

## *Aplysia* from shallow waters along the coasts of Israel

A. J. Susswein, Y. Achituv and S. Markovich

Department of Life Sciences  
Bar-Ilan University, 52100 Ramat-Gan, Israel

**Abstract :** Two species of *Aplysia*, *A. fasciata* and *A. depilans*, are common along the Mediterranean Coast of Israel. In the Red-Sea only *A. oculifera* was found. The sites and environment harboring *Aplysia* are described. The primary determinant for the presence of *Aplysia* at these sites seems to be a strong growth of food algae, especially *Ulva lactuca*.

**Résumé :** Le long de la côte méditerranéenne d'Israel, on rencontre deux espèces d'*Aplysia*, *A. fasciata* et *A. depilans*. A Elat, dans la Mer Rouge, nous n'avons trouvé que l'espèce *A. oculifera*. Nous décrivons ici les milieux où l'on rencontre le genre *Aplysia* ; la principale raison de sa présence semble être une abondante poussée des algues, *Ulva lactuca* surtout.

### INTRODUCTION

The genus *Aplysia* (Gastropoda, Opisthobranchia) has been intensively investigated as a model system for studying the neural basis of behavior (for review, see Kandel, 1976, 1979).

Recent studies have begun to examine *Aplysia* behavior from the point of view of adaptation to the environment (Kupfermann & Carew, 1974 ; Susswein *et al*, 1983 ; Susswein, 1984 ; Susswein *et al*, 1984). However, little information is available on environmental determinants for the presence of *Aplysia* ; only scattered reports have appeared describing some of the habitats where *Aplysia* are found (reviewed in Kandel, 1979).

Barash and Danin (1971 ; 1982) reported the presence of four species of *Aplysia* from the Mediterranean coast of Israel : *A. fasciata* Poiret, *A. juliana* Quoy and Guimard, *A. parvula* Morch and *A. punctata* Cuvier. Another species, *A. depilans* Gmelin, is known from other parts of the Mediterranean (Bebbington, 1975 ; Eales, 1970), but is not reported by Barash and Danin (1971 ; 1982). *A. juliana* and *A. parvula* are recent immigrants to the Mediterranean (Bebbington, 1975 ; Eales, 1970). According to Fiorito (pers. comm.), it is difficult to distinguish between *A. juliana* and *A. depilans* : their foot, radular morphology and egg masses are indistinguishable and specimens supposed to be *A. depilans* and *A. juliana* mate.

In the Red Sea, five species of *Aplysia* were recorded (Eales, 1979), of which *A. oculifera* Adams and Reeve is the most common.

We described the seasonal and topographic factor influencing the presence of Mediterranean *Aplysia* (Gev. *et al*, 1984 ; Achituv & Susswein, 1985). In the present paper, we describe in detail the environment and conditions in which the most

common *Aplysia* are found, both in the Mediterranean and Red Sea coasts of Israel. This provides context for the description of natural behaviour. Because environments harboring different species of *Apfysia* in various parts of the world seem to be similar, our description is likely to be useful to others wishing to utilize local *Apfysia*.

## METHODS

In the Mediterranean, *Apfysia* were searched from July 1980 to August 1983, in water up to 1.5 m in depth, at sites scattered along ca. 150 km coast. Data are based upon more than 100 trips throughout the year. Shores examined include sandy beaches, rocky shores, coastal platforms, jetties, fishing harbors and artificial saltwater pools. Only specific sites described in greater detail below were examined repeatedly. Types of shores that were never found to harbor *Apfysia* were periodically checked, to be certain that absence of *Aplysia* was not due to our oversight. We did not search in waters deeper than 1.5 m, but some information about such sites was available from fishermen and scientists studying deep-water sites. A number of sites along the Red Sea coast of Elat were sampled for the presence of *Apfysia* between March 1980 and June 1984. Environments at Elat are fairly uniform, precluding comparisons between them.

*Apfysia* were located by three methods : visually, while snorkelling ; feeling along the bottom, along and under rocks ; picking algae and searching among them. The last method was particularly effective in finding small individuals. Unless otherwise explicitly stated in the text, observations were performed in daylight hours.

Algae growing in areas harboring *Apfysia* were identified by referring to Nemlich and Danin (1964).

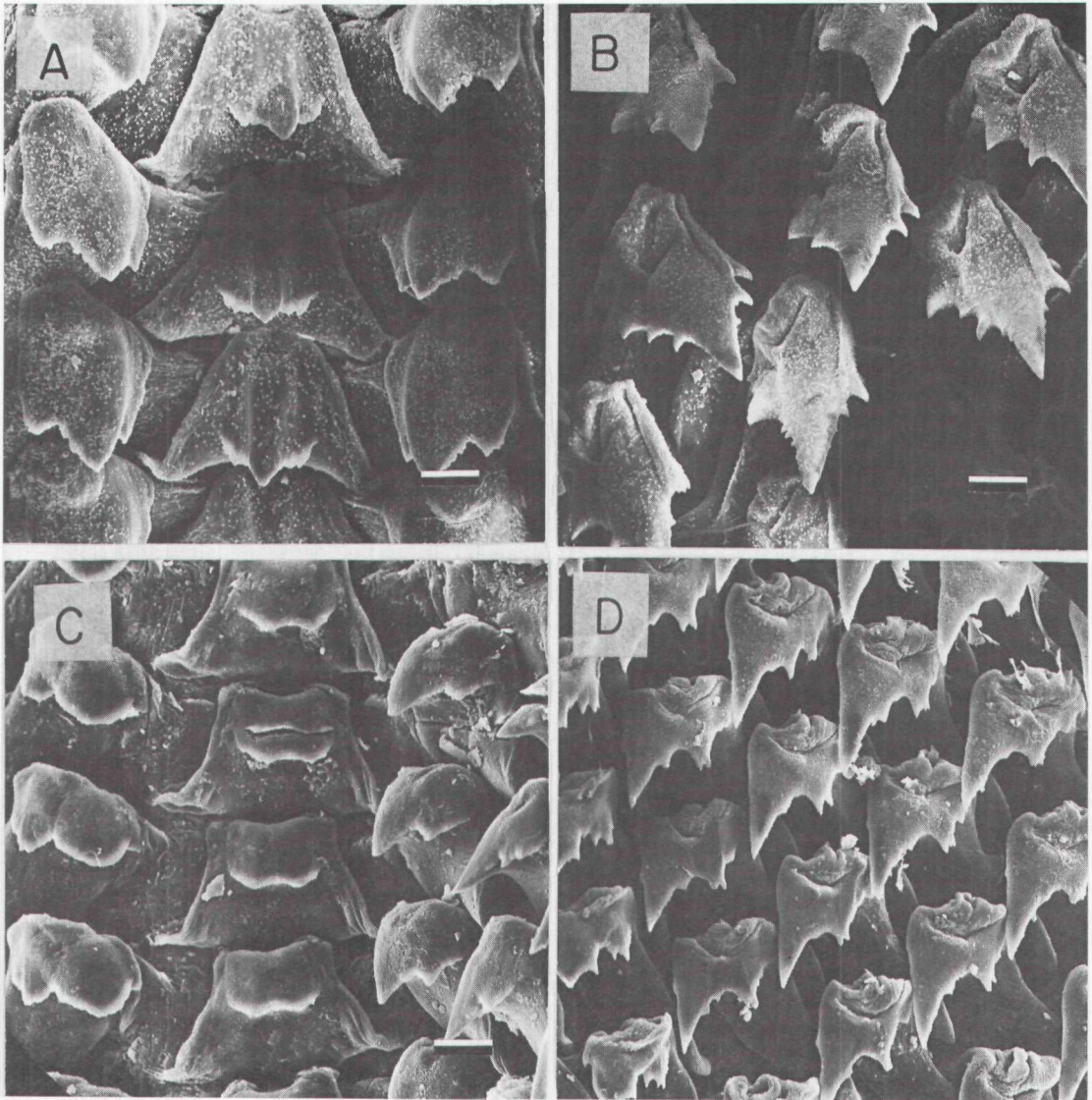
Jaws and radula preparations were examined using scanning electron microscope.

## RESULTS

### MEDITERRANEAN COAST:

#### *Species*

Two species of *Apfysia* were common in the Mediterranean coast of Israel, *A. fasciata* and a second species supposed to be either *A. depilans* or *A. juliana*. A third species, identified as *A. parvula* was rare. The radula of animals showing external feature of both species, *A. depilans* and *A. juliana*, is shown in Fig. 1, and compared to that of a valid specimen of *A. juliana* from Hawaii and to the description of *A. depilans* from Malta and Naples (Bebbington, 1976 ; 1975). The ra-



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Fig. 1 - SEM photograph of radular teeth of *A. depilaos* from the Mediterranean coast of Israel and of *A. Juliana* from Hawaii ; Length of bar is 10  $\mu$ m. A and B = median and lateral teeth of *A. depilaos*. C and D = median and lateral teeth of *A. Juliana*.

dulas of Mediterranean specimens differ from those of *A. juliana* from Hawaii and are similar to the description of the radula of *A. depilans*. Median tooth of *A. depilans* with a narrow head and a narrow notch in it, those of *A. juliana* are with a broader head and trapeze-like. Cusp of the medians of *A. depilans* is with one central large denticle and a few small ones; in *A. juliana*, the cusp shows two large denticles. The laterals of *A. depilans*, with two large denticles of more or less the same length on each side of a median denticle and several fine denticles. In *A. juliana*, the cusp of the laterals with two unequal denticles, one of which is more median, and longer. There are also several small denticles.

#### *Sites and Seasons*

Fig. 2 illustrate sites, dates and quantities of *Aplysia* found along the Mediterranean coast. Descriptions apply only to *A. depilans* and *A. fasciata*. Most sites harbored both *A. fasciata* and *A. depilans*, but the species were not equally distributed. Data presented elsewhere (Achituv & Susswein, 1985) suggest that *A. fasciata* are better adapted for calm, protected waters, while *A. depilans* are more successful in rougher waters. The two species are both present in sites of intermediate roughness.

A number of sites were consistently found to harbor *Aplysia* in every year in which they were examined (Fig. 2). However, in some places, animals disappeared for all or part of a season. At Akhziv, in two outings in 1982, only four animals were found, while in previous and subsequent years hundreds of animals were found at the same site. The reason for the absence of *Aplysia* was not clear, since *Ulva lactuca* L., the primary food of *Aplysia* (Achituv & Susswein, 1985; Susswein *et al.*, 1984), was present in abundance. Sometimes the reason for disappearance of the animals is clear. At the rocky shore of Nof-Yam, in early May 1982, hundreds of dead *Aplysia*, with large quantities of bleached seaweeds were observed. This was due to acid spillage from a nearby chemical plant. Algae rapidly grew back, eliminating all evidence that an accident had occurred. A small population of *Aplysia* was found 6 weeks later, but throughout the rest of the season animals were rarer than in the year before. Had spillage effects not been directly observed, the subsequent disappearance of *Aplysia* at this site would have been inexplicable. Subsequent acid spillage in the 1983 season again eliminated all *Aplysia* at this site. *Aplysia* were again found in large numbers at this location in 1984.

In some sites, a specific rock or crack consistently harbored *Aplysia*. Occasionally, a few weeks after removal all animals, *Aplysia* were again found at the same location. Sometimes the spot repeatedly chosen by animals obviously provided more protection than did adjacent areas, but at other times the choice was enigmatic.

#### *The environment*

Rocky substratum is formed by collapse of the cliffs which run parallel to the shore (Emery & Neev, 1960), or by their penetration into the water, where they form erosion platforms (Safriel, 1966). Tides range from 20 to 30 cm, and are often

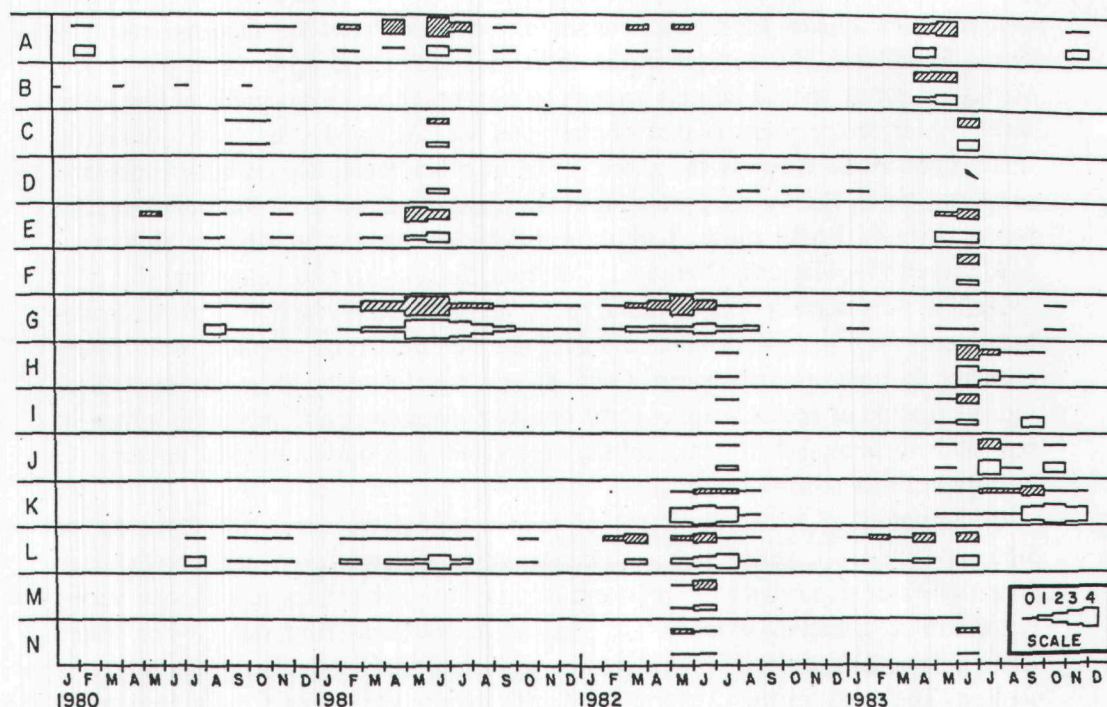


Fig. 2 - Abundance of *A. fasciata* and *A. depilans* at various sites along the Mediterranean coast of Israel were searched more than once, at various times throughout 4 years of research. Abundance is indicated by the thickness of the line. Scale (insert) : in about 1 hr of search, 0 = no animals were found; 1 = 1-10 animals were found; 2 = 10-50 animals; 3 = 50-100 animals; 4 > 100 animals. Where no line is shown, no observations were made. Sites searched are arranged from north to south: A = Akhziv; B = Akko; C = Shiqmona; D = Maagan Michael; E = Mikhmoret; F = Hof Hayaroq (Netanya); G = Nof-Yam; H = Tel-Barukh; I = Country Club (Tel-Aviv); J = Tel-Aviv port; K = Yaffo port; L = Yaffo (platform); M = Bat Yam; N = Palmahim. Shaded areas: *A. depilans*; clear areas: *A. fasciata*.

concealed by waves and water movement due to changes in barometric pressure. From June to October the sea is usually rough, with waves 0.8-2.5 m in height; from October through May the sea is calm, with occasional storms. Prevailing winds are from the north-west. During spring, summer and early fall, local *sharav*, heat waves occur, during which air temperature is at least 5°C higher than the mean value for the period. During a *sharav*, coastal platforms and rocks along the shore are exposed. Sea surface temperature ranges from 17°C in march to 29°C in august (Israel Meterological Service, personal communication).

*Aplysia* were found in five types of environments: 1) rocky shores; 2) platforms of rock extending from shore; 3) protected ports; 4) saltwater pools; 5) deepwater rocks.

1) *Rocky Shores*. In this habitat, rocks or ridges are surrounded by sandy or stony bottom. Rock surfaces immersed in water or subject to spray are generally covered with algae, such as *Ulva lactuca* L., *Enteromorpha Unza* Agardh and *Enteromorpha intestinallis* Link; occasionally a rock is covered by *Caulerpa scalpelliformis* Van Bosse. Rocks begin at the shoreline, and extend up to 50 m out to sea. Rocks are rarely spaced densely enough to trap water and form pools at low water level. Water temperature is that of the open sea. At some sites, waves break directly upon rocks close to the shore, while at other locations, outlying rocks and platforms break the waves, protecting rocks closer to shore from the full impact of waves (Fig. 3). Rocky shores harboring *Aplysia* were found at Akhziv, Shiqmona, Mikhmoret, Hof Hayaroq (Netanya), Nof Yam, Tel Barukh and Palmahim.

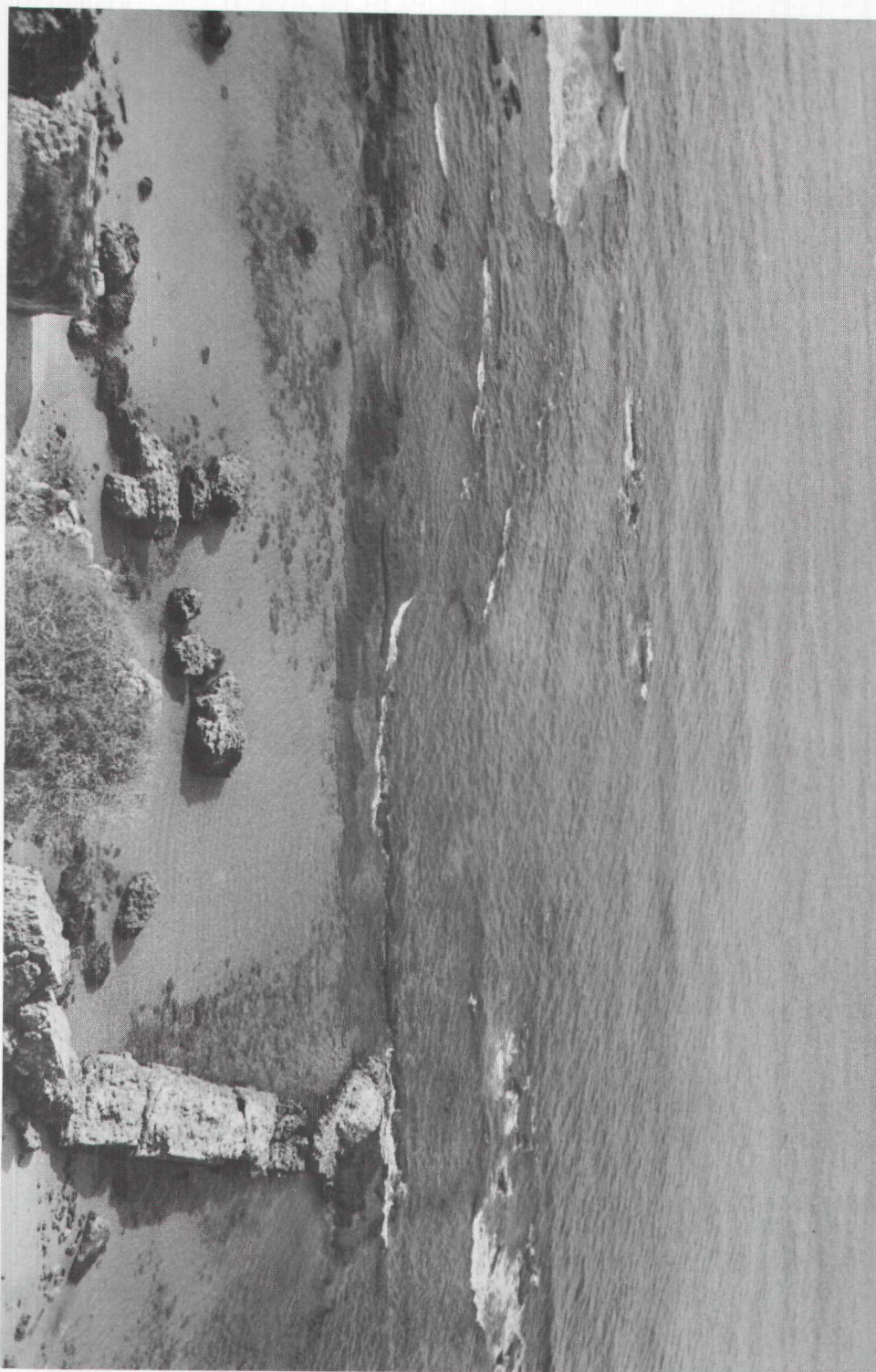
*Aplysia* were usually found under rocks, between closely apposed rocks, in depressions within a rock, or sometimes on the side of a rock. Animals were rarely observed in open areas between rocks. *Aplysia* were close to algae. Animals favored the leeward side of rocks, keeping rocks between themselves and incoming waves. In regions with sandy substratum, *Aplysia* were sometimes buried in sand underneath or adjacent to a rock.

2) *Platforms of Rock*. Platforms of rock extend from shore for distances of 5-50 m; they are covered with a rich population of green, red and brown algae (Fig. 4). Water depth over the platform depends on weather conditions, and varies from zero to a meter or more. Depressions in platforms trap water when water level is low. Temperature is that of the sea or somewhat higher when water is shallow. The edges of the platform are heavily exposed to waves. Central regions of platforms are variably exposed to waves, dependent upon weather conditions. Work on platforms was possible only in calm seas. *Aplysia* were found upon platforms in which the dominant flora was *Ulva lactuca*, generally within cracks, depressions, ridges and holes in the platform, often below or underneath the lip of a ledge surrounding a depression. Animals were sometimes under the margins of a platform. *Aplysia* were rarely observed in ponds cut from the sea. Platforms harboring *Aplysia*, were those of Akhziv, Akko, Mikhmoret and Yaffo.

3) *Protected Port*. In this environment, a breakwater creates a protected bay (Fig. 5). Depth varies from 5 cm to over 2 m. At various points, rocks are adjacent to the breakwater. Prominent cracks, pits, niches and indentations are present in the walls. A rich growth of *Ulva lactuca* was found upon the walls early in the spring; in midsummer, this was replaced with a sparse growth of red seaweeds such as *Jania rubens* Lamouroux and *Pterocladia capillacea* Bornet, mixed with remnants of *Ulva*. Other green algae, such as *Bryopsis adriatica* Meneghini, *Ente-*

Fig. 3 - The rocky shore environment at Nof-Yam (Herzliya). Rocks of various sizes are found along the shore. Waves break upon outlying rocks and platforms, and rocks closer to shore are in relatively calm water.





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*romorpha intestinallis* and *Caulerpa scalpelliformis*, also grew in ports. At Yaffo, at water level there was a shallow ledge about 40 cm wide which was carpeted with *Ulva*, even late in the season. The water in the port is about 2° C warmer than in the open sea. Ports are relatively unaffected by waves, although brisk currents are occasionally present; in ports, *Apfysia* were found adhering to walls, often in cracks or niches, or around rocks adjacent to the walls. *A. fasciata* were sometimes observed swimming close to the port walls. Animals occasionally rise to the *Ulva* - covered ledge to feed. Small groups of animals were also occasionally found buried in sand adjacent to a wall. *Apfysia* were found in three ports : Yaffo, Tel-Aviv and the Tel-Aviv Marina.

4) *Saltwater Pools*. Seawater is aperiodically pumped into pools adjacent to the sea at Kibbutz Ma'agan Michael. The pool bottom is soft sand. Water temperature is variable, and in summer is higher than that of the open sea. Salinity is highly variable, and depends upon rate of pumping. Large populations of another aplysiid, *Bursatella leachii* Blainville were found in this habitat, but occasionally *Apfysia* were also found.

A similar environment harboring *Apfysia* was found at the Dolphinarium, Tel-Aviv. A dense growth of *Ulva* covers the walls of large concrete holding tanks. Temperature and salinity are those of the open sea. *Apfysia* were found adhering to the walls of the tank, among the *Ulva*.

5) *Deepwater Rocks*. *Apfysia* were found by a fisherman in a 14 m deep rocky region ; the site was not directly examined by us. E. Spanier (pers. comm.) noted that *Apfysia* were not encountered in deep-water rocky regions from Caesarea and northward, at depths down to 30 m.

6) *Sites not harboring Apfysia*. *Apfysia* were never found at sandy beaches or bare rock jetties. *Apfysia* were rare, but occasionally present upon platforms in which brown or red algae are the dominant or exclusive flora.

In rough weather, *Apfysia* were difficult to find in rocky shore and coastal platform environments ; when found, *Apfysia* were deeper within holes than they were in a calm sea. During a *sharav*, it was very difficult to find animals, although working conditions are ideal. In areas where hundreds of animals are found in other weather, only a few animals were found under rocks or in tide pools.

By day, individuals of both species in rocky shore and platform environments were usually well hidden, and were consequently inconspicuous, even when present in large numbers. By contrast, in the ports and saltwater ponds, *Apfysia* were conspicuous. Toward evening and at night *Apfysia* of both species were observed to crawl out of holes and begin to eat. At these times, animals were easily observed even in rocky shore and platform environments.

Fig. 4 - One of a number of rock platforms found at Yaffo. The photograph was taken on a calm day.





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## RED SEA COAST

*Species and seasons*

*A. oculifera* was the only species of *Aplysia* that we observed in Elat. In some locations it was interspersed with another aplysiid, *Notarchus indicus* Schweigger.

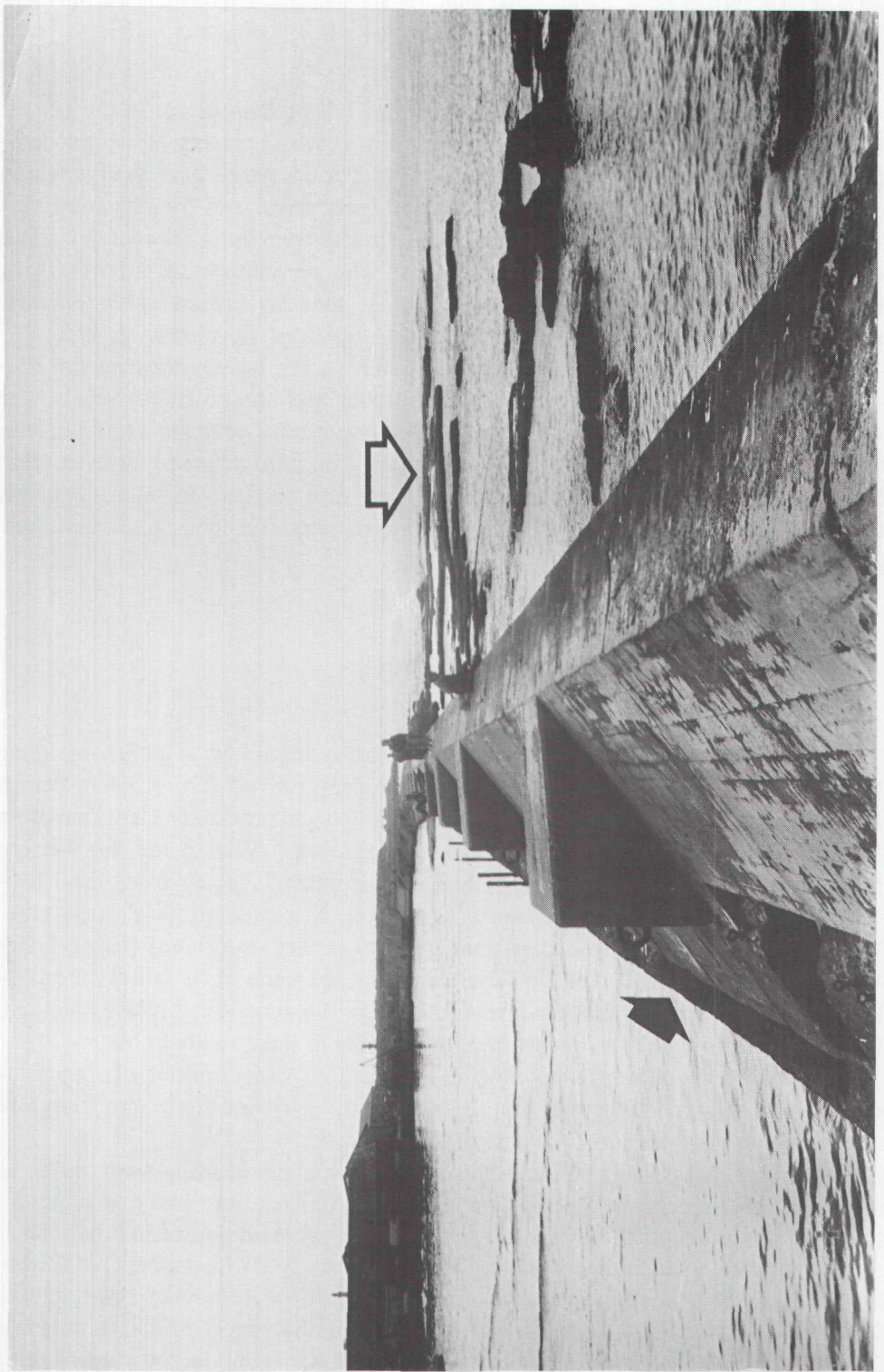
Table 1

Dates, sites and quantities of *Aplysia oculifera* found at three sites that were repeatedly sampled at Elat. A = along a jetty close to the Jordanian border ; B = in the harbor of the glass-bottom boats ; C = stony area in front of the H. Stenitz Marine Biological Laboratory.

Date Month, Year	Site		
	A	B	C
03.80		>100	
04.80		>100	
03.81	>100	>100	5
10.82			0
01.83	>100	>100	
03.83			>100
04.83		>100	>100
01.84	0	>100	5
02.84		>100	
03.84		>100	>100
04.84		25	2

Table 1 indicates the dates and locations of *Aplysia*. Large populations of *Aplysia* were present from January through May. At all times, egg-masses were found adjacent to animals ; *Aplysia* brought back to the laboratory also laid eggs, indicating that they were mature. The lack of *Aplysia* in November, coupled with the size and maturity of populations observed in January, suggest that *Aplysia* metamorphose from December onward ; maturation subsequent to metamorphosis is likely to be rapid, similar to that of *Aplysia* from other warm-water sites (Sarver, 1978 ; Gev *et al.*, 1984). During 1984, *Aplysia* were sparse in June, suggesting termination of the season ; by contrast, in 1983, *Aplysia* and *Notarchus* were also found in very large quantities through June, apparently due to unusual weather conditions which caused an unseasonally abundant growth of *Colpomenia* sp. and *Hydroclathrus* sp. *Aplysia* were found closely associated with these algae.

Fig. S - The protected port of Yaffo. Just outside of the breakwater there is a platform (open arrow). Also shown is a shallow ledge just at water level that is overgrown with *Ulva* (filled arrow).



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### *The Environment.*

Rocky shores occur all along the coast of the Gulf of Elat, except in the alluvial fans of wadis. The rocky shores are composed of seaward dipping layers of beach-rock, cliffs reaching into the sea, or of rocks and stones which have their origin in erosion of nearby cliffs. The shore is protected from waves by a fringing coral reef. Tides in Elat are of the mixed type, with amplitudes from 20 to 90 cm ; deviations due to atmospheric conditions may also occur. The prevailing wind is northerly or northeasterly; wave action is moderate. Average monthly surface water temperature ranges from 20.5 °C in February, to 27.3 °C in August (Klinker *et al.*, 1976).

At Elat, *Aplysia* were found in numerous sites in the lagoon between the fringing reef and the shore. *Aplysia* were found under and around stones which were covered with algae, or close to algae. *Aplysia* were also common at other sites where algae were growing upon rocky substrates. The most common algae in areas harboring *Aplysia* was *Ulva lactuca*. *Aplysia* were also common in saltwater ponds that were not directly examined by us (D. Popper, pers. commun. ; C. Dimentman, pers. commun.).

## DISCUSSION

### *Species Finds*

*A. fasciata* and *A. oculifera* have been previously identified as occurring along the Mediterranean and Red Sea coasts of Israel, respectively (Eales, 1960 ; Barash & Danin, 1971 ; Eales, 1979). *A. depilans* has not been previously identified from the Israeli coast, but is common throughout the Eastern Atlantic and the Western Mediterranean (Eales, 1960). Eales previously identified *Aplysia* from the Mediterranean coast of Israel as *A. juliana*. *A. juliana* is a circumtropical *Aplysia* belonging to the subgenus *Aplysia*, as does the very similar *A. depilans* (Eales, 1960). We assigned our species to *A. depilans* mainly on the basis of its radular morphology. It is suggested that further investigations on the genetic differences between these two species should be undertaken, mainly due to their ability to mate.

Eales (1979) described, in addition to *A. oculifera*, other species of *Aplysia* as occurring in Elat; these were not observed in the present study, and they are either much less common, or occur in different locations.

The environments in which local *Aplysia* were found are in many ways similar to those for other species in other places. Our data are therefore likely to be useful to others who attempt to utilize locally available *Aplysia* as experimental material.

*Rocky shore.* *A. californica* Cooper (Ricketts *et al.*, 1968; Kupermann & Carew, 1974), *A. vaccaria* Winkler (Kupermann & Carew, 1974), *A. kurodai* Baba (Usuki, 1970 ; Nishiwaki *et al.*, 1975), *A. juliana* (Usuki, 1970 ; Sarver, 1978) and *A. punctata* (Carefoot, 1967 a) in California, Hawaii and Wales are found in rocky shore environments, underneath, around and behind rocks.

*Protected port and Saltwater pools.* *A. californica* have been found in protected bays (Kupermann & Carew, 1974) and estuaries (MacGinnitie, 1935). *A. brasiliiana* Rang have been observed in harbors (Hamilton & Russell, 1982), and along rocky jetties, and protected bays and channels (Vance, pers. commun. ; Cobbs & Pinsker, 1982). *A. dactylomela* Rang occur in soft-bottomed flats (Lederhendler *et al.*, 1975).

*Rocky platforms.* This environment, thoroughly described by Safriel (1966), had not been previously searched as a habitat for *Aplysia*. Similar platforms occur in other sites in the Mediterranean, and at some other North Atlantic shores (Safriel, 1966), and these might also harbor *Aplysia*.

*Deep-water areas.* *A. californica* have been found in water up to 8 m in depth, but are not common in water deeper than 5 m (Audesirk, 1979). Our data are not sufficient to make a strong statement about abundance of local *Aplysia* in deeper waters.

Our data, as well as previous work, indicate that all species of *Aplysia* inhabit a wide variety of environments. The feature common to all environments, and which enables animal presence, seems to be a strong growth of food algae, particularly *Ulva*. *Ulva* is also a major components of the diet for *Aplysia* in other parts of the world (Winkler & Dawson, 1963 ; Sarver, 1978 ; Cobbs & Pinsker, 1982), although *Aplysia* have also been described to feed upon a wide variety of other algae (Audesirk, 1979 ; Carefoot, 1967 b ; Cobbs & Pinsker, 1982 ; Hamilton & Russell, 1982 ; Kandel, 1979 ; Kupermann & Carew, 1974 ; Lederhendler *et al.*, 1975 ; Saito & Nakamura, 1961 ; Usuki, 1970). It seems likely that presence of food permitting development and growth is the major variable determining selection of environment by *Aplysia* ; weather-related variables, or local events affecting the environment, may play a role in determining abundance of *Aplysia* at a given site, or selection of a site by a particular species of *Aplysia*.

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