# What biotic indices tell us about ecosystem change: lessons from the seagrass Posidonia oceanica

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# WHAT BIOTIC INDICES TELL US ABOUT ECOSYSTEM CHANGE: LESSONS FROM THE SEAGRASS *POSIDONIA OCEANICA* INDICES APPLICATION ON HISTORICAL DATA

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*POSIDONIA OCEANICA*
SEAGRASS
LIGURIAN SEA
ECOLOGICAL INDICES
HISTORICAL DATA

ABSTRACT. – Anthropogenic pressure on marine ecosystems is affecting water quality and seafloor integrity. Mediterranean seagrass meadows of endemic *Posidonia oceanica* (Linnaeus) Delile are considered a priority habitat under the European Directive 92/43/CEE, given their ecological and economic importance and being an environmental quality indicator. Availability of historical data on three *P. oceanica* meadows along the Ligurian coast (NW Mediterranean Sea) allowed assessing change in the meadow status over time. A number of indicators and ecological indices at different levels of ecological complexity, including the multimetric PREI (Posidonia Rapid Easy Index) adopted by the environmental agencies, were employed and compared. This paper aims at a) defining the health status of the *P. oceanica* meadows and measuring their changes through time collating available historical information; b) evaluating the discriminating power of the different indices and assessing their consistency with each other. The different indices adopted revealed little consistency thus suggesting that no single index can define the health status of *P. oceanica* meadows; as a consequence the use of an indices set is highly recommended to monitor meadow evolution over time.

## INTRODUCTION

Biotic indices have long been used to assess the environmental quality of fresh water and terrestrial ecosystems (Cairns & Pratt 1993, Andreasen *et al.* 2001). The application of naturalistic information to elaborate biotic indices in support of marine management is still under development, while it is current practice on land (Bianchi *et al.* 2012). In the last decades, the use of indices to assess marine environmental status in Europe has become frequent, spurred by European directives. Indeed, EU rules (see Directive Proposal 1999/C 343/01, Official Journal of the European Communities 30/11/1999) emphasized the importance of biological indicators to establish the ecological quality of European seas and estuaries (Borja *et al.* 2000). The EU Water Framework Directive 2000/60/EC (WFD) underlined the need for biotic indices, which have been introduced in considerable number. More recently, the EU Marine Strategy Framework Directive 2008/56/EC (MSFD), introduced the concept of "seafloor integrity" to improve the assessment of ecological quality (Bianchi *et al.* 2012). Therefore, the use of seagrass as biological indicators has become a common practice to assess the environmental quality of coastal seas (Pergent *et al.* 1995, Short & Wyllie-Echeverria 1996, Hemminga & Duarte 2000).

Seagrass meadows are declining worldwide due to natural and human-induced events (Short & Wyllie-Echeverria 1996). The endemic Mediterranean seagrass *Posidonia oceanica* (Linnaeus) Delile, 1813 is the most important and abundant seagrass and it is considered a priority habitat for both animals and plant communities, covering different substrata from the sea level down to 40 m depth (Boudouresque *et al.* 2006). There are many ecosystem services provided by *P. oceanica*: it represents an origin of food for many marine and shore organisms, but also plays fundamental roles such as nursery areas for fish and invertebrates and shoreline protection (Vassallo *et al.* 2013). Thus, *P. oceanica* is mentioned in the Habitat Directive 92/43/CEE and, since 1991, is included in the Red List of the International Union for Conservation of Nature (IUCN) as a threatened species of the Mediterranean Sea (www.iucnredlist.org).

A general regression of *P. oceanica* meadows has been recorded in the Ligurian Sea (Bianchi & Morri 2000). In fact, it has been estimated that in the past century the Ligurian *P. oceanica* meadows lost 50 % of their original extent (Peirano & Bianchi 1997, Peirano *et al.* 2005, Burgos-Juan *et al.* 2016). However, as a consequence of conservation policies enforced in the last decades, the regression of *P. oceanica* in the Ligurian Sea has possibly ceased or at least slowed down (Burgos *et al.* 2017, Bianchi *et al.* 2019) as in several places in the Mediterranean Sea (De los Santos *et al.* 2019).

This paper aims at a) defining the health status of three Ligurian *P. oceanica* meadows, using ecological indices and descriptors that work at different levels of complexity (*i.e.*, individual, population, community, and seascape), and measuring their change through time collating all available historical information; b) evaluating the discriminating power of the different indices and assessing their consistency with each other.

## MATERIAL AND METHODS

*Study area*: This study was carried out in Liguria, an administrative region in NW Italy, whose coast border the central and largest part of the Ligurian Sea. Three *Posidonia oceanica* meadows were analyzed, located in Monterosso (MM), Prelo (PR), and Bergeggi (BE) (Fig. 1), where historical data collected along underwater transects were available since the 1980s (Table I).

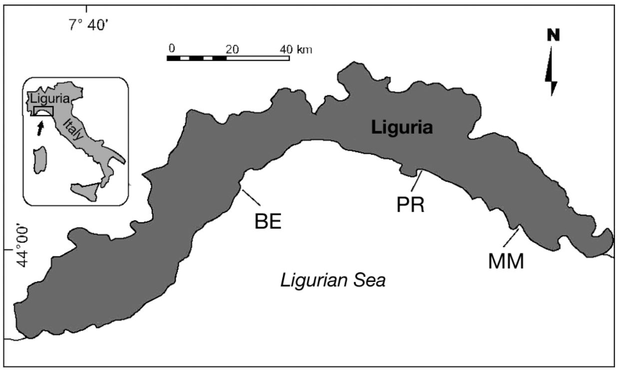


Fig. 1. – Map of the study area and location of the three meadows investigated: Bergeggi (BE), Prelo (PR), and Monterosso (MM).

Table I. – Data sources for the three *Posidonia oceanica* meadows investigated.

| Meadow | Year | References |
|---|---|---|
| Prelo | 2002 | Lasagna *et al*. 2006a, b |
| Prelo | 2003 | Lasagna *et al*. 2006a ,b |
| Prelo | 2004 | Lasagna *et al*. 2006a, b |
| Prelo | 2005 | Lasagna *et al*. 2006a, b |
| Prelo | 2006 | Lasagna *et al*. 2011 |
| Prelo | 2013 | Bianchi *et al*. 2019 |
| Prelo | 2017 | Rigo *et al*. 2019 |
| Bergeggi | 1987 | Vetere *et al*. 1989 |
| Bergeggi | 1992 | Sandulli *et al*.1994 |
| Bergeggi | 2004 | Montefalcone *et al*. 2007 |
| Bergeggi | 2009 | Montefalcone *et al*. 2010 |
| Bergeggi | 2012 | Oprandi *et al*. 2014b |
| Bergeggi | 2016 | Bianchi *et al*. 2019 |
| Monterosso | 1991 | Peirano *et al*. 1999 |
| Monterosso | 1992 | Peirano *et al*. 1999 |
| Monterosso | 1994 | Peirano *et al*. 2001 |
| Monterosso | 1996 | Peirano *et al*. 2001 |
| Monterosso | 1997 | Peirano *et al*. 2011 |
| Monterosso | 2002 | Montefalcone *et al*. 2007 |
| Monterosso | 2008 | Bianchi *et al*. 2019 |
| Monterosso | 2017 | Bianchi *et al*. 2019 |

*Field and laboratory activities*: Historical data were compared with data collected more recently (2016 and 2017). All the historical and recent data considered in the analyses were collected during summer season, along underwater depth transects (Bianchi *et al*. 2004) located in the same area of previous studies (Table I). The sampling activity carried out along each transect consisted in a visual estimation, every 10 m along the marked line, of the percentage cover of the seafloor by living *P. oceanica*, dead matte, sand, rock, and possible substitutes (*i.e.*, *Cymodocea nodosa* Ucria, 1870, *Caulerpa taxifolia* (M. Vahl) C. Agardh, 1817, *Caulerpa cylindracea* Sonder, 1845 and *Caulerpa prolifera* (Forsskål) J. V. Lamouroux, 1809). The meadow shoot density was measured at 15 m depth, as recommended by ISPRA (Italian Higher Institute for Environmental Protection and Research (www.isprambiente.gov.it/files/icram/scheda-metodologia-posidonia-new.pdf). Altogether, 18 shoots were sampled for laboratory analyses through plant phenology (Giraud 1977) and lepidochronology. Further analyses were also conducted on the associated epiphytic community: all the epiphytes were scratched from the leaves, then dried and weighed to assess their biomass.

*Ecological indices and descriptors assessment*: Data obtained from field and laboratory activities were used to define the health status of the three *P. oceanica* meadows, through a set of descriptors and ecological indices working at different ecological complexity levels:

1) Leaf surface ($cm^2$ $shoot^{-1}$) at the individual level, to describe the physiological status of the plant (Leoni *et al*. 2007);

2) Shoot density (shoots $m^{-2}$) and lower limit depth (m) at the population level, to understand dynamics in the meadow structure (Pergent *et al*. 1995);

3) Epiphyte biomass (mgDW $cm^{-2}$) at the community level, which provides rapid information on changes in the water quality (Giovannetti *et al*. 2010);

4) Conservation Index (CI), Phase Shift Index (PSI), and Substitution Index (SI) at the seascape level, to evaluate changes over time of the meadow composition (Moreno *et al*. 2001, Montefalcone 2009);

5) Posidonia Rapid Easy Index (PREI, Gobert *et al*. 2009), which integrates different metrics (shoot density, leaf surface, epiphyte biomass, leaf biomass, and depth and type of the lower limit) and thus encompasses multiple ecological levels.

The above listed indices and descriptors were calculated also from historical data when information was available and complete. Results obtained for each index were then classified in five classes using the reference classifications of ecological quality status (Gobert *et al*. 2009, Montefalcone 2009, UNEP/MAP-RAC/SPA 2011-2015): bad, poor, moderate, good, and high. Only for epiphyte biomass no classification is available.

## RESULTS

### *Meadows ecological quality and trend over time*

At the individual level, analysis of the leaf surface (Fig. 2) showed a worsening in the ecological status in all the three meadows. The status of the *Posidonia oceanica* meadow at Prelo changed from good to poor in the last fifteen years. Also in Monterosso a decline in the meadow ecological status from good to moderate occurred from 1991 to 2017. Regarding Bergeggi, data on leaf surface was available only for two periods: the meadow showed a moderate ecological status in 1992, a poor status in 2016.

At the population level (Fig. 3), all indices evidenced stability or even improvement, of the ecological status. Shoot density increased in Monterosso and Prelo meadows, and the ecological status passed from moderate to good in both meadows. Bergeggi maintained a moderate status, notwithstanding a reduction in shoot density values over time. With regard to the lower limit depth, the status remained poor over time in all the three meadows.

At the community level, epiphyte biomass showed a decrease of its values in all meadows, notwithstanding high temporal variability (Fig. 2).

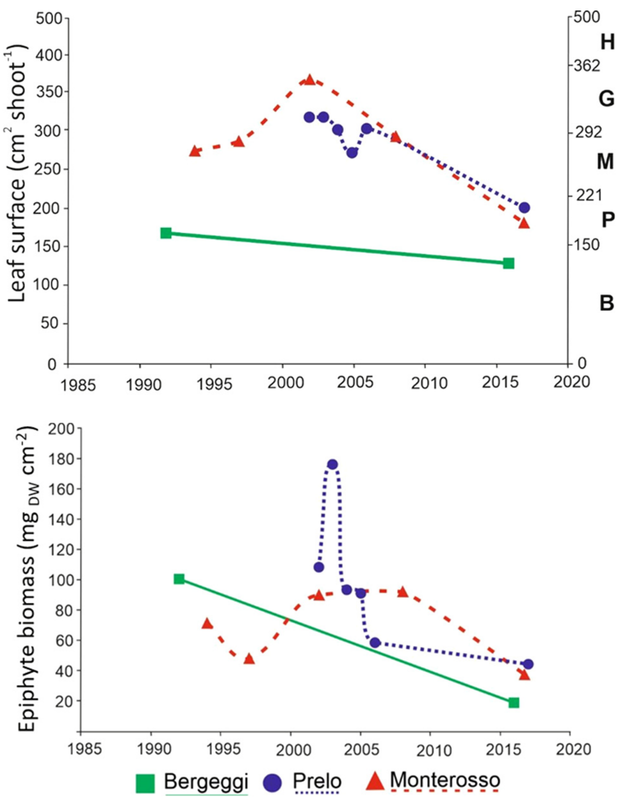


Fig. 2. – Trend over time of the indices at the individual (upper panel) and community (lower panel) level in the three meadows investigated. The y axis on the right side of the leaf surface graph reports reference values of the UNEP/MAP-RAC/SPA (2011-2015). Classification: B: bad, P: poor, M: moderate, G: good, and H: high.

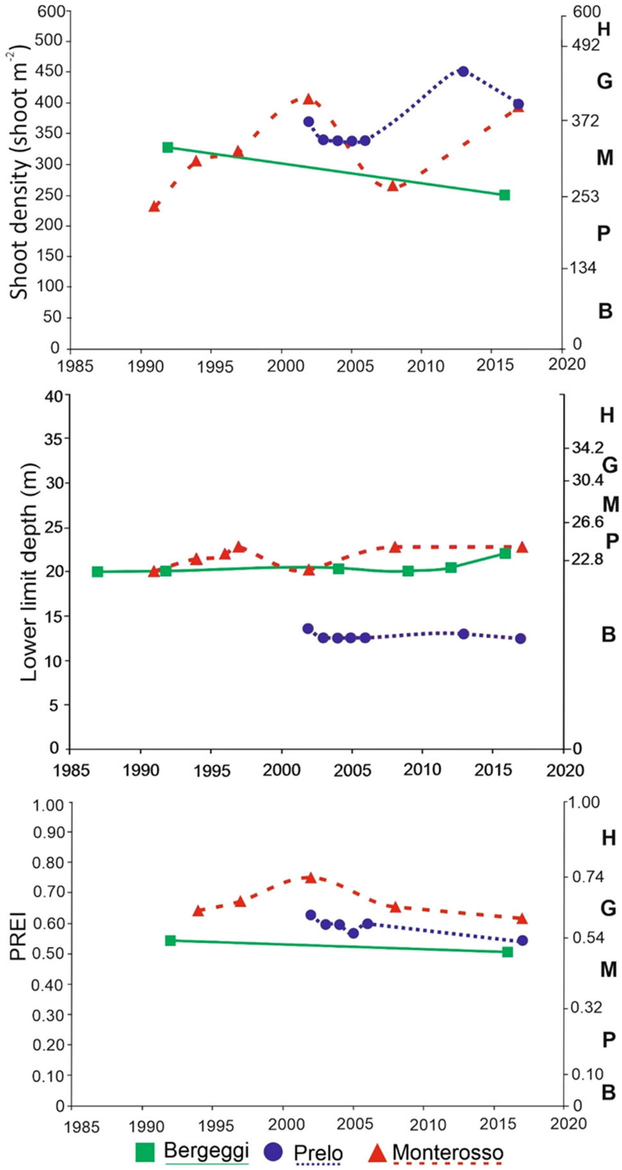


Fig. 3. – Trend over time of the indices at the population level (upper panel: shoot density; middle panel: lower limit depth) and of the multimetric index PREI (lower panel) in the three meadows investigated. The y axes on the right side of the shoot density and the lower limit depth graphs report reference values of the UNEP/MAP RAC/SPA (2011/2015) classification, whilst that of PREI from Gobert *et al*. (2009). Classification: B: bad, P: poor, M: moderate, G: good, and H: high.

At the seascape level, SI and PSI displayed highest temporal variability (Fig. 4). According to CI, Prelo meadow maintained a moderate ecological status, Monterosso showed a slight improvement passing from good to high status, whilst Bergeggi revealed a slight worsening of its status passing from good to moderate. SI evidenced a steady high ecological status in Prelo and Monterosso, but showed a high variability through time in Bergeggi, where it passed from high (1987), good (1992), and moderate (2004), to return again to a high ecological status in 2016. PSI showed different situations in the three mead-

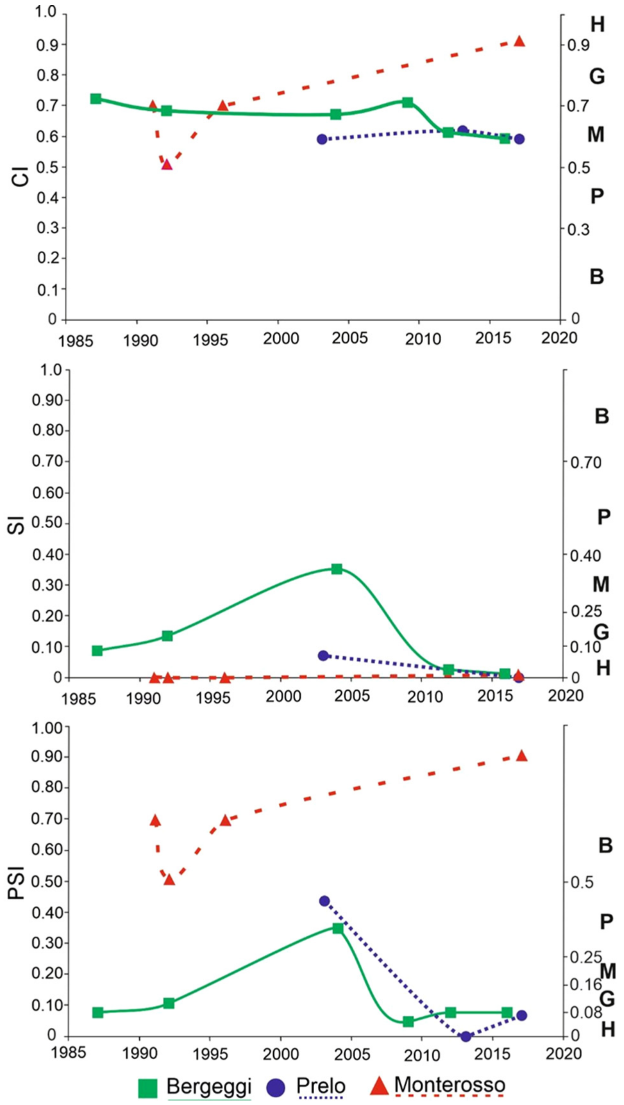


Fig. 4. – Trend over time of the indices at the seascape level (upper panel: CI; middle panel: SI; lower panel: PSI) in the three meadows investigated. The y axes on the right side of the CI, SI, and PSI report values of the classification by Montefalcone (2009): B: bad, P: poor, M: moderate, G: good, and H: high.

| | Leaf surface | Shoot density | Lower limit depth | Epiphyte biomass | CI | SI | PSI | PREI |
|---|---|---|---|---|---|---|---|---|
| Leaf surface | | | | | | | | |
| Shoot density | 0.309 (13) | | | | | | | |
| Lower limit depth | 0.316 (13) | 0.488 (15) | | | | | | |
| Epiphyte biomass | 0.563* (13) | 0.241 (13) | 0.421 (13) | | | | | |
| CI | -0.215 (5) | 0.072 (7) | 0.544 (12) | -0.290 (5) | | | | |
| SI | 0.204 (5) | 0.137 (6) | 0.071 (10) | -0.662 (5) | 0.049 (15) | | | |
| PSI | -0.413 (5) | 0.02 (7) | -0.246 (12) | 0.500 (5) | 0.248 (13) | 0.639** (11) | | |
| PREI | 0.756** (13) | 0.288 (13) | 0.314 (13) | 0.182 (13) | 0.650 (5) | 0.010 (5) | 0.316 (5) | |

Fig. 5. – Correlation matrix among the indices used in this study. *: $p < 0.05$; **: $p < 0.01$. Numbers in parentheses are numbers of cases.

ows. A clear increase of its values was observed in Prelo, which changed from poor to high status. The status of the Bergeggi meadow dropped from high in 1987 to moderate in 2004 and 2017 according to PSI. The Monterosso meadow showed little variation in PSI values over time, always remaining in a bad status.

The PREI (Fig. 3) showed little or no important change in any of the three meadows. Monterosso ecological status was always classified as good, Bergeggi as moderate, whilst Prelo decreased from good to moderate with time.

### *Consistency among indices*

A significant correlation was found between PREI and leaf surface ($p < 0.01$, n = 13), between PSI and SI ($p < 0.05$, n = 11), and between leaf surface and epiphyte biomass ($p < 0.05$, n = 13) (Fig. 5).

## DISCUSSION AND CONCLUSIONS

Most of the indices adopted were consistent in displaying a worsening in the ecological status of the Bergeggi meadow, even though the sampling area is today located within the Marine Protected Area "Isola di Bergeggi". Only SI showed a recovery trend from 2009, thanks to the reduction of the two substitutes *Caulerpa cylindracea* and *Cymodocea nodosa* (Montefalcone *et al.* 2007, Oprandi *et al.* 2014a, b). The Monterosso meadow showed different situations according to the index taken into account. All indices working at the individual and the community levels displayed a worsening trend in the last thirty years. The two indices at the population level, *i.e.*, shoot density and lower limit depth, were discordant: the former showed a recovery, the latter a steady trend. At seascape level only CI vas consistent in showing an increase in the ecological quality of this meadow, while PSI and SI did not show any variations in the ecological status trough the time. The Prelo meadow is affected by a high level of anthropogenic pressures (Lasagna *et al.* 2011). Only indices working at the individual levels showed consistently a worsening in its ecological status during the last fifteen years. On the contrary, the two indices working at the population level and one at the seascape level (CI) showed a steady condition, whilst SI and PSI increased thanks to the reduction of substitutes.

Our results showed that it is not possible to define univocally a trend in the health status of the three *P. oceanica* meadows investigated. The consistency among all the indices was often low (Fig. 6), either considering the same sampling period or among different sampling periods, making even more difficult to identify clear trends over the last thirty years. Indices working at the individual level and the community level often displayed a similar behavior. These indices can be viewed as early warning indicators (Giovannetti *et al.* 2010), responding quickly

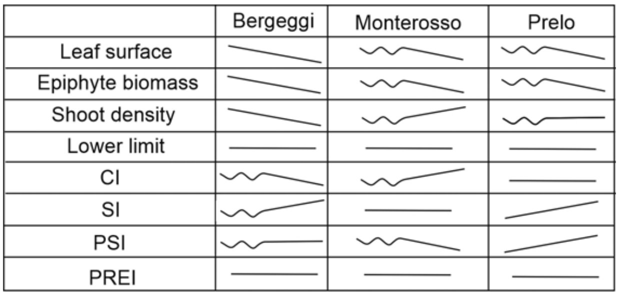


Fig. 6. – Graphical representation of trend over time of each index applied in the three meadows investigated.

to disturbances and to environmental change, and thus being good indicators in short time-scales. Longer times are indeed necessary for descriptors and indices working at the population and the seascape level to show change in the meadow status. Shoot density and lower limit, despite referring to the same ecological level (*i.e.*, population), did not show consistency, probably because the shoot density reacts faster than the lower limit. It should also need to consider that the bad lower limit status could be charged to the climate change occurred in the 21$^{th}$ century that caused a shift in sea level (Bonacorsi *et al.* 2013). Despite the lower limit stability, it should be considered that its limit values, identified by the Mediterranean classification (UNEP/MAP-RAC/SPA 2011-2015) have been recently criticized. In particular they have been considered not completely suitable for the Ligurian coast (Bianchi & Peirano 1995, Oprandi *et al.* 2019) since here *P. oceanica* meadows hardly exceed 30 m depth. This results in a uniform bad status of the analyzed meadows. Local variability in this descriptor could be hidden if the classification at the Mediterranean spatial scale is used. This notwithstanding, the slight increase in the lower limit depth observed in Bergeggi and Monterosso may be a positive signal of meadows recovery.

Shoot density was often consistent with CI. Some authors recognized CI as an index working at population level (Romero *et al.* 2007a), being based on the evaluation of living *P. oceanica* cover along underwater depth transects. It may happen that when the meadow shoots density is high, divers record higher cover values by living plants. Concerning the other seascape indices, *i.e.*, SI and PSI, they react to change only when substitutes are established and a shift in the *P. oceanica* meadow has occurred (Montefalcone 2009).

The multimetric PREI (Gobert *et al.* 2009) always showed a steady trend in all the three meadows, although the single metrics showed changes over time. This result can be due to different situations: i) all the composing metrics display the similar steady behavior; ii) the metrics are discordant, so that a change in each single metric can be mutually counterbalanced by the other metrics in the PREI algorithm, and this is what happened in Monterosso and Prelo meadows; iii) when the majority of the metrics are concordant, as it happened in the Bergeggi meadow, a steady trend of PREI may result when the change is limited. It can thus be concluded that PREI averages and dampens the variability of the single metrics. Integrating a number of metrics into a synthetic index is very useful and effective for monitoring purposes, but it may homogenize the meadow condition. This result pointed out that PREI could not be appropriate, if used alone, to evidence punctual changes in the meadow health. PREI was also significantly correlated only with leaf surface, being the leaf surface one of the metrics used to build this index. Also PSI and SI were highly correlated, considering that PSI contains SI in its formula. Finally, correlation between leaf surface and epiphyte biomass is reasonable as the more the leaf grows the more the epiphytes have space to colonize.

In conclusion, it must be pointed out the importance of long time-series, which are usually very scarce, fragmentary and inhomogeneous, since historical data were collected under different kind of studies and sometimes also with different methodologies. Comparison of data trough time showed inconsistency among most indices, making it difficult to identify a consistent dynamic of Ligurian meadows over time. As a plethora of existing indices, adopting a single index is not recommended to assess the ecological status of *P. oceanica* meadows. All the indices investigated in this paper work at different ecological levels, thus providing different information. This is why many multimetric indices, such as the PosWare (Buia *et al.* 2005, Silvestre *et al.* 2006), the PoMi (Romero *et al.* 2007a, b), the Valencian CS (Fernandez Torquemada *et al.* 2008), the BiPO (Lopez y Royo *et al.* 2010), and PREI have been recently developed to address requirements of the EU directives. However, our study evidenced that using PREI alone would not have evidenced changes at both spatial and temporal scales. For this reason, flanking a multimetric index with other indices, such as for instance the seascape indices here adopted, should be recommended to collect complementary information and to better understand specific drivers of change in seagrass ecosystem.

## REFERENCES

Andreasen JK, O'Neill RV, Noss R, Slosser NC 2001. Considerations for the development of a terrestrial index of ecological integrity. *Ecol Indic* 1(1): 21-35.

Bianchi CN, Morri C 2000. Marine biodiversity of the Mediterranean Sea: situation, problems and prospects for future research. *Mar Pollut Bull* 40(5): 367-376.

Bianchi CN, Peirano A 1995. Atlante delle fanerogame marine della Liguria: *Posidonia oceanica* e *Cymodocea nodosa*. Centro Ricerche Ambiente Marino, ENEA, La Spezia (Italy).

Bianchi CN, Ardizzone GD, Belluscio A, Colantoni P, Diviacco G, Morri C, Tunesi L 2004. Benthic cartography. *Biol Mar Medit* 10(Suppl): 347-370.

Bianchi CN, Parravicini V, Montefalcone M, Rovere A, Morri C 2012. The challenge of managing marine biodiversity: a practical toolkit for a cartographic, territorial approach. *Diversity* 4(4): 419- 452.

Bianchi CN, Azzola A, Bertolino M, Betti F, Bo M, Cattaneo-Vietti R, Cocito S, Montefalcone M, Morri C, Oprandi A, Peirano A, Bavestrello G 2019. Consequences of the marine climate and ecosystem shift of the 1980-90s on the Ligurian Sea biodiversity (NW Mediterranean). *Eur Zool J* 86(1): 458-487.

Bonacorsi M, Pergent Martini C, Breand N, Pergent G 2013. Is *Posidonia oceanica* regression a general feature in the Mediterranean Sea? *Medit. Mar Sci* 14(1): 193-203.

Borja A, Franco J, Pérez V 2000. A marine biotic index to establish the ecological quality of soft- bottom benthos within European estuarine and coastal environments. *Mar Pollut Bull* 40(12): 1100-1114.

Buia MC, Silvestre F, Iacono G, Tiberti L 2005. Identificazione delle biocenosi di maggior pregio ambientale al fine della classificazione della qualità delle acque costiere. Metodologie per il rilevamento e la classificazione dello stato di qualità ecologico e chimico delle acque, con particolare riferimento all'applicazione del decreto legislativo 152/99. APAT, Rome (Italy), 269-303.

Boudouresque CF, Mayot N, Pergent G 2006. The outstanding traits of the functioning of the *Posidonia oceanica* seagrass ecosystem. *Biol Mar Medit* 13(4): 109-113.

Burgos-Juan E, Montefalcone M, Ferrari M, Morri M, Bianchi CN 2016. A century of change in seagrass meadows of Liguria. *Biol Mar Medit* 23(1): 78-81.

Burgos E, Montefalcone M, Ferrari M, Paoli C, Vassallo P, Morri C, Bianchi CN 2017. Ecosystem functions and economic wealth: trajectories of change in seagrass meadows. *J Clean Prod* 168: 1108-1119.

Cairns J, Pratt JR 1993. A history of biological monitoring using benthic macroinvertebrates. *In* Rosenberg DM, Resh VH Eds, Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman & Hall, New York (USA): 10-27.

De Los Santos CB, Krause-Jensen D, Alcoverro T, Marbà N, Duarte CM, Van Katwijk MM, Pérez M, Romero J, Sánchez-Lizaso JL, Roca G, Jankowska E, Pérez-Lloréns JL, Fournier J, Montefalcone M, Pergent G, Ruiz JM, Cabaço S, Cook K, Wilkes RJ, Moy FE, Trayter GMR, Arañó XS, De Jong DJ, Fernández-Torquemada Y, Auby I, Vergara JJ, Santos R 2019. Recent trend reversal for declining European seagrass meadows. *Nat Comm* 10(1): 3356.

Fernandez Torquemada Y, Diaz Valdes M, Luna B, Colilla F, Luna B, Sanchez Lizaso JL, Ramos AA 2008. Descriptors from *Posidonia oceanica* (L.) Delile meadows in coastal waters of Valencia, Spain, in the context of the EU Water Framework Directive. *ICES J Mar Sci* 65: 1492-1497.

Giovannetti E, Montefalcone M, Morri C, Bianchi CN, Albertelli G 2010. Early warning response of *Posidonia oceanica* epiphyte community to environmental alterations (Ligurian Sea, NW Mediterranean). *Mar Pollut Bull* 60: 1021-1039.

Giraud G 1977. Essai de classement des herbiers de *Posidonia oceanica* (Linné) Delile. *Bot Mar* 20(8): 487-492.

Gobert S, Sartoretto S, Rico-Raimondino V, Andral B, Chery, A, Lejeune P, Boissery P 2009. Assessment of the ecological status of Mediterranean French coastal waters as required by the Water Framework Directive using the *Posidonia oceanica* Rapid Easy Index: PREI. *Mar Pollut Bull* 58(11): 1727-1733.

Hemminga MA, Duarte CM, 2000. Seagrass ecology. Cambridge University Press, Cambridge (UK).

Lasagna R, Montefalcone M, Bianchi CN, Morri C, Albertelli G. 2006a. Approccio macrostrutturale alla valutazione dello stato di salute di una prateria di *Posidonia oceanica*. *Biol Mar Medit* 13: 379-385.

Lasagna R, Montefalcone M, Bianchi CN, Morri C, Albertelli G. 2006b. Morphology of a *Posidonia oceanica* meadow under altered sedimentary budget. *Biol Mar Medit* 13: 245-249.

Lasagna R, Montefalcone M, Albertelli G, Corradi N, Ferrari M, Morri C, Bianchi CN 2011. Much damage for little advantage: field studies and morphodynamic modelling highlighted the environmental impact of an apparently small coastal mismanagement. *Estuar Coast Shelf Sci* 94: 255-262.

Leoni V, Pasqualini V, Pergent-Martini C, Vela A, Pergent G 2007. Physiological responses of *Posidonia oceanica* to experimental nutrient enrichment of the canopy water. *J Exp Mar Biol Ecol* 349(1): 73-83.

Lopez y Royo C, Casazza G, Pergent-Martini C, Pergent G, 2010. A biotic index using the seagrass *Posidonia oceanica* (BiPo), to evaluate ecological status of coastal waters. *Ecol Indic* 10: 380-389.

Montefalcone M 2009. Ecosystem health assessment using the Mediterranean seagrass *Posidonia oceanica*: a review. *Ecol Indic* 9(4): 595-604.

Montefalcone M, Giovannetti E, Lasagna R, Parravicini V, Morri C, Albertelli G 2007. Diachronic analysis of a *Posidonia oceanica* meadow in the marine protected area of Bergeggi. *Biol Mar Medit* 14: 82-83.

Montefalcone M, Parravicini V, Vacchi M, Albertelli G, Ferrari M, Morri C, Bianchi CN 2010. Human influence on seagrass habitat fragmentation in NW Mediterranean Sea. *Estuar Coast Shelf Sci* 86(2): 292-298.

Moreno D, Aguilera PA, Castro H 2001. Assessment of the conservation status of seagrass (*Posidonia oceanica*) meadows: implications for monitoring strategy and the decision-making process. *Biol Conserv* 102(3): 325-332.

Oprandi A, Montefalcone M, Ferrari M, Morri C, Bianchi CN 2014a. Invasion of the alien green alga *Caulerpa racemosa* and phase shift within the *Posidonia oceanica* seagrass meadow of Bergeggi. *Biol Mar Medit* 21: 75-78.

Oprandi A, Montefalcone M, Vacchi M, Coppo S, Diviacco G, Morri C, Ferrari M, Bianchi CN 2014b. Combining modelling and historical data to define the status of *Posidonia oceanica* meadows. *In* Langar H, Bouafif C, Ouerghi A Eds, Proceedings of the 5th Mediterranean Symposium on Marine Vegetation. UNEP/MAP-RAC/SPA, Tunis (Tunisia): 119-124.

Oprandi A, Bianchi CN, Karayali O, Morri C, Rigo I, Montefalcone M 2019. Comparison of descriptors at different levels of ecological complexity to define the health status of *Posidonia oceanica* in Liguria. *Biol Mar Medit* (in press).

Peirano A, Bianchi CN 1997. Decline of the seagrass *Posidonia oceanica* in response to environmental disturbance: a simulation-like approach off Liguria (NW Mediterranean Sea). *In* Hawkins LE, Hutchinson S Eds, The Response of Marine Organisms to their Environments. Southampton University Press, Southampton (UK): 87-95.

Peirano A, Savini D, Bianchi CN, Farina G 1999. Long-term monitoring on the *Posidonia oceanica* meadow of Monterosso al Mare (NW Mediterranean): first results. *Proc Ital Ass Oceanol Limnol* 13(1): 129-135.

Peirano A, Bianchi CN, Savini D, Farina G 2001. A long-term monitoring activity on a *Posidonia oceanica* meadow at Monterosso al Mare (Ligurian Sea). *Arch Oceanogr Limnol* 22: 145-148.

Peirano A, Damasso V, Montefalcone M, Morri C, Bianchi CN 2005. Effects of climate, invasive species and anthropogenic impacts on the growth of the seagrass *Posidonia oceanica* (L.) Delile in Liguria (NW Mediterranean Sea). *Mar Pollut Bull* 50(8): 817-822.

Peirano A, Cocito S, Banfi V, Cupido R, Damasso V, Farina G, Lombardi C, Mauro R, Morri C, Roncarolo I, Saldaña S, Savini D, Sgorbini S, Silvestri C, Stoppelli N, Torricelli L, Bianchi CN 2011. Phenology of the Mediterranean seagrass *Posidonia oceanica* (L.) Delile: medium and long-term cycles and climate inferences. *Aquat Bot* 94: 77-92.

Pergent G, Pergent-Martini C, Boudouresque CF 1995. Utilisation de l'herbier à *Posidonia oceanica* comme indicateur biologique de la qualité du milieu littoral en Méditerranée : état des connaissances. *Mésogée* 54: 3-27.

Rigo I, Montefalcone M, Morri C, Bianchi CN, Oprandi A, Vassallo P, Paoli C 2019. Use of ecological indices to assess the health status of *Posidonia oceanica* meadows in Eastern Liguria. *In* Gargiulo C, Zoppi C Eds, Planning, Nature and Ecosystem Services. FedOAPress, Naples (Italy): 271-280.

Romero J, Martínez-Crego B, Alcoverro T, Pérez M 2007a. A multivariate index based on the seagrass *Posidonia oceanica* (POMI) to assess ecological status of coastal waters under the water framework directive (WFD). *Mar Pollut Bull* 55(1-6): 196-204.

Romero J, Begona MC, Alcoverro T, Perez M 2007b. Corrigendum to ''A multivariate index based on the seagrass *Posidonia oceanica* (POMI) to assess ecological status of coastal waters under the framework directive (WFD)". *Mar Pollut Bull* 54(5): 631.

Sandulli R, Bianchi CN, Cocito S, Morgigni M, Peirano A, Sgorbini S, Silvestri C, Morri C 1994. Status of some *Posidonia oceanica* meadows on the Ligurian coast influenced by the "Haven" oil spill. *Proc Ital Ass Oceanol Limnol* 10: 277-286.

Short FT, Wyllie-Echeverria S 1996. Foundation for Environmental Conservation Natural and human-induced disturbance of seagrasses. *Environ Conserv* 23(1): 17-27.

Silvestre F, Iacono G, Tiberti L, Buia CM 2006. *Posidonia oceanica* warehousing. *Biol Mar Medit* 13: 277-281.

UNEP/MAP-RAC/SPA 2011-2015. Draft guidelines for the standardization of mapping and monitoring methods of marine Magnoliophyta in the Mediterranean. Tenth Meeting of Focal Points for SPAs. Marseilles, France, 17-20 May 2011, UNEP(DEPI)/MED WG 359/9, Tunis (Tunisia).

Vassallo P, Paoli C, Rovere A, Montefalcone M, Bianchi CN 2013. The value of the seagrass*Posidonia oceanica*: a natural capital assessment. *Mar Pollut Bull* 75: 157-167.

Vetere M, Pessani D, Gruppo Biologia Marina SSP 1989. Morfologia e fruttificazione della prateria di *Posidonia oceanica* di Bergeggi (Liguria). *Oebalia* 15(1) n.s.: 351-354.