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EFFECT OF POLLUTION ON THE COMMUNITY STRUCTURE OF ANIMALS ASSOCIATED WITH DEAD CORALS IN EILAT (GULF OF AQABA, RED SEA)

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ABSTRACT

A study has been carried out to test the effect of pollution stress on species composition and structure of the fouling community inhabiting dead scleractinian corals. Affinity between samples and diversity indices were compared in mature communities. The diversity was highest in the non-polluted site, decreasing with increased pollution. A diversity index, involving high taxa (classes and orders), is proposed for monitoring of stressed communities. Experiments, in which similar coral skeletons were planted in sites with a varying degree of pollution, as well as established communities were transplanted from non-polluted to polluted sites, all show that diversity is a sensitive device to monitor pollution effects.

INTRODUCTION

Stress produced by pollution has been the cause of concern in many tropical and subtropical shores, due to increased industrialization of coastal regions (Fishelson, 1977; Harmelin et al., 1981). Especially vulnerable are land-locked basins like the Red Sea and its gulfs - Gulf of Suez and Gulf of Aqaba (=Eilat). This hitherto remote and pollution-free sea has become severely polluted by oil (Loya, 1975; Dicks, 1984), phosphates (Fishelson, 1973a; Mergner, 1981) and urban sewage (Walker & Ormond, 1982; Dafni, 1983). Localized acute pollution is also associated with thermohaline discharge of power and desalination plants (Lev-Er et al., 1976; Dafni, 1980). Polluted seawater has been shown to reduce the survival of reef organisms (Fishelson, 1973a,b ; Rinkevich & Loya, 1977), and affect coral recolonization after natural catastrophes (Loya, 1976).
Assessment of pollution in terms of the chemical and physical parameters is often insufficient to evaluate the actual effect of the pollutants on the ecosystem. Certain organisms show remarkable affinity to certain types of pollution, thereby serving as "indicator organisms". The use of "indicator communities" has been recommended for cases where a mixture of different types of pollution are involved (Gaufin & Tarzwell, 1956).
Such a situation has developed in the northern part of the Gulf of Aqaba, with its two fast-growing towns - Eilat and Aqaba. This paper aims to evaluate the influence of the cumulative, possibly synergistic impact of several pollution types, applying the community approach. Here we report the results of an investigation, made on several sites along the Gulf's coastline, using as a model the invertebrate fouling community developing on dead corals. In an effort to simplify monitoring, using such biological communities, an abbreviated diversity index is proposed and experimentally tested.

MATERIALS AND METHODS

A pollution gradient exists along the Israeli coast of the Gulf, being more severe on the northern beach, where sewage is discharged and Eilat Harbour and oil terminal are located, as compared to the non-polluted conditions, prevailing at the Egyptian border, 15 km south of Eilat.

Samples of dead Stylophora pistillata corals, covered with epifauna and algae, were collected during November 1971, from the following sites*: (1) "Power Plant" (PP) - the shore opposite a combined power and desalination plant**. Hot (38 °C) and saline (46 ‰) effluent, denser than seawater, was expelled from this plant through a small outlet. Forming a "plume", these waters crawled offshore along the bottom to a distance of 200m and a depth of 13m. The corals sampled for study were obtained from a coral knoll at the depth of 3m, 60m from the outlet, affected by the plume only in periods of strong current. (2) "Oil Terminal" (OT) - samples were taken at a location 300m south of the oil terminal, next to a yacht pier. This site is influenced both by oil and phosphate dust, settling from the adjacent harbour and terminal. (3) "Nature Reserve" (NR) - a 1200m protected fringing reef, suffering however from a chronic pollution, of 2-3 oil spills per month, from the oil terminal 1km to the north (Loya, 1975). Samples were collected in the <2m deep lagoon. (4) "Control Reef" (CR) - a fringing reef 8km south of the oil terminal and other pollution sources. This site is less affected by pollution, mainly from anchoring ships.

Processing of samples included counting and the identification of all non-colonial invertebrates, separated from the corals, altogether 213 taxa. Some groups (Polychaeta, Decapoda, Mollusca) were separation, by specialists, reached specific level, whereas in the others generic, familial or ordinal level was reached. Nematods, however, were treated as one taxon.

The similarity between samples was defined as percentage affinity - count of individuals of each species common to both samples (nij,nik), divided by sample size. Affinity ranged from 0 to 100% (Sokal & Sneath, 1963):

$$\text{Affinity index} = \frac{100 \times 2}{Nj+Nk} \sum_{i=1}^{s} \min(\, nij,\ nik) \qquad (1)$$

where i = species ; S = number species ; Nj, Nk = number of individuals in sample J and K, respectively. The hierarchial similarity was determined using a cluster analysis, in which the maximal affinity was obtained between any two samples, after which they were pooled and compared to the rest, etc. (Sokal & Sneath, 1963).

Since the term diversity has been treated broadly by numerous authors, and many indices were proposed (see Pielou, 1969; Whittaker, 1972 for review), we chose to calculate most of them, and to compare them with other community structure parameters, using field data. These indices and parameters were : Total number of species, Number of species per 1000 individuals, Margalef's (1951) species richness, McIntosh's (1967) diversity index, and Simpson's (1949) index. Also compared were indices based on the information theory (Brillouin, 1962; Pielou, 1966) - H, Hmax and eveness (J):

$$\text{Brillouin's } H = 1/N \log N!/(N_1!\, N_2! \ldots\ldots Ns!) \qquad (2)$$

and -

$$Hmax = 1/N \log N!/((M'!)^{S-r}\ \ ((M'+1)!)^{r}\ ) \qquad (3)$$

where N is a multiple of S ; M=N/S and M'-r=N/S (r -residual)

*Subsequently the extent of all pollution sources has been greatly reduced.
** The activity of this power plant had ceased in 1981.

When N is sufficiently large, log S may serve as an estimate of Hmax. Eveness (J) is defined as H /Hmax. Logarithm base 2 was used to express diversity values in information units (bits).
The choice of analysed indices was largely influenced by our intention to compare this community with the fouling community that develops on living corals, which was previously analysed by McCloskey (1970).
To provide a practical tool for monitoring community diversity of medium sized samples, without involving highly skilled taxonomists, an abbreviated diversity index, H*, was defined, based on Brillouin's H, with the individuals identified to the classes or ordinal level.
In the field experiments were fouling communities manipulated by:
(1) Planting coral skeletons (live corals killed by immersion in freshwater, and consequently sun-dried for 24 h) as substrates for colonization and development of the fouling community. (2) Detaching and transplanting mature communities from the control reef (CR) within the same site (as control), and into polluted sites (NR and PP). All transplantations were completed within 15 min of removal.

RESULTS AND DISCUSSION

THE COMMUNITY

An intention to compare organism assemblages from various locations is problematic due to the fact that no two substrata are alike. This problem becomes crucial when polluted areas are compared to non-polluted. Maximal uniformity of the substrate is obtainable by using shallow water corals as substrate. Since all Stylophora skeletons are composed of aragonite, having well-defined volume/surface parameters (Falkowski & Dubinsky, 1981) they provide a suitable substrate for a common fouling community, whose biotic parameters are assumed to be influenced mainly by the environmental conditions.

FIELD DATA

A comprehensive list of the 213 taxa identified in this study has been reported elsewhere (Dafni, 1974). In Table 1 lists animals are grouped according to higher taxonomical units. It shows that the more the site is is polluted, the less groups are present, dominated by certain groups.
The highest number of evenly distributed taxa was shown in the control reef samples (CR). In the polluted sites the relative abundance of more sensitive groups, such as crustaceans of the orders Tanaidacea, Isopoda, Amphipoda and Cumacea, decreased. Nematods were least affected by pollution, and their relative abundance in the most polluted site (Power Plant) reached > 80%, apparently facilitated by the dense outgrowth of filamentous algae.
The cluster analysis (Fig. 1) showed that the samples clustered into three distinct groups according to degree of pollution. The highest affinity was found between OT samples (53%), or between the control reef (CR) samples (50%), with 56 and 61 shared species, respectively. Samples of lesser polluted sites, NR and OT, were clustered at >47% affinity.

DIVERSITY INDICES

Following Pielou's (1966) recommendation, that in collections where all individuals are counted, Brillouin's diversity index (H) based on the total numbers, is preferrable to Shannon & Weaver's index based on proportions, we decided to use this index. The other diversity indices were calculated mainly in order to assess their dependence on sample size,-

species count and the eveness component (Table 3).
A good diversity index should be relatively independent of sample size and equally dependent on the components number of species and eveness. While Margalef's index well-adresses the first two requirements, is shows low correlation with the eveness component. Species per 1000, MacIntosh and Simpson's indices are size-dependent, overemphasizing the eveness component (the latter is known to be affected by the first-entered species - Whittaker, 1972). Brillouin's index is not size-dependent, equally expressing the species count and eveness components (Table 3).

Table 1. Frequency of higher taxa collected on the sampled sites.

Taxon	Power Plant	Oil Terminal	Nature Res.	Control Reef
Acarida	-	-	-	1
Amphineura	-	6	-	5
Amphipoda	-	-	1	54
Anthozoa	-	-	-	4
Bivalvia	5	33	33	21
Copepoda	8	168	50	167
Cumacea	-	3	4	15
Decapoda	-	3	10	11
Echinoidea	-	-	-	4
Foraminifera	233	585	644	145
Gastropoda	4	36	35	72
Insecta	1	-	4	21
Isopoda	-	12	6	25
Nematoda	1642	441	128	64
Ophiuroidea	-	-	4	5
Ostracoda	1	3	-	48
Polychaeta	154	1054	295	373
Sipunculida	5	201	91	4
Stomatopoda	-	2	-	-
Tanaidacea	1	-	1	121
Chaetognatha	-	-	-	1
No. of taxa	10	13	14	20

Table 2. Number of shared species (upper right) and percent affinity between the collected samples (lower left). PP1, PP2 = Power Plant; OT1, OT2 = Oil Terminal; NR1, NR2 = Nature Reserve and CR1, CR2= Control Reef.

	PP1	PP2	OT1	OT2	NR1	NR2	CR1	CR2
PP1	x	10	31	26	19	20	23	24
PP2	32.8	x	16	15	18	15	18	18
OT1	45.6	24.3	x	56	39	45	47	44
OT2	40.6	22.5	53.0	x	44	47	48	45
NR1	45.6	18.4	35.3	36.6	x	39	40	39
NR2	37.7	12.6	33.5	52.1	47.7	x	41	41
CR1	24.3	10.4	23.3	22.0	37.3	33.9	x	61
CR2	20.6	7.4	22.6	20.2	27.3	30.8	50.0	x

Another treatment, the cumulative ranked diversity, based on entering first the commonest species, gradually adding the rarer species, showed that while it increases with the number of taxa in the sample, the difference between the samples were noticeable at only 20 of the commonest species..
The abbreviated diversity index (H*) is based on the assumption that species diversity is hierarchial, incorporating diversity of species within the genera, generic diversity within the families etc.(Pielou, 1967,1969). Therefore, H*, based on higher taxa, approximates species diversity.

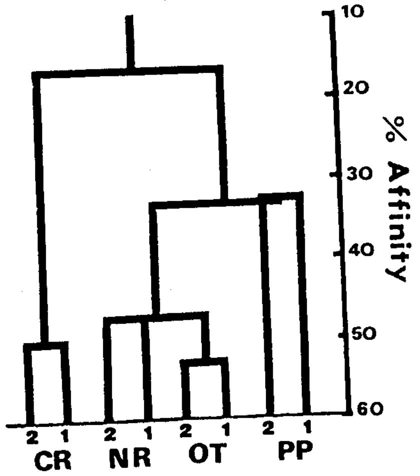

Fig. 1. Cluster analysis for the affinity between the samples (for abbreviations cf. Table 2).

Table 3. Correlation between various diversity indices and community structure parameters : sample size, number of species and eveness (J). (Test for independence: ** = p<0.01 ; * = p<0.05 ; NS = non-significant).

Index	Sample size	No. Species	Eveness
Species per 1000	-.804 (**)	-.235 (NS)	.761 (**)
MacIntosh Div. Index	-.552 (*)	.497 (*)	.979 (**)
Simpson Div. Index	-.549 (*)	.518 (*)	.948 (**)
Margalef sp. richness	.115 (NS)	.980 (**)	.472 (NS)
Brillouin's H	-.272 (NS)	.804 (**)	.802 (**)
H max	.392 (NS)	.931 (**)	.110 (NS)
H*	-.578 (*)	.551 (*)	.863 (**)

In Table 3, the index H* was found to be more size-dependent than H, less sensitive to number of taxa, rather emphasizing the eveness component. Since in H* the number of taxa is deliberately decreased, this component loses its significance and the eveness component plays the main role. In spite of this slight draw-back, the H* index is a well applicable method, as illustrated in some experiments dealt with below.
The data, presented in Table 4., show that >100 species are found in a ca. 50 cubic cm dead coral, with only, in the more diverse samples, 5 individuals per species. Diversity, in bits, in the non-polluted site was, as expected, higher than found by McCloskey (1970) in interstices of the coral <u>Occulina arbuscula</u>. McCloskey found, however, higher Hmax values (>7.0), due to the more richer samples (some attained >20000 individuals). Although both sample size and total number of species vary among the sites, all diversity indices showed appreciable decrease along the pollution gradient (indices other than those based on information theory are presented in Dafni, 1974). Local conditions, such as dense cover of brown algae, that provided shelter for many taxa, in OT samples, are reflected in variation in the species richness, but they are compensated by an increase in dominance (reduced eveness).

Table 4. Community parameters and diversity indices for 8 samples from four sites along the Israeli coast of the Gulf of Aqaba (For abbreviations cf. Table 2).

Sample	Ind's	Species	H	Hmax	J
PP1	501	39	2.723	5.050	0.539
PP2	1564	24	0.799	4.523	0.177
OT1	1286	89	4.505	6.255	0.720
OT2	1285	100	4.521	6.402	0.706
NR1	489	69	4.375	5.733	0.763
NR2	634	68	3.828	5.780	0.662
CR1	488	103	5.309	6.176	0.859
CR2	703	94	4.922	6.189	0.795

EFFECT OF PLANTING DEAD CORALS ON DIFFERENT SITES

The planted coral substrates became gradually populated, and the number of taxa increased considerably throughout the succession (Table 5). The diversity index H* also increased from 1 month to 3 months, but subsequently samples showed different patterns in the various sites (Fig. 2): In the most polluted site (PP) diversity decreased, apparently due to the increased dominance of nematods. In the less-polluted sites (NR,OT) there was a slight increase of diversity, whereas in the control reef a sharp decrease in the diversity was shown between 3-6 months, with a subsequent increase. It is noteworthy that the pattern shown by CR samples corresponds to evolutionary stages, normally shown during the ecological developmental process of ecosystems (Fishelson, 1977).

Fig. 3 shows changes in the relative abundance of four taxonomical groups (copepods, nematods, foraminifers, polychaetes), well-represented in this community. Initially copepods formed the dominant group at all sites. In PP they exceeded 70% of the total, gradually decreasing both in number and in percentage, while nematods took over, forming 40-80% of the community. The relative abundance of the other groups, polychaeta and foraminifera, did not change appreciably. Foraminifera were 10-20% in all sites, increasing to 40% in 6 month samples of the CR, later decreasing, whereas in the other sites their numbers increased.

Polychaetes were dominant in OT samples, obviously due to an excessively dense cover of the alga Pocokiella variegata , interstices of which provided extra refuge for the worms.

These results generally agree with the results obtained from the detailed analysis (Table 4).

TRANSPLANTING LIVE COMMUNITIES FROM CONTROL SITE TO OTHER SITES.

Apparently owing to the short duration of this experiment (2 months), the colonies transplanted into the polluted sites were more affected by deletion of taxa, rather than by an increase in the abundance of the more adaptable taxa (Table 6). This is indicated also by the decrease in their total numbers. Namatods, the great abundance of which in PP mature colonies was associated with the long-term development of filamentous algae, showed approximately the same numbers as in the control samples (CR, non-transplanted and transplanted). Crustacean groups (copepods, cumaceans, tanaids etc.) decreased their abundance in the less polluted NR, entirely missing from PP samples. The communities trasnsplanted to NR and PP sites showed nearly the same diversity, although NR samples had significantly more taxa. It seems that while in PP the number of species decreased without deeply affecting their eveness, in NR the foraminifera dominated the samples attaining 60-80% of the community, thereby reducing the eveness. Since H* is less sensitive to number of taxa, these contradictory changes are not reflected in the diversity index.

Table 5. Changes in the diversity (H*) on dead corals, planted, for various collections on four sites (For abbreviations cf. Table 2). Number of higher taxa, represented in each site is shown in parentheses.

Site	1 month	3 months	6 months	> 1 year
PP	1.27-1.38(9)	1.51-1.80(9)	1.51-1.68(7)	0.52-1.69(10)
OT	1.35-1.40(9)	2.06-2.13(9)	1.96-2.26(9)	2.11-2.28(13)
NR	1.53-1.55(9)	1.97-2.17(13)	- - -	1.96-2.62(14)
CR	1.97-2.62(12)	2.64-2.95(14)	2.34-2.48(12)	2.84-3.29(19)

Table 6. Effect of transplanting colonies from CR (Control Reef) to CR (control), NR (Nature Reserve) and PP (Power Plant), on their abundance and diversity (H*). As control served non-treated samples, taken from CR.

Taxa	Control		Within CR					trans. to NR					trans. to PP			
Anthozoa	-	4	-	1	1	1	-	-	1	3	1	-	-	-	-	-
Nematoda	36	28	23	74	43	57	46	25	30	28	32	12	35	20	28	54
Polychaeta	103	170	74	142	77	60	121	51	62	58	37	33	12	4	22	14
Amphineura	5	2	-	-	1	-	2	-	-	-	1	-	-	-	-	-
Gastropoda	35	45	29	41	20	12	31	6	3	10	6	3	-	-	-	-
Bivalvia	12	9	6	4	6	3	4	4	3	4	1	3	1	-	1	1
Foraminifera	76	69	196	330	239	174	306	185	138	308	302	221	60	28	44	43
Sipunculida	3	1	1	2	-	-	3	1	3	10	2	3	1	-	-	1
Decapoda	7	4	3	1	2	-	3	1	-	2	2	-	1	-	-	-
Isopoda	9	16	2	-	1	-	1	-	-	-	-	-	-	-	2	-
Tanaidacea	47	74	3	2	2	3	8	2	3	47	1	3	-	-	-	-
Cumacea	8	7	7	6	8	3	6	1	-	1	-	1	-	-	-	-
Ostracoda	19	29	29	37	64	50	56	6	6	10	6	2	-	-	-	-
Amphipoda	32	22	3	12	2	2	18	4	6	2	3	-	-	-	-	-
Copepoda	78	116	22	28	41	59	46	21	25	24	13	8	9	12	6	14
Acarida	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Insecta	14	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetognatha	-	-	-	2	-	-	2	-	-	1	-	-	-	-	-	-
Ophiuroidea	5	-	-	2	-	-	2	-	-	1	-	-	-	-	-	-
Echinoidea	1	3	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Total	490	547	398	684	507	427	654	307	280	509	407	289	119	64	103	127
mean H* +/-SD	@ 3.064 (0.099)		2.372 (0.064)					1.766 (0.379)					1.775 (0.077)			

@ - the mean H* for 30 samples, collected at all seasons is 2.603+/-0.278. All means, except NR and PP, differ significantly (T-test, $p < 0.01$).

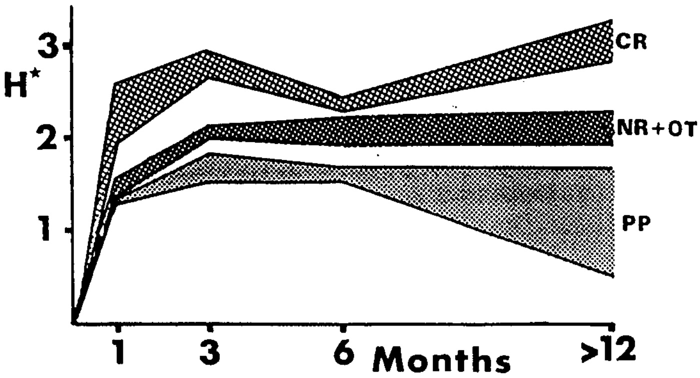

Fig. 2. Temporal changes in the diversity (H*) of planted dead corals in the various sites (For abbreviations cf. Table 2).

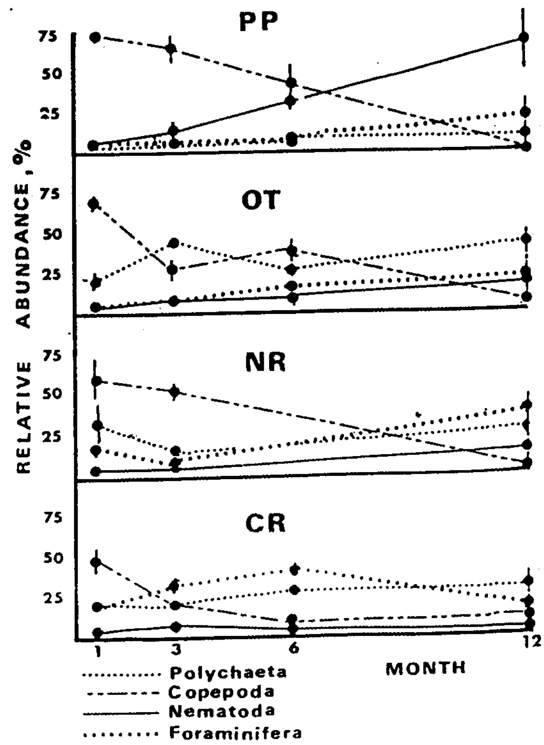

Fig. 3. Temporal changes in the relative abundance of four key groups (polychaetes, copepods, nematods and foraminifera) in planted dead corals (+/- standard deviation). For abbreviations cf. Table 2.

CONCLUSIONS

1. The observed pollution gradient is well-reflected in the diversity of the studied community, which is proposed as an "indicator community".
2. The various diversity indices differ in their depenedence on sample size, species count and the eveness component. Brillouin's index (H) is relatively independent of sample size, and equally correlated with the latter components.
3. The abbreviated index (H*) is a highly applicable tool for pollution monitoring, saving the labourious process of detailed identification of all organisms, without seriously affecting its resolution power.
4. Copepods, polychaetes and nematods are key groups in this community. Copepods appear early in the succession, later succeeded by other groups. Polychaetes are well encouraged by the extra niches supplied by encrusting brown algae, while nematods show a strong affinity to polluted areas. Nematods' abundance seems to be encouraged by the excessive development of filamentous algae.
5. Planting and transplanting experiments showed that while the development of this community takes at least 12 months, the effects of the environmental perturbations were evident after only three months.

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