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A LONG-TERM STUDY OF THE SANDY SHORE ICHTHYOFAUNA IN THE NORTHERN RED SEA (GULF OF AQABA) WITH REFERENCE TO ADJACENT MARICULTURE ACTIVITY

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ABSTRACT. **–** A long-term study (1984 - 2001) of the ichthyofauna of the sandy shore of the Northern Red Sea (Gulf of Aqaba) was conducted. The primary objective was to assess the impact of a neighboring mariculture facility on the study site. The study was performed during three distinct periods: 1) prior to the establishment of local fish farms (1984 - 1986); 2) commencement of low yield fish farming (1989 - 1994) and 3) fish farming in full production (2000 - 2001). Fish assemblages collected during the three study periods were analysed and compared. The following parameters were considered — number of individuals, number of species, biomass per sample and cumulative number of species. Cluster analysis was performed on the data according to time of collection (morning, noon, evening and night) and season. A total of 93 species was collected, of which three species, *Sparus aurata*, *Dicentrarchus labrax* and *Oreochromis mossambicus*, were exotic to the Red Sea and presumably introduced by human activity. Another 22 species (23.7%) were Lessepsian migrants (Red Sea species that invaded the Mediterranean via the Suez Canal). Of these, nine were among the 15 most dominant species in the sandy shore assemblage. The results revealed a high similarity in the structure of the fish assemblage in all three study periods. No significant difference was discerned in any of the parameters. The same species remained significant, retaining their level of relative importance throughout the study. It can be concluded that the mariculture activity in the sandy shore of the Northern Red Sea had no discernable impact on the adjacent soft-bottom ichthyofaunal assemblage.

KEY WORDS. **–** Northern Red Sea, sandy shore, ichthyofauna, mariculture.

INTRODUCTION

The Northeastern branch of the Red Sea known as the Gulf of Aqaba is one of the world's Northernmost regions where coral reefs are found. In the last four decades, there has been a noticeable process of deterioration in the reefs at the very tip of the Western side of the Gulf, off Israel (Fishelson, 1995; Loya & Kramarski-Winter, 2003; Bongiorini et al., 2003a).

This process of reef deterioration has received much attention in scientific literature as well as in the mass media. Several possible causes have been suggested, including pollution from oil spillage, phosphate contamination (Abu Hilal & Badran, 1990; Khalaf & Kochzius, 2002), sewage effluent from the nearby city of Elat (Fishelson, 1995), introduction of new pathogens (Diamant et al., 2000; Diamant, 2001) and other urban pollution, as well as tourism (Riegl & Velimirov, 1991; Hawkins & Roberts, 1994). The rapid increase in local and international tourism at the Northern shores of the Gulf of Aqaba has given rise to accelerated shoreline development, particularly the construction of new hotels, commercial centers and diving facilities that have led to an increase in scuba diving and snorkeling activity (Zakai & Chadwick-Furman, 2002). This direct human impact on the coral reef ecosystem has resulted in an increase in suspended sediments (see Rogers, 1990), sand particles (Angel et al., 1995; Lupatsch & Kissil, 1998; Abelson et al., 1999; Bongiorni et al., 2003b), broken and perhaps bleached corals, as well as elevated levels of nutrient concentrations in the most crowded areas that are adjacent to the coral reefs (Loya et al., 2004).

In the last 10 years, another factor has been added to the ecosystem — the establishment of net pen fish farming at the Northern tip of the Gulf. From the mid 1980's to the mid 1990's, the activity of the fish farms was experimental and produced less than 100 tons per annum. However, since 1995, fish production (particularly of two species of Mediterranean origin; *Sparus aurata* and *Dicentrarchus labrax*), has risen rapidly and production reached 2,000 tons per annum (Gordin, 2001; Snovsky & Shapiro, 1999 - 2004) within five to six years. The resulting increase in mariculture activity also led to a considerable amount of effluent discharge (Loya et al., 2004) and as a consequence, to a fierce public debate regarding the alleged influence of the fish farms on the entire marine ecosystem in the Northern Gulf of Aqaba and especially on the coral reef community (Loya & Kramarski-Winter, 2003; Rinkevich et al., 2003; Atkinson et al., 2004; Rinkevich, 2005).

The objective of this long-term study was to assess the impact of the rapidly developing mariculture activity on the sandy shore ichthyofauna in the vicinity of the fish farms. The hypothesis of this study is that as the mariculture activity increased, there would be a corresponding increase in the level of deterioration in the fish assemblage, as has been documented in the coral reef ecosystem. Deterioration is defined qualitatively and quantitatively in this study by a decreasing number of individuals, as well as a decrease in the number of species in the adjacent assemblage.

MATERIALS AND METHODS

Study site. – The study site was located just West of the Israeli-Jordanian border at the Northern tip of the Gulf of Aqaba. It is about 2 km East of the city of Elat, 4 km Northwest of the city of Aqaba and 250 - 300 m from the fish farm (Fig. 1). The sampling area consisted of a sandy sea bed with a gentle seaward slope extending from a 2 m wide shore belt of coarse gravel to a soft sandy substrate in the deeper seaward portion of the area.

Sampling. – Sampling was conducted with a 30 m long beach seine with decreasing mesh size from 40 mm at the wing to 2 mm at the center (bunt). Each sample was comprised of 2 sequential hauls at depths of 0 - 1.5 m and covered an area of about 1,400 m^2.

In Period 1 (1984 - 1986) and Period 2 (1989 - 1994) of the study, samples were carried out randomly at various hours of the day and night. In Period 3 (July 2000 to June 2001), we conducted six sampling sessions at approximately two month intervals. Each session lasted 48 hours and had 8 samples — 2 morning samples (less than 30 minutes before or after sunrise), 2 at noon, 2 in the evening (30 minutes before or after sunset) and 2 night samples (3 - 5 hours after sunset).

Collected fish were identified to species level. Some juveniles were identifiable only to generic or family level and were treated as distinct taxa. The numbers and weights (to the nearest 0.1 g) of all specimens were recorded.

Data processing and statistical analysis. – The relative importance of each species was calculated separately for each research period, as employed previously (Golani, 1993).

The modified Index of Relative Importance (IRI) (Hyslop, 1980) was calculated as:

$$IRI = F (N + W),$$

where F is the percentage of the frequency of occurrence, N is the numerical percentage and W is the gravimetrical percentage.

It was deemed necessary to curtail some of the numerical and gravimetrical values of certain species that were sampled occasionally but in large numbers and weight. The inclusion of the non-curtailed values of these schooling species would have led to the loss of vital information on species that were sampled in lesser numbers and weight. This was achieved by curtailment of the values in each sample that exceeded 100 individuals and/or 250 g (see Golani, 1993).

The Euclidian distance between all sample pairs from all three periods was calculated based on the non-curtailed number of

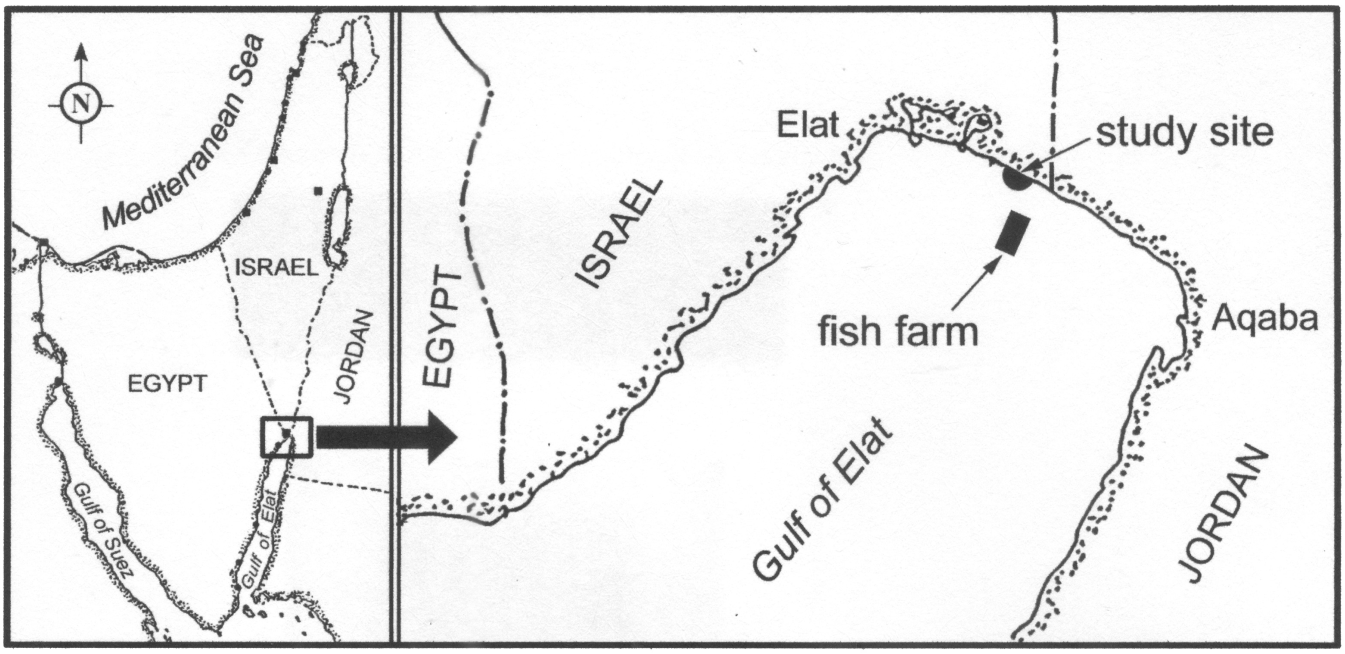

Fig. 1. Map of the study site.

Table 1. List of species sampled in the sandy shore of the Gulf of Aqaba. Families are sorted according to the evolutionary order.

Family	Species
MURAENICHTHIDAE	*Muraenichthys* sp.
CONGRIDAE	*Ariosoma sanzoni* (D'Ancona, 1928)
OPHICHTHIDAE	sp.
CLUPEIDAE	*Etrumeus teres* (DeKey, 1842)*
	Herklotsichthys punctatus (Rüppell, 1837)*
	Spratelloides delicatullus (Bennett, 1831)*
	Spratelloides gracilis (Temminck & Schlegel, 1846)
	sp.
STERNOPTYCHIDAE	*Maurolicus muelleri* (Gmelin, 1789)
SYNODONTIDAE	*Synodus variegates* (Lacepède, 1803)
	Trachinocephalus myops (Bloch & Schneider, 1801)
	Synodus sp.
PARALEPIDAE	*Lestidiops jayakari* (Boulenger, 1889)
HEMIRAMPHIDAE	*Hemiramphus far* (Forsskål, 1775)*
	Hyporhamphus affinis (Günther, 1866)*
ATHERINIDAE	*Atherinomorus lacunosus* (Bloch & Schneider, 1801)*
	Hypoatherina temminckii (Bleeker, 1853)
FISTULARIDAE	*Fistularia commersonii* Rüppell, 1838*
SOLENOSTOMIDAE	*Solenostomus cyanopterus* Bleeker, 1854
SYNGNATHIDAE	*Hippocampus jayakari* Boulenger, 1900
	sp.
SCORPAENIDAE	*Apistus carinatus* (Bloch & Schneider, 1801)
	Dendrochirus brachypterus (Cuvier, 1829)
	Minous coccineus Alcock, 1890
PLATYCEPHALIDAE	*Rogadius prionotus* (Sauvage, 1873)*
MORONIDAE	*Dicentrarchus labrax* (Linnaeus, 1758)**
TERAPONIDAE	*Terapon jarbua* (Forsskål, 1775)
KUHLIDAE	*Kuhlia mugil* (Bloch & Schneider, 1801)
APOGONIDAE	*Apogon coccineus* Rüppell, 1838
	Apogon cookii Macleay, 1881
	Apogon cyanosoma Bleeker, 1853
	Archamia lineolata Cuvier, 1828
	Cheilodipterus lachneri Klausewitz, 1959
	Cheilodipterus quinquelineatus Cuvier, 1828
	Cheilodipterus pygmaios Gon, 1993
	Gymnapogon melanogaster Gon & Golani, 2002
CARANGIDAE	*Decapterus russelli* (Rüppell, 1830)
	Trachurus indicus Necrasov, 1966
LUTJANIDAE	*Lutjanus kasmira* (Forsskål, 1775)
GERRIDAE	*Gerres oyena* (Forsskål, 1775)
HAEMULIDAE	*Pomadasys stridens* (Forsskål, 1775)*
LETHRINIDAE	*Lethrinus variegatus* (Valenciennes, 1830)
	Lethrinus sp.
SPARIDAE	*Acanthopagrus bifasciatus* (Forsskål, 1775)
	Crenidens crenidens (Forsskål, 1775)*
	Diplodus noct (Valenciennes, 1830)
	Rhabdosargus haffara (Forsskål, 1775)*
	Sparus aurata Linnaeus, 1758**
PEMPHERIDAE	*Pempheris vanicolensis* Cuvier, 1831*
CICHLIDAE	*Oreochromis mossambicus* (Peters, 1852)**
MULLIDAE	*Mulloidichthys flavolineatus* (Lacepède, 1801)
	Parupeneus forsskali Fourmanoir & Gueze, 1976
	Parupeneus macronemus (Lacepède, 1801)
	Parupeneus rubescens (Lacepède, 1801)
	Upeneus pori Ben-Tuvia & Golani, 1989*
	sp.
MUGILIDAE	*Crenimugil crenilabis* (Forsskål, 1775)
	Liza carinata (Valenciennes, 1836)*
	Liza subviridis (Valenciennes, 1836)
	Moolgarda seheli (Forsskål, 1775)
	sp.

Table 1. (continued)

Family	Species
SPHYRAENIDAE	*Sphyraena chrysotaenia* Klunzinger, 1884*
	Sphyraena flavicauda Rüppell, 1838*
LABRIDAE	*Stethojulis albovittata* (Bonnaterre, 1788)
	Stethojulis interrupta (Bleeker, 1851)
	Xyrichtys pentadactylus (Linnaeus, 1758)
	Xyrichtys sp.
	sp.
SCOMBRIDAE	*Scomber japonicus* Houttuyn, 1782
TRICHONOTIDAE	*Trichonotus nikii* Clark & Schmidt, 1966
BLENNIDAE	*Istiblennius edentulous* (Bloch & Schneider, 1801)
	Petroscirtes ancylodon Rüppell, 1838*
	Petroscirtes mitratus Rüppell, 1838
	sp.
GOBIIDAE	*Bathygobius cyclopterus* (Valenciennes, 1837)
	Gnatholepis anjerensis (Bleeker, 1851)
	Istigobius ornatus (Rüppell, 1830)
	Silhouettea aegyptia (Chabanaud, 1933)*
	Trimma avidori (Goren, 1978)
	Valenciennea sexguttata (Valenciennes, 1837)
	Valenciennea sp.
	sp.
CALLIONYMIDAE	*Callionymus filamentosus* Valenciennes, 1837*
ACANTHURIDAE	*Acanthurus nigrofuscus* (Forsskål, 1775)
SIGANIDAE	*Siganus luridus* (Rüppell, 1828)*
	Siganus rivulatus Forsskål, 1775*
BOTHIDAE	*Bothus pantherinus* (Rüppell, 1830)
	Engyprosopon hureaui Quero & Golani, 1990
	sp.
SOLEIDAE	*Pardachirus marmoratus* (Lacepède, 1802)
TETRAODONTIDAE	*Arothron hispidus* (Linnaeus, 1758)
	Torquigener flavimaculosus Hardy & Randall, 1983*
DIODONTIDAE	sp.

* = Lessepsian migrants; ** = non-native species.

individuals. The high similarity between the number of individuals and weight per sample that resulted from the small size range allowed this approach to be used.

Cluster analysis was performed using the Unweighted Pair Group Method with Arithmetic mean. Dendrograms were calculated according to the time of the day (morning, noon, evening and night) and by season [winter (January - March); spring (April - June); summer (July - September); fall (October - December)].

RESULTS

A total of 93 species belonging to 41 families were compiled from all sessions (see Table 1). A total of 63 taxa were collected in the first period, 48 in the second and 70 in the last period. Three of the species, *Sparus aurata*, *Dicentrarchus labrax* and *Oreochromis mossambicus* were presumably introduced into the study area unintentionally by human activity. Two species, *Engyprosopon hureaui* (Quéro & Golani, 1990) and *Gymnapogon melanogaster* (Gon & Golani, 2002), were collected in this study and subsequently first described to science. One species, *Ariosoma sanzoi* (D'Ancona, 1928), was a first record for the Red Sea.

A total of 103,634 individuals weighing 312,975 g were sampled in the three study periods. There were 27,264 individuals weighing 81,123 g in the first period, 12,172 individuals weighing 54,171 g in the second period and 64,198 individuals weighing 177,681 g in the third period. Curtailments of 80,280 individuals weighing 234,251 g comprising 77.5% of individuals and 75.0 % of weight of the entire sample (Table 2) were carried out.

The number of individuals and biomass per sample in the third period (Fig. 2) was higher in the July 2000 and June 2001 samples while the number of species remained similar throughout the year. A comparison of the identical parameters according to time of the day for the same period (Fig. 3) revealed clearly that night samples had higher values for all parameters.

Comparison between the periods shows that the third period had higher levels of individuals, species and biomass. This difference is due to the low proportion of rich night samples in the first period (11.4% in the first period as compared to 24.0% and 24.5% in the second and third periods, respectively). Comparison between the three periods excluding night samples (Fig. 4) reveals similar values. The cumulative number of species in all three periods is given in Fig. 5.

Table 2. Curtailments conducted in the three periods of the study enabling calculation of the modified Index of Relative Importance (IRI).

Species	1st Period			2nd Period			3rd Period		
	No.cur[1]	Num.[2]	Grav.[3]	No.cur[1]	Num.[2]	Grav.[3]	No. cur[1]	Num.[2]	Grav.[3]
*Pomadsys stridens**	11	7,852	14,405	7	2,223	3,263	23	14,676	69,507
Hypoatherina temminckii	15	5,938	20,735	4	2,230	9,674	9	1,554	4,860
*Atherinomorus lacunosus**	6	1,957	12,777	7	524	7,302	9	3,819	14,479
Diplodus noct	5	155	1650	7	413	2,425	2	-	185
*Torquigener flavimaculosus**	10	63	3969	-	-	-	4	31	845
*Spratelloides delicatulus**	1	2,655	1458	-	-	-	8	32,871	43,836
*Siganus rivulatus**	-	-	-	1	-	624	6	156	5,113
*Rogadius prionotus**	-	-	-	-	-	-	4	-	1,059
Mulloidichthys flavolieatus	2	-	224	-	-	-	2	-	331
*Upeneus pori**	2	55	441	2	175	323	-	-	-
*Liza carinata**	-	-	-	2	902	6,037	1	-	414
Sparus aurata†	-	-	-	-	-	-	2	-	789
*Etrumeus teres**	-	-	-	2	634	2,210	-	-	-
MUGILIDAE	-	-	-	1	-	62	1	342	-
Trachinocephalus myops	-	-	-	-	-	-	1	-	89
Trachurus indicus	-	-	-	-	-	-	1	-	559
Parupeneus forsskali	-	-	-	1	145	2,603			
MULLIDAE	-	-	-	1	40	599	-	-	-
Moolgarda seheli	-	-	-	-	-	-	1	658	508
Scomber japonicus	-	-	-	1	-	1,004	-	-	-
Engyprosopon hureaui	-	-	-	-	-	-	1	212	-
Total		18,620	55,659		7,286	36,126		54,319	142,574

* = Lessepsian migrants; † = denotes non-native species; No. cur[1] = number of curtailments; Num.[2] = number of individuals curtailed; Grav.[3] = weight curtailed.

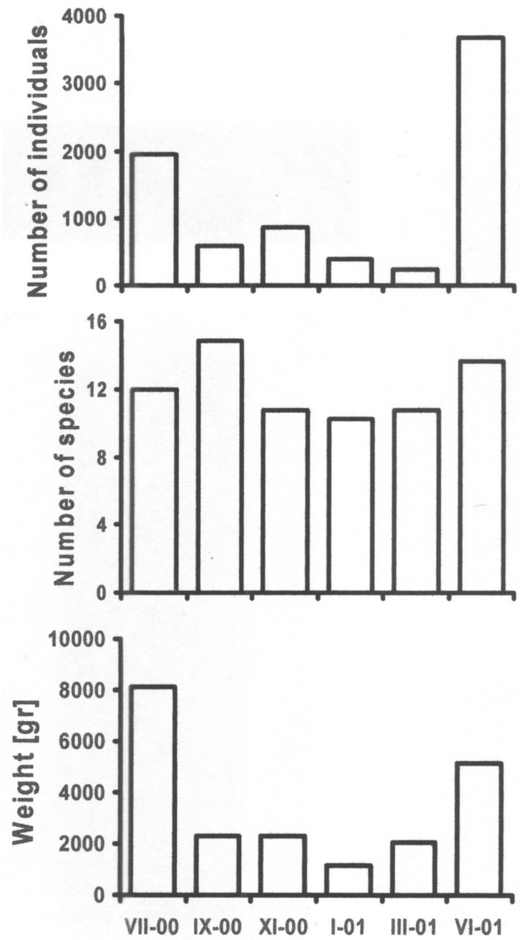

Fig. 2. Average number of individuals, species and biomass per sample collected during Period 3 [July 2000 (VII-00) to June 2001 (VI-01)].

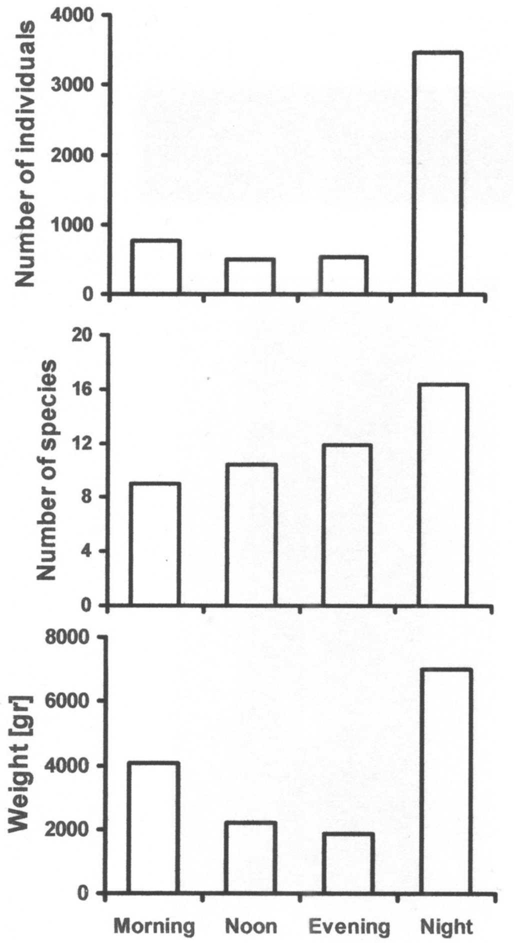

Fig. 3. Average number of individuals, species and biomass per sample by time of day collected during Period 3 (July 2000 to June 2001).

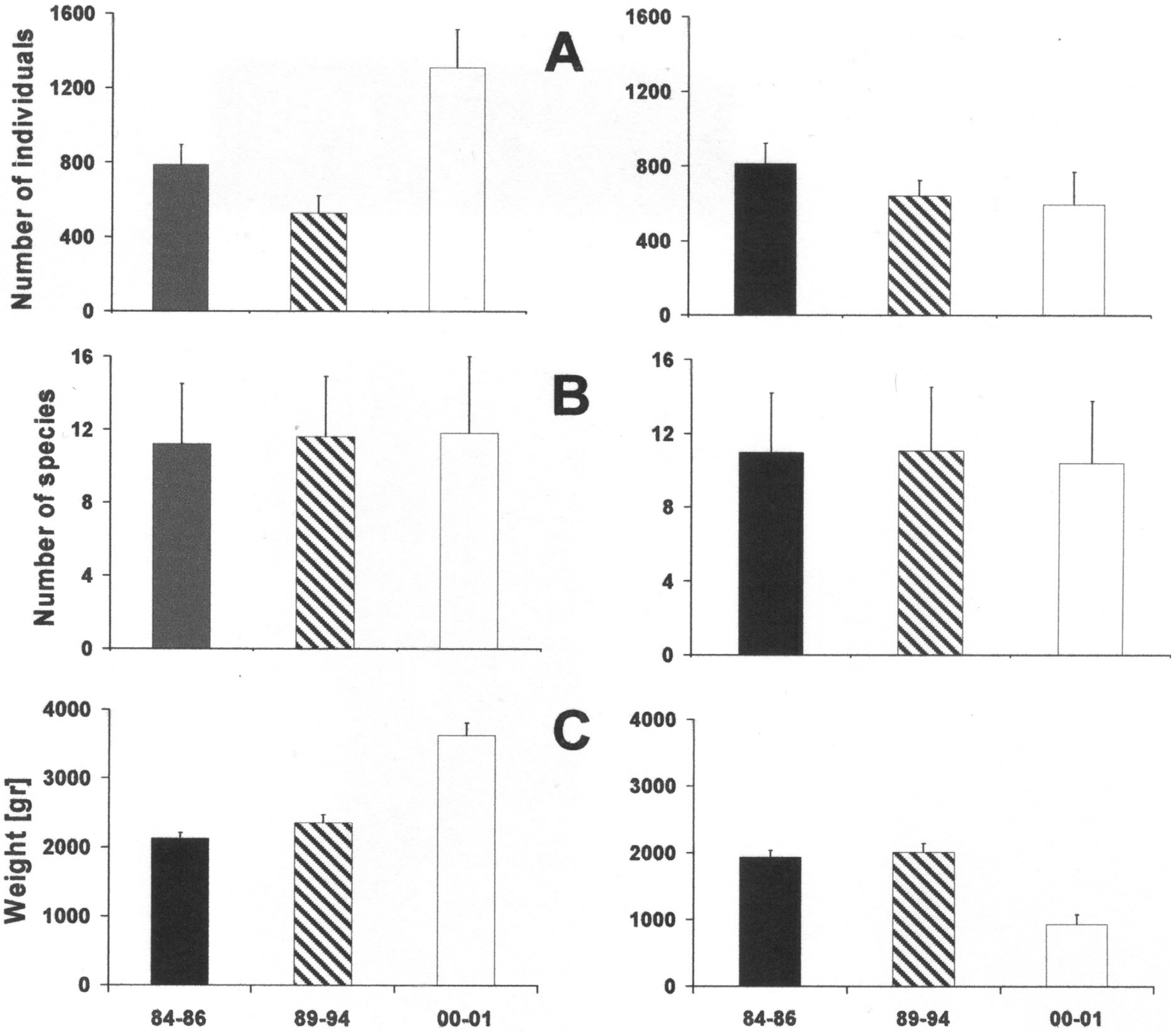

Fig. 4. Comparison of the average values of A) numbers of individuals, B) species, C) biomass per sample collected in the three periods of the study (from 1984 to 2001). Entire data set presented on the left and those with the night samples excluded on the right, variation of the number of individuals and biomass is expressed in coefficient of variance while the number of species is expressed in standard deviation.

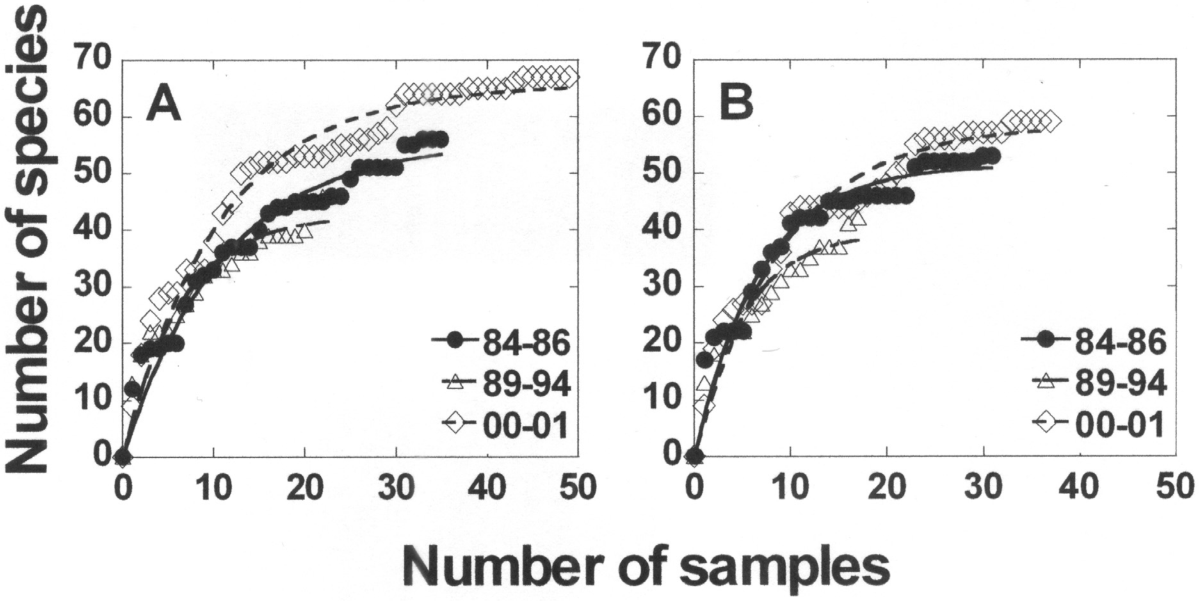

Fig. 5. Cumulative number of species collected in the three periods of the study from 1984 to 2001. A) all data, B) data with night samples excluded.

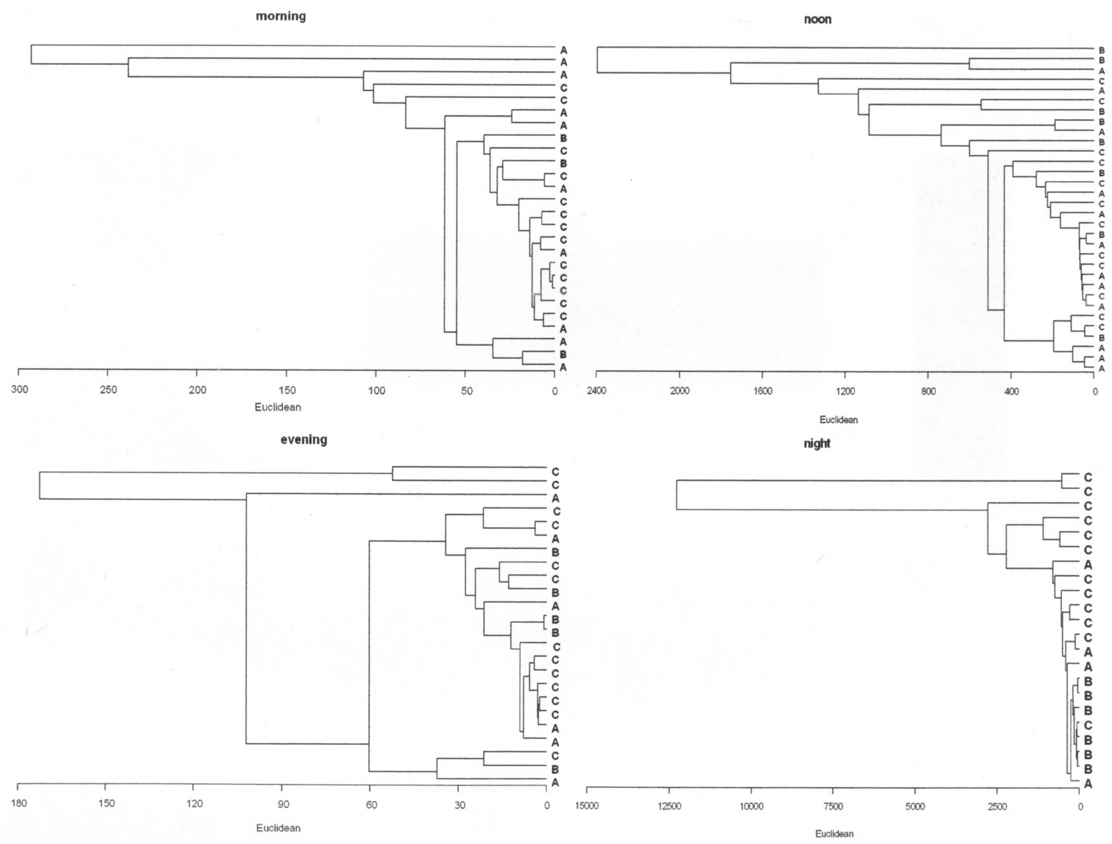

Fig. 6. Dendrograms calculated according to number of fishes of each species by time of day for the three periods of the study. A = first period (1984 - 1986); B = second period (1989 - 1994); C = third period (2000 - 2001).

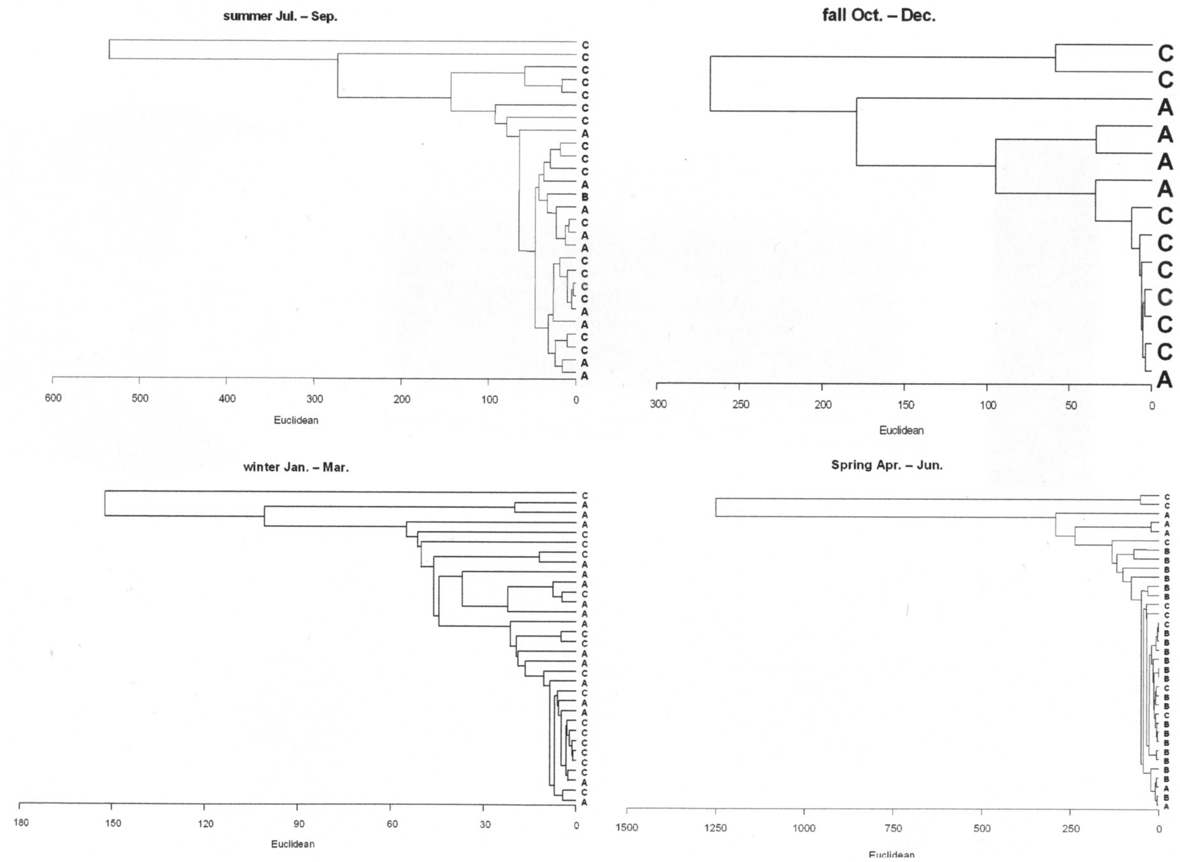

Fig.7. Dendrograms calculated according to number of fishes of each species by season. A = first period (1984 - 1986); B = second period (1989 - 1994); C = third period (2000 - 2001).

Table 3. Species ranking according to their Index of Relative Importance (IRI) values in the three periods of the study and the overall ranking in the sandy shore fish assemblage of the Gulf of Aqaba.

Species	1st Period	2nd Period	3rd Period	Average Rank	S.D. of Rank	Overall Rank
*Pomadasys stridens**	1	2	1	1.33	0.471	1
Hypoatherina temmincki	2	4	4	3.33	0.943	2
*Atherinomorus lacunosus**	3	3	6	4.00	1.414	3
Diplodus noct	7	1	7	5.00	2.828	4
*Callionymus filamentosus**	5	8	3	5.33	2.055	5
Engyprosopon hureaui	8	9	5	7.33	1.700	6
Trachynocephalus myops	9	7	11	9.00	1.633	7
*Rogadius prionotus**	11	11	9	10.33	0.943	8
*Upeneus pori**	6	6	22	11.33	7.542	9
*Torquigener flavimaculosus**	4	24	8	12.00	8.641	10
*Siganus rivulatus**	17	21	2	13.33	8.179	11
*Liza carinata**	21	5	18	14.66	6.944	12
Mulloidichthys flavilineatus	10	32	12	18.00	9.933	13
*Sprateloides delicatulus**	19	33	10	20.66	9.463	14
Parupeneus rubescens	34	10	23	22.33	9.809	15

* = Lessepsian migrants.

Dendrograms calculated according to the non-curtailed numbers of individuals by time of the day and by season are given in Figure 6 and 7, respectively.

DISCUSSION

The main finding of this long-term study is the high stability of the sandy shore fish assemblage throughout the entire study and in all studied parameters. Evaluating the effect of the adjacent mariculture activity on the ichthyofauna of the sandy shore was made possible by the analysis of data gathered prior to the establishment of the fish farms and in the early stages when commercial production was very low. Did the mariculture effluent discharge reach the study site? And if it did, to what extent? Genin & Silverman (2004) examined this by measuring the pH and the concentration of total oxidized nitrogen (NO_3 and NO_2), phosphates (PO_4^{-3}), chlorophyll *a*, silicate [$Si(OH)_4$], ammonia (NH_3) and average organic matter in the sediment, under the fish farm cages, as well as at other stations along the Israeli coast of the Northern Gulf of Aqaba (Elat). They found no significant differences in the first six parameters. The slightly higher values in organic matter in the sediment found in all stations along the Northern beach of Elat may be due to multiple anthropogenic pollution sources such as urban sewage, hotel effluent and other tourist-related pollution.

The higher values of the number of individuals and biomass per sample that appear prima facie in the last period were due to the uneven proportion of night samples. When night samples were excluded from the analysis, the values of all three periods were quite similar (Fig. 4).

Comparison of the cumulative number of species shows a slightly higher rate in Period 3 (Fig. 5a). This is once again a result of the higher proportion of night samples as some species, especially of the family Apogonidae, appear only at night. Figure 5b reveals a similar rate in all three periods when night samples were excluded.

The cumulative number of species was found to be consistent with a high level of stability in the fish assemblage. In a deterministic assemblage (high stability), the cumulative number of species collected rises rapidly, quickly reaching an asymptote. While in a stochastic assemblage (low stability), the rise in number of species is slow, taking longer (i.e., more samples) to reach an asymptote (Richards & Wu, 1985; Cam et al., 2002).

Cluster analysis, according to the time of day and season, showed that the samples did not cluster by period of the study, thus indicating that the species structure of the fish samples did not alter during the research period. This signifies the lack of modification in the fish assemblage over the long run.

Previous studies elsewhere have shown that changes in the dynamics of a fish assemblage can be best detected by concentrating research efforts on the dominant species in that assemblage (Richards & Wu, 1985; Clarke & Green, 1988).

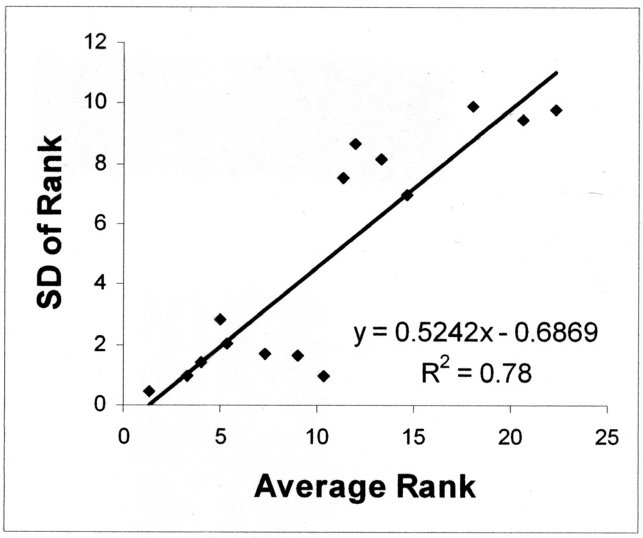

Fig. 8. Correlation of species and variance ranking.

Although the rarer species are of greater interest in terms of biodiversity and conservation, their infrequent or even rare appearance in the sample reduces their importance to research on changes in a particular assemblage. The modified Index of Relative Important (IRI) was deemed suitable to identify such dominant species by combining abundance (number of individuals of a species), biomass and frequency of occurrence in the samples. In the present study, a species was considered dominant if its IRI value was among the top ten in at least one of the three study periods (see: Richards & Wu 1985; Connolly, 1994). Fifteen species (out of 93) were designated as dominant in the sandy shore assemblage but only six of these were ranked in the top ten in all three periods (Table 3). Comparison of the ranking of the dominant species among the three periods (by a two-tailed Spearman's Rank correlation) show that in the first and second periods ($P = 0.0206$; $r = 0.5231$) and first and third periods ($P = 0.0099$; $r = 0.5929$), the rankings showed significant similarity while the ranking was not significantly similar between the second and third periods ($P = 0.1740$; $r = 0.2607$).

It is interesting to note that the higher a species was positioned in the overall ranking, the variance value was lower down the ranking in all three study periods (Fig. 8). This finding supports the conclusion that the fish assemblage maintained stability throughout the study periods.

This stability was also true for the Lessepsian species in the assemblage. Although the extent of Lessepsian species in the assemblage was not directly connected to the question of the influence of the adjacent mariculture activity, it does indicate to a certain degree the stability of this assemblage. Golani (1993) summarized the results of the first study period by presenting the qualitative and quantitative values of the Lessepsian migrant fish species in the sandy shore fish assemblage. He interpreted their dominant presence as pre-adaptation to recipient niches in the Mediterranean. He even referred to the sandy shore of the Red Sea as a 'launching pad' for Lessepsian migrants (Golani, 1993).

The importance of the Lessepsian migrants in the sandy shore remained quite high throughout the study. Twenty-two out of 78 identified species (28.2%) found in the present study are known colonizers of the Mediterranean (Lessepsian migrants). This percentage is significantly higher than that of the 61 Lessepsian species (out of 1,248) (4.8%) in the entire Red Sea (Goren & Dor, 1994). The proportion of the number of the Lessepsian migrant species remained similar in all three periods. In the first period there were 17 Lessepsian out of a total 62 species (27.4%) sampled. In the second period, there were 14 out of 42 species (33.3%) and 16 out of 70 species (22.6%) in the third period. Furthermore, nine of the 15 important species (Table 3) and nine of the 21 curtailed species in this study were Lessepsian migrant species (Table 2).

In conclusion, our hypothesis that the increase in mariculture activity would lead to a corresponding increase in the level of deterioration in the fish assemblage was rejected as indicated by all of the parameters tested. The number of individuals, species and weight per sample, the accumulative number of species, the assemblage structure and the dominant species remained stable throughout the study.

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