paralique. Expressions géologiques, biologiques et économiques du confinement. *Trav. Laboratoire de Gèologie, Ecole Normale Supérieure Paris* 16: 1-136.

Halim, Y. and Guarguess, S.K. (1981) Coastal lakes of the Nile Delta: Lake Manzalah. *UNESCO Technical Papers in Marine Science* 33: 135 - 172

Hili, C., Axiak, V. and Schembri, P.J. (1989) The Għadira Nature Reserve: physico-chemical characteristics of the pool. *Centro* 1 (5): 5 - 11

Hurlbert, S.H. (1971) The nonconcept of species diversity: a critique and alternative parameters. *Ecology* 52: 577 - 586

Jacobs, B.J.M. (1987) A taxonomic revision of the European, Mediterranean and N.W. African species generally placed in *Sphaeroma* Bosc, 1802 (Isopoda: Flabellifera: Sphaeromatidae). *Zoologische Verhandelingen* 238: 1 - 71

Kelly, M. and Naguib, M. (1984) Eutrophication in coastal marine areas and lagoons: a case study of 'Lac de Tunis'. *UNESCO Reports in Marine Science* 29: 1-54.

Kerambrun, P. (1986) Coastal lagoons along the southern Mediterranean coast (Algeria, Egypt, Libya, Morocco, Tunisia). Description and bibliography. *UNESCO Reports in Marine Science* 34, iv + 184pp.

Krumbein, W.; Lasserre, P. and Nixon, S.W. (1981) Task group II: Biological processes and ecology. In: Lasserre, P and Postma, H. (eds) *Coastal lagoon research, present and future*. pp.53-79; UNESCO Technical Papers in Marine Science 32.

Lanfranco, E. (1990) The vegetation of the Għadira Nature Reserve. *Centro* 1 (5): 47-55.
Lanfranco, G. (1967) Geology, flora and fauna of Għadira. In: Malta Ornithological Society/Natural History Society of Malta. *Report on the natural and historical features of Għadira*, pp. 17-20 presented to the House of Repre sentatives, June 1967 (mimeographed)
Malta Ornithological Society (1979) Axell's kiss of life. *Bird's Eye View* 3: 14.
Malta Ornithological Society (1981) Għadira, the making of a reserve. *Bird's Eye View* 4: 10-11.
Malta Ornithological Society (1982) Għadira, the making of a reserve. *Bird's Eye View* 5: 11-14.
Malta Ornithological Society (1983a) Għadira, the making of a reserve, part 3. *Bird's Eye View* 6: 4-8.
Malta Ornithological Society (1983b) Għadira news. *Bird's Eye View* 7: 10-11.
Mitchell, P.K. (1961) The Maltese climate and weather. In: Bowen Jones, H.; Dewdney, J.C. and Fisher, W.B. (eds) *Malta, a background for development.* pp. 48-82; Durham: Durham University Press.
Moore, P.G. and Schembri, P.J. (1986) Notes concerning the semi-terrestrial and freshwater amphipods (*Crustacea:* Peracaridia) of the Maltese Islands. *Animalia* 13: 65-75.
Pedley, H.M., House, M.R. and Waugh, B. (1976) The geology of Malta and Gozo. *Proceedings of the Geological Association* 87: 325-341.
Phleger, F.B. (1981) A review of some general features of coastal lagoons. *UNESCO Technical Papers in Marine Science* 33: 7-14.
Savona Ventura, C.; Schembri, S.P., Lanfranco, E.; Schembri, P.J.; Lanfranco, G. & Schembri, J. (1980) *Report on Għadira prepared by the natural environment study section of the Society for the Study and Conservation of Nature.* Valletta: Society for the Study and Conservation of Nature; 8pp. (mimeographed)
Schembri P.J. (1981) *Second report on Għadira.* Valletta: Society for the Study and Conservation of Nature; 12pp. + Fig. 1 (mimeographed)
Sultana, J. (1990) An introduction to the nature reserve. *Centro* 1 (5): 1-4.
Thake, M.A. (1981) *The Għadira development plan; a reappraisal.* (unpublished and privately circulated mimeographed report) 6pp. + Figs 1 & 2.
United States Department of Commerce (1985) *Tide tables 1986: Europe and the west coast of Africa including the Mediterranean.*