

The solitary ascidian *Herdmania momus*: native (Red Sea) versus non-indigenous (Mediterranean) populations

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Abstract During 2005 monthly samples of the solitary ascidian *Herdmania momus* were collected along the Mediterranean and Red Sea coasts of Israel, in order to investigate possible differences in life history strategies of the two populations. The samples were preserved, dissected, and measurements were made of length, total weight, gonad weight, oocyte diameter and the occurrence of symbionts was recorded. Additionally, field surveys showed that in the Mediterranean *H. momus* exclusively inhabit artificial substrates, and are common at greater depths than in Eilat (Red Sea). Individuals of *H. momus* in Eilat reproduced year round. Although individuals from the Mediterranean were significantly larger than individuals collected in Eilat their gonad indices and oocyte diameter measurements indicate that they have a short reproductive season. Copepods were found in 50% of the samples from both sites, while a pontonine shrimp was found in 14% of the samples from Eilat only. The marked differences between the native vs. non-indigenous populations of *H. momus* are attributed to differential food availability, water temperature, currents and wave exposure. The increasing evidence of negative effects of non-indigenous ascidians on natural fauna from other regions in the

world emphasizes the need for additional research regarding the ecology of ascidians along the coasts of Israel.

Keywords Lessepsian migration · Marine bioinvasion · Ascidians · Anthropogenic transport

Introduction

One of the most extensively documented marine bioinvasion phenomena is the invasion of Red Sea species to the Mediterranean Sea through the Suez Canal (Lessepsian migration, Por 1978 also referred to as Erythrean invasion, Galil 2000). Since the opening of the Suez Canal in 1869, more than 300 Red Sea species of algae, invertebrates and fish have entered the Mediterranean through the canal (Safrieli and Ritte 1986; Spanier and Galil 1991; Barash and Denin 1992; Lotan et al. 1994; Golani 1998; Galil 2000). For example, the invasive jellyfish *Rhopilema nomadica* appears in mass swarms along the Mediterranean coasts of Israel every summer, causing severe damage to coastal fishing, tourism and coastal installations (Spanier and Galil 1991). The Red Sea mussel *Brachidontes pharaonis* forms massive beds and is believed to have displaced the local species *Mytilaster minimus* (Rilov et al. 2004). Other Lessepsian migrants, mostly fish, may be of economic

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importance, as they may be exploited commercially (Goren and Galil 2005).

While invasions of groups such as molluscs, crustaceans and fish have been studied extensively, little is known on Lessepsian migration of ascidians. Ascidians are sessile marine filter feeders with a short-lived non-feeding motile larva (Berrill 1950; Millar 1971). Some species are known to be rapid colonizers of artificial substrates such as marina floats, pilings, buoys, and boat bottoms in protected harbors, where there is reduced wave action and enhanced nutrients from anthropogenic activities (Naranjo et al. 1996; Oren and Benayahu 1998; Lambert and Lambert 1998, 2003; Lambert 2002; Mastrototaro and Dappiano 2005). Generally, solitary ascidian species spawn eggs and sperm while colonial species brood their young and release mature larvae into the water column (Millar 1971; Kott 1985). In temperate and cold seas, breeding is usually seasonal and restricted to the warmer season (Millar 1952, 1954; Millar 1971; Becerro and Turon 1992) but in tropical waters it may continue throughout the year (Goodbody 1961; Millar 1971, 1974; van Duyl et al. 1981; Stoner 1990). Since the larval stage is relatively short (6–24 h, Berrill 1950) it is believed that the primary mode of invasion is by the transport of adult forms overgrowing boat hulls or other fouled surfaces (Lambert and Lambert 1998; Lambert 2002).

Introductions of non-indigenous ascidians into harbors in both tropical and temperate waters are now commonplace, with the rate of introductions increasing yearly (Monniot et al. 1991; Lambert and Lambert 1998; Coles et al. 1999; Lambert 2002). Most of these non-indigenous species tolerate wide fluctuations in temperature, salinity, and even pollution (Sims 1984; Naranjo et al. 1996; Nomaguchi et al. 1997; Stachowicz et al. 2002b). The impact of non-indigenous ascidians on local species and habitats is currently being studied in several sites around the world (Lambert 2002, 2003; Stachowicz et al. 2002a). Despite this, to date there is only one study in which life-history parameters have been compared between two geographically separated populations of the same species (Rocha et al. 1999) and no comparative study has been conducted between the source and the non-indigenous populations. Such data is of great importance since it will provide tools for estimating invasion rates and possible effects on the natural fauna in the “invaded” site. For instance, higher winter

temperatures may result in higher recruitment rates and faster growth rates of non-indigenous species (Stachowicz et al. 2002b). In addition, since it is common to find in the branchial cavities of many solitary ascidians different crustaceans (Millar 1971; Monniot et al. 1991; Dalby 1996) the study of these “hitchhikers” in their new environment may provide unique information on the mode of invasion and the origin of the non-indigenous host.

The solitary ascidian *Herdmania momus* (Savigny, 1816) is common in the Red Sea including the Gulf of Suez, Aqaba and Aden. It was first recorded in the Suez Canal in 1924 (Harant 1927). It was recorded in the eastern Mediterranean by Pérès (1958) and Nishikawa (2002), who reported it is from Israel, Lebanon and Cyprus. It is considered as a Lessepsian migrant (Por 1978). The proximity of the Red Sea coral reef environment and the Israeli Mediterranean rocky shore, together with the opening of the Suez Canal, provides opportunities for comparative studies of ascidian distribution and migration. The aim of this study is to investigate possible differences in life history strategies of two populations of the ascidian *H. momus*—the native population in Eilat, Red Sea and a non-indigenous population in Hadera, Mediterranean Sea. We hypothesize that differences in environmental factors such as, food availability, water temperature ranges, currents and differential exposure to wave action will have a strong effect on the spatial distribution, body size, reproductive cycles and symbiotic relationships of *H. momus* in the Mediterranean Sea.

Materials and methods

The study was conducted during 2005–2006 in two study sites: (1) the pier of the Electric Company in Hadera, Mediterranean coast of Israel: 32°28'16" N, 34°53'06" E and (2) the Eilat-Ashkelon pipeline pier in Eilat, Red Sea 29°31' N 34°55' E (Fig. 1a). In both sites supporting pillars distributed from the shore to a 25 m depth inhabited by the solitary ascidian *Herdmania momus*. Water temperature in Eilat varies from 20 to 27°C, and salinity is ca. 40.5‰ throughout the year (Loya 2004). In Hadera, water temperature varies from 17 to 30°C and salinity is ca. 39.0‰ throughout the year (Por 1978). During the study sea water temperature for the Hadera site was obtained from the

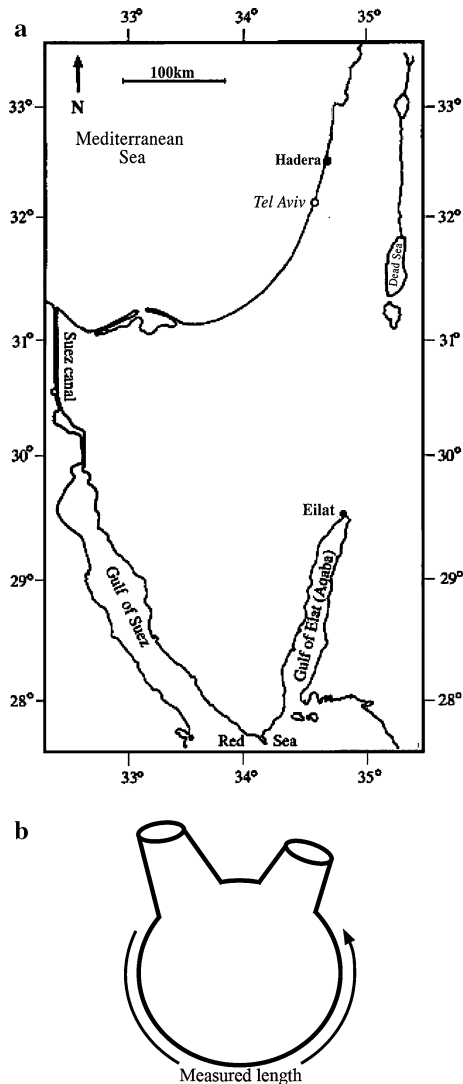


Fig. 1 (a) The study area, showing sampling location in Eilat (Red Sea) and Hadera (Mediterranean Sea) coasts of Israel. (b) Animal “length” measurements between the siphons along the mid-ventral line

Geology and Coastal Processes Department, Israel Oceanographic & Limnological Research (IOLR) and for the Eilat site from The National Monitoring Program (NMP, <http://www.iui-eilat.ac.il>).

In addition to taxonomic identification of the ascidians based on morphological characters, a successful cross fertilization experiment was conducted between six pairs of *H. momus* individuals from the Mediterranean and Red Sea sites following Degnan et al. (1996) suggesting the populations represent the same species.

Between March 2005 and May 2006, monthly samples ($n = 5-9$) were randomly collected from each site. The samples were narcotized with menthol crystals for up to three hours and fixed in 4% formalin in filtered sea water. Each of the samples was lightly blotted on absorbent paper and wet weights of the whole animal, its tunic and gonads were weighed to the nearest 0.001 g. The gonad index (in percentage, GI) was calculated as the ratio of gonad weight to the whole animal weight. In addition, the samples were photographed with Sony T-1 camera and the “length” of the animal was measured as the distance between the siphons nearest edge along the mid-ventral line (Fig. 1b) using UTHSCSA Image Tool for Windows version 3. In order to observe the symbionts inhabiting the branchial sac the samples were opened along the endostyle. The branchial sac was examined under a dissecting microscope and the presence of crustaceans was recorded.

To assess reproductive state of the studied population, each month gonads from three individuals from each site were further processed for histology. The gonads were repeatedly washed with running fresh water and maintained in 70% Ethanol. They were prepared for histological examination using a Citadel 2000 Tissues Processor, embedded in paraffin, sectioned and stained in Hematoxylin-Eosin. The slides were photographed using Nikon Digital Sight DS-L1 and scanned to JPG format. The diameter of each oocyte which appeared sectioned at the nucleolus level was measured using CPCe (Kohler and Gill 2006) program. Whenever possible, a total of one hundred oocytes from each individual were measured.

In order to study the distribution of *H. momus*, field surveys were conducted using SCUBA along the Mediterranean and Red Sea coasts of Israel (Fig. 1a). The presence of *H. momus* was documented along with the substrate type. To ascertain the recruitment density of *H. momus* along a depth gradient, 12 ceramic plates 20 × 20 cm each, were attached in August 2004 at 5, 10 and 15 m depth to a supporting pillar at each site. The plates in Eilat were removed after 4 months of submersion and in Hadera after 6 months. After removal the panels were immediately transported in seawater to the lab and examined under a dissecting microscope. The number of *H. momus* individuals was recorded on each plate.

During August 2005 ascidian density was examined in Hadera using a 50 × 50 cm quadrat. Twenty quadrats were placed around the pillars at 5, 10, 15 and 20 m depth. The number of *H. momus* and other dominant species was recorded in each quadrat. This method could not be used in Eilat due to potential damage to the corals overgrowing the pillars.

All statistical analyses were carried out using Statistica 7. The data were tested for normality and homogeneity of variances. Statistics of gonad indices were carried out after arcsin transformations. In order to ascertain if there are significant differences in GI throughout the study period a one way ANOVA was carried out for each of the sites. A nested design ANOVA (oocyte diameters nested within individuals) was used in order to test possible differences in oocyte diameter during the study for each site. Fisher's least significant differences (LSD) tests were used as post hoc comparisons when significant differences were detected. Separate *t*-tests were performed in order to test differences in GI measurements between the sites at each month. Results are presented as averages ± standard errors throughout the text unless denoted otherwise.

Results

Geographic and depth distribution of *Herdmania momus* along the Israeli coast

Field surveys revealed that *Herdmania momus* in Eilat (Red Sea) is common along the entire coast on artificial substrates (piers, artificial reefs) and in the natural environment, on the base of stony corals and underneath rock pebbles. In contrast, along the Mediterranean coast of Israel *H. momus* is restricted to artificial substrates and only few individuals were found on natural substrate.

In Eilat *H. momus* is common from shallow (<1 m) to 15 m depth. There was no significant association ($r^2 = 0.06$, $y = -0.113x + 2.583$, $P > 0.05$) between *H. momus* recruits density to the settlement plates and water depth, although a higher density was found in 5 and 10 m depth in comparison to 15 m depth (Fig. 2a). In contrast, in Hadera (Mediterranean Sea), no *H. momus* recruits were found in 5 m depth. As water depth increases the density of *H. momus* recruits increases significantly ($r^2 = 0.88$, $y = 0.917x - 1.11$,

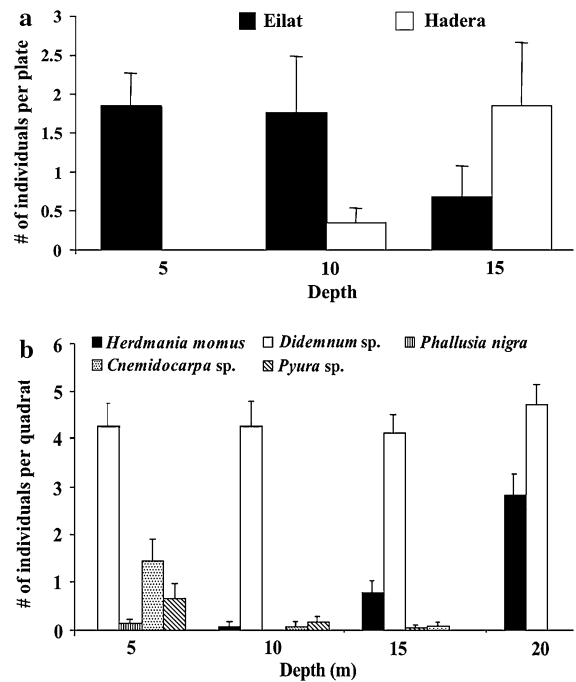


Fig. 2 Depth distribution of ascidians in Eilat (Red Sea) and Hadera (Mediterranean Sea). (a) Average number of *Herdmania momus* individuals (+SE) per plate (20 × 20 cm, $n = 12$) at 5, 10, 15 m depth in Eilat (black bars) and Hadera (blank bars). (b) Average number of individuals for ascidian species (+SE) per quadrat (50 × 50 cm, $n = 20$) at 5, 10, 15, 20 m depth in Hadera

$P < 0.05$) to 1.83 ± 0.8 individuals per plate at 15 m depth and to 2.85 ± 0.4 individuals per quadrat at 20 m depth ($r^2 = 0.81$, $y = 0.185x - 1.37$, $P < 0.05$, Fig. 2b).

Size measurements

Herdmania momus measured from monthly samples at Hadera are significantly larger than at Eilat (*t*-test, $P < 0.01$, Fig. 3). Thus, the total wet weight of the Mediterranean ascidians was 11.07 ± 1.0 g ($n = 95$) in comparison to 3.9 ± 0.3 g ($n = 115$) from the Red Sea, and the average *H. momus* length was 9.1 ± 0.3 cm in Hadera compared to 6.87 ± 0.2 cm in Eilat (Fig. 3).

The maximum total wet weight of *H. momus* from Eilat was 17.5 g and 12 cm in length (in August 2005) compared to *H. momus* from Hadera that reached 50.2 g total wet weight and 18 cm in length (in November 2005).

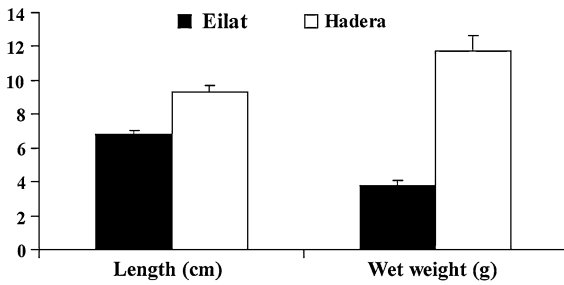


Fig. 3 *Herdmania momus*. Size comparison—average (+SE) length (cm) and weight (g) of individuals from Eilat, Red Sea (black bars, $n = 115$) and Hadera, Mediterranean Sea (white bars, $n = 95$)

Occurrence of symbionts

In 38% of the samples from Hadera ($n = 95$) and 30% of the samples from Eilat ($n = 115$) copepods were found inhabiting the branchial sac. In 14% of Eilat samples a pontonine shrimp, identified as *Odontonia sibogae* (Bruce, 1972) was found in the branchial sac and in the atrial cavity of *H. momus* ranging from 4.2 to 12 cm (0.54–17.5 g, respectively). This is the first record of this species in the Red Sea. It was absent from the Mediterranean samples.

Seasonality of reproduction

Both GI and average oocyte diameters showed similar trends throughout the study period (Fig. 4b, c). High values were obtained for the gonad indices (above 2%) of *H. momus* in Eilat throughout the year (excluding April 2005, January and June 2006). Although a strong peak (5.7%) was measured during February, no significant differences (one-way ANOVA, transformed data, $P > 0.05$) were found in GI of the Eilat *H. momus* samples throughout the study period. This suggests that in the northern Red Sea this species reproduces year round (Fig. 4b). This data concur with personal observations of monthly recruitment panels on which *H. momus* were recorded throughout the year (Shenkar et al. in prep). On the other hand, the low GI values ($1.2 \pm 0.1\%$, $n = 26$) measured in the Mediterranean (Hadera) during summer months (July–September 2005) and winter months (January–May 2006, $1.24 \pm 0.6\%$, $n = 35$) indicate that the reproduction *H. momus* along the

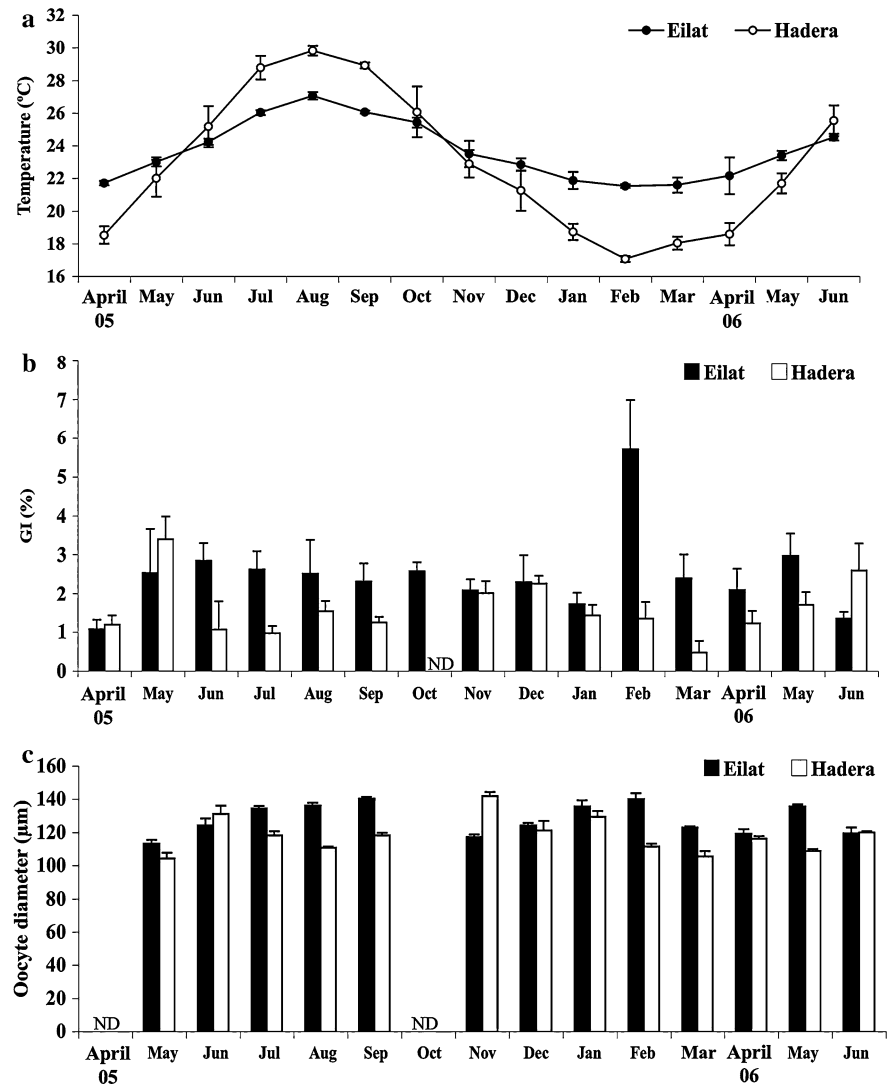
Mediterranean coast of Israel is seasonally limited. Significantly higher values of gonad indices (one-way ANOVA, transformed data followed by Fisher LSD, $P < 0.05$) in the Mediterranean were obtained twice a year, when the water temperature conditions in the Mediterranean were similar to those measured in the Red Sea (22–25°C). This similarity occurred in May 2005, in November–December 2005 and once again in June 2006 (Fig. 4a). A monthly comparison of the GI recorded in both sites showed significantly higher values in Eilat than in Hadera in July 2005, February and March 2006 (t -tests, transformed data, $P < 0.05$). Correspondingly, a significant difference in mean oocyte diameter between months was found only in the Mediterranean population (nested design ANOVA, $P < 0.05$, Fig. 4c). Mature oocytes ($>120 \mu\text{m}$) appeared in high numbers ($>50\%$) in the Eilat samples throughout the study period (excluding May 2005), whereas in Hadera, gonads with high numbers of mature oocytes were measured only in June 2005, September through January 2006 and once again in June 2006.

Discussion

Introduction of non-indigenous species into new regions, accidentally or deliberately, is now commonplace causing severe threats to terrestrial and marine biodiversity (Grosholz 2002). In general, increasing diversity of the recipient assemblage is associated with a lower recruitment of non-native species (Stachowicz et al. 1999). The nearly tropical temperature and salinity conditions along the Mediterranean coasts of Israel measured during the summer combined with the relatively low species diversity in this region (Spanier and Galil 1991; Fishelson 2000) results in thriving populations of Red Sea species along the Levantine coasts. The current work is the first to conduct a simultaneous comparative study of native versus non-indigenous ascidian populations revealing differences in their distribution, occurrence of symbionts and reproductive activity.

Lambert (2002) suggests two criteria for the designation of introduced ascidians species in Guam (1) be restricted to artificial surfaces and (2) have an extra Indo-West Pacific distribution. Using similar criteria; since *Herdmania momus* was found along the Mediterranean coast only on artificial substrates, has

Fig. 4 *Herdmania momus*. (a) Temperature data at both sites (means \pm std). (b, c) Seasonal variations (means \pm SEs) of GI ($n = 5-9$) and oocyte diameter ($n = 3$) in Eilat, Red Sea (black bars) and Hadera, Mediterranean Sea (blank bars)



an Indo-Pacific origin (Kott 2002), is recorded through the Suez Canal (Ghobashy and Abdel Messeih 1991), and so far has been recorded in the Mediterranean only from the Levant basin (Nishikawa 2002) it should be considered a non indigenous species, which most likely arrived to the Mediterranean through the Suez Canal. In addition, the absence of *H. momus* from the natural environment along the Mediterranean coast may indicate it is currently in its primary stages of establishment and in the future it may possibly be found in the natural environment as well.

In Eilat (Red Sea) *H. momus* was found on settlement plates from shallow (<1 m) to 15 m depth (Fig. 2a) while in Hadera (Mediterranean Sea) no

H. momus were found in shallow depths. Additionally, as water depth increased the density of *H. momus* increased significantly on settlement plates and on the nearby pillars (Fig. 2a, b). This disparity might be a result of the strong wave exposure that is typical of the Mediterranean site (1–2 m waves, IOLR Mediterranean Wave Forecast, <http://isramar.ocean.org.il>) which prevents the attachment of *H. momus* to the substrate in shallow depths and causes detachment in greater depths following strong winter storms (N.S. personal observations).

A few studies have demonstrated that ascidians can show differences in life history traits between subpopulations in different seas (Millar 1952, 1954; Davis 1989). Rocha et al. (1999) compared the body size of

the solitary ascidian *Phallusia nigra* at São Sebastião, Brazil in a subtropical environment with a population studied in a Caribbean coral reef at Jamaica (Goodbody 1962). The largest animals in Brazil were 7–8 cm whereas in the Caribbean they reach 10–12 cm in length. In the present study we also showed a significant difference in body length and weight (Fig. 3) between *H. momus* populations from Eilat and Hadera. However, in this case the animals from the temperate environment (Hadera) were significantly larger than the animals from the coral reef environment (Eilat) in both parameters. Since ascidians are filter feeding organisms, it is most likely that this is a result of the higher organic material ($\sim 0.35 \mu\text{g/l}$ chlorophyll *a*, IOLR database, <http://www.ocean.org.il>) in the coastal waters of the Mediterranean in contrast to the oligotrophic conditions in the coral reefs of Eilat ($\sim 0.16 \mu\text{g/l}$ chlorophyll *a*, NMP database, <http://www.iui-eilat.ac.il>).

Another disparity between the two populations was the occurrence of symbionts. The study of invasive species of symbionts may indicate if a given species invaded as a larva or as an adult. For instance, based on parasitological evidence, Diamant (1998) claims that rabbitfish invaded the Mediterranean through the Suez Canal as active adult fish and not as passively swept planktonic larvae, since they were found containing parasites that occur only on adult forms and are not known from the Mediterranean. In the current study, approximately one third of the samples from both localities had copepods in the branchial cavity. However, we found the pontonine shrimp *Odontonia sibogae* (Bruce, 1972) only in the samples of *H. momus* from Eilat. This species can also be found in the ascidians *Cnemidocarpa padata*, *Rhopalaea crassa*, and *Polycarpa* sp. (Fransen 2002). They often live in pairs ensuring sexual reproduction, and have colors to match those of their ascidian hosts (Monniot et al. 1991). Eilat is the most northern locality where *O. sibogae* is recorded (AJ Bruce, personal communication). The absence of *O. sibogae* from Mediterranean samples may be either because *H. momus* arrived to the Mediterranean coasts as small juveniles (less than 4.2 cm) or it arrived as adult with symbionts, but they failed to survive and establish a population in the Mediterranean. Since *O. sibogae* is recorded only from coral reef environments, it is possible that the wide water temperature fluctuations along the Mediterranean shores (16–31°C)

inhibit the establishment of a population of this pontonine shrimp.

Temperature has been suggested as the main factor regulating the sexual reproduction of ascidians (Millar 1971). However, other parameters such as food availability (Yamaguchi 1975; Sahade et al. 2004), turbidity (Millar 1974) and depth (Svane 1984) may also influence gametogenesis. The results of the present study (Fig. 4b, c) show that the two populations of *H. momus* have different reproductive peaks. The population in Eilat reproduces year-round with a strong peak in February. Year-round reproduction is typical to tropical coral reef ascidians (Goodbody 1961; van Duyl et al. 1981). In more fluctuating environments, ascidians usually exhibit seasonal breeding (Becerro and Turon 1992; Durante and Sebens 1994; Sahade et al. 2004) as we found for *H. momus* in the Mediterranean. Our results show that the Mediterranean population reproduces only when the water temperature conditions are similar to those measured in the Red Sea (22–25°C). The ability to change reproductive periods is known from other Lessepsian migrants, such as molluscs (Atad 2005) and fish (Golani 1990). However, these species had a wider reproductive period (4–5 months during the year) in comparison to *H. momus* that is limited to approximately two months a year (May–June and November) when the GI is high and the oocytes are mature. We suggest that the limited reproductive period of *H. momus* in the Mediterranean is preventing the dispersal of this species to colder areas in the region. Nevertheless, taking into account the anticipated rise in sea-water temperature, due to global warming (Rahmstorf and Ganopolski 1999), it is possible that *H. momus* will spread farther in the Mediterranean in the future.

We conclude that *H. momus* in the Mediterranean compared to the Red Sea is restricted to artificial substrates, found in greater depths, larger in size, has different symbionts and has a limited reproductive season. These differences are attributed to differential temperature ranges, food availability and wave exposure. Future results from molecular analysis may contribute to a better understanding of the arrival and dispersal modes of this species. The increasing evidence of negative effects of non-indigenous ascidians on natural fauna (Cohen et al. 2005) emphasizes the need for additional research regarding the ecology of ascidians along the coasts of Israel.

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