Razy Hoffman*, Marcelo Sternberg and Donatella Serio

First report of *Laurencia chondrioides* (Ceramiales, Rhodophyta) and its potential to be an invasive in the eastern Mediterranean Sea

Abstract: The Mediterranean coast of Israel is well known as a hotspot of invasive marine species, mostly from the Indian and Pacific oceans. Here, we report the first occurrence of the red seaweed *Laurencia chondrioides* in the eastern Mediterranean Sea. Large quantities of this species were observed in the algal drift on the sandy shores as well as on rocky surfaces of the upper and middle infralittoral zone. This highly abundant invasive species, present along the northern shore of Israel, represents a serious threat to the local marine flora. Some aspects of its ecology and invasive behavior in this region are also discussed.

Keywords: algal drift; alien species; invasive species; Mediterranean Sea; seaweed.

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Introduction

The overall worrying number of non-indigenous species reported thus far from the Mediterranean Sea has almost reached 1000, from which nearly 780 species were found in the eastern Mediterranean basin alone (Zenetos et al. 2010, 2012, Hoffman 2013). Many of these species show invasive characteristics and, therefore, threaten the native biodiversity (Streftaris and Zenetos 2006, Occhipinti-Ambrogi et al. 2011, Hoffman 2013).

More than 130 alien macrophytes (seaweeds and one species of seagrass) have been found in the Mediterranean Sea (Zenetos et al. 2010, 2012, Hoffman 2013). Some of these species are especially worrying because they may alter ecosystem structure and functioning by monopolizing space and acting as ecosystem engineers (Zenetos et al. 2012).

At the AlgaeBase website, about 130 species of the genus *Laurencia* J.V. Lamouroux (Ceramiales, Rhodophyta) are reported as currently accepted taxonomically, 10 of which occur in the Mediterranean Sea (Guiry and Guiry 2014). *Laurencia chondrioides* was originally described by Børgesen (1918) from a specimen collected at Saint John Island, in the Virgin Islands. The species is mainly distributed in the central-west Atlantic region where it was recorded in Florida, Cuba, Puerto Rico, Bahamas, Greater Antilles, Lesser Antilles, and the Western Caribbean Sea (Taylor 1960, Almódovar and Ballantine 1983, Littler and Littler 2000, Suárez 2005, Dawes and Mathieson 2008, Wynne 2011). This species was also recorded in the Philippines (Silva et al. 1987). However, it should be noted that before its description (Børgesen 1918), the species was already present in the Canary Islands, as shown by Prud'homme van Reine et al. (1994) who attributed to this species a specimen from the Island of Lanzarote, Canary Islands. This specimen was originally identified as *Chondriopsis dasyphylla* Woodward by Piccone (1884). Considering that *L. chondrioides* was not found in any recent floras of the Canary Islands and all previous reports of the species from this archipelago (John et al. 1994, Afonso-Carrillo and Sansón 1999, Haroun et al. 2002, Gil-Rodríguez et al. 2003, John et al. 2004) were based on Piccone's specimen, Gil-Rodríguez et al. (2012) concluded that after 1884 the species was not found there anymore.

At the end of the 20th century, *L. chondrioides* was reported for the first time from the Aeolian Islands, Balearic Islands, and Lachea Island located in the western basin of the Mediterranean Sea (Boisset et al. 1998). Since then, it was found in Spain, Italy, France, and the Adriatic coast of Greece (Furnari et al. 1999, Cormaci et al. 2000, Gómez Garreta et al. 2001, Rindi et al. 2002, Furnari et al. 2003, Alongi et al. 2004, Tsirika and Haritonidis 2005, Catra et al. 2006, Serio et al. 2006, Piazzi et al. 2007, Catra and Giardina 2009, Klein and Verlaque 2011).

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In late October 2007, 9 years after the first report of *L. chondrioides* in the western Mediterranean, individuals of this species (Figure 1) were found for the first time in the eastern Mediterranean basin, at the coast of Haifa in Israel. These samples were collected from the algal drift washed ashore. Later on, during the winter of 2013, *L. chondrioides* was commonly found all along the northern Israeli Mediterranean shore. This indicates the extension of its distribution northward as well, and that this introduced species became established in that area.

Materials and methods

Morphological study

Morphological examinations took place using specimens from the Tel Aviv University (TAU) National Algae Collection: TAU s.n.24, TAU s.n.488, and TAU s.n.683. Cellular morphology was examined microscopically by the use of Zeiss Axioplan 2 imaging (Jena, Germany). Digital images were acquired with an Olympus DP71 microscope digital camera (Tokyo, Japan). We compared the anatomical and structural features of these samples to all *Laurencia* specimens stored at the National Seaweed Herbaria of Israel. Literature reports of algal surveys from the Israeli Mediterranean (Edelstein 1960, 1962, 1964, Lipkin and Safriel 1971, Lundberg 1986, 1991, 1995, 1996), other Levant states (Basson et al. 1976, Mayhoub 1976), Cyprus (Taşkın et al. 2013), Turkey (Aysel 1997, Taşkın et al. 2008, Taşkın and Sukatar 2013), and Egypt (Aleem 1993) were also examined.

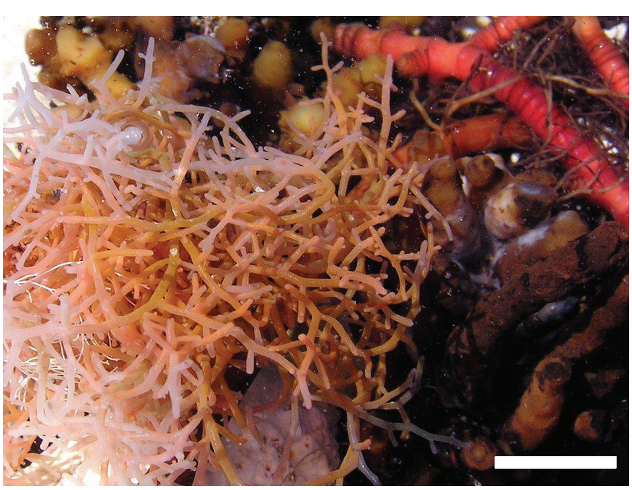

Figure 1 Habit of the thallus of the first sample of *Laurencia chondrioides* collected in Haifa Bay during October 2007. Scale bar, 10 mm.

Sampling and quantitative study

Seaweed surveys were carried out along the entire Israeli Mediterranean coastline, to map the distribution of the newly found species. Specimens were found and collected, by snorkelers and free divers, from natural habitats (upper infralittoral zone to 8-m depth and the intertidal zone) as well as from algal drift, placed in plastic bags, and labeled with location and collection data. Herbarium specimens were dried or preserved in 70% alcohol. Habitats were also documented. Scuba divers were interviewed to complete the information about this species in deeper water.

After the distribution was determined, random sampling of algal drift took place in late November 2013 at five sites (Table 1, Figure 2) using 20×20 cm quadrats (Figure 3). The biggest algal patch of drift that was lying on the sandy areas along the shore at each site was sampled three times using a metal quadrat. All algae sampled within the quadrat were collected, identified, and classified. Individuals of each species that were clearly identified were counted, cleaned, and dried with paper towel, and the overall wet biomass of each taxon was measured per quadrat. Average numbers of individuals and biomass of all components, with standard deviations, were calculated per quadrat for each species within and across sites.

Ecological study

To understand the additional life traits and ecological features of the new species, snorkelers and scuba divers documented its depth distribution and preferred habitats. Each collected sample, either from the upper infralittoral zone, intertidal, or from the algal drift, was checked carefully for epiphytes and attached fauna such as Hydrozoa.

Table 1 Study site locations along the Israeli Mediterranean northern coast.

Site number	Site name	Geographical coordinates
1	Rosh Hanikra	33°4′56.95″N, 35°6′21.47″E
2	Achziv reserve	33°3′9.35″N, 35°6′8.8″E
3	Achziv beach	33°2′32.21″N, 35°5′55.95″E
4	Shavei Zion	32°59′0.164″N, 35°4′53.7″E
5	Haifa-Bat Galim beach	32°49′56.47″N, 34°58′20.92″E

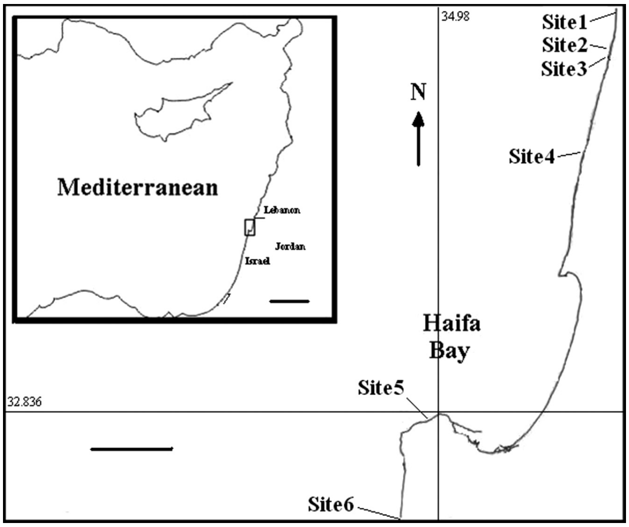

Figure 2 Map of study sites.
Scale bars: inset, 100 km; main map, 5 km.

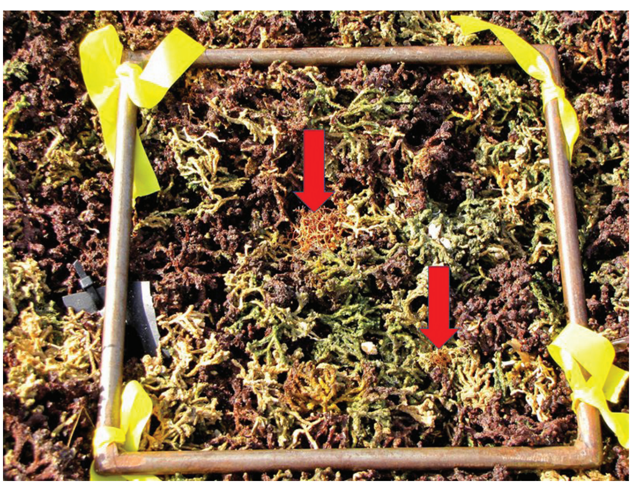

Figure 3 Quadrat placed on algal drift at site 4 before seaweeds were sampled.
Red arrows indicate *Laurencia chondrioides* specimens.

Results

Morphology

Morphological traits of specimens found were consistent with the published descriptions of *Laurencia chondrioides* (Børgesen 1918, Boisset et al. 1998, Littler and Littler 2000). The thallus is light pink to rosy-red throughout, up to 7 cm high, usually sprawling and prostrate. The axes are 350–600 µm in diameter, flexuous, terete, and arise from a discoidal holdfast. The main axis is often encrusted with the calcareous alga *Melobesia membranacea* (Esper) J.V. Lamouroux. The branching is alternate to irregular. Branches are curved (Figure 4A), rarely opposite or subverticillate. Up to three orders of branching occur. Branches and branchlets are often inserted at a right angle. Branchlets are 2–4 mm in length, 0.3–0.5 mm in width, tapered at their base (Figure 4B), and obtuse at the apices. Surface epidermal cells are polygonal (Figure 4C) in surface view, their outer walls projecting near the apices, and connected by secondary pit connections. Surface cells of young and mature branches are 30–50 and 50–110 µm long, respectively. Plastids are discoid to filiform. Transverse sections near the branchlet apex show an axial cell surrounded by four pericentral cells. The central axial cell is readily distinguishable in the median portion of the main branch (Figure 4D).

All samples collected during the surveys were sterile with neither spermatangial branches nor cystocarps observed. Conversely, tetrasporangial thalli were found with tetrasporangia produced by pericentral cells in parallel arrangement at stichidial branchlets (Figure 4E). Tetrasporangia are spherical, 62–86 µm in diameter.

This is the first record of *L. chondrioides* from the eastern Mediterranean basin. This species is absent in all algal checklists of the eastern Mediterranean published to date, and no herbarium specimens were found in the Herbaria of Israel, Lebanon, Syria, Cyprus, Turkey, or Egypt.

Distribution and drift results

Surveys clearly indicated that *Laurencia chondrioides* populations are concentrated along the northern Mediterranean shore of Israel, between Atlit (Site 6; Figure 2) in the south to the border with Lebanon in the north.

Random samplings of the algal drift revealed 16 taxa of seaweed in the drifts (Table 2). Ten taxa are indigenous in the Mediterranean Sea [*Cladophoropsis membranacea* (Hofman Bang *ex* C. Agardh) Børgesen, *Cystoseira rayssiae* E. Ramon, *Dictyota dichotoma* (Hudson) J.V. Lamouroux, *Digenea simplex* (Wulfen) C. Agardh, *Ellisolandia elongata* (J. Ellis *et* Solander) K.R. Hind *et* G.W. Saunders, *Jania rubens* (Linnaeus) J.V. Lamouroux, and *Jania adhaerens* J.V. Lamouroux, but also *Jania virgata* (Zanardini) Montagne, *Jania longifurca* Zanardini, and *Stypocaulon scoparium* (Linnaeus) Kützing], whereas five are regarded as alien species [*Asparagopsis taxiformis* (Delile) Trevisan de Saint-Léon, *Codium arabicum* Kützing, *Codium parvulum* (Bory *ex* Audouin) P.C. Silva, *Galaxaura rugosa* (J. Ellis *et* Solander) J.V. Lamouroux, and *Padina boergesenii* Allender *et* Kraft (Hoffman 2013)]. *Laurencia chondrioides* is regarded as alien to Israel and the Levant Mediterranean.

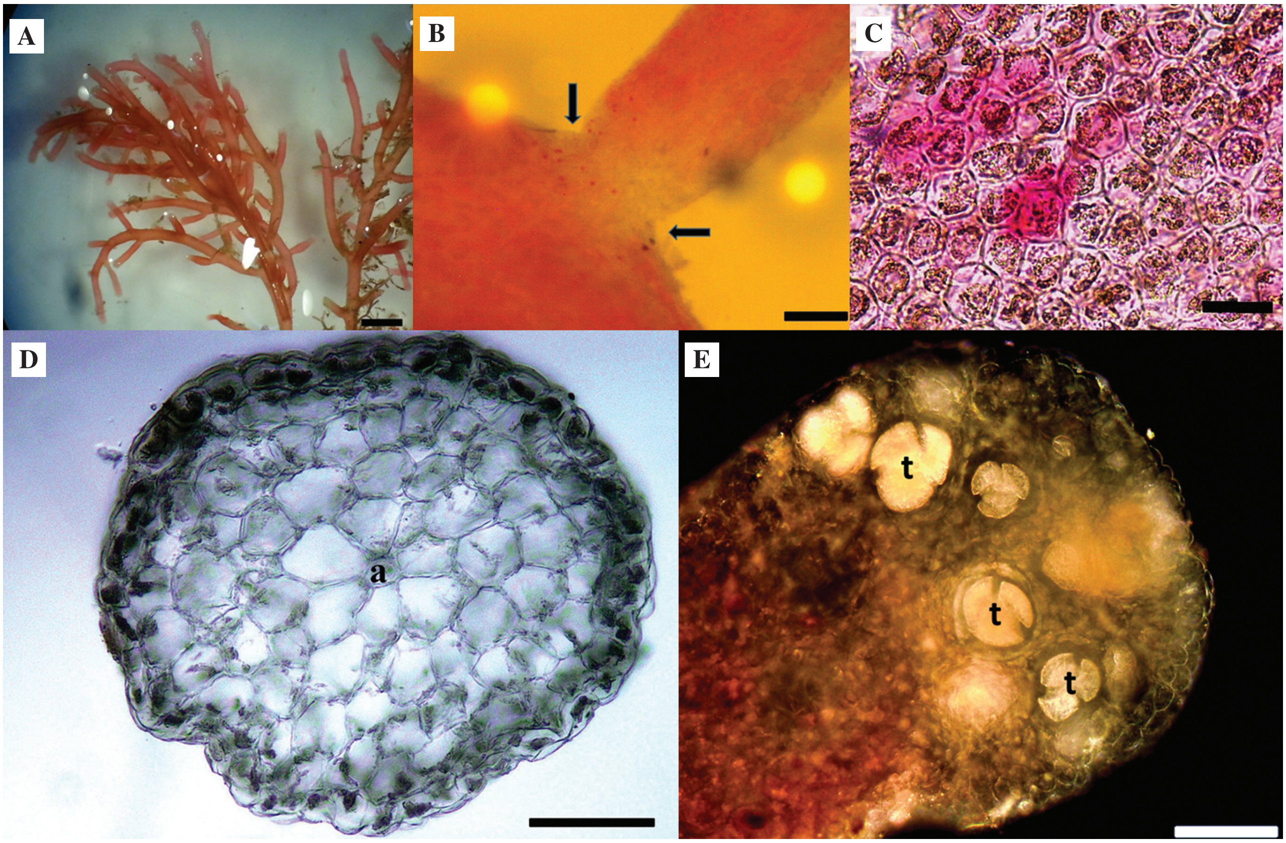

Figure 4 Morphological features of *Laurencia chondrioides*.
(A) Curved branches. Scale bar, 3 mm. (B) Typical narrow connection between branch and branchlet (arrows). Scale bar, 100 μm. (C) Polygonal epidermal cells of young branch. Scale bar, 40 μm. (D) Transverse section of main branch showing central axial cell (a). Scale bar, 100 μm. (E) Parallel arrangement of tetrasporangia (t) in the stichidial branchlet. Scale bar, 100 μm.

Table 2 Average number of individuals (In.#) and biomass (g) of each taxon collected per quadrat (±SD, n=3) in the algal drift at the study sites.

Taxon	Site 1		Site 2		Site 3		Site 4		Site 5	
	In.#	Biomass	In.#	Biomass	In.#	Biomass	In.#	Biomass	In.#	Biomass
Alien										
Asparagopsis taxiformis[a]	7±0.14	12.3±0.17	0.3±1.0	0.2±1.0						
Codium arabicum									1.3±0.6	8.6±0.5
Codium parvulum	6.3±0.1	92.3±0.08	0.3±1.0	0.7±1.0			0.3±1.0	2.1±1.0	7.3±0.2	121.4±0.3
Galaxaura rugosa	31.3±0.3	383.9±0.2	58.3±0.06	531.7±0.07	53.7±0.15	493.3±0.2	40±0.39	607±0.34	9±0.39	99.7±0.41
Laurencia chondrioides	16±0.16	18.3±0.12	6.3±0.05	5.7±0.15	12.3±0.07	6.8±0.03	5.3±0.44	4.4±0.27	7±0.44	10±0.41
Padina boergesenii									7.3±0.4	7.3±0.29
Indigenous										
Cladophoropsis membranacea					0.3±1.0	0.5±1.0			0.3±1.0	0.7±1.0
Cystoseira rayssiae									0.3±1.0	0.2±1.0
Dictyota dichotoma	1±0.01	47.4±0.15	1±0.01	6.9±0.56	1±0.02	12.6±0.7			1.3±0.2	1.1±0.27
Digenea simplex									0.3±1.0	0.2±1.0
Ellisolandia elongata	2±0.1	9.5±0.1			2±0.29	1.2±0.25				
Jania spp.[b]	1.7±0.53	1.5±0.7	9.3±0.13	29.9±0.29	9.7±0.34	15.3±0.35	1±0.58	0.3±0.75	7.3±0.36	9±0.47
Stypocaulon scoparium							0.7±1.0	1±1.0	87±0.31	66.4±0.27

[a]First report from the Israeli Mediterranean.
[b]Mostly *J. rubens* and *J. adhaerens*, but in some sites also *J. virgata* and *J. longifurca*.

The overall individual numbers of alien and indigenous species collected during the random sampling were 809 and 366, respectively. More than 71% of alien samples collected were of the red seaweed *Galaxaura rugosa*. The high number (141) of specimens of *L. chondrioides* collected during the algal drift survey clearly indicated that this species became very common at all five study sites along with *G. rugosa*. Other alien seaweeds collected – *Codium parvulum*, *Codium arabicum*, *Asparagopsis taxiformis*, and *Padina boergesenii* – were not found in the drift at all sites during this survey. The only indigenous seaweed species found at all sites were *J. rubens* and *J. adhaerens*. Forty-eight individuals of *L. chondrioides* were found under the quadrats at site 1 (Figure 2), near the border with Lebanon. The lowest contribution of this species to the drift was observed at site 4, with only 16 specimens collected.

Alien seaweeds showed a wider distribution (Figure 5A) and much higher biomass (Figure 5B) in the algal drift, compared with indigenous seaweeds. This phenomenon was most obvious at site 4 (Figure 2), where only five individuals of indigenous seaweeds were found in comparison with 137 individuals of alien species. Alien seaweeds, especially *G. rugosa*, represented 99.9% of the average wet biomass at this site. Site 5 (Figure 2) showed the opposite result, with only 96 individuals of alien seaweeds found in comparison with 290 indigenous species. However, alien individuals represented 76% of the wet biomass.

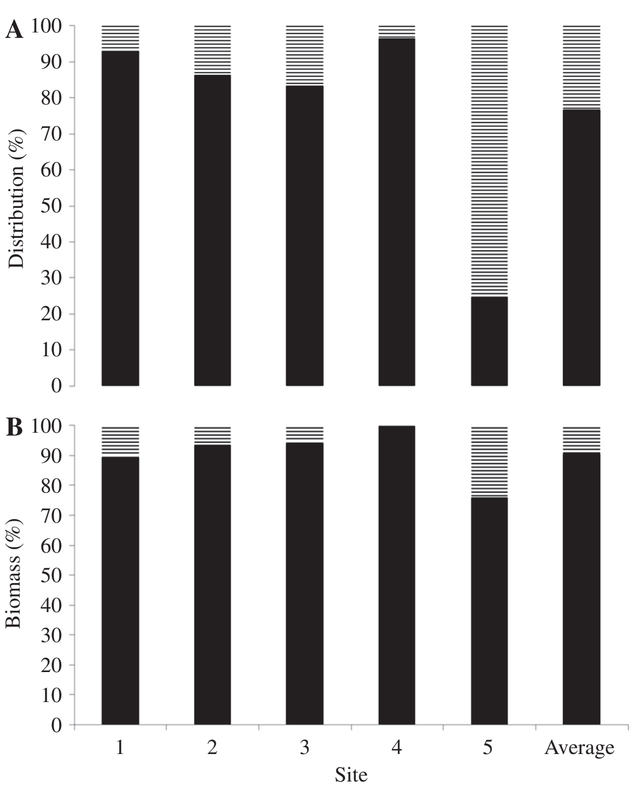

Figure 5 Contribution of alien (black) and indigenous (horizontal hatching) seaweeds to the algal drift at each site.
(A) Average distribution (i.e., numbers of individuals) and (B) average biomass of alien and indigenous seaweeds. Right-hand bar represents the average across all sites.

Ecology

More than 200 specimens of *Laurencia chondrioides* were collected during the present surveys, most of them from the algal drift. Snorkeling at site 5 (Figure 2), located in Haifa Bay, and around Achziv Islet (about 1.4 km west of Site 3; Figure 2) revealed that *L. chondrioides* is common at depths of 1–6 m, with the densest populations occurring at depths of 3–6 m. Divers collected some specimens and reported that this species became very common at 10–25 m depth between sites 1 and 2 (Figure 2). Two specimens of *L. chondrioides* were found growing in a shaded habitat at the bottom of a pothole located in the intertidal zone near site 4 (Figure 2) at a depth of 0.6 m.

Laurencia chondrioides populations observed in the infralittoral zone preferred growing on either flat rocks or vertical rocky substratum. Nevertheless, three individuals of *L. chondrioides* were found growing as epiphytes attached to the main axis of *Stypocaulon scoparium* and *Galaxaura rugosa*.

Seventeen taxa of seaweed and four species of Hydrozoa were found growing on *L. chondrioides* (Table 3). The vast majority of epiphytic seaweeds belong to Rhodophyta, and most of them are local Mediterranean species. These epiphytes and the hydrozoan species were observed attached to the main axes and mature branches of *L. chondrioides*.

Dynamena quadridentata (Figure 6) is a new hydrozoan invader that was found attached to several individuals of *L. chondrioides* collected at a depth of 2–6 m at site 5 (Figure 2).

Discussion

As mentioned above, *Laurencia chondrioides* was first recorded in the Mediterranean Sea in 1998 (Boisset et al. 1998) in deep habitats. Since then, the species has also been recorded in shallow habitats in different Mediterranean localities from France (Porquerolles Island by Klein and Verlaque 2011), northward to Greece (Zakynthos Island by Tsirika and Haritonidis 2005, and Karpathos Island by

Table 3 Seaweeds and Hydrozoa growing on *Laurencia chondrioides*.

Phylum	Class	Taxon	Comments
Chlorophyta	Ulvophyceae	*Cladophora* sp.	
Rhodophyta	Florideophyceae	*Anotrichium tenue* (C. Agardh) Nägeli	
		Asparagopsis taxiformis (Delile) Trevisan de Saint-Léon[a]	Falkenbergia phase (sporophyte)
		Centroceras clavulatum (C. Agardh) Montagne	
		Ceramium codii (H. Richards) Mazoyer[b]	
		Colaconema daviesii (Dillwyn) Stegenga[b]	
		Crouania attenuata (C. Agardh) J. Agardh	
		Gayliella mazoyerae T.O. Cho, Fredericq *et* Hommersand[b]	
		Griffithsia schousboei Montagne	
		Herposiphonia tenella (C. Agardh) Ambronn	
		Heterosiphonia crispella (C. Agardh) M.J. Wynne	
		Hypnea valentiae (Turner) Montagne[a,b]	
		Jania adhaerens J.V. Lamouroux	
		Jania rubens (Linnaeus) J.V. Lamouroux	
		Melobesia membranacea (Esper) J.V. Lamouroux	Encrusted to mature branches
Rhodophyta	Stylonematophyceae	*Stylonema alsidii* (Zanardini) K.M. Drew	
Heterokontophyta	Phaeophyceae	*Sphacelaria rigidula* Kützing	
Cnidaria	Hydrozoa	*Dynamena quadridentata* (Ellis *et* Solander)[a]	
		Kirchenpaueria pinnata (Linnaeus)	
		Obelia dichotoma (Linnaeus)	
		Ventromma halecioides (Alder)	

[a]Alien species in the Mediterranean.
[b]First report from the Israeli Mediterranean.

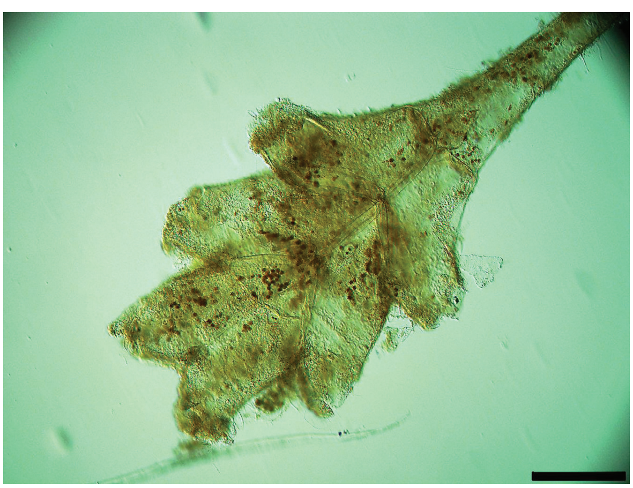

Figure 6 The alien hydrozoan *Dynamena quadridentata* found attached to a sample of *Laurencia chondrioides* (TAU s.n.683) collected at Haifa.
Scale bar, 200 μm.

Catra and Giardina 2009). This fact does not necessarily demonstrate an extension of its Mediterranean distribution area during recent years, as the species could have been previously overlooked in those localities due to its external similarity to *Chondria* spp. (Boisset et al. 1998). In addition, this species was not listed among alien species by Zenetos et al. (2010, 2012). Nevertheless, *L. chondrioides* was listed by Occhipinti-Ambrogi et al. (2011) among the non-native species displaying natural range expansion through the Strait of Gibraltar. Our findings strongly support the idea that this overlooked alien species is becoming ecologically invasive along the eastern Mediterranean coast of Israel. The open question remaining is, how did *L. chondrioides* reach the Mediterranean Sea from the Virgin Islands – naturally or via shipping ballast water? This question remains unresolved for the moment.

Different conclusions may be drawn regarding the arrival of *L. chondrioides* at the Israeli Mediterranean coast. The first specimens of *L. chondrioides* found in Israel were collected during an intensive algal survey conducted along the entire Israeli Mediterranean during the years 2006–2010 (Hoffman, unpublished). These specimens were found exclusively at site 5 (Figure 2), located in Haifa Bay. As many cargo ships anchor near the Port of Haifa on their way from the Mediterranean to the Indo-Pacific Ocean and vice versa, it is highly probable that this species arrived at Haifa through shipping, and the vector of introduction was ballast water or hull fouling, as was probably the case with other alien seaweeds such as *Galaxaura rugosa*, *Codium arabicum*, and *Codium parvulum* that were first recorded in the Mediterranean at Haifa (Hoffman et al. 2011, Hoffman 2013). The occurrence of

L. chondrioides in the Philippines (Silva et al. 1987) and sea routes mainly followed by cargo ships anchoring near Haifa could support the introduction of the species through the Suez Canal. That would explain the high abundance of *L. chondrioides* along the Israeli Mediterranean where it can be considered an alien species. The invasiveness of *L. chondrioides* that forms large populations along the Israeli coastline could be related to the values of annual mean surface seawater temperatures along the Israeli Mediterranean coast, similar to those found in tropical seas that are probably highly favorable for the development of this species (Hoffman 2013).

The present survey shows that this red alga is distributed along 55 km of the shoreline, from Atlit in the south to the border between Israel and Lebanon in the north. As both algal and algal drift surveys revealed >50 specimens of *L. chondrioides* near that border, there is a big chance that it is also found on the southern shores of Lebanon. As *L. chondrioides* spread northward so quickly, probably through the natural northward currents of the eastern Mediterranean, we believe that these currents might play an important role, expanding the distribution of this seaweed to the northern Levant shores and even to Turkey.

Considering that algal drift reflects the composition of underwater flora, we used it as a quantitative index to evaluate the state of *L. chondrioides* along the Israeli shoreline and to confirm the assumption that this species has become established. The high number of individuals (141) found under the quadrats during our study, as well as others found during the surveys of the upper infralittoral zone at all sites, clearly indicate that this species shows invasive properties. Moreover, it seems that this species reached stage IVb of Colautti and MacIsaac's (2004) model of invasion, meaning that it "remains localized (found only at the northern Israeli Mediterranean shore) but dominant."

Results of the random sampling also indicate that the overall number of specimens of all alien seaweed species and their total biomass are much higher than those of the indigenous macroalgae. These data faithfully support snorkelers' and scuba divers' observations and findings. It is now obvious that there is an enormous bloom of non-indigenous seaweeds and that the vast majority of seaweeds growing on rocks located in the infralittoral zone (up to 25-m depth) at some sites along the northern Israeli Mediterranean shore are aliens. The most frequent seaweed found at all sites that contributes nearly 85% of the total algal biomass expressed in the algal drift is *G. rugosa*. This invasive species was the most common seaweed in the upper and middle infralittoral zones as well as in the drift, with a total of 577 individuals collected under the quadrats across all sites, corresponding to the important value of nearly 6500 g wet biomass compared with the negligible contribution of 141 individuals of *L. chondrioides* that weighed only 135 g.

Sexual reproduction of *L. chondrioides* in the Mediterranean Sea occurs during summer and autumn. During these seasons, male and female plants were found, laden with spermatangia and cystocarps, respectively (Boisset et al. 1998). As all samples collected during the winter surveys were sterile, we assume that this species does not reproduce sexually during the cold season.

Laurencia chondrioides grows attached to hard substrata such as rocks and corals but also as an epiphyte on other seaweed species and the endemic Mediterranean seagrass *Posidonia oceanica* (L.) Delile (Boisset et al. 1998, Littler and Littler 2000, Piazzi et al. 2007, Klein and Verlaque 2011). Along the northern Mediterranean shore of Israel, this species was mainly found growing on rocks, although a few individuals were found attached to other seaweeds.

Indigenous species of Hydrozoa and seaweeds found attached to *L. chondrioides* indicate that this species has become an integral part of the local flora, taking part in the natural ecology. However, this species of Atlantic origin also provides a substratum for alien algae and non-indigenous Hydrozoa such as *Dynamena quadridentata* originating from the Indo-Pacific Ocean.

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