Mediterranean Marine Science

Vol 13, No 1 (2012)

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doi: 10.12681/mms.18

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net

Surveying *Caulerpa* (Chlorophyta) species along the shores of the eastern Mediterranean

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Received: 22 March 2011; Accepted: 11 October 2011; Published on line: 24 February 2012

Abstract

Caulerpa (Chlorophyta) species inhabiting intertidal and shallow subtidal areas along the Israeli Mediterranean shores (i.e., presence/absence) were surveyed on a seasonal basis from 2007 to 2009. We recorded the presence of three species: *C. prolifera*, *C. mexicana*, and *C. scalpelliformis*. These species were noticeable in autumn and inconspicuous during winter, thus revealing seasonality and population dynamics. There were no indications of well-known invasive species such as *Caulerpa racemosa* var. *cylindracea* and *Caulerpa taxifolia*. This study is the first of a kind that assesses the geographical distribution and seasonality of the genus *Caulerpa* along the Israeli shores.

Keywords: *Caulerpa*, distribution, Mediterranean.

List of nonstandard abbreviations: C, Center; **M,** *C. mexicana***; N,** North; **P,** *C. prolifera***; R,** *C. racemosa*; **S,** *C. scalpelliformis*; **So,** South

Introduction

Caulerpa species are common in both shallow and deep waters of tropical and subtropical seas. They are multinucleated (coenocyte), colonial, modular, and lack cellulose in their cell walls (Silva, 1992). *Caulerpa* species produce branched axes and attaching rhizoids, and are capable of vegetative reproduction. The genus includes over 75 species worldwide (Famà *et al.*, 2002), with only six described for the Mediterranean Sea, namely, *C. prolifera, C. mexicana, C. scalpelliformis, C. ollivieri, C. racemosa* [with *C. racemosa* var. *lamourouxii* f. *requienii*, *C. racemosa* var. *turbinata* and *C. racemosa* var. *cylindracea* – all recognized as separate taxonomical identities (see Verlaque *et al.,* 2003)], and *C. taxifolia (*Guiry & Guiry, 2011; UNEP, 1999; Einav & Israel, 2007, Table 1*)*. Two of these, *C. racemosa* var. *cylindracea* and *C. taxifolia,* are known to be invasive and have caused great environmental concern in Mediterranean countries during recent years (Boudouresque *et al*., 1995; Meinesz *et al*., 1998; Verlaque *et al*., 2000, 2003).

The eastern and western basins of the Mediterranean Sea have different thermal regimes. In the eastern Mediterranean Sea, temperatures range from 17 to 30°C in winter and summer, respectively, and are higher than those in the western basin by about 1.5°C for both seasons (Kress & Herut, 2001). The eastern Mediterranean basin has a wide, shallow, and sandy continental shelf as well as prominent abrasion intertidal platforms made of limestone and biogenic rocks (Einav & Israel, 2007). In addition, salinities at the eastern basin are higher, with values of 3.9% and 3.6% for the eastern and western basins, respectively (Berman *et al*., 1984). The eastern Mediterranean Sea is especially susceptible to biological invasions through the Suez Canal. Indeed, most of the approximately 100 known aquatic macrophytes introduced into the Mediterranean Sea have originated from the Indo-Pacific Sea (Galil *et al.,* 1990; Boudouresque & Verlaque, 2002, 2005; Ribera, 2002; Boudouresque *et al*., 2005; Zenetos *et al*., 2005; Rilov & Galil, 2009).

Ecological studies of the genus *Caulerpa* have focused on *Caulerpa taxifolia* and *Caulerpa racemosa* because of their invasive properties (Meinesz & Hesse, 1991; Argyrou *et al*., 1999; Meinesz, 2001; Verlaque *et al*., 2000, 2003). Up to now, *C. taxifolia* has not been reported for the Israeli Mediterranean (Einav & Israel, 2007). *C. racemosa* was collected for the first time in 1926 by Hamel in Sousse Harbor, Tunisia, and later its presence was reported throughout the eastern basin of the Mediterranean Sea (Verlaque *et al*., 2000; Aleem, 1950;

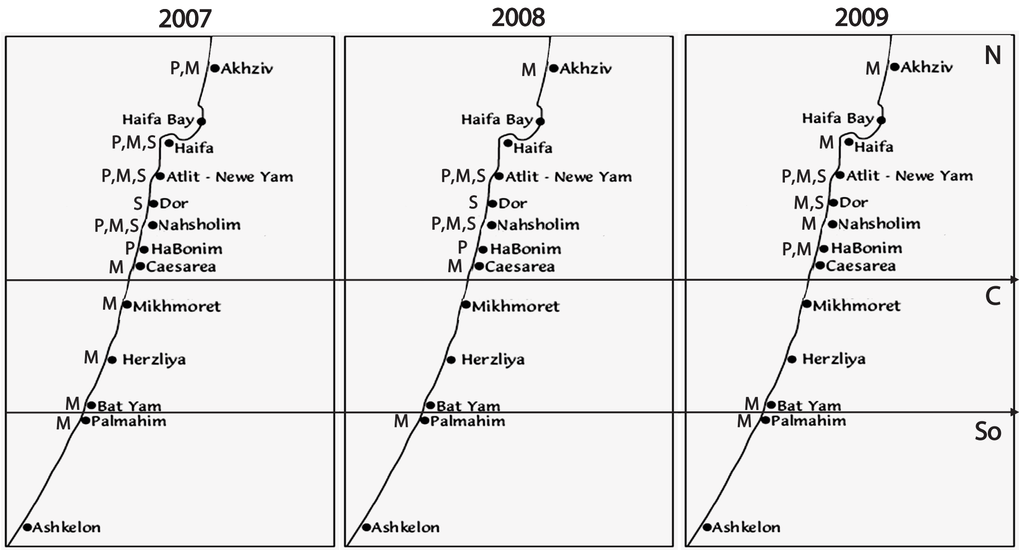

Fig. 1: Distribution of *Caulerpa* species along the Israeli Mediterranean coast (N – north, C – central, So – south) during 2007-2009 (P – *C. prolifera*; M – *C. Mexicana*; S – *C. scalpelliformis*).

Lipkin, 1975), including Israel (Rayss & Edelstein, 1960). At that time, no reports of invasive properties for *C. racemosa* var. *cylindracea* were suggested. *C. racemosa* var. *lamourouxii f. requienii* has been spreading within the Levantine area since the early 50s, intensifying during the 90s (Verlaque *et al*., 2000). The variant *C. racemosa* var. *cylindracea* (Verlaque *et al*., 2003; ARGYROU *et al*., 1999), which is native of southwest Australia, has reached the shores of over 15 Mediterranean countries, including all major Mediterranean islands, such as the Balearic Islands, Corsica, Crete, Cyprus, Sardinia, and Sicily (Verlaque *et al*., 2003; Klein & Verlaque, 2008; Rivera-Ingraham *et al*., 2010).

Studies conducted during 1922-1999 (Fig. 1 and references therein) identified 4 species for the Israeli Mediterranean Sea (*C. prolifera, C. mexicana, C. scalpelliformis* and *C. racemosa*). From these and other investigations, the importance of seasonality on population dynamics in the Mediterranean Basin, in which high algal densities are apparent during autumn each year, has been underlined (www.algaebase.org; UNEP, 1999, Table 1). In the current study, we aimed to address the diversity and seasonal as well as longitudinal distribution of *Caulerpa* species along the shores of the Israeli Mediterranean Sea.

Materials and Methods

Caulerpa species were surveyed during the years 2007-2009 from the intertidal and subtidal zones by snorkeling and visually monitoring the rocky and sandy bottoms of 11 field sites. These locations cover ca. 135 km of exposed shoreline, from north to south. The sites were further divided into three geographical areas: northern stations (Akhziv, Haifa, Atlit, Dor, Habonim, Nahsholim, and Sdot Yam), central stations (Michmoret, Herzliya, and Bat-Yam), and a southern station (Palmahim). For comparison purposes, the sampling sites included those in which *Caulerpa* species were described in previous studies (see Figure 1 and references therein). Monitoring strips 150 m long and 3 m wide in the intertidal, as well as snorkeling down to 2-3 m depth in the subtidal, both served to verify the presence or absence of *Caulerpa* at each site. In addition, potholes and tide pools from the intertidal were surveyed for the possible presence of the species. Therefore, mapping of *Caulerpa* in this study was based on whether the algae were present or not in a defined sampling site. The survey was conducted on a seasonal basis with nearly monthly visits to the sites on days with low tides and calm seas.

Results and Discussions

The goal of our study was to follow the seasonal changes of *Caulerpa* species that could be related to their geographical distribution. The results showed that only *C. mexicana* grows at all sampling sites, with *C. prolifera* and *C. scalpelliformis* predominant in the northern locations (Fig. 1). All three *Caulerpa* species prevail during the entire year except for winter, when seaweeds were scarce and hard to find (Table 2). Seasonality was particularly noticeable when mapping during 2007 and 2009. C. *racemosa* was never observed during the course of this study (Fig. 1 and Table 2).

Summarizing seaweed surveys carried out for the Israeli Mediterranean shores between 1926 and 1999 (Fig. 2) revealed that (1) *C. prolifera* is abundant in the northern areas; (2) *C. scalpelliformis* thrives in the central ar-

Table 1. Distribution of *Caulerpa* species from Mediterranean countries.

Countries	***C. Prolifera***	***C. mexicana***	***C. scalpelliformis***	***C. taxifolia***	***C. racemosa***	***C. ollivieri***	**Reference (UNEP, 1999; Portal: www.algaebase.org)**
Albania	+	-	-	-	+	-	UNEP, 1999; Verlaque *et al.*, 2000
Algeria	+	-	-	-	-	-	Gallardo *et al.*, 1993
Croatia	+	-	-	+	+	-	UNEP, 1999; Verlaque *et al.*, 2000;Nuber *et al.*, 2007; Blazina *et al.*, 2009
Cyprus	-	-	-	-	+	-	UNEP, 1999;Argyrou *et al.*, 1999; Verlaque *et al.*, 2000
Egypt	+	+	+	-	+	-	Papenfuss, 1968, UNEP, 1999; Aleem, 1993;Gallardo *et al.*, 1993; Aleem 1950;Verlaque *et al.*, 2000;
France	+	-	-	+	+	+	Gallardo *et al.*, 1993; UNEP, 1999; Uchimura *et al.*, 2000; Chisholm *et al.*, 2007;Hill *et al.*, 1998;Thibat *et al.*, 2004; Belsher & Meinesz, 1995; Boudouresque & Verlaque, 2005;Bartoli & Boudouresque, 1997; Pawlowski *et al.*, 1998; Verlaque *et al.*, 2000; Renoncourt & Meinesz 2002; Ruitton *et al.*, 2005, 2006; Meinesz & Hesse, 1991;Meinesz *et al.*, 1993; Boudouresque *et al.*, 1994; Meinesz *et al.*, 1998;Gayol *et al.* ., 1995; Komatsu *et al.*, 1997
Greece	+	-	-	-	+	-	Gerloff & Geissler 1974;Haritonidis & Tsekos 1976;Tsekos & Haritonidis 1977; Athanasiadis 1987; Gallardo *et al.*,1993; Donat *et al.*, 1997; UNEP, 1999;Tsirika & Haritonidis 2005;Panayotidis & Montesanto ,1994,1998; Panayotidis & Zuljevic , 2001;Verlaque *et al.*, 2000
Israel	+	+	+	-	+	-	Hoffman, 2004; Rayss & Edelstein, 1960; Einav, 1993, 1998; Lundberg, 1986; Pawlowski *et al.*, 1998; UNEP, 1999;Lipkin & Safriel, 1971;Levi & Friedlander, 2004; Friedlander *et al.*, 2006; Rayss,1941;Lipkin & Friedmann 1967; Lipkin, 1972; Gallardo *et al.*, 1993
Italy	+	-	-	+	+	-	UNEP, 1999;Gallardo *et al.* 1993; Rindi *et al.*,2002; Piazzi *et al.*, 1994, 1997a,b, 2001, 2007; Piazzi & Ceccherelli, 2002; Ceccherelli & Cinelli, 1997; Pawlowski *et al.*, 1998;Montefalcone *et al.*, 2007; Giaccone, 1969; Feoli & Bressan, 1972; Piazzi *et al.*, 2000; Cecere *et al.*,.1996; Furnari *et al.*, 1999; Alongi *et al.*, 1993; Verlaque *et al.*, 2000; Serio *et al.*, 2006; Valera-Alvarez *et al.*, 2006; Bussotti *et al.*, 1996; Gambi & Terilzzi, 1998; Piazzi & Cinelli, 1999; Fama *et al.*, 2000;Buia *et al.*, 1998; Raniello *et al.*, 2004, 2006;Piazzi & Balata, 2008; Durano *et al.*, 2002; Sant *et al.*, 1996; Gacia *et al.*, 1996; Delgado *et al.*, 1996
Lebanon	+	+	+	-	+	-	UNEP, 1999; Hamel, 1926, 1931a, 1931b; Verlaque *et al.*, 2000; Gallardo *et al.*, 1993
Libya	+	-	-	-	+	-	Gallardo *et al.*, 1993; Nizamuddin, 1991; Verlaque *et al.*, 2000; UNEP, 1999
Malta	+	-	-	-	+	-	Price, 1970; UNEP, 1999; Gallardo *et al.*, 1993
Morocco	+	-	-	-	+	-	Gallardo *et al.*, 1993; UNEP, 1999; Benhissoune *et al.*, 2001; Verlaque *et al.*, 2000; Conde Poyales, 1992;
Spain	+	+	+	+	+	-	Gallardo *et al.* 1993; UNEP, 1999; Valera-Alvarez *et al.*, 2006; Terrados& Marba. 2006; Ferrer *et al.*, 1997; Pawlowski *et al.*, 1998; Bellón, 1921; Bellón, 1940; Seoane-Camba, 1965; Ballesteros & Romero 1982; Barcelo & Seoane 1982; Pérez-Ruzafa & Honrubia 1984; Gallardo *et al.* 1985; Soto & Conde 1989; Pérez-Ruzafa 1990; Terrados & Ros 1992; Flores-Moya *et al.* 1995; De la rosa *et al.*, 2006; Rueda & Salas 2003; Pérez-Ruzafa *et al.* 2008; de los Santos *et al.*, 2009; Mercado *et al.* 2009; Holmer *et al.*, 2004; Pena Martín *et al.* 2003
Syria	+	+	+	-	+	-	UNEP, 1999; Bitar *et al.*, 2003; HuveA, 1957; Verlaque *et al.*, 2000; Gallardo *et al.*, 1993
Tunisia	+	-	-	-	+	-	Ben Maiz *et al.*, 1987; Gallardo *et al.* 1993; UNEP, 1999; Hamel, 1926, 1930, 1931a, Djellouli *et al.*, 1998; Verlaque *et al.*, 2000
Turkey	+	-	+	+	+	+	Aysel *et al.*, 2006; Ertan *et al.*, 1998; Gallardo *et al.*, 1993; Güven & Öztig, 1971; Güner *et al.*, 1985; UNEP, 1999; Taskin *et al.,* 2008; Cevik *et al.*, 2006; Evirgen, 1997; Mayhoub,1976

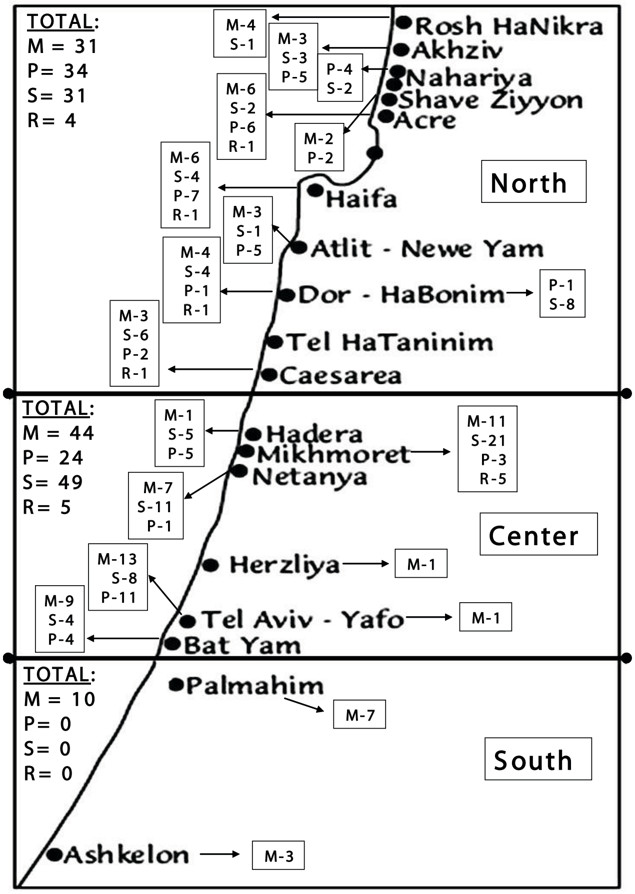

Fig. 2: *Caulerpa* species (P – *C. prolifera*, M – *C. mexicana*, S – *C. scalpelliformis*, and R – *C. racemosa*) monitored along the Israeli Mediterranean shores between 1926 and 1999. Observations of each of the species are indicated by numbers for the specific sampling site and for each geographical location (summarized from Rayss (1941); Edelstein (1960, 1962); Rayss & Edelstein (1960); Lipkin (1962); Lipkin & Safriel (1971); Ramon (1985); Lundberg (1986, 1996); Einav (1993, 1998); Einav & Israel (2007).

eas; (3) *C. mexicana* is the only species that expands to the south; and (4) C. *racemosa* is rare and described in the central and northern stations only (Rayss, 1941; Edelstein, 1960, 1962; Rayss & Edelstein, 1960; Lipkin, 1962; Lipkin & Safriel, 1971; Ramon, 1985; Lundberg, 1986, 1996; Einav, 1993, 1998; Einav & Israel, 2007). These studies made no reference to the presence of *C. taxifolia*. Thus, altogether, it seems that *Caulerpa* distribution has remained quite the same, except for the fact that *C. racemosa* was unaccounted for in this study.From a seasonal viewpoint, data of 1926-1999 indicate that *C. mexicana* thrives along the coast from north to south all year long, although it was described as being "more abundant" in autumn and summer at the central stations, and in winter at the northern stations (Fig. 3). These observations suggest physiological features allowing a broader tolerance to temperatures among species (Streftaris *et al*., 2005), and may be based on fast acclimation of photosynthesis and respiration to changing seawater temperatures, such as for *C. prolifera* (Terrados & Ros, 1992). *C. prolifera, C. scalpelliformis*, and *C. racemosa* were not observed in the south at all, with *C. racemosa* scarcely observed except in summer and winter (Figs. 2 and 3). Seasonality for *C. scalpelliformis* was evident by the fact that its presence occurred mainly during summer at the north and central sampling sites, in agreement with findings in this (Fig. 1 and Table 2) and other studies (Womersley, 1984; Ertan *et al*., 1998).

Seawater flows from the Atlantic Ocean into the western basin of the Mediterranean Sea, thus buffering water characteristics such as salinity, temperature, nutrient concentrations, and currents (Lascaratos *et al*., 1999). The eastern basin is largely oligotrophic and exhibits exceptionally low primary productivity (Berman *et al*., 1984; Yacobi *et al*., 1995) and low nutrient concentrations, particularly during summer (Salihoglu *et al*., 1990; Krom *et al*., 1991; Psarra *et al*., 2000). However, occasional nutrient-rich upwellings during this time of the year have been reported (Yacobi *et al*., 1995). A warm-core eddy south of Cyprus and a cold-core eddy near Rhodes are localized sites with nutrient enrichment that might support high biological activity (Yacobi *et al*., 1995). These eddies create a unique oceanographic condition along the Israeli coast, characterized by fast and strong current velocities in winter and summer, which get slower during spring and autumn, with a general counter-clockwise movement of seawater masses in the eastern basin (Oren & Komarovsky, 1961; Pinardi *et al*., 2003). Therefore, such a unique natural barrier impedes seawater from the west to move and replace seawater masses in the east. Consequently, we argue that the quite different oceanographic conditions for the eastern and western basins may be among the reasons why the invasive *C. taxifolia* has not yet penetrated into this part of the Mediterranean. Similar temperature barriers may have prevented the spread of *C. racemosa* var. *cylindracea. C. racemosa* has not been observed on the Israeli Mediterranean shore for at least two decades, nor was it found during the course of this study.

Conclusions

This survey corroborated the presence of three out of the four *Caulerpa* species described in previous studies for the Israeli Mediterranean Sea. The invasive *C. taxifolia* and C. *racemosa* var. *cylindracea* were unaccounted for. This study also emphasizes the effect of seasonality on population dynamics, with high and visible biomasses in autumn and ephemeral presence during winter. The present survey should encourage long-term monitoring to assess climate-change effects and biodiversity of seaweeds in the Mediterranean Sea.

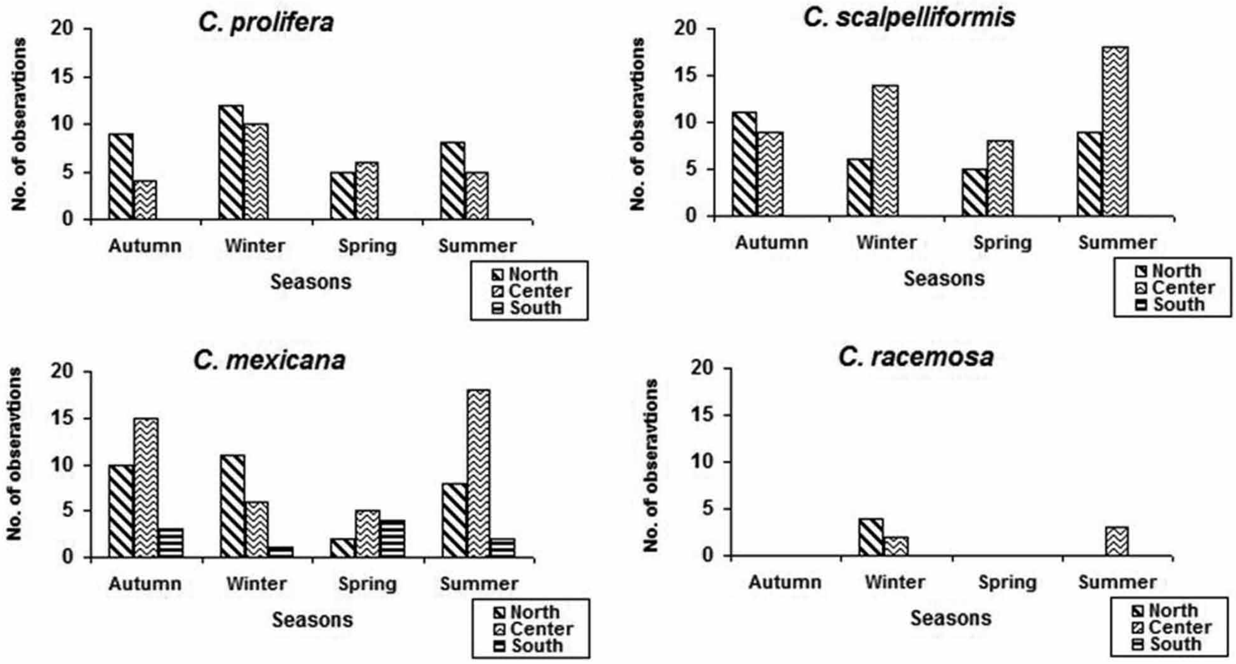

Fig. 3: Seasonal distribution of *Caulerpa* species (*C. prolifera*, *C. mexicana*, *C.* *scalpelliformis*, and *C. racemosa*) along the Israeli Mediterranean shores, as surveyed during 1926-1999.

Table 2. *Caulerpa* species found along the Israeli Mediterranean cost at different location (North, Center, South) during different seasons along the study years 2007-2009. (**S-***C. scalpelliformis*, **P**-*C. prolifera*, **M-***C. mexicana*)

		NORTH			CENTER			SOUTH		
YEAR	**Seasons/ species**	**S**	**P**	**M**	**S**	**P**	**M**	**S**	**P**	**M**
2007	winter	+	+	+	–	–	–	–	–	–
	spring	+	+	+	–	–	+	–	–	+
	summer	+	+	+	–	–	+	–	–	+
	autumn	+	+	+	–	–	+	–	–	+
2008	winter	+	+	–	–	–	–	–	–	–
	spring	+	+	+	–	–	–	–	–	+
	summer	+	+	+	–	–	–	–	–	–
	autumn	–	–	+	–	–	–	–	–	–
2009	winter	–	–	–	–	–	–	–	–	–
	spring	–	+	+	–	–	–	–	–	+
	summer	+	+	+	–	–	+	–	–	+
	autumn	–	–	–	–	–	+	–	–	–

Acknowledgements

We are thankful to Mr. Razy Hoffman for his assistance with the surveys and his expertise in seaweed taxonomy. We are also grateful to members of the Marine Biology labs of the Israel Oceanographic & Limnological Research in Haifa for their assistance. Special thanks to Ms. Sharon Victor for her useful comments. This research is part of the Ph. D. thesis of Shimrit Ukabi.

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