15. Diversity and Recent Changes in the Echinoderm Fauna of the Gulf of Aqaba with Emphasis on the Regular Echinoids

(color plates pp. 240-242)

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Introduction

The Echinodermata are a relatively small group of animals in the Red Sea. Yet, several species of this group are keystone organisms with an important ecological role: Several regular echinoids are algal grazers that check the dominance of algae over corals, while the Crown-of-thorns starfish (*Acanthaster* planci, L., 1758), a coral predator, is a potential threat to coral reefs throughout the Indo-Pacific Ocean. The ecological role of other echinoderms is probably unappreciated due to our ignorance.
The following is an attempt to summarize the author's results of a research in the echinoderms of the northern Red Sea and the Gulf of Aqaba over the last 30 years, and non-quantitative observations.

Red Sea Echinoderm Research: Past and Present

Early echinoderm data from in the Red Sea (17th to early 20th centuries) are mainly taxonomic. Sporadic research and several expeditions provided new species to an ever-growing taxonomic list. Only in the second half of the 20th century, did echinoderm ecology research begin in the Red Sea main basin (Hughes, 1977; Campbell, 1987), in the Gulf of Suez (GS) (Pearse, 1969a, b) and in the Gulf of Aqaba (Magnus, 1963; Tsurnamal and Marder, 1966; Mergner and Schuhmacher, 1974; Lawrence and Ferber, 1971; Dafni, 1980, 1983b, 1992; Jafari and Mahasneh, 1987; Dotan, 1990). Most of these studies dealt with the behavior or ecology of single species, genera or families. Only two quantitative studies on the distribution and ecological status of the echinoderms in the Gulf of Aqaba were made (Benayahu and Loya 1976, 1977; Mastaller 1979). Lately, genetic studies (Lessios et al., 2001, 2003) have tried to establish the degree of genetic diversity among populations of the tropical echinoid genera *Diadema*, *Echinothrix* and *Tripneustes*, represented in the Red Sea, applying mitochondrial DNA techniques, whereas Coppard and Campbell (2004, 2006) study morphological varieties in the sea urchins *Diadema* and *Echinothrix*.

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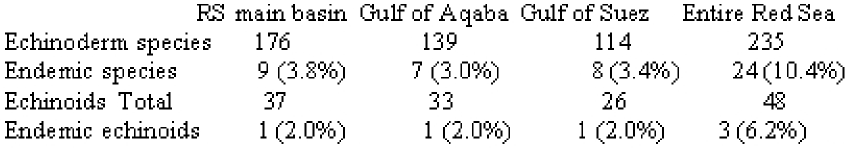
Species Richness

The biogeographic origin of the present Red Sea (RS) fauna consists of (1) Tethys relics and Mediterranean Miocene immigrants, (2) Pliocene-Pleistocene pre-glacial Indo-Pacific (IP) fauna, which survived the extreme climatic stresses throughout the Pleistocene, and (3) newly settled post-glacial IP invaders (Klausewitz, 1972; Por, 1975). All this is reflected in the distribution and endemism of the RS echinoderms.

Price (1982) recorded 170 echinoderm species from the RS, 137 in the Gulf of Aqaba (GA) and 110 in the Gulf of Suez (GS). The rate of endemic species was 5.3%, 5.1% and 7.3%, respectively. Campbell's (1987) species estimate, based on Clark and Rowe (1971), was of 189 species for the entire RS, and the rate of endemism was 14%. The low number of species and high percentage of endemics, recorded in the two distant northern Gulfs could have been expected, due to their smaller size, and the ecological gradients due to a *cul-de-sac* effect. The fact, however, that > 50 non-endemic species in Price's (1982) list, recorded exclusively in the GA or GS, are absent from the RS main basin, is apparently a result of inadequate taxonomical research of the latter area. If these species are added to the RS count the percentage of species unique to the Gulfs (real endemics) will be strongly reduced. In a later paper a modified estimate of 235 echinoderm species for the entire RS is presented (Price and Izsak, 2005), and the endemic rate is corrected to 10.4%. The endemic rate for the RS main basin and the Gulfs is expressed as percentage of the total count for the entire RS (Table 1). In this paper I want to draw more conclusions from the available sources, and my own unpublished observations during almost 30 years, with a special emphasis on echinoids, which are my personal research topic.



	RS main basin	Gulf of Aqaba	Gulf of Suez	Entire Red Sea
Echinoderm species	176	139	114	235
Endemic species	9 (3.8%)	7 (3.0%)	8 (3.4%)	24 (10.4%)
Echinoids Total	37	33	26	48
Endemic echinoids	1 (2.0%)	1 (2.0%)	1 (2.0%)	3 (6.2%)

Table 1. The species count of echinoderms listed for the Red Sea and Gulfs (after Price, 1982; Price and Izsak, 2005). Echinoid endemics based on Dollfus and Roman (1981) and additions discussed in text.

The Issue of Echinoid Endemism

Endemism refers to species that occur naturally only in a specific region or site. The Late Cenozoic history of the Red Sea presented spells of relative or even total isolation from the Indian Ocean (Klausewitz, 1972). The RS endemic species are either pre-Glacial or post-Glacial. The pre-Glacial endemics are often dispersed also in the adjacent seas, Gulf of Aden and the Arabian Gulf, where they presumably found shelter during the isolation crises, while the post-glacial RS endemics differ only slightly from their oceanic conspecifics, and are usually ranked as varieties or subspecies, with a restricted RS distribution.

A. RS endemic echinoids, described as varieties or sub-species:

- *Nudechinus gravieri* var. *suezensis* Dollfus and Roman, 1981 was recorded both for the GS, and GA, where it is sympatric with the IP species *Nudechinus scotiopremnus* H.L. Clark, 1912.

- *Echinothrix calamaris* (Pallas, 1774) is common in the GA. Throughout the IP it is known as the "banded sea urchin." In the RS it is invariably pitch-black ("dark morph"), a coloration similar to the IP species *E. diadema* (L., 1758). Nevertheless, *calamaris* juveniles in the RS are banded. They often show the habit of clustering their spine tips in five directions, mimicking the shape of a large starfish.
- *Diadema setosum* (Leske, 1778) is a keystone species in the RS reefs. It feeds on benthic algal cover, thus facilitating settlement of coral larvae. It is widely distributed throughout the IP. Dollfus and Roman (1981) described *Diadema setosum* forma *depressa* from the GS to represent the morphology of a local RS variety. A recent mitochondrial DNA study (Lessios et al, 2001) showed that the species *D. setosum* forms two lineages: Lineage A, for the entire IP, and lineage B for the RS and Arabian Gulf. Based on these results they suggested that *D. setosum* Lineage B split from their mother population in the Pliocene (4 my) to disperse later around the Arabian Peninsula.

Coppard and Campbell (2006) defined two distinct morphs of *E. calamaris* -a white, banded color morph and a non-banded brown color morph (which looks black in the sea). Examining several specimens from Eilat, I found that they show mixed characters. In one specimen, the upper IA plates lack spine tubercles, as characterized for the white morph. Both species bare tests are easily differentiated: while *E. calamaris* test is bald near the apex, and the Ambulacral column (=Amb) is wider and bulging, *E. diadema* has more IA spine tubercles, and a less pronounced Amb area (Fig. 1, color plate p. 240).

I propose that this species underwent selection for the darker morph, which may deceive the predators or other observers as a large *Diadema*, which is apparently a case of Müllerian mimicry. It is relatively less vulnerable to predation by the echinoid predating fish *Pseudobalistes fuscus* (Bloch and Schneider, 1801) (Fricke, 1971).

Mastaller's (1979) report on the occurrence of *E. diadema* in the Gulf of Aqaba is probably a misidentification. He mistook the dark morph of *E. calamaris* for *E. diadema* and the juveniles for *E. calamaris*. A RS variety, *E. calamaris* var. *desorii* (Agassiz and Desor, 1846), was proposed by Dollfus and Roman (1981), as a distinct Northern RS variant.

- *Tripneustes gratilla* was the subject of long-term research, initiated by the appearance of extreme deformities in polluted sites at Eilat (Dafni, 1980, 1983b). A RS variant of this species was described as a sub-species, *T. g. elatensis* (Fig. 2A, color plate p. 240), based on the following differences (Dafni, 1983a): Larger individuals have significantly fewer IA plates per column than *T. g. gratilla* (Fig. 2B,color plate p. 240); it has fewer spines -fewer than 1 primary spine per each IA plate, compared with 2-3 spines per IA plates in the latter; it shows a flatter profile than *T. g. gratilla*, which has a more conical appearance.

Another conspicuous phenomenon in *T. g. elatensis* is the excessive number of pedicellaria, which are probably its most efficient measure of protection. The color of the pedicellaria, extremely variable, is the most dominant color determinant. The oceanic T. g. gratilla, on the other hand, has a more uniform coloration.

Another difference between the RS and IP *Tripneustes* is their habitat preference. While *T. g. gratilla* dwells mainly in sea grass meadows, covered by organic debris and pebbles, *T. g. elatensis* prefers rocky substrates, and is vulnerable in soft bottom habitats. This was shown in Mastaller's (1979) experiment. He transferred 850 living animals from hard substrate to a sea grass meadow in front of a reef slope, 12 m deep. The stressed animals clumped into large groups, masking themselves with sea grass leaves. Four days after onset of this experiment only half of the animals survived, and only 14% were found in the sea grass lawn after 10 days. More than 40 urchins found refuge in rock holes in the near reef wall. The empty tests scattered in the experimental site proved that predation was the main cause of their demise.

B. The enigmatic case of the Gulf of Aqaba endemic species

- *Pericosmus akabanus* Mortensen, 1939, dredged from a depth of 272 m during the R/V "Mabahith" expedition, has been considered a GA endemic. The genus *Pericosmus* is a common genus with at least 10 species throughout the IP and extinct species are known from the Lower Eocene to Recent (Smith, 2007). M. Jensen (quoted by Türkay, 1996) found it in the Indian Ocean, which may suggest that *P. akabanus* is a pre-Glacial RS endemic.
- *Asthenosoma marisrubri* Weinberg and de Ridder, 1998, formerly known as *Asthenosoma varium* (Grube, 1868), was described from the northern RS. It is well distinguished from the oceanic *A. varium* by its spine and test morphology: The IA spines regularly cover the entire aboral side in *A. marisrubri*, but grouped in rectangular patches, separated by naked areas, in *A. varium*. Since Weinberg and de Ridder found no evidence of the occurrence of *A. varium* east of the Maldive Islands, and of *A. marisrubri* extending towards the southern RS and the adjacent Western IP waters, pre-Glacial endemism is also a possibility.

Population fluctuations at Eilat – are they natural or man-made?

Throughout the last three decades I have noticed extreme temporal fluctuations in the distribution of several common echinoderms. In the following I would like to distinguish between natural fluctuations and possible anthropogenic influences.

Tropical echinoids are usually short-lived, and have high growth rates (Ebert, 1975). On the other hand, regular sea urchins in the RS show large annual fluctuations that question the reliability of the observed statistics. Unpredictable settlement of the planktonic larvae, and environmental factors may account for the observed extreme fluctuations in *Tripneustes gratilla elatensis*, from great abundance in 1979 to total absence in 1980 (Dafni, unpublished). Similarly, Mastaller (1979) recorded fluctuations of this sub-species within one year (0.3-0.9/m^2 in 1976 to 6.2-7.9/m^2

in 1977). Dotan (1990) found similar fluctuations in southern Sinai *T. gratilla* 1.4 ± 2.7/m^2, 4.9 ± 3.1/m^2 , 0.4 ± 0.8/m^2 (SD larger than mean).

In a long-term study of its life history, Dafni and Tobol (1987) showed that *T. g. elatensis* has an annual life cycle (rapid growth and early reproduction) in wave exposed shores dominated by an abiotic factor, such as destructive winter storms It has a perennial life cycle in protected reef environment, with predation by large labrid fishes as a dominant biotic factor.

Temporal fluctuations were shown by several other RS echinoderm species, such as *Lovenia elongata* (Gray, 1845)*, Clypeaster humilis* (Leske, 1801), and to a lesser extent by *Echinodiscus auritus* (Leske, 1778). During the early 1980s many specimens of the sea star *Choriaster granulatus* (Lutken, 1869) (Fig. 3, color plate p. 240) existed at Eilat, whereas in the southern part of the GA, and the northern RS they were totally absent (Crane, 1986).

Possible man-made perturbations

My observations reveal a trend of temporal population frequency decrease among the echinoderms of the Eilat coast for the last decades. Common species have become rare, and rare species have almost disappeared. The list includes the regular echinoids *Phyllacanthus imperialis* (Lamarck, 1816); *Prionocidaris baculosa* (Lamarck, 1816); *Heterocentrotus mammilatus* (L., 1758) and *Microcyphus rousseaui* Agassiz and Desor, 1846; the irregular echinoids *Laganum depressum* (L. Agassiz, 1841); *Echinodiscus auritus; Paraster gibberulus* (Agassiz and Desor, 1847), and *Metalia sternalis* (Lamarck, 1816); the asteroids *Choriaster granulatus; Astropecten polyacanthus* Müller and Troschel, 1842; *Linckia multifora* (Lamarck, 1816); the ophiuroids *Ophiocoma scolopendrina* (Lamarck, 1816) (Fig. 4, color plate p. 241); *O. valenciae* Müller and Troschel, 1842; *O. pica* Müller and Troschel, 1842; *Ophiolepis cincta* Müller and Troschel, 1842 and *O. superba* H.L. Clark, 1915**.** The basket star *Astroboa nuda* (Lyman, 1894**)** (Fig. 5, color plate p. 241), have become extremely rare.

An exceptional phenomenon was the total disappearance for a decade of the common crinoids *Heterometra savignyi* (Müller, 1841) and *Lamprometra klunzingeri* (Hartlaub**,** 1890) from the Eilat coral reefs, and their re-appearance, although in smaller numbers, in the mid-2000s.

Some of these phenomena are undoubtedly connected with the deterioration of the shallow water environment. We should also consider the possibility that shifts in larval dispersal or recruitment conditions may have caused it.

Other invertebrates having symbiotic association with echinoderms also show degradation. The sessile ctenophore *Coeloplana bannwarthi* Krumbach, 1933, that crawls on *Diadema* spines was not observed here for at least a decade. Other organisms associated with echinoids, namely the apogonid fish *Siphamia permutata* Klausewitz, 1966; the shrimps *Athanas indicus* (Coutière 1903) and *Tuleariocaris zanzibarica* Bruce, 1967; the parasitic sea star gastropods *Stylifer linckiae* Sarasin and Sarasin, 1887 and *Thyca ectoconcha* Sarasin, 1887 (Fig. 6, color plate p. 241) also have become extremely rare.

On the other hand, *Acanthaster planci* (Fig. 7, color plate p. 242) which was rare in the northern RS and the GA during the first half of the 20th century have become rather common, and its deleterious effects are seen in many reefs. Lately, its numbers in the Eilat Nature Reserve are being monitored to prevent damage to the corals within the marine Reserve (Zakai, pers. comm.).

The Effect of Pollution

The urban development of the northern Gulf of Aqaba, from several hundreds of inhabitants in the 1950s to over 150,000 in four ever-increasing towns, namely Aqaba (Jordan), Eilat (Israel), Nuweiba (Egypt) and Haql (Saudi Arabia), presents an increasing challenge to the impoverished tropical habitats. The impact of phosphate pollution on holothurians was studied in Eilat (Shlesinger, 1986). The effect of sewage and nutrient pollution on crinoids and other suspension feeders was often mentioned in context to their disappearance from the Eilat coast during the 1990s.

In the early 1980s I reported the discovery of two mass-deformity types in *Tripneustes gratilla elatensis* from Eilat (Dafni, 1980, 1983b). Type A deformity involved up-bulging, Amb narrowing and “pinching,” affected >60% of a population opposite an electric power station, combined with thermal seawater desalination (Site A). Pollution Type B showed extreme flattening and apical depressions of 76% of the individuals of an artificial lagoon population (Site B), suspected of being polluted by hotel laundry detergents (Fig. 8, color plate p. 242).

These deformities disappeared in 1982, due to closure of the power station and the lagoon’s deterioration, but reappeared during 2005, in another site, opposite a hotel facing the open gulf (Site C).

A measure was developed to describe these deformities, the ratio between vertical and horizontal diameter (H/D ratio). In type A deformity H/D increased to 1.3, compared with the 0.55 normal ratio. In type B H/D decreased to 0.3. However, deformity types did not intermix (deformity type B not found in site A and vice versa).

In a long-term study I discovered that four main processes were involved in the deformities:

- Calcification inhibition (by chemical reagents)
- Inter-plate collagen softeing (chemical) reducing test consistency
- Mechanical effects of muscles and mesenterial filaments, deforms their shape
- “Post-traumatic” calcification charecterized by resorption and allocation of $CaCO_3$, stabilizing the deformed morphology.

For a more detailed description of thne deformities and pollutants involved see Dafni (2007).

Discussion and Conclusions

Regular sea urchins play an important role in the ecology of rocky substrates. It is well established that *Diadema setosum* is the main algal feeder, and that depletion of it may cause "phase shift," i.e., the replacement of coral covered substrate with turf algae (Abelson et al., this volume).

The role of *Tripneustes* is usually underestimated, possibly because it is less common in the reef, but since Mastaller (1979) demonstrated its continuous circadian activity, the effects of this species should be more appreciated. Both *D. setosum* and *E. calamaris* are strictly nocturnal.

Three main factors determine the distribution of the IP and RS organism in the northern RS and its Gulfs: First, the sea temperature which declines from the southern to the northern part of the sea; second, the increase in salinity, from about 35 psu in the south to > 41 psu in the northern gulfs. Third, the Gulfs are subtropical dead-end bodies of water in terms of species distribution. It is conceivable that invertebrate species enter the gulfs as planktonic larvae, ready to settle. The above fluctuations and unpredictable recruitment of several echinoderm species in the GA may result from constrained larval dispersal, due to temperature and salinity gradients along the gulf, and shifting current directions at the Tiran Straits. However, the fact that many common species of echinoderms, mollusks and arthropods have become extremely rare in the northern tip of the GA over the last decades may also point to pollution or other anthropogenic influences (eutrophication, disturbance by urban development and recreational activities).

Aquantitative database of echinoderms is needed for future monitoring the existence and welfare of these interesting organisms. The absence of past quantitative records is deplorable. It is highly recommended to create such a database, comparing with Mastaller's (1979) quantitative records made in Aqaba in the 1970s.

Although pollution-induced deformities are well-known in larval echinoids (Kobayashi, 1977), a thorough literature and web survey shows that pollution-induced mass deformities in post-larval echinoids are not on record world-wide. The phenomenon of deformities emphasizes the extreme vulnerability of *T. g. elatensis* to chemical pollution, it provides insights to the morphogenetic process of echinoid skeletal development and finally illustrates that even a "small" pollution event may cause long-term changes in biological systems.

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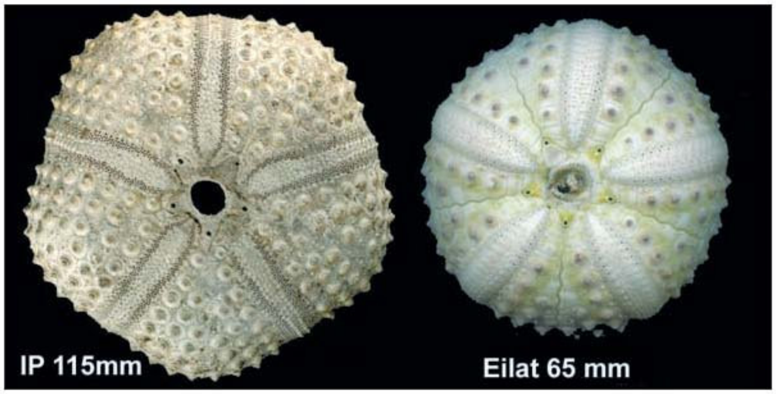

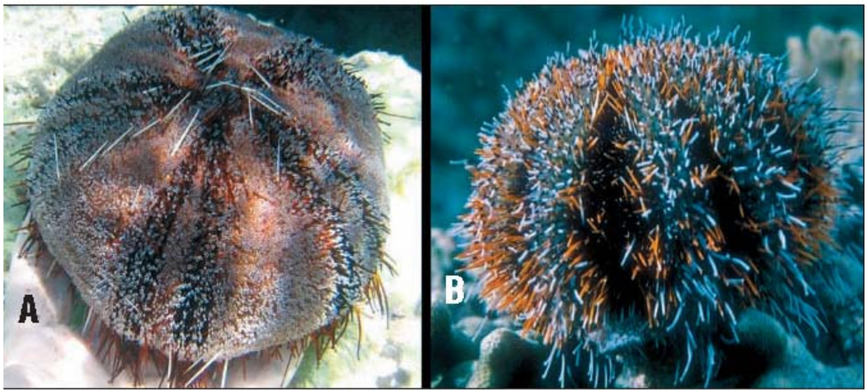

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Fig. 1. Two *Echinothrix* tests: Indo-Pacific *E. diadema*, (left) and Red Sea *E. calamaris* (right). Note the fewer spine tubercles and wider Amb in the latter. Photo (left): Echinold directory, MNH.

Fig. 2. Two sub-species of *Tripneustes gratilla.* A, Red Sea T. g. *elatensis* and B, the Indo-Pacific *T. g. gratilla*. Note the flatter appearance of the former, fewer aboral spines and high abundance of globiferous pedicellaria (grayish in this individual), compared with the very narrow dark pedicellaria "field" in the latter. Photo: (A) J. Dafni, Eilat ; (B) M. Boyer, Sulawesi, Indonesia.

Fig. 3. The sea star *Choriaster granulatus*. Contrary to common belief, it is not a coral predator. It feeds mainly on foraminifers and small invertebrates. Eilat; Photo: A. Colorni

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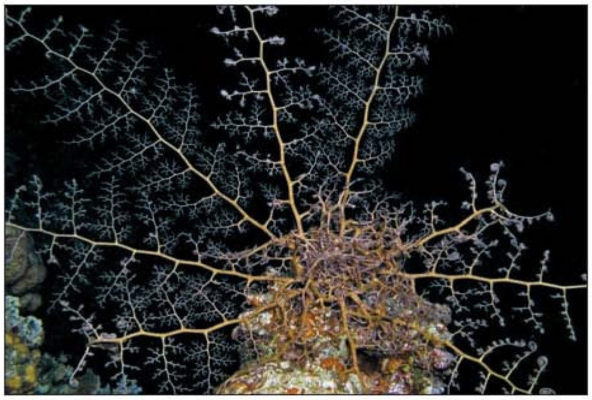

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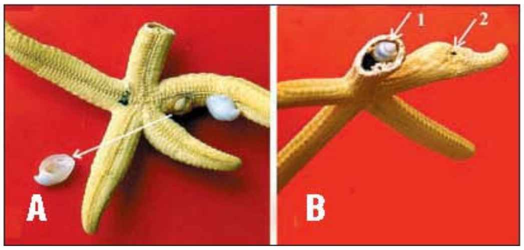

Fig. 4. The Brittle star *Ophiocoma scolopendrina* feeds on floating debris at low tide, Eilat; Photo: J. Dafni

Fig. 5. The nocturnal filter feeding basket star, *Astroboa nuda* (Ophiuroida). Dahab, 2004; Photo: I. Ben-Tov

Fig. 6. Molluscan parasites of the sea star *Linckia multiflora*. A. *Thyca ectoconcha*, an ecto-parasite, and B. *Stilifer linckiae*, an endo-parasite of the same. (1): an embedded snail in the coelomic cavity of the sea star, and (2): penetration hole in the arm and bulging, indicating the inner presence of another snail. Eilat; Photo: J. Dafni.

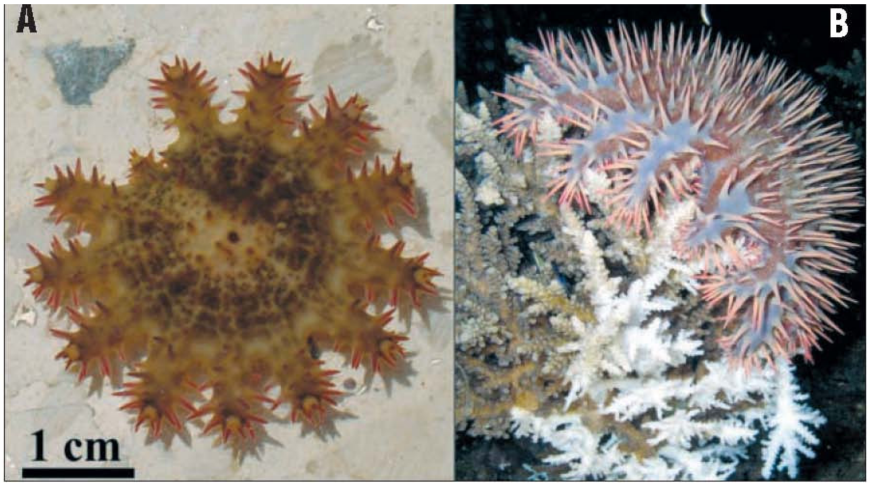

Fig. 7. The notorious coral predator *Acanthaster planci*. A, Juvenile. B, Adult sea star, feeding on a branching coral colony (*Acropora sp.*). Below, the denuded skeleton of the partly devoured coral is shown. Photos: A, J. Dafni; B, O. Lederman

Fig. 8. Two types of skeletal deformities in *Tripneustes gratilla elatensis*. A. Excessive vertical growth and up-bulging (Deformity type A); B. Deformity type B, showing extreme flattening and deep apical depressions. Photo: J. Dafni