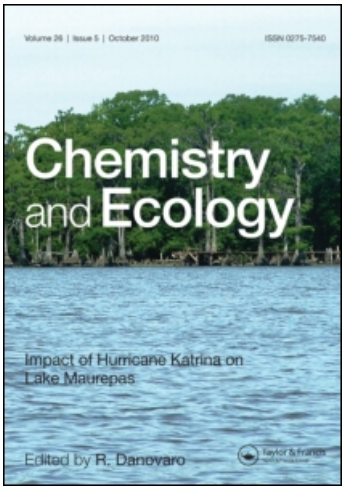

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Macrophytobenthos and the ecological status of coastal waters around Sicily

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This article gives a picture of recent studies on the phytobenthos of Sicily, paying particular attention to research carried out in the last 10–15 years. Twenty new taxa have been described from Sicily, and floristic studies have recorded 823 taxa at the specific and infraspecific levels. Vegetational studies have been used to verify changes that have possibly occurred in Sicilian areas over the last 30 years. Particular attention was also paid to 22 taxa considered to have been introduced into the Mediterranean Sea and which are found along the Sicilian coast. Applied research dealt mainly with management of the territory, promotion of a sustainable development model for the coastal zone, and using macroalgal communities to assess the quality of Sicilian waters. Finally, some suggestions for studies that should be carried out to increase phytobenthic knowledge of Sicilian coastal waters are made.

Keywords: biodiversity; ecological status; flora; macrophytobenthos; Sicily; vegetation

1. Introduction

Studies on the macrophytobenthos occurring along the coasts of Sicily and adjacent islands date back to the end of the 19th and beginning of the 20th centuries [1–7], after which almost no studies were performed for several decades. At the end of the 1960s, the current generation of phycologists from three Sicilian universities (Catania, Messina and Palermo) again began to study the macrophytobenthos. Since then, both basic and applied phycological studies have been carried out. The former dealt with macroalgal taxonomy and biodiversity at both the floristic and vegetational levels of macrophytobentic communities; the latter dealt with sustainable development in integrated coastal zone management and the conservation of marine macrophyte biodiversity. These studies were supported by the above-mentioned Sicilian universities, the Italian Ministry for the Environment and Protection of Land and Sea (MATTM), the Ministry of University and Scientific and Technological Research (MIUR), the High Institute for Environmental Protection and Research (ISPRA) [*ex* Central Institute for Scientific and Technological Research applied to the Sea (ICRAM)], the Italian Society of Marine Biology (SIBM) and the National Interuniversity Consortium for Marine Sciences (CoNISMa). This article aims to give a picture of recent studies

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on the phytobenthos of Sicily, paying particular attention to those carried out in last 10–15 years and suggesting studies which should be still carried out in order to increase the phytobenthic knowledge of that area.

2. Results and discussion

The phytobentic biodiversity of Sicily and the adjacent islands was assessed on a bibliographic basis in a catalogue of the macrophytobenthos of the Italian coast [8]. It consists of 42 Cyanophyta, 480 Rhodophyta, 1 Chrysophyta, 168 Phaeophyta, 127 Chlorophyta and 5 Spermatophyta, giving a total of 823 taxa at the specific and infraspecific levels (*taxa inquirenda* excluded). Such floristic richness is rather high, because it represents 89% of the flora of Italy, which consists of 924 taxa in total. This richness is because of the geographical position of Sicily between the western and eastern sectors of the Mediterranean Sea, and due to the numerous different habitats occurring along the Sicilian coast, which is washed by three different seas (Tyrrhenian, Ionian and South Mediterranean). Moreover, it should be pointed out that because of the accuracy of taxonomic studies, numerous taxa new to science have been described at the generic, specific and infraspecific levels (Table 1).

In the last 10 years, Sicilian phycologists have carried out research aimed at verifying the floristic and vegetational changes that may have occurred in Sicilian areas in the last 30 years.

Table 1. New taxa described from Sicily.

Taxa	Type locality	Year of description	Ref.
Genera			
Halosia Cormaci *et* G. Furnari	Vulcano Island	1994	[62]
Woelkerlingia Alongi, Cormaci *et* G. Furnari	Salina Island	2007	[63]
Species			
Antithamnion piliferum Cormaci *et* G. Furnari	Capo Passero	1987	[64]
Ceramium giacconei Cormaci *et* G. Furnari	Lachea Island	1991	[65]
Chylocladia wynnei Alongi, Cormaci *et* G. Furnari	Salina Island	2008	[66]
Cordylecladia guiryi Gargiulo, G. Furnari *et* Cormaci	Bay of Augusta	1990	[67]
Crouania francescoi Cormaci, G. Furnari *et* Scammacca	Castelluccio	1978	[68]
Cystoseira hyblaea Giaccone	Cava d'Aliga	1986	[69]
Halosia elisae Cormaci *et* G. Furnari	Vulcano Island	1994	[62]
Hypnea furnariana Cormaci, Alongi *et* Dinaro	Maddalena Peninsula	1993	[70]
Osmundea maggsiana Serio, Cormaci *et* G. Furnari	Pantelleria Island	1999	[71]
Osmundea pelagiensis G. Furnari	Lampedusa Island	1994	[72]
Polysiphonia perforans Cormaci, G. Furnari, Pizzuto *et* Serio	Aci Castello	1998	[73]
Symploca codiiformis Giaccone [now *Schizothrix codiiformis* (Giaccone) Giaccone]	Punta Raisi	1969	[74]
Taonia lacheana Pizzuto, Cormaci *et* G. Furnari	Lachea Island	1994	[75]
Verosphacela silvae Alongi, Cormaci *et* G. Furnari	Salina Island	2007	[76]
Woelkerlingia minuta Alongi, Cormaci *et* G. Furnari	Salina Island	2007	[63]
Infraspecific taxa			
Antithamnionella elegans (Bertold) J.H. Price *et* D.M. John var. *decussata* Cormaci *et* G. Furnari[a]	Augusta	1988	[77]
Cystoseira balearica Sauvageau v. *claudiae* Giaccone [now *C. brachycarpa* J. Agardh *emend.* Giaccone v. *claudiae* (Giaccone) Giaccone]	Linosa Island	1985	[30]
Laurencia minuta Vandermeulen, Garbary *et* Guiry ssp. *scammaccae* G. Furnari *et* Cormaci	Capo Passero	1990	[78]

Note: [a]We follow Furnari et al. [8] and Gómez Garreta et al. [79] in considering this taxon distinct from *A. sublittoralis* (Setchell *et* N.L. Ardner) Athansiadis, which differs from that proposed by Athanasiadis [80].

In particular, the Maddalena Peninsula (east coast of Sicily) [9,10], Pantelleria Island [11], the Egadi Islands [12], Linosa Island [13], Ustica Island [14] and the Aeolian Islands [15] have been studied. Comparisons with data from previous studies carried out at Maddalena Peninsula, Pantelleria Island, the Egadi Islands, Linosa Island, Ustica Island and the Aeolian Islands [16–21], have shown different changes, according to area. In fact, in Tyrrhenian areas (e.g. Ustica Island, the Aeolian Islands), there was no significant change in vegetation, and communities with *Cystoseira* spp. (*Cystoseira amentacea*, *Cystoseira brachycarpa*, *Cystoseira sauvageuana*, *Cystoseira spinosa*, *Cystoseira zosteroides*) were well structured. Conversely, in the Straits of Sicily (e.g. at Pantelleria Island and Linosa Island) and the Ionian Sea (at Maddalena Peninsula), disappearance of the above-mentioned species of *Cystoseira* and the resulting communities (excluding those occurring in shallow water), and their substitution by less-structured communities of Dictyotaceae, Sphacelariaceae and Udoteaceae were observed. In those areas, no increase in water turbidity, overgrazing by sea-urchins or eutrophication were observed, and so the disappearance of stenoecious species of *Cystoseira* is related to an increase in the temperature of superficial waters caused by global climate change, together with changes in the deep circulation of the eastern Mediterranean basin recorded in the last 30 years [11]. This is supported by: (1) the higher R/P Index due to the increase in species with a warm water affinity (mainly Rhodophyceae) and the decrease in species with a cold water affinity (mainly Phaeophyceae); and (2) the higher number of species belonging to the circumtropical and Indo-Pacific biogeographical areas and the decrease in the number of species belonging to the circumboreal area [9,11,13].

Particular attention was also paid to introduced macrophytes. Of 80 alien species that, according to Cormaci et al. [22], occur in the Mediterranean Sea, only 22 (14 Rhodophyta, 4 Ochrophyta, 3 Chlorophyta and 1 Spermatophyta) were found in Sicily (Table 2). However, despite the relatively high number of alien species, only four are invasive [23]. Both *Caulerpa racemosa* v. *cylindracea*,

Table 2. Alien species occurring in Sicily.

Rhodophyta
Acrothamnion preissii (Sonder) E.M. Wollaston
Antithamnion hubbsii E.Y. Dawson
Agardhiella subulata (C. Agardh) Kraft *et* M.J. Wynne
Asparagopsis armata Harvey
Bonnemaisonia hamifera Hariot
Botryocladia madagascariensis Feldmann-Mazoyer
Ceramium strobiliforme G.W. Lawson *et* D.M. John
Chondria pygmaea Garbary *et* Vandermeulen
Griffithsia corallinoides (Linnaeus) Trevisan
Hypnea spinella (C. Agardh) Kützing
Lophocladia lallemandii (Montagne) F. Schmitz
Neosiphonia harveyi (J.W. Bailey) M.S. Kim *et al*.
Plocamium secundatum (Kützing) Kützing
Womersleyella setacea (Hollenberg) R.E. Norris

Ochrophyta
Colpomenia peregrina Sauvageau
Halothrix lumbricalis (Kützing) Reinke
Leathesia difformis (Linnaeus) Areschoug
Padina boergesenii Allender *et* Kraft

Chlorophyta
Caulerpa racemosa (Forsskål) J. Agardh v. *cylindracea* (Sonder) Verlaque *et al*.
Caulerpa taxifolia (Vahl) C. Agardh
Codium fragile (Suringar) Hariot ssp. *tomentosoides* (Goor) P.C. Silva

Spermatophyta
Halophila stipulacea (Forsskål) Ascherson

a taxon from Western Australia, and the circumtropical species *Womersleyella setacea*, are particularly invasive because of their high vegetative reproductive capacity, high ecological valence and the absence of competitors, whereas both *Asparagopsis armata*, a species of Australian origin, and the lessepsian species *Lophocladia lallemandii*, show high seasonality in their invasive behaviour (occurring in late spring–early summer), when they epiphytise other algae or grow directly over rocky substrata.

Taxonomic studies have not only been devoted to the description of new taxa, but have also studied related species or complex genera like the *Laurencia* complex [24], *Gracilaria* (also studied using a molecular approach) [25,26], *Bangia* [27,28] and *Cystoseira*. This last genus has been studied using embryologic [29], chemotaxonomic [30–32], morphological and phenological [33–38] approaches. Moreover, both the taxonomy and the vegetational role of some Coralline algae occurring along the Sicilian coast have been studied [39–44].

Vegetational studies have been carried out on rocky substrata communities [45–51] and on the distribution, structure and phenology of *Posidonia oceanica* meadows [52]. In particular, the first meadows studied were those occurring at Capo Passero and Isola delle Correnti [53,54], at Carini Bay [55] and at Stagnone of Marsala [56]. More recently, studies were carried out on meadows occurring at the Oriented Natural Reserve 'Oasi faunistica di Vendicari' [57,58] and at the Marine Protected Area 'Isole Ciclopi', a lepidochronological analysis of which was also made [59].

Table 3. Ecological status of Sicilian sites, from Giaccone and Catra [60].

Locality	Community with	Ecological status
Capo S. Alessio (ME)	*Cystoseira amentacea*	5
Taormina (ME)	*Cystoseira amentacea*	5
Torre Archirafi (CT)	Ulvales	2
Santa Tecla (CT)	*Cystoseira mediterranea*	5
Santa Caterina (CT)	*Cystoseira mediterranea*	4
Capo Molini (CT)	*Pterocladiella capillacea*	3
Capo Molini (CT)	*Cystoseira amentacea*	4
Is. Lachea (CT)	*Cystoseira amentacea*	4
Cannizzaro (CT)	*Cystoseira amentacea*	5
Brucoli (SR)	*Cystoseira compressa*	4
Augusta (SR)	Ulvales	2
Augusta (SR)	Ulvales	2
Augusta (SR)	Cyanophyceae/Diatomee	1
Santa Panagia (SR)	*Cystoseira amentacea*	5
Capo Murro di Porco (SR)	*Cystoseira amentacea*	5
Marina di Avola (SR)	*Cystoseira compressa*	5
Vendicari (SR)	*Cystoseira amentacea*	4
Pachino (SR)	Ceramiales	3
Isola di Capo Passero (SR)	*Cystoseira amentacea*	5
Terrasini (PA)	*Cystoseira amentacea*	4
Punta Molinazzo (PA)	*Cystoseira amentacea*	5
Cinisi (PA)	Ulvales	3
Torre Orsa (PA)	*Cystoseira amentacea*	5
Caletta Orsa (PA)	*Cystoseira amentacea*	4
Capo Gallo (PA)	*Cystoseira amentacea*	5
Torre Mondello (PA)	*Cystoseira amentacea*	5
Addaura Roosvelt (PA)	*Pterocladiella capillacea*	4
Aspra (PA)	Ulvales	1
Capo Zafferano (PA)	*Cystoseira amentacea*	5
Porticello Olivella (PA)	*Cystoseira amentacea*	5
Scogli Formica (PA)	*Cystoseira amentacea*	5
Isolotto Zafferano (PA)	*Cystoseira amentacea*	4
Scogli Scopello(TP)	*Cystoseira amentacea*	5
Termini Imerese (PA)	Cyanophyceae/Diatomee	1

Applied research has mainly focused on: (1) management of the territory and the promotion of a sustainable development model for the coastal zone; (2) feasibility studies of Marine Protected Areas; (3) requirements for Specially Protected Areas of Mediterranean Interest (SPAMI); (4) census and revision of marine Community Interest Sites (CIS); (5) monitoring and research protocols in Marine Protected Areas; (6) study of the Environmental Impact (EI) for procedures of Environmental Impact Evaluation (EIE), Environmental Strategic Evaluation (ESE) and Incidence Evaluation (IE); and (7) biocoenotic and thematic cartography for industrial settlements like energetic and petrochemical plants, commercial and tourist ports, etc. Moreover, within implementation of the Water Framework Directive (EC 60/2000) [81], an index of ecological status based on macroalgae was proposed by Giaccone and Catra [60]. This index was applied to several sites along the Sicilian coast, thus allowing estimatation of the ecological status of shallow waters (Table 3).

3. Conclusions

Although a large amount of work dealing with the macrophytobenthos of Sicily and the adjacent islands has been performed, there are several gaps. For example, knowledge of both the flora and vegetation of some segments of the coast (e.g. Trapani to San Vito lo Capo, Sciacca to Capo Passero) is poor. Macrophytes are a quality marker to be used in implementation of the EC Water Framework Directive, and further studies are required in this subject. The effects of alien invasive species on indigenous communities is also an issue that needs further study. Finally, because the only multidisciplinary study on the oceanography, physics, chemistry, sedimentology and biology of Sicilian coastal waters dates back to 1984/85 [61], an analogous study, performed with updated methodologies, is now required, including a georeferenced map of marine habitats.

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