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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.

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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 shell-fish 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

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