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Socio-economic impacts of ocean acidification in the Mediterranean Sea

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ABSTRACT

Ocean acidification appears as another environmental pressure associated with anthropogenic emissions of carbon dioxide. This paper aims to assess the likely magnitude of this phenomenon in the Mediterranean region. This involves translating expected changes in ocean chemistry into impacts, first on marine and coastal ecosystems and then, through effects on services provided by these to humans, into socio-economic costs. Economic market and non-market valuation techniques are needed for this purpose. Important sectors affected are tourism and recreation, red coral extraction, and fisheries (both capture and aquaculture production). In addition, the costs associated with the disruption of ecosystem regulating services, notably carbon sequestration and non-use values will be considered. Finally, indirect impacts on other economic sectors will have to be estimated. The paper discusses the framework and methods to accomplish all of this, and offers a preliminary, qualitative overall assessment.

1. Introduction

The potential economic and societal implications of ocean acidification (OA) have received little attention thus far. The present study aims to focus attention on socio-economic impacts of OA in the Mediterranean region.[2] This area includes many countries and a large population with heterogeneous cultural background. The Mediterranean Sea is already subject to various environmental pressures, affecting both its shores and open-sea areas. OA, climate change, over-fishing and pollution are some of the stressors that put at risk the high diversity of marine species and unique habitats, such as seagrass meadows, vermetid reefs, and coralligenous areas. Moreover, the current resolution of IPCC scenarios of OA does not allow proper characterization of the changes occurring in the Mediterranean Sea basin. For these various reasons, there is a need for a study that focuses specifically on this area.

OA arises from the increase in the dissolution of atmospheric carbon dioxide (CO_2) in seawater that is caused by its increased atmospheric concentration. It results in less alkaline water and lower concentration of dissolved carbonate ions [1,2]. Some climate change scenarios predict that carbonate concentration may descend below saturation level [1]. A lower concentration of carbonate ions could threaten species that depend on it to form skeletal and shell structures [3,4]. These include, *inter alia*, planktonic calcifiers, corals, and molluscs. Moreover, habitats that are composed at a structural level by marine calcifiers are additionally pressured (*e.g.*, coral reefs). Although more difficult to predict, direct impacts of OA also appear to extend beyond calcifier species, affecting some finfish species [5]. Other marine species could be affected through changes in trophic relations, although the current understanding of how the effects of OA can spread through the food web is uncertain. Alongside with the impacts on processes such as calcification, primary production, and nutrient cycling, the capacity of the oceans to absorb additional emissions might be affected, thus extending the potential climate change effects [1,3].

Direct and indirect socio-economic impacts of OA in the Mediterranean region are related to major impacts on ecosystem services provided by the Mediterranean marine and coastal ecosystems. The following typology of ecosystem services is considered: provision of food and other marine resources; climate regulation; carbon sequestration; coastal protection; support of recreational activities; and

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other cultural services associated with bequest and existence values of habitats and species [6,7,8]. These generate various benefits associated with particular economic sectors, which include coastal tourism and recreation, extraction of red coral (*Corallium rubrum*) for jewellery production, and capture fisheries and aquaculture. Loss of benefits due to OA will also likely be associated with regulating services, notably marine carbon sequestration which contributes to regulating the concentration of greenhouse gases (GHGs) in the atmosphere, thus ameliorating global warming. Finally, passive benefits need to be assessed, such as existence and bequest values. These reflect the satisfaction that people obtain from knowing that particular emblematic habitats or species are protected and preserved for present and future generations.

In order to adequately estimate the impact of OA on human well-being, one needs to study the susceptibility and resilience of key-stone species and ecosystems to acidification of the Mediterranean Sea. Analysis of experimental results in relevant fields of natural science will allow the identification of the most relevant changes in species, ecosystems and regions, and subsequently a projection of changes in the associated ecosystem services. Furthermore, economic analyses will use scenarios developed to which will be added assumptions about relevant economic developments, such as income growth, travel costs, climate regulation of air traffic, and demand for tourism. A complicating issue that needs attention is the synergetic effects of multiple stress factors on the marine ecosystem such as climate change and the resulting alteration in sea level and weather patterns, overfishing, water pollution and hypoxia (or deoxygenation, *i.e.,* the decline of oxygen concentration in marine and coastal ecosystems). These factors make it difficult in some cases to disentangle the individual effect of OA.

Scenarios will have a geographical dimension which may allow the scaling up of local, regional or national assessments to the whole Mediterranean area. In this context valuation studies may be transferred using value (benefit) transfer techniques, which aim at transposing monetary values from a study site to one or more policy sites [9]. Meta-analysis, *i.e.*, the statistical synthesis or aggregation of results and findings of primary studies can be used as a value transfer technique and to scale up values at larger geographical scales [10].

The valuation approach will involve market-based economic valuation tools, *e.g.*, market price, demand analysis, partial equilibrium modelling (PEA), general equilibrium modelling (GEM). These techniques can assess market impacts of OA on the previously identified economic sectors and indirect effects in the economy at large. In parallel, several non-market valuation tools are available to capture unpriced values, notably stated and revealed preference techniques, such as travel cost method, contingent valuation and choice experiments.

The remainder of this document is organized as follows. Section 2 reviews economic studies on OA. Section 3 discusses the monetary valuation methods to assess the changes in ecosystem services under OA. Section 4 presents some background data on the Mediterranean area. Section 5 provides some details on the main socio-economic effects of OA in the Mediterranean area. Section 6 concludes.

2. A review of economic studies of ocean acidification

There is a growing literature focusing on the potential socio-economic impacts of ocean acidification. Most of the published studies identify the combined ecological and economic implications of OA [11,12,13]; the socio-economic dimensions that are at stake (*e.g.,* fisheries revenues, jobs, and food security) [13–17]; distributional issues in the impacts of OA [17,18]; the need to respond to OA at the policy level [19–23]; and the conditions for good economic research on OA [12,24].

Four studies provide monetary estimates of economic losses due to OA, three of which focus on the economic impact of OA on commercial mollusc fisheries.

Brander et al. [25] assess the economic costs of a worldwide loss in reef area due to OA over the 21st century. The effect of atmospheric [CO_2] on ocean acidity is approximated by a nonlinear power function, while the impact of ocean acidity on reef area is simulated by a logistic function. The values of the model parameters are derived from previous empirical estimates. A meta-analysis is undertaken to determine the coral reef value per square km, which accounts both for use and non-use values. The future annual economic damage due to OA is determined by combining the results of reef area decrease and unit area value with projections for atmospheric [CO_2] and tourist arrival numbers under four of the IPCC marker scenarios. The annual damage on coral reefs is predicted to increase over time to a maximum of 870 billion US$ for the A1 scenario in 2100, which corresponds to 0.14% of the global GDP. A relatively higher damage is found for scenario B2, namely 0.18% of GDP. By contrast, scenario B1, which is associated with lower CO_2 emissions projections, generates low damage during most of the 21st century and even economic benefits in the two last decades.

Cooley and Doney [15] investigate the impact of OA on the revenues of US mollusc fisheries. They estimate that the net present value (NPV) of economic losses up to 2060 will range from 324 millions US$ to 5.1 billion US$ depending on the considered IPCC scenario (B1 or A1F1) and discount rate used. In this study, harvest losses are implicitly assumed to be in a one-to-one correspondence with the decrease in calcification rates. Regional variability in acidification, damages to other species and food webs, maintenance of fishing intensity, price effects on demand and supply are not accounted for in the analysis.

Narita et al., [26] use a partial-equilibrium analysis to estimate the global costs of production losses of molluscs as a result of OA. The sum of consumer and producer surpluses losses, caused by OA on markets for molluscs, could reach more than 100 billion US$ by 2100. This corresponds to a share of the world GDP ranging from 0.018% to 0.027%, according to GDP projections by [27] and [28], respectively. Such an estimate assumes similar effects on capture and aquaculture, climate conditions based on the IPCC IS92a business-as-usual scenario, projected rates of harvest loss of shellfish based on a one-to-one correspondence with calcification and survival rates of molluscs, and an expected increasing demand of molluscs due to GDP growth which follows the IPCC A1B scenario.

Moore [29] assesses the impacts on US mollusc fisheries from a welfare perspective. Estimates of compensating variation are generated through changes in household consumption, which are assessed using a multistage demand system that integrates income changes, price changes of molluscs and substitution between molluscs and other food items. The price elasticity of molluscs to changes in supply due to OA is determined by using a Cobb–Douglas function with environmental quality as an input. In the biogeochemical component of the model, changes in sea surface temperature (SST) to baseline (high-pathway) and policy (medium-high pathway) emission scenarios are considered and an ocean carbon model is applied to predict changes in OA. Biological impacts are determined by assessing the response of growth of molluscs to OA. The compensating variation associated with the difference between the baseline and policy scenarios increases over time. The net present value of compensating variation (using a discount rate of 5%) over the period from 2010 to 2100 is 4.83 US$ at the household level and 734 million US$ for the whole US economy.

The cost estimates of OA obtained in the previous studies represent a small fraction of the estimated costs of future climate change and a very small fraction of the global GDP. Based on estimates by [30] of the costs of climate change and GDP projections by [28], Narita et al., [26] found that the costs of OA impacts on molluscs represent only 1.5% of the costs of climate change. Due to the restricted focus of these studies, these estimates reflect only part of the potential economic impacts of OA and do not account for the fact that the changes in marine carbonate chemistry caused by OA may be irreversible on the timescale of decades to centuries [17]. Moreover, the available monetary estimates of the impacts of OA acidification rely on questionable assumptions such a linear relationship between the reduction of calcification rates and production levels in [15,26,27]. This assumption could potentially lead to both over- or under-estimation of the actual damage. According to [26], a decrease in the calcification rate of molluscs might not translate into a proportional commercial loss as the molluscs could maintain an economical value despite having thinner shells. In addition, most of the data used to upscale the OA effects on species from individuals to the community level are usually obtained through controlled conditions, notably, laboratory and mesocosm experiments, which do not fully capture the characteristics of natural environments in which biological species live. Hence, lacking empirical field observations, uncertainty regarding the effects of OA on particular species and their adaptive capacity remains. Furthermore, little is known about ecosystem responses, such as trophic changes, and the effects produced in combination with other stressors. The estimates of the loss in coral reef area in [25] illustrate this last problem as other important pressures (*e.g.*, climate change effects, and damages caused by tourism activities) were omitted from the analysis, which may mean-bias the estimated loss in reef area. Another priority is the need to work on better forecasts of regional variability of OA, with a focus on estuaries and coastal areas as these concentrate an important part of sea-based economic activities [12]. In addition, more accurate estimates of economic impacts of OA could benefit from the integration of agent and market responses, such as changes in fishing intensity and possible price effects on demand and supply changes due to OA, which were not taken into account in [15]. Finally, a better understanding of the possible differences between the effects of OA on capture and aquaculture production, assumed as equal in [26], could lead to better cost estimates as well as refined management strategies for both types of production.

3. Valuation of marine and coastal ecosystem services under ocean acidification

A comprehensive approach to valuing the economic impact of OA on ecosystem services involves assessing both changes in the inputs to economic production processes and impacts on human welfare. This is not an easy task as ecosystems are "complex systems" and changes, such as induced by OA, may be characterized by feedbacks, lags and synergies with other pressure factors. As a result, it is often difficult to discern the relationships between ecosystem structure, processes and services [31].

A benchmark for the analysis of ecosystem services is the Millennium Ecosystem Assessment (MEA) [6], an initiative undertaken with support from the United Nations. It recognizes that humans can benefit directly or indirectly from ecosystems through four categories of ecosystem services: Provisioning services, related to the resources obtained from ecosystems, such as food, timber, fibre, and medicinal and genetic resources; cultural services, linked to the non-material benefits that people obtain from the ecosystem through, among others, aesthetic experience, reflection, recreation activities; regulating services, which are to the benefits obtained through the regulation of ecosystem processes (*e.g.*, climate regulation, erosion control, regulation of human diseases); and supporting services, which are necessary for the production of all other ecosystem services, for example, photosynthesis, primary production, nutrient cycling and provisioning of habitat.

Several typologies of ecosystem services further elaborated the MEA approach for various types of biomes and ecosystems [32] or specifically for marine ecosystem services [7,8,33]. Table 1 presents a widely accepted typology of ecosystem services based on such previous inventories.

Within environmental economics, a widely agreed-upon taxonomy of values of environmental resources, including ecosystems, is "Total Economic Value". This is defined as the sum of their use and non-use (or passive) values [34]. Use values are further classified in direct and indirect use. Non-use values include bequest, warm glow and existence value. [8]. Other categories include option and quasi-option values, which are sometimes defined as use values and in other instances as non-use values. Fig. 1 shows the various components of total economic value for coastal and marine ecosystems. It further mentions commonly associated valuation methods, which will be briefly discussed hereafter.

Benefits of use of ecosystem services can be obtained through the direct or indirect use of a particular resource (use values). Direct use values include the exploitation of fisheries resources. Indirect uses are, for example, regulating processes of a marine ecosystem like CO_2 sequestration, which indirectly creates benefits for humans through a stable climate.

By contrast, other benefits are of a passive character. In this case, the values individuals attach to an environmental resource do not require that they use the services or goods it generates. This involves existence and bequest values, which refer to the satisfaction obtained from the knowledge of the existence and conservation of seas and species [8]. In addition, option and quasi-option refer to values attached to potential future use opportunities and their benefits, and to the yet unknown information about potential uses and values of certain ecosystems or species, respectively. With regard to the latter, preservation of tropical rainforests, for instance, may offer information about species that can fulfill a useful function in agriculture or in developing new medicines in the future.

It should be noted that many people do not feel comfortable with placing an instrumental value on biodiversity [36]. The common

Table 1
A general classification of ecosystem goods and services of marine and coastal ecosystems.
Source: adapted from [6,7,8,33]

Types of ecosystem services	Examples
Provisioning services	Provision of food, raw materials, ornamental and other marine resources.
Regulating services	Gas and climate regulation, water regulation, flood and storm protection, erosion prevention, bioremediation of waste, carbon sequestration.
Cultural services	Support for recreational activities, aesthetic values, cultural heritage values, cognitive and educational values, bequest and existence values of habitats and species.
Supporting services	Resilience and resistance, biologically mediated habitat, nutrient cycling.

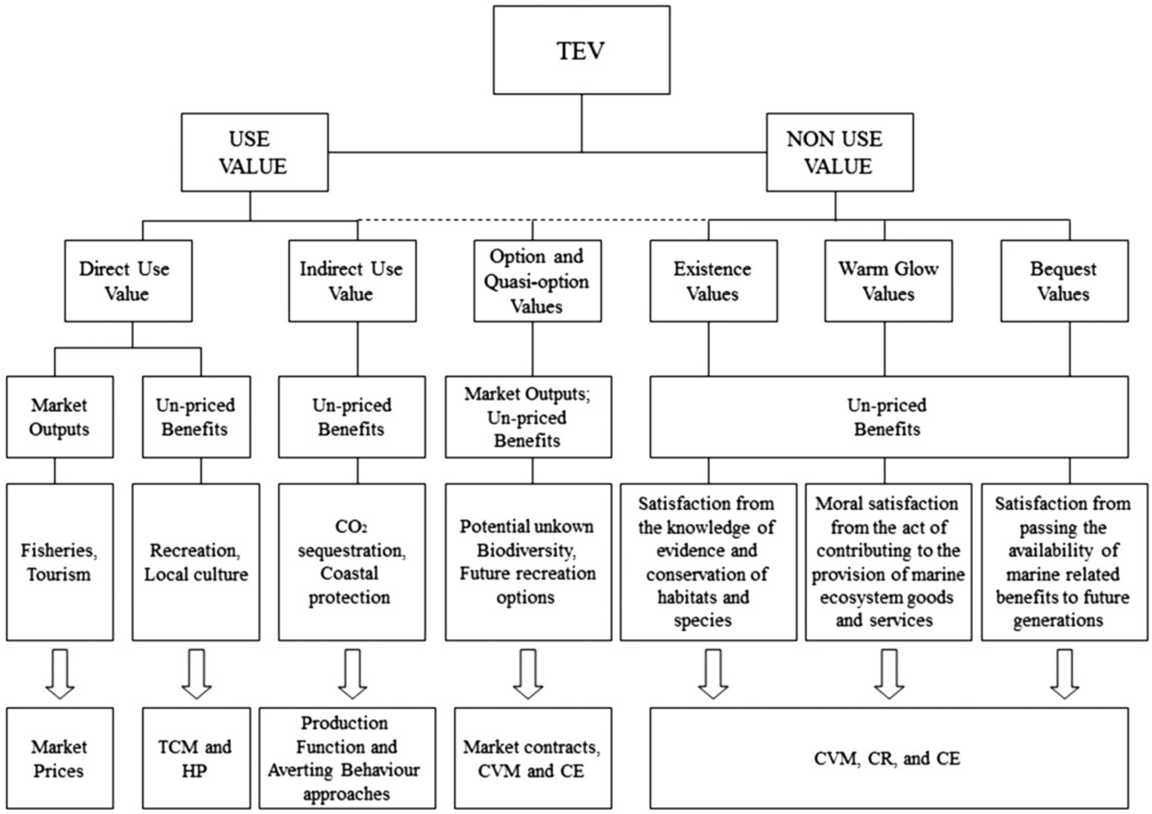

Fig. 1. Components of total economic value (TEV) and associated valuation methods, illustrated for coastal and marine ecosystems. *Source:* adapted with minor changes from [8], which was based on [35].

argument is that biodiversity has a value on its own—known as 'intrinsic value'. Others, however, feel that such a value is vague as any value requires the interaction of a subject (human being) and an object (ecosystem). Of course, the acceptance of intrinsic values does not imply the non-existence of instrumental values. Many others, furthermore, accept to put a monetary, instrumental value on biodiversity. One important argument used is that this merely makes explicit the fact that biodiversity is used for instrumental purposes, in terms of production and consumption opportunities [37]. Two additional, related motivations are as follows. First, making public or private decisions which affect biodiversity – irrespective of whether they concern conservation, use or destruction of ecosystems – implicitly means attaching a value to it. Second, monetary valuation can be considered a democratic approach to decide about public issues, including those related to biodiversity conservation or loss [38]. To illustrate this democratic feature, note that valuation techniques often make use of a referendum format or a multiple choice framework where each choice has multiple attributes like in real markets.

Sometimes philanthropic values are also considered. These reflect altruism towards other individuals currently living, to be distinguished from bequest values, which denote altruism towards future generations (or in a more restricted sense kin altruism towards one's offspring). The concept of warm glow somewhat relates to the previous notions of altruism insofar as it can be considered a more utilitarian or self-centred type of altruism. A rather cynical interpretation of it is that it rewards people in the sense that they feel good when they give to others because it raises their self-esteem.

With the purpose of measuring the different types of values discussed before, several valuation techniques can be chosen. For the case of 'use values' associated with particular environmental goods and services, it is possible to find an indication of its monetary value provided by some market transaction [39]. This may be done by market valuation (*e.g.*, for fish based on their price and cost of fishing activity) or revealed preference techniques. The latter can be done by using the relation of housing prices with environmental characteristics as in the hedonic pricing method, or by using information on transport costs made by users in order to reach and enjoy a particular nature area as in the travel cost method. In the case of market valuation, different terms are used such as production function approach or partial equilibrium modelling, which can take into account smaller and larger changes, ranging from effects of environmental changes only on producers, or also on market prices and consumers.

If economic impacts involve the wider economy, because the environmental change is large or the economy is sensitive, indirect market-based techniques can be used to estimate the effect on welfare or costs and benefits. Two often used methods are Input/Output (I/O) and computable general equilibrium (CGE) models (CGEM). The first used fixed I/O coefficient to describe interactions or interdependencies between different economic sectors. The second is more flexible, but requires more assumptions (*e.g.*, on production functions and behavior of economic agents) as well as more data. Furthermore, it allows assessment of a wider range of impacts, including on input substitution, particular markets, income distribution, and prices and costs. [40,41] give a particular example of a study in which CGEM was developed for addressing induced climate change impacts in various economic sectors.

In addition, there are some non-market environmental goods and services that are not exchanged in formal markets, and thus generate un-priced benefits. If they do not have a connection with marketed goods or services, revealed preference techniques like hedonic prices and travel costs methods cannot be used. A possibility is then to employ stated preference techniques, which

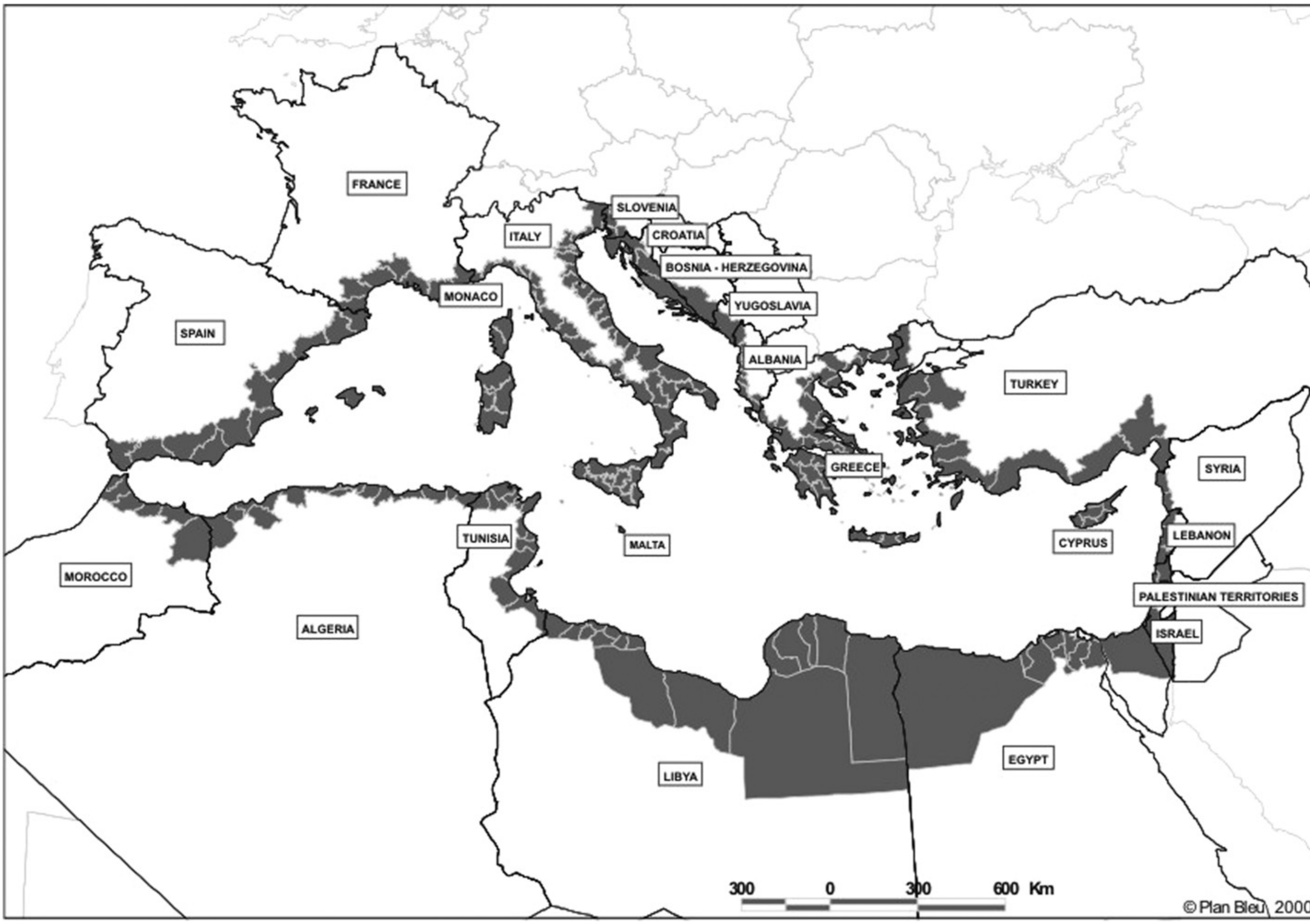

Fig. 2. Mediterranean countries and coastal regions. Source: [46]. Note: the coastal area of the territory designated in the map as Yugoslavia corresponds nowadays to Montenegro.

create hypothetical markets to directly assess the value. This involves subjecting respondents to a questionnaire or quasi-experiment.

The latter methods are the only options when the assessment concerns an ecosystem or species with non-use values, or when hypothetical policies or scenarios (*e.g.*, future climate change) are being investigated. The two most widely used stated preference techniques are contingent valuation (CV) and choice modelling (CM), which is conjoint analysis with monetary traits. These are survey-based methods in which respondents are asked to state their willingness to pay for enjoying or protecting a natural resource [42,43].

4. Background data on the Mediterranean region

Although it is considered a relatively small marine ecosystem as it only represents approximately 0.8% of surface area of the world oceans, *i.e.*, 2.5 million km^2 [44,45], the Mediterranean Sea connects three continents (Europe, Africa, Asia) and is semi-enclosed by 22 territories.[3] Following the same classification found in [46] these can be divided into three areas:

- Northern-rim countries: Albania, Bosnia and Herzegovina, Croatia, France, Greece, Italy, Malta, Monaco, Montenegro, Slovenia, Spain;
- Eastern-rim countries: Cyprus, Israel, Lebanon, Palestinian Territories, Syria, Turkey; and
- Southern-rim countries: Algeria, Egypt, Libya, Morocco, Tunisia.

In terms of population, in 2010, these countries together had 470.6 million inhabitants, with Egypt being the most populated territory with 81.1 million inhabitants. However, despite their much larger surface area (approximately 70% of the total land area), North African Mediterranean countries had fewer inhabitants than European countries (165.4 million *versus* 195.3 million, respectively). [47,48].

Continental and island surfaces border the sea through 45,830 km of coastline. Greece and Italy have the largest coastlines, namely 15,021 km and 7375 km, respectively. Following [46,47], the Mediterranean area includes 234 coastal regions. In 2005, roughly 30% of Mediterranean countries total population lived in coastal regions, even though this represents only 12% of the total area. Greece, Malta, Cyprus and Lebanon are among the countries with a very high percentage of their populations living in coastal areas (approximately 90% or more). By contrast, Montenegro, Slovenia and Syria had relatively few inhabitants in coastal areas (less than 10%). Fig. 2 presents a map of the Mediterranean countries and coastal regions.

[3] Although Gibraltar (UK) has natural borders with the Mediterranean Sea, this territory was not included due to its statistical irrelevance. Monaco, on the other hand, although also small, was included in line with the normal procedure of statistical departments (*e.g.*, FAO Fisheries and Aquaculture Department).

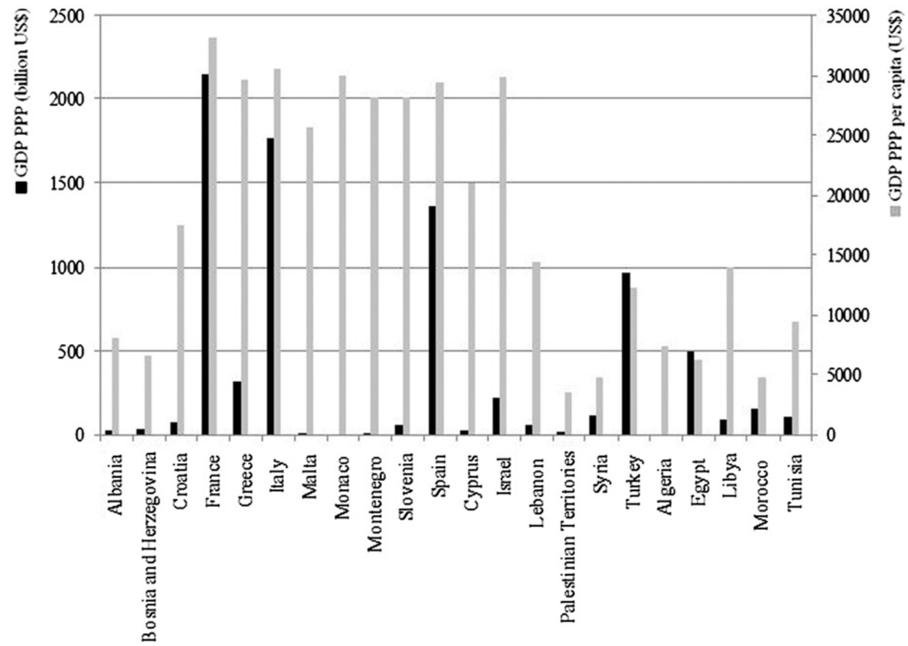

Fig. 3. Mediterranean coastal countries GDP PPP and GDP per capita in 2010. *Source:* [44,49]. *Notes:* data for Monaco and for Palestinian Territories corresponds to 2006. Data were calculated in 2010 US$, with exception of Palestinian Territories which was calculated in 2005 US$.

In 2010 Mediterranean coastal countries altogether reached 11.1% of the world GDP.[4] France, Italy and Spain together represented approximately 64% of the total Mediterranean GDP in the same year. Regarding GDP *per capita*, the upper range of 30,000 — 35,000 US$ was reached by several northern-rim countries. For the other areas, only Israel falls into the same income range. (See Fig. 3)

Regarding the economic relevance of Mediterranean Sea-based activities, a notable fact is that this region is one of leading tourist destinations in the world, with especially France, Spain and Italy being extremely popular. The Mediterranean Sea is, moreover, an important shipping channel, with almost a third of all international cargo traffic passing through it. In addition, despite having a low productivity ecosystem, or in other words, one that is relatively scarce in nutrients, the Mediterranean Sea basin (which, however, also includes terrestrial areas) is one of the world's 25 hot spots for biodiversity, holding 7% of world marine species [44]. The Mediterranean Sea is also characterized by intensive fishing activity, both in terms of capture and aquaculture.

As a consequence of the large number of people living in coastal zones, the intense overall economic activity and a large flow of national and international tourists, the Mediterranean Sea is subject to a range of environmental pressures. Important ones are overfishing, alien species invasion and water pollution [44]. In addition to regional issues, the Mediterranean Sea is also exposed to global environmental changes, such as those related to climate change effects (rise of sea level and water temperature increase) and OA. Synergetic effects among these environmental pressures are poorly understood.

5. Connections between Mediterranean OA and economy

The proposed approach to assess the socio-economic impacts of OA in the Mediterranean is summarized in Fig. 4. The first stage of assessment refers to the evaluation of the ecological impacts of OA. This can be regarded as the result of the work of natural scientists and input to economic analysis. Ecological impacts include effects on benthic, pelagic and other, higher trophic species both commercial and non-commercial and directly or indirectly affected by OA. Impacts on habitats and ecological processes are also included here. Second, one must evaluate how ecological impacts translate to the provision of marine and coastal ecosystem services. Such impacts are likely to differ across different types of ecosystems in the Mediterranean Sea, such as open sea, rocky seabed with photophilic algae, sandy seabed, corallogenic concretions, and seagrass meadows [33]. Areas vulnerable to OA can be identified at this stage. At the third stage, economic theory and valuation methodologies can be applied to assess the socio-economic relevance of these impacts. For a thorough assessment of the impacts of OA on the Mediterranean Sea and its ecosystems, both use and non-use values will need to be assessed and a combination of valuation techniques will be required. The selection of suitable valuation methods will follow from the particular combination of ecosystem or species, sector and type of value to be assessed.

OA may impact several economic sectors in the Mediterranean region, including tourism and recreation, extraction of red coral (*C. rubrum*) for jewellery production, and fisheries (both capture and aquaculture production). Assessing the impacts of OA in the Mediterranean on these sectors requires measuring changes in several socio-economic indicators, *inter alia*, production, employment, income (average level and distribution), and trade. In addition this environmental phenomenon could affect indirect use values, such as those related to carbon sequestration, as well as non-market use and non-use values associated with particular species and habitats. The following sections describe a framework for the evaluation of the socio-economic effects of OA.

5.1. Tourism and recreation

Tourism is a crucial economic sector in the Mediterranean region. In 2007, its coastal countries received 30% of the world's international tourism [44]. The tourism sector and the related coastal

[4] Total GDP and GDP *per capita* were calculated based on the purchasing power parity (PPP) exchange rates, that is, the sum value of all goods and services produced in the country were valued at prices prevailing in the United States [49].

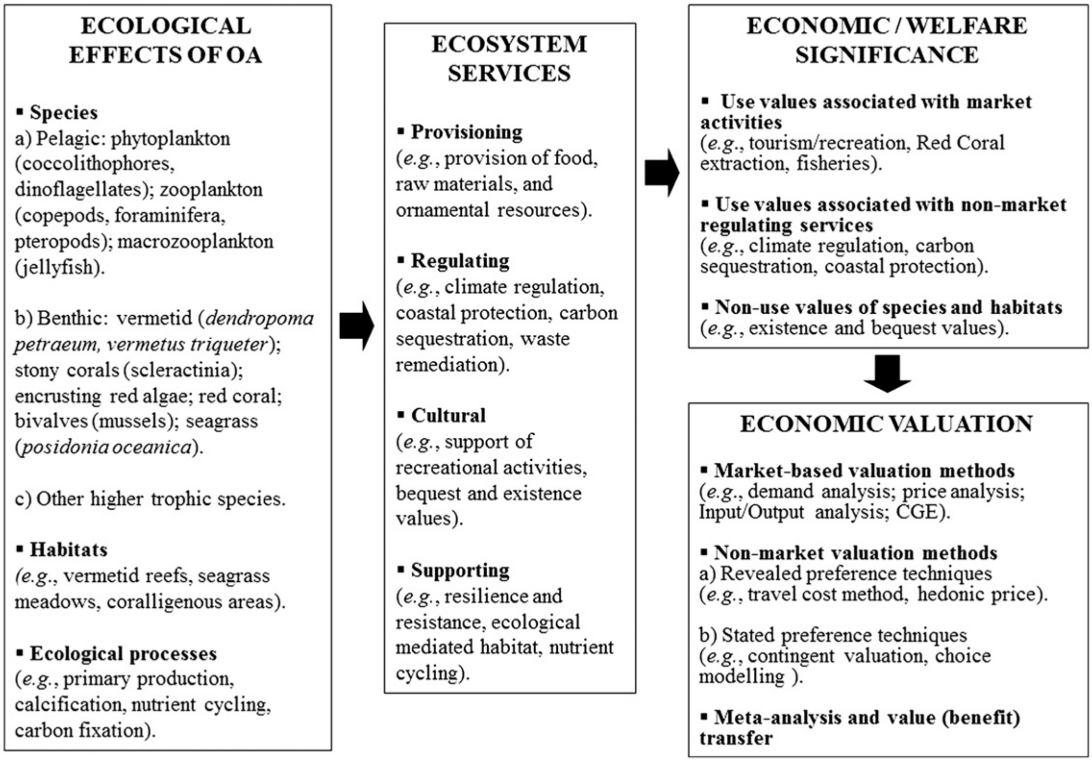

Fig. 4. A framework for valuation of the socio-economic impacts of OA.

recreational activities (*e.g.*, swimming, diving, and recreational fishing) could be affected by several environmental changes related to OA. For example, jellyfish and harmful algal blooms may cause health problems for swimmers, and the reduction of red coral populations may affect recreational divers. The welfare impact associated with possible disruptions of these activities can be reflected by the contraction of market transactions but also remains in a great part outside the scope of market analysis [50]. In order to capture this hidden or non-market value, several techniques can be used: the travel cost method, through the observation of travel behavior of users; or contingent valuation and choice modelling, which assess behavior in hypothetical markets [51]. A particularly relevant issue is how tourists and recreationists respond to uncertainty about impacts of OA, which depends on their knowledge, perception and preferences regarding risk [52]. Economic valuation of the impacts of OA on tourism and recreation should focus on the assessment of the main drivers that determine the attractiveness of coastal areas to visitors and on disentangling the relative contribution of OA, thereupon, from that of other anthropogenic pressures.

5.2. Multiple values of red coral

Red coral (or *C. rubrum*) is an endemic species of the Mediterranean Sea. It is considered vulnerable to OA and in some locations is already facing other pressures such as over-exploitation [53]. This species represents a profitable resource: its calcified axis is used to make jewellery [54]. The importance of commercial exploitation of this resource is due to its high value, the presence of regional industries, and the relevance for international trade [53]. In addition, it attracts recreational divers in the Mediterranean Sea. The degradation of red coral due to OA may thus affect different market benefits, notably income losses in the jewellery and tourism sectors. Given these direct use values, market-based economic valuation tools using market price and demand analysis can be used. Non-market techniques such as travel cost method could be employed to assess hidden market values related to diving.

Red coral populations can also be associated with indirect use values due to their relevance for ecosystem supporting services, in particular as nursery habitat for certain marine species. Important examples are demersal marine fish, cephalopods, and crustaceans species [33]. As a result, the deterioration of coralligenous habitat due to OA could have negative indirect consequences for commercial fishing of any of these. Assessing such links, however, requires a transfer of biological knowledge, and possibly more research, on the various interactions between marine species. For the moment, it seems that red coral is not so extensive that one can expect a very high value of such ecosystem support functions (personal communication with Dr. S. Rossi, ICTA-UAB).

Finally, a pertinent issue regarding the valuation of this species is the need to estimate non-use values, such as existence and bequest values. Humans often value emblematic species and habitats for reasons that do not necessarily include their actual or potential use. Stated preference techniques, namely choice experiments and contingent valuation, are appropriate for dealing with assessing such values.

5.3. Fisheries sector: Capture and aquaculture production

The high intensity of capture fisheries in the Mediterranean Sea represents a serious threat to the maintenance of the fish stocks [44]. Overexploitation is expected to complicate the assessment of OA impacts as the former type of stressor may dominate the latter in the short run. OA evidently is an additional stressor that is capable of threatening the resilience of fisheries. The effects of OA on the fisheries will strongly depend on the degree to which aquaculture production may be controlled and sheltered from its negative impacts.[5] Some

[5] Capture and aquaculture production reflect standard FAO terminology [55]. Capture production here refers to catch of fish in coastal and open sea, while aquaculture production denotes farming of marine organisms, notably fish,

Table 2
Overview of potential economic impacts of OA in the Mediterranean region.

Economic welfare significance		Estimated magnitude of economic effects of OA	Methods for estimating	Difficulties involved
Direct use values	*Tourism and recreation*	+/++ (depending on species, ecosystem and type of tourism/activity)	Market-based valuation (*e.g.*, demand analysis; price analysis; partial equilibrium analysis); Non-market valuation (*e.g.*, travel cost method, hedonic price).	Responses of tourists to biological-ecological; changes are uncertain as there are no concrete field cases reported and thus no empirical studies available.
	Red coral extraction	+/++	Market-based valuation (*e.g.*, demand analysis; price analysis; partial equilibrium analysis)	Over-exploitation and other environmental pressures may dominate the observable effects.
	Fisheries (capture production)	+/++ (depending on the species).	Market-based valuation (*e.g.*, demand analysis; price analysis; partial equilibrium analysis).	Over-exploitation may dominate the observable effects; unknown effects at the individual and ecosystem level; adaptation responses unknown.
	Aquaculture	0/+/++ (depending on the species and type of management)	Market based valuation (*e.g.*, demand analysis; price analysis; partial equilibrium analysis).	Can control avoid any effects?
Indirect economic effects		0/+	Market-based valuation (*e.g.*, input/output analysis; general equilibrium analysis).	Connection of resource-based sectors with the rest of the economy.
Indirect use values	*Carbon sequestration*	+/++	Non-market valuation (*e.g.*, avoided damage of CO_2 emissions).	Uncertainty about the underlying natural processes.
Non-use values	*Existence and bequest values associated with species and habitats*	0/+	Non-market valuation methods (*e.g.*, contingent valuation, choice modelling).	Awareness of relevant species and habitats; it is problematic to assign a value to nature.

aquaculture marine species such as bivalve molluscs need to spend certain periods of their culture in open water, or they are fed by other organisms that grow in open water (*e.g.*, planktonic organisms) [26]. In both cases there is a possible impact of OA. For some countries, seafood is an important part of their income and nutrition, a fact that highlights the need to consider the OA impacts on this sector as well the adaptive capacities [17]. Assessments here mostly involve market analysis. OA has the potential to enforce revenue changes through alterations on fisheries. Through the identification of the commercial species more likely to be affected it is possible to assess their economic value. This logic is followed, for example, by [15], in which commercial marine species are classified into calcifier organisms, related predators and supposedly uninfluenced species. Based on the classification of the most vulnerable commercial species, estimates of physical change in capture and aquaculture productivity under scenarios of OA, which include modelling responses at the ecosystem-level, will allow for the quantification of possible decreases in the value added by those species using the production function method. In addition, changes in consumer and producer welfare surpluses for Mediterranean countries could be assessed.

(*footnote continued*)
molluscs, crustaceans and aquatic plants. This covers various specific activities, such as production, stocking, feeding and protection against predators.

5.4. *Impact of OA on carbon sequestration*

Estimations indicate that oceans currently capture around 25% of the CO_2, emitted by human activities [1,56,57,58,59]. Coastal ecosystems such as estuaries, salt marshes and seagrasses play a particularly crucial role for their capacity as carbon sinks and for their potential role in mitigating the effects of climate change [60]. Assessing the impact of OA on carbon sequestration is thus a relevant component of the economic analysis. Through the ‘damage cost avoided’ method it is possible to estimate the costs of losing carbon sequestration capacity of the sea [61]. These costs, irrespective of whether damage, mitigation or adaptation costs could be regarded as a measure of the costs of losing carbon sequestration capacity.

5.5. *Multiple non-market use and non-use values associated with species and habitats*

Non-use values may be associated with iconic species of the Mediterranean Sea such as red coral (*C. rubrum*) and seagrass (*P. oceanica,* also known as Neptune grass or Mediterranean tapeweed). In addition, some of the species such as *P. oceanica* are habitat-forming organisms, which suggest the need to value both the species and their habitats. Assessing non-use values is not a straightforward process. Added to the difficulty of separating use and non-use values, the estimation of a monetary non-use value of species and habitats may be met with scepticism by the public and policy-makers. For some types of species, ecosystems or biodiversity-related issues, expert views or participatory processes may provide an informative insight (*e.g.*, the importance for ecosystem resilience of soil biodiversity). In addition, one should realize that non-use values often are not expressed as monetary values in the public view but rather as "rights", which evidently cannot be monetized, so that perhaps even the term "value" can turn out to be confusing or misplaced. Nevertheless, specific non-market valuation methods as contingent valuation or choice modelling might be used for the estimation of particular non-use values.

5.6. CGE analysis of economy-wide impacts

Economic impacts of OA will not only involve direct effects on activities that use marine resources but also indirect effects at a larger geographic scale and economy-wide changes. A consolidated method to estimate the overall economic effects is computable general equilibrium (CGE) modelling. One can apply a multi-country, multi-sector economic CGE model to assess – starting from the direct impacts on economic sectors affected by OA – tourism and fisheries, effects on other markets and sectors, income generation, associated consumer expenditures, and international trade. The reduction of tourism flows to Mediterranean coastal areas due to OA may, for instance, lead to income losses in activities within the tourism sector, such as transportation, accommodation, restaurants and food processing industry, or even construction and other services. There is currently much experience with CGE models [39,40,41,62,63,64], though it is necessary to extend the standard framework to give explicit attention to 'ecosystem- or resource-based sectors', specifically adapted to, or connected with, the marine ecosystem.

5.7. Summary

Table 2 summarizes the value categories, methods, problems and hypothesized magnitudes of the effects of OA.

6. Conclusions

Ocean acidification (OA) is an anthropogenic pressure that could weaken the capacity of marine and coastal ecosystems to provide services to humans. Its potential impacts are relevant to the Mediterranean Sea as it includes important sea-based economic activities, notably tourism, extraction of red coral for jewellery production, and fisheries (capture and aquaculture). Additional human benefits might be at stake, such as associated with the disruption of the carbon sequestration service of the sea, which indirectly affects climate stability, and non-use values related to some iconic species, such as red coral and *P. oceanica*, and their habitats. Accordingly, OA may affect multiple nature-dependent human benefits. These include both use and non-use (passive) values, that is, benefits connected to a direct or indirect use of a resource, as well as to intangible benefits (*e.g.*, existence and bequest values), respectively.

This paper has identified and described several economic valuation tools that could be applied to assess such aforementioned impacts. First, using trough market-based techniques (*e.g.*, input/output analysis and partial equilibrium modelling) it is possible to measure the changes in use values that capture the associated monetary value provided by some market transaction. Furthermore, when use values are of a non-market nature but have a behavioral trace in related markets, revealed preference techniques, notably travel cost and hedonic pricing methods could be used. Finally, when there is no trace of a market being connected to a value (*e.g.*, existence and bequest values) the most common approach includes using stated preference techniques such as contingent valuation and choice modelling. Another relevant issue to be considered is the wider socio-economic impact of OA-induced changes in resource based sectors (fisheries, tourism) within the scope of national, regional or international economies. General equilibrium modelling (GEM) is considered to be an appropriate technique to assess such impacts.

To address the socio-economic impacts of OA, one can use scenarios reflecting different reactions of key-stone species, habitats and ecological processes to OA. Based on these, an inventory of the affected ecosystem services can be made according to different types of ecosystems. Through the spatial identification of the most affected ecosystem services it will be possible to estimate the magnitude of the socio-economic costs and classify the economic sectors and Mediterranean regions according to its vulnerability to OA.

Within the different phases of the 'impact chain of OA' several constraints can be observed. First, ecosystems are "complex systems" subject to change, which deeply challenges our understanding of the biological impacts of OA. Indeed, OA is a nonlinear phenomena, characterized by time lags, complex responses at the ecosystem level, spatial heterogeneity, and synergies with other pressure factors, *inter alia*, climate-change effects, overfishing, hypoxia (deoxygenation), and water pollution. This in turn complicates the assessment of accurate economic effects, even for concrete scenarios of OA and other environmental pressures. Second, facing the difficulty of assessing in detail the impact of OA on the entire Mediterranean Sea area requires a pragmatic approach that makes use of techniques such as meta-analysis and value transfer to scale up local, regional or national assessments to a larger geographical area. Finally, one needs to be aware of the fact that measuring non-use values is particularly challenging and requires serious attention.

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