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CHANGES IN THE BENTHIC ALGAL FLORA AND VEGETATION OF A SEMI-ENCLOSED MEDITERRANEAN COASTAL LAGOON (STAGNONE DI MARSALA, WESTERN SICILY)

SUMMARY

A study of the benthic macroalgal flora and vegetation of the Stagnone di Marsala (Trapani) has been performed in order to provide an up-to-date review of the status of and verify main changes that have occurred in the area over the past three decades. The flora of this study was poorer in *taxa* than that of literature (94 *taxa* against 108), with an increase in Chlorophyta and a decrease in Rhodophyta and Phaeophyceae. Only 48 *taxa* in the present flora have been previously reported, while 46 are new for the Stagnone. Among these, it was noteworthy, from both floristic and ecological point of view, the record for the first time of *Cystoseira compressa* (Esper) Gerloff & Nizamuddin and the invasive algae *Caulerpa cylindracea* Sonder and *Lophocladia lallemandii* (Montagne) F. Schmitz. On the contrary, 60 *taxa* previously reported have not been detected during the present study. Among these, *Lamprothamnium papulosum* (Wallroth) Groves and *Cystoseira barbata* (Stackhouse) C. Agardh f. *aurantia* (Kützing) Giaccone have been the most significant disappearances. High degree of confinement and sediment composition were the major factors affecting number of *taxa* and abundance of the phytobenthic communities, with maximum values in the stations characterized by a good water exchange and/or presence of *Cystoseira* assemblages. As a result of the effects of global warming over the past few years, noticeable changes in composition and structure of phytobenthic communities in the lagoon have been observed and some hypotheses of expected changes are here proposed.

Key words: Algal flora, Coastal lagoon, Marine vegetation, Stagnone di Marsala, Transitional waters.

RIASSUNTO

Variazioni nella flora e nella vegetazione macroalgale in una laguna costiera del Mediterraneo (Stagnone di Marsala, Sicilia occidentale). È stato condotto uno studio sulla flora e vegetazione macroalgale dello Stagnone di Marsala (Trapani) con l'obiettivo di fornire una revisione dei dati riportati in letteratura ed esaminare i principali cambiamenti che si sono verificati nell'intera area negli ultimi tre decenni.

La flora algale è risultata più povera rispetto al passato (94 *taxa* contro 108), mostrando un incremento delle Cloroficee e una riduzione delle Rodoficee e delle Feoficee. Solo 48 *taxa* sono stati riportati precedentemente, mentre 46 sono nuovi per lo Stagnone. Tra questi, è interessante sottolineare sia da un punto di vista floristico che ecologico, il ritrovamento per la prima volta dell'alga bruna *Cystoseira compressa* (Esper) Gerloff & Nizamuddin e delle alghe invasive *Caulerpa cylindracea* Sonder e *Lophocladia lallemandii* (Montagne) F. Schmitz. Al contrario, 60 *taxa* riportati precedentemente non sono stati trovati nel presente studio. In particolare, si annovera la scomparsa dell'alga verde *Lamprothamnium papulosum* (Wallroth) Groves e dell'alga bruna *Cystoseira barbata* (Stackhouse) C. Agardh f. *aurantia* (Kützing) Giaccone. L'elevato grado di confinamento e la natura del substrato sono stati i principali fattori che hanno influenzato il numero dei *taxa* e l'abbondanza delle comunità fitobentoniche, con valori massimi nelle stazioni caratterizzate da un buon ricambio idrico e/o dalla presenza di comunità dominate da *Cystoseira*. Nel presente studio vengono proposte alcune ipotesi per descrivere i cambiamenti nella composizione e struttura delle comunità fitobentoniche all'interno della laguna come conseguenza degli effetti del riscaldamento globale in atto negli ultimi anni.

Parole chiave: Flora algale, Laguna costiera, Vegetazione marina, Stagnone di Marsala, Acque di transizione.

INTRODUCTION

The Stagnone di Marsala is the largest coastal lagoon of Sicily and, from a hydrobiological point of view, represents one of the most characteristic and interesting wetlands of the entire Mediterranean (MAZZOLA *et al.*, 2010). For its importance in terms of plant and animal biodiversity (VIZZINI & SCILIPOTI, 1999; MIRTO *et al.*, 2004; CALVO *et al.*, 2009; TOMASELLO *et al.*, 2009) and as zone of migration and hibernation of aquatic birds (MASSA, 1973, 1985; LO VALVO & MASSA, 1999), the lagoon has been declared Regional Nature Reserve (Riserva Naturale Regionale delle Isole dello Stagnone di Marsala) since 1984 by the Decree n°215 of 7 July 1984, managed by the Province of Trapani (Decree n°360 of 14 February 1987). Lately, the islands and their depths have been included in the Natura 2000 Network as Sites of Community Importance called respectively "SCI-ITA010001 - Islands of the Stagnone di Marsala" and "SCI-ITA010026 - Depths of the islands of the Stagnone di Marsala" identified by Habitat Directive 92/43/EC which aims at the preservation of natural habitats.

Given the paucity of recent data on both the marine algal flora and vegetation, a survey was carried out in order to improve and update the knowledge regarding the macroalgal biodiversity and phytobenthic communities currently occurring in the Stagnone di Marsala. The aim of this paper is to describe the qualitative and quantitative composition of benthic macroalgal assemblages and examine temporal changes by comparing the results with previously published data.

MATERIALS AND METHODS

Study site

The Stagnone di Marsala is a semi-enclosed oligotrophic brackish coastal lagoon in western Sicily (Fig. 1) about 20 km^2 in area and geomorphologically divided into two sub-basins by an emerging *Posidonia oceanica* (Linnaeus) Delile reef barrier (CALVO *et al.*, 2010).

The northern sub-basin (14 km^2, mean depth 1 m) communicates northwards with the open sea via a shallow (mean depth *ca.* 30 cm) channel 400 m wide. The presence in this sub-basin of the islands Santa Maria, San Pantaleo (more frequently referred to as Mothya) and La Scuola as well as emerging vegetation and the submerged relict of a Phoenician road contribute to reduce the flushing and water circulation with a renewal time calculated at about 65 days (MAZZOLA & SARÀ,1995; CALVO *et al.*, 2005). The northern sub-basin shows greater lagoon characteristics and a higher annual variability of temperature and salinity than the southern basin (SARÀ *et al.*, 1999; VIZZINI *et al.*, 2002). This last (6 km^2, mean depth 2 m) is characterized by a good water exchange and turnover (about 22 $m^3 s^{-1}$) with the open sea (LA LOGGIA *et al.*, 2004).

Because of the small tidal range (about 0.3 m), the Stagnone lagoon hydrodynamic regime and general overturning circulation are expected to be mainly driven by the intensity and direction of the wind (MAZZOLA & VIZZINI, 2005; DE MARCHIS *et al.*, 2011). As a result, no stratification exists in the water column. The main physical-chemical parameters recorded within the Stagnone pointed to the good condition of the lagoon since nutrients are presents in low concentrations and the trophic response, in terms of chlorophyll *a* (1.0 g l^{-1}), indicates the relative oligotrophy of the waters (MAIMONE *et al.*, 1998; SARÀ *et al.*, 1999). Hard substrata are characterized by small pebbles, shells and man-made objects. Calcareous outcrops are frequently detected in the area between the islands of Mothya and Santa Maria. A dense monospecific meadow of the rooted phanerogam *Cymodocea nodosa* (Ucria) Ascherson covers most of the bottom of the northern sub-basin and prevails in areas where hydrological turnover is greater (CALVO *et al.*, 1982). A patchy distribution of *P. oceanica* covers the central-southern area forming peculiar atoll-shaped structures between the islands of Mothya and Santa Maria (TOMASELLO *et al.*, 2009). The other two rooted phanerogams *Zostera noltei*

Hornemann and *Ruppia* sp. are scattered in small isolated patches in the north-eastern and central areas, respectively (CALVO *et al.*, 1982, 2009).

Literature analysis

Bibliographical research was performed by using peer-reviewed journal articles (searched in Scopus and Science Direct) and books (searched in Digital Libraries) for studies from 1980 to date, while grey literature (available in the Dipartimento di Scienze della Terra e del Mare, University of Palermo) for the oldest ones.

Sampling procedure and data analysis

Fieldwork was carried out in summer 2012 (the same sampling seasonal period as that of previous studies) at the northern sub-basin of the Stagnone di Marsala lagoon (Fig. 1), following the sampling design by CALVO *et al.* (1982). Ten stations were selected and georeferenced using a differential GPS

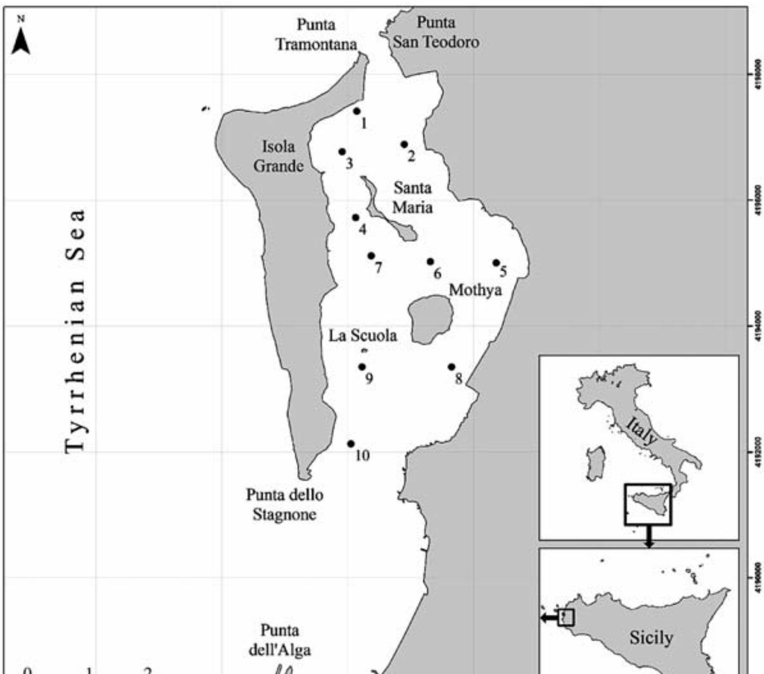

Fig. 1 — Map of the Stagnone di Marsala lagoon showing sampling stations.

with a marginal error of *ca*. 1 m (Table 1). At each sampling station inside a homogeneous area of 5 m x 5 m, a small pick was used to remove the vegetation from three randomly placed plots of 1600 cm^2 and 3600 cm^2 on hard and soft substrata, respectively. The material collected was sealed in individual plastic bags and preserved in 4% formalin in seawater for subsequent identification. In the laboratory, algal specimens were carefully sorted and examined by both stereo and optical microscope, while a light microscopy was used to detect the presence of reproductive structures. All the specimens were identified at species level, while taxonomically difficult *taxa*, due to the absence of reproductive structures and/or diacritical features that are traditionally used to identify a species, were summarized to genus level as 'spp'.

Table 1
Number of stations, type of substratum and total sample size (cm^2) at the Stagnone di Marsala lagoon (UTM coordinates WGS84).

Number of station	Type of substratum	Total sample size	Coordinate X	Coordinate Y
1	Hard	1600	276143	4197414
2	Soft	3600	276896	4196890
3	Soft	3600	275913	4196771
4	Soft	3600	276124	4195723
5	Soft	3600	278357	4195006
6	Hard	1600	277310	4195025
7	Soft	3600	276372	4195117
8	Soft	3600	277650	4193352
9	Hard	1600	276225	4193352
10	Soft	3600	276051	4192130

Voucher specimens for most of the species identified were deposited in the Phycological Herbarium of the Dipartimento di Scienze della Terra e del Mare of the University of Palermo, Italy. For comparison with our present work the floristic lists by previous studies were corrected according to the most recent taxonomic literature (CORMACI *et al.*, 2012; GUIRY & GUIRY, 2014). Conversely, it was impossible to compare quantitative data with literature ones (CALVO *et al.*, 1982) since this study took into account smaller sampling surface areas (cm^2 *vs*. m^2), in order to collect also the numerous small-sized species of marine vegetation. The abundance of sorted specimens was considered as the total percentage of surface covered by each taxon in vertical projection (BOUDOURESQUE, 1971) and the percent cover value was expressed according to the values of the scale of BRAUN-BLANQUET (1928). The diversity for each sampling station was calculated as number of *taxa*, total percent cover, Shannon-Weaver (log_2 basis) and Pielou evenness indices.

RESULTS

Literature data

The early floristic studies about the benthic marine macroalgae from the Stagnone lagoon date back to the half of the last century by MOLINIER & PICARD (1953) and CAVALIERE (1961). However, these authors do not report lists of species but only some notes and observations on a few *taxa*. To date, the available information about the benthic algal flora and vegetation are mostly due to phycological studies dating back to the early 1980s. The first survey and mapping of the submerged vegetation as well as information on the distribution and biomass of benthic macroalgae were given by CALVO *et al.* (1979, 1980a, 1980b, 1982) and SORTINO *et al.* (1981) who reported 41 *taxa* for the whole northern basin. CALVO *et al.* (1981) and CALVO & RAGONESE (1982) carried out the first observations and descriptions on peculiar ball-like forms, known as "aegagropilae", of unattached seaweeds providing a contribution towards knowledge of the hydrodynamic conditions of the northern basin. Later, FRADÀ ORESTANO & CALVO (1985) reported the ball-form phytocenoses of the Stagnone detecting 4 *taxa* previously unrecorded. Moreover, an investigation on the distribution of the phytocenoses and their relationship with physico-chemical composition of sediments was undertaken by GENCHI *et al.* (1985) who reported 12 dominant species (in terms of cover values) in summer marine vegetation. Finally, a complete revision with a nomenclatural update of *taxa* found in the Stagnone lagoon up to 1993 is by CALVO *et al.* (2009) who reported for the whole northern basin 108 *taxa* of which 21 recorded to genus level as 'spp'.

Floristic data

In the northern sub-basin of the Stagnone di Marsala lagoon, a total of 94 *taxa* at specific and infraspecific rank was identified: 48 Rhodophyta (51.06%), 12 Phaeophyceae (12.77%) and 34 Chlorophyta (36.17%) (Table 2). In particular, 4 specimens of 3 Rhodophyta (*Polysiphonia*, *Amphiroa* and *Audouinella*) were recorded to genus level.

On the basis of literature data (Fig. 2), the algal flora of the Stagnone consisted of 108 *taxa*, comprising 59 Rhodophyta (54.63%), 16 Phaeophyceae (14.81%) and 33 Chlorophyta (30.56%). Therefore, the flora of this study was slightly lower than that reported previously (94 *taxa* compared to 108), with an increase in Chlorophyta of 5.61% and a decrease in Rhodophyta and Phaeophyceae of 3.57% and 2.04%, respectively. Only 48 *taxa* (27 Rhodophyta, 6 Pheophyceae and 15 Chlorophyta) of the present flora have been previously reported, while 46 *taxa* (21 Rhodophyta, 6 Pheophyceae and 19 Chlorophyta) are new reports for the Stagnone lagoon (Fig. 2, Table 2). It is remarkable that most of new *taxa* recorded and those not found in this study are opportunistic species with wide ecological valence. From a floristic point of view, it's noteworthy the finding for the first time of the invasive Chlorophyta *Caulerpa cylindracea* Sonder and Rhodophyta *Lophocladia lallemandii* (Montagne) F. Schmitz in the northern (station 1) and southern area (station 10) of the sub-basin, respectively. On the contrary, 60 *taxa* (34 Rhodophyta, 10 Phaeophyceae and 16 Chlorophyta) previously reported

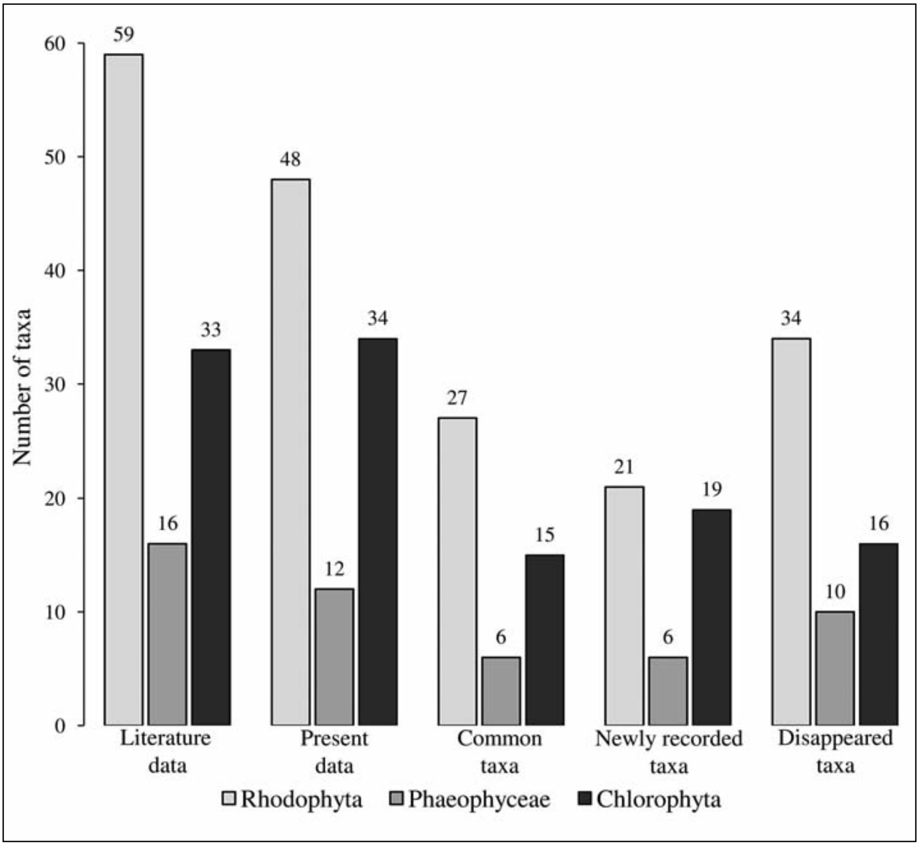

Fig. 2 — Comparison between the floristic richness of literature and present data showing the number of common, newly recorded and disappeared *taxa*.

Table 2

Macroalgal species composition of the Stagnone di Marsala lagoon. Species are listed first in decreasing order of cover and then in decreasing alphabetically order of presence; the cover values are expressed according to the values of the scale of BRAUN-BLANQUET *(1928): + = ≤1%; 1 = 1–5%; 2 = 6–25%; 3 = 26–50%; 4 = 51–75%; 5 = 76–100%. Reproductive phenology of species: m = male gametophyte; f = female gametophyte (including carposporophyte); g = monoecious gametophyte; t = tetrasporophyte; u = unilocular cysts. * = newly recorded taxon from the Stagnone.*

Station	1			2			3			4			5			6			7			8			9			10			
Plot	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	Presence
Depth (cm)	30	30	30	70	70	70	90	90	90	50	50	50	30	30	30	70	70	70	80	80	80	70	70	70	90	90	90	110	110	110	
Per cent total cover (x 10)	9	9	9	10	8	9	7	8	7	9	9	8	8	7	7	10	9	9	8	9	8	8	9	8	9	9	9	10	10	10	
Number of species per plot	28	33	25	25	20	22	26	21	24	21	18	20	16	12	10	44	38	40	9	8	8	17	15	12	31	28	30	37	33	32	
Cystoseira spinosa Sauvageau				5g	5g	5g										5g	5g	5g							g3	g3	g3g				9
**Cystoseira foeniculacea* (Linnaeus) Greville f. *tenuiramosa*																															
(Ercegovi) Gómez Garreta, Barceló, Ribera & Rull Lluch				2	2	2																			4g	4g	4g	5g	4g	4g	9
Caulerpa prolifera (Forsskål) J.V. Lamouroux				2	2	2	5	5	5	2	2	2	2	2	2	2	2	2	2	2	2	5	4	5				2	2	2	24
Spongites fruticulosa Kützing										1	1	1							4	4	4				1	1					8
Cystoseira barbata (Stackhouse) C. Agardh										4g	4g	4g																			3
Rytiphlaea tinctoria (Clemente) C. Agardh										2	2	2	2	2	2	1		1	2	3	3							2	2	2	14
**Cystoseira compressa* (Esper) Gerloff & Nizamuddin	3g	3g	3g													2g	2g	2g													6
**Cladophora prolifera* (Roth) Kützing	+	+	+	2	1	2	2	2	2				+															+	+	+	13
Dictyota implexa (Desfontaines) J.V. Lamouroux	1	1	+				1	1	1	3	2	3				2	1	2				3	3	2	1	1	1	1	1	+	21
Halimeda tuna (J. Ellis & Solander) J.V. Lamouroux				1	1	+				3	3	2				1			1	1	1										10
Phymatolithon calcareum (Pallas) W.H. Adey & D.L. McKibbin	3	3	3													1	1	1													6
Anadyomene stellata (Wulfen) C. Agardh																2	2	1				1	1	1	2	2	2				9
Sphacelaria fusca (Hudson) S.F. Gray	+	+	+	+	+	+	+		+	2	2	1	+	+	+	2	2	1	1	1	1	+	+	+	1	1	+	1	1	+	29
**Caulerpa cylindracea* Sonder	2	2	2																												3
Dasycladus vermicularis (Scopoli) Krasser																2	2	2													3
**Lophocladia lallemandii* (Montagne) F. Schmitz																												2f,t	2f,t	2t	3
**Dictyota mediterranea* (Schiffner) G. Furnari	1	2	2				+	+	+							1	1	1													9
**Ulva prolifera* O.F. Müller	2	2	1																									+		+	5

**Cladophora fracta* (O.F. Müller *ex* Vahl) Kützing				2	1	1																									3
**Ulva flexuosa* Wulfen	1	2	1																												3
Chaetomorpha linum (O.F. Müller) Kützing	1	1	1	1	1	1	1	1	1	1	1	1	+	+	+	1	1	1	+	+		+	+		+			1	1	1	27
**Cladophora liniformis* Kützing	1	1	1				1	+	+	+	+	+	+	+	+	+	+	+										1	1	1	18
Acetabularia acetabulum (Linnaeus) P.C. Silva	1	1	1	1			+	+	+	1	1	+				+												+	+		13
**Anotrichium tenue* (C. Agardh) Nägeli				+		+	+	+	+	+	+	+				1	1	1				1	1	1	+	+	+	+	+	+	21
Spyridia filamentosa (Wulfen) Harvey				1	1	+										+	+	+										1	1	1	9
Cladophora echinus (Biasoletto) Kützing	+	+		+	+	+							1	1	1	1		1										+	+	+	13
Alsidium corallinum C. Agardh																									1	1	+	1	1	1	6
Valonia aegagropila C. Agardh													1	1	1	1	+	+													6
Mesophyllum lichenoides (Ellis) Lemoine																												1	1	1	3
**Laurencia chondrioides* Børgesen	+	+																							1	+	+	1			6
**Irvinea boergesenii* (Feldmann) R.J. Wilkes, L.M. McIvor & Guiry																1	+	+							1	+	+				6
**Cladophora vadorum* (Areschoug) Kützing	+	1																										1	+	+	5
Lophosiphonia obscura (C. Agardh) Falkenberg	+	+	+	+	+	+	1	+	+				+		+	+	+	+							+	+	+	+	+	+	20
**Polysiphonia elongata* (Hudson) Sprengel							1	+	+																						3
Phaeophila dendroides (P.L. Crouan & H.M. Crouan) Batters	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+		+	+	+	+	+		3
Chroodactylon ornatum (C. Agardh) Basson	+	+		+		+	+	+	+	+						+	+	+	+	+	+							+	+	+	27
Polysiphonia breviarticulata (C. Agardh) Zanardini		+	+	+f	+	+	+t	+f	+				+t	+		+	+					+f	+f	+m		+	+	+	+	+	20
**Hydrolithon cruciatum* (Bressan) Y.M. Chamberlain							+	+	+	+	+	+	+t		+	+	+	+				+t	+t	+	+	+	+	+	+		17
**Chondria mairei* Feldmann-Mazoyer				+t	+t	+							+	+	+	+	+	+							+	+	+	+	+		14
**Laurencia minuta* Vandermeulen, Garbary & Guiry ssp.																															
scammaccae	+	+	+													+	+					+	+	+	+	+	+	+	+	+	14
G. Furnari & Cormaci																															
Stylonema alsidii (Zanardini) K.M. Drew	+	+	+										+	+		+	+	+				+	+	+	+	+	+				14
Polysiphonia scopulorum Harvey	+	+	+	+	+	+	+	+	+							+	+	+													12
Lithophyllum cystoseirae (Hauck) Heydrich				+	+	+				+	+	+				+		+										+	+	+	11

continued

Table 2: *continued*

Station	1			2			3			4			5			6			7			8			9			10			
Plot	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	Presence
Depth (cm)	30	30	30	70	70	70	90	90	90	50	50	50	30	30	30	70	70	70	80	80	80	70	70	70	90	90	90	110	110	110	
Per cent total cover (x 10)	9	9	9	10	8	9	7	8	7	9	9	8	8	7	7	10	9	9	8	9	8	8	9	8	9	9	9	10	10	10	
Number of species per plot	28	33	25	25	20	22	26	21	24	21	18	20	16	12	10	44	38	40	9	8	8	17	15	12	31	28	30	37	33	32	
**Bryopsis hypnoides* J.V. Lamouroux																+	+	+				+	+	+	+	+	+				9
**Hydrolithon boreale* (Foslie) Y.M. Chamberlain							+	+	+							+t	+	+										+	+	+	9
Polysiphonia subulata (Ducluzeau) Kützing		+	+										+	+		+		+										+m	+	+	9
**Ceramium diaphanum* (Lightfoot) Roth	+	+	+	+	+	+																						+		+	8
**Ulvella lens* P.L. Crouan & H.M. Crouan																+	+	+				+	+	+	+		+				8
Chondria capillaris (Hudson) M.J. Wynne																						+			+	+	+	+	+	+	7
Cladophora dalmatica Kützing							+	+	+	+	+	+										+									7
Cladophora glomerata (Linnaeus) Kützing							+	+					+	+		+	+	+													7
Dasya rigidula (Kützing) Ardissone				+	+	+	+			+t	+	+																			7
Polysiphonia dichotoma Kützing							+		+													+t	+t	+				+		+	7
Lithophyllum racemus (Lamarck) Foslie										+	+	+													+	+	+				6
Myrionema orbiculare J. Agardh	+	+	+																									+	+	+	6
**Pneophyllum confervicola* (Kützing) Y.M. Chamberlain																+t	+	+										+	+	+	6
Callithamnion corymbosum (Smith) Lyngbye	+	+																										+	+	+	5
**Chaetomorpha aerea* (Dillwyn) Kützing		+	+				+	+	+																						5
Chondria coerulescens (J. Agardh) Falkenberg				+t	+t	+	+		+																						5
**Cladophora sericea* (Hudson) Kützing										+	+	+							+	+											5
Polysiphonia sp. 1										+		+													+	+	+				5
**Spermothamnion repens* (Dillwyn) Rosenvinge v. *variabile* (C. Agardh) Feldmann-Mazoyer		+	+																									+	+	+	5
**Ulvella viridis* (Reinke) R. Nielsen, C.J. O'Kelly & B. Wysor										+		+				+	+	+													5
**Acrosorium ciliolatum* (Harvey) Kylin																+	+	+													3
**Blastophysa rhizopus* Reinke							+	+	+																						3
**Blidingia minima* (Nägeli *ex* Kützing) Kylin																									+	+	+				3

Bryopsis duplex De Notaris												+	+	+										3
Ceramium codii (H. Richards) Mazoyer																		+	+	+				3
Ceramium tenerrimum (G. Martens) Okamura v. *brevizonatum*																								
(H.E. Petersen) Feldmann-Mazoyer																		+	+	+				3
**Dictyota fasciola* (Roth) J.V. Lamouroux v. *repens*																								
(J. Agardh) Ardissone																		+	+	+				3
**Dipterosiphonia rigens* (Shousboe *ex* C. Agardh) Falkenberg																		+	+	+				3
Erythrotrichia carnea (Dillwyn) J. Agardh												+	+	+										3
**Feldmannia* cf. *irregularis* (Kützing) G. Hamel												+u	+u	+										3
**Herposiphonia tenella* (C. Agardh) Ambronn																					+	+	+	3
**Lomentaria clavaeformis* Ercegović																					+	+	+	3
Lophosiphonia cristata Falkenberg									+	+	+													3
Padina pavonica (Linnaeus) Thivy																		+	+	+				3
**Pedobesia simplex* (Meneghini *ex* Kützing) M.J. Wynne & Leliaert												+	+	+										3
Polysiphonia sp. 2																		+		+				3
**Stilophora tenella* (Esper) P.C. Silva				+u	+	+																		3
**Syncoryne reinkei* R. Nielsen & P.M. Pedersen												+	+	+										3
Ulothrix flacca (Dillwyn) Thuret												+	+	+										3
**Ulva clathrata* (Roth) C. Agardh	+	+	+																					3
**Ulvella leptochaete* (Huber) R. Nielsen, C.J. O'Kelly & B. Wysor													+	+	+									3
Valonia utricularis (Roth) C. Agardh																		+	+	+				3
**Amphiroa* sp.		+	+																					2
Audouinella sp.	+	+																						2
**Ceramium comptum* Børgesen	+	+																						2
**Cladophora albida* (Nees) Kützing																		+		+				2
Cladophora laetevirens (Dillwyn) Kützing				+		+																		2
**Lophosiphonia reptabunda* (Suhr) Kylin							+	+																2
**Pterosiphonia pennata* (C. Agardh) Sauvageau	+	+																						2
**Spermothamnion repens* (Dillwyn) Rosenvinge																+	+							2
Laurencia obtusa (Hudson) J.V. Lamouroux				+																				1

have not been detected during the present study (Fig. 2, Table 3). Among these, the Charophyta *Lamprothamnium papulosum* (Wallroth) Groves and the Phaeophycea *Cystoseira barbata* (Stackhouse) C. Agardh f. *aurantia* (Kützing) Giaccone have been the most significant disappearances. The highest species richness was found at station 6 (44 *taxa*) where hard substrata occurred, while the lowest floristic diversity was recorded at station 7 (8) where muddy sediments were observed (Table 2).

Table 3
Macroalgal species previously reported from the Stagnone di Marsala lagoon and not found in the present study (1 = CALVO et al.*, 1979; 2 = CALVO* et al.*, 1980a; 3 = CALVO* et al.*, 1980b; 4 = SORTINO* et al.*, 1981; 5 = CALVO* et al.*, 1982; 6 = FRADÀ ORESTANO & CALVO, 1985; 7 = CALVO* et al.*, 2009).*

Rhodophyta
Acrochaetium leptonema (Rosenvinge) Børgesen: (7) as *Audouinella leptonema* (Rosenvinge) Garbary
Audouinella sp. 1: (7)
Audouinella sp. 2: (7)
Bangia fuscopurpurea (Dillwyn) Lyngbye: (4) as *Bangia atropurpurea* (Roth) C. Agardh
Botryocladia sp.: (7)
Ceramium sp.: (7)
Chondria dasyphylla (Woodward) C. Agardh: (3), (5)
Chondria scintillans G. Feldmann: (7)
Chondria sp.: (7)
Corallina officinalis Linnaeus: (7)
Corallina sp.: (7)
Dasya ocellata (Grateloup) Harvey: (7)
Dasya sp.: (7)
Gayliella mazoyerae T.O.Cho, Fredericq & Hommersand : (7)
Gelidiella ramellosa (Kützing) Feldmann & Hamel: (7)
Halopithys incurva (Hudson) Batters: (4)
Halurus sp.: (7)
Herposiphonia secunda (C. Agardh) Ambronn: (7)
Hydrolithon farinosum (Lamouroux) Penrose & Chamberlain: (7)
Jania rubens (Linnaeus) Lamouroux: (4), (7)
Lithophyllum corallinae (P.L. Crouan & H.M. Crouan) Heydrich : (7)
Lythothamnion sp.: (7)
Melobesia membranacea (Esper) Lamouroux: (7)
Osmundea truncata (Kützing) K.W. Nam & Maggs: (7)
Palisada perforata (Bory de Saint-Vincent) K.W. Nam : (7) as *P. papillosa* (C. Agardh) K.W. Nam
Peyssonnelia polymorpha (Zanardini) Schmitz: (4)
Peyssonnelia squamaria (S.G. Gmelin) Decaisne: (7)
Phyllophora sp.: (7)
Pneophyllum fragile Kützing: (4), (5)
Polysiphonia brodiei (Dillwyn) Sprengel: (7)
Polysiphonia denudata (Dillwyn) Greville *ex* Harvey: (7)

Polysiphonia tripinnata J. Agardh: (6), (7)
Polysiphonia sp. 1: (7)
Polysiphonia sp. 2: (7)

Phaeophyceae
Cladosiphon cylindricus (Sauvageau) Kylin: (4)
Cladosiphon mediterraneus Kützing: (5)
Cystoseira barbata (Stackhouse) C. Agardh f. *aurantia* (Kützing) Giaccone: (5) and (7) as *C. barbata* f. *repens* Zinova & Kalugina according to GÓMEZ GARRETA *et al.*, (2001)
Cystoseira foeniculacea (Linnaeus) Greville f. *schiffneri* (Hamel) Gómez Garreta, Barceló, Ribera & Rull Lluch: (1), (4), (7) as *Cystoseira ercegovicii* Giaccone
Cystoseira sp.: (7)
Dictyota fasciola (Roth) J.V. Lamouroux: (7)
Dictyota sp.: (7)
Ectocarpus siliculosus (Dillwyn) Lyngbye: (7)
Giraudia sphacelarioides Derbès & Solier: (5)
Sphacelaria sp.: (7)

Chlorophyta
Aegagropila linnaei Kützing: (7) as *Cladophora aegagropila* (Linnaeus) Trevisan
Cladophora nigrescens Zanardini *ex* Frauenfeld: (4)
Cladophora pellucida (Hudson) Kützing: (7)
Cladophora sp.1: (7)
Cladophora sp. 2: (7)
Codium bursa (Olivi) C. Agardh: (7)
Flabellia petiolata (Turra) Nizamuddin: (7)
Lamprothamnium papulosum (Wallroth) Groves: (2), (3), (5), (7)
Pringsheimiella scutata (Reinke) Marchewianka: (7)
Pseudochlorodesmis furcellata (Zanardini) Børgesen: (4), (7)
Ulothrix sp.: (7)
Ulva intestinalis Linnaeus: (7)
Ulva laetevirens Areschoug: (7)
Ulva sp. 1: (7)
Ulva sp. 2: (7)
Valonia sp.: (7)

The mean number of *taxa* identified at all sampling stations was 23.4 ±9.7 (Fig. 3a). Higher mean values were recorded at stations 6 (40.7) and 10 (34), while the lower ones at stations 5 (12.7) and 7 (8.3). As regards the total percent cover, the mean value recorded at all sampling stations was 127.3% ±38.8 (Fig. 3b). The highest mean values were observed at stations 6 (185.6%) and 4 (171.1%), while the lowest abundance was found at station 5 (35.9). The mean Shannon–Weaver index was 2.02 ±0.6 and varied irregularly at all sampling stations (Fig. 3d). The highest mean values were recorded at stations 6 (2.76) and 1 (2.71) while the lowest ones were observed at stations 3 (1.19) and 8 (1.18). A similar trend was also observed for Pielou index that showed at all sampling stations a mean value of 0.46 (Fig. 3e). The highest mean values were found at stations 4 (0.59) and 1 (0.56), while the lowest ones at stations 8 (0.30) and 3 (0.26).

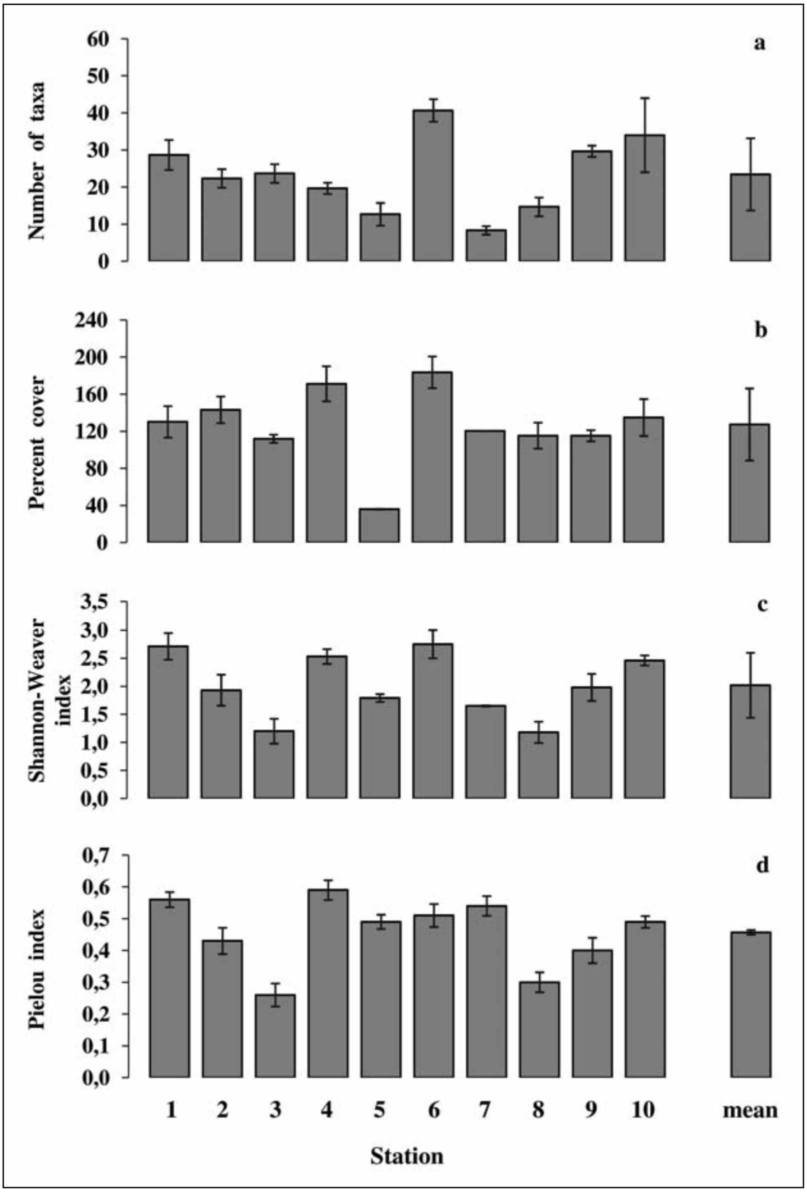

Fig. 3 — Number of *taxa* (a), percent cover (b), Shannon-Weaver index (c) and Pielou index (d) with standard deviation bars (± sd) at each sampling station and on average.

Vegetation

The photophilic plant association *Caulerpetum proliferae* Giaccone & Di Martino dominated the central part of the northern sub-basin. In particular, the characteristic species of this association, the Chlorophyta *Caulerpa prolifera* (Forsskål) J.V. Lamouroux, was found in association with *C. nodosa* on well-calibrated fine-grained sands scarcely oxygenated. *C. prolifera* was the most common and abundant macroalgal species throughout the basin and it was found at almost all stations with the highest percent cover at stations 3 and 8 (Table 2). In this area, due to the lack of hard substrata, many algal species were present and abundant in a unattached form exhibiting typical ball-like forms. This was the case of the Rhodophyta *Rytiphlaea tinctoria* (Clemente) C. Agardh and the Chlorophyta *Cladophora echinus* (Biasoletto) Kützing, constituting the plant association *Cladophoro-Rytiphloetum tinctoriae* Giaccone, that formed ball-form assemblages remaining lying on the bottom or slowly rolling on it. Unattached population of *R. tinctoria* was also detected with high percent cover in the area near Punta dello Stagnone (station 10), but here unattached thalli were morphologically different from the conspecific ball-like forms showing a peculiar "intermediate" form (see CALVO & RAGONESE, 1982). Moreover, ball-like forms, known as rhodoliths, of the coralline Rhodophyta *Mesophyllum lichenoides* (Ellis) Lemoine and *Spongites fruticulosa* Kützing were also recorded in proximity of southern channel and at the northwest of Mothya Island, respectively. In this latter area, the occurrence of weak bottom currents favored the development of the plant association *Chaetomorpho-Valonietum aegagropilae* Giaccone with the characteristic species, the Chlorophyta *Chaetomorpha linum* (O.F. Müller) Kützing and *Valonia aegagropila* C. Agardh, forming ball-shaped masses freely floating on the bottom. On the scattered hard substrata, the vegetation was characterized by large and mature thalli of the brown algae of genus *Cystoseira* genus. The community with *Cystoseira spinosa* Sauvageau was found in three stations but with high cover values at stations 2 and 6 (Table 2). At station 4, there was a community characterized by *Cystoseira barbata* (Stackhouse) C. Agardh forming erect and branched thalli up to 40 cm long, while a community with *Cystoseira foeniculacea* (Linnaeus) Greville f. *tenuiramosa* (Ercegovi) Gómez Garreta et al. occurred at stations 2, 9 and 10 with higher cover values in the latter two stations. Also, a community classified into the *Cystoseiretum crinitae* subassociation *Cystoseiretum compressae* Molinier was found at station 6, in correspondence to the Phoenician road, with relatively high cover values of *Cystoseira compressa* (Esper) Gerloff & Nizamuddin. All the above species of *Cystoseira* supported communities of epiphytic and understory algae with the phaeophyceans *Dictyota implexa* (Desfontaines)

J.V. Lamouroux and *Sphacelaria fusca* (Hudson) S.F. Gray dominating both qualitatively and quantitatively (Table 2).

DISCUSSION

From the comparison with the available literature it seems that the benthic algal flora of the Stagnone di Marsala lagoon has not undergone any drastic changes in the last 2-3 decades. The 46 *taxa* newly reported against 60 *taxa* not found this time highlighted a slight reduction of species richness with a loss of only 14 *taxa*.

However, the results of this study showed qualitative changes to the benthic algal flora that strongly depended on the changing environmental conditions. The increase in both confinement and temperature over the last decades could explain the variation of biodiversity within the lagoon (CALVO *et al.*, 2001). Natural stress levels due to the shallowness and reduced water exchange raise with increase in confinement resulting in a decrease in the variety of species (REIZOPOULOU & NICOLAIDOU, 2004). Although this trend was observed in the present study, our data also showed that the highest values of species richness and diversity were observed mostly in the stations characterized by the presence of *Cystoseira*-dominated assemblages. *Cystoseira* spp. are considered the most important habitat-forming algal species in Mediterranean shallow waters, providing shade and shelter for a diversified assemblage of animals and plants (BALLESTEROS, 1992; BELLISSIMO *et al.*, 2014). Among *Cystoseira* species found in the Stagnone, the record for the first time of *C. compressa* is noteworthy. Although this euryoecious species could be present and/or misidentified in the past, its current presence would provide evidence of the increased degree of sedimentation and reduced hydrodynamic regime that have occurred in the area over the past two decades.

The reduction of the ball-like forms of unattached drifting assemblages detected in this study with respect to the past (FRADÀ ORESTANO & CALVO, 1985) would constitute a more indicator of the diminished water circulation within the lagoon. A consistent water movement is actually essential to their formation since it allows the radial growth of the thallus by rolling it on the bottom and thus continuously varying its exposure to light. This hypothesis is supported by the almost complete closure of the northern entrance as a consequence of the current coast dynamics that caused the dispersion of sediments coming from the north (AGNESI *et al.*, 1993).

A generalized state of regression of *P. oceanica* stands and a concomitant settlement and proliferation of *C. nodosa* and *C. prolifera* have been associated with the increase of sea water temperature and salinity due to global climate changes (CALVO *et al.*, 2009). In this context, the high abundance of *C. prolifera* observed in this study with respect to the past (CALVO *et al.*, 1982) should confirm the regression tendency of *P. oceanica* but, unfortunately, the absence of studies between 1993 and the present makes it impossible to ascertain if such changes occurred gradually or more or less abruptly throughout the last twenty years.

The disappearance of *L. papulosum* and *C. barbata* f. *aurantia* may be due to the rise of mean sea water temperatures due to global warming that, on the contrary, seems likely to have favored the settlement of invasive species with warm-water affinities like *C. cylindracea* and *L. lallemandii*. Both of species are considered ecosystem engineers by being capable to alter ecosystem structure and function reducing the biodiversity of macroalgae in the invaded assemblages (PIAZZI *et al.*, 2001; BEDINI *et al.*, 2011). Besides, these species show high potential for dispersal, fast growth and great ability to adapt to new environments (PETROCELLI & CECERE, 2006), suggesting that warm-water introduced species could spread and become even dominant in stressful environments like coastal lagoons.

To conclude, this study pointed out to a certain degree of vulnerability of phytobenthic communities of the lagoon under expected environmental changes in the next decades as a consequence of the effects of global warming. These effects may include an increase in sea water temperature, changes in the hydrodynamism of water masses and in water salinity, an increase in frequency of extreme weather events and a loss of marine macrophytes.

Therefore, further sampling campaigns in different seasons are in progress to better appreciate the dynamics of the Stagnone di Marsala vegetation. Moreover, a continuous and exhaustive monitoring program aiming at sampling macroalgal and seagrass assemblages is needed to assess the long-term climate change effects that may determine extremely negative impacts on the lagoon biodiversity.

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