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Ecology of Coral Reefs in the Gulf of Aqaba (Red Sea) Influenced by Pollution*

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Summary. 1. This paper summarizes observations performed during 1966, 1968, and 1972, on coral reef flats 7 km south of Eliat (Gulf of Aqaba, Red Sea). The aim of this research was to describe the change in numbers of living coral colonies found on the coral tables in connection with pollution occuring in this habitat. A transect technique, developed by Loya and Slobodkin (1971) was used in this research.

2. In each of the three years, 19 ten metre transects were performed in various directions, on the same coral tables.

3. In 1966, 541 living coral colonies were counted in a total of 190 m of transects. At the identical place, this number had decreased to only 195, in 1972. The decrease in corals was found to be accompanied by a prominant increase in algae growth, that expand and develop, thus covering the coral specimens.

4. Especially sensitive to algal development are the branching micropolypal, coral species, that are the representatives of the genera *Acropora*, *Seriatopora*, and *Stylophora*. Of the above three genera counted in 1966, only 10 out of 192 colonies were found intact, in 1972.

5. The high mortality of corals in this locality occured during the years in which an oil terminal plus a mineral and phosphate loading harbour were developed at Eilat.

6. The frequent oil spills, together with the phosphate dust that reaches the sea, seem to be the factors that cause eutrophication in the shallow lagoon waters of the coral region, and thus the development of algae on the coast of corals is stimulated.

Introduction

The scientific literature of the last decade is very rich with evidence concerning the negative influence of pollution on marine ecosystems. In all of the sources that I am familiar with, hardly anything is mentioned about the effects of pollution on coral ecosystems, except for the destruction of corals, which is caused by the crown-of-thorn starfish, the *Acanthaster planci*; a coral predator, whose outbreak might have been caused by pollution.

Investigations performed in these regions from 1960 until 1970, indicated a high coral species diversity (Fishelson, 1968; Loya and

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Slobodkin, 1971; Loya, 1972), even on the very shallow coral tables, which extend along the shore line at 0.20–0.80 m below the main water level.

It should be mentioned that in this region, 1965 was marked as the beginning of the Eilat harbour's very active technological development, which was mainly channelled in two directions: Firstly, an oil terminal has been constructed 1.5 km north of the Nature Coral Reserve, whereby oil tankers have frequently started to visit this region. From the beginning, the oil pumping activities caused oil spills, which occured at least 2–3 times a month. These oil patches, caught by the prevalent N-S currents of the surface water, are moved within 1 or $1^1/_2$ hours, into the coral reef region. Such oil patches are often moved back by sothern winds, after they pass the Nature Coral Reserve, and they are therefore again forced into the investigated area, where the killing of intertidal animal communities, especially those of barnacles and limpets (Fishelson, 1970) was visible right from the beginning.

The second aspect of the technological development concerns the main harbour at Eilat, found approximately 0.7 km north of the oil terminal, that was extensively modernized especially for loading of large amounts of phosphates and other minerals and fertilizers which were mined in Israel, and later destined to Africa, Australia, and the Far East. From storage houses constructed at the harbour, the aggregated phosphates are loaded onto the ships by conveyer belts. This open transport of minerals caused the rise and expansion of dense clouds of minerals, during each loading session. The N-S wind that almost constantly blow here, move these dusts to the south, over the coral regions and shallow waters, where they sink slowly, and are visible in the air, up to a distance of 1.5 to 2.0 km from the harbour. Using the molybdat-acid reaction, the preliminary analysis of total P within the bottom sediments 2.0 m below the water line, demonstrates 15 mg P/1 in the Nature Reserve, as compared to 3 mg P/1 from places 30 km south of the harbour (August, 1972).

Methods

For this ecological investigation, a region situated 7.0 km south of the harbour town of Eilat and declared as a Nature Coral Reserve, was chosen. Using a 10 m long line divided into single meters, transects were performed during each of the years on the same coral tabls, by means of a technique used by Loya and Slobodkin (1971) and Loya (1972). All living colonies of coral, found below such an extended line, were counted. The first results showed that on each linear meter, an average of 2.0 to 2.5 coral species could be counted, and that each 10 m of a transect crossed approximately 10 to 12 coral species, including the hydrocoralinean *Millepora dichotoma* and *M. platyphylla*, which are important reef builders in this area.

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Initial measurements performed in 1966, showed that along a one 10 m transect, an average of more than 30 living coral colonies could be counted. Each year, a total of 19 transects (i.e. 190 m) were recorded in various directions of the reef, and the results obtained, serve as the basis for this comparison.

The central part of the Nature Coral Reserve at Eilat, was first transected in 1966, and then retransected in 1968 and 1972, in the same way.

Results

The results of the three samplings of 1966, 1968, and 1972, are demonstrated in Table 1. Two important points are visible from this table. Firstly, during the initial stage of research—the years between 1966 and 1968—45% of the living coral colonies within the transect, were destroyed. Comparing the density of the living coral colonies transect in 1966 and 1968, it becomes apparent that this degeneration had a dispersed character. In 1966, 51.3% of the coral colonies found in transect, with a density of 30 to 40 specimens per 10 m line, whereas in 1968, only 26.5% of the colonies were found in such a density. This significant decrease is even more pronounced when we compare transects with the lowest density of coral colonies. In 1968, 21.6% of the corals were found in densities less than 10 specimens per transect. Such a low density was not found at all in 1966. Now a question arises whether this dying out of coral colonies involved only some taxonomical groups of corals, or if it is uniformally spread out among most of the coral species found on the investigated tables. The investigation of Fishelson (in press) showed that the bush-like micropolypal branching forms, such as species of the genera *Acropora*, *Stylophora*, and *Seriatopora*, are much more sensitive to severe ecological conditions, such as dessication, than the brain-like macropolypal species, such as those from the genera *Platygyra*, *Favia*, *Favites*, and *Lobophyllia*.

On the investigated table, colonies of bush-like coral species were found including *Acropora variabilis*, *Stylophora pistillata*, and *Seriatopora*

Table 1. Average number (%) of living coral colonies in a 10 m. Transect ($n = 19$ transects) in 1966, 1968, and 1972

	1966	1968	1972
Total living colonies	*511*	*245*	*195*
One to ten colonies	0	26.6%	37.4%
11 to 20 colonies	11.5%	25.4%	62.5%
21 to 30 colonies	25.5%	18.5%	0
31 to 40 colonies	54.3%	27.5%	0
More than 41 colonies	7.5%	0	0

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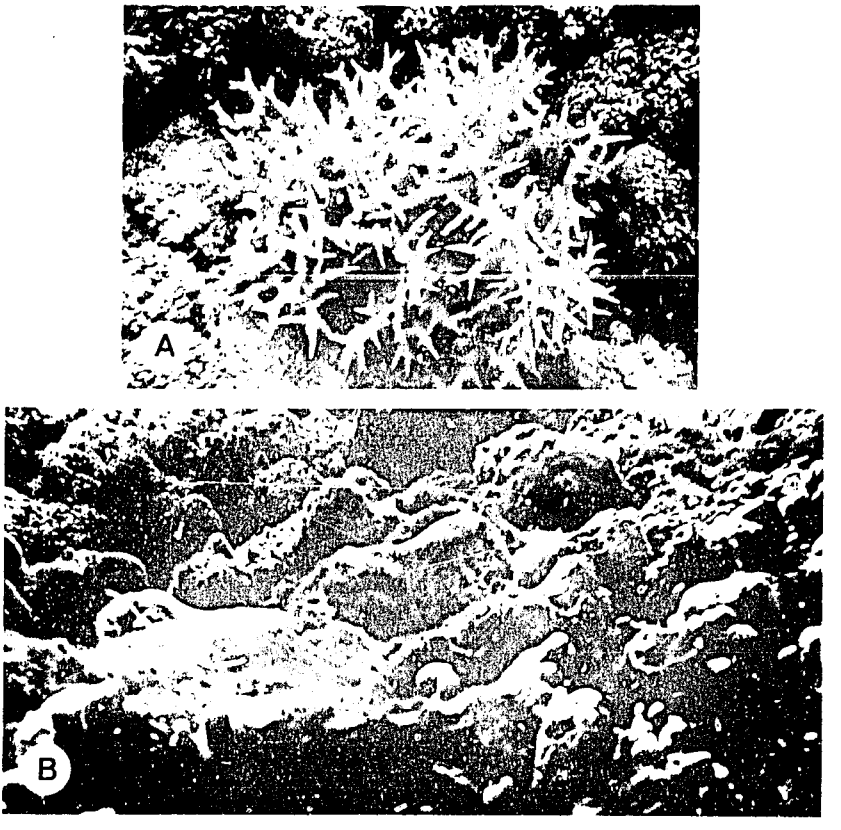

Fig. 4. A A living colony of *Seriatopora angulata*. B Cover of *Dictyota-Dichotrix* algae on the surface of the table reef

angulata (Fig. 4 A) and therefore, it was interesting to see what happened to them during the period of degenerative development. Table 2 summarizes the information available for each of the 10 m transects. It was apparent from the 24 coral species that were found here, those three species constitute almost 36% of all the colonies found within the transects. Those three species also constitute almost $^1/_3$ of the dead colonies: namely 90 specimens from a total of 300. However, within the three bush-like coral species, the mortality rate of the specimens is different. Table 2 demonstrates that in 1966, from 192 bush-forms counted, *Acropora* formed approximately 42%, *Stylophora pistillata* 47%, and *Seriatopora angulata* 11%.

The transects of 1968 demonstrate an entirely different picture! *Seriatopora* almost vanished from the transects, being only 1% of the

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Table 2. The number of *Acropora viariabilis*, *Stylophora pistillata*, and *Seriatopora angulata*, within transects of 1966, 1968 and 1972

Transect no.	1966			1968			1972		
	Total		192	Total 90			Total 10		
	Styl	Acr	Ser	Sty	Acr	Ser	Sty	Acr	Ser
1	3	7	3	3	3	0	0	0	0
2	3	7	1	4	4	0	0	1	0
3	3	2	1	3	0	0	0	1	0
4	3	0	0	5	7	0	0	0	0
5	2	3	1	10	0	1	0	1	0
6	8	4	1	4	0	0	0	0	0
7	4	1	1	4	6	0	0	0	0
8	3	3	1	1	0	0	2	0	0
9	7	6	0	1	0	0	0	0	0
10	5	9	0	5	0	0	1	0	0
11	9	2	0	4	0	0	0	1	0
12	10	5	1	3	0	0	0	0	0
13	2	6	2	4	0	0	0	0	0
14	9	2	1	4	0	0	0	0	0
15	2	9	3	0	0	0	0	1	0
16	9	5	0	1	0	0	0	1	0
17	2	5	2	4	0	0	0	0	0
18	2	2	2	2	2	0	0	1	0
19	5	4	0	4	1	0	0	0	0
Total	91	81	20	66	23	1	3	7	0

total: *Acropora* constitutes only 25.5%, while *Stylophora pistillata* is now much more dominating, forming 73.7% of the sample.

This species of *Stylophora* was found to be one of the most euryeucous species of scleractinians in the northern part of the Red Sea. The colonies of this species form extensive growths in the shallow and sediment rich waters of the Gulf of Suez, and they even grow attached to the roots of the mangrov *Avicennia marina* (Fishelson, 1970).

Before comparing the findings of the most recent investigation in 1972, with those mentioned above, it should be emphasized that during the middle of 1970, an extremely low water level developed in the northern part of the Gulf of Aqaba, thus exposing and partly dessicating large numbers of coral colonies occuring on the coral tables. The investigation that was started in those days and continued until Spring 1972 (Fishelson, in press), supported the idea that a great number of those denuded colonies would recover, due to their ability to regenerate. It could also

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be predicted that after this unusual low water level will subside, new coral colonies will develop on the table from the larvae produced by intact specimens found in slighly deeper waters. Such development was observed on various reefs of the Gulf. Unfortunately, from January 1971 until March 1972, 28 large and small oil spills occured in this region, and consequently, the area that once flourished with a diverse coral community, is presently brown-gray, covered by algae and tiny soft sediment (Fig. 1 B). Transects performed on August 20 to 21, 1972, on the same coral tables as in previous years, emphasized the drastic change that occured here during the last years. Out of 190 m transects, 61 meters were found "empty", without any living corals, and only covered by algae. Along those transects, 195 coral colonies were counted that were actually only 36% of the stock observed in 1966. Of those 195 colonies, only 109 were scleractinians, while the others were soft alcyonarian corals such as: *Sinularia graye*, *Lobophytum pauciflorum*, *Alcyonium f. fulvum*, *Lithophytum arboreum*, as well as the hydrocoralinean *Millepora dichotoma*. It is important to note that *M. dichotoma* has not "suffered" too much from the severe conditions of the environment. In the transect of 1966, 55 colonies of *Millepora* were counted, while 50 were found in the 1972 transect.

Among the bush-like sceeractinians, forms like *Seriatopora angulata* vanished; *Acropora variabilis* was found to be represented only by seven colonies (81 in 1966), and *Stylophora pistillata*, by three colonies, that are a remnant of the 91 found in 1966. Table 3 summarizes the density of the coral specimens per 10 m transects in each of the years 1966, 1968, and 1972. It is obvious that not only the bush-like forms were destroyed. There is a great decrease in all the population of corals, and today, after six years that the studies have been initiated, only 35% of theirs

Table 3. Density of coral colonies per nineteen 10 m transects during 1966, 1968, and 1972

Years	No. of transects with colonies			
	0-1	11-20	21-30	31-40
1966	0	4	6	9
1968	5	7	5	2
1972	7	12	0	0

Fig. 2. A Growths of the algae *Hydroclathrus clathratus* on and among living coral colonies (in the center *Platygyra lamellina*). B *Turbinaria elatensis* on the coral reef table

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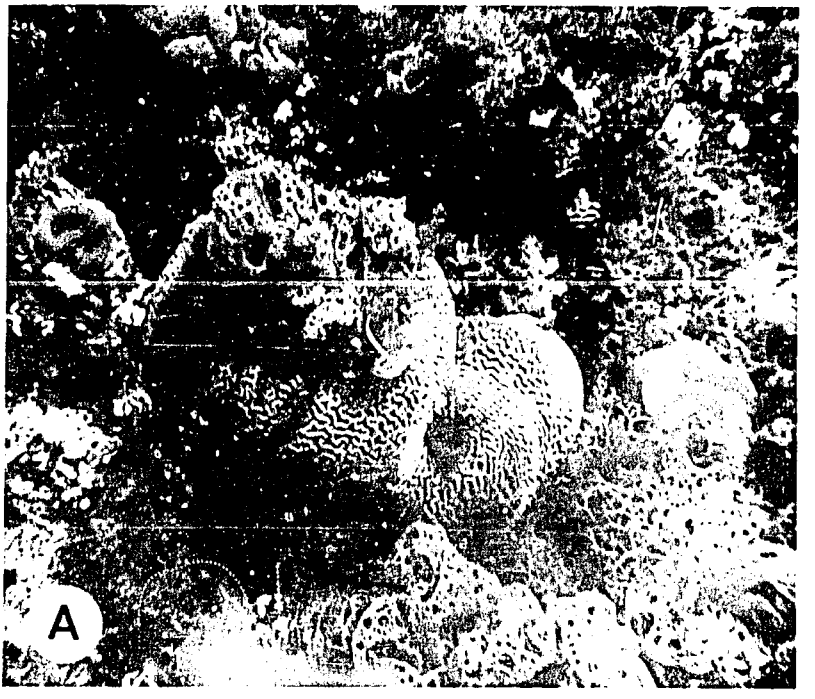

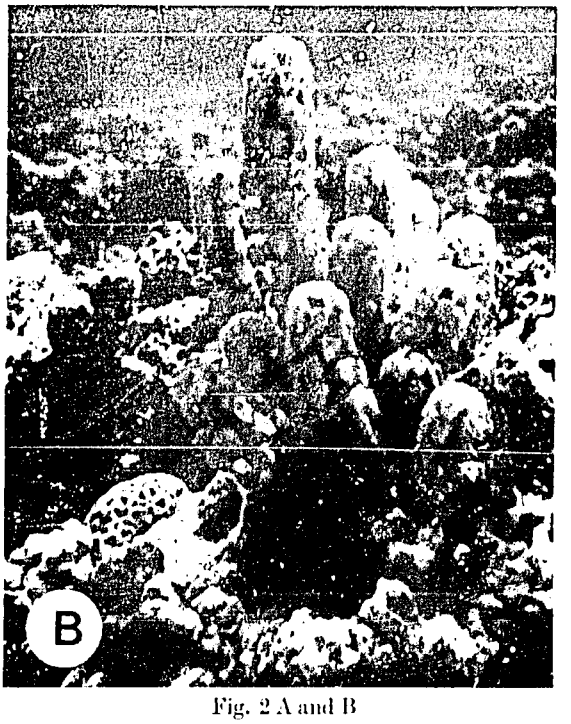

Fig. 2 A and B

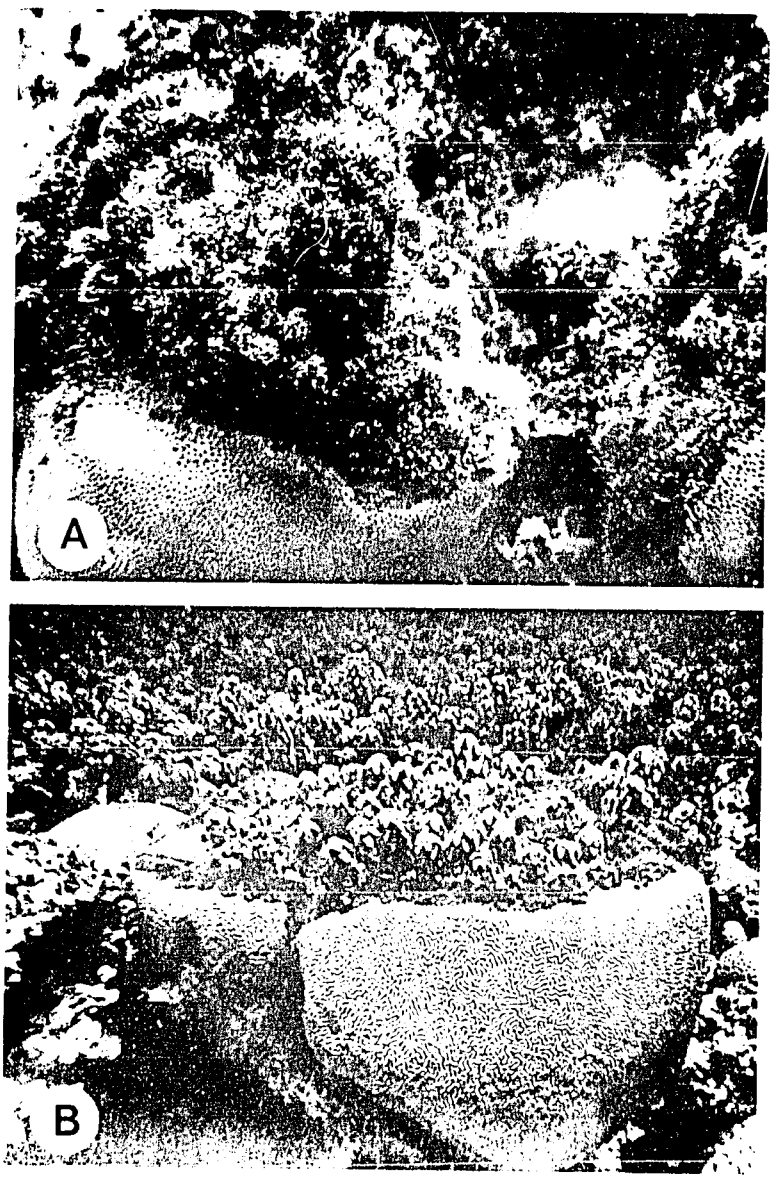

Fig. 3. A Damaged parts of coral *Porites lutea* covered by *Ectocarpus* sp., *Dictotrix* sp., and other algae. B Growths of *Turbinaria*-algae dominating the coral reef table

standing crop remained more or less intact on the table. The spaces between the coral colonies, as well as the surfaces of the dead corals, are covered by algae.

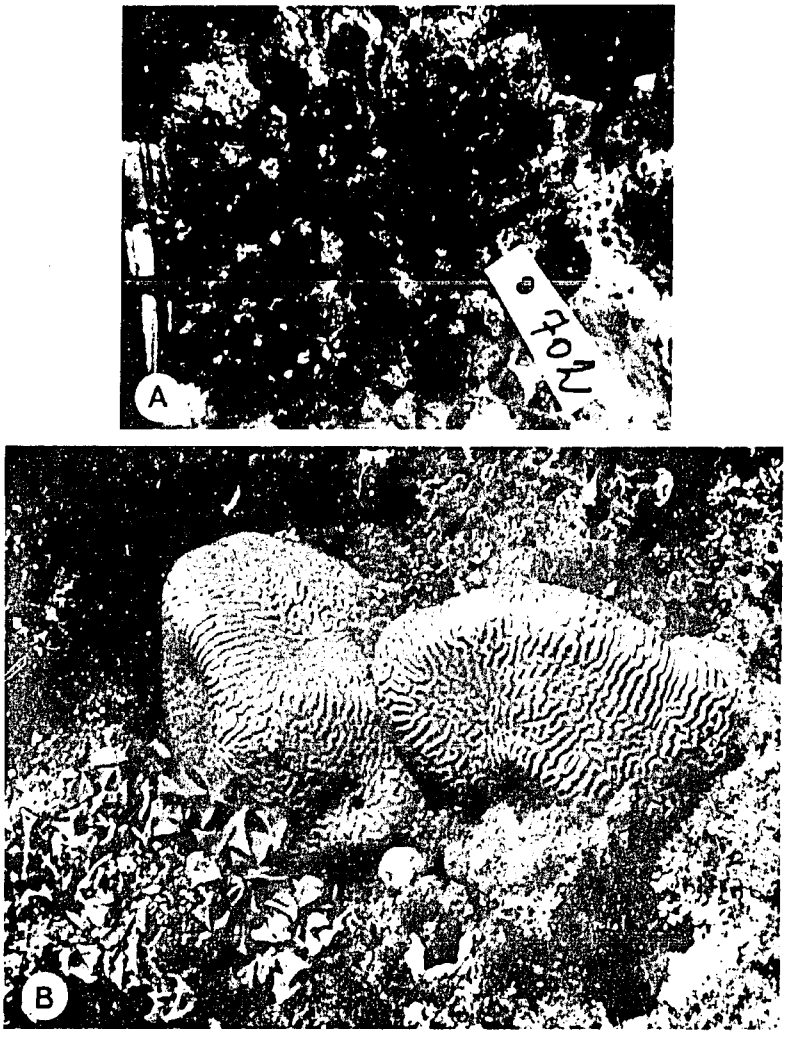

Fig. 4. A An *Acropora*-colony marked on January 1972, was found dead and covered by algae on August 1972. B Two living colonies of *Platygyra lamellina* on the table reef, surrounded by growths of various algae

This vegetation that was observed on the coral tables, always showed some pattern of seasonal fluctuation and succession, as it has in the past. As I noted in the initial stages of my research, at Eilat (1953–1963), their development usually started whith the winter drop in water temperature to 20–21° C in November and December, and extends until the rise in temperature begins in April and May, at about 24–25° C.

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During those months, the first algae to develop are those that form low covers on the bare, rocky surfaces. Dominating among them are the blue-green *Dichotrix* spp. mixed with the species of the brown algae, *Sphacelaria* (*S. tribuloides*) the red *Herposiphonia tanella*, *Jania rubens*, and *Dictyota dichotoma*. With the onset of winter, the development of large algae started with *Enteromorpha Hopkirki*, *Padina pavonia*, *Cystoseira myrica*, and some species of the genus *Sargassum*. The development of dense and thick growths of *Hydroclathrus clathratus* starts in March (Fig. 2 A). Towards April and May, the reef flats were usually dominated by *Turbinaria elatensis* (Fig. 2 B). With the onset of high water temperature in August and September (26–28° C in the lagoon) as well as the development of nip tides (Fishelson, in press), the large algae growing on the coral flats occassionally became exposed, covered by growths of filamentous algae, and killed. By this time, the *Dictyota dichotoma*-*Dichotrix penicillata* algal cover became 2 to 3 cm thick, covering and killing everything below them. Those alga also became traps for sediments that contribute to the continuity of this cover. In the past, this development of algae, their detachment from the substrate, and the reexposition of the bare, rocky surfaces on the coral platform, normally marked the decline of the algal growth. Such substrates provided localities for the re-establishment of various animal species, including corals.

Today, within the area investigated, such a denudation from algae is not observed. All the rocky surfaces are always covered by carpet-like growths of algae species, especially from the genera *Dichotrix*, *Ectocarpus*, *Sphacelaria* (Fig. 3 A) as well as by the leaf-like *Pocockiella variegata* and *Turbinaria* (Fig. 3 B). No place is left for the settlement and development of new coral colonies; they were not observed in the investigated region. 26 colonies that were marked during the super-low tide of September 1970, and that were observed regenerating almost fully during 1971, were found dead and entirely covered by algae, in August 1972 (Fig. 4 A). On similar coral tables, situated some 30 km south of the study area, and visited during the same time, the coral population was found to flourish and only a few signs of algae development were observed with their described pattern of succession.

Discussion

The development of dense covers of marine algae in the sea, over places once populated by living coral colonies with their associated fauna, seems to be a typical case of eutrophication, which is so often described for lakes and rivers. In this case, overfertilization was caused mainly by oil and minerals. As mentioned by several authors (Riley and Chester,

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1971; Stumm and Stumm-Zellinger, 1972), phosphorus seems to be the main element limiting algae development in the sea. Usually, an anual cycle of phosphorus concentration in sea water is observed, in which seasons with a high phosphorus content interchange with seasons of high algae development, and consequently, by a strong decrease of P. As mentioned by several authors, such variations are very small in tropical waters, and it is possible that the seasonality of algae development at Eilat, was regulated not only by the changes in temperature, as mentioned, but also by those small changes of P. With the addition of huge amounts of phosphates as other inorganic materials, as well as oil from the oil terminal, this regular system became destroyed and the algae started to dominate the environment all year long. As demonstrated by Nichols (1967) some of these algae are able to accumulate and solubilize insoluble phosphates, whereby entirely new parameters are introduced into the coral environment, causing expansion of the algae on the coast of corals. This development destroyed existing coral colonies, while the occupation of space by algae, and the accumulation of sediments between them, prevent the renovation by settlement and development of new coral colonies (Fig. 4 B). The eutrophication and development of thick algae growth seems to also prevent the normal development of food chains occuring on a reef surface. These food chains, with some of their lines, also supply the carnivorous corals.

An additional phenomenon that was observed during the last years, is the accumulation of detached carpets of algae within the lagoon, behind the coral reefs. It seems that during the low waters at the end of the summer, from July until September, also accompanied by high temperatures, a deficit of oxygen developes below the dense algal covers on the coral surfaces. This causes mortality of those inner parts of algae, and detachment from the substrate. Trapped by the surf movements, this vegetation is accumulated within the lagoon where the bulk of the algae are only partly biodegraded. During low waters and high temperatures of this time, there seems to be a lack of oxygen in the lagoon. Parts of the algae decayed, forming thick organic deposits on the soft, calcareous substrate. Thus it seems that this "natural pollution" may also contribute to the changes observed within the framework of the coral reef, especially within the invertabrate communities of the shallow subtidal. Of course, this biodegredation and decaying of algae, returns some part of the phosphorus to the environment, and in this way, supports renovation of algal development. During the same time, huge oil spills destroy large parts of the tropical intertidal communities represented by giant barnacles, oysters, periwinkles, serpent-stars and limpets; species that produce high amounts of planktonic larvae that can serve as food to organisms on the reef table. As a result of the above

process, starvation may develop among the carnivorous corals, and thereby accelerating their degeneration.

The fact that such damaged coral ecosystems could re-establish and regenerate, was well documented by Stephenson and Wells (1956), by Stephenson *et al.* (1958) and also observed by Fishelson (in press). This can occur by regeneration by partly damaged colonies, and by the development of new colonies from larvae that invade and settle in the area. One of the basic conditions for such a development is the prevention of the synergetic action of pollutants and fertilizers over this region. Especially important is the prevention of "chronic" (although small) pollutions, like those that frequently occur at Eilat. As emphasized by Foodgate (1971), such chronic injections of pollutants could be more dangerous to an ecosystem than a single disaster. The use of chemical oil dispensers in such a system will be more harmful than beneficial (see also Ehrlich and Ehrlich, 1972). Continuous interference with the ecosystem will lead to a reduction of complexity, leaving only those that are flourishing in the overfertilized regions (Ryther, 1954; Odum, 1972). Furthermore, this will lead to deep alterations of the ecosystem and habitat on the coral reefs, and at the same time, to the expansion of algae covers. It therefore seems that if such interference will stop on time, before the entire coral system is destroyed, recovery could begin. Since it is well known that algae are able to store and reuse large amounts of phosphorus, the possibility exists that even if the impact of phosphate from other sources will stop in the near future, the bulk of it trapped within the vegetation will continue to stimulate the algal cover, from time to time. The duration of the possible re-establishment and formation of the initial intertidal and coral community is not known. Castenholz (1967), mentioned that the re-establishment of a growth of *Mytilus californicus* over a rocky surface took more than 8 years, and this species is a fast growing animal, as compared to the coral species.

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