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-

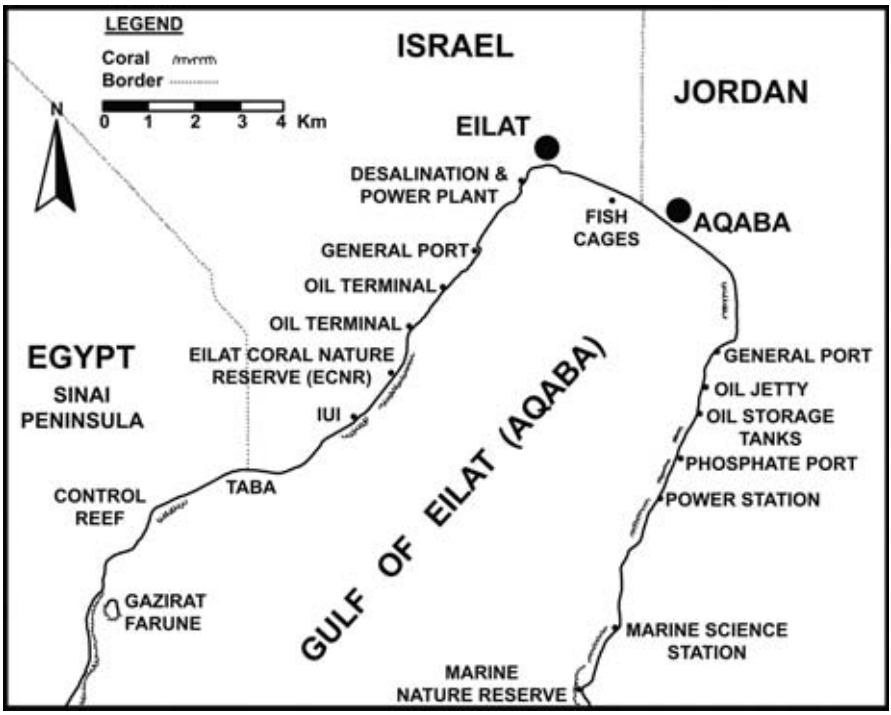
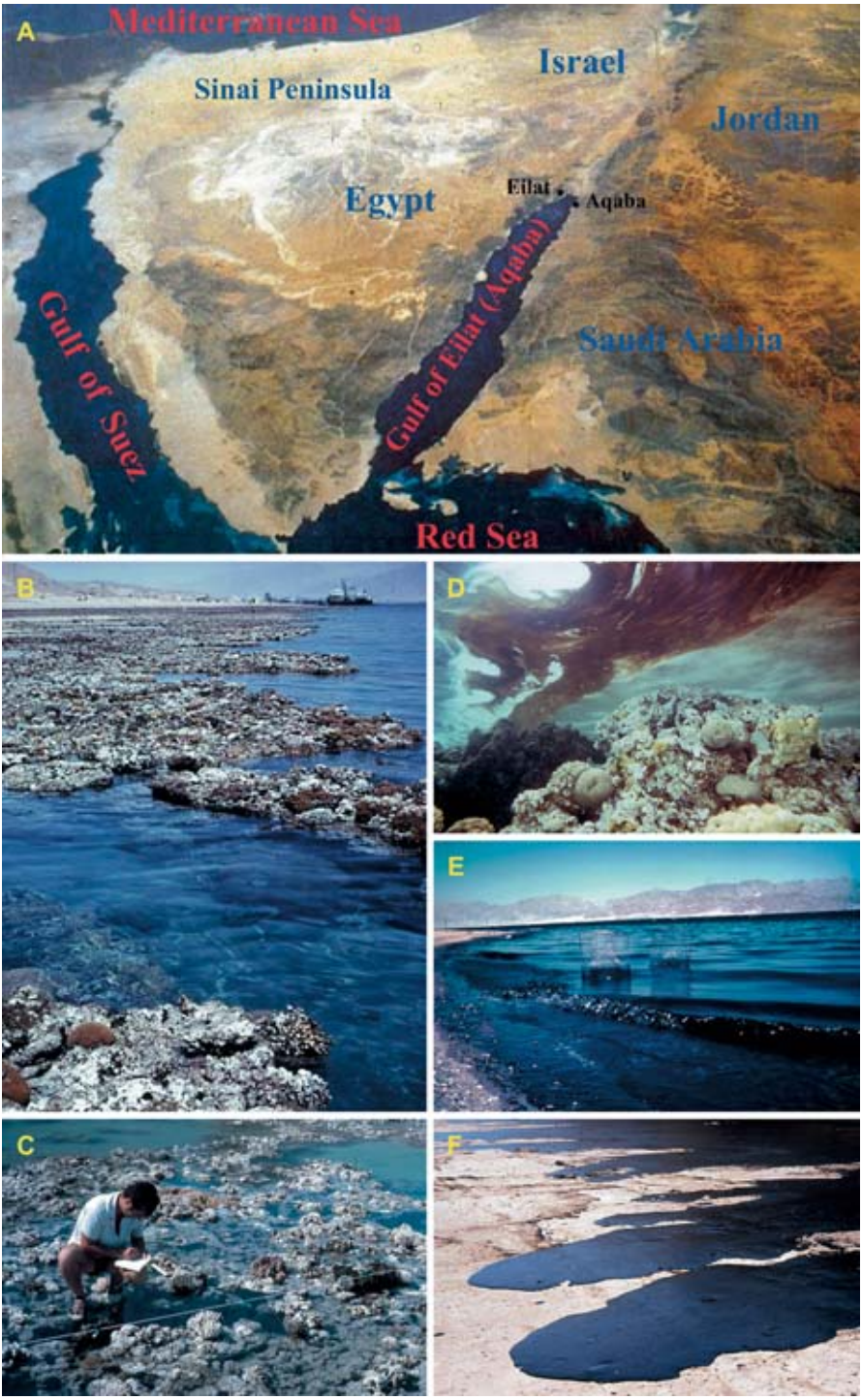


Fig. 1.1. General map of the northern Gulf of Eilat/Aqaba indicating the work sites: Eilat Coral Nature Reserve (ECNR), the Control Reef, the Interuniversity Institute (IUI) and the mariculture fish cages

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 ▶

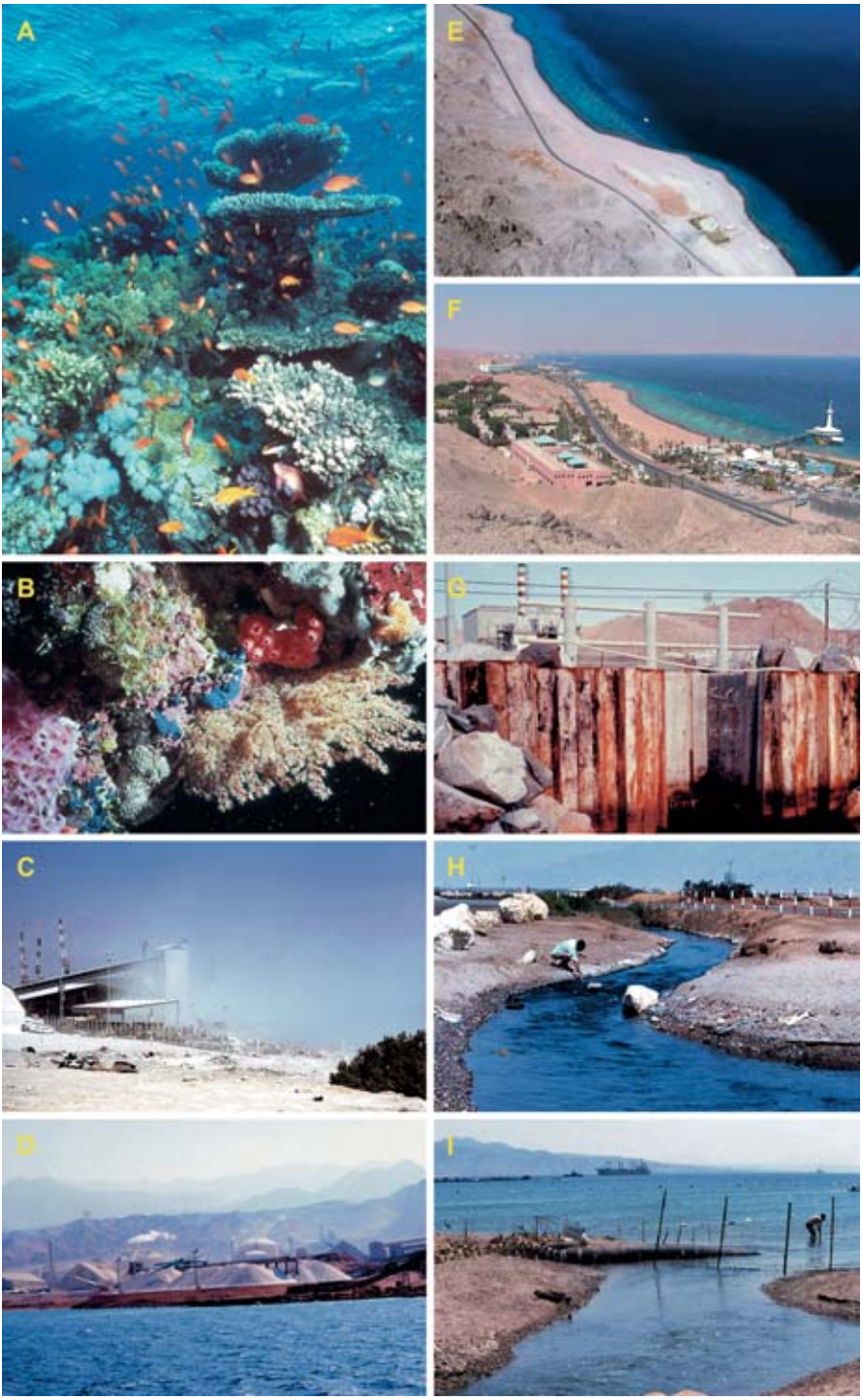

A
Mediterranean Sea
Israel
Sinai Peninsula
Jordan
Egypt
Eilat
Aqaba
Gulf of Eilat (Aqaba)
Saudi Arabia
Gulf of Suez
Red Sea
B
D
E
C
F

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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I

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