1 The Coral Reefs of Eilat – Past, Present and Future: Three Decades of Coral Community Structure Studies

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1.1 Introduction

Here, I shall present a brief review of ca. 35 years of our studies on changes in the coral species diversity and community structure at Eilat, Red Sea, at several scales in space and time. In the following, I shall: (1) summarize the geographical setting and the geological, physical and biological characteristics of the Gulf of Eilat/Aqaba, then point out the uniqueness of the coral reefs of Eilat, which are situated at the most northerly boundary of coral reef distribution, yet exhibit extraordinarily high within-habitat coral species diversity; (2) present the changes that took place in coral species diversity and community structure on the reef flats in the northern Gulf of Aqaba/Eilat (during the 1969–1980), due to natural disturbances (extreme midday low tides) and man-made perturbations (chronic oil spills); (3) discuss possible mechanisms that generate and maintain the high within-habitat coral diversity typifying pristine reefs in the Gulf of Eilat/Aqaba; (4) discuss the opposite mechanisms that caused a dramatic decrease in coral abundance and living cover at the Eilat Coral Nature Reserve (ECNR) during 1986–2000. I will also point out two major anthropogenic disturbances: first, eutrophication caused by Eilat's sewage discharge to the sea until 1995; and second, further eutrophication originating from intensive net pen mariculture off the northern coast of Eilat, which exponentially expanded activity from 1994–1995 to present times. The grave implications for the coral reefs of Eilat caused by this chronic eutrophication will be presented. Finally, (5) I conclude with a warning that, at present, the coral reefs of Eilat are severely damaged and subsist in a critical state. If eutrophication of the northern Gulf is not halted immediately, the final collapse and total destruction of the unique coral reefs of Eilat are certain. In their present fragile state, the only chance for the restoration of the Eilat reefs is extreme and instant protection measures against all man-made disturbances.

1.1.1 The Gulf of Eilat/Aqaba: Geographical Setting, Geological, Physical and Biological Characteristics

The Red Sea is a long body of water separating northeastern Africa from the Arabian Peninsula. Nearly 2000 km of water connects the south with the In-

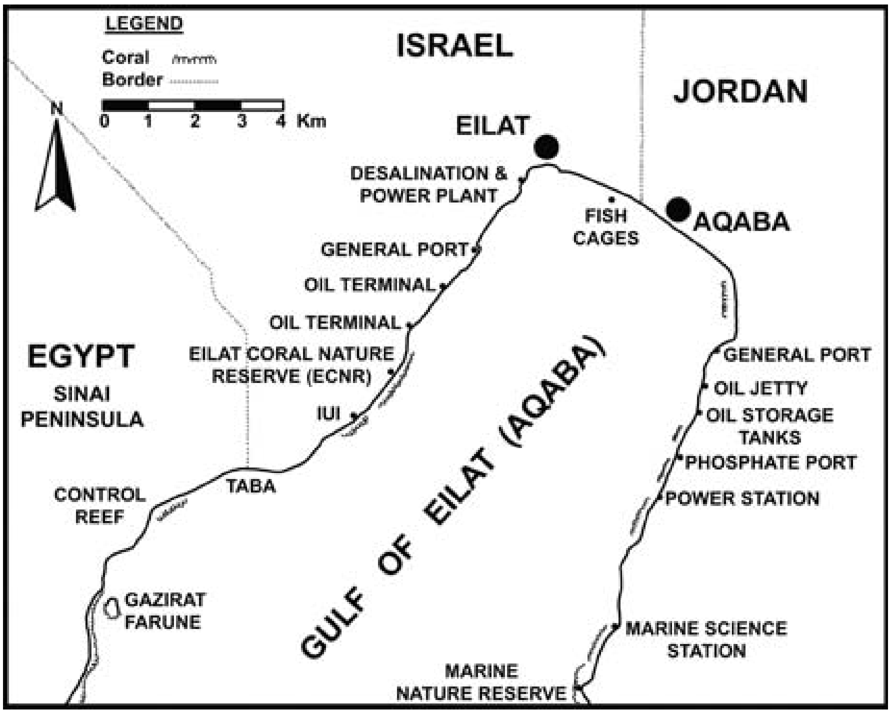
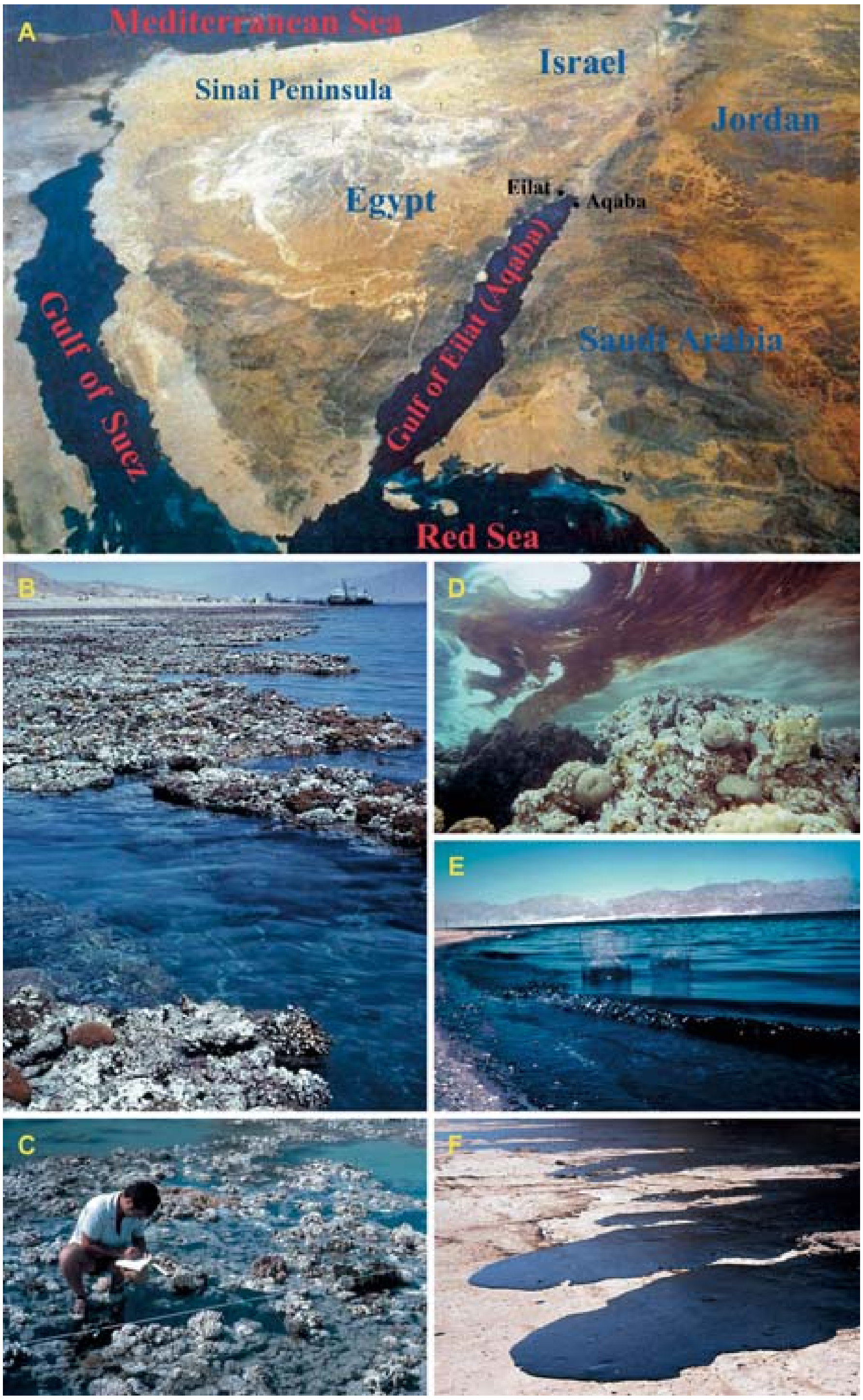


Fig. 1.1. General map of the northern Gulf of Eilat/Aqaba indicating the work sites: Eilat Coral Nature Reserve (ECNR), the Control Reef, the Interuniversity Institute (IUI) and the mariculture fish cages

dian Ocean and almost joins the Mediterranean Sea at the north of the Gulf of Suez. When Ferdinand de Lesseps completed the Suez Canal in 1869, the connection became direct. The Red Sea is connected to the Indian Ocean by the relatively shallow Bab el Mandeb Straits (270-m depth). Although it is relatively young, the Red Sea evolved to harbor a number of unique ecosystems. Its pelagic ecosystem is characterized by a photic zone (0–200 m depth) and an aphotic zone (200–2500 m depth).

The Gulf of Eilat/Aqaba (Figs. 1.1, 1.2A) is part of a major geological formation, the 1000-km-long Dead Sea rift, which is a portion of the 6000-km Syrian African rift that extends from Mozambique to Turkey. The rift was formed by the

Fig. 1.2. A Satellite view of the geographical setting. **B, C** Unpredictable extreme low tide at the northern Gulf of Eilat/Aqaba exposed corals during midday (September 1970) on the reef flats for 4 days (3–4 h every day) to high irradiance and air temperature of ca. 40 °C. The consequences were massive mortality of ca. 90% of the coral populations on the reef flats of the northern Gulf of Eilat/Aqaba. The coral community structure at the oil-polluted ECNR and a clean control reef (CR) 5 km further south were studied in detail by means of line transects, before, during and after the catastrophic low tide (see Fig. 1.4 for details). **D–F** During 1969–1980 an average of two to three oil spills per month covered the ECNR with crude oil ▶

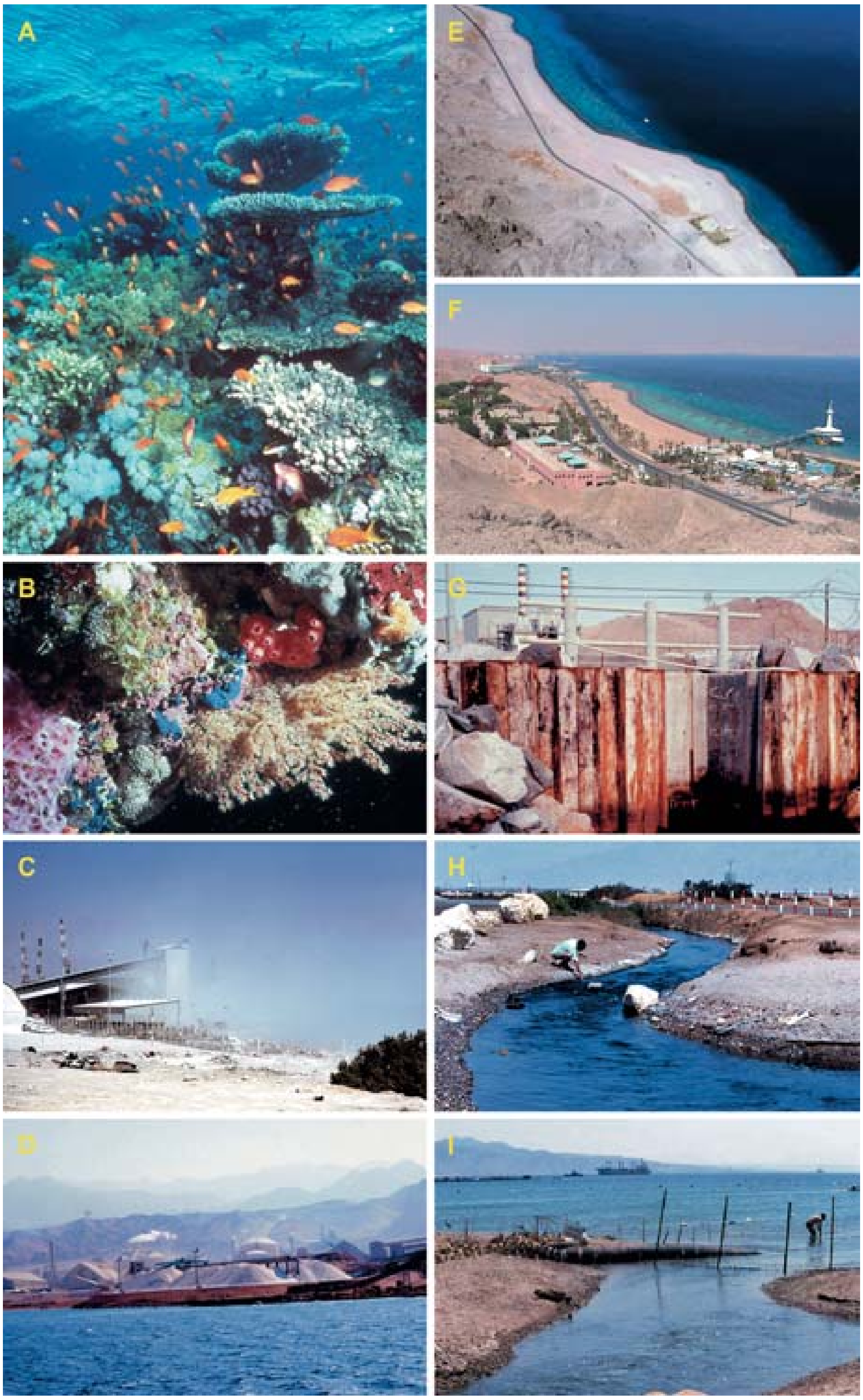

A
Mediterranean Sea
Sinai Peninsula
Israel
Jordan
Egypt
Eilat
Aqaba
Gulf of Suez
Gulf of Eilat (Aqaba)
Saudi Arabia
Red Sea
B
C
D
E
F

opposing movement of the African and Arabian continents. The Gulf is the more eastern of the two northern horns of the Red Sea, which are separated by the Sinai Peninsula. It is surrounded by desert; hence, water inflow from land-based sources is negligible. The Gulf is ca. 180 km long, very steep-sided and deep (although it is only 5–26 km wide), reaching a maximum depth of over 1800 m near the eastern coast. The Gulf's photic zone is stratified, nutrient-depleted and has exceptionally crystal-clear surface waters (no river runoffs).

The climate in the region is arid with an average net evaporation of 1 m^3/day. Predominant northern winds enhance the evaporation. As a result, the Gulf's waters are extremely saline, ranging between 40 and 41.5 ‰. Temperature ranges from 20.5 (winter, northern Gulf) to 27.3 °C (summer, southern Gulf). Tides in the Gulf are minimal with a maximal range in the order of 1 m. Extreme midday low tides, which expose entire reef flats to the air are quite rare, but when they do occur, they may cause complete desiccation of the coral populations (Fig. 1.2B, C; see also Sect. 1.2.1).The general circulation pattern consists of an inflow of less saline Red Sea water in the upper layers through the straits of Tiran and an outflow of bottom heavier, more saline, Gulf water near sill depth. The coral reefs along the Gulf are of the fringing type and among the most spectacular and diverse in the world (Fig. 1.3A, B). Both the coral reefs and the mangroves are among the world's northern-most such ecosystems. The semi-isolation of the Red Sea from the main body of the Indian Ocean, as well as the semi-enclosed nature of the Gulf and the rather extreme oceanographic conditions resulted in the evolution of a high proportion of endemic species typical of the Red Sea flora and fauna (Sheppard et al. 1992).

Coral reef ecosystems are the most spectacular and diverse marine ecosystems. They form reservoirs of the highest marine biological diversity, including genetic resources and bioactive compounds. Unfortunately, coral reefs are also among the most heavily degraded marine ecosystems. Over the last two decades, coral reef communities have been experiencing increasingly stressful conditions due to a combination of natural and anthropogenic detrimental factors (Wilkinson 2000).

Fig. 1.3. The coral reefs of Eilat: past. **A, B** The ECNR 1969 (see Fig. 1.1). High within habitat diversity typified the ECNR in the past. **C–F** Urban development (Eilat) and pollution sources in the northern Gulf during the last three decades. **C** Phosphate pollution caused by the poor loading procedures used in Eilat port brought about eutrophication of the reef during the 1970s and 1980s. During the last decade, environmental law enforcement resulted in improved loading technology decreasing this pollution source almost to nil. **D** The Aqaba phosphate port has been another eutrophication source in the Gulf, but in the last decade has decreased substantially due to improved loading procedures. **E** Aerial view of the surroundings of the Inter University Institute at Eilat (IUI) in 1970. **F** Aerial view of the same surroundings in 2000 demonstrating the fast urban development of the area. **G** Discharge outlet of the desalination power plant of Eilat (operated during the early 70's). **H, I** Eilat's municipal sewage was flowing into the northern Gulf of Eilat until 1995. Since then, this source of nutrient pollution was stopped after a modern sewage treatment facility was built 6 km north of the city ▶


A
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Scleractinian corals are the most important hermatypic (reef-building) organisms in the Gulf of Eilat (Loya and Slobodkin 1971). Hermatypic corals play a key role in forming the structure of coral reefs and in providing substrate and shelter for a wide variety of organisms. Acute damage to the corals may result in the collapse of the complex community of organisms that live in close association with them. Since the Gulf is a semi-enclosed basin, and the prevailing winds and currents are predominantly from the north, the Gulf is potentially vulnerable to pollution, particularly at its northern tip. The two cities located there, Eilat, in Israel, and Aqaba, in Jordan (Fig. 1.1), are both industrial and tourist centers to their respective countries. In the last three decades, the area has gone through rapid urban development (Loya 1995), increasing anthropogenic pressures on the reefs (Figs. 1.2D–F, 1.3C–I). Hence, the potential threat of pollution is very real, including possible spills from maritime activities and oil transport in the Gulf. In addition, chemical pollutants that may pollute the Gulf during transport and loading of phosphates (Fig. 1.3C, D), potash bromides and other cargoes, in both the commercial ports of Eilat and Aqaba (Loya 1995). Other major sources of human stresses to the reefs in the most northern section of the Gulf include eutrophication from Eilat's municipal wastewater (Fig. 1.3H, I), discharged in the past into the sea (stopped in 1995, see Sect. 1.4.), unregulated mariculture effluents in Eilat, which at present are the major source of coastal eutrophication of the northern Gulf of Aqaba/Eilat (Sect. 1.4.), as well as occasional ballast and bilge water spilled from various boat activities, occasional discharges of fuel, crude oil and detergents. In addition, due to tourism, physical damage to corals occurs, mainly by boat anchors, scuba divers and snorkelers.

1.1.2
The Coral Reefs of Eilat

Although situated in the most northern boundaries of coral reefs distribution, the pristine reefs of the northern Gulf of Aqaba (ca. 30°N), along the shorelines of the Sinai Peninsula (Fig. 1.1), exhibit extraordinary high within-habitat coral species diversity (sensu MacArthur 1972), among the highest in the world (Fig. 1.3A, B). Unfortunately, those reefs that have been chronically perturbed by anthropogenic activities, such as the coral reefs of Eilat, have severely deteriorated in the last three decades, especially in the last decade (Loya 1976a, 1990 and this chapter).

In 1968–1969, the community structure of the coral reefs in the northern Gulf of Eilat/Aqaba was studied in detail by means of 10-m-long line transects at the Eilat Coral Nature Reserve (ECNR, Loya 1972, 1975) and a site referred to as 'the control reef' (Figs. 1.1, 1.2C), 5 km further south. Both reefs were pristine at that time. The exact locations of the transects on both reefs were marked by stainless steel pegs, which enabled repeated long-term monitoring of the same transects in the following years (Loya et al. 1999). Any coral species that overlapped the line was recorded, and its projected length on the line was measured to the nearest centimeter. The line transects were surveyed from the reef flat to

30-m depth. The data provide estimates of the number of coral species, number of colonies, percentage of total living coverage, and diversity of corals. This large data set served as a baseline for continued long-term monitoring of the scleractinian coral populations of the northern Gulf until today.

In 1969, the average number of species per transect obtained at the two sites in the northern Gulf of Eilat/Aqaba (see below) was 13.5±3.8 (ECNR) and 15.7±3.4 (control reef, CR) species per 10-m transect (Loya 1972, 1976a). This diversity is very high for corals measured on reef flats (within-habitat diversity) in view of the low total number of species known from Eilat (ca. 100, Loya and Slobodkin 1971), and the fact that the coral reefs of Eilat are among the most northern reefs in the world. By contrast, about 360 coral species are known in the Great Barrier Reef (GBR, Veron 1986). Yet, within-habitat diversity on reef flats is higher in Eilat than on either the Australian inshore fringing reefs or the GBR proper.

A similar methodology suggested by Loya (1972) was used to study coral diversity on the GBR reef flats, with the only difference being the length of the transect lines (30 m). On Lizard Island, the average number of coral species per transect was 11.1±4.8 (data computed from Pichon and Morrissey 1981); on Heron Island, 9.8±4.1 (n=12 transects; Pichon, Weizman-Best and Loya, unpubl. data); and on an inshore reef at Magnetic Island, 4.8±3.7 (n=9 transects; Pichon, Loya and Bull, unpubl. data). Clearly, if the GBR data were transformed into 10-m transects, as performed in Eilat, the average number of species per transect would have decreased. Since information on community structure and species diversity of the GBR corals is limited and most probably regionally different (2500 km of reefs), any generalization on local patterns of diversity in the GBR would be premature.

Two major environmental disturbances dictated the changes in the coral community structure at Eilat for years to come. Firstly, an unexpected and extremely low tide that occurred in the northern part of the Gulf of Eilat/Aqaba in September 1970 killed almost all the corals on the reef flats (Fig. 1.2B, C; see Sect. 1.2.1), and secondly, the harmful effect of chronic oil spills that occurred during 1970–1980 in the vicinity of the ECNR to the coral populations (Fig. 1.2D–F, see Sect. 1.2.2).

1.2 Changes in Coral Community Structure at Eilat Due to Natural Perturbations and Human Disturbances During 1969–1982

1.2.1 Natural Catastrophes: Extreme Midday Low Tides

The Eilat Coral Nature Reserve (ECNR) is located 3 km south of the general port of Eilat, approximately 1 km south of two major oil terminals (Fig. 1.1). Oil tankers using the port of Eilat after 1970 caused two or three major oil spills every month, during which the ECNR was completely blackened by oil (Fig. 1.2D–F). This chronic oil pollution continued until ca.1979–1980. Since then, oil spills at

Eilat have become rare. A major reason for this remarkable improvement is the drastic decrease in the number of oil tankers arriving at Eilat (political reasons), in addition to the establishment of a Pollution Prevention Control Station by the Israeli Ministry of the Environment and the stiff fines imposed on the shipping companies.

Since the wind direction along the Gulf of Aqaba/Eilat is predominantly from the north or northeast, oil spilled around the terminals is carried by surface currents towards the ECNR. It does not, however, reach the 'control reef', a pristine coral reef located 5 km further south. The control reef (CR) has been termed so, since it has been found to be free of oil pollution (Loya 1975) and has served as a comparatively pristine site for studies on changes in the community structure of corals in the polluted ECNR.

An unexpected and extremely low tide occurred in the northern part of the Gulf from 15–20 September 1970 (Fig. 1.2B, C; Loya 1972). The water level fell approximately 20–25 cm below the reef flats. As a result, they were completely exposed to air and sun for 3–4 h during the hottest time of the day. The air temperature ranged from a minimum of 34 °C on 16 September to a maximum of 38.4 °C on 18 September. The immediate consequence of the low tide was the death of approximately 80–85% of the hermatypic corals along the northern part of the Gulf (Loya 1975, 1976a). The high temperatures and desiccation were probably the direct causes of the rapid coral mortality. The community structure and species diversity of hermatypic corals had been studied in several reef locations along the northern Gulf before the low tide (Loya 1972). Hence, the incident provided a unique opportunity to study recruitment patterns in both a chronically polluted reef (ECNR) and a clean control reef (CR).

During the low tide, the corals below the lowest water level were unharmed. Since the ECNR and the CR were similar in community structure (Loya 1975), it was reasonable to assume that a similar stock of coral propagules existed in both. Theoretically, providing human activities had not had a harmful effect on the coral communities at the ECNR, a similar recruitment rate of corals could have been expected in both localities. The parameters compared were the average number of coral species, colonies, living coverage, and diversity (Shannon and Weaver's H'n index 1948) per transect, in both reefs, during 1969 to 1986. In 1969, no significant difference was found between the coral community structure of the ECNR and that of the CR, when all four statistics were compared (Loya 1972; Fig. 1.4). A detailed account of changes in the community structure and species diversity of corals in 1969 and 1973 is given in Loya (1975, 1976a). Although both reefs suffered similar mass mortality of corals during the low tide (85% at the ECNR and 81% at the CR), a marked difference was observed in recovery 3 years later. The extent of recruitment was 23-fold greater at the CR. No significant difference was found in coral community regeneration (15% at the ECNR and 19.2% at the CR). Three years after the low tide, the number of species, number of colonies, living coverage and H'n remained very low on the reef flat of the ECNR, while the reef flat of the CR exhibited rapid recruitment and recovery (Fig. 1.4). The significantly higher coral cover at the CR was mainly due to

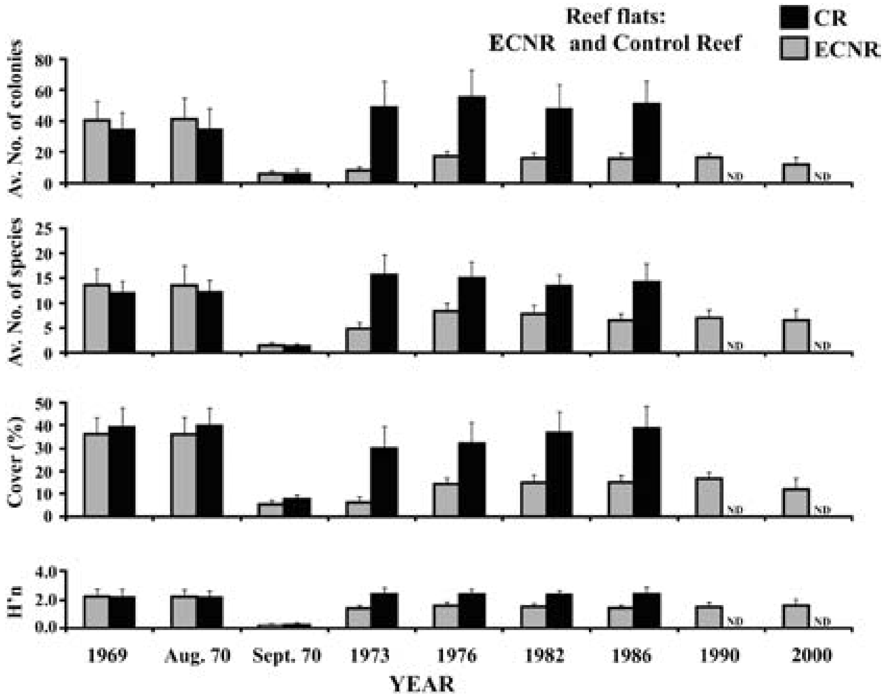


Fig. 1.4. The scleractinian coral community structure at the chronically polluted reef flat of the ECNR (Fig. 1.1) and a pristine control reef (CR), 5 km further south, were studied in detail by means of 10-m line transects in 1969 (prior to the unpredictable catastrophic low tide), during the low tide in 1970 and 3 years later in 1973 (see Loya 1976a for details). The same transects were resurveyed periodically until 1986 in both localities (in ECNR until 2000) for coral living cover, number of colonies and number of species, providing a long-term database of changes that took place in the coral community structure. No further monitoring was possible in the CR beyond1986 because of regional political reasons. (n=12 to 21 10-m transects; H'n = Shannon and Weaver's [1948] index of diversity. *ND* No data, *bars* represent ± SD

mass recruitment of the most abundant species (40% more colonies per transect in 1973 compared to 1969), in addition to the full regeneration of massive colonies that had suffered partial mortality during the low tide (Loya 1976a). Further monitoring throughout the years, in both sites, indicated that in 1976, 1982 and 1986 all monitored factors were significantly higher at the pristine CR compared to the ECNR (Loya 1990; Loya et al. 1999; Fig. 1.4).Unfortunately, further monitoring at the CR was not possible beyond 1986, due to regional political reasons. However, monitoring of the ECNR reef flat and deeper reef at 4 m depth ("Japanese Gardens") continues until today (see Sect. 1.4.1).

1.2.2 Coral Community Stability

Interpretation of stability in ecological systems has long been a matter of controversy among researchers (see selected literature: Margalef 1969; Woodwell and Smith 1969; Pimm 1991; Knowlton 1992; Holling 1996, 2001; Lewin 2000; Nystrom et al. 2000; Ives et al. 2003 and others). In this paper, I adopt, as a measure of community stability, Margalef's (1969) definition, i.e., the likelihood of a community to bounce back after external disturbance and return to its former state. Hence, there are marked differences between the ECNR and the CR. The ECNR has still not regained its former community structure and species diversity almost two decades after the low tide (Loya 1990), and unfortunately continues to remain poor in coral diversity and living cover to this day (Loya et al. 1999, this chapter). By contrast, the pristine CR showed remarkable resilience (i.e., capacity for self-repair) and only 3 years after severe perturbation, (the catastrophic low tide), it had returned to its former configuration. A significantly high correlation was found between the percentage contribution of the most common coral species to the total number of colonies and to the total living cover in the CR, before the low tide and 3 years later. Nonsignificant correlations were obtained when the same parameters were tested at the ECNR (see Loya 1976a for details). I concluded (Loya 1976a) that one of the differences between the effects of human impacts (chronic oil spills) and natural disturbances (extreme low tides) on coral reefs is the prolonged failure of a human-perturbed reef to return to its former state, whereas restoration of reef areas denuded by natural disturbances is a function of a relatively short time period. There have been, unfortunately, insufficient long-term quantitative coral reef community studies to test this hypothesis (for further discussion, see Johannes 1975; Loya 1976a; Brown and Howard 1985; Bythell et al. 1993; Dollar and Tribble 1993; Hughes 1994; Connell et al. 1997; Guzman and Cortes 2001). al. 2001).

1.2.3 Oil-Pollution Effects on Eilat Corals

Up to 1975 there was no conclusive evidence that oil floating above the reef damages stony corals (Johannes 1975). At that time, most of the studies of the effects of oil pollution on corals were either short-term incidental observations or laboratory experiments that did not reflect the effects on corals in nature. Our long-term quantitative studies in situ and in the laboratory have established the vulnerability and sensitivity of hermatypic corals to crude oil and oil components (Loya 1975, 1976a; Rinkevich and Loya 1977, 1979a; Loya and Rinkevich 1979, 1980).

As discussed before, clear differences have been shown in coral recovery between the chronically polluted ECNR (Fig. 1.2D–F) and the pristine CR. I have suggested (Loya 1975) that chronic oil pollution could damage coral communities, inhibiting coral recruitment in oil-polluted reefs, by (1) harming the reproductive system of corals, (2) decreasing the viability of coral larvae, or (3) changing some physical properties of the reef flat, thus interfering with normal settlement of coral larvae (any combination of these is also possible). We tested these hypotheses in a series of field and laboratory experiments summarized below.

We chose the coral *Stylophora pistillata* as our model experimental coral, since this is the most abundant coral in the Eilat reefs (Loya 1972), and its life history has been studied in detail (Loya 1976b–d; Rinkevich and Loya 1979b, c). Field experiments, observations, and histological studies on two populations of *S. pistillata* in a chronically oil-polluted reef near the oil terminals (ECNR, Fig. 1.1) and at the pristine CR revealed detrimental effects on the polluted corals. The coral population at the polluted reef showed a higher mortality rate of colonies, a smaller number of breeding colonies, a decrease in the number of female gonads per polyp, a smaller number of planulae produced per coral head (fecundity was four times higher in the CR than that in the ECNR), a decrease in the viability of planula larvae with increasing concentrations of oil and lower settlement success of larvae on artificial objects with the increase in oil concentrations (Rinkevich and Loya 1977).

Further studies on the effects of crude oil on the reproduction of *S. pistillata* in the laboratory, using large tanks with running seawater, supported the field results (Rinkevich and Loya 1979c). Large and mature colonies of *S. pistillata* were cut into halves at the beginning of the reproductive period; to avoid expected variation between different colonies, one was placed in a periodically oil-polluted tank, the other in a clean tank. After 2 months a significantly lower number of female gonads per polyp were recorded in 75% of the polluted halves, compared to the controls. An additional effect of low concentrations of crude oil on *S. pistillata* is the immediate indication of mouth opening followed by abortion of premature larvae. Since premature extrusion of planulae occurs during an oil spill, their chances of survival or successful settlement are very low (Loya and Rinkevich 1979).

Our field and laboratory studies on the effects of oil pollution on corals may explain the lack of recruitment of corals in the chronically polluted ECNR until 1979–1980. However, although no major oil spills have occurred in Eilat since 1980, to date the reef flats at the ECNR have not returned to their former community structure (Fig. 1.4). In the last two decades, other man-made perturbations (mainly eutrophication) have increased in severity (Sect. 1.4), preventing rehabilitation of the coral reefs of Eilat. Rather than speculating on this subject, I prefer, at this stage, to address the wider issue of the mechanisms that generate and maintain the diversity of organisms. Below, I present two hypotheses stemming from our long-term studies at the northern Gulf, to help interpret possible mechanisms that promote and maintain high coral diversity on pristine reefs of the northern Gulf.

1.3 Mechanisms That Generate and Maintain Coral Diversity in the Northern Gulf of Eilat/Aqaba

1.3.1 Hypothesis 1

Unpredictable midday low tides act as diversifying forces by preventing monopolization of the reef flat by individual or a few competitively superior species.

Because space for settlement and development is one of the most important limiting resources on coral reefs, overlap in the utilization of space may result in acute competition among coral populations (Lang 1973; Grigg and Maragos 1974; Porter 1974; Jackson and Buss 1975; Connell 1976, 1978; Loya 1976a; Jackson 1977; Buss and Jackson 1979; Lang and Chornesky 1990; Hughes 1994; Abelson and Loya 1999; Hughes and Connell 1999).

Resource monopolization by corals may take place through competitive interactions such as extracoelentric digestion, whereby the mesenterial digestive filaments of a dominant species extend onto the living tissues of an adjacent subdominant and destroy it (Lang 1973; Richardson et al. 1979), rapid growth (Connell 1973), overtopping morphology (Porter 1974), or allelopathic effects (Jackson and Buss 1975; Sammarco et al. 1983). Abilities in these competitive mechanisms are species-specific, and in areas of high densities on the reef have been shown to affect patterns of coral abundance and distribution (Lang 1973; Grigg and Maragos 1974; Porter 1974; Connell 1976, 1978; Loya 1976a; Porter et al. 1982; Sheppard 1985).

Coral mass mortality on reefs may result from a variety of causes such as (below selected references) mechanical destruction during tropical storms (Woodley et al. 1981; Rogers 1993), abnormally low or high seawater temperatures (Glynn 1981; Jokiel and Coles 1990), sedimentation (Loya 1976e; Rogers 1990) exposure to air during midday air temperature maxima (Glynn 1976; Loya 1976a), bleaching (Glynn 1993; Brown 1997; Hoegh-Guldberg 1999; Ostrander et al. 2000; Loya et al. 2001), diseases (Kushmaro et al. 1996; Harvell et al. 1999), *Acanthaster* predation (Lourey et al. 2000) and anthropogenic activities (Brown and Howard 1985; Nystrom et al. 2000). The period of time required for recruitment and recovery of reefs after such disturbances varies from very short (2 years; Shinn 1972) to prolonged (50 years or more; Grigg and Maragos 1974; Pearson 1981) and largely depends on local settings.

The role of disturbance on community structure and species diversity of natural communities has been documented and discussed by many investigators. (For selected bibliography and reviews, see Dayton 1971; Connell 1978; Paine and Levin 1981; Miller 1982; Porter et al. 1982; Sousa 1984; Pickett and White 1985; Knowlton 1992; Karlson and Hurd 1993; Hughes and Connell 1999 Nystrom et al. 2000; Holling 2001 and others.)

Grigg and Maragos (1974) suggested a model for coral community succession based on patterns of recruitment on submerged historic lava flows in Hawaii. By analyzing data sets from progressively older flows, they found that diversity at first increased and then gradually decreased as more and more species became established. They hypothesized that the decline in diversity in older flows was due to space limitation and competitive exclusion by dominant species, a process that took over 50 years. Glynn (1976) attributed the diversifying effect to recurrent and extreme tidal exposures of reef flat corals off the Pacific coast of Panama. Tide-induced mortality of pocilloporid corals, which are prime-space monopolists at that site, resulted in increased coral species diversity.

I have suggested (Loya 1976a) that the unpredictable low tides at Eilat act as a diversifying force in a way similar to storm and swell damage in Hawaii (Grigg and Maragos 1974; Grigg 1983), and the extreme tidal exposures of reef flats off the Pacific coast of Panama (Glynn 1976). Connell's (1978) 'intermediate-disturbance' hypothesis, stating that the highest diversity of natural communities will be maintained in areas suffering intermediate disturbances on the scales of frequency and intensity, fits these examples.

The higher diversity recorded at the pristine CR 3 years after the low tide, compared to the diversity at the CR prior to the devastation, may reflect a situation in which diversity continues to increase in time after a catastrophe until space for coral settlement becomes limiting and competitive interactions between species may cause a decline in diversity. The results obtained for the average number of species recorded on the reef flat of the CR between 1970 and 1986 support this pattern (Fig. 1.4). The time interval required to reach "species equilibrium" (sensu Wilson 1969) is quite short (approx. 5–7 years). The time interval for full recovery and for competitive interactions to take place is expected to be much longer and more variable between different reefs depending on local conditions (15–30 years or more; see Loya 1976a).

The frequency of extremely low tides at the Gulf of Eilat/Aqaba seems to be such that full recovery is never reached on the reef flats, and interspecific competition is not carried out to completion. Monopolization of the reef flats by competitively superior species is interrupted, providing an opportunity for more species to colonize vacant spaces. Hence, the exceptionally high diversity recorded on pristine reef flats in the northern Gulf probably reflects early successional stages.

1.3.2 Hypothesis 2

Temporal reproductive isolation (i.e., discrete breeding period) and intraspecific synchronization of spawning of northern Red Sea corals generates high diversity by preventing hybridization (i.e., minimizing gametogenic wastage) and decreasing interspecific competition.

Information on reproductive patterns in corals has progressively accumulated in the last 20 years (see Fadlallah 1983; Harrison et al. 1984; Richmond and Jokiel 1984; Shlesinger and Loya 1985; Shlesinger et al. 1998; Babcock et al. 1986; Szmant 1986; Harrison and Wallace 1990; Richmond and Hunter 1990;

Ward and Harrison 2000 for reviews and selected regional patterns). However, no study has attributed coral community structure and species diversity in relation to coral reproductive patterns. In trying to explain the high within-habitat diversity of hermatypic corals on reef flats in the northern Gulf, my second hypothesis relates to the phenomenon of temporal reproductive isolation exhibited by the most abundant coral species at Eilat (Shlesinger and Loya 1985; Shlesinger et al. 1998).

We have examined the reproductive patterns of 13 ecologically important coral species at Eilat (Fig. 1.5; Shlesinger and Loya 1985). Although these species comprise only 13% of the total known species there, they are among the most abundant, contributing approximately 60–70% of the total living cover of coral communities on the reef flats (Loya 1972). The major reproductive activities of these species (planula shedding or gamete spawning) occur in different seasons, different months, or different lunar phases within the same month (Fig. 1.5). A similar conclusion was obtained for the reproductive patterns of an additional 11 coral species studied at a later stage (Shlesinger et al. 1998). By contrast, many corals of the GBR of Australia are synchronous multispecific spawners (Harrison et al. 1984; Babcock et al. 1986, Harrison and Wallace 1990). The coral mass spawning event takes place at the GBR during a few nights in late spring, between the full and last quarter of the moon.

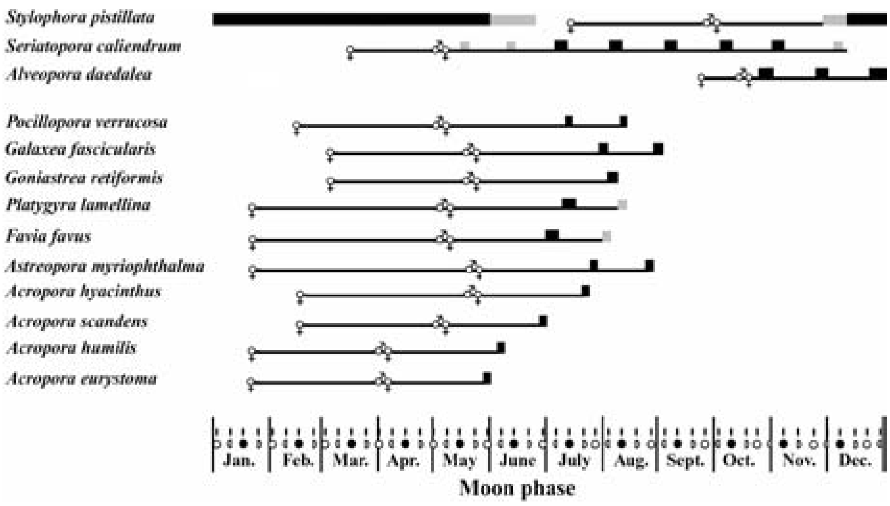


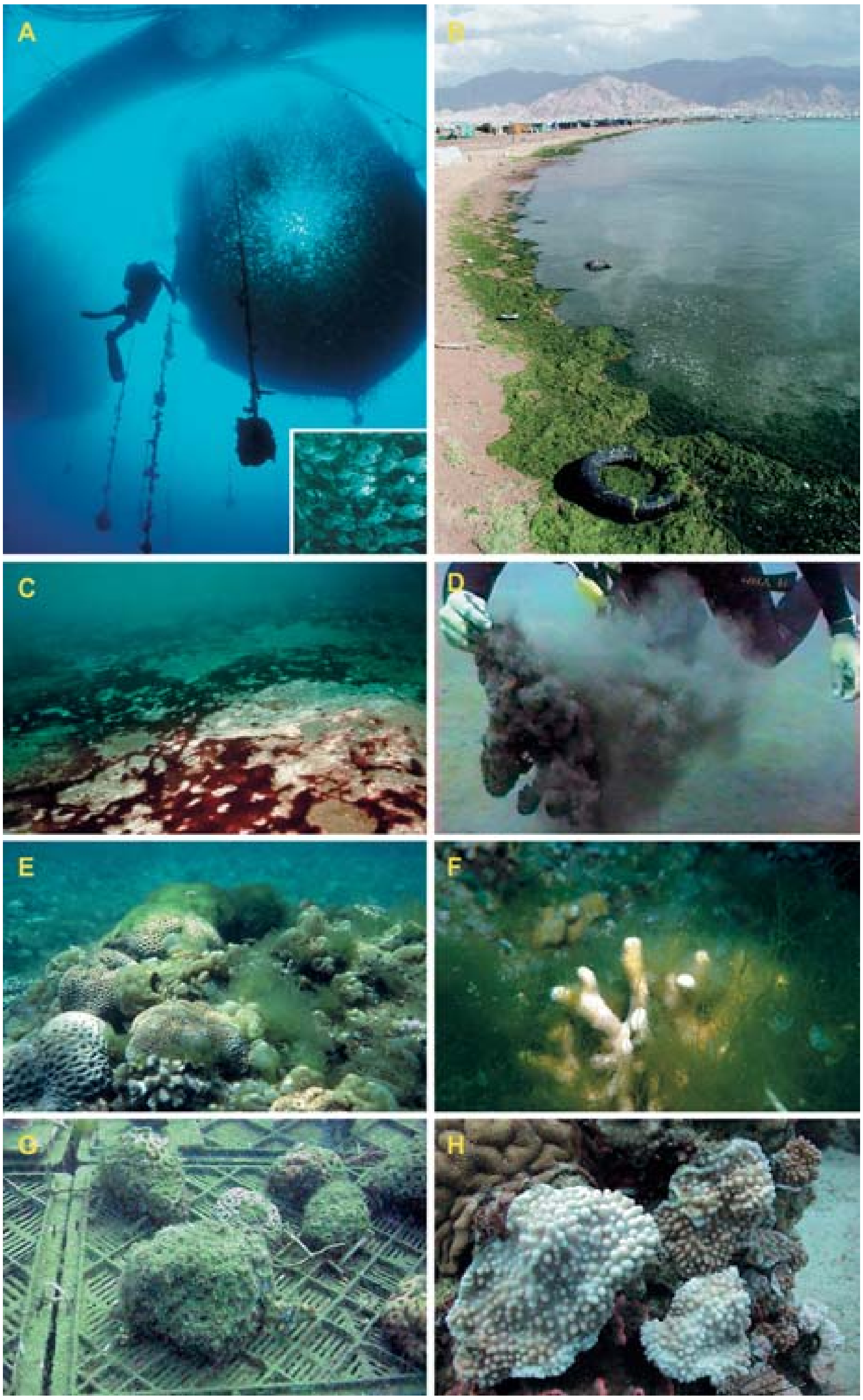
Fig. 1.5. Reproductive patterns of 13 scleractinian corals at Eilat in 1980 (after Shlesinger and Loya 1985). The first three species are brooders and the rest are broadcasting spawners. The results presented are in accordance with the lunar calendar, as follows: *black circle* new moon, *half circle to the right* first quarter, *blank circle* full moon, *half circle to the left* last quarter. The period of gonad development is represented by a *solid line* with indications of the onset of oogenesis (female sign), and spermatogenesis (male sign). Further development of both gonads is indicated by the line following the male and female signs. *Black bars* represent massive spawning (90–100% of the population), and *gray bars* represent sporadic spawning (10–20% of the population)

I have mentioned that space is a major limiting resource for settlement, growth, and development of reef corals. The reproductive activity of the vast majority of coral species at Eilat coincides with the seasonal disappearance of benthic algae, a major competitor for space on the reef flats of Eilat (i.e., mainly during June to September; Benayahu and Loya 1977a, b, 1981; Fig. 1.6C–F). Various species of algae progressively decline in abundance during the summer months, creating more space for coral settlement. During winter, algal cover on the reef flats is very high and space for settlement is scarce (Sect. 1.4; Fig. 1.6E). At any given time, space availability for settlement on the reef flats is more predictable during summer than winter. Thus, summer breeders among the corals maximize their reproductive success by concentrating their reproductive effort into a relatively short period of time (Fig. 1.5). By contrast, winter breeders like *S. pistillata* adopt an opposite strategy, spreading the risks of reproduction over a long period of time (December to May in the case of *S. pistillata*). During the winter, the availability of space in time is random, due to occasional denudation of small areas by winter storms (Fig. 1.6B) and, to a limited degree, by grazers. Therefore, a long reproductive period is advantageous for winter breeders.

Intraspecific synchronization of spawning and a discrete breeding period may be advantageous to each coral species in the northern Red Sea, not only by reducing gametogenic wastage and preventing hybridization, but also by reducing interspecific competition among corals and between corals and algae. Thus, temporal reproductive isolation may act as a mechanism that generates high coral diversity in the northern Red Sea. By contrast, the mass spawning exhibited by the GBR corals probably increases interspecific competition among them. However, whether this may be a cause for the relatively lower within-habitat diversity of corals on the reef flats of the GBR compared to that in the northern Red Sea remains to be shown.

The two hypotheses presented here are not mutually exclusive. The net result of high coral diversity on pristine reefs along the Gulf of Eilat may be a cumulative synergistic effect of external abiotic factors, such as intermediate disturbance on reef flats (sensu Connell 1978), through exposure to air during midday air temperature maxima, and biotic factors, such as temporal reproductive isolation. (reef flats and deeper reef regions).

While these hypotheses may elucidate the exceptionally high diversity of pristine reefs in the northern Gulf, the chronic disturbance of the coral reefs of Eilat, caused by a variety of human activities, are undoubtedly the major cause for their continued deterioration and critical state of health nowadays.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1.4 Man's Destructive Activities: Acute Degradation of the Coral Reefs of Eilat Due to Eutrophication

1.4.1 Acute Degradation of Coral Diversity and Living Cover at Eilat During 1986-2000 Due to Eutrophication by Urban Sewage and Net Pen Fish Farms

During the 1980s, the city of Eilat went through rapid development and population growth (20,000 people in 1980; 40,000 in 1990; 54,000 in 1995), which increased human stress on the reefs. The decline of the reefs of Eilat at that time was probably due to a combination of anthropogenic disturbances (i.e., phosphate dust, urban sewage, siltation, tourist diving activities and port ballast water). However, while most of these harmful activities have been minimized by strict environmental enforcement, the sewage of Eilat continued to flow to the sea (Fig. 1.3G–I) and stopped only after a sewage treatment plant was built north of the city in 1995. Atkinson et al. (2001) estimated that in 1980 the total annual nitrogen and phosphate release into the northern Gulf of Eilat/Aqaba originating from Eilat's urban sewage was 5×10^6 mol N and 0.24×10^6 mol P. These quantities doubled in 1990, with the doubling of the population number, and stopped in 1995 after the sewage treatment plant was built. Since coral reefs flourish in oligotrophic waters, eutrophication of reef waters is considered to be one of the main causes for their decline (see literature in Lapointe 1997; Roberts et al. 2002). Although there is no direct evidence, it is most likely that the nutrient enrichment caused by Eilat's sewage as well as the activities of Aqaba's and Eilat's phosphate ports were among the major causes for the decline of coral populations at the reefs of Eilat until 1995 (Fig. 1.3H, I).

At that time, intensive net-pen fish farms (Figs. 1.1, 1.6A), situated at the northernmost section of the Gulf of Eilat ("the North Beach") have increased their fish production exponentially. The fish farms utilize large fish cages, 12 m in diameter and 10 m in length, densely populated mainly with the gilthead sea bream *Sparus aurata* (Fig. 1.6A, insert). In 1991, the annual fish yield was

◀ **Fig. 1.6.** **A** The intensive net-pen fish farms situated at the northernmost section of the Gulf (Fig. 1.1) utilize large fish cages, mostly for the gilthead sea bream *Sparus aurata* (*insert*). **B** A southern storm detached vast amounts of macro-algae from the vicinity of the fish farm onto the northern shoreline. **C, D** The seafloor in the vicinity of the fish cages forms an anaerobic benthic habitat which supports the growth of bacterial mats and sulfide-resistant populations. **E** Vertical mixing of the water column during winter results in "algal blooms" and competitive exclusion of stony corals by algae. **F** *Stylophora pistillata*: enhanced eutrophication of the reefs encourages proliferation of filamentous algae overgrowing and smothering corals at the northern Gulf of Eilat. **G** Transplanted *Favia favus* colonies on inverted plastic boxes near the fish cages site were overgrown by algae and died within a year. **H** *Montipora lobulata*: in summers 2002 and 2003 sporadic coral bleaching was observed for the first time, in some coral species, at the northern Gulf of Eilat/Aqaba

200 tons, it grew to 700 tons in 1995 and 2300 tons in 2000 (Atkinson et al. 2001). The fish are nourished with a total of 4200 tons/year of protein-rich added food (Gordin 2000). Waste food and fish feces deposited in the vicinity of the cages, or in the direction of the prevailing currents, result in substantial accumulation of organic material (OM) on the seafloor (Fig. 1.6C, D). Such OM enrichment leads to sediment anoxia, sulfate reduction and drastic changes in the sediment porewater chemistry (Holmer and Kristensen 1992). This anaerobic benthic habitat supports the growth of widespread bacterial mats and sulfide-resistant populations. Part of the sinking organic particles are carried a large distance southward by sea currents (Abelson et al. 1999).

After the sewage treatment plant had been built and the flow of sewage into the sea had been halted (in 1995), the fish cages remained the major source of organic enrichment (N and P) to the northern Gulf, releasing an estimated 18×10^6 mol/year N and 2×10^6 mol/year P (Atkinson et al. 2001). Gordin (2000) estimated that ca. 68% of the nitrogen and 27% of the phosphorus fed to the fish are subsequently excreted and released into the water in a dissolved form. In addition, 10% of N and 44% of P are excreted as solid excretions; hence, the annual amount of nutrients released into the surrounding water totals ca. 240 tons of N and 40 tons of P. (i.e., the input of the fish farms alone contributes 97% of N and 66% of P to the northern Gulf of Eilat. Thus, after 1995, the fish farms "replaced" Eilat's sewage, as the major source for eutrophication of the reefs continuing the mass killing of Eilat's corals (Fig. 1.7). Indeed, long term monitoring of the coral community structure at the "Japanese Gardens" site of the ECNR (has been closed to tourist diving activity in the last 8 years), at 4m depth, reveals a decrease of 76% and 73% in coral cover and abundance, re-

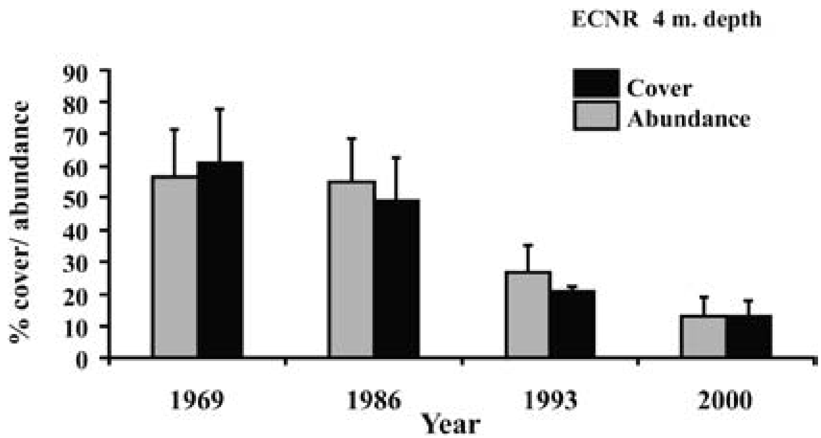


Fig. 1.7. Long-term monitoring of the coral community structure at the "Japanese Gardens" site, ECNR (4-m depth). The percent living cover of stony corals decreased in the last 15 years by 76% and the number of coral colonies decreased by 73%. Data for 1969 from Loya (1972). (n=9–21 transects, each 10 m in length, *bars* represent ± SD)

spectively. If one further examines this time period between 1986-1993 (during which Eilat's sewage was flowing to the sea but stopped in 1995)and between 1993-2000 (during which the fish cages were, and still are, the major nutrification source of the northern Gulf of Eilat/Aqaba), it is most probable that Eilat's sewage was the major cause for the decrease of 51% and 57% in coral living cover and abundance, respectively, during 1986-1993, while the fish farm industry, which grew exponentially in their fish production during 1993-2000 "replaced" Eilat's sewage contribution to nutrification of the northern Gulf, causing a further decrease of 62% and 49% in coral living cover and abundance, respectively (Fig. 1.7).

1.4.2 Eutrophication Effects on the Reef's Food Chain, Metabolism, Interspecific Interactions and Genetic Structure of Coral Populations

In 1998, the waters of the northern Gulf of Aqaba/Eilat contained at over 500-m depth a max. 4 µmol/l nitrate and 0.3 µmol/l phosphate. In 2000, they were nutrient-enriched to 7 and 0.5 µmol/l, respectively. This dramatic increase results essentially from the fish farm nutrient pollution (Lazar et al. 2000). In 1999–2000, surplus nitrate accumulating in >500-m depth equaled 200 tons; during this period the fish farms polluted the water column with 500 tons of nitrates available for primary production (i.e., N accumulating in deep water equalled ca. 40% of N originating from the fish farms; Lazar et al. 2000).

As a result of nutrient enrichment the phytoplankton, which multiplies rapidly (can double every 1–2 days), is eaten by zooplankton and the latter is preyed upon by fish. Thus, the nutrients that were passed on to higher trophic levels in the food chain, are distributed over wide areas in the northern Gulf. At each stage in this process, part of the nutrients is removed from the living system as solid excretions that drop to the depths of the sea. Finally, a surplus of nutrients is accumulating in the depths and the seafloor of the northern Gulf (Atkinson et al. 2001). During winter, cold surface waters sink to deeper layers creating vertical mixing, "pumping" nutrient-rich waters to the surface, resulting in "algal blooms" (Genin et al. 1995; Fig. 1.6B) and competitive exclusion of stony corals by algae (Fig. 1.6E, F). Genin et al. (1995) reported that the deep vertical mixing during winter 1992 resulted in excessive eutrophication of the upper illuminated reef layers, generating wide-scale algal blooms which killed 25% of the corals in Eilat.

Silverman et al. (Chap. 21, this Vol.) proposed an index of reef metabolism (RM, i.e., the proportion of reef calcification to P/R ratio) as an index for the reef's health. High RM values denote a healthy reef, while low RM values denote deteriorating reefs. The RM measured in 1991 at the ECNR was ca. 200 µM C m^{-2} day^{-1}, similar to values reported from pristine Indopacific reefs during the 1970s and 1980s. In winter 2000, RM decreased in the ECNR to a value of ca. 6 µM C m^{-2} day^{-1} (i.e., five- to sixfold lower than the values obtained in winter 1998 and over 20-fold lower than the values obtained in 1991 from the same reef). This means that the reef growth at the ECNR virtually stopped. The authors attributed these alarming results to the extreme increase in eutrophication of the Gulf in recent years.

A recent study of the genetic structure of *S. pistillata* populations in four distinct sites at the northern Gulf of Eilat/Aqaba (Zvuloni (2003) adds to our great concern for the persistent detrimental effects of the fish farms on coral populations. Zvuloni (2003) found that the genetic variation within *S. pistillata* coral populations was much greater (90.2%) than among populations (9.8%), suggesting a high level of connectivity among the coral populations in the region. Nevertheless, a significant variation was found between the adult *S. pistillata* population in the 'Peace Lagoon' (located ca. 400 m west of the fish farms) and all other adult *S. pistillata* populations in three further away southern sites. Moreover, the genetic variation within young recruits of this species in the Peace Lagoon was found to be significantly larger than within adult coral colonies at the same site. He suggested that a selection process, taking place immediately after settlement of *S. pistillata* juvenile spat, permitted only individuals from particular genotypes to survive there. Furthermore, he attributed these results to the higher pollution levels reported by other studies in the vicinity of the Peace Lagoon study site.

1.4.3
Detrimental Effects of Eutrophication on Coral Reproduction

Recently, we have assessed the impact of the fish farms on the survival of two branching corals (*Stylophora pistillata* and *Acropora variabilis*) and two massive and encrusting species (*Favia favus* and *Coscinarea monile* respectively, Fig. 1.6G) and the impact of the fish farm on the reproduction of *S. pistillata* (see details in Loya et al. 2004). For the reproduction study, we collected 40 mature *S. pistillata* colonies (larger than 20 cm in diameter) from a site mid way between the IUI and the fish farm site (at 15 m depth) and transplanted 20 colonies at each of the two sites: (1) 200 m west of the fish farm cages at a depth of 19 m, and (2) at the Interuniversity Institute (IUI) reef at the same depth. Over the next two consecutive years, histological studies of the reproductive effort of the experimental corals showed that there were more oocytes per polyp in colonies sampled from the fish farm site than at the IUI reference site (Fig. 1.8), but they remained significantly smaller than the IUI oocytes throughout the reproductive season. Monitoring changes in oocyte size frequency distribution in the colonies throughout the reproductive cycle, we found that polyps from the IUI colonies contained significantly more oocytes, which reached the mature size of over 200 μm, than those from the colonies near the cages. Moreover, the percentage of polyps with planulae was significantly higher in colonies from the IUI site than from those under the cages (Figs. 1.8, 1.9). In comparing number of planulae per polyp in the experimental colonies transplanted at both sites (Fig. 1.9), we found significantly larger numbers of polyps with planulae both in 2001 and 2002 in the IUI reference site than near the fish cages (Loya et al. 2004).

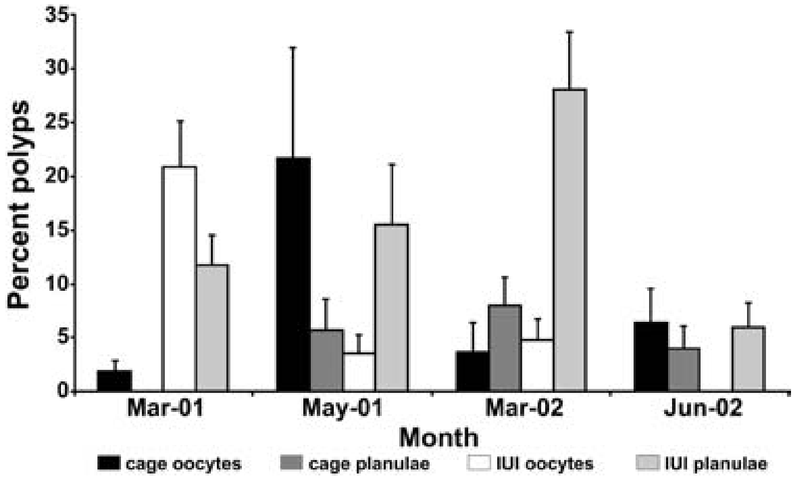


Fig. 1.8. *Stylophora pistillata*: percent polyps with oocytes and planulae (± SE) in mature experimental colonies transplanted in the vicinity of the mariculture fish farm (Fig. 1.1) and at a reference site across from the Interuniversity Institute of Eilat (IUI), during 2000–2001 (after Loya et al. 2004). (For 2001: March n=11 colonies 534 polyps, May n=11 colonies, 439 polyps, for 2002: March n=11 colonies, 840 polyps, June n=10 colonies, 577 polyps)

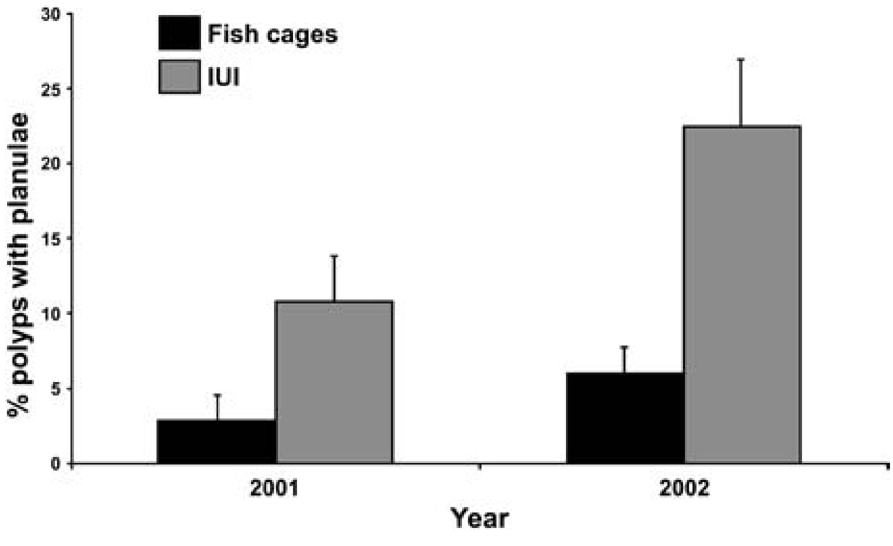


Fig. 1.9. *Stylophora pistillata*: fecundity (percent polyps with planulae, ± SE) of mature experimental colonies transplanted at the vicinity of the mariculture fish farm (Fig. 1.1) and at a reference site across from the IUI during 2000–2001 (after Loya et al. 2004)

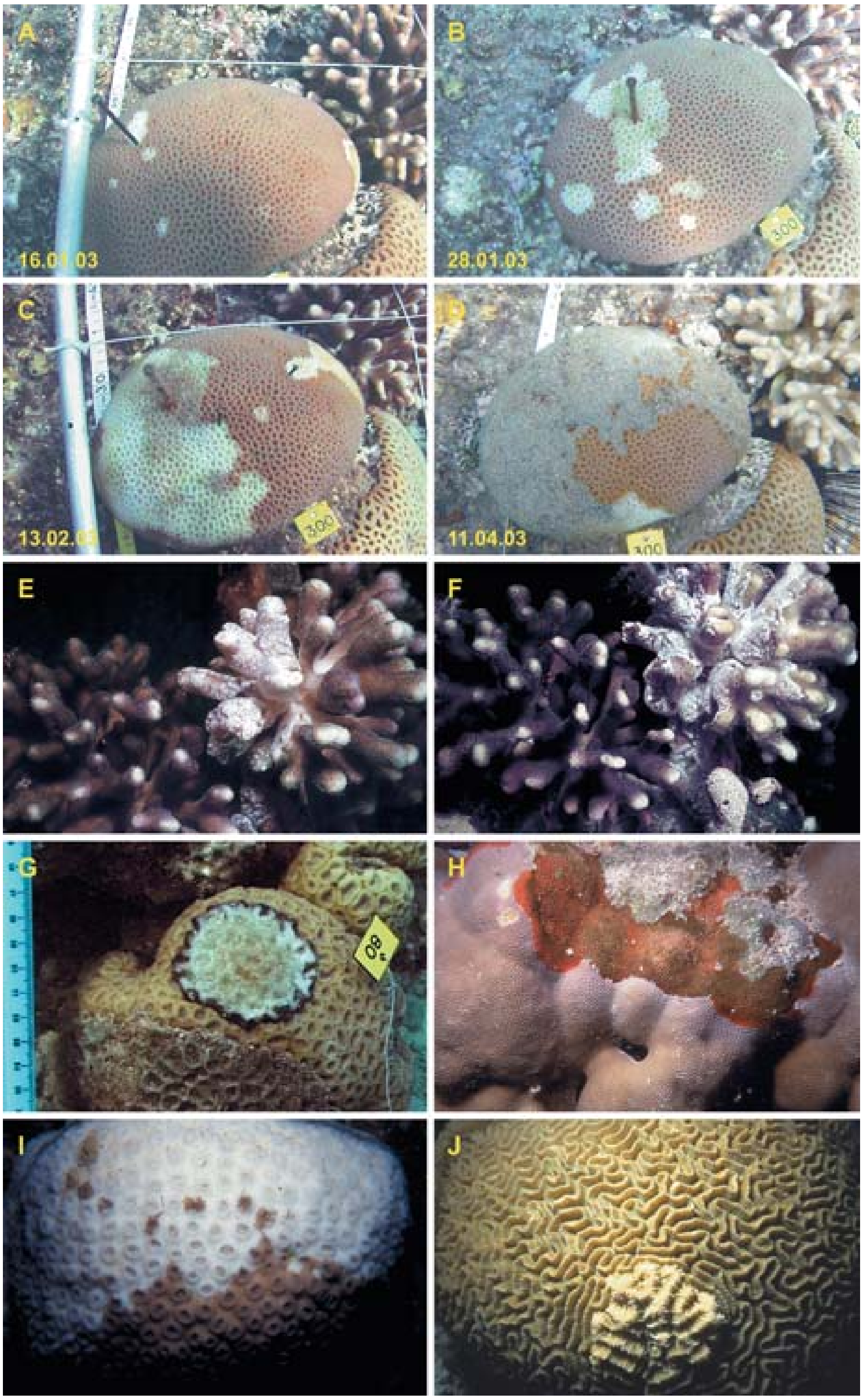
For comparative studies on coral survival, we transplanted in November 2000, massive *Favia favus* and encrusting *Coscinarea monile* colonies (Fig. 1.6G) as well as branching mature *S. pistillata* and *A. variabilis* colonies (ten colonies of each species, at each of the two sites). The colonies were collected from the same "midway" site. Most transplanted branching colonies in both sites survived and still continue to grow well (ca. 3 years after transplantation). In contrast, almost all transplanted massive and encrusting colonies at the fish farm site were overgrown by algae and died within a year, while those at the IUI are still growing well today. These results are not surprising in view of the fact that both *Acropora variabilis* and *S. pistillata* are more abundant than any other coral species in the vicinity of the fish farms. Although these species are also abundant on reefs further south, they are among the very few coral species that may be found growing on artificial objects in the vicinity of the fish farms. Both *A. variabilis* and especially *S. pistillata* are typical "weedy" species. Among other attributes, they are the first to settle where new space becomes available, grow quickly, mature sexually at a small size (age) and have wide genetic variability. These characteristics may explain their relative survival success in the vicinity of the fish cages compared with other more specialized species, such as the *F. favus* and *C. monile*, which did not survive in this environment.

The conclusions derived from our study (Loyat et al. 2004) are in variance with the conclusions of a similar study that was carried out at the same sites (for details see Bongiorni et al. 2003; Loya and Kramarsky-Winter 2003; Rinkevich et al. 2003). In contrast to the interpretations and conclusions of Bongiorni et al. (2003), we suggest that the results presented in their paper, together with our own results, actually attest to a severe reduction in the reproductive success of coral colonies near the fish farms (Loya et al. 2004). This leads to the inference that the conditions at this site are harmful to these corals. Moreover, Abelson et al. (1999), demonstrated that particulate matter from point sources at Eilat's "North Beach" (close to the fish farms) reached coral reefs 8 km further south, both as bed-load and suspension-load particles. Indeed, much of the nutrients originating from the fish farms were found to reach the reefs further south, accumulating on the seafloor at depths >500 m (Lazar et al. 2000). Hence, these reefs are affected as well, especially during the vertical mixing events of the water column during cold winters (section 1.4.2). It is thus possible that the continuous eutrophication of the northern Gulf of Eilat/Aqaba has marked deleterious effects on coral reproductive effort even in areas distant from the fish farm site. Indeed, Zakai and Furman-Chadwick (pers. comm.) have recorded marked decreases in planulation of the coral *S. pistillata* in the ECNR and the IUI reef in the last 5 years, compared with known records from the mid-1970s (Rinkevich and Loya 1979a, b). We, therefore, concluded that nutrients released from the fish farms are the most probable and direct cause of harmful effects to *S. pistillata*'s reproduction, and most likely to the reproduction of other coral species, as reported from other reefs around the world (Tomascik and Sander 1987; Ward and Harrison 2000; Harrison and Ward 2001).

1.4.4 Coral Diseases and Syndromes

In the last 3 years (2000–2003) we have witnessed further deterioration of corals in the northern Gulf, due to coral diseases and syndromes infecting Eilat's corals (Fig. 1.10). Coral diseases are among the most recent in a series of threats affecting coral reefs (e.g., eutrophication, coral bleaching, oil and heavy metals pollution, coastal development, increased sedimentation and over-exploitation of marine species) that is challenging the resilience of coral reef communities. Since the first report of coral disease by Antonius in 1973, the rate of discovery of new diseases has increased dramatically with ca. 30 coral diseases now described (Green and Bruckner 2000; Weil 2003). Although coral disease is emerging as a serious cause of coral reef deterioration in many reefs around the world, at present we know very little about the ecology or pathology of coral diseases in Red Sea reefs in general (Antonius and Riegl 1997), and Eilat's reefs in particular (Ben-Haim et al. 2003). Figure 1.10A–D illustrates the fast spreading rate in which an unidentified disease affects a *Goniastrea* sp. colony in Eilat. Additional examples of field appearance of diseases and syndromes infecting Eilat's corals are illustrated in Fig. 1.10E–J. Increasing epizootiological knowledge of coral diseases (i.e., distribution, host range, prevalence and incidence at the species and community levels, spatial and temporal variability, epidemiology, etc.) will also help to identify the origins and reservoirs of pathogens and the vectors involved in disease transmission, all of which are important for building capacity in the management of potential disease outbreaks. At present, we are compiling a base-line data set on the presence, distribution, abundance and pathology of scleractinian coral diseases in the northern Gulf of Eilat/Aqaba (Sulam et al., Barash et al., unpubl. data).

During the summers of the last 2 years (2002/2003), we have also observed for the first time in Eilat, sporadic coral bleaching (Fig. 1.6F). The bleaching or paling of corals, through the loss of their zooxanthellae and/or their pigments, is a global phenomenon that is probably linked to global climate change and increasing ocean temperatures (Glynn 1993; Brown 1997; Hoegh-Guldberg 1999). Recent reports of wide-scale coral bleaching from all the major tropical oceans of the world during 1997–1998, and the unprecedented coral mortality that resulted (Wilkinson 1998, 2000), are a major concern among scientists and resource managers. In 1998, more than 90% of shallow corals were killed on most Indian Ocean reefs. High sea surface temperature (SST) was a primary cause, acting directly or by interacting with other factors. Even with their marked temperature acclimatization, most corals in the Arabian Gulf were killed by the 1998 peak SSTs (Sheppard 2003 and references therein). Until today, the northern Red Sea has remained relatively unaffected. However, the phenomenon of global warming, resulting in an increase in the frequency and intensity of world-wide coral bleaching events (Hoegh-Guldberg 1999), sets the ground for additional severe threats to our reefs, which is superimposed on their present fragile situation. In case of future abnormal increases in SSTs in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the northern Gulf of Eilat, which might result in mass coral bleaching, the chances of coral communities recovering are minute, in view of their critically frail state of health.

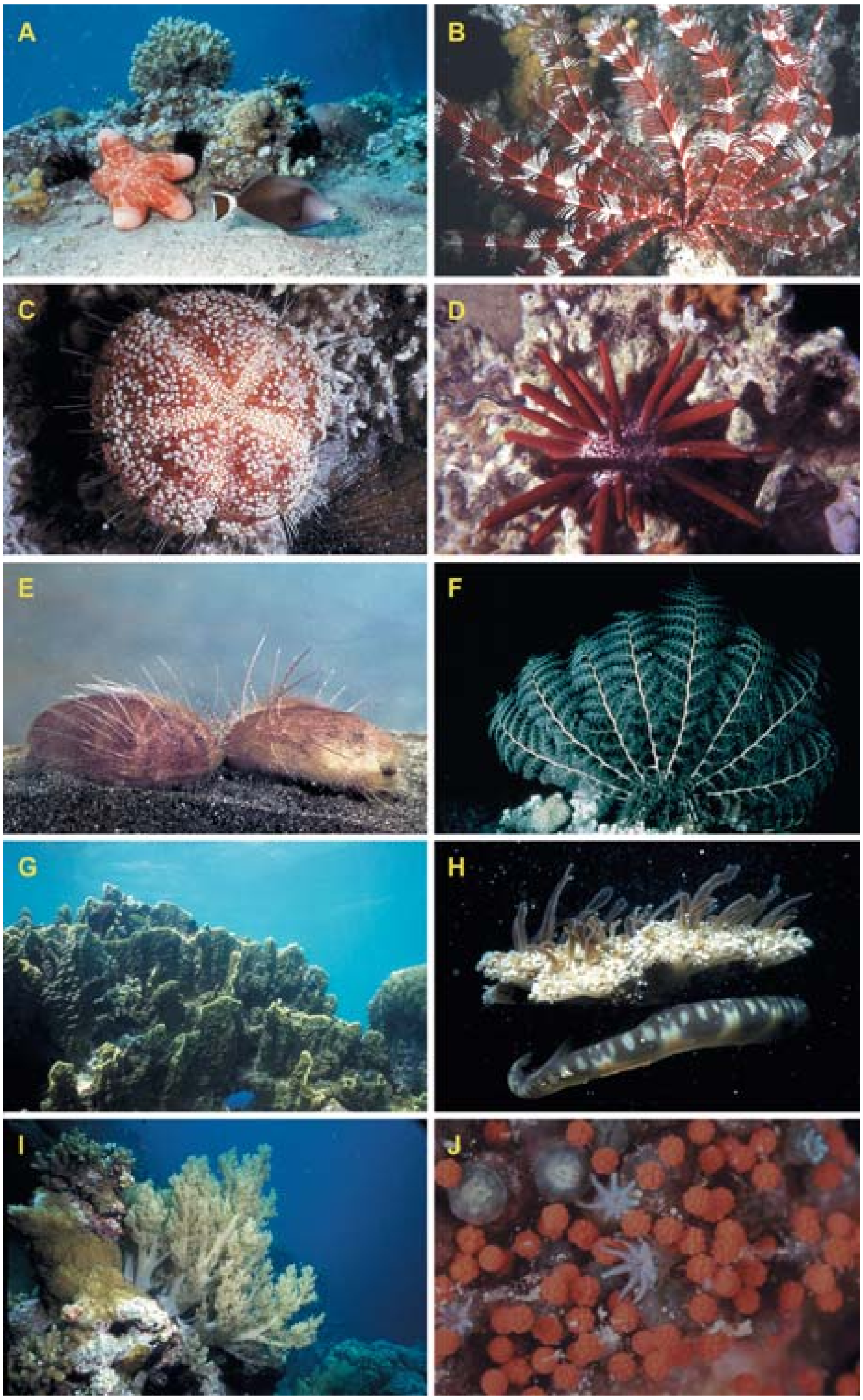
1.4.5 Local Extinction or Decrease in Abundance of Organisms Associated with Corals

The extreme deterioration in coral abundance and living cover at the northern Gulf of Eilat might have directly or indirectly caused the local extinction or severe decrease in abundance of other reef organisms, which live in close association with the corals (Fig. 1.11). Genin et al. (2001) provide a partial list of such species. It is noteworthy that echinoderms are among the most conspicuous group of such organisms (Fig. 1.11A–E). Some examples include: the sea star *Choriaster grannulatus* (Fig. 1.11A), the crinoids *Lamprometra klunzingeri* (Fig. 1.11B) and *Heterometra savignyi*, which were very abundant in the past in the ECNR (up to 50 m^2; Fishelson, pers. comm.) are virtually extinct there, the sea urchins *Asthenosoma varium*, *Heterocentrotus mammilatus*, *Lovenia elongata* (Fig. 1.11C–E, respectively), and the basket star *Astroboa nuda* (Fig. 1.11F). Distinct examples of organisms from other phyla include the hydroid coral *Millepora platyphylla* (Fig. 1.10G), the scyphozoan medusa *Cassiopea andromeda*, and the soft corals *Litophyton arboreum* and *Clavularia hamra* (Fig. 1.11H–J, respectively).

1.4.6 Recent Assessments of the Effects of the Fish Farms on the Coral Reefs of Eilat

The critical state of health of the coral reefs of Eilat (Figs. 1.5–1.11) led 14 marine scientists in Israel to express to the Israeli Minister of the Environment their growing concern with respect to the grave fate of the reefs (Genin et al. 2001). This document (known as the "Scientist's Document") lists the major detrimental effects and potential threats that the fish cage mariculture industry poses to the Gulf. There is a wide consensus that the coral reefs of Eilat are deteriorating. However, acute controversy exists between the mariculture industry vs. conser-

◀ **Fig. 1.10.** Field appearance of diseases and syndromes infecting Eilat's scleractinian corals. **A** An unidentified disease is noticeable on the surface of *Goniastrea* sp. The colony was tagged (No. 300) on 16 January2003 and a stainless steel nail marked the edge of the white area devoid of live tissue. **B, C** The disease spread very quickly and **D** within 3 months, 80% of the coral was dead and its surface covered by sediment. **E** An unidentified (fungal?) disease has recently been observed on *Stylophora pistillata* colonies. **F** The same colony 1 month later. **G** Black band disease (BBD) in *Favia favus*. A mat of filamentous cyanobacterium *Phormidium corallyticum* causes the black coloration of the black band bordering the healthy tissue. **H** *Porites lobata*. **I** Unidentified disease (patchy white spots) in *Echinopora gemmacea*. **J** Tumorous skeletal growth in the brain coral *Platygyra lamellina*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vation organizations, and a large proportion of leading Israeli marine scientists, concerning the role of the fish farms in the decline of the reefs. Hence, an International Expert Team (IET) was appointed by the Israeli Government to evaluate the pollution sources in the northern Gulf of Aqaba/Eilat and recommend steps to ameliorate the Gulf's ecological situation (Atkinson et al. 2001). Both documents evaluated published and unpublished reports on this problem, and pointed out potential harmful effects that the fish farms may be or already are inflicting on the reefs (i.e., persistent eutrophication of the reef, organic enrichment of the sea bottom in the "North Beach", a point source for the initial outburst of pathogenic diseases in wild coral reef fish and the introduction of nonindigenous fish species into the Gulf's ecosystem). It is not within the scope of this paper to go into the details of these documents. It will suffice to mention that the "Scientist's Document" recommended relocation of the mariculture operation into inland ponds. The IET document presented a list of recommendations that essentially advocated a risk management approach: recognizing that the fish farms were the unequivocal and foremost source of the persistent influx of nutrients to the Gulf, they recommended ways to substantially reduce the nitrogen loading from this source. Since then, 3 years have elapsed, but virtually non of the recommendations made to ameliorate the Gulf's ecological situation in either document have been carried out and the severe situation in the reef worsens every day.

1.5 Conclusions and a Word of Warning

At present, the coral reefs of Eilat are severely damaged and exist in a critical state. The alarming records of coral mortality in recent years, the increasing percentages of corals affected by pathogenic diseases and the first accounts of coral bleaching observed in the last 2 years, are strong indications of the fragile state of health of the coral populations in Eilat. I should perhaps emphasize the fact that the coral reefs of Eilat are no more than ca. 4 km in length. However, their uniqueness has been recognized worldwide due to their extraordinary biodiversity and beauty. There is no doubt in my mind that if a similar situation would have occurred on the Great Barrier Reef of Australia (2500 km), or for that matter, any other country that values its natural resources, there would have been immediate action to remedy the situation. The coral reefs of Eilat are a national as well as a global treasure. Therefore, even if there is the slightest doubt concerning the detrimental effect of eutrophication on reef corals, we

◀ **Fig. 1.11.** Examples of abundant species in the past at the northern Gulf of Eilat/Aqaba, which are rare or locally extinct today. **A** The sea star *Choriaster grannulatus*, **B** the feather star *Lamprometra klunzingeri*, **C** the sea urchin *Asthenosoma varium*, **D** the pencil sea urchin *Heterocentrotus mammilatus*, **E** The tiny sea urchin *Lovenia elongata* (maximum length 5 cm), **F** the basket star *Astroboa nuda*, **G** The hydroid fire coral *Millepora platyphylla*, **H** The medusa *Cassiopea andromeda*, **I** the soft coral *Litophyton arboreum*, **J** the soft coral *Clavularia hamra* cannot afford to let our reefs wait for "unequivocal scientific proof". First-rate scientific fieldwork in coral reefs requires much effort, long time and large budgets. To date, sufficient evidence has accumulated from research performed by leading marine scientists in Israel to indicate that environmental eutrophication caused by Eilat's sewage in the past (until 1995) and in recent years by the fish farms is a major cause of the deterioration of the reefs. While most other harmful man-made activities have been minimized by strict environmental enforcement (see 1.2.3., 1.4.1), the persistent influx of nutrients from the fish farms continues to pollute the Gulf without any control. The phenomenon of global warming sets the ground for additional severe threats to our reefs, which is superimposed on their critically frail state of health. In case of future abnormal increases in SSTs in the northern Gulf, which might result in mass coral bleaching, the chances of Eilat's coral communities to recover are minute, in view of their critically frail state of health. Our reefs are dying at an alarmingly fast rate. Any further bureaucratic delays imposed by the government concerning the fate of the fish farming mariculture at Eilat will condemn the reefs to their final destruction. I strongly advocate adoption of the major recommendation given in the "Scientist's Document" (Genin et al. 2001), i.e., immediate relocation of the fish farm operation to inland ponds. Continuation of the present persistent influx of nutrients originating from the fish farms constitutes a major cause for the continued deterioration of the coral reefs of Eilat and comprises a serious threat to their very existence. If eutrophication of the reefs is not stopped immediately, the total destruction and final collapse of the unique coral reefs of Eilat are a certainty. In the past, this process might have taken 15–20 years. However, in view of the ever-increasing demands we impose on our reefs, in addition to the problem of global warming, the process of the diminution of our reefs will probably be much faster. We cannot and should not let this happen. In their present fragile state of health, the only chance for restoration of the reefs is instant and extreme protection measures against all man-made perturbations.

Acknowledgments. It is a pleasure to thank my past students and present colleagues, who, throughout the years, participated and contributed to different parts of the research reviewed in this paper: A. Abelson, Y. Benayahu, I. Brickner, M. Ilan, R. Klein, E. Kramarsky-Winter, A. Kushmaro, H. Lubinevsky, O. Mokady, B. Rinkevich, M. Rosenfeld, Y. Schlesinger and M. Shpiegel. I am especially indebted to the Interuniversity Institute of Eilat (IUI) for being my "second home institute", for the continued support and hospitality during more than three decades. I am mostly indebted to the following people who kindly contributed part of the photos in this chapter: Fig. 1.2C (F. Grassle); Fig. 1.3F (R. Shem-Tov); Fig. 1.6A (I. Grinberg); A insert (D. Zakai); B (A. Diamant); C (Z. Livnat); D, G (J. Batist); H (O. Ben-Zvi); Fig. 1.10A–D (R. Sulam); Fig. 1.11H (R. Klein); Fig. 1.10E, J (A. Shoob); The research reported in Section 1.4 was partially supported by the monitoring program for the Jordanian–Israeli Red Sea Marine Peace Park Program, the Israeli Science Foundation and the Raynor Chair for Environmental Conservation Research.

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