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SGHAIER Y. — Regional Activity Centre for Specially Protected Areas (RAC/SPA)

ZAKHAMA-SRAIEB R. — Université de Tunis El Manar, Faculté des Sciences de Tunis, UR 11ES11 Bio-Ecologie et Systématique Evolutive, 2092 Tunis

MOUELHI S. — Université de Tunis El Manar, Faculté des Sciences de Tunis, UR 11ES11 Bio-Ecologie et Systématique Evolutive, 2092 Tunis

VAZQUEZ M. — Instituto Español de Oceanografía, Centro Oceanográfico de Baleares, Muelle de Poniente s/n, 07015 Palma de Mallorca

VALLE C. — Universidad de Alicante, Departamento de Ciencias del Mar y Biología Aplicada, 03080 Alicante

RAMOS-ESPLA A.A. — Universidad de Alicante, Departamento de Ciencias del Mar y Biología Aplicada, 03080 Alicante

ASTIER J.M. — 79 Bvd St Hélène, Le Mourillon, Toulon

VERLAQUE M. — Aix-Marseille University and Toulon University, Mediterranean Institute of Oceanography (MIO), CNRS, IRD, UM 110, F-13288 Marseille Cedex 09

CHARFI-CHEIKHROUHA F. — Université de Tunis El Manar, Faculté des Sciences de Tunis, UR 11ES11 Bio-Ecologie et Systématique Evolutive, 2092 Tunis

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Review of alien marine macrophytes in Tunisia

Y. R. SGHAIER[1,2], R. ZAKHAMA-SRAIEB[2], S. MOUELHI[2], M. VAZQUEZ[3], C. VALLE[4], A.A. RAMOS-ESPLA[4], J.M. ASTIER[5], M., VERLAQUE[6] and F. CHARFI-CHEIKHROUHA[2]

[1] Regional Activity Centre for Specially Protected Areas (RAC/SPA), Boulevard du Leader Yasser Arafat, BP 337, 1080 Tunis cedex, Tunisia
[2] Université de Tunis El Manar, Faculté des Sciences de Tunis, UR 11ES11 Bio-Ecologie et Systématique Evolutive, 2092 Tunis, Tunisia
[3] Instituto Español de Oceanografía, Centro Oceanográfico de Baleares, Muelle de Poniente s/n, 07015 Palma de Mallorca, Spain
[4] Universidad de Alicante, Departamento de Ciencias del Mar y Biología Aplicada, 03080 Alicante, Spain
[5] 79 Bvd St Hélène, Le Mourillon, Toulon, France
[6] Aix-Marseille University and Toulon University, Mediterranean Institute of Oceanography (MIO), CNRS, IRD, UM 110, F-13288 Marseille Cedex 09, France

Corresponding author: yassineramzi.sghaier@rac-spa.org

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Abstract

In the present study, the list of alien marine macrophytes introduced into Tunisia was updated in light of available data and new observations. A total of 27 alien marine macrophytes has been recorded so far from Tunisia: 18 Rhodophyta, 3 Ochrophyta, 5 Chlorophyta and 1 Magnoliophyta. For each species, the locality (-ies), the year (or) period and the source of the first observation in Tunisia are given. The distribution and the status (casual, cryptogenic, established or questionable) of species in Tunisia were evaluated and, where appropriate, discussed. Among them, *Hypnea cornuta* is reported for the first time from Tunisia. Fourteen alien marine macrophytes are established, whereas seven cryptogenic and two casual species require further investigation. Eleven species are considered as invasive or potentially invasive in the Mediterranean Sea: *Acrothamnion preissii, Asparagopsis armata, A. taxiformis* Indo-Pacific lineage*, Hypnea cornuta, Lophocladia lallemandii, Womersleyella setacea, Caulerpa chemnitzia, C. cylindracea, C. taxifolia, Codium fragile* subsp. *fragile* and *Halophila stipulacea*. Finally, the case of four questionable species is also discussed.

Keywords: Alien, invasive species, marine macrophytes, *Hypnea cornuta,* Tunisia, Mediterranean.

Introduction

Biological invasions are now recognized as a major agent of global change, following the spectacular increase in invasions by alien marine and estuarine species in various regions of the world (Occhipinti-Ambrogi, 2007). The Mediterranean Sea is one of the regions worldwide which is most severely affected by alien marine invasions, fostered by the opening of the Suez Canal, fouling and ballast transportation along shipping lines, aquaculture, the aquarium trade and global climate change (Zenetos *et al*., 2010, 2012). The number of alien marine species reported so far from the Mediterranean Sea has almost reached 1,000 (approximately 6% of the total flora and fauna; Hoffman, 2014). The vast majority of alien species (775) occur in the eastern Mediterranean basin, whereas a lower number of species are known for the western Mediterranean (308) and the central Mediterranean (249) and, to an even lesser degree, for the Adriatic Sea (190) (Zenetos *et al*., 2010, 2012). The origin of these species is mainly the Red Sea, followed by the Indo-Pacific and the Atlantic oceans (Zenetos *et al*., 2012). As far as marine macrophytes are concerned, a total of 133 species have been listed as possible aliens; of these 23 belong to the Chlorophyta, 79 to the Rhodophyta, 30 to the Ochrophyta, and one is a seagrass species (Magnoliophyta) (Verlaque *et al*., 2015).

With more than 1,400 km of coastline, and located at the crossroads between the different Mediterranean basins, Tunisia occupies a key position in the context of the Mediterranean Sea. The Tuniso-Sicilian strait is the passageway from south to north and from east to west, and is crucial in the analysis of the spread of alien species introduced into the Mediterranean Sea.

During the last decade, the monitoring of marine aliens in the Mediterranean Sea has attracted strong interest from the scientific community, international organizations, and has been the focus of environmental programs (Marine Strategy Framework Directive, the European Strategy for Marine and Maritime Research, the Marine Spatial Planning and the Ecosystem Approach within the Barcelona Convention by UNEP/MAP, as well as many initiatives of the UNEP RAC/SPA). However, records of alien marine species from Tunisia are sparse and scat-

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tered. Because of the large stretch of coastline and lack of research programs focusing on the subject, there are many gaps in the knowledge of alien marine species.

The aim of this paper is to provide a robust baseline for the monitoring of alien marine macrophytes (hereafter AMM) of Tunisia through a critical compilation of all the available historical data. In parallel, several dedicated field surveys were conducted along the coast to search for AMM and to establish their current distributions. Results will be presented online on the Marine Mediterranean Invasive Alien Species (MAMIAS) database (UNEP-MAP RAC/SPA, 2015), and questionable records are discussed.

Materials and Methods

Compilation of the available historical data

The list of AMM reported from Tunisia was critically established on the basis of a compilation of existing information/observations (scientific and grey literature, newspapers, online databases, internet forums and unpublished data from regional experts). Native range, locality (-ies) and date (year or period) of first sighting (or of the first publication in few cases) in Tunisia, and the status of the alien (casual, cryptogenic, established or questionable) according to Zenetos *et al*. (2010) were evaluated for each species. Casual species are those having been recorded only once. Cryptogenic species are species with no definite evidence of their native or introduced status. Established species are species known from more than two Tunisian localities or records. Finally, questionable species are species with insufficient information. The species considered as invasive are species that can have an obvious ecological and/or economic impact.

Field studies

Sixty-seven sampling sites distributed along the whole of the Tunisian coastline were investigated, from July 2009 to April 2014 (Fig. 1, Table 1). At each site, a standardized one-hour transect was surveyed by snorkeling or/and SCUBA diving in the depth range 0 to 30 m depth. All the AMM present were listed and, if necessary, collected for confirmation in the laboratory.

The following voucher specimens were deposited in the Verlaque Herbarium (HCOM), Marseille, France, with references: *Hypnea cornuta* (Kützing) J. Agardh, H8272, dried and wet specimens preserved in 4% buffered formalin/seawater, Sidi Jmour, Jerba, Tunisia, 13/8/2014, coll. J.M. Astier. *Acanthophora nayadiformis* (Delile) Papenfuss, H8273, dried specimen, Sidi Jmour, Jerba, Tunisia, 13/8/2014, coll. J.M. Astier.

Mapping

The updated range expansion in Tunisia was established for each alien species, taking into account both already available data and new records. In the distribution maps, when there was a series of sightings (> 5) with a maximum distance between consecutive sightings of less than 50 km, it was assumed that the species was present along the entire coastline and its distribution was depicted by a continuous line. In all the other cases, sightings of species were depicted by symbols.

Results

During our survey along the 1400 km of the Tunisian coast, ten AMM were encountered at 70.1% of sampling sites: *Acanthophora nayadiformis, Asparagopsis armata*, *A. taxiformis*, *Hypnea cornuta, Lophocladia lallemandii*, *Caulerpa chemnitzia*, *C. cylindracea*, *C. taxifolia*, *Codium fragile* subsp. *fragile* and *Halophila stipulacea* (Table 1).

Hypnea cornuta is reported for the first time from Tunisia. Our specimens are well characterized by their habit and the presence of stellate vegetative propagules on the axes (Fig. 2). Sexual reproductive structures were not observed. The species was only found in Jerba in 2014.

On the basis of the available literature and field surveys, a total of 27 AMM is listed for Tunisia: 18 Rhodophyta, 3 Ochrophyta, 5 Chlorophyta and 1 Magnoliophyta (Table 2). For four species, *Bonnemaisonia hamifera* in 1909, *Gracilaria arcuata* in 1934, *Caulerpa chemnitzia* in 1926 and *Caulerpa cylindracea* in 1985, their discovery in Tunisia constitutes the first reports of each species in the Mediterranean Sea.

The main putative donor regions are the Red Sea and the Indo-Pacific province (Table 2). Only two species, *Chondria coerulescens* and *Polysiphonia fucoides*, have a distribution restricted to the Atlantic Ocean and the Mediterranean Sea. The other Atlantic species are also present in the Indo-Pacific Ocean. Among these 27 species, we found two casual, seven cryptogenic, 14 established and four questionable species (Table 2).

The first casual species is *Hypnea cornuta,* hitherto only known from Jerba, and the second is the Red Sea Rhodophyta *Gracilaria arcuata* that was originally described from the Red Sea (Gulf of Aqaba; Zanardini, 1858). Seven species, *Acanthophora nayadiformis, Anotrichium okamurae, Chondria coerulescens*, *Colaconema codicola, Polysiphonia atlantica*, *P. fucoides* and *Pylaiella littoralis,* are regarded as cryptogenic species. *Acanthophora nayadiformis* was found for the first time at Jerba.

The status of the Atlantic species *Griffithsia corallinoides*, which was collected in the Bizerte Lagoon, was not considered as cryptogenic but established because an introduction via oyster transfers is highly probable as in the case of the French lagoon of Thau (Verlaque, 2001).

The distribution of AMM (casual, cryptogenic and established) differs according the different areas in Tunisia (Figs 3 & 4). The northern zone has received the highest number of AMM (18 species of which 14 are Rhodophyta and four are Chlorophyta) compared to the

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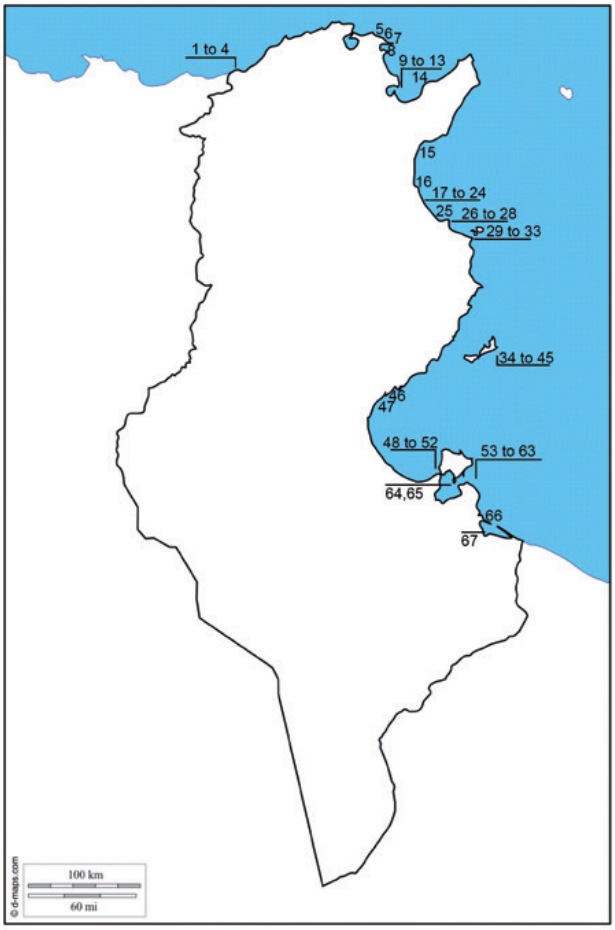

Fig. 1: Location of sampling sites in Tunisia. The characteristics of site numbers are given in the Table 1.

central zone (10 species of which five Rhodophyta, four Chlorophyta and one Magnoliophyta), and the southern zone (11 species: seven Rhodophyta, one Ochrophyta, two Chlorophyta and one Magnoliophyta).

On the basis of certain characteristics, such as fast dynamics in areas of introduction, development of dense populations, intense vegetative multiplication, production of repellent metabolites, broad ecological niches and obvious ecological and/or economic impact, 11 species are considered as invasive or potentially invasive in the Mediterranean Sea: *Acrothamnion preissii, Asparagopsis armata, A. taxiformis, Hypnea cornuta, Lophocladia lallemandii, Womersleyella setacea, Caulerpa chemnitzia, C. cylindracea, C. taxifolia, Codium fragile* subsp. *fragile* and *Halophila stipulacea* (Table 2). All of these are widely distributed along the Tunisian coasts except for *A. preissii, H. cornuta* and *W. setacea* (Fig. 2).

Asparagopsis armata was found at El Kantaoui at 1m depth on rocks. The gametophytic phase of *A. taxiformis* was recorded at eight sampling sites out of 67 (11.9 %). *Lophocladia lallemandii* was found at 12 sampling sites out of 67 (17.9%). It was well established in the Gulf of Gabes (Kerkennah Islands, 1-13 m depth; eastern Jerba, 4-25m depth) where it was very abundant in July 2009 and 2010 on disturbed and dead *Posidonia oceanica* (Linnaeus) Delile meadows and *Cymodocea nodosa* (Ucria) Ascherson meadows. *Caulerpa chemnitzia* was found at Monastir. Given the features common to all species of *Caulerpa* (mainly: vegetative multiplication, holocarpy, repellent secondary metabolites, permanent and dense meadows), this species is considered as potentially invasive for Tunisia. *Caulerpa cylindracea* was the most frequent AMM, with an occurrence at 34 sampling sites out of the 67 (50.7%). Locally abundant, it grew on soft substrates, dead *Posidonia oceanica* meadows, and in small patches (ca. 2 m^2) on rocky substrates. In the Gulf of Gabes, *C. cylindracea* was very common between 0 and 15 m depth on disturbed *P. oceanica* meadows and *C. nodosa* meadows, especially in the south and west of Kerkennah, whereas it was rare at Jerba between

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Table 1. Sampling sites in Tunisia: GPS coordinates, date, depth, substrate and alien marine macrophytes (AMM) observed. (An: *Acanthophora nayadiformis*; Aa : *Asparagopsis armata*; At : *Asparagopsis taxiformis*; Hc : *Hypnea cornuta*; Ll : *Lophocladia lallemandii*; Cch : *Caulerpa chemnitzia*; Ccy : *Caulerpa cylindracea*; Ct : *Caulerpa taxifolia*; Cf: *Codium fragile* subsp. *fragile* and Hs : *Halophila stipulacea*).

	Locality (north to south Tunisia)	Coordinates (Lat. N - Long. E)	Date	Depth (m)	Substrate	Alien marine macrophytes
1	Malloula	36.9628-08.7139	July 2010	0-5	Sand/Rock	
2	TabarkaBay	36.9708-08.7400	June 2010	0-8	Sand	
3	TabrakaCap	36.9603-08.7556	June 2010	0-15	Sand/Rock	
4	Tabarka Fort	36.9631-08.7628	June 2010	0-10	Sand/Rock	
5	Sounine	37.2114-10.1811	July 2010	0-5	Sand	
6	Rafraf - Ras Blat	37.1969-10.2089	July 2010	0-5	Sand/Rock	Ccy, At
7	Rafraf - Ras Ettarf	37.1822-10.2653	July 2010	0-5	Sand	At
8	Ghar El Melh lagoon	37.1625-10.2147	July 2010	0-2	Sand/Mud	Ccy
9	La Marsa	36.8956-10.3219	May 2011	0-5	Sand/Rock	Ccy
10	Sidi Bou Saïd	36.8661-10.3519	April 2014	0-1	Rock	
11	Salammbo Port punique	36.8447-10.3272	April 2014	0-2	Rock	
12	Le Kram	36.8294-10.3181	April 2014	0-3	Rock	
13	La Goulette	36.8172-10.3081	April 2014	0-4	Rock	
14	Sidi Rais	36.7703-10.5483	July 2010	0-6	Sand	Ccy
15	Hammamet	36.3956-10.5819	July 2010	0-7	Sand	Ccy
16	Hergla City	36.0353-10.5053	June 2010	0-5	Sand	Ccy
17	Hergla - Falaise	36.0017-10.5231	June 2010	0-5	Sand/Rock	
18	Chott-Mariem Aquaculture	35.9650-10.5403	July 2012	0-5	Sand/Rock	Ct,Cf
19	Chott-Mariem	35.9394-10.5603	July 2010	0-7	Sand	Ccy, Ct, At, Cf
20	Tantana	35.9283-10.5728	July 2013	0-7	Sand	At, Ct
21	El Kantaoui	35.9033-10.5914	March to Dec. 2012	0-8	Dead matt/Sand	Ccy
22	El Kantaoui	35.8983-10.5961	March to Dec. 2012	0-8	Dead matt/Sand	At
23	El Kantaoui	35.8919-10.6006	March to Dec. 2012	0-8	Dead matt/Sand/Rock	At,Ct,Ccy,Cf,Aa
24	El Kantaoui	35.8772-10.6053	March to Dec. 2012	0-8	Sand	Ccy
25	Monastir Dkhila	35.7772-10.7736	July 2010	0-5	Sand	Ct, Ccy
26	Monastir Marina Cap	35.7789-10.8353	May 2011	0.5-2	Sand/Muddy sand	Ccy, Hs, At
27	Monastir Climant	35.7900-10.8383	August 2013	20-25	Rock/Muddy sand	
28	Monastir - Karraïa	35.7739-10.8378	May 2011	0-5	Sand	At, Cch
29	Kuriat Island	35.7650-11.0075	July 2010	0-1	Sand	Ccy
30	Kuriat Island	35.7661-11.0142	July 2010	0-5	Sand	Ccy
31	Kuriat Island	35.7978-11.0233	July 2010	0-3	Sand	Ccy
32	Kuriat Island	35.8033-11.0286	July 2010	0-3	Sand/Rock	At
33	Bekalta	35.6333-11.0400	July 2010	0-1	Sand	
34	Kerkennah Islands - Abbassya	34.7097-11.2408	July 2010	0-1	Sand	
35	Kerkennah Islands – Ouled Yaneg	34.6725-11.1458	July 2010	0-1	Sand	
36	Kerkennah Islands – Ouled Ezzedine	34.6447-11.0903	July 2010	0-1	Sand	
37	Kerkennah Islands - Allama	34.6128-11.0478	July 2010	0-1	Sand	Hs, Ccy
38	SE Kerkennah Islands	34.6650-11.2769	July 2009	1.0	Muddy sand/*C. nodosa* meadow	Ccy
39	SE Kerkennah Islands	34.6872-11.3894	July 2009	1.3	Muddy sand/*C. nodosa* meadow	Ccy, Ll
40	SE Kerkennah Islands	34.6414-11.2797	July 2009	11.9	Dead *P. oceanica* meadow/Sand	Ccy
41	SW Kerkennah Islands	34.4383-11.0917	July 2009	30.4	Muddy-Sand	Ccy
42	Kerkennah Islands Al Attaya	34.6869-11.3906	July 2010	1.5	*P. oceanica* meadow	Ccy, Hs
43	SE Kerkennah Islands	34.6517-11.2717	July 2010	6.6	*P. oceanica* meadow	Ccy, Ll
44	SW Kerkennah Islands	34.5044-11.0164	July 2010	12.4m	*P. oceanica* meadow	Ccy, Ll
45	SW Kerkennah Islands	34.5944-11.2756	July 2010	20.4m	Muddy sand	Ccy
46	Kneiss Islands	34.3719-10.3183	July 2010	0-1	Sand	
47	Kneiss Islands Jaboussa	34.3472-10.2094	July 2010	1.0	Muddy sand	Hs
48	W-Jerba	33.7831-10.7231	July 2009; 2014 (for Hc)	8.2	Rock/sand/*C. nodosa* meadow	An, Hc, Ccy
49	W-Jerba	33.9475-10.6381	July 2009	15.2	Dead *P. oceanica* meadow/Sand	Ll
50	W-Jerba	33.9550-10.6928	July 2010	13.5	Dead *P. oceanica* meadow	Ccy
51	E-Jerba	33.7494-11.0139	July 2009	4.2	*C. nodosa & P. oceanica* patches	Ll
52	E-Jerba	33.8086-11.0631	July 2009	6.9	*C. nodosa & P. oceanica* patches	Ll
53	E-Jerba	33.7161-11.1358	July 2009	20.4	Dead *P. oceanica* meadow	Ccy, Ll
54	E-Jerba	33.8936-11.1256	July 2009	25.0	Dead *P. oceanica* meadow	Ccy, Ll
55	E-Jerba	33.7492-11.0139	July 2009	4.2	*C. nodosa meadow*/Coarse sand	Ll

(continued)

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Table 1. *(continued)*

	Locality (north to south Tunisia)	Coordinates (Lat. N - Long. E)	Date	Depth (m)	Substrate	Alien marine macrophytes
56	E-Jerba	33.8931-11.0947	July 2009	19.6	Dead *P. oceanica* meadow	Ccy
57	E-Jerba	33.7261-11.1753	July 2009	25.8	Dead *P. oceanica* meadow	Ccy
58	E-Jerba	33.7814-11.0658	July 2010	4.4	Rock/*P. oceanica* meadow	Ccy, Ll
59	E-Jerba	33.8119-11.0922	July 2010	8.8	Dense *P. oceanica* meadow	Ll
60	E-Jerba	33.8136-11.1086	July 2010	14.6	Sparse *P. oceanica* meadow	Ll
61	E-Jerba	33.7572-11.1097	July 2010	17.1	Dead *P. oceanica* meadow	Ccy
62	Jerba Island - Ajim	33.7417-10.7342	July 2010	0-1	Sand	Ccy
63	Jerba Island - Borj Jeliz	33.8889-10.7467	July 2010	0-1	Sand	
64	Bou Ghrara Lagoon	33.6914-10.7428	July 2009	2.0	*Caulerpa prolifera* meadow	Ccy
65	Bou Ghrara Lagoon	33.6222-10.9303	July 2010	0-1	Sand	
66	El Bibane Lagoon - Jedeiria	33.2869-11.2667	July 2010	0-1	Sand	
67	El Bibane Lagoon - Ben Guerdane	33.1950-11.3006	July 2010	0-1	Sand	

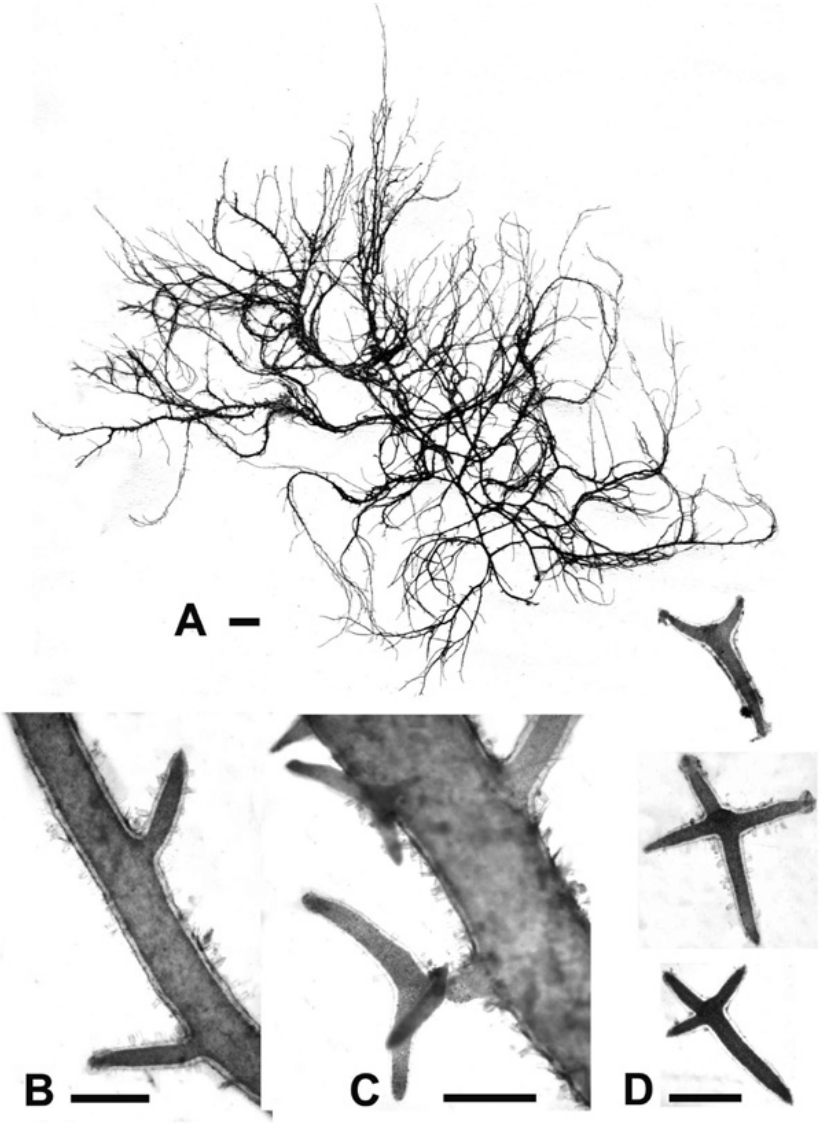

Fig. 2: *Hypnea cornuta* (Kützing) J. Agardh, specimens H8272. A. Dried specimen. B. Axis with young branches. C. Stellate vegetative propagules on the axis. D. Three detached stellate vegetative propagules. Scale bars: A = 1 cm; B-D = 500 µm.

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Table 2. Alien marine macrophytes introduced in Tunisia with the native range, the locality and the date of first sighting, with references. Abbreviations: Atl = Atlantic Ocean; Cos = Cosmopolite; Ind = Indian Ocean; Pac = Pacific Ocean; Pan = Pantropical; Ques = Questionnable; RS = Red Sea; Cas = Casual; Cry = Cryptogenic; Est = established. *: Species potentially invasive for Tunisia.

note [1]: Athanasiadis (1996) separated two other introduced species, *A. boergesenii* (Cormaci & Furnari) Athanasiadis and *A. sublittoralis* (Setchell & Gardner) Athanasiadis, from *A. elegans*. It is not possible to say if other members of this species complex have been introduced in Tunisia.

		North Tunisia (Western Mediterranean)			Central-South Tunisia (Central Mediterranean)		
Species	**Native range**	**First sighting**	**Status**	**References**	**First sighting**	**Status**	**References**
Rhodophyta							
Acanthophora nayadiformis (Delile) Papenfuss= *A. delilei* J.V. Lamouroux	RS - Pan	Carthage, 1931	Cry	Feldmann, 1937; Meñez & Mathieson, 1981; Ben Maiz *et al.*, 1987; Ben Maiz, 1995	Jerba, 2009	Cry	Present study
Acrothamnion preissii (Sonder) E.M.Wollaston *	Ind - Pac	Bizerte, Cap Zebib, Raf-Raf, 2005-2006	Est	Zerzeri *et al.*, 2010			
Anotrichium okamurae Baldock as *Neomonospora furcellata*; Feldmann-Mazoyer and Meslin	Pac	Bizerte, 1926	Cry	Herbier J. Feldmann, sonneratphoto.mnhn.fr, 1938; Ben Maiz *et al.*, 1987			
Antithamnionella elegans (Berthold) J.H.Price & D.M. John = *Antithamnion elegans* Berthold[1]	Pac	Zembra, 1969	Est	Boudouresque, 1970; Ben Maiz *et al.*, 1987; Ben Maiz, 1995; Djellouli *et al.*, 2000; Boudouresque *et al.*, 2006			
Asparagopsis armata Harvey *	Ind - Pac	Cap Serrat, 1973-1975	Est	Meñez & Mathieson, 1981; Ben Maiz & Boudouresque, 1986; Ben Maiz, 1995; Boudouresque *et al.*, 2006; Shili *et al.*, 2010; Zerzeri *et al.*, 2010; present study	Hammamet, 1985	Est	Ben Maiz *et al.*, 1987
Asparagopsis taxiformis (Delile) Trevisan de Saint-Léon *	Ind-Pac	North coast, 2009	Est	Shili *et al.*, 2010; present study	Mahdia, 2003	Est	Andreakis *et al.*, 2004, 2007, 2009; present study
Bonnemaisonia hamifera Hariot = *Trailliella intricata* Batters	Pac	La Galite, 1909	Est	Petersen, 1918; Feldmann, 1931; Meñez & Mathieson, 1981; Ben Maiz & Boudouresque, 1986; Ben Maiz *et al.*, 1987; Ben Maiz, 1995; Boudouresque *et al.*, 2006			
Chondria coerulescens (J.Agardh) Falkenberg	Atl	Raouad, Sidi Bou Said, La Marsa, 1973-1975	Cry	Meñez & Mathieson, 1981; Ben Maiz *et al.*, 1987; Ben Maiz, 1995; Zerzeri *et al.*, 2010			
Colaconema codicola (Børgesen) H. Stegenga, J.J. Bolton & R.J. Anderson = *Acrochaetium codicola* Børgesen	Cos				Sousse, 1973-1975	Cry	Meñez & Mathieson, 1981, misspelled *Acrochaetium codiculum*; Ben Maiz *et al.*, 1987
Gracilaria arcuata Zanardini	RS - Ind-Pac	Carthage, 1931	Cas/Requires confirmation	Feldmann, 1931; Meñez & Mathieson, 1981; Ben Maiz *et al.*, 1987; Ben Maiz, 1995			
Griffithsia corallinoides (Linnaeus) Trevisan	Atl - Pac	Tabarka, Rass El Fartass, 1969; Bizerte, 1989	Est	Boudouresque, 1970, with doubts; Ben Maiz *et al.*, 1987; Ben Maiz, 1995; Djeloulli *et al.*, 2000			
Hypnea cornuta (Kützing) J. Agardh*	RS - Pan				Jerba, 2014	Cas	Present study
Hypnea spinella (C. Agardh) Kützing = *H. cervicornis* J. Agardh	RS - Pan	Zembra, 1986	Est	Ben Maiz & Boudouresque, 1986; Ben Maiz, 1995; Boudouresque *et al.*, 2006; Zerzeri *et al.*, 2010	Kerkennah, 1995	Est	Ben Maiz, 1995
Lophocladia lallemandii (Montagne) F. Schmitz *	RS- Ind-Pac				Gabes, 1938	Est	Feldmann & Feldmann, 1939; Ben Maiz *et al.*, 1987; Ben Maiz, 1995; present study

(continued)

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Table 2. *(continued)*

Species	Native range	North Tunisia (Western Mediterranean)			Central-South Tunisia (Central Mediterranean)		
		First sighting	Status	References	First sighting	Status	References
Polysiphonia atlantica Kapraunand J.N. Norris= *P. macrocarpa* Harvey	Atl - Pac	Raouad, 1973-1975	Cry	Meñez & Mathieson, 1981; Ben Maiz *et al*., 1987; Ben Maiz, 1995	Jerba, 1973-1975	Cry	Meñez & Mathieson, 1981; Ben Maiz *et al*., 1987; Ben Maiz, 1995
Polysiphonia fucoides (Hudson) Greville = *P. nigrescens* (Hudson) Greville *ex* Harvey	Atl	Carthage, 1969	Cry	Ben Alaya, 1972; Meñez & Mathieson, 1981; Ben Maiz *et al*., 1987; Ben Maiz, 1995	Nabeul and Jerba, 1973-1975	Cry	Meñez & Mathieson, 1981; Ben Maiz *et al*., 1987; Ben Maiz, 1995
Womersleyella setacea (Hollenberg) R.E. Norris*	Pan	Cap Bon, 1996-1997	Est	Piazzi *et al*., 2001; 2002			
Neosiphonia sphaerocarpa (Børgesen) M.S. Kim & I.K. Lee	Cos	Golf of Tunis, 1970	Ques	Ben Alaya, 1970			
Ochrophyta							
Pylaiella littoralis (Linnaeus) Kjellman	Atl				Sfax, 1924	Cry	Schiffner, 1926, Ben Maiz *et al*., 1987
Leathesia marina (Lyngbye) Decaisne = *Leathesia difformis* Areschoug	Atl	Tunisia, 1992	Ques	Ribera *et al*., 1992			
Padina boryana Thivy = *P. tenuis* Bory	Pac	Bay of Tunis, Tabarka and Ain Oktor, 1991	Ques	Nizamuddin, 1981	Gulf of Gabes, 1991	Ques	Nizamuddin, 1981
Chlorophyta							
Caulerpa chemnitzia (Esper) J.V.Lamouroux* = *C. racemosa* var. *chemnitzia* (Esper) Weber-Van Bosse = *C. racemosa* var. *turbinata* (J. Agardh) Eubank	RS - Pan	Cani Island and Bizerte harbour, 1997	Est	Verlaque *et al*., 2000, 2003; Djellouli *et al*., 2006	Sousse, 1926	Est	Hamel, 1926; Ben Alaya, 1971; Ben Maiz, 1985; 1995; Ben Maiz *et al*., 1987; Ben Mustapha & Hattour, 1992; Bradai & Jribi, 1997; Belkhiria, 1999; Verlaque *et al*., 2000, 2003; Ben Mustapha *et al*., 2002, 2004; Langar *et al*., 2002, 2007; Ben Mustapha & Afli, 2007; Mezgui *et al*., 2007; Shili *et al*., 2010; Zerzeri *et al*., 2010; present study
Caulerpa cylindracea Sonder * = *C. racemosa* var. *cylindracea* (Sonder) Verlaque, Huisman & Boudouresque	Ind-Pac	North coast, 1996	Est	Djellouli, 2000; Ben Mustapha *et al*., 2002; 2004; Langar *et al*., 2006; 2007; Piazzi *et al*., 2005; Djellouli *et al*., 2006; Ben Mustapha & Afli, 2007; Mezgui *et al*., 2007; 2010a, b; 2014; Shili *et al*., 2010; Zerzeri *et al*., 2010; present study	Mellita, 1985	Est	Hamza *et al*., 1995; Djellouli, 2000; Ben Mustapha & Hattour, 1992; Ben Mustapha *et al*., 2002; Langar *et al*., 2002, 2006, 2007; Piazzi *et al*., 2005; Djellouli *et al*., 2006; Ben Mustapha & Afli, 2007; Zaouali & Ben Charrada, 2010; Shili *et al*., 2014; present study
Caulerpa taxifolia (Vahl) C. Agardh *	Pac	Sidi Daoud, 2001	Est	Langar *et al*., 2006, 2007, 2010; Ben Mustapha *et al*., 2004; Ben Salem *et al*., 2004; Ben Mustapha & Afli, 2007; Ben Salem & Gaamour, 2007	Sousse, 2000	Est	Langar *et al*., 2000, 2001, 2002, 2006, 2007, 2010; Ben Mustapha *et al*., 2002; 2004; Ben Mustapha & Afli, 2007; present study
Codium fragile subsp. *fragile* (Suringar) Hariot *	Pac	Bizerte, 1985	Est	Djellouli, 1987; Ben Maiz, 1995; Shili *et al*., 2010, 2014; Zerzeri *et al*., 2010	Chott-Mariem, 2010	Est	Present study
Ulva lactuca Linnaeus	Cos	North Coast, Bay of Tunis, 1987	Ques	Ben Maiz *et al*., 1987	Hammamet Golf, 1987	Ques	Ben Maiz *et al*., 1987
Magnoliophyta							
Halophila stipulacea (Forsskål) Ascherson *	RS - Ind				Sfax, 2003	Est	Missaoui *et al*., 2003, 2006; Sghaier *et al*., 2011, 2014; present study

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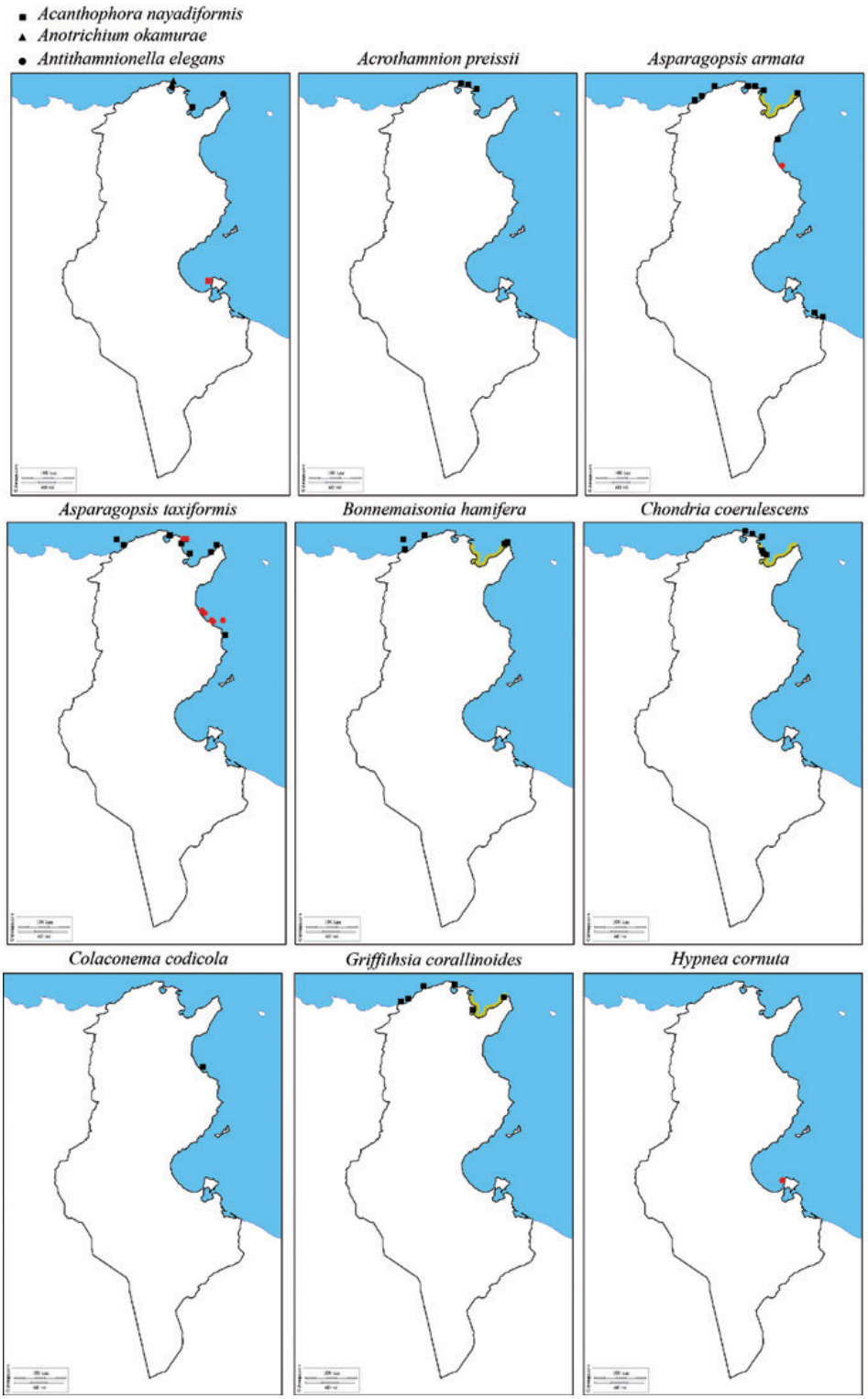

Fig. 3: Records of alien marine macrophytes (established, casuals, cryptogenic) by species in Tunisia until 2014. Black symbols and yellow lines: available historical data; red symbols: new records.

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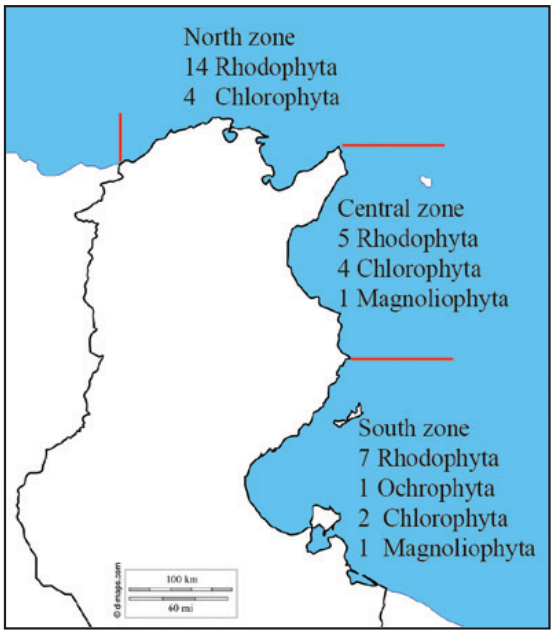

Fig. 4: Number of alien marine macrophytes (established, casuals, cryptogenic) recorded in Tunisia until 2014.

9 and 24 m depth. *Caulerpa taxifolia* was found at five sampling sites out of 67 (7.5%). *Codium fragile* subsp. *fragile* was uncommon in Tunisia, with occurrences at only three sampling sites out of the 67 (4.5 %). It grew between 1 and 5 m depth on hard substrates.

Like *Asparagopsis taxiformis, Halophila stipulacea* is a recent invader in Tunisia with a first sighting in 2003 at Sfax (Missaoui *et al*., 2003). During field studies, the species was observed at the Cap Monastir and the Kerkennah Islands (4.5% of sampling sites).

Questionable species

Neosiphonia sphaerocarpa *(Børgesen) M.S. Kim & I.K. Lee (Rhodophyta)*

Cormaci *et al*. (2004) considered *N. sphaerocarpa* to be introduced in the Mediterranean Sea where the species was first recorded in 1970 from Tunisia (Ben Alaya, 1970, misspelled *P. sphaerocaspa*). However, the species is distributed worldwide and molecular data are needed to locate its place of origin. Moreover, its identification is not easy, so the absence of *N. sphaerocarpa* in the Mediterranean prior to 1970 could simply mean that it was overlooked or mistaken for another species. Pending further investigations, Tsiamis *et al*. (2010) provisionally consider this species as native in the Mediterranean Sea.

Leathesia marina *(Lyngbye) Decaisne (Ochrophyta)*

Described from Scandinavia (Lyngbye, 1819, as *Chaetophora marina*), *L. marina* was introduced along the French Mediterranean coasts (Verlaque, 2001). Ribera *et al*. (1992) reported the species (as *L. difformis*) from Tunisia, referring to Ben Maiz *et al*. (1987), but these authors cited only the native species *L. mucosa* J. Feldmann. The occurrence of *L. marina* in Tunisia is possible since it was recorded from Sicily (Marino *et al*., 1998), but as for other Atlantic species, its status in the southern Mediterranean Sea is cryptogenic.

Padina boryana *Thivy (Ochrophyta)*

The species was reported from Tunisia (Bay of Tunis, Gulf of Gabes, Tabarka and Ain Oktor) (Nizamuddin, 1981, as *P. tenuis* Bory) but Verlaque *et al*. (2015) considered these records as doubtful.

Ulva lactuca *Linnaeus (Chlorophyta)*

This species has frequently been reported from Tunisia (see Ben Maiz *et al*., 1987). However, all the records of *U. lactuca* over the past 200 years refer to another species (Butler, 2007; F. Mineur, pers. comm.) and should be cited as *U. lactuca auctores.* The genuine *U. lactuca* is a warm water species long misspelled as *U. fasciata* Delile, a later heterotypic synonym taxon described from Alexandria (Egypt) (Delile, 1813, 1826) and distributed worldwide. Its introduction, probably from Japan, was identified with certainty in France (Verlaque, 2001; Verlaque *et al*., 2015). Along the North Africa coasts, the species was reported as *U. fasciata* from Algeria, Egypt, Libya and Morocco (Bazairi *et al*., 2013; Verlaque *et al*., 2015), so its presence in Tunisia is highly probable. The introduced status of *U. lactuca* in the southern Mediterranean Sea is cryptogenic.

Discussion

A total of 27 alien marine macrophytes were recorded from Tunisia, which is low compared to the 129 AMM listed for the Mediterranean Sea (Verlaque *et al*., 2015). However, compared to nearby Mediterranean regions, this number is close to that reported in the Straits of Sicily (18) (Occhipinti-Ambrogi *et al*., 2011) and Algeria (17) (Verlaque *et al*., 2015), and higher than those recorded in Malta (12) (Sciberras & Schembri, 2007; Evans *et al*., 2015a,b; Schembri *et al*., 2015), and Libya (14) (Bazairi *et al*., 2013). This number has greatly increased since the late 20th century, with sixteen new AMM reported after 1960. *Hypnea cornuta* is reported for the first time from Tunisia. This pantropical species was recorded first in the Mediterranean Sea in 1894 from Rhodes Island, Greece (Reinbold, 1898, as *H. valentiae* (Turner) Montagne), and was successively recorded in Israel (Nemlich & Danin, 1964; Hoffman & Dubinsky, 2010), Syria (Mayhoub, 1976, as *H. hamulosa* (Esper) J.V. Lamouroux), Egypt: Alexandria (Aleem, 1993), Lebanon (Lakkis & Novel-Lakkis, 2000, as *H. hamulosa*), Italy: Mar Piccolo di Taranto (Cecere *et al*., 2004) and Sicily: Cape Peloro Lagoon (Manghisi *et al*., 2011), and Saronikos Gulf, Greece (Tsiamis *et al*., 2010). Although *H. cornuta* was only found at Jerba, its

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casual status needs to be confirmed. The species could be more widely distributed in Tunisia since, in the absence of the characteristic propagules, the species can be easily confused with *H. spinella*.

Gracilaria arcuata, the second casual species, was first reported in the Mediterranean Sea from Carthage (Feldmann, 1931), before being successively recorded from Egypt (Alexandria; Aleem, 1993) and Turkey (Sea of Marmara; Taşkin *et al*., 2008). A report without description from France (Corsica; De Casabianca *et al.,* 1972-1973, as *G.* cf. *arcuata*) is considered as a misidentification (Verlaque *et al*., 2015). According to Gargiulo *et al*. (1992), all the Mediterranean records of *G. arcuata* are doubtful. Consequently, its introduction into the Mediterranean Sea and its occurrence in Tunisia require confirmation.

Of the 27 alien marine macrophytes of Tunisia, 14 species (51.9% of total number of species) are classified as established and seven as cryptogenic (25.9%). Most of AMM are widely distributed and the apparently restricted distribution of the others may be an artifact due to insufficient investigation.

As far as the cryptogenic species are concerned, *Acanthophora nayadiformis,* a species described from both the Red Sea (Suez, Egypt) and the Mediterranean Sea (Alexandria, Egypt) (Delile, 1813, 1826, as *Fucus nayadiformis*), was successively reported throughout the Mediterranean basin. Although Cormaci *et al*. (2004) did not consider the species as introduced into the Mediterranean Sea, the oldest Mediterranean records are after the opening of the Suez Canal. Jerba constitutes its southernmost locality for the Tunisia.

Under the name *Anotrichium okamurae*, two cryptic taxa have been confused in the Atlantic Ocean and the Mediterranean Sea: *A. furcellatum* (J. Agardh) Baldock, a Mediterranean species described from Naples (Agardh, 1842, as *Griffithsia furcellata*), and *A. okamurae*, an introduced species described from Japan (Okamura, 1934, as *Monospora tenuis*) exhibiting an invasive behaviour pattern. Cormaci *et al*. (2004) did not consider *A. okamurae* as a putative introduced species. However, in the absence of molecular studies, we consider that it is preferable to maintain *A. okamurae* and *A. furcellatum* as distinct species. The identity and the introduced or native status of the Tunisian populations need further investigation.

The introduction of *Chondria coerulescens, Colaconema codicola, Polysiphonia atlantica*, *P. fucoides* and *Pylaiella littoralis,* five species described from the north-eastern Atlantic Ocean (Linnaeus, 1753; Hudson, 1762; Agardh, 1863; Børgesen, 1927; Kapraun & Norris, 1982), were identified with certainty along the French Mediterranean coasts (Ben Maiz, 1986; Verlaque & Rioual, 1989; Verlaque, 2001; Verlaque *et al*., 2015). However, these species are widely distributed in the Mediterranean Sea and the co-occurrence of introduced and native populations cannot be excluded, especially along the North African coasts where the native flora possesses many Atlantic-Mediterranean species. Moreover, although the introduction of *C. codicola* in Tunisia is highly probable since its privileged host *Codium fragile* is established, this requires confirmation because the single Tunisian record was epiphytic on *Cymodocea nodosa* (Meňez & Mathieson, 1981). Consequently, the confirmation of the introduced status for each of these species in Tunisia calls for further studies.

Some localities such as Bizerte, El Kantaoui, Cap Monastir and Tunis displayed a high number of recorded aliens compared to the average, confirming that hotspots for marine species introduction are coastal lagoons and harbours where human activities such as shipping and fishing activities, recreational marinas and aquaculture affect the health of ecosystems and facilitate the introduction and the secondary dispersal of alien species (Cohen & Carlton, 1998; Verlaque, 2001; Occhipinti-Ambrogi & Savini, 2003; Rilov & Crooks, 2009; Hoffman *et al*., 2011; Occhipinti-Ambrogi *et al*., 2011).

Most of the AMM in Tunisia show warm-water affinities since only five North Atlantic AMM can be considered as cold-water species. As expected, the main donor regions are the Red Sea and the Indo-Pacific province. The identity and abundance of AMM in Tunisian waters could be explained by its southern geographical position located at the crossroads between the eastern and western basins of the Mediterranean Sea.

On the 21 invasive or potentially invasive AMM listed by Zenetos *et al*. (2010), nine have been identified in Tunisia: *Acrothamnion preissii, Asparagopsis armata, A. taxiformis, Lophocladia lallemandii, Womersleyella setacea, Caulerpa cylindracea, C. taxifolia, Codium fragile* subsp. *fragile* and *Halophila stipulacea.* To this list, we have added *Caulerpa chemnitzia* and *Hypnea cornuta* that are spreading in the Mediterranean Sea. In Tunisia, all of them were already widely distributed in 2014 except for *A. preissii, H. cornuta* and *W. setacea,* whose apparent scarcity could be merely an artefact due to problems of identification in the field.

Asparagopsis armata was first recorded in Tunisia (Cap Serrat) in the 1970s (Meňez & Mathieson, 1981). By 2010, it was reported on the north-east coast of Tunisia (Bizerte, Cap-Zebib and Raf-Raf) (Zerzeri *et al*., 2010). Our new record was approximately 300 km south of its previously documented distribution in Tunisia.

Asparagopsis taxiformis was only recently recorded from Tunisia (Andreakis *et al*., 2004). Since 2003, it has been observed, from 0 to 10 m depth, on rocky substrates and dead *Posidonia oceanica* meadows. On the four *Asparagopsis taxiformis* lineages hitherto identified in the world, two occur in the Mediterranean Sea: the non-invasive lineage 3 of putative Atlantic origin and the invasive lineage 2 originate from the Indo-Pacific region. The invasive lineage 2 was identified at Mahdia (Andreakis *et al*., 2004, 2007, 2009). The identification of lineage(s) occurring in the other Tunisian localities requires further

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investigation; however, the recent spread observed in the central zone of Tunisia is in good agreement with the invasive behaviour of lineage 2.

Caulerpa chemnitzia was first reported from the Mediterranean Sea in 1926 in Tunisia (Sousse Harbour; Hamel, 1926). Hereafter, it remained restricted to the eastern basin (Cyprus, Egypt, Israel, Lebanon and Syria) for a long time. Since the early 21st century, the species has been spreading in the Mediterranean Sea. It was recently discovered in Algeria (Verlaque *et al.,* 2015) and the number of populations is increasing in Tunisia.

Until 2010, *Caulerpa taxifolia* was locally very abundant in Tunisia, forming dense extensive meadows on soft substrates and dead *Podisonia oceanica* meadows. However, in late 2011 and early 2012, the abundance of *C. taxifolia* declined significantly (up to 90%) in the central zone of Tunisia (pers. obs.).

The record of *Codium fragile* at El Kantaoui was approximately 300 km south of the previously documented range of distribution in Tunisia.

The most harmful alien marine macrophytes in Tunisia is probably *Caulerpa cylindracea.* Its rapid spread in the Mediterranean Sea has profoundly altered benthic communities and reduced seaweed diversity (Piazzi *et al*., 2005; Klein & Verlaque, 2008). It is worth noting that, contrary to the generally accepted opinion, the first observation of the species in the Mediterranean Sea was not in Libya in 1990 (Nizzamudin, 1991), but five years earlier in 1985 in Tunisia, at Mellita (see Hamza *et al*., 1995). This point, which has hitherto gone unnoticed, is important because it dates the introduction of the two invasive *Caulerpa* species, *C. cylindracea* and *C. taxifolia,* into the Mediterranean Sea during the same period (1984-1985) (see Meinesz & Hesse, 1991, for *C. taxifolia*).

As far as the other potentially invasive AMM in Tunisia are concerned, the literature reports a conspicuous ecological impact in the invaded regions for *Acrothamnion preissii, Lophocladia lallemandii, Womersleyella setacea, Caulerpa taxifolia, Codium fragile* and *Halophila stipulacea* (Verlaque & Fritayre, 1994; Villèle & Verlaque, 1995; Piazzi *et al*., 2001, 2002, 2012; Provan *et al*., 2005; Ballesteros *et al*., 2007; Willette & Ambrose 2009, 2012).

In conclusion, the high number of potentially invasive alien marine macrophytes already introduced in the country and its geographical position between the eastern and the western Mediterranean basins, on the westward migration route of Lessepsian species, make the monitoring of alien marine species in Tunisia a scientific priority.

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