ASSESSMENT OF THE ECOLOGICAL STATUS OF SICILIAN COASTAL WATERS ACCORDING TO A MACROALGAE BASED INDEX (CARLIT)

Giancarlo Bellissimo, Benedetto Sirchia, Vincenzo Ruvolo
Regional Agency for the Environmental Protection (ARPA Sicilia),
Department State of the Environment and Ecosystems, Complesso monumentale Roosevelt,
Lungomare Cristoforo Colombo 4521, Loc. Addaura - 90149 Palermo (Italy),
phone +39 091 532197, e-mail: gbellissimo@arpa.sicilia.it

Abstract – Macroalgal communities is one of the four key Biological Quality Elements (BQEs) proposed in the Water Framework Directive (WFD, 2000/60/EC) to be used for the assessment of the Ecological Status (ES) of coastal waters bodies. Here we report the application of a macroalgae based index (CARtography of LITtoral and upper-sublittoral rocky-shore communities) along the Sicilian coastline in order to obtain a first assessment of its ecological status and collect accurate information on the distribution and abundance of shallow-water communities, especially of those most sensitive (e.g. *Cystoseira* belts).

Overall, the EQR-CARLIT values showed "high"/"good" levels in all water bodies with lushy forests of *Cystoseira amentacea* var. *stricta* except two with "moderate" level due to the presence of stress-tollerant species related to local factors. The present paper represents a baseline for monitoring long-term changes related to antropogenic disturbances and gives useful tools for the management of human impacts on the Sicilian coasts.

Introduction

In the context of the European Water Framework Directive (WFD, 2000/60/EC), the Ecological Status (ES) of coastal waters has to be quantified through indices based on appropriate Biological Quality Elements (BQEs) as bio-indicators. The assessment of water quality is based on the extent of deviation from Reference Condition (RC). A ratio between the values of the BQE observed in the sector of shore that is being assessed and the reference ones (Ecological Quality Ratio, EQR) of the indicator with no or low pressures from human activities allows to rank a given body of surface water from 0 (bad ecological quality) to 1 (high ecological quality) identifying five different ES classes: bad, poor, moderate, good and high. Intertidal macroalgal communities associated with rocky littoral habitats are known to respond significantly to different sensivity levels of environmental conditions [4, 5, 15], thus they have been proposed as a BQE for the assessment of the ES of coastal water bodies (WBs) in the Mediterranean Sea for the implementation of the WFD. Phytoplankton, angiosperms and benthic fauna are the other BQEs to be considered.

As required by the Italian national law (Ministerial Decree n. 260/2010), the CARLIT index (CARtography of LITtoral and upper-sublittoral rocky-shore communities) is the WFD-compliant monitoring method being regularly applying in Italy as a tool for the Regional Agencies to assess the environmental quality of marine and coastal waters [8]. According to this methodology, the communities are visually assessed and ranked

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according to their sensitivity to perturbation: *Cystoseira amentacea* assemblages, as well as almost all other surface *Cystoseira* species, that are particularly sensitive to water quality and other disturbances [5, 8, 9], are associated to the highest values of ES. *Cystoseira compressa*, which is able to thrive in slight polluted waters [8], is associated to a lower value of ES. In contrast, stress-resistant species (e.g. articulated Corallinales and Dictyotales), that are ubiquitous and tolerant, are associated to medium values. The lowest ES values are associated to very low structured communities dominated by opportunistic species such as green algae (e.g. *Ulva* spp. and *Cladophora* spp.) and cyanobacteria [5, 19]. In addition, the distribution of the littoral and sub-littoral communities is affected not only by water quality but also by the natural geomorphological variability of the coastal environment [7].

At present, CARLIT index is widely used all around the Mediterranean Sea [6 and references therein] since: (i) it is a fast, non-destructive and simple method; (ii) it potentially takes into consideration the entire rocky coastline of an area; (iii) it does not require further analyses in the laboratory reducing the total cost of monitoring; (iv) it is based on widely distributed communities that are relatively easy to identify and whose response to anthropogenic pressures is well-known [8, 19].

In Sicily, the first attempt of the application of the CARLIT method was performed in 2008 by the Regional Agency for the Environmental Protection of Sicily (ARPA Sicilia) as part of the institutional monitoring programme (Monitoring plan of the Sicilian marine and coastal waters under the Italian Legislative Decree 152/06) [1]. However, since the network of reference sites for Italy was lacking at that time, only a first environmental quality assessment of any stretch of coastline was provided. Conversely, a monitoring through the CARLIT index was carried out by ARPA Sicilia in 2013 exclusively in the south coast of Sicily within the "Caulerpa project" funded by the Mediterranean Fisheries Department of the Sicily Region [2]. Nevertheless, no CARLIT monitoring data are available in literature with the requirements of the WFD along the totality of the Sicilian rocky coasts. For this purpose, the present work aims to apply the CARLIT index under the institutional monitoring program of the Sicily Region (Water and Waste Department - "DAR project") for the implementation of the Italian national law (L.D. 152/06) in order to obtain for the first time an evaluation of the ES of the Sicilian coastal waters.

Materials and Methods

The island of Sicily is located in the south of Italy and encompasses more than 1150 km of coast (1600 km including the small islands).

In 2010, according to the Management Plan of the Hydrographic District of Sicily, the coast was divided into 65 WBs identified by ARPA and Sicily Region mainly taking into account the following factors: natural geomorphological features (morphology of the coast, including the adjacent mainland area and type of substrate) and hydrologic features (vertical stability of the water column), as proposes the Annex II of the WFD and Ministerial Decree n. 131/2008 [1]. In 2016, an update of the above-mentioned Management Plan was performed with the aim of identifying 30 WBs homogeneously distributed along the entire Sicilian coast [3]. In the context of the L.D. 152/2006, 19 WBs were subjected to the surveillance monitoring and the remaining 11 WBs to the operative one (Table 1). From a geomorphological point of view, the 30 WBs were divided taking into consideration five

coastal typologies [11]: 9 water bodies (WB 2-4-6-10-12-15-25-27-28) were classified as A3 (Mountain coast), 9 water bodies (WB 3-5-7-11-14-17-18-26-30) as B3 (Terrace coast), 1 water body (WB 13) as C3 (Littoral plain), 8 water bodies (WB 1-8-9-16-19-21-22-24) as E3 (River plain) and 3 water bodies (WB 20-23-29) as F3 (Dune plain) (Table 1). The CARLIT index was performed during April-June 2017, when macroalgae reach their growth peak, at 24 out of the 30 WBs. Six water bodies (WB 8-9-11-12-14-29) were completely devoid of rocky shores and thus they were not considered in the monitoring program (Fig. 1). Sandy beaches and highly modified areas such as harbors and marinas were excluded, according to [8]. CARLIT monitoring involved 244 km of rocky coast representing about 70 % of the potentially investigable rocky coastline of the Sicily (350 km at a scale 1:5000). The CARLIT method was implemented both along the totality of the rocky coast or in representative stretches of coasts long at least 3 km in 18 water bodies (WB 3-4-6-7-10-13-15-16-17-18-19-20-22-23-25-26-28-30) and in stretches of rocky coast long less than 3 km in the remaining 6 water bodies (WB 1-2-5-21-24-27). Each WB was divided into a variable number of areas (1 to 13) and sites (1 to 14) composed by 1 to 20 sectors (50 m each), depending on the lenght of the rocky shore and the presence of anthropized areas (ports and marinas) [1]. These WBs were selected in order to be representative of the entire Sicilian coastline (Fig. 1): 11 are located in the northern (WB 1 to 11), 9 in the eastern (WB 12 to 20) and 10 in the southern side (WB 21 to 30). Additionally, sites are differently affected by anthropogenic pressures, since they are located in harbor areas (WB 5-6-16) or within the NATURA 2000 network (WB 2-4-10-15-16-18-19-20-21-23-28). All the other sites are not subject to particular protection restrictions.

Figure 1 - Geographical distribution of the stretches of rocky coast monitored within the 24 water bodies (1-30) along the Sicilian coast.

Table 1 - Coastal typology and type of monitoring for each water body (WB).

WB	Typology		Monitoring
1	E3	River plain	Surveillance
2	A3	Mountain coast	Surveillance
3	B3	Terrace coast	Operative
4	A3	Mountain coast	Surveillance
5	B3	Terrace coast	Surveillance
6	A3	Mountain coast	Surveillance
7	B3	Terrace coast	Surveillance
8	E3	River plain	Surveillance
9	E3	River plain	Surveillance
10	A3	Mountain coast	Operative
11	B3	Terrace coast	Surveillance
12	A3	Mountain coast	Surveillance
13	C3	Littoral plain	Surveillance
14	B3	Terrace coast	Surveillance
15	A3	Mountain coast	Surveillance
16	E3	River plain	Surveillance
17	B3	Terrace coast	Operative
18	B3	Terrace coast	Operative
19	E3	River plain	Surveillance
20	F3	Dune plain	Operative
21	E3	River plain	Surveillance
22	E3	River plain	Operative
23	F3	Dune plain	Operative
24	E3	River plain	Operative
25	A3	Mountain coast	Operative
26	B3	Terrace coast	Operative
27	A3	Mountain coast	Operative
28	A3	Mountain coast	Surveillance
29	F3	Dune plain	Surveillance
30	B3	Terrace coast	Surveillance

The sampling survey was performed with a different boat (kayak or inflatable boat) depending to the coast typology, moving at low speed and proceeding as close as possible to the shoreline, in order to record both the upper-infralittoral algal communities and the geomorphological features. When hardly accessible by boat, some sectors were sampled by snorkeling or walking.

In each sector, the main community categories (defined in Table 2) and geomorphological features were visually recorded and noted directly on a cartographic support using the Quantum Geographical Information System (QGIS).

During the sampling procedure no endangered or protected species has been collected or damaged. Each WB was sampled in one day; the same team of experts, applying the identical methodology, was involved along the considered time-frame (the whole spring season), in order to overcome the possibile bias related to operator subjectivity that can potentially confound the attribution of the correct community category, affecting the CARLIT Index calculation.

The Ecological Quality value of any sector of coast was calculated as $EQV = \Sigma(l_i * SL_i)/\Sigma l_i$ where l_i represents the lenght of the coastline occupied by the community category i and SL_i the sensitivity level of the community category i (Table 2). The EQR

value was obtained, in each sector, comparing the EQV to the corresponding values calculated at reference sites, according to the six different geomorphological relevant conditions described by [8]. EQR values range from 0 to 1, but values higher than 1 may be found when the EQV of the considered sector is higher than the EQV of the reference sites. The rating scale of EQR values was defined by [8]: 0–0.25 (bad), >0.25–0.40 (poor), >0.40–0.60 (moderate), >0.60–0.75 (good) and >0.75–1 (high).

Table 2 - Summarized description and sensitivity levels (SL, from 20 to 1) of the main community categories as reported in the methodological contribution published by ISPRA (modified from [18]).

Community category	Description	SL	Comm. Acronim
Trottoir[a]	Large organogenic build-ups of *Lithophyllum byssoides, Lithophyllum trochanter, Dendropoma*[b]	20	TR
Cystoseira brachycarpa / crinita / elegans	Community dominated by *Cystoseira brachycarpa / crinita / elegans*	20	CB
Cystoseira sheltered	Community dominated by *Cystoseira foeniculacea / barbata / humilis / spinosa*	20	Cs
Cystoseira amentacea / mediterranea 5	Continuous belt of *Cystoseira amentacea / mediterranea*	20	CA5
Cystoseira amentacea / mediterranea 4	Almost continuous belt of *Cystoseira amentacea / mediterranea*	19	CA4
Cystoseira amentacea / mediterranea 3	Abundant patches of dense stands of *Cystoseira amentacea / mediterranea*	15	CA3
Cystoseira amentacea / mediterranea 2	Abundant scattered plants of *Cystoseira amentacea / mediterranea*	12	CA2
Cystoseira compressa	Community dominated by *Cystoseira compressa*	12	CC
Cystoseira amentacea / mediterranea 1	Rare scattered plants of *Cystoseira amentacea / mediterranea*	10	CA1
Dictyotales / Stypocaulaceae	Community dominated by *Padina / Dictyota / Dictyopteris / Taonia / Stypocaulon*	10	DS
Corallina	Community dominated by *Corallina* spp. (including *Ellisolandia elongata*)	8	Cor
Encrusting corallinales	Community dominated by *Lithophyllum incrustans, Neogoniolithon brassica-florida* and other encrusting corallines	6	EC
Mussels	Community dominated by *Mytilus galloprovincialis*	6	Mgal
Pterocladiella / Ulva / Schizymenia	Community dominated by *Pterocladiella / Ulva / Schizymenia*	6	Ulva
Green algae	Community dominated by *Ulva* and / or *Cladophora*	3	GA
Blue greens	Community dominated by *Cyanobacteria* and *Derbesia tenuissima*	1	BG
Posidonia reef	Barrier and fringing reefs of *Posidonia oceanica*	20	Pos
Cymodocea nodosa	Superficial *Cymodocea nodosa* meadows	20	Cym
Zostera noltii	Superficial *Zostera noltii* meadows	20	Zos

[a]Except for the category Trottoir, which is generally found in the mediolittoral zone, all the other categories only have be taken into account when present in the infralittoral fringe zone.

[b]*Dendropoma* forms organogenic build-ups typical of Sicily and other South Italian regions.

In the case of rare scattered plants of *Cystoseira amentacea / mediterranea*, the dominant community also has to be noted down. (Sensitivity level—SL: average value).

In case of sectors equally dominated by two different community categories, the average value between the two is taken into account (e.g. Cor+Mgal: SL = 7)

Results

According to the results reported in Fig. 2, the ES of the Sicilian rocky shores showed overall quite positive evidences: 18 out of the 24 WBs were classified as "high" and 4 out of the 24 WBs as "good" with EQR-CARLIT values ranging from 0,72 to 1,35 (Fig. 3). On the contrary, the two remaining water bodies (WB 16 and 24) were classified as "moderate" with EQR-CARLIT values of 0,54 and 0,43, respectively (Fig. 2 and 3). In the present study, the two lowest ecological status classes, "poor" and "bad", have never been recorded along the Sicilian coast.

Cystoseira amentacea was the dominant community of the shallow rocky coasts of Sicily, homogenously distributed in the different categories, from scattered plants to continuous belts (CA1-CA5). In particular, dense stands of *C. amentacea* were observed often associated with large vermetid reefs of *Dendropoma* (TR) in the north-western coast (WBs 1 to 6) or with small reefs, shaped as ledges and encrustations of *Lithophyllum byssoides* (TR) in the eastern coast (WB 13 and 18). Barrier and fringing reef of *Posidonia oceanica* (Pos) were observed along stretches of coast of four water bodies (WB 1-23-26-28). In the eastern side of Sicily (WB 15 and 16), a community dominated by *Corallina* spp. (Cor) and green algae (GA) was observed along most of rocky coast.

In the south-east side (WBs 20 to 25), the community was generally dominated by *Cystoseira compressa* (CC) that formed a mixed community with *C. amentacea* in four water bodies (WB 20-21-25-26) or with GA in other two water bodies (WB 22 and 24). Other less sensitive photophilic algae, such as species belonging to the orders Dictyotales and Sphacelariales (DS) or to the *Laurencia complex group* represented the dominant community in some stretches of coast (WB 6-20-21).

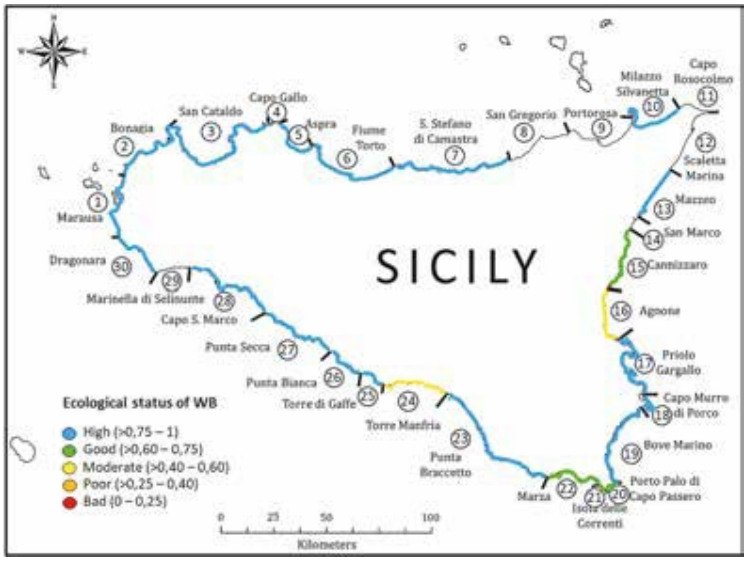

Figure 2 - Cartographical representation of the ES of the 24 WBs (1-30) monitored in the Sicilian coast through the CARLIT Index.

Discussion

The main goal of the WFD is to achieve and maintain a "good" ES of all the European waters by 2015 in its first management cycle. All the 24 Sicilian water bodies considered in the present study (with only two exceptions) reached the "good" ES that represents the WFD's goal by 2021 in the second management cycle. Such a result is in agreement with a general improvement of the ecological quality, based on CARLIT index, observed recently at a larger scale in the North-Western Mediterranean basin [10, 14]. Moreover, this study highlights a remarkable positive trend that has always been maintained for over a decade since a first ecological quality assessment of the intertidal macroalgal assemblages has been carried out along the Sicilian coastline [1]. In addition, a recent application of the CARLIT protocol along the southern coast of Sicily revelead a "good" ES of coastal waters pointing out the lack of significant changes in ES related to anthropogenic impacts along a decade [2].

"High" class of the ES was related to the presence of *Cystoseira amentacea* and vermetid reefs, the latter commonly referred to by the French name of *trottoir*, that both act as biological engineers creating complex habitats on the narrow Mediterranean intertidal fringe and are essential for biodiversity and ecosystem functioning [12, 13].

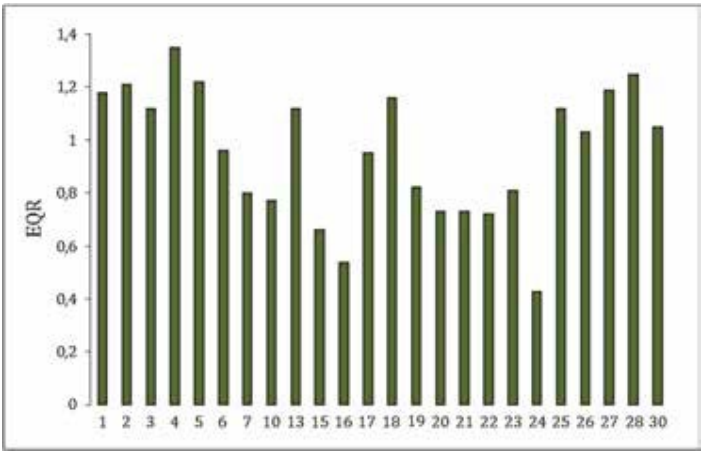

Figure 3 - CARLIT EQR values of the 24 water bodies (1 - 30) monitored along the Sicilian coastline.

C. amentacea is completely missing in some stretches of coast free of human-induced impacts in the south side of the Sicilian coastline in favour of photophilic intermediate sensitive communities (*i.e.* DS and Cor). Despite the absence of the species with the highest sensitivity level (*C. amentacea*), ES values belonging to the "good" class have been recorded also in this area within some water bodies. This outocome matched with the findings of a recent study according to which, in absence of anthropogenic pressures, the distribution of *C. amentacea* of the infralittoral fringe can be induced by the morphology of the coast,

mainly related to the coastline slope [16]. Urbanization, including artificialization of the coastline and sewage, are known to affect the very shallow communities, together with industrial impacts, as observed in many Mediterranean areas [5, 6, 19]. Agricultural discharges and illegal domestic/urban outfalls are most likely responsible of a moderate to poor ES in some sectors of the Sicilian coastline (WB 5, 15, 16, 17, 22, 23, 24). However, only two water bodies (WB 16 and 24) did not yet fulfill the WFD requirements being classified as "moderate". In Agnone (WB 16), urbanization impact related to the Catania urban center and freshwater input from the Simeto river, are the major pressures typologies, mirrored by the presence of communities categories with low sensitivity levels (*i.e.* Ulva and Mgal). Similarly, Torre Manfria (WB 24) was characterized by freshwater inputs from several waterways that favoured the development of a community dominated by tionitrophilous species (*i.e. Ulva* spp.).

Conclusion

The implementation of CARLIT in the areas surveyed so far has provided valuable data on the ES of the water bodies, but also on the present distribution and abundance of shallow water assemblages dominated by *Cystoseira* spp.

Cystoseira forests are common in almost all Sicilian rocky coasts and the understanding of mechanisms that affect their distribution is a relevant issue in the framework of coastal zone management. Moreover, the application of CARLIT along years will allow to build a long-term dataset useful to assess the temporal and spatial variability of *Cystoseira* species in the light of monitoring and conservation of such assemblages.

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