The scientific literature on *Posidonia oceanica* meadows and related ecosystem services

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Abstract. *Posidonia oceanica* is an endemic seagrass of the Mediterranean Sea. It has recently raised particular interest for its key role in enhancing climate change mitigation. Actually, *P. oceanica* is one of the most important marine-coastal ecosystems able to sequester and store considerable quantities of carbon, thus being recognized as a "Coastal Blue Carbon System". However, due to their coastal position, *P. oceanica* meadows are often subjected to intense human activities that affect their distribution, health and ecological condition, and the capability of generating ecosystem services, including carbon sequestration and storage. Therefore, it is important to identify strategies to protect *P. oceanica* meadows, also increasing the awareness on the value of the benefits they generate for human well-being. In this context, environmental accounting tools are much needed to assess the biophysical and economic value of the ecosystem services provided by *P. oceanica* meadows. In this study we explored the scientific literature on *P. oceanica,* also investigating the relationships between "*Posidonia oceanica*" and "Ecosystem Services". The VOSviewer software was used to create maps based on network data of scientific publications using specific keywords to explore the co-occurrence of different terms connected to the considered research topics. Results showed that the most common keywords in scientific publications on *P. oceanica* were "Biodiversity", "Environmental monitoring", and "Conservation". The analysis on "*Posidonia oceanica*" and "Ecosystem Services" showed some gaps in terms of standardized approaches for the ecosystem accounting of *P. oceanica* meadows. Therefore, further efforts are needed to assess the value of ecosystem services generated by *P. oceanica* through standardized accounting

frameworks making visible its contribution to human well-being at different levels of decision-making processes.

Keywords: Seagrass; Marine ecology; Blue Carbon; Climate Change Mitigation; SEEA-EA; VOSviewer

1. Introduction

Posidonia oceanica is an endemic and abundant seagrass of the Mediterranean Sea, where it forms extensive meadows from the surface down to 40 m depth (Boudouresque et al., 2006). It is a plant (with roots, stems, leaves, flowers and fruits) that during its evolutionary history has returned from the land to the sea (Cantasano, 2023). Meadows occur in coastal areas, where they are often subjected to intense human activities that inevitably affect their distribution, either directly by physical damages (Meinesz et al., 1991) or indirectly through the impact on the quality of waters and sediments (Duarte, 2002). This has led to a 34% regression of meadows globally (Telesca et al., 2015) that, in turn, implies the loss of natural capital stocks, ecosystem services flows, and thus also human benefits.

P. oceanica meadows generate a wide set of ecosystem services (MA, 2005; Hein et al., 2006). Primary production (and related carbon fixation) of *P. oceanica* is similar or greater than other highly productive environments, both terrestrial (e.g., temperate or tropical forests) and marine (e.g., upwelling areas, mangroves, coral reefs) (Fergusson et al., 1980). Sediment retention and hydrodynamics attenuation lead to an effective protection from littoral erosion and reduce the hydrodynamic forces (from 10% to 75% under the leaves) of waves and bottom currents. In particular, the meadow damps the swell forming an obstacle to the movement of sediments on the bottom (Brunel and Sabatier, 2009) and playing an active role in the sedimentary balance of the beach both supplying biogenic sand and trapping sediments in eventual offshore migrations (Basterretxea et al., 2004). Moreover, the presence of a *P. oceanica* meadow in the coastal zone produces deposits of dead leaves on the shore, called banquettes, able to reduce the wave effect on the shoreline (Rotini et al., 2020). *P. oceanica* meadows also represent a biodiversity hotspot due to the presence of a highly diversified community of both sessile species, thanks to the leaves and rhizomes that increase their available area, and mobile ones, including several species of commercial interest, to which meadows ensure a nursery role providing them shelter. For this high concentration of biodiversity, *P. oceanica* meadows also represent a source of attraction for tourists and recreational activities, such as SCUBA diving.

P. oceanica has recently raised particular interest especially for its key role in carbon sequestration and storage, mitigating climate change and contributing to the achievement of European objectives of containing and reducing greenhouse gas emissions into the atmosphere (Pergent-Martini et al., 2021). Actually, *P. oceanica* is one of the so-called "Coastal Blue Carbon Systems" (together with salt marshes, mangroves and other species of seagrass), the marine-coastal ecosystems able to sequester and store considerable quantities of carbon. Posidonia meadows are about ten times more efficient than terrestrial forests in sequestering and storing carbon, thanks to some distinctive characteristics typical of this species (Fourqurean et al., 2012). In particular, in addition to its photosynthetic activity and related carbon sequestration, *P. oceanica* is able to store large amounts of carbon within the "matte", a bioconstruction formed by the complex interweaving of rhizomes and roots that can trap a large amount of sediment in which organic carbon can be immobilized for long periods of time. In this poor-oxygen environment, organic carbon is very stable, resulting in a storage even for millennia (Monnier et al, 2022).

Overall, the provisioning of these important ecosystem services depends on the health of natural capital stocks of *P. oceanica*, that for such exposed environments to human activities because of their coastal distribution, is highly related to conservation plans. Actually, since the 90s, *P. oceanica* is included in the Red List of Mediterranean marine threatened species (Boudouresque et al., 1990) with a decreasing population trend (IUCN, 2016) and its meadows are defined as priority natural habitats by the Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (EEC, 43/1992).

Nevertheless, in recent decades, the increased urbanization in coastal areas are putting a strain on the resistance and resilience of this ecosystem, causing physical damages to the meadows and their consequent regression at an alarming rate.

To contrast this negative trend, the increasing ecological awareness of scientists and policy makers on the importance of having healthy *P. oceanica* meadows also for human well-being has encouraged the adoption of ecosystem accounting framework to assess the value of natural capital stocks and ecosystem services flows (Vassallo et al, 2013, 2017; Buonocore et al., 2021; Catucci et al., 2022) Among these frameworks, the adoption of international standards for seagrass accounting, such as the System of Environmental-Economic Accounting-Ecosystem Accounting (SEEA-EA), is recommended (Edens et al., 2022). The latter constitutes an integrated statistical framework for organizing biophysical data, measuring ecosystem services, tracking changes in ecosystem assets and linking this information to economic and other human activity (United Nations et al., 2021).

Given this premise, the present study aims at exploring the global scientific literature on *P. oceanica* meadows and related ecosystem services. In particular, a bibliometric network analysis was conducted to create maps based on network data of scientific publications exploring the main topics connected to the research on *P. oceanica* meadows and ecosystem services and also research gaps.

2. Matherial and methods

2.1 Bibliometric network analysis

Bibliometric network analysis was used to review the scientific literature on the topic (i) "*Posidonia oceanica",* and (ii) "*Posidonia oceanica"* and "Ecosystem services".

Bibliometric network analysis is a powerful tool to quantitatively analyse trends and patterns of large amounts of data such as academic literature (Otte and Rousseau, 2002). This approach combines bibliometrics and social network analysis (SNA). Bibliometrics uses statistics and quantitative analysis to investigate knowledge structure and development of research fields (Reuters, 2008; Zou et al., 2018). SNA is a methodology useful to study social relations and has been applied in many fields for investigating social structures (Scott, 2007). Applied to academic literature, bibliometric network analysis allows for the quantitative investigation of network structures based on the relationships among researchers, organizations, countries, and keywords dealing with the investigated topic (Chen et al., 2016).

In this study, the bibliometric analysis was performed using VOSviewer (version 1.6.17), a software allowing the creation, visualization, and interpretation of maps based on bibliometric network data displaying clusters that support the classification of output results. The main technical terms used by the software are explained in Table 1.

Table 1. Terminology used by VOSviewer software (Van Eck and Waltman, 2018).

Terms	Description
Items	Objects of interest (e.g., publications, researchers, keywords, authors).
Link	Connection or relation between two items (e.g., co-occurrence of keywords).
Link strenght	Attribute of each link, expressed by a positive numerical value. In the case of co-authorship links, the higher the value, the higher the number of publications the two researchers have co-authored.
Network	Set of items connected by their links.
Cluster	Sets of items included in a map. One item can belong only to one cluster.
Weight attribute: number of links	The number of links of an item with other items.
Weight attribute: total link strenght	The cumulative strength of the links of an item with other items.

VOSviewer can generate different types of analysis (Table 2). In this study, we performed co-occurrence analysis to create maps showing the network of the co-occurrence of keywords (Table 2). In each of these maps, the size of items is determined by their "total link strength" while the thickness of each connection is based on the "link strength" (Table 1). The number of clusters is determined by the resolution parameter. The higher its value, the higher the level of detail and consequently the number of clusters. Its value can be arbitrarily set by the user to visualize an appropriate number of clusters in the maps (Van Eck and Waltman, 2018). In our case, we applied a resolution equal to 1 for all the analysis.

Table 2. Different VOSviewer types of analysis (Van Eck and Waltman, 2018). The co-occurrence one was used in this study.

Types of analysis	Description
Co-authorship	In co-authorship networks, researchers, research institutions, or countries are linked to each other based on the number of publications they have authored jointly.
Co-occurrence	The number of co-occurrences of two keywords is the number of publications in which both keywords occur together in the title, abstract or keyword list.
Citation	In citation networks, two items are linked if at least one cites the other.

2.2 Bibliographic research and data collection

Documents were collected on July 13th, 2023 from the web search engine Scopus. The search string used was composed by the terms: (i) *Posidonia oceanica* and (ii) "*Posidonia oceanica*" and "Ecosystem Services", to explore the relationship between them. The research was performed using a time frame period of about 20 years, specifically from 2000 to 2023. The data were exported as .csv files and imported into the VOSviewer software.

3. Results and discussion

3.1. *P. oceanica*

The research on the Scopus database resulted in 2,216 documents published since the year 2000. Table 3 shows the main keywords related to "*Posidonia oceanica*" classified according to "total link strength". Keywords ranking higher by "total link strength" reflect the topics most related to the theme "*Posidonia oceanica*". In the network map (Figure 1), the thickness of each connection is instead based on the "link strength". The analysis of the co-occurrence of keywords produced 11,793 results. Applying a threshold of 10 occurrences and inserting a thesaurus file to avoid repetitions (i.e., between the singular and plural form of the same word), 612 keywords were selected and grouped into clusters (Figure 1), referred to different disciplinary fields among which zoology (red cluster), physiology (yellow cluster), chemistry

(blue cluster), and ecology (green cluster). In the network map, the larger the size of the items and the smaller the distance between them, the greater is the strength of correlation.

Table 3. Keywords most related to the theme "*Posidonia oceanica*".

Key words	Co-occurrence
Seagrasses	1071
Mediterranean sea	757
Alismatatidae	290
Ecosystems	215
Controlled study	150
Plants	195
Environmental monitoring	127
Italy	188
Leaf	150
Algae	165

Besides the recurrence of terms linked to the biological characteristics of the species, the presence of the theme "environmental monitoring" should be remarked. Actually, it represents the fundamental tool for analyzing the health status of *P. oceanica* meadows over time and, consequently, for the planning of conservation strategies also aimed at preserving the provisioning of vital ecosystem services, such as carbon sequestration and storage. It is also interesting to note that, although the research was carried out on the global scientific literature, "Italy" is among the first ten keywords related to *P. oceanica*. This result highlights the importance in the Italian national context of *P. oceanica* meadows, covering the widest area in Europe (Telesca et al., 2015).

Figure 1. Co-occurrence map of keywords related to the theme "*Posidonia oceanica*".

3.2. *P. oceanica* and Ecosystem Services

In order to obtain a more comprehensive understanding on the scientific literature focused on the relationship between *P. oceanica* seagrass beds and the benefits they generate for human well-being, a further investigation was performed jointly using the terms "*Posidonia oceanica*" and "Ecosystem Services" as research string. Again, a keyword co-occurrence analysis was performed.

The research on the Scopus database resulted in 75 published documents published since the year 2009 (year of publication of the first article on these topics). Table 4 shows the first 10 keywords classified according to "total link strength". In the network map (Figure 2), the thickness of each connection is instead based on the "link strength". The analysis of the co-occurrence of keywords produced 835 results. Applying a threshold of 5 occurrences, and

again, by inserting a thesaurus file to avoid repetitions (i.e. between the singular and plural form of the same word), 37 keywords were selected and grouped into 3 clusters (Figure 2), referred to the following different areas: natural capital and biodiversity (green cluster), carbon sequestration and storage (red cluster) and human interactions (blue cluster). In the network map, the larger the size of the items and the smaller the distance between them, the greater is the strength of correlation.

In this joint investigation, it is noteworthy that the keyword "human activity" appeared (Table 4), highlighting the interest on the strong relationships between Posidonia meadows and humans, both in terms of anthropogenic impacts and benefits derived for human well-being. The term "Biodiversity" also resulted in the top 10 keywords list (Table 4), underlying the research interest on the importance of maintaining the biodiversity of this ecosystem also for ensuring the provisioning of ecosystem services.

Table 4. Keywords most related to the theme "*Posidonia oceanica*" and "Ecosystem Services".

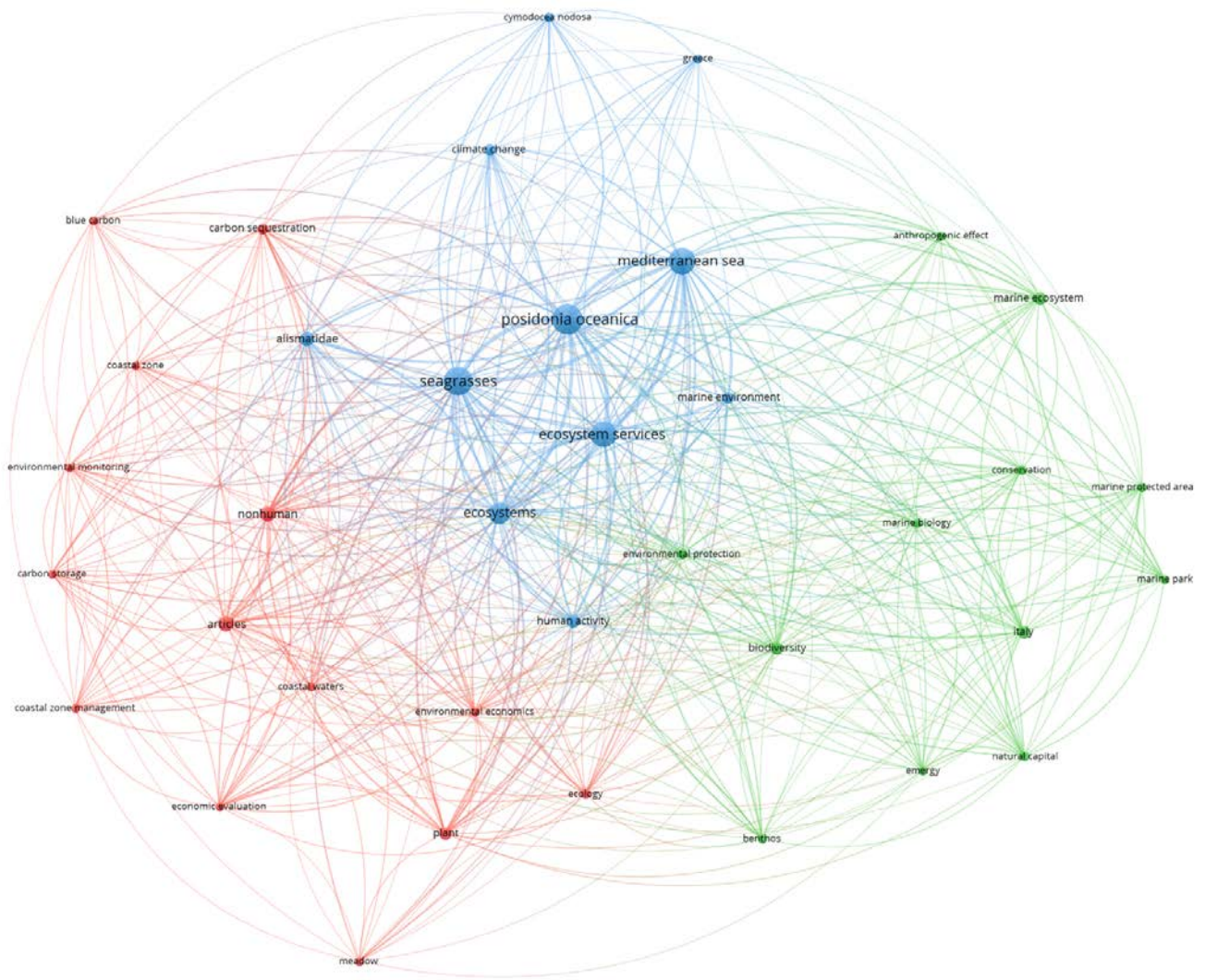| Key words	Co-occurrence
Seagrasses	51
Mediterranean sea	45
Ecosystem services	43
Ecosystems	31
Alismatidae	13
Plant	11
Human activity	12
Biodiversity	10
Environmental protection	7
Environmental economics	6

Figure 2. Co-occurrence map of keywords related to the themes "*Posidonia oceanica*" and "Ecosystem Services".

Among the top 10 keywords, also the keywords "Environmental protection" and "Conservation" appeared (Table 4) showing the attention to actions directed to preserve Posidonia meadows, their health and ecological status in line with the current perspective of achieving sustainable development goals.

In addition, the temporal distribution of keywords among the scientific publications related to "*Posidonia oceanica*" and "Ecosystem Services" was also performed to explore the evolution along a temporal gradient in the scientific literature of the investigated topics, identifying the trends in the research areas (Figure 3).

The analysis shows the more recent focus (yellow cluster) on the topics of "blue carbon" and "carbon sequestration", the recent increase awareness on the important role that *P. oceanica* meadows play in mitigating climate change. Among recent keywords, "human activity" is also

included, probably due to the increasing understanding of the alarming regression rate of Posidonia meadows due to human activities causing the loss of ecosystem services and human benefits.

It is noteworthy that "ecosystem accounting" is not included among the main keywords on the topic although there is a wide interest both in scientific and policy contexts in the assessment of the biophysical and economic value of ecosystem services generated by *P.oceanica* meadows (Vassallo et al., 2013). Similarly, there is no mention of the SEEA-EA framework, that is the standard framework adopted by United Nations for ecosystem services assessment, showing some research gaps in the application of this ecosystem accounting framework to *P.oceanica* meadows.

Therefore, future studies are needed to implement integrated and standardized biophysical and economic assessment of natural capital and ecosystem services generated by *P.oceanica* meadows to make more visible the importance of this marine ecosystem in decision making processes.
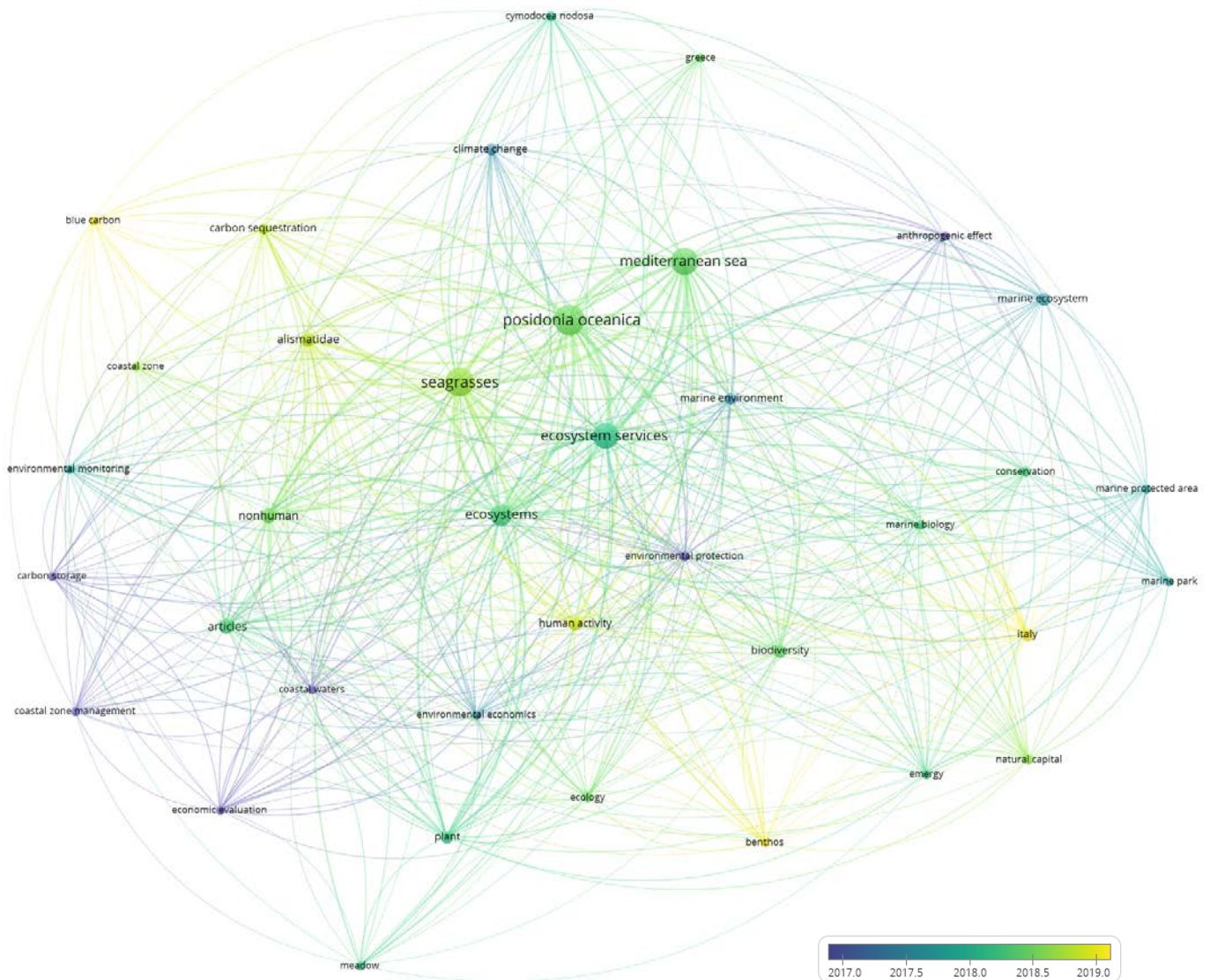
Figure 3. Temporal distribution analysis of keywords on "*Posidonia oceanica*" and "Ecosystem Services".

4. Conclusions

In this study, the global scientific literature on *P. oceanica* was explored through a bibliometric network analysis focused on two main topics: (i) *Posidonia oceanica* and (ii) the relationships between "*Posidonia oceanica*" and "Ecosystem Services".

The bibliometric network analysis allowed the creation, visualization and exploration of bibliometric data through network maps expressing the relationships among items related to the investigated topic.

Results showed that the global scientific literature on "*P. oceanica*" is mainly focused on its biological features and environmental monitoring. Instead, the research on "*Posidonia*

oceanica" and "Ecosystem Services" highlighted a strong interest on the relationships between *P. oceanica* meadows and humans, both in terms of anthropogenic impacts and benefits derived for human well-being.

The analysis of the temporal evolution of keywords in the scientific literature on "*Posidonia oceanica*" and "Ecosystem Services" showed the more recent focus on the topics of blue carbon and carbon sequestration. In fact, *P. oceanica* is considered as one of the most important "Coastal Blue Carbon Systems", for its capacity to store considerable quantities of carbon over long periods of time. Still, the analysis showed a research gap in the application of environmental accounting systems to seagrasses.

Therefore, an integration of biophysical and economic assessment methods is recommended for a comprehensive understanding of the benefits provided by *P. oceanica* meadows. In this perspective, the SEEA-EA framework constitutes a standardized integrated framework that should be used for organizing biophysical data on *P. oceanica* meadows, measuring related ecosystem services, tracking changes in ecosystem assets and linking this information to economic and other human activity.

It would support policy makers in developing effective strategies for the conservation and sustainable management of *P. oceanica* meadows.

References

Appolloni L., Sandulli R., Vetrano G., Russo G.F., 2018, A new approach to assess marine opportunity costs and monetary values-in-use for spatial planning and conservation; the case study of Gulf of Naples, Mediterranean Sea, Italy, Ocean & Coastal Management, 152: 135-144.

Basterretxea G., et al., 2004, Seasonal Dynamics of a Microtidal Pocket Beach with *Posidonia oceanica* Seabeds (Mallorca, Spain), Journal of Coastal Research, 20 (4): 1155-1164.

Boudouresque C.F., Bernard G., Bonhomme P., Charbonnel E., Diviacco G., Meinesz A., Pergent G., Pergent-Martini C., Ruitton S., Tunesi L.,, 2012, Protection and conservation of *Posidonia oceanica* meadows, RAMOGE and RAC/SPA publisher, Tunis: 1-202.

Brunel B., Sabatier P., 2009, Potential influence of sea-level rise in controlling shoreline position on the French Mediterranean Coast, Geomorphology, 107: 47-57.

Buonocore E., Buia M.C., Russo G.F., Franzese P.P., 2021, Exploring the convergence of natural flows for the generation of natural capital stocks in marine ecosystems, Ecological Complexity, 46.

Buonocore E., Grande U., Franzese P.P., Russo G.F., 2021, Trends and Evolution in the Concept of Marine Ecosystem Services: An Overview, Water, 13: 2060.

Cantasano N., 2023, Back to the Sea: The Long and Winding Road of the Seagrass Species *Posidonia oceanica*, Advances in Environmental and Engineering Research, 4: 1.

Catucci E., Buonocore E., Franzese P.P., Scardi M., 2022, Assessing the natural capital value of *Posidonia oceanica* meadows in the Italian seas by integrating Habitat Suitability and Environmental Accounting Models, ICES Journal of Marine Science, 80: 739–750.

Chen D., Liu Z., Luo Z., Webbe M., Chen J., 2016, Bibliometric and visualized analysis of emergy research, Ecological Engineering, 90: 285-293.

Council of the European Communities, 1992, Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.

Donnarumma L., Sandulli R., Appolloni L., Di Stefano F., Russo G.F., 2018, Morpho-structural and ecological features of a shallow vermetid bioconstruction in the Tyrrhenian Sea (Mediterranean Sea, Italy), Journal of Sea Research, 131: 61- 68.

Duarte C.M., 2002, The future of seagrass meadows, Environmental Conservation, 29 (02): 192 – 206.

Edens B., Maes J., Hein L., *et al.*, 2022, Establishing the SEEA Ecosystem Accounting as a global standard, Ecosystem Services, 54.

Fergusson R.L., Thayer G.W., Rice T.R., 1981, Functional Adaptations of Marine Organisms. Marine primary producers, Academic Press, 2: 9–69.

Fourqurean J.W., Duarte C., Kennedy H., *et al.*, 2012, Seagrass ecosystems as a globally significant carbon stock, Nature Geoscience, 5: 505-509.

Hein L., van Koppen K., de Groot R.S., van Ierland E. C., 2006, Spatial scales, stakeholders and the valuation of ecosystem services, Ecological Economics, 57(2): 209-228.

International Union for Conservation of Nature (IUCN), Red List of Threatened Species. www.iuncredlist.org

Millennium Ecosystem Assessment (MA), 2005, Ecosystems and Human Well Being: Synthesis, Island Press, Washington DC.

Meinesz A., Levefre J.R., Astier J.M., 1991, Impact of coastal development on the infralittoral zone along the southeastern Mediterranean shore of continental France, Marine Pollution Bulletin, 23: 343-347.

Monnier B., Pergent G., Mateo M.A., Clabaut P., Pergent-Martini C., 2022, Quantification of blue carbon stocks associated with *Posidonia oceanica* seagrass meadows in Corsica (NW Mediterranean), Science of The Total Environment, 838: Part 1.

Otte E., Rousseau R., 2002, Social Network Analysis: a powerful strategy, also for the Information Science, Journal of Information Science, 28: 441-453.

Pauna V.H., Picone F., Le Guyader G., Buonocore E., Franzese P.P., 2018, The scientific research on ecosystem services: A bibliometric analysis, Ecological Questions, 29 (3): 53–62.

Pergent G., Gerakaris V., Sghaier Y.R., Zakhama-Sraier R., Fernández Torquemada Y., Pergent-Martini C., 2016, The IUCN Red List of Threatened Species: *Posidonia oceanica*.

Pergent-Martini C., Pergent G., Monnier B., Boudouresque C.F., Mori C., Valette-Sansevin A., 2021, Contribution of *Posidonia oceanica* meadows in the context of climate change mitigation in the Mediterranean Sea, Marine Environmental research, 165.

Reuters T., 2008, Whitepaper Using Bibliometrics, Thomson Reuters, 12 pp.

Rotini A., Chiesa S., Manfra L., *et al.*, 2020, Effectiveness of the "Ecological Beach" Model: Beneficial Management of Posidonia Beach Casts and *Banquette*, Water, 12: 3238.

Scott J., 2007, Summary for Policymakers. Intergovernmental Panel on Climate Change (Ed.), Climate Change 2013. The Physical Science Basis, Cambridge University Press, 1-30.

Telesca L., Belluscio A., Criscoli A., *et al.*, 2015, Seagrass meadows (*Posidonia oceanica*) distribution and trajectories of change, Scientific Reports, 5: 12505.

United Nations, *et al.*, 2021, System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA EA), White cover publication, pre-edited text subject to official editing.

Van Eck N.J., Waltman L., 2018, Manual for VOSviewer version 1.6.8. CWTS Meaningful Metrics, Universiteit Leiden.

Vassallo P., Paoli, C., Buonocore, E., Franzese, P.P., Russo, G.F., Povero, P., 2017, Assessing the value of natural capital in marine protected areas: A biophysical and trophodynamic environmental accounting model, Ecological Modelling, 355(C): 12 – 17.

Vassallo P., Paoli C., Rovere A., Montefalcone M., Morri C., Bianchi C.N., 2013, The value of the seagrass *Posidonia oceanica*: A natural capital assessment, Marine Pollution Bulletin, 75: 157 – 167.

Zou X., Long Yue W., Le Vu H., 2018, Visualization and analysis of mapping knowledge domain of road safety studies, Accident Analysis & Prevention, 118: 131-145.