HUMAN PRESSURES AND CARBON ASSESSMENT OF POSIDONIA OCEANICA MEADOWS IN THE AEGEAN SEA: LIMITATIONS AND CHALLENGES FOR ECOSYSTEM-BASED MANAGEMENT

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Abstract

In the last decades the interaction between marine users is becoming more complex as there are growing needs of different sectors competing for the limited sea space. EU has adopted new institutional structures such as the Marine Strategy Framework Directive (MSFD) and the Maritime Spatial Planning (MSP) Directive promoting the sustainable management of marine and coastal areas. A key aim of these structures in line with "Blue Growth" objectives is the sustainable use of maritime space following an ecosystem-based approach. This study explores interactions among existing human activities in the Aegean Sea (Greece) so as to identify areas which would be mostly benefited by spatial planning. Conflicts between existing uses are discussed along with the cumulative impacts of these uses on a key priority habitat, the seagrass Posidonia oceanica that provides important services to human well-being. Then the study links impacts with the value of a key service provided by seagrasses, carbon sequestration. Finally, it discusses the potential of such a joint analysis to support prioritization of areas or stressors of concern. In this context, limitations and challenges arising due to the inherent complexity of the involved factors and parameters are acknowledged.

Keywords: cumulative impact assessment, ecosystem services, Posidonia oceanica, carbon stock provision, maritime spatial planning

JEL classification:

1. Introduction

The demand for sea space is rising rapidly because of different and mostly competitive human uses (aquaculture, fishing, transportation, oil and gas exploration, wind parks etc.); it is more prominent in multi-use coastal areas, where various social and economic factors interplay adding to the complexity of adopting a sharing understanding of existing conflicts and finding resolutions. The major environmental and social management challenges that we face today are the result of cumulative impacts from a large number of activities that although individually may be insignificant, synergistically they may have regional or even global repercussions (IFC, 2013). Understanding how coastal/marine space is used, and how human pressures interact with natural drivers of change ultimately affecting marine ecosystems is a priority for effective management (Guarnieri et al., 2016).

Indeed, escalating impacts of human activities on the marine environment imperil the delivery of important ecosystem services (ES) (Salomidi et al., 2012) and hence of goods and benefits contributing to human welfare. These range from the provision of fish and aggregates, to regulation of the planet's climate and protection of our coastlines, offering a setting for recreation, cultural and spiritual experiences (Mace et al., 2011; Liquete et al., 2013; Hattam et al., 2015). Marine ecosystems today contribute with services that can be valued at more than 2,5 trillion USD annually to the global economy (Global Opportunity Explorer, 2017, accessible at: http://www.globalopportunityexplorer.org/markets/regenerative-ocean-economy-accessed 06/12/2017), whilst the livelihoods of over 3 billion people worldwide depend upon services from marine and coastal biodiversity. Hence, the collection of information regarding the distribution and intensity of stressors on marine ecosystems, and particularly conservation priority ones, is a prerequisite to ensure the adoption of suitable measures for collective pressures to be kept within levels compatible with the preservation or restoration of Good Environmental Status (GES) sensu the Marine Strategy Framework Directive (MSFD) (EC, 2008). The latter implies that human pressures should not exceed the capacity of the marine ecosystem to withstand human-induced changes, whilst enabling the sustainable use of the marine environment now and in the future (MSFD Article 1(3)) (Crise et al., 2015).

A key ecosystem component for the Mediterranean is the endemic seagrass, Posidonia oceanica, extending from the coastline down to 40–45 m depth, being a priority habitat for conservation under the Habitats Directive (Council Dir 92/43/CEE) (Díaz-Almela and Duarte, 2008). It is used to develop biotic indices for the purposes of the EU Water Framework Directive (WFD) (EC, 2000) monitoring, and has been suggested as a useful tool for the MSFD monitoring (Panayotidis et al., 2015). Posidonia meadows provide, among other services, an essential habitat contributing to food provision and opportunities for recreational fishing (Jackson et al., 2015), leaves are used as material, it contributes to wastewater treatment (Lamb et al., 2017), protection from coastal erosion, carbon sequestration (Duarte, 2000). Indeed, the outstanding role of P. oceanica as a carbon sink in the Balearic Islands, with an accumulation five times higher than the average recorded for the whole region, has been also confirmed recently (Serrano et al., 2014). In addition, Posidonia meadows contribute indirectly through fish production to local traditional fisheries communities by sustaining livelihoods (Vlachopoulou et al., 2013) through the creation of revenue, employment, food security, especially where alternative employment and income resources are limited. On a global scale, seagrasses undoubtedly provide many ecosystem services that benefit human needs directly or indirectly (Nordlund et al., 2016); they are usually assigned an annual economic value between €12.000 and €16.000 per hectare, while estimates may reach €25.000 per hectare in seagrass beds in Florida, taking into account profits from fishing only (OCEANA, 2010).

However, intensive coastal anthropogenic pressures, contribute to the ecological degradation of this major benefit provider. A recent study in Greek waters has shown that the main human activities/uses affecting seagrass meadows status were small and medium scale fisheries, land-based activities (agriculture, industry, urbanization), aquaculture and coastal defence infrastructures (Brodersen et al., 2017). Furthermore, declining of the meadows at alarming rates (34% in the last 50 years) has been documented and was mainly ascribed to cumulative effects of multiple local stressors (Telesca et al., 2015).

Although there are gaps and challenges for treating uncertainty in cumulative impact assessments, with most efforts lacking standardization of processes when conducting assessments (Stelzenmüller et al., 2011), they remain one of the few comprehensive quantitative tools to measure how humans are affecting natural systems. Hence, they have helped identify which areas and ecosystem types are relatively pristine or heavily impacted, where hotspots of biodiversity and impacts overlap, and which stressors dominate human impact. In this way, biodiversity conservation, threat mitigation and spatial planning decision processes can be informed (Halpern et al., 2013) and improved (Fernandez et al., 2017), especially in the light of the European Directive on maritime spatial planning (MSP) (EC, 2014).

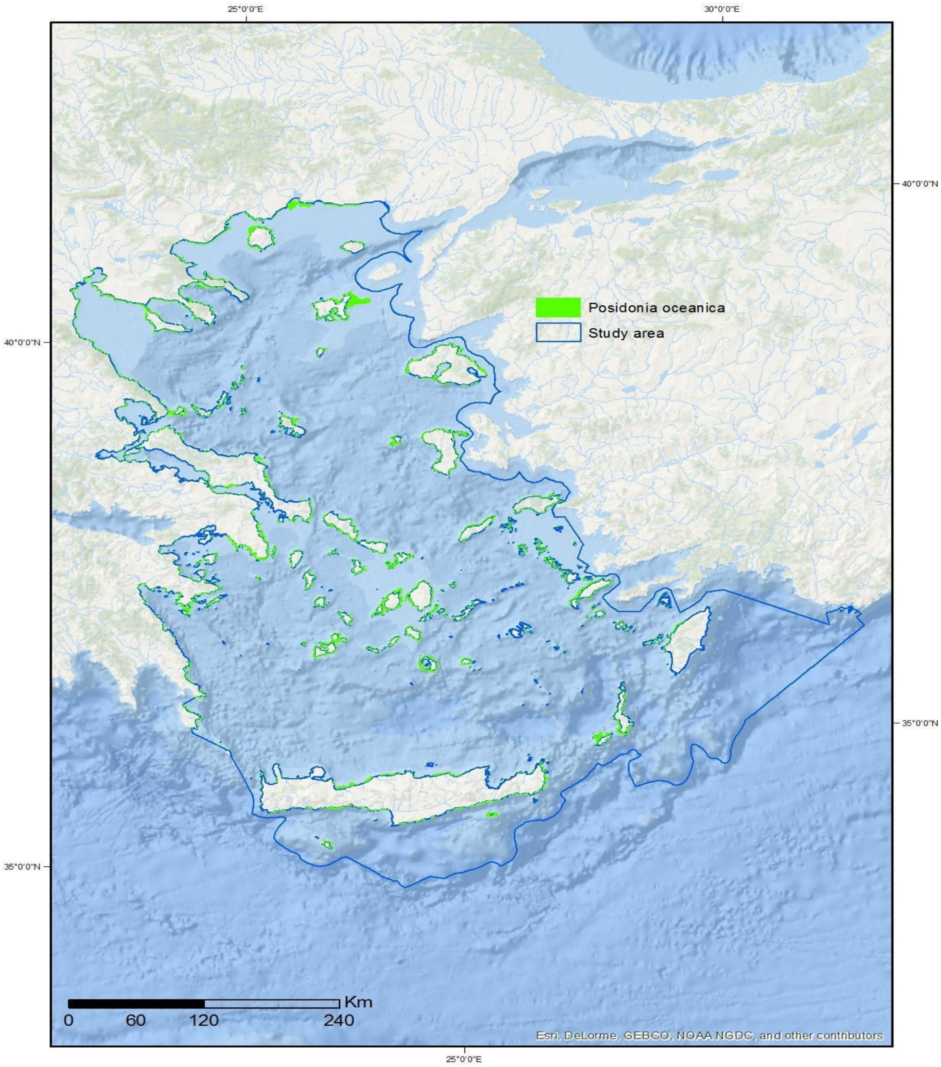
In the present study, cumulative impact assessment was used to explore the impact of human activities on Posidonia oceanica meadows in the Aegean Sea (Greece) and relate it to a key ecosystem service that of carbon stock provision. The ultimate aim was to investigate the potential of such a joint analysis to derive a more informed spatial management plan that would thus more effectively sustain delivery of ecosystem services (Arkema et al., 2015).

2. Material and methods

2.1. Study area

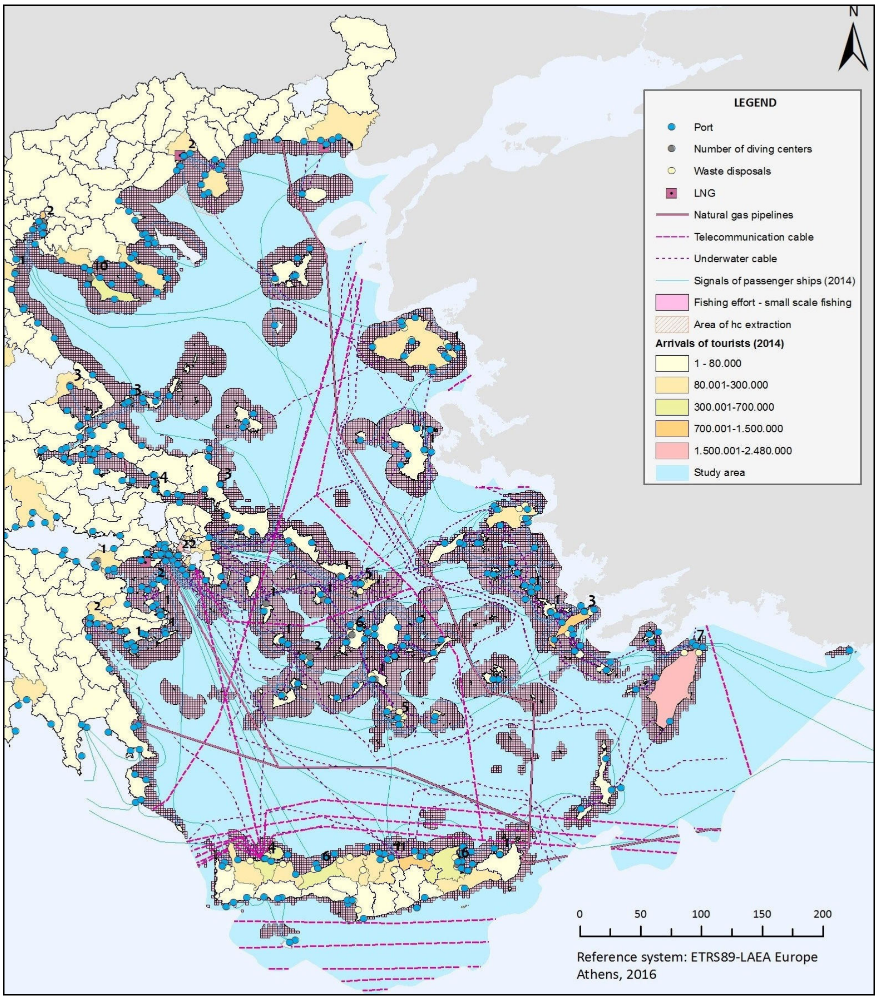
Aegean Sea is located in East Mediterranean Sea, it covers 213.168 km^2 (Figure 1) where a number of conservation priority habitats such as *Posidonia oceanica* meadows, coralligenous formations, as well as essential fish habitats such as nursery grounds for target commercial species exist. In Figure 1 the distribution of *Posidonia oceanica* is presented. At the same time, the Aegean Sea is an area with various human uses such as tourism, transportation, fishing, aquaculture (Figure 2).

Figure 1: Study area and *Posidonia oceanica* meadows



Source: Topouzelis *et al*. (2018)

Figure 2: A subset of the activities that are present in Aegean Sea



Source: Katsanevakis *et al*. (2017)

2.2. Assessment of human impacts on *Posidonia oceanica*

The first steps for the cumulative impact analysis are to define: (a) the goal of the study (which ecosystem components are to be examined), (b) the cause of the changes that add pressure on the ecosystem, and (c) the relation between ecosystem components and the cause of the changes that is translated to sensitivity or vulnerability to these factors of change. The outputs of a cumulative impact assessment, are the following:

- areas where the density of human uses and impacts is equally high
- areas where the density of human uses is low but the density of impacts is high (in this case the ecosystem components can be really sensitive to a human use)
- areas with high density of human uses and low impacts (in this case human uses have not great impacts in ecosystem components)

Cumulative impacts assessment is based on a methodology suggested by Halpern *et al*. (2007) applied to a global scale (oceans) and then used widely in many studies such as the analysis of the Mediterranean Sea (Micheli *et al*., 2013) and Baltic Sea (Andersen *et al*., 2013 & Korpinen *et al*., 2012).

According to this methodology, pressures from human activities are converted to impacts and represented as total scores of cumulative impacts allowing the identification of vulnerable areas. The modelling of cumulative impacts is based on the consideration that human activities act separately and therefore the sensitivity of each ecosystem component to these can be estimated as a cumulative score. The normalization and homogenization of the available spatial data based on a grid using a cell size that can be determined by the maximum analysis of the available spatial data (Stelzenmüller *et al*., 2011).

Halpern *et al*. (2008) estimate a unitless human impact score **I** for each cell (x,y) of a regular grid as

$$I_{\text{sum}}(x,y)=\sum_{i=1}^{n}\sum_{j=1}^{m}D_i(x,y)e_j(x,y)\mu_{i,j}$$

where:

- D_i is the log(X+1)-transformed and rescaled (to maximum 1) intensity of stressor i
- e_j is the presence (1) or absence (0) of ecosystem component j
- $\mu_{i,j}$ is a weight representing the sensitivity of ecosystem component j to stressor i.

The main output of this model is a regular grid where each cell contains an impact score representing the per-pixel average of each ecosystem vulnerability-weighted stressor intensities was calculated and mapped for selected ecosystems.

According to the model, the total impact is zero when no human activity or ecosystem component is present while the more ecosystem components and human activities are present in an area the more is the total impact score I.

For the purposes of our analysis, the study area was divided into a regular square grid of 1 km^2. In order to apply the methodology, we used human uses as separate activities (e.g., small-scale fishing) and not as general categories (e.g. fishing) because of the study area's particularity (large extent, small island areas) and the available data. The cell size set as calculation unit was 1km * 1km which was considered as suitable - after various experiments with different cell sizes (2 km * 2km, 100m *100m etc.) – for the selected study area and the data resolution. We collected data for the following datasets:

- Fishing effort for small scale fishing, purse seiners and for trawlers (Kavadas and Maina, 2012; Kavadas *et al*, 2015).
- Areas of aquaculture Passenger and commercial ports, marinas, anchorages and fishing ports
- Route of Passenger and commercial ships
- Areas of research and exploitation of hydrocarbon
- Gas pipelines as well as main underwater telecommunication cables
- High developed touristic areas Population of coastal areas
- Public wastewater treatment plants areas Main industrial units
- Agricultural runoffs

The ecosystem component that was examined was *Posidonia oceanica* meadows (1,618.7 Km^2). The vulnerability assessment of the ecosystem components to human pressures was calculated by experts' judgement based on Halpern *et al*. (2007) criteria. To calculate the total impact scores, we used the model given by Halpern. Each D_i * E_j was multiplied by the corresponding weighting factor and then summed up for the ecosystem component resulting to the cumulative impact score (I) for each cell of the study area. The cumulative impact scores were mapped using the same thresholds used in Halpern *et al*. (2008) to define meaningful categories of the cumulative impact scores: high (12–15,52); medium high (8,47–12); medium (4,95–8,47); low (1,4–4,95); and very low impact (1,4).

2.3. Assessment of carbon storage

Estimates on the economic value of carbon sequestration and storage in coastal and marine vegetated ecosystems are limited and vary widely. *Posidonia* acts as the best marine carbon sink of the Mediterranean (Luisetti *et al*., 2013), linked to a vast long-term carbon stock accumulated over millennia, creating a reservoir representing 11 to 42% of the CO_2 emissions produced by Mediterranean countries since the beginning of the Industrial Revolution (Pergent *et al*., 2012). Available estimates demonstrate that this seagrass species has an estimated carbon burial rate of 1,82 t C ha/year (Gacia *et al*., 2002). Barron *et al*. (2006) estimate that this specific meadow can fix 400 g C /m^2/year while, Pergent *et al*. (2012) report that the carbon storage capacity varies between 8-487 g C /m^2/year for the short term (1-6 years) and 6-175 g /m^2/year for the long term (> 100 years).

Considering the price per ton of CO_2, estimates of this service have been produced. Campagne *et al*. (2015) use the above long-term sequestration of carbon estimate achieved by

P. oceanica, a price of 35 €/t (€2014) and elicit a value between 7,7 and 230 €/ha/year (€ 2014) (770 to 23.000 €/km^2/year), that is between 688.000 and 20.550.500 €/year (€ 2014) (in France). At a regional scale, Diaz-Almela (2014) estimated that the *P. oceanica* meadows in Andalusia sequester 31.531 CO_2 tons (8.592 C tons) per year, equivalent to a total value of 83.854.149 € (€ 2011) (4,80 €/ tCO_2) if traded in the voluntary carbon market, and 315.850.629 € (€ 2011) (18,08 €/ tCO_2) if traded in the Kyoto carbon market. Mangos *et al.* (2010) assess benefits relating to climate regulation based on the marine environment's capacity to absorb anthropogenic CO_2, valued at the price per tonne of CO_2 in force under the European Emission Trading Scheme in 2005 (i.e., 20,5€/tCO_2). In order to quantify this ecosystem service, the estimate provided by Huertas (2009) was used (an annual average rate of anthropogenic CO_2 sequestration amounting to 11,8 t/km²/year), which gave a total sequestered volume of 108 million tonnes of CO_2 per year for the Mediterranean as a whole. Regarding Greece the authors estimate a value of 98 M/year (€ 2005).

Furthermore, Luisetti *et al.* (2013) estimate the accounting value of the stock of carbon storage service in currently existing seagrass beds (*P. oceanica* and *Z. marina*) in Europe at US$168.749.727 (in 2012), using mean EU allowances price of traded carbon and Gacia *et al.* (2002) storage estimate of carbon for *P. oceanica*. They also estimate the present value (US$) of the C storage service loss economic value in European seagrass beds in three scenarios, the optimistic, pessimistic and ultra-pessimistic scenario, over 50 years (2010–2060), discounted at 3,5% discount rate, at 'social cost of carbon' prices (US$ 5, 50, 312) and 'British Department of Energy and Climate Change' prices (all relevant year values).

In our study, in order to estimate the accounting value of the stock of carbon storage service in currently existing *Posidonia* in Aegean Sea, the following assumptions are made. We use the long-term sequestration of carbon estimate of Pergent *et al.* (2012), that is the 6-175 g C/m^2/year estimate (plant and matte), that corresponds to 22-642 t CO_2 /km^2/year, assuming 1 C t = 3,67 t CO_2 (Trumper *et al.*, 2009). Furthermore, the current extent of *Posidonia oc.* of 1.618,7 km^2 (Topouzelis *et al.*, 2018) is considered, while regarding price we use the mean price of traded carbon from EU Emissions Trading System in 2015 (8 €/tCO_2). It is noted that prices seem very volatile as from 30 €/tCO_2 in 2008 plunged to as low as 5 €/tCO_2 in 2014 (Carbon Market Watch, 2014), while in 2015 had an annual average value of about 8 €/tCO_2 (Investing.com, 2017 accessible at: http://www.investing.com/commodities/carbon-emissions-historical-data,accessed 06/12/17).

In addition, we value economic losses due to a potential degradation from cumulative impacts in the area for a 10-year period and we estimate the present value of the flows of carbon storage benefits foregone over this time horizon using a 3,5% constant discount rate (HM Treasury, 2013). Finally, the impact of price changes on foregone benefits estimation is assessed. It is reminded that future benefit losses are based on the risk identified from the assessment of human impacts (previous section) considering a scenario of lack of protection for this ecosystem in that area.

Overall, it is acknowledged that the analysis here is for illustrative purposes and that it is a snapshot i.e. it describes the loss in benefits from losing a specific area of *Posidonia oc.* in the near future. In reality this loss might be reached over time however, this is hard to assess. Nevertheless, the analysis helps to provide a rough indication of the magnitude of benefits forgone from potential degradation on the particular habitat as a result of marine activities.

3. Results

3.1. Cumulative impacts in the Aegean Sea

Results are presented in Table 1 and Figure 3. According to the assessment, areas of high anthropogenic impacts are mainly located in Chalkidiki (Area 1), Attica (Area 2), Cyclades (Area 3) and Crete (Area 4) areas (Figure 4). The activities that mainly contribute to these pressures (Table 2) are small scale fishing (89,5% of the total area), population density (88,3%), agriculture (71,3%) and tourism (60,2%). However, total pressure from all activities is low-very low at the 89,1% of the total area under study.

Table 1. Cumulative impacts on Posidonia oceanica

Total impact	Score	Number of cells	% of the total area
Very low	0-1,4	465	9,3%
Low	1,4-4,95	3977	79,8%
Medium	4,95-8,47	471	9,4%
Medium to high	8,47-12	69	1,4%
High	12-14,01	5	0,1%
Sum		4987	100%

Figure 3: Cumulative impacts on *Posidonia oceanica* in Aegean Sea

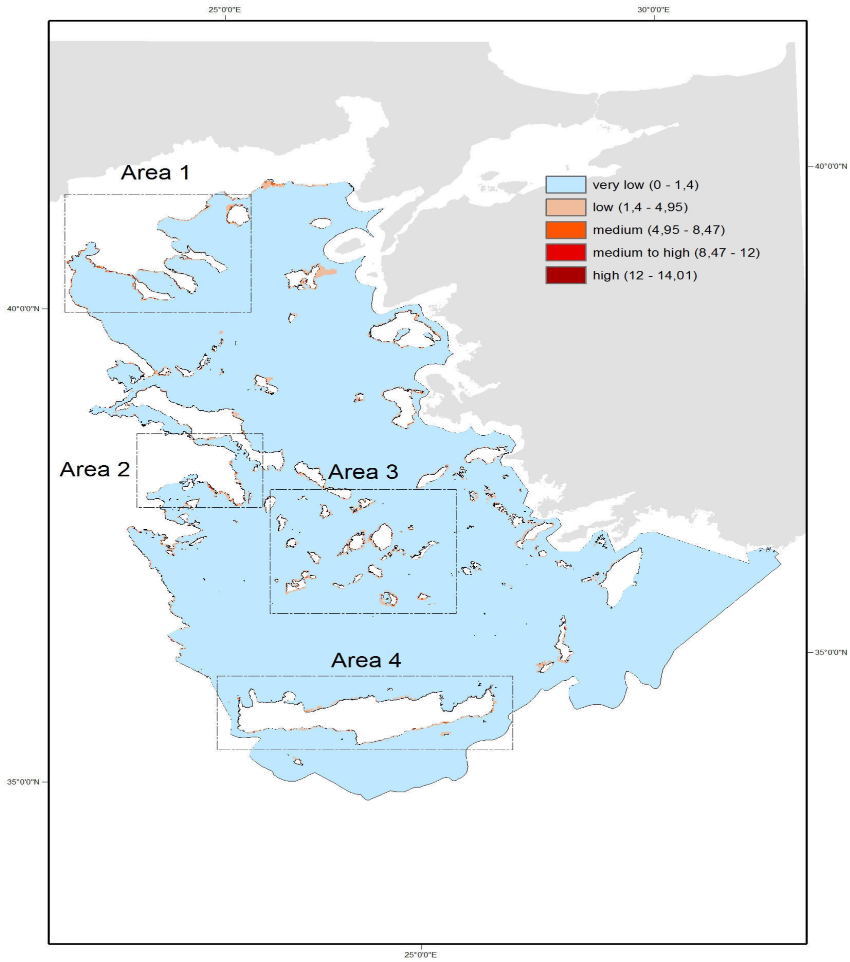


Figure 4: Cumulative impacts on *Posidonia oceanica* (a) Area 1: Chalkidiki, (b) Area 2: Attica, (c) Area 3: Cyclades, and (d) Area 4: Crete

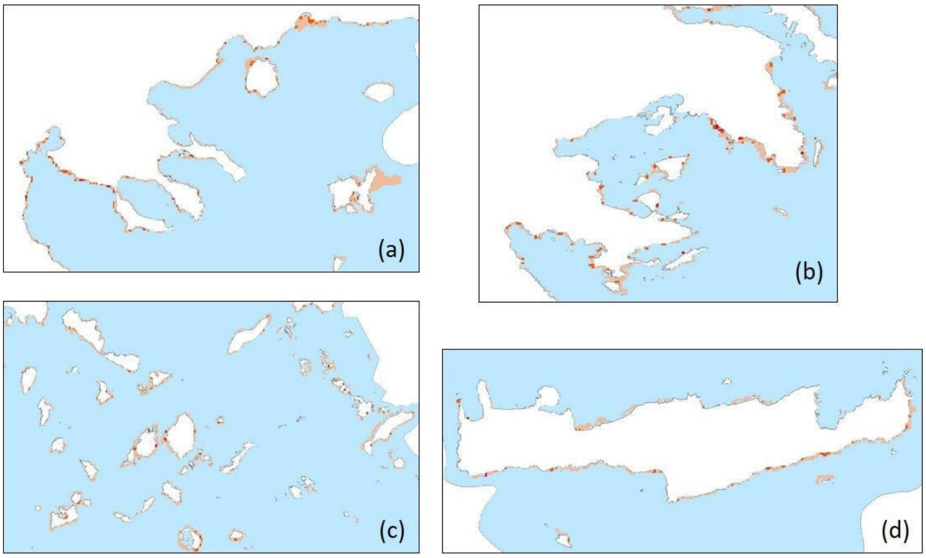


Table 2. Impacts on Posidonia oceanica per activity

Human activity	% of the total area	Number of cells with impacts
Population of coastal areas	88,3	5850
Agricultural run offs	71,3	4818
Tourism	60,2	4789
Fishing ports	19	1809
Ports	12,4	1155
Marinas	0,5	38
Anchorages	0,9	70
Aquaculture	8,6	792
Public wastewater treatment plants areas	3,3	290
Industrial units	0,4	52
Fishing effort for purse seiners	43,6	3292
Fishing effort for small scale fishing	89,5	7884

3.2. Assessment of the value of the stock of carbon storage service

Regarding the assessment of the value of the stock of carbon storage service in currently existing *Posidonia oc.* in our case study area, it could range between 285.000 to 8 M € /year or 176 to 5.000 € /km^2/year (€ 2015). For this estimation we consider the distribution of the habitat (i.e., about 1.618 km^2), a range of 35.600 – 1.038.700 tCO_2 /year (potential long-term sequestration) and the 2015 mean price of traded carbon. Then, this information is combined with cumulative impacts analysis to explore the potential risk of degradation. In particular, it is assumed that those areas where cumulative impacts are 'medium' (i.e., about 10%), that is about 162 km^2, will likely lose the capacity to offer this service. This degradation could be translated to 28.500 to 810.000 €. Hence, the present value of loss in flows of carbon storage benefits over for example a 10-year period using a 3,5% discount rate may range from about €245.000 to 7M. As highlighted before, this simplistic analysis is only presented for illustrative purposes as uncertainty is involved in initial estimation of carbon sequestration as well as present value estimations. Regarding the latter, we can see here for example how sensitive results are to price change. Hence, considering a scenario of average yearly price increase of about 16% for the next years (e.g., till 2024) (Carbon Market Watch, 2014), the present value of loss in benefits over 10 years using a 3,5% discount rate may range from €557.000 to 16M. Finally, with regards to the analysis here it should be also noted that the beneficiaries of this service are not strictly national since benefits are transboundary.

4. Discussion and conclusions

Seagrasses provide essential ES at different scales, for example from supporting key commercial fisheries and local livelihoods to regulating the climate through carbon sequestration at national and international level. In this study, we attempt to explore the importance of carbon provision in relation to *Posidonia* meadows by using a joint analysis and new available data, i.e., seagrass distribution using satellite images (Topouzelis *et al*., 2018). Although, it is noted that a considerable number of ES research efforts in Greece focus on marine and coastal ecosystem services (Dimopoulos *et al*., 2017), we are not aware of any studies with a focus on the valuation of this particular service in the scale of our case study area. With regards to the particular habitat, Halkos and Galani (2016) value *Posidonia oceanica* in Greece by employing non-market methods. In this choice experiment study related to MSFD, the habitat is an attribute defined as the '% of *Posidonia* that is not impacted by anchors. Analysis showed that respondents of three Aegean regions were willing to pay €4,46 per household (in 2012 prices), through increased water bill for eight years, to maintain the good environmental status of *Posidonia oceanica* in the country compared to the business as usual. However, the authors in their analysis note the low total adaptation of the model.

The results of our combined analysis highlight that although cumulative impacts may be low at the scale of Aegean Sea region, when proceeding to fine scale assessments results are not negligible, emphasizing the issue of scale in relation to the availability of geospatial data. The human uses potentially contributing to final scores include small scale fishing, urbanization and tourism. Furthermore, results demonstrate the economic importance of the carbon storage service of *Posidonia oceanica* meadows which might be impacted by cumulative activities in the case study area. For the purposes of this study, this can increase awareness, across local authorities, users of the marine and coastal space and the general public, about the contribution of the marine environment to human wellbeing, especially considering that *P. oceanica* re-growth requires several centuries. Overall, the estimation of the value of organic carbon (C) stocks in *P. oceanica*, provide a baseline against which future change scenarios can be compared (e.g. with or without management measures that might be required to achieve MSFD goals). Hence, the availability of a baseline can enable an informative marine management by investigating areas that maximize ES and minimize the cost of degradation. Of course, in such an assessment consideration should be also given to social sustainability (who benefits and who losses). It is also noted that cumulative impact assessments and/or combination of these with other scenario development tools can be employed in generating options while operationalizing MSP (Stithou 2017). In addition, there is a clear role for ecosystem service valuation not only to be combined with cumulative impact assessment for generating options, but also at many stages of the marine planning process as presented in Börger *et al*. (2014).

Nevertheless, the methodology used is quite sensitive to specific factors. Regarding cumulative impacts assessment, geospatial data is one of the key factors: despite existing maps illustrating human impacts on marine ecosystems, information remains either large scale but rough and insufficient for stakeholders (1 km² grid, lack of data along the coast) or fine scale but fragmentary and heterogeneous in methodology (Holon *et al*., 2015). Acquiring data at a finer scale is either difficult or of high cost and it is usually used in order to respond to specific and local objectives (the study of protected areas, a specific habitat or particular features). As a result, they mostly remain local and thus these studies are heterogeneous in their methodology. Another factor of crucial importance is scale. As Korpinen *et al*. (2013) point out, with too large scales, a severe local human impact would be diluted among weaker impacts, whereas too detailed scale is laborious to work on and is useful only for assessments on smaller scales. Moreover, large-scale predictions and their limitations may be particularly hard to use for regional managers and local policy makers focusing on specific interests (i.e. < 1km² grid cells) (Holon *et al*., 2015).

A third element to be considered is the weighting factors assigned by the experts. The assessment of habitat vulnerability based on expert opinion can be a practical solution in large-scale evaluations of potential effect of human pressure but is probably unrepresentative of the actual vulnerability at local scale (Guarnieri *et al*., 2016, p.12). The use of expert judgment instead of direct empirical assessments to calculate impact weights greatly increases uncertainty of impact scores. Empirical quantification of the ecological impacts of drivers is currently unavailable and filling this gap is acritical need within the Mediterranean and other regions (Micheli *et al*., 2013). Regarding carbon storage assessment, variations in both price and storage in coastal and marine vegetated ecosystems are large. This is due to uncertainties about the amount of carbon stored and/or released, and by the lack of common value assigned to a unit of carbon (Russi *et al*., 2016). Hence, the monetary assessments may change greatly over time because of fluctuations in price and quantity. The estimated physical quantity at local level involves uncertainty as it depends on biological processes, which in turn depend on ecosystem quality and environmental conditions. As a result, the estimated amount of carbon storage may vary significantly in time and spatially (Duarte *et al*., 2011). Values of the sites that can be effective for blue carbon and conservation, are the sites where seagrass have significant matte and thickness, reflecting a long period of good environmental conditions for plant growth. However, this information is not available yet in the study area and our analysis is based on seagrass distribution using satellite images (Topouzelis *et al*., 2018), which is related to specific limitations. Furthermore, variations in the degree of emissions triggered by different levels of destruction (conversion) (Luisetti *et al*., 2013) are also to be expected and hence further investigated. Finally, it is also acknowledged that the assessment of a potential degradation over time is simplified here as the analysis describes the loss in benefits from losing a specific area of *P. oceanica* tomorrow.

Overall, it is emphasized here that as also demonstrated in other cases (e.g., restoration investments) a joint spatial analysis of stressors and ecosystem services can provide a critical foundation for maximizing social and ecological benefits (Allan *et al*., 2013). However, challenges and limitations exist and should be prioritized and targeted to get overcome. Through our experience broad recommendations in order to increase the robustness of results include further research with regards to better knowledge linking the impact of marine activities on the specific ecosystem and the provision of not only the particular service but also other prioritized services, if our aim is to use these tools for marine management and planning. Availability of habitat mapping enriched with information about local conditions and habitats status (e.g., its density, quality), apart from distribution would add towards this attempt. Importantly, while planning can be based on the best information available at the time while keeping in mind the "precautionary" and "proportionality" principles, the adoption of an adaptive management is expected to reduce uncertainty over time.

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