USE OF ECOLOGICAL INDICES TO ASSESS THE HEALTH STATUS OF POSIDONIA OCEANICA MEADOWS IN EASTERN LIGURIA

INFLUENCE OF ECOLOGICAL STATUS ON NATURAL CAPITAL

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ABSTRACT

Posidonia oceanica (L.) Delile is an endemic Mediterranean seagrass and a key species of coastal marine ecosystems listed among the priority habitats in the European Directive 92/43 / EEC. P. oceanica is a good biological indicator to define the quality of coastal marine ecosystem, because its high sensitivity to environmental conditions changes. The aim of this study is 1) to investigate if the health status of some P.oceanica meadows located in different sites influences the ability of the system to stock natural capital and 2) to quantify changes in natural capital value in both biophysical and monetary terms. Health status of five different meadows along Liguria coast was evaluated by means of different indicators such as: Conservation Index, Substitution Index, Phase Shift Index and Posidonia Rapid Easy Index. Natural capital has been assessed through emergy analysis, a biophysical approach able to account the resources directly and indirectly used up to reach a certain product or mantain a system. Results showed that healthier meadows are located in marine protected areas or far from main sources of anthropic pressures and that higher values of natural capital is stored in healthy seagrass.

KEYWORDS
Posidonia Oceanica; East of Liguria; Ecological Indices; Natural Capital

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1 INTRODUCTION

In the Mediterranean Sea more than two thirds of the coastline is now urbanized. The huge edification causes anthropogenic pressures that generate changes in coastal ecosystems and that could represent a serious threat for natural environment (Montefalcone et al., 2009).
Good coastal management practices, even on a local scale, may lead to restoration of natural conditions and, in turn, increase resistance and resilience of marine habitats. The Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) are the European umbrella regulations for water systems (Van Hoey et al., 2010). In this context, it is a challenge for the scientific community to translate directives principles into operational approaches and to make people aware about the consequences of human activities on marine habitats. Specifically, the main goal of the MSFD is to achieve Good Environmental Status (GES) of EU marine waters by 2020 with the aiming at a sustainable exploitation of marine resources, ensuring their continuity for future generations. Costanza and Daly (1992) presented the concept of natural capital that includes land, air, water, sea and ecosystems therein. The term ecosystem goods and services (ES hereinafter) refers, instead, to the benefits that populations derive, directly or indirectly, from ecosystem functions (Costanza et al., 1997; MEA, 2005). A tight link exists between ES provision and natural capital (NC hereinafter), since only if NC is preserved intact the supply of services in the future and at the current level can be guaranteed (De Groot et al., 2012). The goal is then to achieve GES so that the provision of ES to human population is maintained in the long run. In the last decades the link between ecosystems and human economy became manifest (Vassallo at al., 2017). As a consequence a growing interest for the assessment of ecosystems'value, particularly in ES theory. Efforts were then addressed to the monetisation of ecosystems but also to employ their evaluation to 1) raise general public awareness and to 2) address decisional processes by means of new instruments for policy makers (Beaumont et al., 2008; Brown et al., 2001; Costanza et al., 1997; Odum, 2000). In this context, among marine habitats, seagrasses are considered of main concern since they are able to provide key ES. Moreover to assess the environmental health status, European Community requires use of biological indicators, which allow an ecological characterization of the system, together with chemical-physical analysis. In this context, Posidonia oceanica (L.) Delile is recognised as a bioindicator to study environmental quality (Ferrat et al., 2003). The aim of this study is then to evaluate how the conservation status of meadows affects NC value. To this end, an estimate of P.oceanica health state was carried out in five P.oceanica meadows along the eastern Ligurian coast.
We calculated a set of ecological descriptors and indices able to assess current state of meadows. The Conservation Index (CI), and Phase Shift Index (PSI) were calculated to get

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information about disturbance events and potential recovery ability, evaluating the presence of dead matte and the appearance of substitutes (Cymodocea nodosa and Caulerpa spp.). Besides, Posidonia Rapid Easy Index (PREI), an integrated index composed by five different descriptors, was calculated to determine the ecological status of water as required by the WFD. NC value was calculated by means of emergy analysis, following Vassallo et al. (2017). Emergy is a methodology able to quantify solar energy directly and indirectly necessary to generate and maintain a system and its functioning. It is thus a donor-side estimate of the value of a system measured as production cost in terms of the resources investment.

2 METHODOLOGY

Study area is located along the eastern Ligurian coast, between cities of Genoa and La Spezia. Analysed meadows are located in Camogli, Punta Pedale, Prelo - San Michele di Pagana, Framura and Monterosso (Fig. 1).

Fig. 1 Study sites along East Liguria

The data gathering was carried out by scuba diving (two transects perpendicular to coast in each site) in the period between May and October 2017. From the lower limit of each meadow, every 10 m, we recorded data about depth and about the percentage of surface covered by live Posidonia oceanica, dead matte, sand, rock and any substitutes (Cymodocea nodosa, Caulerpa prolifera, Caulerpa taxifolia and Caulerpa cylindracea). Contemporarly information about depth and type of the lower limit were collected. Furthermore, leaf density was recorded by means of a 40 x 40 cm2 quadrat where the number of shoots was counted (9 replications at 15 m, following the ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) protocol (www.isprambiente.gov.it/it). Finally, in each transect, 18 orthotropic (vertical) rhizomes were taken in three not contiguous zones. Laboratory activities consisted

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of phenological analyses, lepidocronological analyses and study of associated foliar epiphytes. Phenological analysis was carried out using standardized method (Buia et al., 2004; Giraud, 1977). On each harvested shoot, we obtained leaf number (n_ leaves/shoot), leaf width (cm) and leaf length (cm), necessary to calculate the leaf area for shoot (cm2 shoot-1). Leaf biomass, as grams of dry weight, was estimated after incubation at 70 °C for 48 h. Lepidocronological analysis is a retrospective technique that consists of studying leaves life cycles of seagrass P. oceanica, that allows to define the age of meadows, through the thickness of slivers, and the environmental variability within which it develops. All data collected from the lepidocronological analysis were then examined to obtain the biomass over year, both in terms of rhizome lengthening and leaf production. Epiphytic biomass was taken from each adult and intermediate leaf using the grating method, dried in a stove and weighted separately. Foliar epiphytes are early warning indicators capable of responding to changes in the water column (Giovannetti et al., 2010): an increase in their quantity is linked to a decrease in environmental quality. Data collected were used to calculate P. oceanica descriptors at different levels: individual, population and community. Descriptors were used to obtain ecological indices, such as: CI (Moreno et al., 2001) which compares the cover of alive P. oceanica to dead matte; SI (Montefalcone et al., 2007) which identifies substitutes; PSI (Montefalcone et al., 2009) that measure level of ecosystem change due to regression; PREI (Gobert et al., 2009) that calculates the ecological quality ratio which includes EQR' expressed in the following formula:

$$\boldsymbol{EQR'} = \frac{\left(\boldsymbol{Ndensity} + \boldsymbol{Nleafsurfaceofshoot} + \boldsymbol{N}\dfrac{\boldsymbol{epiphyticbiomass}}{\boldsymbol{leafbiomass}} + \boldsymbol{Nlowerlimit}\right)}{\boldsymbol{3,5}}$$

Indices estimating the health status of meadows are reported in Tab. 1 together with their calculation formulae and reference values. Calculated values of these indices have been then classified in accord with five quality classes (UNEP-MAP-RAC/SPA, 2015) providing information on the health status of the system. The status is classified as: high, good, moderate, poor, bad (Directive 200/60/EC). Furthermore, in order to get the value of meadow's natural capital, emergy analysis was applied. This approach is able to to assess the effort made by natural system (measured as resources, space and time invested) to produce biomass stock. Emergy analysis is a quantitative analysis that standardizes the amount of different resources types in a common unit of measure: solar energy (Brown & Herendeen, 1996), so its units is solar emergy Joules (sej). If the emergy flow required for a process is higher, the amount of solar energy it "consumes" and the environmental cost to maintain it are great.In this work emergy analysis was applied according to the methodology described by Vassallo et al. (2017).

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Total emergy value of natural capital of P.oceanica meadows was finally converted to monetary units by using the emergy-to-money ratio.

	FORMULA	REFERENCE VALUES				
		High	Good	Moderate	Poor	Bad
CI	$CI = P/(P + D)$	≥0.9	0.7-0.9	0.5-0.7	0.3-0.5	<0.3
SI	$SI = S/(P + S)$	<0.1	0.1-0.25	0.25-0.4	0.4-0.7	≥0.7
PSI	PSI = {[(1-CI) · 1] + (SICn · 2) + (SICp · 3) + (SICt · 4) + (SICr · 5)}/6	<0.08	0.08-0.16	0.16-0.25	0.25-0.5	≥0.5
PREI	$EQR = (EQR' + 0{,}11)/(1 + 0{,}10)$	1-0.775	0.774-0.550	0.549-0.325	0.324-0.100	<0.100-0

Tab. 1 Ecological indices formulas and UNEP-MAP-RAC/SPA reference classes

At the end, it was assessed how much of NC been stored in the below-ground component rather than in the above-ground to underline which component holds a greater part of the capital. The whole information flow stemming from field and laboratory activities and leading to data analyses is summarized in Fig. 2.

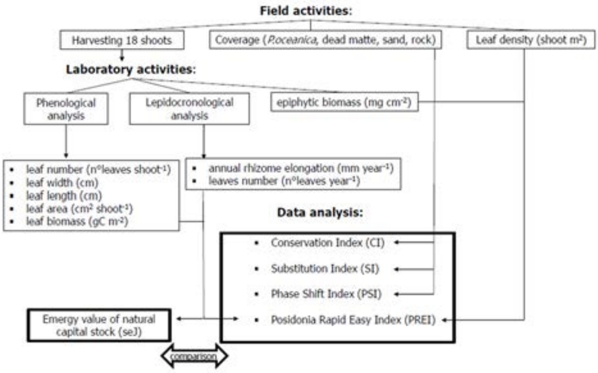

Fig. 2 The phases for the development of the study

3 RESULTS AND DISCUSSIONS

Tab. 2 shows indices and natural capital values obtained for the five meadows and analysis according to identified quality classes. All sites reported a good state of health as no one falls into a status considered "poor" or "bad"; specifically CI denoted a particularly high ecological status for sites of Framura and Monterosso, where, according to the classification in literature (Montefalcone et al., 2009), there is a state of conservation ranging from good to very good. "Good" values were also recorded in Camogli. Only Punta Pedale and Prelo-S.Michele meadows reported a "moderate" conservation status. All investigated seagrasses had PSI values lower than 0.08 that describe an "high" ecological status according to the classification

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reported in the literature (Montefalcone et al., 2009). Therefore PSI seems to be more effective in recording differences in meadows health status and to be then less descriptive. Finally, PREI had highest values at Framura: that is the only site recording a "high" ecological status according to the classification of Gobert et al. (2009). "Good" values have been identified at Camogli and Monterosso; instead lower quality of P.oceanica meadows has been reported for stations of Punta Pedale and Prelo-San Michele, where the ecological status is "moderate". The lower limit is regressive in all stations, exception of Framura, where the excellent state of the lower limit is probably linked to the greater distance from sources of anthropic impact. This is also the case for Camogli and Monterosso transects, located within the protected marine areas of Portofino and Cinque Terre, where many human activities, such as anchorages, diving and fishing, are forbidden. Also the analysis of variance (ANOVA) on epiphytic biomass values (mg ps cm-2) showed significant differences between sites ($p < 0.01$) placed within controlled or urbanized areas. The Tukey test showed that epiphytes were significantly greater at Punta Pedale where transect 1 reported an average biomass of 0.44 mg cm-2 and transect 2 showed 0.69 mg cm-2, instead of all the other sites with average values around 0.20 mg cm-2. Natural capital resulted positively correlated ($n=10$, $p=0.9$) with better ecological status and the highest natural capital value was found in transect T2 of Framura. On the contrary, results identified Punta Pedale and Prelo-S.Michele as meadows with lowest natural capital values. Moreover, it turned out that 65% of natural capital calculated is represented by the below underground part of seagrasses and only 35% instead by the foliar component. Rhizomes tend to grow more slowly, storing biomass for a longer period of time. Therefore considering biomass data and age of rhizomes for emergy evaluation leads to increase capital value.

		CI		PSI		PREI		NATURAL CAPITAL (sej m-2)
CAMOGLI	T1	0.87	good	0.02	high	0.66	good	2.31E+12
	T2	0.83	good	0.03	high	0.67	good	2.96E+12
PUNTA PEDALE	T1	0.70	moderate	0.05	high	0.52	moderate	1.33E+12
	T2	0.88	good	0.02	high	0.50	moderate	2.85E+12
PRELO-S.MICHELE	T1	0.59	moderate	0.07	high	0.54	moderate	3.20E+12
	T2	0.54	moderate	0.08	high	0.53	moderate	1.81E+12
FRAMURA	T1	0.88	good	0.02	high	0.72	good	3.36E+12
	T2	0.99	high	0.00	high	0.78	high	3.97E+12
MONTEROSSO	T1	0.99	high	0.01	high	0.62	good	2.76E+12
	T2	0.89	good	0.02	high	0.62	good	2.75E+12

Tab. 2 Values obtained from calculation of indices and natural capital

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3.1 CONCLUSION

Landscape descriptors (CI, PSI) and the PREI index values were consistent reporting better health state for Framura, Monterosso and Camogli meadows, and worse for Punta Pedale and Prelo-S. Michele. This is probably due to the greater anthropic influence on these meadows, due to coastal urbanization and tourist pressure during the summer period and to the absence of protection measures. In particular, bay of Prelo, at the beginning of the 20th century, was subjected to the presence of a system of catenaries for mooring small pleasure boats, which still forms an underwater network on the seabed colonized by P. oceanica (Montefalcone et al., 2006). The status of Prelo-S.Michele and Punta Pedale meadows is also confirmed at community level by the biomass epiphytic measurement, which shows above-average values. As leaf epiphytes are early warning indicators able to react more quickly than other descriptors to changes in water column (Giovannetti et al., 2010), it is assumed that an increase of their quantity is linked to a decrease of environmental quality. It could be due to pollutants carried by currents from the nearby river and by discharges of many boats that stop in bays during the summer period. Using CI as a synthetic measure of the conservation status of P.oceanica is effective for investigated seagrasses, where observed areas characterized by dead matte represent mainly human-induced impacts (Peirano & Bianchi, 1997). Natural capital evaluation, used as tool to summarize system's complexity, have reported higher values for meadows of Framura, Camogli and Monterosso and lower values for bays of Punta Pedale and Prelo San Michele. So the ability of ecosystems to store natural capital and in turn to provide ecosystem services resulted influenced by meadows ecological status confirming how human disturbance on ecosystems may hamper the functioning of the system and thus reducing the benefits humans may obtain in terms of ecosystem services provisioning.

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AUTHOR'S PROFILE

Ilaria Rigo, Bachelor's degree in Science and Tecnology for the Environment and Territory at Milan Bicocca University (Italy), during February 2016. Graduated in Marine Science at Genoa University for master in September 2018, I am now a phD student in Marine Ecology at the Department of the Earth, Environment and Life Science (DiSTAV) at the University of Genoa, dealing with evaluation of natural capital and ecosystem services provided along the Ligurian coast. Doctorate aim is to identify distribution of ecosystem services, quantify and find any possible external forcings.

Monica Montefalcone is a researcher in Ecology (BIO07) at the Department of the Earth, Environment and Life Science (DiSTAV) at the University of Genoa (Italy) and a professor of Tropical Marine Ecology, of Scientific Diving and of Managing Marine Biodiversity. She started to study seagrasses in 1999, she took her PhD in 2007 on Posidonia oceanica ecology, and today she is working in the field of applied research on coastal marine environment, which includes monitoring, characterization, cartography, biodiversity assessment and evaluation of ecological status and changes over time of coastal habitats, such as seagrasses, rocky reefs and coralligenous, submerged caves, and coral reefs. She is member of several scientific societies, and recently she has been working as a scientific consultant of the RAC-SPA (Regional Activity Centre for Specially Protected Areas).

Carla Morri teaches Ecology and Seascape Ecology at the University of Genoa, School of Science. Has research experience in taxonomy, faunistics and ecology of hydrozoans and scleractinian corals. Synecology of the marine benthos. SCUBA survey methods. Semiotics and diagnostics of underwater seascape. Most familiar ecosystems are submarine caves, rocky reefs, coral reefs, seagrass meadows, lagoons and shallow-water hydrothermal vents. Academic Editor of Mediterranean Marine Sciences and Diversity. More than 300 scientific papers published, including four books and several book chapters. Her papers are frequently cited by other authors, allowing for an H-index of 47 (Google Scholar). Her research touched at various aspects of the ecology of coastal marine and transitional environments, focusing on three main research topics, strictly interconnected: ecology of marine Cnidaria; biodiversity of the marine benthos; biological zonation along ecological gradients.

Carlo Nike Bianchi is Professor of Ecology at the University of Genoa, Faculty of Sciences. Has research experience on biodiversity, bionomics, mapping and biogeography of the marine coastal environment. Special topics include benthic community structure, gradient analysis, bioconstruction,

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Alice Oprandi is a PhD student in Marine Ecology at the Department of the Earth, Environment and Life Science (DiSTAV) at the University of Genoa (Italy) under the supervision of Carlo Nike Bianchi and Monica Montefalcone. She works on coastal marine ecosystems, in particular, regarding the change and conservation of P. oceanica meadows, coralligenous reef and tropical coral reefs. She got the bachelor degree in Environmental Science (specialization management and conservation of the marine environment) in 2010 and the master degree in Marine Science at the University of Genoa during June 2013 with an experimental thesis titled "Status of Posidonia oceanica meadows between Capo Vado and Capo Noli: diachronic analysis and influence of hydrodynamic constrains through the application of a predictive model".

Paolo Vassallo got a degree in Environmental Science (specialization in Marine Environment) at the University of Genoa (Italy) in 2002, discussing a thesis about "analysis of the energetic fluxes in benthic marine environments by means of holistic indicators". During 2003 he signed a three months contract with Department of Physics of the University of Genoa and he had a grant in 'Applied Ecology' at the University of Genoa for the application of Exergy and Ascendency to benthic marine environments. From 2004 and 2007 he was PhD student in Environmental science at the University of Genoa while from 2007 to 2009 he signed a two year post-doc grant at the University of Genoa for the analysis of sustainability of coastal zone. From 2009 to 2012 I collaborated with Giardini Botanici Hanbury, to carry out the SUMFLOWER LIFE project. In 2010 he held the chair of "Environmental evaluation" at the University of Genoa. Since June 2013 he is assistant professor in ecology at the the Department for the study of Land, Environment and Health at the University of Genoa where he held the chairs of "Coastal Zone Management" and "Evaluation and management of the Environment". The main research interests are: 1) ecosystem health assessment by means of whole system analyses (e.g. network and exergy analysis); 2) sustainability evaluation of products, services and territories (e.g. ecological footprint, emergy analysis); 3) ecosystem functions and services evaluation; 4) ecosystem modelling and spatial ecology. He is author of more than 40 international scientific publications and participated to more than 40 international scientific conferences.

Chiara Paoli got a five years degree in Environmental Science at the University of Genoa (Italy) during April 2005, with an experimental thesis about "environmental sustainability analysis of water cycle" of Genova province. The study was aimed at identifying a methodology for administrations and managers to adress the choice of sustainable management techniques of water cycle.During 2006 she realised a research about sustainable management of marinas and she collaborated with the Univesity of Genova as external expert. In 2010 she had a PhD student in Environmental sciences at the University of Genova with a study about the development of an integrated methodology for coastal zone sustainability and ecosystem services valuation. From 2010 to 2012 she signed a two year post-doc grant at the University of Genova for the analysis of sustainability of coastal zone. During 2013 she collaborated with Giardini Botanici Hanbury, a regional protected area, to carry out a European project (SUMFLOWER) founded under the LIFE founding scheme. At present she is a post-doc at the University of Genova and her main topic are coastal zone sustainability and management, marine protected areas management, natural capital and ecosystem services biophysical and economic evaluation, ecological economics in general, system analyses applied to sustainability, system ecology.

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