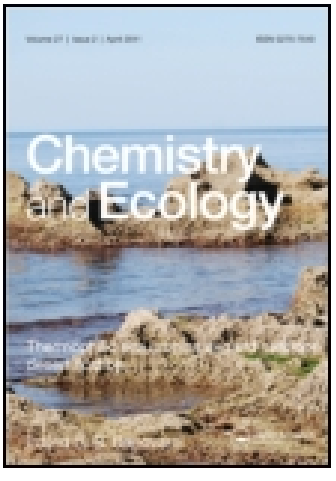

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Climate change, marine policy and the valuation of Mediterranean intertidal ecosystems

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This commentary describes a gap in the qualitative and quantitative knowledge of the provision of benefits to humans from the intertidal ecosystems of the Mediterranean and offers a framework for quantification of the benefits provided by these systems. The identification of such benefits, understanding their spatial distribution and their subsequent quantification will be critical to the design of policy responses to future climate change, sea level rise and seawater acidification. A baseline understanding of the current state of ecosystem functions, as well as of the provision of related ecosystem services, is therefore needed. Further, researchers must strive to generate forecasts of the changes in these functions and services conditional on policy responses and the range of expectations for climate change.

Keywords: Mediterranean Sea; intertidal; climate change; ecosystem services; benefits; economic value

1. Introduction

The Mediterranean Sea accounts for $< 1\%$ of the total ocean surface, but its coasts are home to > 150 million permanent residents. This coastal population doubles in the summer season. Set at the crossroads of international sea-borne traffic and a popular tourist destination, the natural ecosystems and the benefits they provide to this region are threatened by, *inter alia*, urbanisation, pollution and climate change [1–3]. As with many natural systems, intertidal systems are responsible for a range of benefits to humans [4,5]. Among the several supplied by coral reefs, disturbance prevention is strongly associated to reef crests, flats and lagoons [6,7]. Reef flats and lagoons are important nursery and refugium habitats for many coral reef species [8]. Further, these peculiar systems are key to traditional and economic activities such as gathering, subsistence or artisanal fisheries that bear crucial social implications seeing a substantial involvement of women (see for these aspects the series 'Women in fishery information bulletin', http://www.spc.int/coastfish/en/publications/bulletins/women-in-fisheries.html). Salt marshes and mangrove systems play a pivotal role in disturbance prevention [7,9], support coastal and marine fishery [8,10,11]

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and are significant carbon sinks [12]. Rocky intertidal shores worldwide have been, and still are, crucial to our understanding of marine habitat functioning [13], are a destination for leisure, exploration and relaxation [13–15], and are the object of extractive activities for food, bait or ornamental purposes [14,15]. Hence, identifying the benefits provided by the Mediterranean intertidal, and the associated economic values, becomes relevant in the perspective of integrated coastal zone management [3] and under the current climate change scenario.

As described in the conceptual framework of the Millennium Ecosystem Assessment – the international work programme centred on the relationships between ecosystems, ecosystem changes and human well-being – humans depend on ecosystems for life-support, as well as 'spiritual, recreational, educational and other non-material benefits' [16]. Although the term 'benefits' may be unusual to ecologists, it may be useful to quote the definition by Costanza et al. [17] and find a common ground with economists [18]: 'Ecosystem goods (...) and services (...) are the benefits human populations derive, directly or indirectly, from ecosystem functions', the latter referring to the properties or processes of the ecosystems themselves [17]. A summary scheme of the relationships between ecosystem functions and services, the derived benefits to humans and attached values is given in Figure 1 (after [10,16,19]) with specific examples form the Mediterranean rocky intertidal (original examples). A complementary list of ecosystem services following the categories displayed in Figure 1 is given in Table 1 (after [5,20]). Figure 1 also synthesises the utilitarian value paradigm, centred on the human sphere and grounded on two main categories of values that humans derive from ecosystems: use and non-use values. Use values are received by direct or indirect interaction with the ecosystem in question (respectively, direct use values such as recreation and extractive activities, and indirect use values such as habitat provision and erosion regulation). Use values also include option and quasi-option values, respectively associated with benefits that may be derived from an ecosystem at some time in the future, and with delaying irreversible loss of a natural asset before uncertainty about the benefits of the asset is resolved. Non-use or existence values are those associated with benefits not involving any interaction with the ecosystem. For example, existence values can be observed in individuals' willingness-to-pay for the protection of ecosystems they will never visit. Bequest values, i.e. the values deriving by knowing that an ecosystem or a service will be passed on to the next generation, are also included in the non-use category. Together, use and non-use values form the Total Economic Value (TEV) of a natural asset [21,22]. This paradigm is strictly anthropocentric and implies the direct or indirect satisfaction of humans, whereas non-utilitarian paradigms recognise that ecosystems have a value per se (intrinsic value), irrespective of any mediation by human appreciation. Although other managerial bases exist grounded on non-utilitarian paradigms [16], the translation of ecosystem benefits into monetary terms makes their quantification explicit and allows for direct computation, for example, into cost–benefit analysis models. The valuation of ecosystem services, i.e. attaching a monetary value to the benefits provided by ecosystems, is a strong support to decision-making, as well as in forecasting the differential outcomes of alternative management strategies [16,17]. However, attaching a value to ecosystem benefits is not always straightforward. Where natural goods and services can be traded in the market, as for several direct use values, market prices are taken into account. More often, this is not the case and non-market techniques must be used. The latter involve the observation of human choices [revealed preference methods, e.g. Travel Cost Method (TCM) and Hedonic Prices (HP)] or the direct elicitation of hypothetical choices [stated preferences methods, e.g. Contingence Valuation Method (CVM) and Choice Experiments (CE)]. A detailed review of the theory of ecosystem valuation is beyond the scope of this article, but those interested will find useful introductory background elsewhere [16,17,19,22,23].

This commentary describes a gap in the qualitative and quantitative knowledge of the provision of benefits to humans from the intertidal ecosystems of the Mediterranean and offers a framework for quantification of the benefits provided by these systems. The thorough identification of these benefits, the understanding of their spatial distribution and the subsequent quantification of the

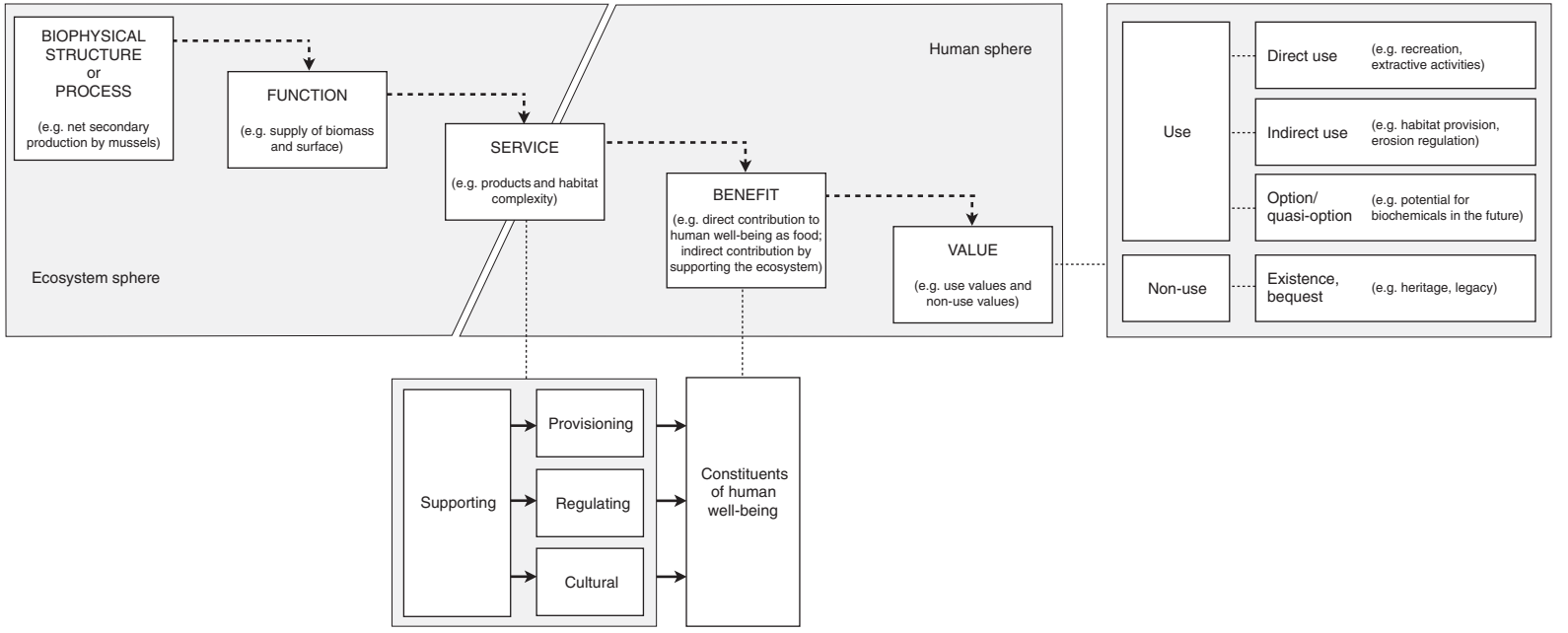

Figure 1. Relationship among functions, services, benefits and values with examples from the Mediterranean rocky intertidal. Solid arrows indicate direct influences between blocks. Adapted from Barbier [10], MEA [16] and Mangos et al. [19].

Table 1. Tentative list of ecosystem services and goods provided by the Mediterranean rocky intertidal ecosystems.

Services and goods category	Mediterranean rocky intertidal	Extra-Mediterranean rocky intertidal
Provisioning		
Food[1]	x[a]	x
Fibres[1,3]		x[b]
Genetic resources[1,2]	x	x
Biochemicals, natural medicines, pharmaceuticals[1,2]	x	x
Ornamental resources[1,2]	x	x
Human habitation[1]		
Human navigation[1]		
Energy (for human use)[1]		
Regulating		
Air quality regulation[1]		
Climate regulation[1,2]		
Erosion regulation[1]	x	x
Water purification/waste treatment[1,2]		
Disease regulation[1]		
Pest regulation[1]		
Pollination (and seed dispersal)[1,2]		
Natural hazard regulation[1]		x
Freshwater storage and retention[1,4]		
Gas regulation[1,2]		
Disturbance prevention[2]		?
Biological control[2]		?
Cultural		
Cultural diversity[1]		
Spiritual and religious values[1,2]	x[c]	
Knowledge systems[1,2]	x	x
Educational values[1,2]	x	x
Inspiration[1]		?
Aesthetic values[1,2]	x	x
Social relations[1]	x	x
Sense of place[1]		
Cultural heritage values[1]	x[d]	x
Recreation and eco-tourism[1,2]	x	x
Artistic info[5]		?
Historic info[6]		?
Supporting		
Habitat and refugia[1,2]	x	x
Photosynthesis[1]	x	x
Primary production[1]	x	x
Nutrient cycling[1,7]		
Water cycling[1,8]		
Soil retention[2]		
Soil formation[2]		
Nursery function[2]		?
Organic matter cycling*		
Provision of food to adjacent systems*	x	x
Provision of organisms to adjacent systems*	x	x

Note: The list is based on Wilson et al. [5] and Raheem et al. [20], amended and integrated according to the Mediterranean setting. *Original categories; [1]from Raheem et al. [20]; [2]from Wilson et al. [5]; [3]"Raw material" in Wilson et al. [5]; [4]"Water supply" in Wilson et al. [5]; [5]"Cultural and artistic info" in Wilson et al. [5]; [6]"Spiritual and historic info" in Wilson et al. [5]; [7]"Nutrient regulation" in Wilson et al. [5]; [8]"Water regulation" in Wilson et al. [5]. ?, services that might be provided but further evidence is required. [a]Direct consumption, bait; [b]algal biopolymers; [c]religious events take place there; [d]traditional extractive activities.

attached values will be critical to the design of policy responses to future climate change, sea level rise and seawater acidification. A baseline understanding of the current state of ecosystem functions, as well as of the provision of ecosystem services, is therefore needed. Further, researchers must strive to generate forecasts of the changes in these functions and services conditional on policy responses and the range of expectations for climate change.

2. What is known about the economic values of the Mediterranean intertidal?

'INTERMED – The impact of climate change on Mediterranean intertidal communities: losses in coastal ecosystem integrity and services', is a CIRCLE-MED project that aims to evaluate climate change impacts on intertidal communities in the Mediterranean basin taking socio-economic consequences into account. Intertidal ecosystems are defined as the benthic marine environments between the high and low tide lines along the coasts. These systems provide extensive ecosystem services and goods, sustaining the well-being and economy of coastal populations throughout the world. Among the ecosystem services and goods provided by intertidal habitats worldwide are disturbance prevention, nutrient regulation, nursery and refugium functions, provision of food, and many others depending on the specific intertidal habitat [4–15].

Preliminary results from INTERMED (this issue) indicate that the Mediterranean intertidal may not be easily compared with any other, primarily because of the very limited amplitude of tidal span in the basin (between 30 and 50 cm, with the notable exception of North Adriatic Sea and Gulf of Gabes). Although the bio-ecological implications of this are being addressed under the climate change perspective (this issue), this commentary considers the socio-economic consequences of such differences. It may be useful to mention that the results of the current analysis, which was primarily focused on climate change impacts in the frame of the abovementioned project, may also hold for other relevant drivers such as pollution and overharvesting.

The unique bio-geography of Mediterranean intertidal systems suggests that they are poor candidates for the 'benefit-transfer' method of valuation, whereby aggregate estimates of economic values derived for similar systems elsewhere are applied to a particular natural system of interest. A first step then is to determine if any original research in the Mediterranean has found estimates of economic values of intertidal ecosystems. We carried out a systematic review process focusing on the following initial questions: (1) Can we identify quantitative records of the flows of benefits (ecosystem services) from Mediterranean intertidal systems to humans? and (2) How do residents and visitors perceive and value these systems? The systematic review process involved searching three databases (Scirus, ISI Web, JSTOR) for the following keywords: Mediterranean intertidal AND: econom*; valuation; attitude; perception. The search yielded a total of 1251 documents, but none actually relevant to the questions above. Indeed, very few deal, even partially, with the valuation of intertidal systems [5,14] and none directly addresses the Mediterranean intertidal. In spite of further search using these sources' reference lists and other libraries (i.e. EVRI, http://evri.ca), almost no paper/report specifically dealing with the socio-economic evaluation of the Mediterranean intertidal was found. This dearth of knowledge is not very surprising given the scant literature concerning the economic valuation of the Mediterranean Sea, in general [19,23]. The Plan Blue report [19] is likely the most up-to-date and complete analysis of the benefits and values provisioned by the Mediterranean Sea. Although offering invaluable information, especially precious in the generally poor scenario of valuation studies for the basin, it focuses on a set of services and aggregate ecosystems selected because of their clear relevance and on the basis of available data. Ideally, and whenever possible, ecosystem functions, services and benefits should be addressed at a variety of scales to capture discontinuities and peculiarities that might otherwise go unnoticed [16]. Unfortunately, not even here it is possible to find intertidal-specific data, which

indirectly confirms our (lack of) findings. Finally, no source concerning the perception/attitude of people towards the Mediterranean intertidal could be found.

Although apparently similar, the Mediterranean intertidal has little in common with that of other basins. As such, benefits, uses and research in the intertidal of other basins cannot be easily translated to the Mediterranean Sea, nor can the valuation of such uses [15] be transferred to this basin. Key intertidal habitats such as mangroves and upper coral reefs, which have received considerable attention from bio-economists (reviewed in [5,20]), do not exist in the Mediterranean basin. Mediterranean lagoons have been addressed in a number of studies [24–26]. However, these do not pertain to the intertidal proper and, despite their ecological and economic importance, represent a very limited fraction of the Mediterranean coastline which is, *de facto*, characterised by rocky shores or beaches (the latter ranging from sand to gravels/pebbles). Although the ecosystem services identified in Table 1 for the Mediterranean intertidal are likely also provided in other regions, we expect their magnitude, intensity and ecological/economic relevance to vary in the different basins and with the different socio-economic settings, and to be a nonlinear function of the amplitude of the intertidal habitat itself. Furthermore, the very limited range of the Mediterranean intertidal may influence the perception and even awareness of the public relative to areas where tidal flats are a common leisure ground. Public perception and understanding of natural assets, ecosystem functioning and of the services they provide is crucial not only to conservation, but also to quantification of the benefits that humans derive from the environment. These are likely to go unnoticed or underestimated, especially when associated with indirect use or non-use values [16]. A similar situation has recently been described for deep-sea habitats which, being far from reach to most, and still highly unresolved to science, are hardly taken into account as a component of human well-being and do not usually show up in current policy making schemes [27].

3. Qualitative information to inform predictions of benefits lost from Mediterranean intertidal systems due to climate change

There is some research that sheds light on the ecological importance of Mediterranean intertidal habitats, which expressly refers to rocky shores. These are biologically rich and diverse habitats (see, for example, the species lists provided in [28–31]), a diversity multiplied from the local scale up to the basin level by the interplay of biotic and abiotic factors such as interaction among species, exposure, microtopography, island or mainland location and latitude. The presence of ecosystem engineering species also plays a crucial role here, where their disappearance is typically associated with radical changes in the structure of the assemblages. Therefore, it is not surprising that several such key organisms are protected at the international level (according to the following documents: Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean – SPA/BD Protocol, [32]; Convention on the Conservation of European Wildlife and Natural Habitats – Bern Convention, [33]; Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora – Habitats Directive [34]). The genus *Cystoseira*, for example, includes low-shore canopy algae responsible for habitat formation for sessile invertebrates requiring high humidity and low light levels, such as sponges and tunicates [30,31,35]. This supporting service would otherwise not be present in intertidal habitats. Loss of *Cystoseira* canopies results in disruptions to habitat complexity and species diversity patterns, and in the development of algal turfs associated with low-abundance invertebrate assemblages [31,35]. Several *Cystoseira* species are listed in Annex II of the SPA/BD Protocol and in Appendix I of the Bern Convention.

The gastropod *Dendropoma petraeum* is an intertidal reef-building organism, characteristic of southern Mediterranean latitudes from southern Spain to Sicily and along the entire North

African coast [36]. As well as providing a three-dimensional structure for low-shore organisms, *D. petraeum* is identified as a powerful tool to track sea-level and sea-surface fluctuations in the basin [36]. Because of its extreme sensitivity to disturbance and its low growth rate, the species has been listed in Annex II of the SPA/BD Protocol and in Appendix II of the Bern Convention. The same holds for intertidal reef-forming Corallinaceae of genus *Lithophyllum*.

Mytilus galloprovincialis is an edible mussel, widespread in the intertidal and shallow subtidal throughout the Mediterranean Sea, where it is also cultured. The loss or reduction in natural *M. galloprovincialis* populations [37] and in another autochthonous element of bivalve fauna, *Mytilaster minimus* [38], has been shown to produce changes in the associated assemblages, enhanced when the contemporary reduction in canopy-forming algae occurs [39]. Although not an endangered species its presence and abundance might be altered by the establishment of invasive species like the mussel *Brachidontes pharaonis* [40].

While becoming increasingly aware of the complexity and ecological value of these systems, we also need to know the potential and realised effects that disturbances may have on them. Benedetti-Cecchi et al. [35] found that anthropogenic disturbances and an altered scheme of climatic variance [41] may be responsible for the decline of intertidal populations. However, this knowledge is not definitive and further research is necessary to determine the likelihood that climate change will further the loss of this habitat and reduce the abundance of food and bait species. The narrow range of the intertidal in the Mediterranean has particular implications for its resilience to climate change and sea level rise. For example, in the Mediterranean, the potential harsh effects of tidal aerial exposure on the ecological responses of intertidal organisms is, in fact, usually buffered by wave splashing [37]. This might help limit the otherwise detrimental impacts of increasing aerial temperature and dryness on organisms. However, the limited amplitude of the Mediterranean intertidal implies a very small optimal range of environmental features. As such, some species may be able to adapt and migrate as sea levels rise, but others will not.

Connectivity in other marine systems such as coral reefs is known to be critical for quantifying the benefits of these systems [42–44]. Set at the interface between land and open sea, the intertidal likely exchanges functional support with adjacent ecosystems (supralittoral/adlittoral systems, lagoon/estuaries and subtidal habitats). These are known to provide benefits but the extent to which they depend on the intertidal is not known.

Further to the still scant knowledge concerning the actual functioning of the Mediterranean intertidal and of the delivered services, there is virtually no information available on the uses (direct or indirect) that people make of them, or on the attached values. Many invertebrates housed in the intertidal, facilitated by the presence of the abovementioned habitat-forming species or flourishing on intertidal biogenic reefs are harvested for food and bait, a practice often associated with local traditions. Assessing the cultural and traditional relevance of intertidal systems and species to the local human communities would be helpful in highlighting overlooked benefits that have been not yet captured by valuation studies [16]. Anecdotal observations (see for example [45]) are consistent with the demonstrated decline in some intertidal species due to over-collection. The limpet *Patella ferruginea* has been chronically removed throughout the basin and is now listed in Annex II of the SPA/BD Protocol, in Appendix II of the Bern Convention and in Annex IV of the Habitats Directive as a threatened/endangered species. However, official quantitative data concerning the extent and the economic value of such extractive activities are generally missing (but see [46], where shellfish collection on the rocks accounts for $\sim$ 13% of the total recreational fishing in the Natural Park of Cap de Creus, Spain). Tourism, and particularly eco-tourism, are likely large components of the overall benefits of intertidal systems. Eco-tourism is an increasingly popular phrase used to draw tourists to destinations in the Mediterranean. Stylistically, there may be a relationship between the health of the ecosystem and tourists' eagerness to visit a site or their willingness to pay for the experience (see, for example, [47–49]). Whether this relationship holds for the status of Mediterranean intertidal systems cannot be inferred on the basis of the

published literature. The studies above, for example, refer to beaches and leisure settings as aggregate objects, including an array of different habitats essentially adjacent to the intertidal, and not to the latter specifically. However, anecdotally, there are regions where the health of the intertidal is correlated with tourism demand. For example, Cala Cote, on the Island of Capraia is both one of the most visited sites and one of the shores where the topshell *Osilinus turbinatus* is most abundant. This gastropod has been extensively harvested and nearly driven to extinction in other places (unpublished data in [45]). The relationship between the demand for tourism and the quality of intertidal habitats is important to quantify. This information will be critical for policy makers in nations where tourism makes a significant contribution to national income.

4. Valuing the Mediterranean intertidal and predicting changes: future directions

We suggest a two-pronged approach to address the knowledge-gap described here: (1) ecological field research and modelling to compile an inventory of intertidal ecosystem functions (also determining their current state), to identify the associated services and to predict responses to climate change; and (2) identify and quantify the benefits derived from such services (and the changes thereof). This will be done by acquiring and using existing data from governments and tourism industry sources (to determine the scale of intertidal-related tourism and describe its spatial distribution) and by surveying direct and indirect users of these systems (to determine baseline values and predict responses to changes in ecosystem health and function). The latter point should also take due care of cultural and traditional aspects, which may primarily be associated with local users.

Ecological research must explore the connectivity between the intertidal and its directly adjacent systems. This is essential to provide further insight into the benefits it contributes. However, adjacent systems may influence the intertidal through the interplay with anthropogenic and climatic drivers. Predictions of the future state of the Mediterranean intertidal and adjacent systems are needed to inform any forecasts of their value (including that derived from direct use by tourism or extractive activities). What will intertidal (and adjacent) regions in the Mediterranean look like as sea levels rises, and the sea warms and acidifies? Which species will adapt and persist and which will be lost? Will conditions improve for nuisance species to encroach on valuable habitat or recreational sites?

Long-term data on tourism and extractive activities associated with intertidal habitats may not exist in many cases. But to the extent that governments and private entities have collected data on the spatial distribution of tourism and the associated expenditures, researchers should acquire these data. Existing data may allow for reduced form relationships between habitat condition and economic outcomes to be estimated. This may help predict long-term changes to the spatial patterns of tourism and extractive activities. These relationships may also help to identify priority subregions for research and for conservation policy.

Social scientists should identify the direct users (extractive and non-extractive) of these habitats. Stated-preference and other surveys of these individuals are required to fill the gap where data on these activities are missing. Extractive users should be surveyed to determine which species are extracted and for what they are used. If harvests are sold, market prices will be needed. If the harvests are consumed or used as input for other production (e.g. fishing bait), the market prices of substitute inputs should be collected. The knowledge, perception and preferences of non-extractive users of the intertidal, including local populations, are vital to complete the research agenda. This may again relate to tourism, but also to other forms of uses rooted in the local heritage. In concert with predictions of the future state of these ecosystems, the factors influencing cultural services will need to be determined. What features of the ecosystem and its functions are important to

draw people to intertidal areas? Which species are they aware of, which species do they like to see and which do they dislike? What types of changes would discourage them from returning? These questions must be scoped by cooperation with ecologists [18].

This commentary highlights a gap in policy-relevant ecological and economic knowledge in the Mediterranean. The unique nature of these intertidal systems suggests that original research should be conducted to further the understanding of the function of this system and the knowledge, beliefs and preferences of those who benefit from it. Given the highly complex nature of this coupled natural and human system, it is vital that ecological and socio-economic research be undertaken in parallel and in concert. The information provided by this research will only be of use to policy makers if the results are complementary so as to provide conditional forecasts of ecosystem function and benefits.

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