MONITORING OF POSIDONIA OCEANICA MEADOWS IN THE SICILIAN COASTS UNDER THE WATER FRAMEWORK DIRECTIVE (WFD)

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Abstract – The present paper aims to assess for the first time the ecological status of the Sicilian water bodies (WBs) using the PREI (Posidonia oceanica Rapid Easy Index) method according to the Water Framework Directive (WFD, 2000/60/EC) requirements. The PREI is based on five metrics: shoot density, shoot leaf surface area, E/L ratio (Epiphytic biomass/Leaf biomass), depth of lower limit, and type of this lower limit. Monitoring of the 29 P. oceanica meadows allowed to classify the 20 WBs of Sicilian coasts in the first two levels of status: 10 as "high" and 10 as "good" with the PREI values ranged between 0,551 and 1. This classification is in accordance with our field knowledge and with our knowledge of the literature.

Introduction

In the Mediterranean Sea, the endemic seagrass *Posidonia oceanica* (L.) Delile forms monospecific meadows widely distributed, from the surface up to more than 40 m deep depending upon water transparency [6], constituting an engineering ecosystem and playing a major ecological, geological and economic role in coastal water areas [7, 20].

Due to its high sensitivity to human-induced disturbances, *P. oceanica* is considered to be appropriate for biomonitoring because of its wide geographical distribution, reasonable size, sedentary habit, longevity, permanence over the seasons and easy collection [6, 13, 14, 19]. *P. oceanica* meadows are susceptible to regression in response to specific impacts, thus their presence and abundance is an indicator of the overall environmental quality of the coastal zone [11, 15]. Indeed, the monitoring of structural and functional descriptors of *P. oceanica* meadow health status [8] provides important information about the vitality and dynamic of meadows [18].

Over recent decades, *P. oceanica* is listed as a protected species under several international conventions ratified by most countries of the Mediterranean and as priority natural habitat type for conservation (1120 *Posidonia* beds) under the Habitat Directive (92/43/EEC). Also, *P. oceanica* is one of the four Biological Quality Elements (BQEs) that is regularly used in the evaluation of the Ecological Status (ES) of any given coastal Water Body (WB) in accordance with the Water Framework Directive (WFD, 2000/60/EC) requirements. Phytoplankton, macroalgae and benthic fauna are the other BQEs to be considered. Recently, *P. oceanica* has been selected as an indicator of the Good Environmental Status for marine areas within the Marine Strategy Framework Directive (MSFD, 2008/56/EC).

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In Sicily, *P. oceanica* is the most common seagrass covering about 76 000 ha of coastal areas, with dense and extensive meadows mainly distribuited along the western and south-eastern coasts [10].

As required by the Italian national law (Ministerial Decree n. 260/2010), the PREI index (*Posidonia oceanica* Rapid Easy Index) is being regularly applying in Italy as a monitoring tool for the Regional Agencies to assess the environmental quality of marine and coastal water bodies [11]. The first application of this index was carried out by ARPA Sicilia in 2013 exclusively in the south coast of Sicily within the framework of "Caulerpa Project" funded by the Mediterranean Fisheries Department of the Sicily Region [3]. Nevertheless, no PREI monitoring data are available in literature with the requirements of the WFD along the totality of the Sicilian coasts. Here we present a first assessment of the environmental quality of marine and coastal waters along the Sicilian coastline using the PREI method in the framework of the institutional monitoring program of the Sicily Region (Water and Waste Department - "DAR Project") for the implementation of the Italian national law (Legislative Decree 152/06).

Materials and Methods

In the context of a regional agreement (Management Plan of the Hydrographic District of Sicily of 2010) between the Regional Agency for the Environmental Protection of Sicily (ARPA Sicilia) and the Water and Waste Department of the Sicily Region, the Sicilian coastline was divided into 65 WBs identified by ARPA and Sicily Region [2]. In 2016, an update of the Management Plan was performed with the aim of identifying 30 WBs homogeneously distributed along the entire Sicilian coast [4]. Monitoring was carried out in spring-summer 2018 in 20 out of the 30 WBs identified along the entire coastline of the Sicily Region. Indeed, 10 WBs were characterized by the lack of *P. oceanica* meadows and thus they were not considered in the monitoring program (Fig. 1).

However, on the basis of the above-mentioned agreement that planned the overall monitoring of 29 *P. oceanica* meadows, further 9 meadows were chosen and monitored within the 20 WBs (Fig. 1). In particular, two more meadows were selected within the WB 17 and one more within seven water bodies (WB 1-2-3-19-23-28-30). Four *P. oceanica* meadows settled exclusively on sandy bottom (WB 5-9-11-30) while the remaining twenty-five meadows on both sandy bottom and *matte*. Also, 20 out of the 29 *P. oceanica* meadows were located in the sites of the Natura 2000 Network.

The PREI was used with metrics selected according to the requirements of the WFD: shoot density, shoot leaf surface area, *E/L* ratio (ratio between epiphytic biomass and leave biomass) measured on shoots sampled at the same depth, depth of lower limit and type of this limit (progressive, clear-cut, erosive or regressive). These metrics were selected because they provide pertinent information on the vitality of the meadow (at the individual and population level) for a wide spectrum of disturbance (water transparency, nutrient concentrations and eutrophication, sedimentary dynamics, grazing pressure) regularly described in the Mediterranean Sea [17].

The classification of ecological status is based on the deviation of the status of the BQE from its potential status under pristine conditions (reference conditions: RC). The PREI values range from 0 (worst conditions where the BQE is badly affected or missing) to 1 (RC) corresponding to Ecological Quality Ratio (EQR) boundaries reported in the WFD.

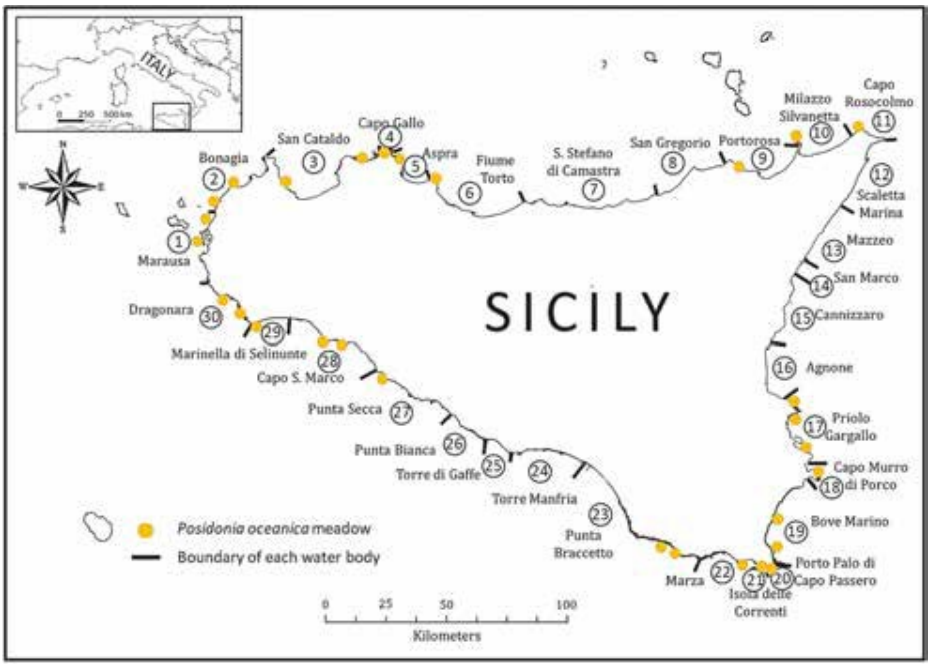


Figure 1 - Location of *Posidonia oceanica* meadows distributed along the Sicilian coastline within 20 water bodies (1-30).

A hierarchical sampling design was used to investigate structural and biological characteristics of the 29 meadows along Sicilian coasts. Sampling procedures as well as laboratory analyses (phenology, lepidochronology and biomass) were carried out following ISPRA (Italian National Institute for Environment Protection and Research) methodological report indications [5].

In each meadow, two sampling stations were investigated by scuba divers: one at the fixed depth of 15 m (A) and one in correspondence of the lower limit (B). At each station (A), three areas of 400 m² were selected at the distance of tens of meters each other within which 3 replicates measures of shoot density (40 cm x 40 cm) were carried out and 6 orthotropic (vertically oriented) shoots as well as a sediment sample were collected.

Likewise, at each station (B) along an horizontal transect, the same number of replicates measures of shoot density (3) and samples (6) was considered. In addition, in both stations estimates of some descriptors (flowering, bottom type, meadow continuity and cover, % dead *matte*, % invasive algae) were carried out, while measures of depth, lower limit type and rhizome baring were also recorded exclusively at each station B.

In both stations, *P. oceanica* shoots were sampled only in meadows settling on sandy bottom or *matte*, excluding rocky bottom as in accordance with [5].

In this study, only the results of the PREI metrics have been reported whereas all the other togheter with leaf biometry and primary production are available in the ARPA Sicilia monitoring report [4].

Results

The 20 WBs monitored were classified in the first two levels of status: 10 as "high" and 10 as "good" (Fig. 2) with PREI values ranging from 0,551 (WB 27) to 1 (WB 29) (Fig. 3). In the present study, the three lowest ecological status classes, "moderate", "poor" and "bad", have never been recorded along the Sicilian coast.

Mean values for measured PREI metrics are shown in Figure 4 (a-e). In particular, shoot density values ranged from 242,13±66,46 (WB 17) to 498,61 shoot m^{-2} (WB 29), with 7 meadows belonging to the "higher sub-normal density" [WB 2(2)-3(2)-9(1)-29(1)-30(1)], 20 to the "normal density" [WB 1(2)-4(1)-5(1)-6(1)-10(1)-11(1)-17(1)-18(1)-19(2)-20(1)-21(1)-22(1)-23(2)-27(1)-28(2)-30(1)] and 2 [WB 17(2)] to the "lower sub-normal density" *sensu* [8,16]. Shoot leaf surface area from 181,49 (WB 21) to 549,96 cm^2 $shoot^{-1}$ (WB 29), epiphytic biomass from 105,56 (WB 27) to 413,68 mg dw $shoot^{-1}$ (WB 5), leaf biomass from 905,38 (WB 18) to 2534 mg dw $shoot^{-1}$ (WB 29) and lower depth limit from 12 m (WB 27) to 37 m±1,4 (WB 3). Most of *P. oceanica* meadows (17) showed a progressive lower limit [WB 1-2(2)-3(2)-4-6-10-11-18-19(2)-21-22-28(2)-30] while 7 an erosive lower limit [WB 1-5-17(3)-23(2)], 4 a clear-cut lower limit (WB 9-20-29-30) and 1 a regressive lower limit (WB 27). On the basis of the water transparency evaluation scale related to the depth of the lower limit [17], three meadows [WB 2(1) and 3(2)] belonged to the class *Very transparent waters*, thirteen meadows [WB 1(2)-4(1)-6(1)-10(1)-11(1)-18(1)-19(1)-20(1)-21(1)-29(1)-30(2)] to the *Transparent waters*, twelve meadows [WB 5(1)-9(1)-17(3)-18(1)-19(1)-22(1)-23(2)-28(2)] to the *Slight transparent waters* and only one meadow (WB 27) to the *Turbid waters*.

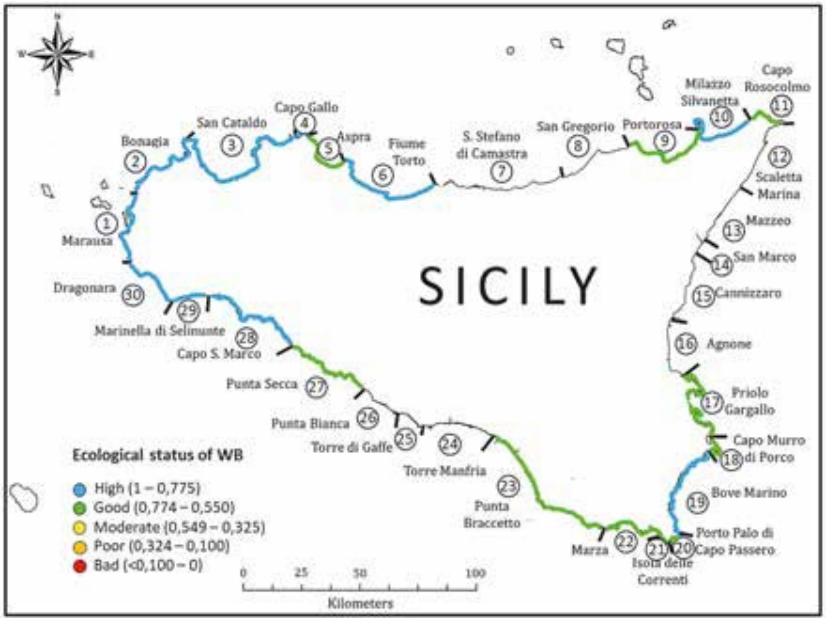


Figure 2 - Cartographical representation of the ES of the 20 WBs (1-30) along the Sicilian coastline.

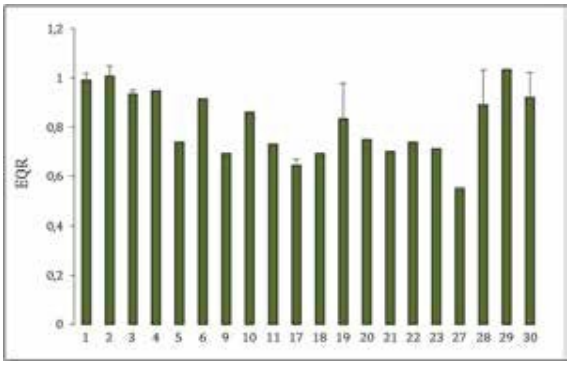


Figure 3 - EQR values for each of the 20 water bodies monitored along the Sicilian coastline (1-30). Error bars: standard deviation.

Discussion

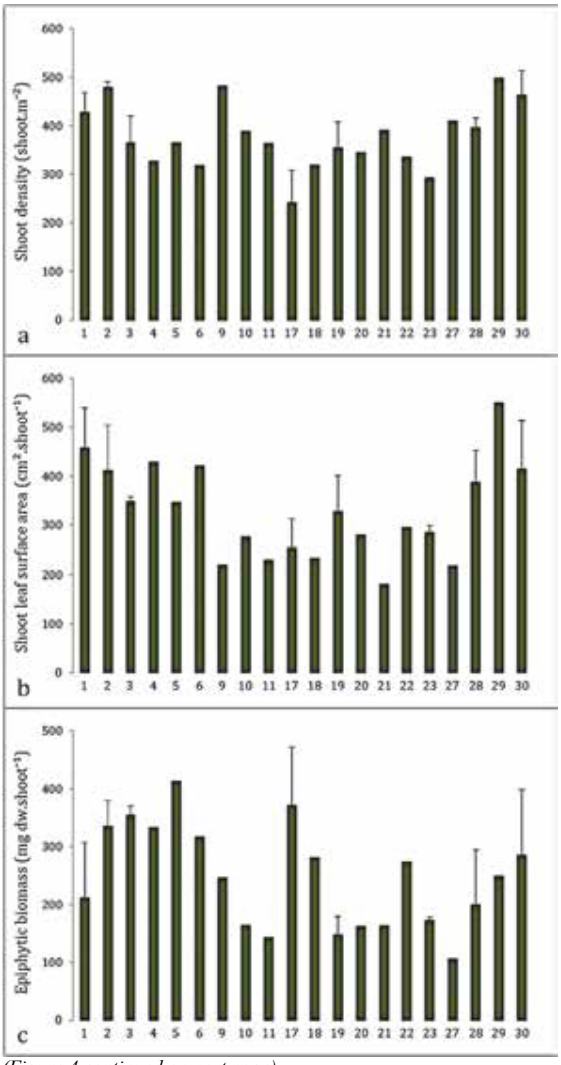
The ES of the Sicilian coastline reflected a good environmental quality. In fact, all the 20 Sicilian water bodies considered in the present study reached the "good" ES that represents the WFD's goal by 2021 in the second cycle of monitoring. Such results are in line with a positive trend of the ecological quality based on *P. oceanica* that has always been maintained along the Sicilian coasts for over a decade [1, 3, 10]. Low anthropogenic pressure, sedimentation rate and favourable temperature are some factors likely to explain the good health status of the Sicilian meadows [10].

Among the PREI metrics, *P. oceanica* density is considered an important structural descriptor for assessing the state of the vitality of a meadow and provides information on the changes to which the meadows are subject when measured on a plurennial time scale [15,19]. According to the standardized scale for density classification [16], all the *P. oceanica* meadows appeared to be in "equilibrium" at the depths where sampling was done, except for two meadows in the WB 17, probably affected by industrial activities of the petrochemical complex of Augusta-Priolo. In this area, signs of evident regression up to complete disappearance have been already detected in the past [10].

Based on the literature data, the highest values of density were recorded along the western and south-eastern Sicilian coasts [10]. Our results showed a similar finding only in the western coast while, on the contrary, no significative values were recorded in the south-eastern one. In addition to the density, the western sector of the Sicilian coastline showed the highest values of shoot leaf surface area and leaf biomass as in accordance with previous studies [1,10], providing evidence of the good condition of Sicilian meadows.

The typology of the lower depth limit of *P. oceanica* meadows is considered an important descriptor to evaluate extension/regression balancing conditions of the meadows, allowing to detect the principal local factors controlling the bathymetric distribution of the plant along Sicilian coasts [19]. The high frequency of the progressive limit typology found along the Sicily coasts reflected the high water transparency with the exception of the southern coasts where morphology and composition of the bottom reduce water

transparency. In particular, in some areas the increased torbidity seemed to be the main factor limiting the meadow's progression. The epiphyte biomass of *P. oceanica* plays an important role in marine ecosystems contributing significantly to the primary production of the meadow [12] and is considered a useful biological indicator of environmental changes with evidences of positive relationships of epiphyte load to nutrients concentration [16]. The presence of untreated wastewater sewages close to the municipality of Palermo (WB 5) and the industrial area of Augusta (WB 17) are likely to justify the highest values of epiphyte biomass detected in some meadows.



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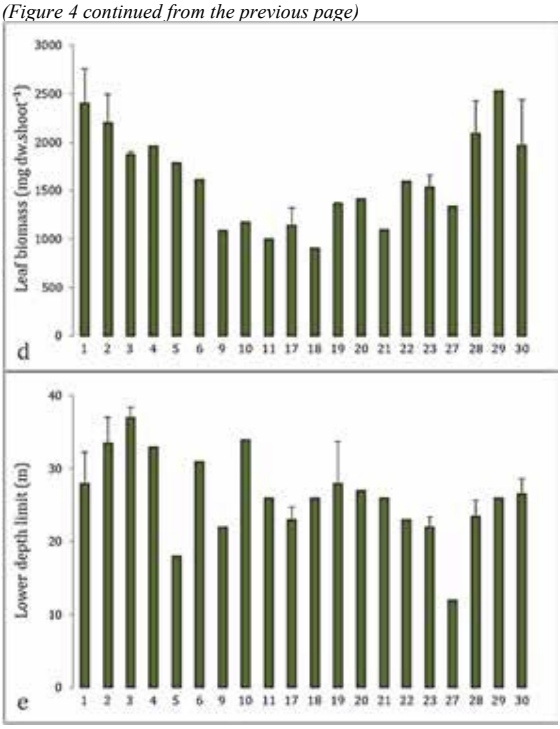

Figure 4 - a-e. PREI metrics values (a. shoot density, b. shoot leaf surface area, c. epiphytic biomass, d. leaf biomass, e. lower depth limit) for each of the 20 water bodies (1-30) monitored along the Sicilian coastline. Error bars: standard deviation.

Conclusion

The outcomes of the present study represent the first data available in the evaluation of the ecological quality of Sicilian coastal waters based on PREI index and are critical as a first baseline to ensure that habitat changes are monitored and managed appropriately. Further long-term observations are needed and more information on other possible sources of impact should be gathered to obtain more reliable conclusions.

Acknowledgments

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