

## **New contribution to the knowledge of the genus *Cystoseira* C. Agardh in the Mediterranean Sea, with the reinstatement of species rank for *C. schiffneri* Hamel**

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**Abstract** – A survey of the species of *Cystoseira* (Fucales, Phaeophyceae, Ochrophyta) of Tunisia highlighted six Mediterranean endemic taxa rare or new for this country: *C. barbata* f. *aurantia*, *C. brachycarpa* var. *claudiae*, *C. compressa* subsp. *pustulata*, *C. foeniculacea* f. *dubia*, *C. hyblaea* and *C. spinosa* var. *tenuior*. The discovery and the study of these species, some of which were little known, have allowed some taxonomic and biogeographical uncertainties to be identified and discussed. On the basis of the results, the transfer of *C. discors* f. *dubia* to *C. foeniculacea* as *C. foeniculacea* f. *dubia* and the reinstatement of species rank for the Mediterranean endemic species *C. schiffneri* are proposed.

***Cystoseira* / *Cystoseira schiffneri* / Sargassaceae / Ochrophyta / rare species / endemic species / Tunisia / Mediterranean**

**Résumé** – Une prospection du littoral Tunisien a mis en évidence six nouveaux taxons du genre *Cystoseira* (Fucales, Phaeophyceae, Ochrophyta) endémiques méditerranéens rares ou nouveaux pour ce pays : *C. barbata* f. *aurantia*, *C. brachycarpa* var. *claudiae*, *C. compressa* subsp. *pustulata*, *C. foeniculacea* f. *dubia*, *C. hyblaea* et *C. spinosa* var. *tenuior*. La découverte et l'examen de ces espèces, dont certaines sont peu connues, étaient l'occasion d'élucider et de discuter certaines ambiguïtés taxonomiques et biogéographiques. Sur la base de ces résultats, le transfert de *C. discors* f. *dubia* à *C. foeniculacea* comme *C. foeniculacea* f. *dubia* et le rétablissement du rang d'espèce pour l'endémique méditerranéenne *C. schiffneri* sont proposés.

***Cystoseira* / *Cystoseira schiffneri* / Sargassaceae / Ochrophyta / espèces rares / espèces endémiques / Tunisie / Méditerranée**

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## INTRODUCTION

In the Mediterranean Sea, Fucoïd species of the genera *Cystoseira* C. Agardh and *Sargassum* C. Agardh are the main habitat-forming species of the photophilous rocky substrates from the littoral fringe to the lower photic zone (down to 70-80 m depth in the clearest waters) (Giaccone & Bruni, 1973; Giaccone *et al.*, 1994). Despite this, their Mediterranean distribution is still poorly understood. Of close to 300 taxons of *Cystoseira* described worldwide (Guiry & Guiry, 2015), 29 species and more than fifteen infra-specific taxa are currently accepted taxonomically in the Mediterranean Sea, most of them having specific ecological constraints that limit their development to specific habitats (Gómez Garreta *et al.*, 2001; Cormaci *et al.*, 2012).

In a first study (Bouafif *et al.*, 2014), four species and three infraspecific taxa of *Cystoseira* new for Tunisia were reported, extending representatives of the genus in the region to 26 taxa. During a second survey conducted on the Tunisian coasts, several other endemic Mediterranean taxa rare or new for the region were identified, including some that are little known and threatened at Mediterranean scale. Hereafter, a detailed analysis of these new records is given and discussed.

## MATERIAL AND METHODS

Sampling was undertaken by snorkeling, between the sea surface and 4 m depth, at 14 localities distributed along the Tunisian coast, from March 2014 to June 2015 (Fig. 1).

Since most taxa of *Cystoseira* are rare and threatened in many Mediterranean regions, the number of samples was limited to 5-10 individuals per taxon. Samples were cleaned of epiphytes, and transferred to the laboratory in fresh seawater in an icebox. Samples were then rinsed with freshwater, and a subsample of each one was preserved in absolute Ethanol for eventual DNA analyses. The rest of the samples were either preserved in 4% buffered formalin/seawater or pressed and prepared as herbarium specimens. Voucher specimens were deposited in the Herbarium of the Faculty of Sciences of Tunis in the Department of Biology, Tunis, Tunisia.

Collected samples of *Cystoseira foeniculacea* taxa were compared to specimens from Tunisia and from several additional sites deposited respectively in the Herbarium of the Faculty of Sciences of Tunis and in the Herbarium HCOM of the Mediterranean Institute of Oceanography, Aix-Marseille University (Herbarium abbreviation follows Thiers, 2015) (Table 1).

Criteria of identification are based on the mode of attachment to the substratum, the number and the form of axes, the aspect of apices and tophules if present, the phyllotaxy and the morphology of branches, the occurrence and the arrangement of cryptostomata and aerocysts, and the location and the morphology of reproductive structures (see Sauvageau, 1912, 1920; Hamel, 1939; Ercegović, 1952; Gómez Garreta *et al.*, 2001; Cormaci *et al.*, 2012). The nomenclature followed that adopted by Guiry & Guiry (2015).

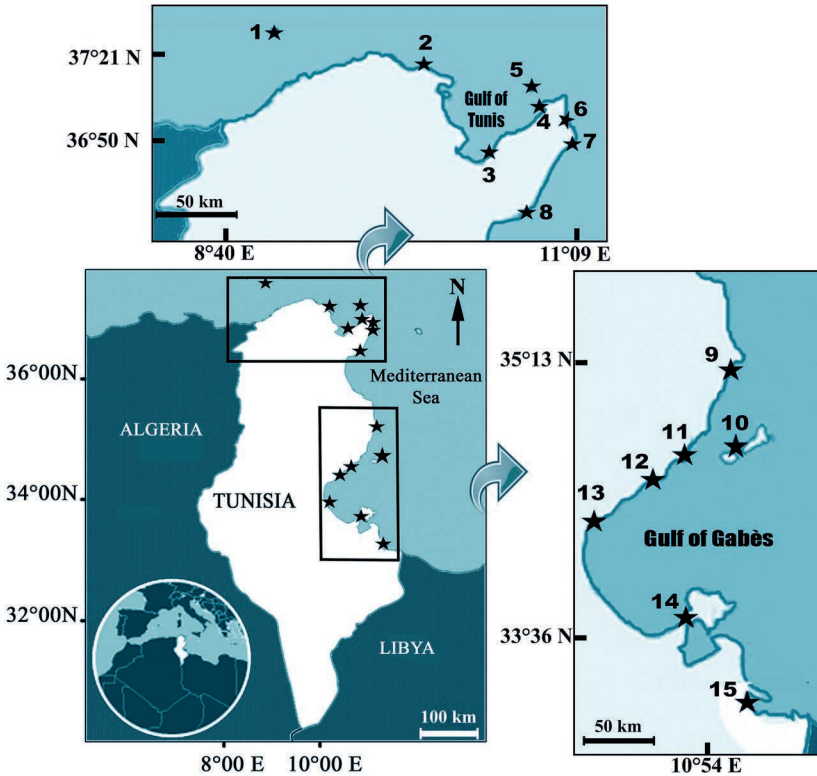


Fig. 1. Collection sites in Tunisia: 1. La Galite Archipelago. 2. Cap Zebib. 3. Sidi Rais. 4. Sidi Daoued. 5. Zembra Island. 6. Dar Allouche. 7. Kelibia. 8. Beni Khiar. 9. Melloulèche. 10. Kerkennah Islands. 11. Thyna. 12. Mahrès. 13. Skhira. 14. Djerba and 15. El Bibane Lagoon.

## RESULTS

During the field surveys conducted from March 2014 to April 2015, six endemic Mediterranean taxa of *Cystoseira* rare or new for Tunisia were collected.

*Cystoseira barbata* (Stackhouse) C. Agardh f. *aurantia* (Kützing) Giaccone in Amico *et al.* (1985: 906) **Figs 2-3**

**Basionym:** *Cystoseira aurantia* Kützing, 1843: 357.

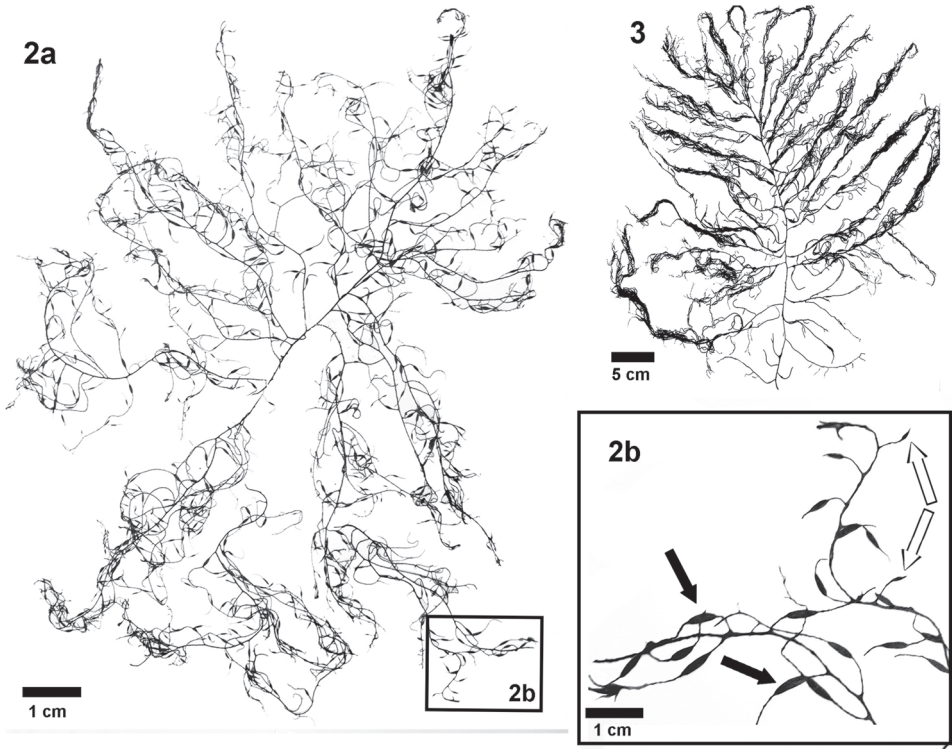
**Synonym:** *Cystoseira barbata* f. *repens* A.D.Zinova & Kalugina, 1974: 121.

**Specimens studied.** Melloulèche, Skhira, Thyna, Djerba, April & June 2014, free-living between the sea surface and 2 m depth, coastal lagoon and sandy pools; Kerkennah Islands, March 2014, free-living between the sea surface and 30 cm depth, sandy-muddy substrates; Mahrès, June 2014, floating at the sea surface, exsiccata ref. A3520.

**Description.** Unattached plant, up to 60 cm long, dark brown, non-iridescent, free-living on the substrate; holdfast and axis absent; tophules absent; primary branches

Table 1. Herbarium specimens consulted

	Herbarium	Reference	Locality, collector and date of the collection	Habitat	
<i>C. foeniculacea</i> f. <i>latiramosa</i> (Ercegović) A. Gómez Garreta et al.	Herbarium of the Faculty of Sciences of Tunis	A2325	Sidi Rais (Gulf of Tunis), Tunisia, coll. C. Bouaffif & H. Langar, 16 March 2012.	0.5 m depth, rocky shores.	
		A2652	Dar Allouche (Cap Bon Peninsula), Tunisia, coll. C. Bouaffif & H. Langar, 06 October 2012.	0.5 m depth, rocky shores.	
	HCOM of the Mediterranean Institute of Oceanography, Aix- les-Bains	H5229	Monte Cristo Island, Italy, coll. H. Frick, 1 October 1985.	30 m depth, rocky shores.	
		H5230	Galeria Corsica, coll. M. Verlaque, 8 February 1990.	38 m depth, rocky shores.	
		H5238	Athens, Greece, coll. A. Diapoulis, 5 August 1980.	0.3 m depth, rocky shores.	
		H5247	Scandola, Corsica, coll. M. Verlaque, 23 June 1998.	35 m depth, rocky shores.	
		A2575	Kelibia, (Cap Bon Peninsula), Tunisia, coll. C. Bouaffif & H. Langar, 14 July 2013.	1 m depth, rocky shores.	
		H5231- H5232	Kraten (Kerkennah Islands), Tunisia, coll. C.F. Boudouresque, December 1980.	0.6 m depth, rocky shores.	
	HCOM of the Mediterranean Institute of Oceanography, Aix- Marseille University	H5233- H5235	Gulf of Tunis, Tunisia, coll. C.F. Boudouresque, 17 April 1980.	Rocky shores.	
		H5236	Sidi Fredj (Kerkennah Islands), Tunisia, coll. N. Ben Maiz, 12 August 1985.	1 m depth, sandstone substrates.	
A2326		Sidi Rais (Gulf of Tunis), Tunisia, coll. C. Bouaffif & H. Langar, 16 March 2012.	0.5 m depth, rocky shores.		
A3910		Kelibia, (Cap Bon Peninsula), Tunisia, coll. C. Bouaffif & H. Langar, 24 April 2014.	0.5 m depth rocky shores.		
<i>C. foeniculacea</i> (Linnaeus) Greville f. <i>foeniculacea</i>	Herbarium of the Faculty of Sciences of Tunis	H5220	Collioure, France, coll. C.F. Boudouresque, 20 July 1981.	Rock pools.	
		H5222	Lazaret Bay, Toulon, France, coll. M. Verlaque, 6 March 1979.	1 m depth, rocky shores.	
	HCOM of the Mediterranean Institute of Oceanography, Aix- les-Bains	H5245- H5246	Kolombos Bank, Greece, coll. P. & H. Huvé, 21 May 1964.	18 m depth, rocky shores.	
		A2697	Sidi Youssef (Kerkennah Islands), Tunisia, coll. C. Bouaffif & H. Langar, 2 December 2012.	1 m depth, free living, sandy-muddy substrates.	
	Herbarium of the Faculty of Sciences of Tunis	A4108	Ouled Bouali (Kerkennah Islands) Tunisia, coll. C. Bouaffif & H. Langar, 9 April 2014.	0.3 m depth, free living, sandy-muddy substrates.	
		A4110	Ouled Bouali (Kerkennah Islands) Tunisia, coll. C. Bouaffif & H. Langar, 28 March 2014	0.5 m depth, free living, sandy-muddy substrates.	
		A2463	El Bibane Lagoon, Tunisia, coll. C. Bouaffif & H. Langar, 5 June 2013	0.3 m depth, fixed on <i>Neogoniolithon</i>	
	<i>C. schiffneri</i> Hamel	HCOM of the Mediterranean Institute of Oceanography, Aix-Marseille University	H5301- H5302- H5305	Kraten (Kerkennah Islands), Tunisia, coll. C.F. Boudouresque, 17 December 1980	0.8 m depth, <i>C. prolifera</i> (Forsskål) J.V. Lamouroux, <i>C. nodosa</i> (Ucria) Ascherson and <i>V. aegagropila</i> C. Agardh assemblages, sandy substrate
			H5304	Stagnone, Sicily, coll. C.F. Boudouresque, November 1984.	1 m depth, sandy substrate.
		Herbarium of the Faculty of Sciences of Tunis	H5306	Alataya (Kerkennah Islands), Tunisia, coll. N. Ben Maiz, 13 August 1985.	0.5-1 m depth, sandy-muddy substrates



Figs 2-3. Free living *Cystoseira barbata* f. *aurantia*. **2a.** Habit, fertile specimen (Melloulèche, A3520, April 2014). **2b.** Detail showing filiform branchlets with terminal fusiform receptacles (white arrows) and aerocysts (black arrows). **3.** Non-fertile specimen (Mahrès, A3530, June 2014).

cylindrical, up to 10-40 cm long and 1-2 mm in diameter; secondary branches cylindrical, without spinose appendages; ultimate branches filiform; cryptostomata abundant; aerocysts abundant, ovoid, 4-6 mm long and 1-2 mm in diameter, isolated or in short series of 2-4; conceptacles grouped in terminal receptacles, compact, fusiform-mucronate, 1-3 mm long and 1 mm in diameter.

**Habitat.** *C. barbata* f. *aurantia* was found in sheltered stations, coastal lagoons and in littoral pools, floating or free-living on sandy-muddy substrate, between 0 and 2 m depth.

**Distribution.** Atlantic Ocean: only reported from Cádiz; Black Sea and Mediterranean Sea: Adriatic Sea, Balearic Islands, Corsica, France, Italy, Tuscany, Sardinia, Sicily, Spain, Tunisia, Turkey (Zinova & Kalugina, 1974; Kalugina-Gutnik, 1975; Giaccone, 1978; Pellegrini *et al.*, 1985; Ben Maiz *et al.*, 1988; Ribera *et al.*, 1992, 1995; Furnari *et al.*, 1999; Gómez Garreta *et al.*, 2001; Rindi *et al.*, 2002; Thibaut *et al.*, 2005; Taşkin *et al.*, 2008, 2012; Hernández *et al.*, 2010). In Tunisia, the taxon was previously reported from El Bibane Lagoon, Djerba and Kerkennah Islands (Gómez Garreta *et al.*, 2001, as *C. barbata* f. *repens*). During our field surveys, *C. barbata* f. *aurantia* was rare and only present on the southern coasts of Tunisia (Melloulèche, Skhira, Thyne, Djerba and Kerkennah Islands).

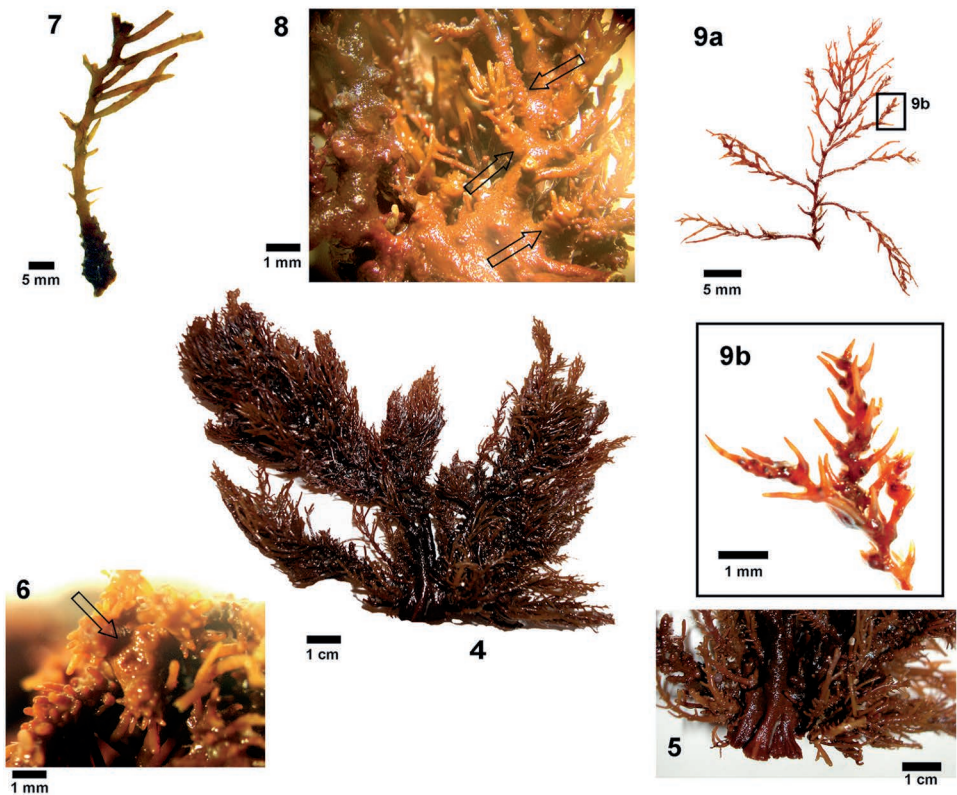


**Comment.** The Tunisian specimens agree well with previous descriptions and illustrations of the taxon (Zinova & Kalugina, 1974; Amico *et al.*, 1985; Giaccone, 1985; Pellegrini *et al.*, 1985; Gómez Garreta *et al.*, 2001; Cormaci *et al.*, 2012). Gómez Garreta *et al.* (2001) considered *C. barbata* f. *aurantia* as synonym of *C. barbata* f. *repens*, but erroneously since the former form has priority vs the latter (Cormaci *et al.*, 2012).

*Cystoseira brachycarpa* J. Agardh var. *claudiae* (Giaccone) Giaccone in Ribera *et al.* (1992: 124) **Figs 4-9**

**Basionym.** *Cystoseira balearica* Sauvageau var. *claudiae* Giaccone in Amico *et al.*, 1985: 906.

**Specimens studied.** Cap Zebib: March 2014, 50 cm depth, rocky beach; La Galite Archipelago: September 2014, 2 m depth, rocky shores, exsiccata ref. A3411, A3413; Zembra Island: June 2014, 1 m depth, rocky shores, exsiccata ref. A3406, A3407.



Figs 4-9. *Cystoseira brachycarpa* var. *claudiae* (La Galite Archipelago, A3411, September 2014). 4. Habit. 5. Discoid compact base formed of haptera. 6. Apical view of an axis showing the not prominent apex (arrow). 7. Lower part of primary branch with hemitophule. 8. Detail of the insertion of primary branches on an axis; arrows: basal part of branches swollen in hemitophules (arrows). 9a. Fertile branch with terminal receptacles. 9b. Detail showing spinose receptacles with conceptacles at the base of spinose appendages.

**Description.** Plant caespitose, erect, up to 15 cm in height, brown, slightly iridescent *in situ*, attached to the substrate by an irregular basal disc or haptera; axes erect numerous (3- 9), cylindrical, up to 6 cm in height, with stumps of deciduous old primary branches; apex flattened, not very prominent and surrounded by spinose appendages; tophules and aerocysts absent; primary branches cylindrical, with a slightly swollen spinose basal part (hemitophules *sensu* Amico *et al.*, 1985), 2-4 mm long and 2 mm in diameter, and with loose long spinose appendages alternating with secondary branches; conceptacles grouped in diffuse to slightly compact terminal receptacles, 10-15 mm long, with long spinose appendages.

**Habitat.** *Cystoseira brachycarpa* var. *claudiae* grew on moderately exposed rocky shores between 1m to 4 m depth, below the *C. amentacea* (C. Agardh) Bory var. *stricta* Montagne belt.

**Distribution.** Described from Linosa Island, *C. brachycarpa* var. *claudiae* was successively recorded in the Balearic Islands, Sicily and adjacent Islands (Cinelli *et al.*, 1976; Giaccone *et al.*, 1985; Ribera Siguán & Gómez Garreta, 1985; Soto & Conde 1989; Cormaci *et al.*, 1992; Ribera *et al.*, 1992; Mannino & Mancuso, 2009; Taşkin *et al.*, 2012). The taxon is reported for the first time from Tunisia and from North Africa. In Tunisia, *C. brachycarpa* var. *claudiae* was only found on the northern coasts (Cap Zebib) and near the northern islands (La Galite Archipelago and Zembra Island).

**Comment.** The Tunisian specimens agree well with previous descriptions and illustrations of the taxon (Cinelli *et al.*, 1976; Amico *et al.*, 1985, as *C. balearica* var. *claudiae*; Gómez Garreta *et al.*, 2001; Mannino & Mancuso, 2009; Cormaci *et al.*, 2012).

*Cystoseira compressa* (Esper) Gerloff & Nizamuddin subsp. *pustulata* (Ercegovič) Verlaque in Thibaut *et al.*, (2015: 219-220) **Figs 10-12**

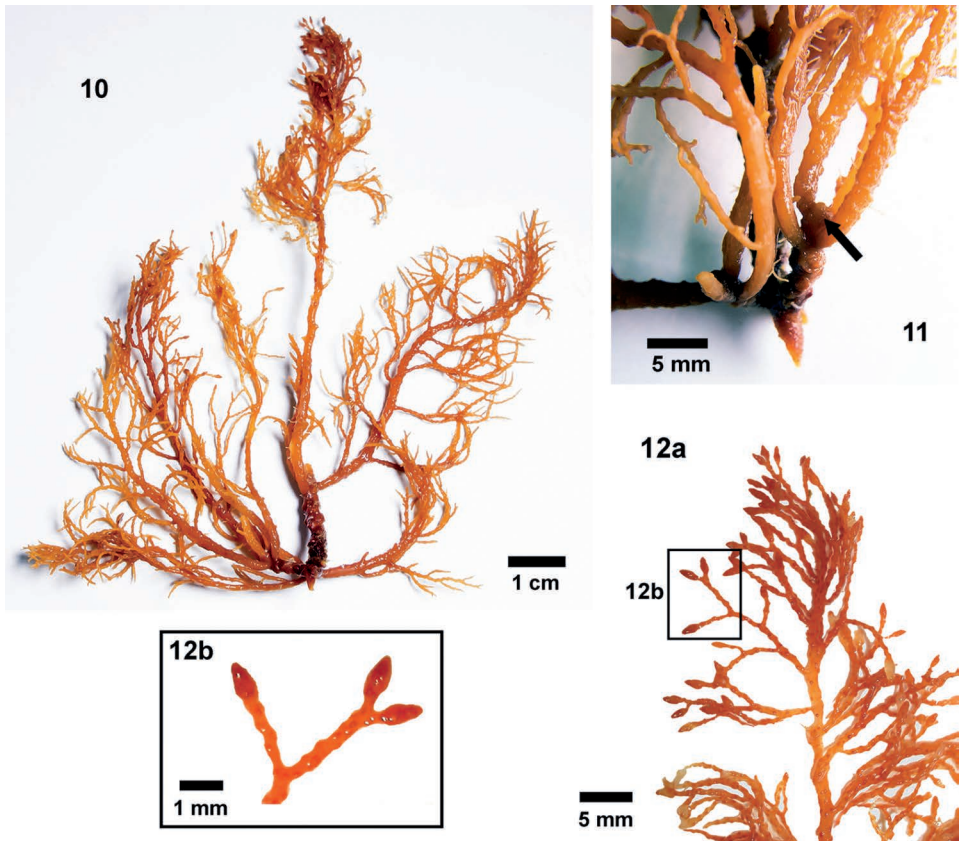
**Basionym.** *Cystoseira abrotanifolia* (Linnaeus) C. Agardh subsp. *pustulata* Ercegovič, 1952: 113, pls XXIVe, XXX.

**Synonyms.** *Cystoseira planiramea* Schiffner ex Gerloff & Nizamuddin, 1975: 567-568, pls 5-8; *C. epiphytica* Schiffner ex Gerloff & Nizamuddin, 1976: 165, pls 1-3; *C. compressa* var. *pustulata* Ercegovič ex Verlaque, 1988: 191, *nom. inval.*

**Specimens studied.** El Bibane Lagoon: March 2014, epiphyte on *Cystoseira schiffneri* Hamel, sandy substratum, 50 cm depth, exsiccata ref. A3711; Kerkennah Islands, epiphyte on *Cystoseira elegans* Sauvageau, sandy substratum, 1 m depth, exsiccata ref. A3712.

**Description.** Plant caespitose, erect, 10-15 cm in height, yellowish-brown, non-iridescent, epiphytic, attached to the host plant by haptera; axes erect, cylindrical, 1-3 cm long, bearing stumps of deciduous old primary branches; apices smooth and prominent; tophules absent; primary branches cylindrical, darker and slightly compressed at their base, up to 10 cm in length; secondary branches and branches of higher order cylindrical, filiform, arranged distichously in one plane; cryptostomata abundant on all branches, prominent (whence the name "*pustulata*"); spinose appendages absent; aerocysts not observed; conceptacles grouped in small terminal receptacles, simple or rarely bifurcate, compact and fusiform, 1 mm long and 0.5 mm in diameter.

**Habitat.** On the southern coasts of Tunisia, *C. compressa* subsp. *pustulata* grew in shallow water up to 1m depth, epiphyte on other *Cystoseira* species in moderately exposed littoral pools and coastal lagoons with sandy substrates. It was found attached to *C. schiffneri* and *C. spinosa* var. *tenuior* in El Bibane Lagoon and on *C. elegans* in Kerkennah Islands. The taxon was already observed attached to



Figs 10-12. *Cystoseira compressa* subsp. *pustulata* (El Bibane Lagoon, A3711, March 2014). **10.** Habit. **11.** Basal part of thallus with smooth apex (arrow). **12a.** Fertile primary branch with terminal receptacles. **12b.** Detail showing small fusiform receptacles.

*C. barbata* and *C. compressa* in muddy to sandy-muddy lagoons of the Adriatic Sea (Thierry Thibaut, pers. com.). Its epiphytic status on other species of *Cystoseira* in a sandy environment is probably an adaptive response to the scarcity of suitable surfaces for its development. On the northern rocky coasts of Tunisia (Cap Zebib, Sidi Rais), where available substrates are not limiting, the taxon has never been found epiphyte on other algae.

**Distribution.** The distribution of this Mediterranean endemic taxon requires a revision due to its previous confusion with the Atlantic taxon *C. humilis*. Originally described from the Adriatic Sea, *C. compressa* subsp. *pustulata* was successively reported from the Aegean Sea (Nikaria Island) (Gerloff & Nizamuddin, 1975, as *C. planiramea*), Spain, the Balearic Islands, Sardinia, Sicily and adjacent islands and Turkey (Gómez Garreta *et al.*, 2001, as *C. humilis* var. *humilis*; Taşkin *et al.*, 2012, as *C. humilis* var. *humilis*), Corsica (Verlaque, 1988, as *C. compressa* var. *pustulata*) and from continental France (Thibaut *et al.*, 2015). The report of *C. humilis* var. *myriophylloides* (Sauvageau) J.H. Price & D.M. John from Tunisia (Meñez & Mathieson, 1981, as *C. myriophylloides*) could correspond to this taxon. Our investigations confirm the occurrence of the taxon in Tunisia and in North Africa.



**Comment.** Except for the absence of aerocysts, the Tunisian specimens agree well with the original diagnosis and illustrations of *C. abrotanifolia* subsp. *pustulata* (Ercegović, 1952), *C. planiramea* (Gerloff & Nizamuddin, 1975), *C. epiphytica* (Gerloff & Nizamuddin, 1976), with descriptions of Mediterranean specimens attributed to *C. humilis* Kützing (Amico *et al.*, 1985; Gómez Garreta *et al.*, 2001; Mannino & Mancuso, 2009; Cormaci *et al.*, 2012; see Thibaut *et al.*, 2015), and with other descriptions and illustrations of the taxon (Rodríguez-Prieto *et al.*, 2013).

*Cystoseira foeniculacea* (Linnaeus) Greville f. *dubia* (Ercegović) Bouafif, Verlaque & Langar **comb. nov.** **Figs 13-15**

**Nomenclatural note.** In 1952, Ercegović described *Cystoseira discors* f. *dubia* Ercegović from the Adriatic Sea. Given that the currently accepted name for *C. discors* (Linnaeus) C. Agardh is *C. foeniculacea* (Linnaeus) Greville (Gomez Garreta *et al.*, 2001), we conserve the ranking of forma and we validate, hereafter, the transfer of this entity from *C. discors* to *C. foeniculacea*.

**Basionym.** *Cystoseira discors* (Linnaeus) C. Agardh f. *dubia* Ercegović, 1952: 113, pl. XXVIII.

**Type locality.** Otok Maun and Vir (Puntadura) Islands, 5 March 1949, 70 m depth, Croatia.

Published in: Ercegović, A. (1952). *Fauna i Flora Jadrana. Jadranske cistozire. Njihova morfologija, ekologija i razvitak/Fauna et Flora Adriatica. Sur les Cystoseira adriatiques. Leur morphologie, écologie et évolution.* Vol. 2 pp. 1-172 (Croatian), 173-210 (French), 211-212 (references), Map. Institut za Oceanografiju i Ribarstvo Split/Institut d'Océanographie et de Pêche, Split.

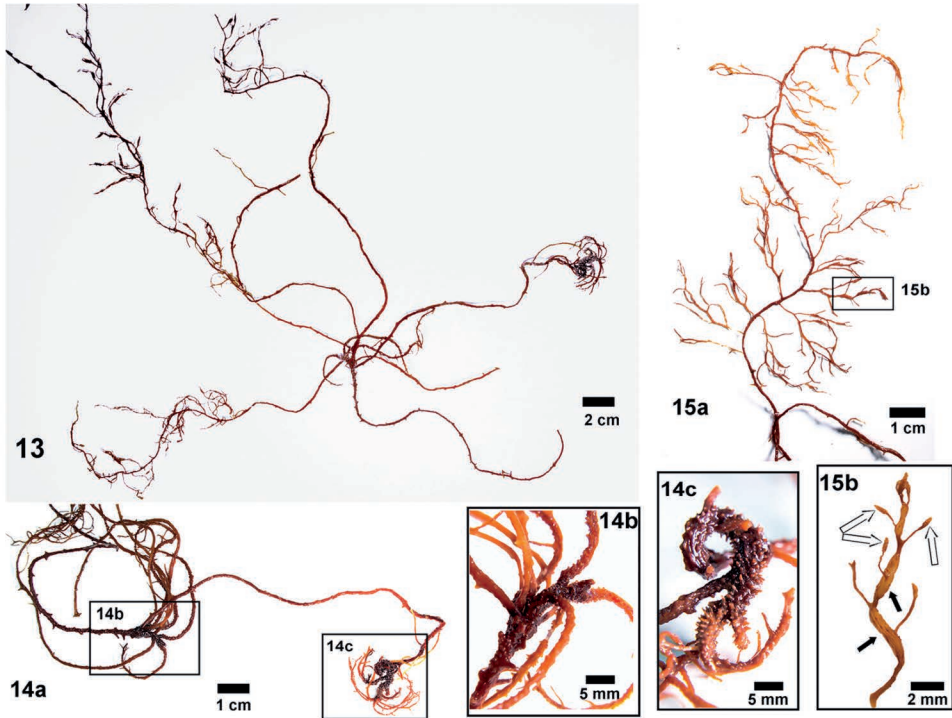
**Specimen studied.** Kerkennah Islands: March 2014, free-living on sandy substrate, exsiccata ref. A3940.

**Description.** Unattached plant free-living on sandy substrate, 80 cm long, brown to orange-brown, non-iridescent; holdfast, axis and tophules absent; primary branches cylindrical, 20 cm long and 2-3 mm in diameter, covered with spaced short small spinose appendages that become more condensed in their apical and their basal parts, and with stumps of deciduous old branches; apical part very prominent and spinose with a group of 11 secondary branches cylindrical, 5-50 cm long, spinose, one of them ending by a new group of apical branches; branches of higher orders cylindrical, spinose, deciduous; aerocysts oblong, 3-4 mm long and 1-2 mm in diameter, arranged in chains of 2-6; receptacles terminal, compact, fusiform, 1-2 mm long and 0.5-1 mm in diameter, associated with the aerocysts (Figs 13-15). By breaking away, a secondary branch seems able to turn into a primary one leading to a new free-living thallus.

**Habitat.** Specimen found free-living on sandy-to-sandy-muddy shallow substrate in a sheltered area, associated with *C. schiffneri*. Individual possibly carried to shallow waters from deeper areas by current or waves.

**Distribution.** *Cystoseira foeniculacea* f. *dubia* had been never found again since its discovery in deep waters in Croatia (Ercegović, 1952). This is the first report of the taxon outside Adriatic Sea. In Tunisia, the taxon was only observed at Kerkennah Islands.

**Comment.** The Tunisian specimen agrees well with the original diagnosis and illustration of *Cystoseira discors* f. *dubia* (Ercegović, 1952). Compared to the diagnosis : “*Differt a typo absentia caulis proprie dicti et ramis primariis maiori ex parte decumbentibus, inferne foliaceo-compressis, apicem versus subcylindraceutis*

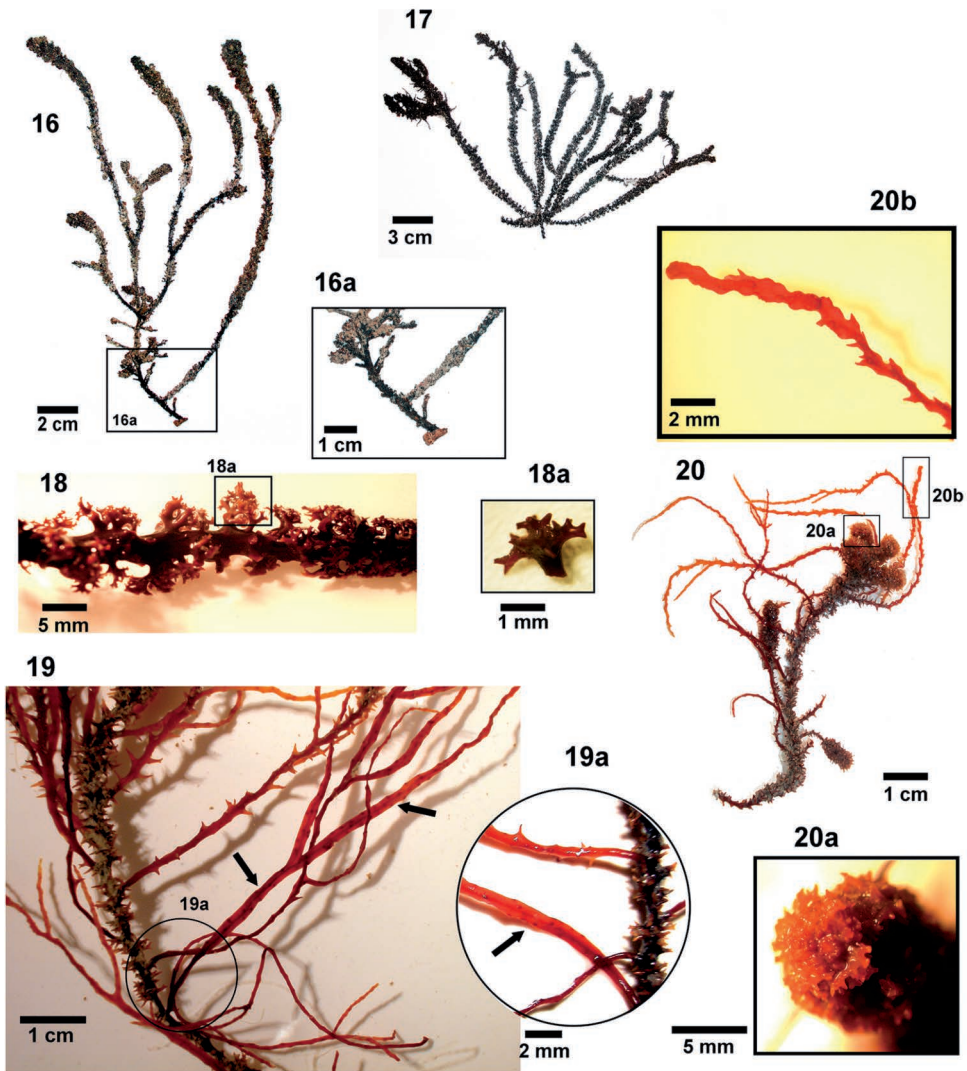


Figs 13-15. Free-living *Cystoseira foeniculacea* f. *dubia* (Kerkennah Islands, A3940, March 2014). Fig. 13. Habit. 14a. Cylindrical and spinose axes with repetitive terminal branching. 14b-c. Details showing spinose basal parts of secondary branches. 15a. Fertile branch. 15b. Detail showing terminal fusiform receptacles (white arrows) and oblong aerocysts (black arrows).

*ibique formam et functionem apicis caulis praestantibus et novos ramos sibi similes producentibus. Conceptaculis nullis. Propagatio tantum vegetativa adesse et crescentia indefinita ramorum primariorum fieri videtur*”, our specimen only differs by the lower part of branches, which are not flattened and have no midrib, a character that is a non-fixed criterion in *C. foeniculacea* (Gómez-Garreta *et al.*, 2001), and by the presence of receptacles. Described from only one specimen, Ercegovič considered *C. foeniculacea* f. *dubia* as a rare free-living form very close to the type form of *C. discors* (= *C. foeniculacea*). We agree with his analysis since in Tunisia we have also found a single individual associated with individuals of the type form of *C. foeniculacea*.

### Relationships between *C. foeniculacea* f. *dubia* and *C. schiffneri* Hamel

Associated with *C. foeniculacea* f. *dubia*, it is worth noting the presence of fixed and free living individuals of *C. schiffneri* Hamel, a taxon described from Sfax, Djerba and Kerkennah Islands (Hamel, 1939) before being reduced to an infra-specific taxon of *C. foeniculacea* as *C. foeniculacea* f. *schiffneri* (Hamel) Gómez Garreta, Barceló, Ribera & Rull Lluçh (Gómez Garreta *et al.*, 2001; Cormaci *et al.*, 2012). Our free-living specimen of *C. foeniculacea* f. *dubia* clearly differs from



Figs 16-20. Free living and fixed *Cystoseira schiffneri*. **16**. Habit of a fixed individual (El Bibane Lagoon, A2463, June 2012). **16a**. Detail of basal part showing a single cylindrical axis and a basal disc. **17**. Old free-living individual deprived of deciduous thin branches (A4108, Kerkennah Islands, April 2014). **18**. Detail of axes showing the dense cover of short branched spinose appendages. **18a**. Detail of branched spinose appendages showing multifid apex. **19**. Detail of upper branches showing cylindrical and compressed branches (black arrows). **19a**. Detail of compressed branches with midrib slightly prominent and scattered cryptostomata (black arrows). **20**. Fertile individual. **20a**. Detail showing obtuse apex totally covered by very short multifid spinose appendages. **20b**. Detail showing long terminal diffuse receptacle with spaced small axial conceptacles and small simple spinose appendages.

free-living individuals of *C. schiffneri* in having (i) a greater size of the thallus (80 cm rather than 30 cm long), (ii) the absence of axis, (iii) the branches flexible with spaced simple spinose appendages that become slightly grouped in apical and basal parts of branches, (iv) the presence of numerous aerocysts, and (v) the receptacles terminal, short, compact, lanceolate to fusiform (Figs 13-15; Table 2). Except for the absence of axes and the free-living habit, by all the other characters, i.e. the muricate axes, the flattened to cylindrical branches, the aerocysts oblong in chains and the receptacles compact, fusiform to lanceolate, *C. foeniculacea* f. *dubia* agrees well with *C. foeniculacea sensu lato*.

The discovery of young *C. schiffneri* fixed on the substrate showed that it belongs to the group of non-caespitose species in contrast to *C. foeniculacea sensu lato*, which is a caespitose taxon. Compared to other species of *Cystoseira*, *C. schiffneri* is a well characterized species in having (i) an attached non-caespitose habit in early stades becoming unattached free-living later, (ii) a cylindrical axis branched with a quasi-continuous cover of short multifid spinose appendages, (iii) ultimate branches quickly deciduous, filiform with spaced simple short spinose appendages or slightly compressed with midrib, (iv) no aerocysts, (v) receptacles terminal, diffuse, 1.5-3.5 cm long and 0.5-1 mm in diameter, with few small simple spinose appendages, and (vi) small conceptacles axial, spaced, immersed and independent of spinose appendages (Figs 16-20; Table 2).

Giaccone (1985) reduced *C. pycnoclada* Schiffner *ex* Gerloff & Nizamuddin, a species described from Croatia (Distribution: Lago Grande, Meleda and Cherso Islands) (Gerloff & Nizamuddin, 1976), to a heterotypic synonym of *C. schiffneri* (as *C. Ercegovičii* f. *schiffneri*). However, the original description of *C. pycnoclada*, which was based only on herbarium specimens, widely differs from *C. schiffneri* in having the following features: “All axes with small congested branches. These branches are irregularly arranged, up to 1(-2) cm long, cylindrico-foliaceous, up to 1.5 mm broad, irregularly branched spinose. Foliaceous one with prominent midrib and distantly dentate. Spines often dichotomous”. By these characters, *C. pycnoclada* is closer to *C. corniculata* f. *imperfecta* Ercegovič (1952), an Adriatic form of *C. corniculata* (Turner) Zanardini, than from *C. schiffneri*. Consequently, pending consideration of the original material, it seems preferable to maintain *C. pycnoclada* distinct from *C. schiffneri*.

Since fixed and free-living specimens of *C. schiffneri* and *C. foeniculacea* cohabited in the same place, there can be no doubt about the necessity of reinstating *C. schiffneri* at a specific rank.

In conclusion, on the basis of literature data and new morphological and ecological observations, the reinstatement of species rank for the Mediterranean endemic taxon *C. schiffneri* Hamel (Homotypic synonyms: *C. Ercegovičii* f. *schiffneri* (Hamel) Giaccone, *C. foeniculacea* f. *schiffneri* (Hamel) A. Gómez Garreta *et al.*; heterotypic synonym: *C. acanthophora* Schiffner, nom. illeg.) is proposed.

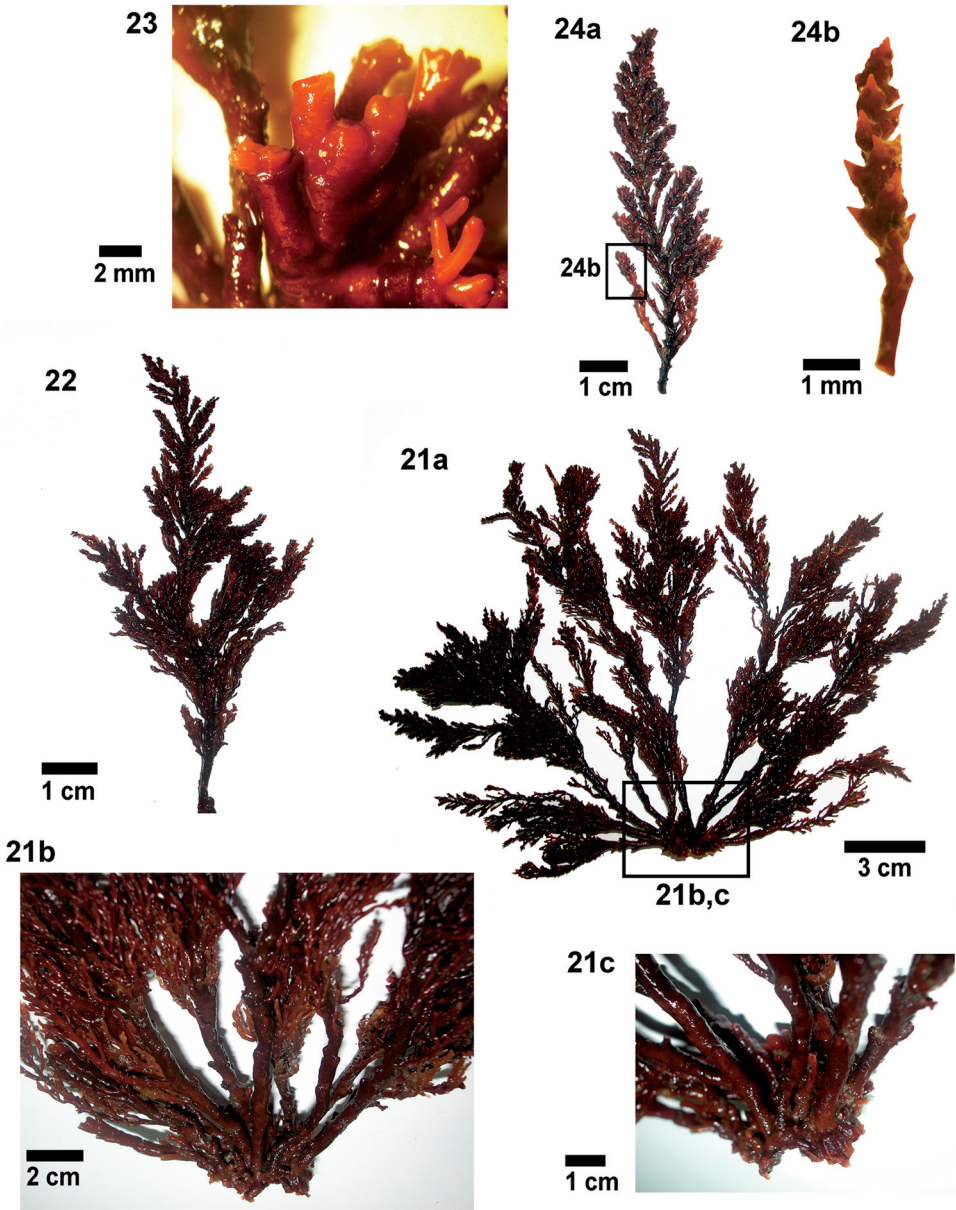
*Cystoseira hyblaea* Giaccone (1985: 432, figs 1, 2)

**Figs 21-24**

**Specimen studied.** Kelibia: May & July, 2014, 0.2-1.5 m depth, rocky shores, exsiccate ref. A3607 (May).

**Description.** Plant caespitose, erect, robust, up to 30 cm in height, brown to dark brown, non-iridescent, attached to the substrate by an irregular basal disc, 2-4 cm in diameter; numerous axes erect (4-20), cylindrical, 2-15 cm long and 2-5 mm in diameter, slightly rugged, bearing stumps of deciduous old primary branches on





Figs 21-24. *Cystoseira hyblaea* (Kelibia, A3607, May 2014). **21a**. Spring habit. **21b-c**. Detail showing the lower part of the axis with irregular basal disc. **22**. Cupressoid outline of primary branch. **23**. Apex of axis. **24a**. Upper part of fertile branch with cupressoid outline and terminal receptacles. **24b**. Detail of spinose compact receptacle.



Table 2. Comparison of diagnostic characters of the different forms of *Cystoseira foeniculacea* and *Cystoseira schiffneri*

Species	<i>Cystoseira foeniculacea</i> (Linnaeus) Greville			<i>Cystoseira schiffneri</i> Hamel
	<i>f. foeniculacea</i>	<i>f. latiramosa</i> (Eregeović) A. Gómez Garreta <i>et al.</i>	<i>f. dubia</i> (Eregeović) Bouafif <i>et al.</i>	
Basionym	<i>Fucus foeniculaceus</i> Linnaeus, 1753: 1161	<i>C. discors</i> subsp. <i>latiramosa</i> Eregeović, 1952: 113	<i>C. discors f. tenuiramosa</i> Eregeović, 1952: 113	<i>C. schiffneri</i> Hamel, 1939: 412
Synonyms	<i>Fucus discors</i> Linnaeus <i>C. discors</i> (L.) C. Agardh <i>f. discors</i> <i>C. eregeovicii</i> Giaccone <i>f. eregeovicii</i>	<i>C. eregeovicii f. latiramosa</i> (Eregeović) Giaccone <i>C. schiffneri f. latiramosa</i> (Eregeović) Giaccone	<i>C. eregeovicii f. tenuiramosa</i> (Eregeović) Giaccone <i>C. schiffneri f. tenuiramosa</i> (Eregeović) Giaccone	<i>C. acanthophora</i> Schiffner, nom. illeg. <i>C. eregeovicii f. schiffneri</i> (Hamel) Giaccone <i>C. foeniculacea f. schiffneri</i> (Hamel) A. Gómez Garreta <i>et al.</i>
Type localities	Habitat in Oceano	Adriatic Sea	Adriatic Sea	Sfax (Tunisia)
References (Illustrations)	Linnaeus, 1753; Greville, 1830; Kützinger, 1860 (pl. 51a-c); Valiante, 1883 (pl. VI); Hamel, 1939 (pl. IX); Roberts, 1968 (Figs 1-6, 8-11), 1978; Gómez Garreta <i>et al.</i> , 1982 (Fig. 7); González & Alfonso Carrillo, 1990 (Figs 51-58); Gómez Garreta <i>et al.</i> , 2001 (Fig. 37); Furnari <i>et al.</i> , 2003; Taşkın & Öztürk, 2007; Mannino & Mancuso, 2009 (pp. 41-44); Cormaci <i>et al.</i> , 2012 (pl. 104, figs 1-3); Taşkın <i>et al.</i> , 2012 (pp. 39-40); Rodríguez-Prieto <i>et al.</i> , 2013 (p. 241); Guiry & Guiry, 2015 (Figs 1-12)	Adriatic Sea Kützinger, 1860 (pl. 51d-f); Eregeović, 1952 (pl. XXVIII); Roberts, 1968 (Figs 7, 14); Amico <i>et al.</i> , 1985 (Fig. 55); Gallardo, 1992; Furnari <i>et al.</i> , 1999, 2003; Gómez Garreta <i>et al.</i> , 2001 (Fig. 38); Taşkın & Öztürk, 2007 (Fig. 1); Mannino & Mancuso, 2009 (pp. 45-47); Cormaci <i>et al.</i> , 2012 (pl. 105, fig. 1); Taşkın <i>et al.</i> , 2012 (pp. 41-42); Rodríguez-Prieto <i>et al.</i> , 2013 (p. 243); Guiry & Guiry, 2015 (Fig. 1)	Adriatic Sea Eregeović, 1952 (pl. XXVI); Roberts, 1968 (Fig. 12); Gallardo, 1992; Amico <i>et al.</i> , 1985 (Fig. 56); Furnari <i>et al.</i> , 1999, 2003; Gómez Garreta <i>et al.</i> , 2001 (Fig. 39); Taşkın & Öztürk, 2007; Mannino & Mancuso, 2009 (pp. 48-51); Cormaci <i>et al.</i> , 2012 (pl. 106, fig. 1); Taşkın <i>et al.</i> , 2012 (pp. 44- 45); Rodríguez-Prieto <i>et al.</i> , 2013 (p. 244); Guiry & Guiry, 2015	Hamel, 1926, 1939; Schiffner, 1926; Amico <i>et al.</i> , 1985 (Fig. 57); Giaccone & Bruni, 1973; Giaccone, 1985; Gallardo, 1992; Ribera <i>et al.</i> , 1992; Furnari <i>et al.</i> , 1999, 2003; Gómez Garreta <i>et al.</i> , 2001; Cormaci <i>et al.</i> , 2012 (pl. 107, figs 1-3); Taşkın <i>et al.</i> , 2012 (p. 43); Guiry & Guiry, 2015; Present study (Figs 16-20)
Height, cm	30-40 (60-90*)	10-50 (-70)	20-30	15-30
Plants	Caespitose	Caespitose	Caespitose	Single axis when young/free-living
Axes	Spinose, 2-5 mm in diameter, 10-20 cm long	Spinose, up to 3 mm in diameter, 5-20 cm long	Spinose, up to 3 mm in diameter, 5-20 cm long	Spinose, up to 4-7 mm in diameter, 5-20 cm long

Spinose appendages of axes	Simple, short and spaced (axes muriculate)	Simple, short and spaced (axes muriculate)	Simple, short and spaced (axes muriculate)	–	Multifid, short, densely arranged (axis with a quasi-continuous cover) and usually coated with sponges
Apex of axes	Not very prominent, with small simple spinose appendages	Not very prominent, with small simple spinose appendages	Not very prominent, with small simple spinose appendages	–	Obtuse and totally covered by very short multifid spinose appendages
Topohules	Absent	Absent	Absent	Absent	Absent
Primary branches	Cylindrical and spinose with spaced simple spinose appendages	Flattened with toothed margins and a prominent midrib	Cylindrical and spinose with spaced simple spinose appendages	Cylindrical and short simple spinose appendages to flattened with a prominent midrib	Similar to the axes: cylindrical with a dense and quasi-continuous cover of multifid spinose appendages
Branches of upper order	Flattened with toothed margins and a prominent midrib to cylindrical filiform	Flattened with toothed margins and a prominent midrib	Cylindrical filiform	Similar to primary branches	Cylindrical, filiform or slightly compressed with midrib, and quickly deciduous
Aerocysts	Oblong in chains, 3-4 mm × 1-1.5 mm	Oblong in chains, 3-4 mm × 1-1.5 mm	Oblong in chains, 3-4 mm × 1-1.5 mm	Oblong in chains, 3-4 mm × 1-2 mm	Absent
Receptacles	Terminal, compact, lanceolate-fusiform, 1-6 mm × 0.5-1.5 mm, often associated with aerocysts	Terminal, compact, lanceolate-fusiform, 1-6 mm × 0.5-1.0 mm	Terminal, compact, lanceolate-fusiform, 1-4 mm × 0.2-0.5 mm, often associated with aerocysts	Terminal, compact, lanceolate-fusiform, 1-2 mm × 0.5-1.0 mm, associated with aerocysts	Terminal, diffuse, 1.5-3.5 cm × 0.5-1 mm, with few small simple spinose appendages
Conceptacles	Grouped and slightly salient	Grouped and slightly salient	Grouped and slightly salient	Grouped and slightly salient	Axial, spaced, immersed, independent of spinose appendages
Habitat	Rock pools, upper sublittoral zone, 0-1 m depth, on open and exposed rocky shores and in semi-sheltered inlets	Usually lower sublittoral zone, (10-) 30-50 (-110) m depth	Rock pools, upper sublittoral zone, 0-1 m depth, on open and exposed rocky shores	Free-living specimens drifted to the coast or exported in deep habitats (down to 70 m depth)	Upper sublittoral zone, 0-2 m depth, on open and sheltered sandy shores, in semi-closed areas and coastal lagoons
Distribution	Mediterranean, NE Atlantic	Mediterranean, NE Atlantic	Mediterranean, NE Atlantic	Adriatic: Croatia Mediterranean: Tunisia (Kerkennah)	Mediterranean: Sicily (Stagnone), Tunisia (Sfax, Kerkennah, Djerba)

\* Atlantic Ocean.

which can grow adventitious branches; apices smooth, not prominent, obtuse, surrounded by young primary branches; primary branches cylindrical, 8-15 cm long; branches of higher order cylindrical, subequal in size, conferring to primary branches a cupressoid outline, especially when fertile; tophules and aerocysts absent; spinose appendages absent except on receptacles; cryptostomata scattered; receptacles terminal, cylindrical-oval to clavate, 0.5-1 cm long and 1 mm in diameter, verrucose, with deciduous spinose appendages; conceptacles subspherical, located at the base of spinose appendages.

**Habitat.** *Cystoseira hyblaea* grew on semi-exposed rocky shores, between 0.2 and 1.5 m depth, above mixed *Cystoseira* spp. populations of *C. brachycarpa* and *C. foeniculacea* f. *latiramosa*.

**Distribution.** Hitherto, *C. hyblaea* was known only from the type locality in Sicily where it apparently disappeared (Giaccone, 1985; Catra & Cormaci in Cormaci *et al.*, 2012). The Tunisian observations confirmed the validity of the taxon and extended its restricted distribution to the Cap Bon (Kelibia), 300 km to the west and at about the same latitude as the type locality (Punta d'Aliga, Ragusa, Sicily).

**Comment.** Our Tunisian specimens agree well with the original diagnosis of *C. hyblaea* (Giaccone, 1985) and with later descriptions and illustrations of the taxon (Amico *et al.*, 1985; Cormaci *et al.*, 2012; Taşkın *et al.*, 2012). *Cystoseira hyblaea* is a well characterized species in having (i) a caespitose habit, (ii) large axes rugged with apices smooth, not prominent, (iii) vegetative branches without spinose appendages, (iv) primary branches with a cupressoid outline, and (v) receptacles terminal, compact, cylindrical-oval to clavate, verrucose, with deciduous spinose appendages.

*Cystoseira spinosa* Sauvageau var. *tenuior* (Ercegovič) M. Cormaci, G. Furnari, G. Giaccone, B. Scammacca, & D. Serio (1992: 30) **Figs 25-28**

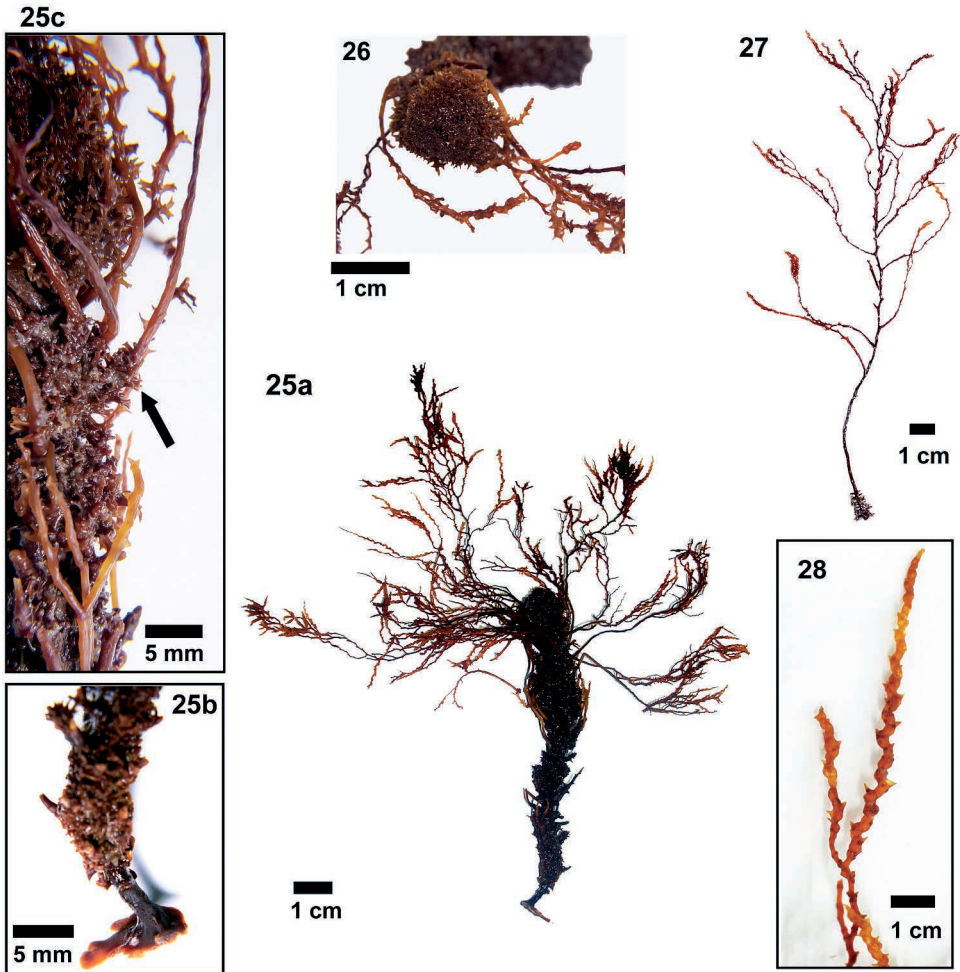
**Basionym.** *Cystoseira adriatica* Sauvageau subsp. *tenuior* Ercegovič, 1952: 107-108, pl. XII, figs 13-14.

**Synonyms.** *Cystoseira adriatica* f. *tenuior* (Ercegovič) Giaccone in Giaccone & Bruni 1973: 74; *C. adriatica* subsp. *reducta* Ercegovič, 1952: 108, pls X-XIa; *C. rechingeri* Schiffner ex Gerloff & Nizamuddin, 1975: 568, pls 9-12; *Cystoseira gerloffii* Nizamuddin, 1978: 471, pls 1-3, figs 1-6.

**Specimens studied.** Zembra Island: June 2014, rocky substratum, exsiccata ref. A4606; Kerkennah Islands: April 2014, 50 cm depth, sandstone pebbles, exsiccata ref. A2352; El Bibane Lagoon: March 2014, 30 cm depth, lagoon area, fixed on *Neogoniolithon brassica-florida*.

**Description.** Plant not caespitose, up to 30 cm in height, non-iridescent, attached to the substrate by an irregular basal disc, 5-15 mm in diameter; axis erect, cylindrical, up to 20 cm in height, with an apex not prominent and finely spinose; tophules densely spinose, ovoid, oblong, 10 mm long and 5 mm in diameter, densely inserted on the axis; primary branches slender, cylindrical, up to 15 cm long; branches of higher order cylindrical and thin; spinose appendages usually simple and regularly spaced on all branches; aerocysts absent; cryptostomata scattered; receptacles terminal, cylindrical, tuberculate, up to 7 cm long and 2-3 mm in diameter; conceptacles axial, sub-alternately arranged, sometimes at the base of spinose appendages.

**Habitat.** *Cystoseira spinosa* var. *tenuior* grew in the upper sublittoral zone of moderately to highly exposed rocky shores and in littoral rock pools, between 0 and 2 m depth, in mixed *Cystoseira* spp. populations, associated with *C. sauvageauana* on the north coast, and with *C. schiffneri* on the south coast.



Figs 25-28. *Cystoseira spinosa* var. *tenuior* (Kerkennah Islands, A2352, April 2014). **25a.** Habit. **25b.** Detail showing the lower part of the axis with the holdfast. **25c.** Detail showing the axis with small spinose tophules (arrow) and basal part of primary branches with spinose appendages. **26.** Apical view of the axis showing the finely spiny apex. **27.** Slender primary branch with spaced spinose appendages and terminal receptacles. **28.** Receptacles.

**Distribution.** Described from the Adriatic Sea (Ercegovič, 1952, as *C. adriatica* subsp. *tenuior*), *C. spinosa* var. *tenuior* was reported from Greece (Gerloff & Nizamuddin, 1975, as *C. rechingeri*; Tsiamis *et al.*, 2013), Libya (Nizamuddin 1978, as *C. gerloffii*), Malta (Cormaci *et al.*, 1997), France (Thibaut *et al.*, 2016) and Italy (North Adriatic, Sicily and adjacent Islands) (Giaccone, 1978, as *C. adriatica* f. *tenuior*; Furnari *et al.*, 1999, 2003; Mannino & Mancuso, 2009). The taxon is reported for the first time from Tunisia where it was found around Zembra and Kerkennah Islands and in El Bibane Lagoon. Its discovery in Tunisia fits well with the previous records in Sicily and in Libya.

**Comment.** The Tunisian specimens agree well with the original diagnosis of *C. spinosa* var. *tenuior* (Ercegovič, 1952, as *C. adriatica* subsp. *tenuior*) and with later descriptions and illustrations of the taxon (Amico *et al.*, 1985, as *C. adriatica* f. *tenuior*; Mannino & Mancuso, 2009; Cormaci *et al.*, 2012; Taşkin *et al.*, 2012; Rodriguez-Prieto *et al.*, 2013). *Cystoseira spinosa* var. *tenuior* differs from *C. spinosa* Sauvageau var. *spinosa* and *C. spinosa* var. *compressa* (Ercegovič) Cormaci, G. Furnari, Giaccone, Scammacca & D. Serio in having the branches thin, cylindrical, sometimes slightly compressed with spinose appendages simple, and the receptacles terminal, spinose, with conceptacles axial and sub-alternately arranged. We do not agree with the authors who consider *C. jabukae* Ercegovič as a heterotypic synonym of *C. spinosa* var. *tenuior* (Cormaci *et al.*, 2012; Taşkin *et al.*, 2012). *Cystoseira jabukae* clearly differs from *C. spinosa* var. *tenuior* in having (i) a thallus slender with tophules smoothly to verrucate, never spinose, (ii) the basal part of primary branches smooth or with rare simple spinose appendages, (iv) the branches of higher order without or with rare simple spinose appendages, (v) the receptacles, up to 7.5-10 cm long, moniliform, loosely branched, without or with few spinose appendages, and (vi) the small axial conceptacles spaced and independent of spinose appendages.

## DISCUSSION

In the Mediterranean Sea, the *Cystoseira* genus is still insufficiently investigated, probably because of the rarity of experts in algal taxonomy. In a first study, we listed 18 accepted taxa of *Cystoseira* previously reported from Tunisia and we identified seven taxa new for the region (Bouafif *et al.*, 2014). In the present study, we confirm the presence of *C. barbata* f. *aurantia* in Tunisia and five other Mediterranean taxa are reported and described for the first time from the country. The transfer of *C. discors* f. *dubia* to *C. foeniculacea*, as *C. foeniculacea* f. *dubia*, and the reinstatement of species rank for the Mediterranean endemic species *C. schiffneri* are proposed. These results bring the taxonomical diversity of *Cystoseira* of Tunisia to 31 taxa. However, the real diversity of the genus in this country is probably slightly lower because there are some doubts regarding several previous reports. The report of *C. nodicaulis* (Whitening) M. Roberts in Tunisia attributed to Ben Maiz *et al.* (1987) by Ribera *et al.* (1992) is clearly erroneous. The alga identified as *C. humilis* Kützinger var. *myriophylloides* (Sauvageau) J.H. Price & D.M. John by Meñez & Mathieson (1981) was probably a misidentification of *C. compressa* subsp. *pustulata*.

Among the taxa newly reported from Tunisian, it is worth noting the re-discovery of *C. foeniculacea* f. *dubia* and *C. hyblaea*, two endemic Mediterranean taxa that were until now known only from the type locality, the latter being considered as extinct (Cormaci *et al.*, 2012). In Tunisia, *C. hyblaea* was discovered, as isolated thalli or in small patches, in a small locality, between 36°54'50.22"N; 11° 6'20.99"E and 36°55'32.57"N; 11° 6'9.54"E, in the east of the Cap Bon Peninsula. Effective legislative conservation measures should be taken to protect this Mediterranean species that is highly threatened with extinction. We suggest including the Tunisian localities where *C. hyblaea* is present within a Protected Area network (see UNEP-MAP, 2012).



**Acknowledgements.** This work was partly funded through the project “MedKeyHabitats – RAC/SPA”. The first author is indebted to Mr. Atef OUERGI, Coordinator of the project “MedKeyHabitats”.

We are grateful to the Agency for Coastal Protection and Management (APAL) and General Directorate of Forestry (DGF) for facilitated access to La Galite Archipelago. Our thanks to the military personnel of the Zembra National Park and La Galite Archipelago for their help and their kindness. The authors wish to thank the Mediterranean Institute of Oceanography of Aix-Marseille University (MIO) for hospitality, especially all the staff of the “Marine Ecology and Biodiversity” Laboratory (EMBIO team), Michèle PERRET-BOUDOURESQUE for documentation assistance, Prof. Charles François BOUDOURESQUE and Dr. Thierry THIBAUT for their useful advice. We are indebted to Mr. Michael PAUL for revising the English language. Many thanks go to the anonymous reviewers for their comments and constructive criticism of the manuscript.

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