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Original Article

When ecosystems and their services are not co-located: oceans and coasts

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Local, regional, and global policies to manage protect and restore our oceans and coasts call for the inclusion of ecosystem services (ES) in policy-relevant research. Marine and coastal ES and the associated benefits to humans are usually assessed, quantified, and mapped at the ecosystem level to inform policy and decision-making. Yet those benefits may reach humans beyond the provisioning ecosystem, at the regional or even global level. Current efforts to map ES generated by a single ecosystem rarely consider the distribution of benefits beyond the ecosystem itself, especially at the regional or global level. In this article, we elaborate on the concept of "extra-local" ES to refer to those ES generating benefits that are enjoyed far from the providing ecosystem, focusing on the marine environment. We emphasize the spatial dimension of the different components of the ES provision framework and apply the proposed conceptual framework to food provision and climate regulation ES provided by marine and coastal ecosystems. We present the different extents of the mapping outputs generated by the ecosystem-based vs. the extra-local mapping approach and discuss practical and conceptual challenges of the approach. Lack of relevant ES mapping methodologies and lack of data appeared to be the most crucial bottlenecks in applying the extra-local approach for marine and coastal ES. We urge for more applications of the proposed framework that can improve marine and coastal ES assessments help fill in data gaps and generate more robust data. Such assessments could better inform marine and coastal policies, especially those linked to equal attribution of benefits, compensation schemes and poverty alleviation.

Keywords: conceptual framework, ecosystem services, human dimension, mapping, telecoupled systems.

Marine and coastal ecosystems and associated services

Marine and coastal ecosystems support human populations around the globe through food provision, natural, and cultural heritage, protection from natural disasters, and other services (Adger *et al.*, 2005; Martínez *et al.*, 2007). Marine resources affect not only people that are located close to them, but through trade they also provide benefits and sometimes create costs for people around the globe (Fabinyi *et al.*, 2014; He, 2015). The high recreational value of coastal areas and oceans is experienced locally

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through the enjoyment of a seascape or charismatic species (Willemen *et al.*, 2015) and globally through tourism (Rees *et al.*, 2010). Coastal mangroves, seagrass beds and salt marshes regulate the global climate through carbon sequestration (the so-called "blue carbon") that benefits humans globally (Pendleton *et al.*, 2012).

The Anthropocene era (Ellis, 2015) has brought heavy pressure on ocean socio-ecological systems through the overexploitation of living oceanic resources (e.g. through fisheries and aquaculture) (Österblom *et al.*, 2015), coastal development, and through increasingly busy and environmentally damaging shipping routes (Corbett and Koehler, 2003). These over-used and highly crowded ecosystems, although vital for our survival, are under threat and require science-based policies to ensure their ecological sustainability and economic viability. Spatial information is critical to inform the design of pragmatic ocean policies (Young *et al.*, 2007), by highlighting for instance the way marine resources are distributed around the globe through trade.

Such policy instruments are for instance maritime spatial planning (MSP) and the establishment of marine protected areas (MPAs), increasingly employed to manage the use of the marine environment by different sectors from the local to national level (Chaigneau and Brown, 2016). Such instruments set spatial boundaries to help manage the impact of human activities; delimit areas of sustainable human intervention; or to identify areas aimed at protecting high value for biodiversity or associated ecosystem services (ES).

Although marine spatial planning has long involved mapping ecosystems and human activities that affect them, increasingly spatial planning requires an understanding of the benefits generated through marine ecosystem services (MES) (Katsanevakis *et al.*, 2011; White *et al.*, 2012), and identification of the associated beneficiaries to account for the social drivers of ecosystem change. Including MES in the maps used for MSP and MPA design is straightforward when the benefits and costs of MES (and the people who are affected) occur in the ecosystem where the MES occurs (e.g. local use of beaches or reefs). Such an approach becomes more challenging when the beneficiaries and those who bear the cost of MES may live far from the ecosystem where these goods and services (or disservices) are produced. (Note, henceforth for simplicity we refer to both costs and benefits as just benefits and ES and disservices as services, but remind the reader that our discussion and examples apply to both positive and negative impacts.) For instance, carbon stored by mangroves may benefit stakeholders around the world by mitigating the impacts of climate change (Conchedda *et al.*, 2011) while generating local opportunity costs from foregone agriculture or shrimp farming (Richards and Stokes, 2004; Pendleton *et al.*, 2012). Tuna caught in the Indian Ocean may be captured by nomadic fleets, processed in a different location, and sold in markets around the world (Pacific Possible. The World Bank, 2016). Incorporating these "extra-local" benefits into marine spatial planning and MPA assessment requires finding ways of assessing and mapping MES that do not occur in the ecosystems where they are produced. This challenge is even more pronounced in the high seas, where new regional and global efforts are underway to create MPAs to manage these vast and dynamic ecosystems that are invaluable to society even though they are far from people (Sumaila *et al.*, 2007).

Beyond spatial planning, ES assessments have been used to highlight and raise awareness on human-nature interactions, and draw attention to potential bottlenecks in science-policy-practice dialogues. Significant efforts have been made, especially over the last decade, to use and adapt ES methods to incentivize people towards a more sustainable use of marine resources, show the magnitude of problems related to overexploitation, and propose sustainable solutions (Liquete *et al.*, 2013b; Townsend *et al.*, 2014; Tempera *et al.*, 2016). Simultaneously, efforts that attempt to account for interactions between human and natural systems across distance, referred to as telecoupling (Liu *et al.*, 2013, 2015), are on the rise. Still, such an ES approach (that takes into account the interactions between humans and nature across distances or across changing temporal or spatial scales) focusing explicitly on the marine and coastal environment is lacking.

In this work, we aim to highlight the importance and challenges of mapping MES that are not co-located with the ecosystems that produce them, hereafter called "extra-local" ES. To do this, we propose a framework that builds on existing frameworks for ES assessment and mapping, and integrates concepts from the literature on ES benefit flows and telecoupled human and natural systems. We then demonstrate the validity of the framework using two examples of marine ES, identify gaps in data and assessment methods, and give recommendations for future research and data collection to support mapping of extra-local marine ES.

The emergence of frameworks

A number of frameworks exist to describe human-nature interactions in order to assess, map and model ecosystems and their associated services (Haines-Young and Potschin, 2010; Díaz *et al.*, 2015). Recently such frameworks have been tailored to explicitly consider the spatial or scalar mismatch between humans and nature (Syrbe and Walz, 2012; Liu *et al.*, 2013, 2015; Serna-Chavez *et al.*, 2014) and account for cases where a human action in one ecosystem can impact the condition of a different ecosystem. Furthermore, while several frameworks have been designed to address MES, they do not take into account the spatial disconnect between marine ecosystems and the people who depend upon them (Böhnke-Henrichs *et al.*, 2013; Liquete *et al.*, 2013a).

An increasing part of the ES literature focuses on the spatial differentiation between ecosystems and human beneficiaries. Syrbe and Walz (2012), Serna-Chavez *et al.* (2014) and others have defined four types of relationships that can be used to account for the spatial interaction among the locations where ES are produced [service providing area (SPA)], the locations where benefits are enjoyed [service benefiting area (SBA)], and the locations that connect those two [service connecting areas]. The spatial relationships are defined as: (i) spatial co-occurrence between SPA and SBA spatially; (ii) SBA extends beyond SPA; (iii) the SPA is connected with SBA through a connecting area, which distributes the benefits to one or many directions; (iv) scale-divergent ES, to account for services (e.g. carbon sequestration) where the SPA and SBA are in different spatial scales (e.g. local to global).

The significance of the distant interactions among humans and ecosystems, [points (iii) and (iv) above] has been explicitly addressed in the last few years with targeted research on the topic—albeit with a terrestrial focus. Liu *et al.* (2013) as part of their work on coupled human and natural systems emphasize interactions between social and ecological systems over distances, what they call "telecouplings". One of the benefits of this approach lies in its capacity to highlight the significance of distant interactions and help identify and mobilize governance mechanisms in different locations across the human and natural system of reference.

Understanding these processes across space is essential in the present era, where the management of socio-ecological systems locally, can induce impacts globally. Mapping can account for the spatial dimension (Clec'h *et al.*, 2016), and also illustrate the spatial or scalar differentiation among ecosystems, services and beneficiaries. Spatial boundaries are a key element needed to map ecosystems, services, and the distribution of benefits, and consequently defining access rights to natural resources for users and beneficiaries (Ostrom, 2007). Therefore, the spatial dimension needs to be clearly identified and spatial boundaries need to be set, for mapping to be able to inform decision-making. Within the marine socio-ecological systems literature, spatially explicit assessments that can highlight all of the above are lacking.

The case of marine ecosystems

To date, attempts to map and model spatially distant ecosystems and services have been applied in very few cases to the marine environment (e.g. Kittinger *et al.*, 2015). Adapting and integrating the existing approaches of ES assessment and mapping to the marine environment requires taking into account the challenges that confront those working with marine ecosystems (Leenhardt *et al.*, 2015).

Much of the world's marine ecosystems are poorly mapped and understood compared with terrestrial environments. One major reason for this is that marine ecosystems, habitats, and species may not be bound by spatially explicit boundaries (Klain *et al.*, 2014) and in fact some marine scientists consider the world's oceans as a single ocean ecosystem (O'Dor *et al.*, 2009). In addition, specific challenges exist for mapping MES (Jobstvogt *et al.*, 2014; Townsend *et al.*, 2014). Marine ecosystems and environments are highly dynamic in nature, especially in the pelagic zone (Webb *et al.*, 2010). Currents, daily vertical and seasonal lateral migrations, and seasonal changes in basic physico–chemical conditions, may cause important ecological attributes to vary minute-to-minute, season-to-season, and year-to-year. Due to the lack of complete datasets, averaging data over time and space is often necessary; hence the level of spatial accuracy for MES information, including social data, is low. Information on the distribution of habitat is scarce or patchy for most of the world's marine ecosystems (Townsend *et al.*, 2014). The ecological functions and processes required to produce many ES, such as biological control on the spread of vector borne human diseases, are poorly understood or not easily quantified (Goffredo *et al.*, 2014). Social and economic data on ES demand are incomplete or not collected for ES with low economic value, and may be challenging to collect for sensitive or proprietary ES with high commercial value (e.g. food provision from export fisheries) (Conchedda *et al.*, 2011). The significant remaining uncertainty underlying some types of marine ES data and maps is so high that researchers have been reluctant to map them, slowing the development of this important area of research (Leenhardt *et al.*, 2015).

Nevertheless, the mapping of MES continues to move forward. Still, existing analyses and future data collection need to be guided by recognition of the importance of "extra-local" ES if these maps are to give an accurate and policy-relevant representation of the distribution of ES benefits. By considering the specific challenges inherent in marine and coastal ecosystem research, along with the knowledge gained from terrestrial ES research, we propose an adapted framework that facilitates quantification and mapping of the marine and coastal "extra-local" ES, whose benefits are enjoyed far from the ecosystem that provides them.

An integrated framework

We propose a framework that integrates existing knowledge from ES provision frameworks (e.g. Haines-Young and Potschin, 2010) with the spatially explicitly approaches outlined by Syrbe and Walz (2012) and the telecoupled approach of Liu *et al.* (2013), to demonstrate how a more complete spatial representation of MES could be created. More specifically, we use a conceptual framework of ES provision which assumes that ecological functions, characterized by ecological attributes, generate ecological outcomes that generate both benefits and costs (including positive or negative externalities) that have different types of impacts on the wellbeing of people (Figure 1). More specifically, in this framework:

(i) The ecosystem (E) is the place where biotic and abiotic elements interact with each other resulting in ecological functions that generate ecological outcomes.

(ii) Ecological outcomes can benefit people directly or indirectly through interim processes (IPs), and collectively these outcomes are referred to as ES.

(iii) These ES provide benefits (B) associated with the ES. Those benefits can be assessed in a variety of ways, including lives affected, nutritional value, and other economic and non-economic measures of human wellbeing. Note that our definition of benefits is broader than traditional welfare economic measures of final benefits (Ringold *et al.*, 2013) and recognizes that some outcomes (e.g. jobs) that would be considered "costs" in a neo-classical economic approach could be viewed as benefits to individuals, depending upon one's perspective. Similarly, we consider the value added or lost (indicated as $\pm$ in the figure) along each step of the process (including those associated with positive and negative externalities) to contribute to the net benefit (NB) felt at each spatial scale. These benefits may occur at the ecosystem level, through the IPs and/or downstream of the process chain. The benefits that occur throughout IPs we refer to as interim net benefits.

(iv) The operational space (s) for each component in this framework is defined as the spatial territory, namely both the location and extent where each framework component spatially occurs.

When services and benefits occur in the same area, mapping the human benefits that flow from an ecosystem is straightforward (e.g. when one looks at a salt marsh and derives aesthetic benefit). In most cases though, interim steps occur between the ecological outcome and the final NB. An ecological outcome may generate different types of benefits to humans through varying IPs (e.g. fish harvest could generate benefits to the fisher, processor, and to the final consumer). In Figure 1, arrows identify the different steps that occur within this process, and show generically the different interim "goods or services" (ES) and the associated net benefits (IB) that could be generated.

Ecological outcomes and human NBs can either occur in the same space ($s1 = sN$), or benefits can accrue to people in different

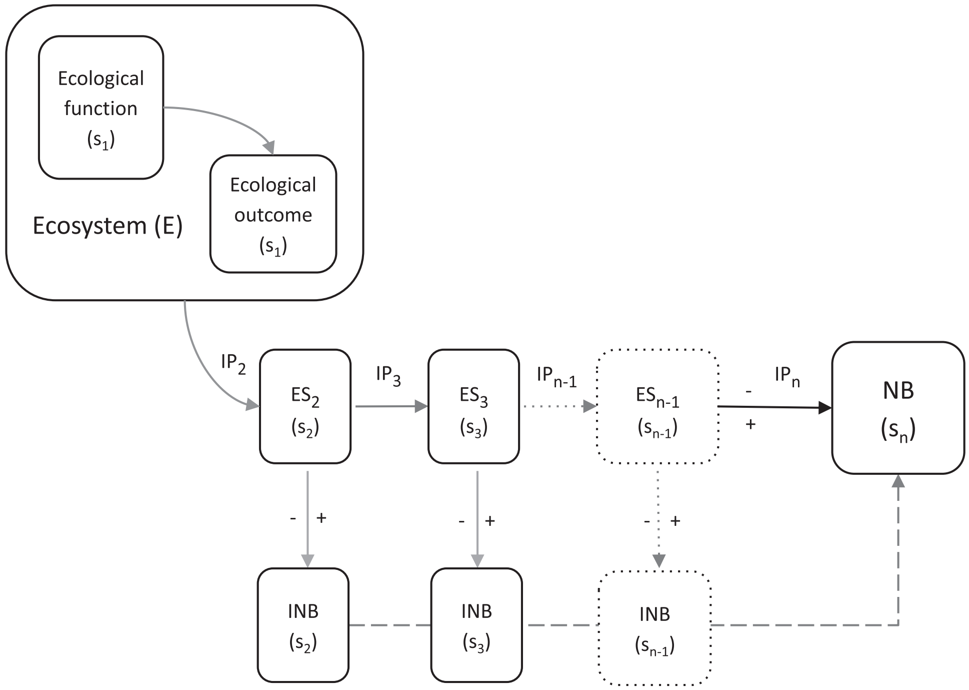

Figure 1. The proposed extra-local ES provision framework. The ecosystem (E) is home to ecological functions that generate ecological outcomes in space s1. Through interim processes (IP) taking place in locations s2, s3,...,sN−1, generated ES provide benefits (B), either throughout the process, interim benefits (IB), or at the end of the process chain. Applications of this framework are given in Figures 2 and 3.

spaces (s1 ≠ s2 ≠ s3 ≠ . . . .≠ sN). It may be that the ecological outcome is transported away from the ecosystem and the NB is received in a different space without interim steps in the ES provision process (e.g. the aesthetic benefit generated by an osprey that that lives near the coast, but may be seen far inland). In other cases, different processes take place before the ecological outcome reaches the beneficiary, each of which can occur in a different space (e.g. an export fishery where fish are harvested in one location, processed in a second location, and consumed in a third location while generating costs to the environment, for instance through pollution due to transportation or the generation of waste).

We call the benefits that occur in a space different from the ecosystem (where s1 ≠ sN), "extra-local" ecosystem benefits. The concept of "extra-local" has been used in ES research to refer to beneficiaries of some ES that act at an extra-local spatial scale (Carpenter, 2003). Crang *et al.* (1999) refer to extra-local benefits as the final products in the production and consumption process. Fisher *et al.* (2009) and Syrbe and Walz (2012a) have also addressed this concept by differentiating service-providing from service-benefiting areas. Liu *et al.* (2013) in their "telecoupled" framework provide a typology that accounts for different types of distant interactions and the way these are linked to sustainability. Elsewhere, the term "remote" ES has been used (Carpenter *et al.*, 2009), but this may overemphasize the distance from the ecosystem which need not be large to be important.

Applying the framework

To demonstrate the implications and advantages of considering a spatially explicit understanding of the distribution of MES Net Benefits, we apply the proposed framework through two examples focused on food provision from tuna fisheries and climate regulation provided by carbon storage and sequestration by mangroves. For each case, we use maps to illustrate the difference between mapping outputs produced using the traditional ecosystem-based approach and the proposed "extra-local" mapping approach. For each case, we identify existing methods and tools that can be used to implement an assessment of ES that incorporates extra-local benefits.

Food provision from tuna fisheries

We first apply the conceptual framework of extra-local ES to the tuna fishery of the West and Central Pacific Ocean region (WCPO) (Figure 1). The WCPO (s_1) supports four tuna species that feed and spawn in the region. The WCPO tuna fishery accounts for nearly 60% of the global tuna supply. The purse seine fishery alone produced an estimated 2.02 million metric tons of landed tuna in 2013, caught almost entirely in the tropical waters of the equatorial band of the region (West and Central Pacific Fisheries Commission, 2014). Within these waters, roving fleets follow the tuna stocks as they migrate through national waters and the high seas, including four main distant water fleets from Chinese Taipei, Japan, Korea and the United States, as well as a growing Pacific Islands fleet and fleets operating in Indonesia and the Philippines. Once caught, the fish is loined and canned in Thailand (s_2) or Papua New Guinea (s_3) and then exported to Europe (s_4), USA (s_5), Australia (s_6), and China (s_7) (Pacific Possible, The World Bank. 2016).

Tuna fisheries within the WCPO region have supported the livelihoods of local communities since the 1950s (s_1) e.g. through job creation and additional revenues, but also provide nutritional and consumptive value to tuna consumers around the globe (s_N). Environmental costs, like pollution from shipping also occur throughout the chain. A "traditional" ES map of food provided

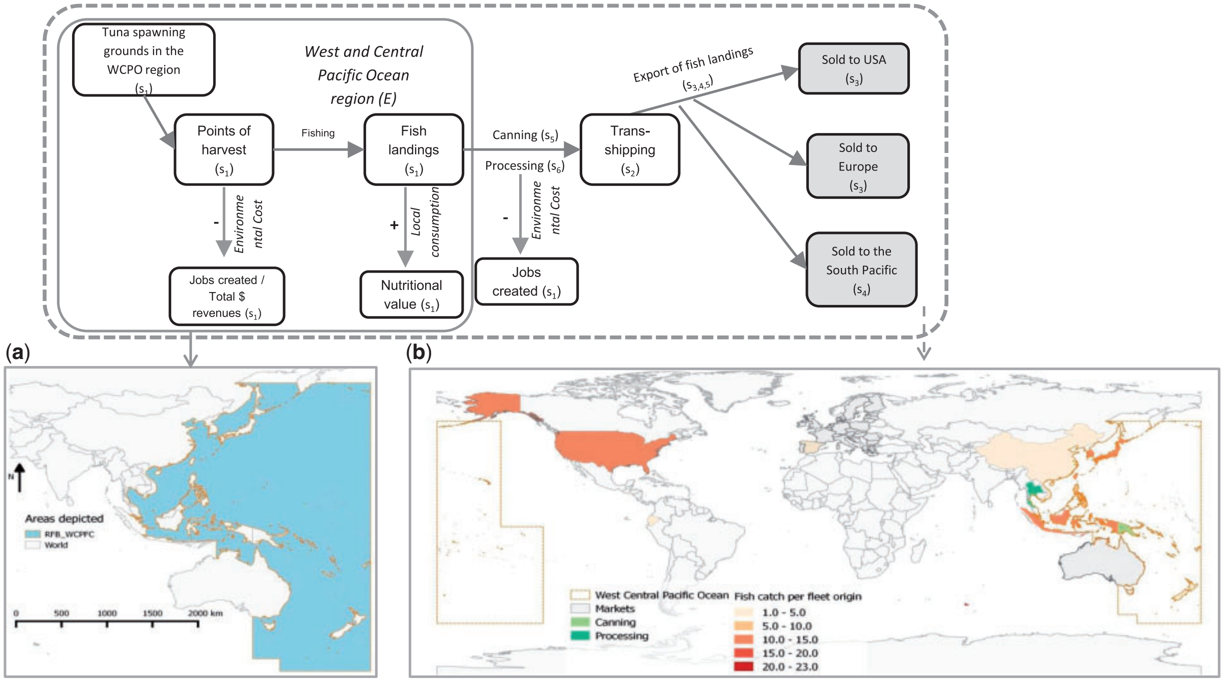

Figure 2. Application of the proposed framework for food provision generated by tuna fisheries in the West and Central Pacific Ocean region. (a) The extent of the fishing grounds of the WCPO region at the ecosystem level. The map in figure (b) shows the extent of a map done with the extra-local ES approach (considering the elements within the larger dashed box). In the map of figure (c), we can see that the beneficiaries from the nutritional and financial value of the WCPO tuna fisheries are distributed across 20 countries and 5 continents.

by fisheries for the WCPO tuna stock would spatially represent either the location of tuna stocks (e.g. Figure 2a), or the benefits received globally but assigned to the ecosystem area of origin (per unit area measure). A map that applies the extra-local framework (Figure 2b) would instead provide information that combines the two traditional approaches above, by creating a clear line of sight between the location of ecological outcomes and beneficiaries. For instance, a map of extra-local services might provide information on the nutritional benefits that global tuna consumers receive, or the financial benefits foreign shipping companies receive through exporting tuna from WCPO waters. The extra-local ES map of Figure 2b shows the worldwide distribution of benefits that arise from tuna fisheries dependent on the WCPO ecosystem, with benefits distributed across 20 countries and 5 continents.

Climate regulation through carbon storage and sequestration by mangrove forests

Given the pace of global greenhouse gas emissions, there has been a flurry of recent efforts to assess the carbon sequestration benefits provided by mangrove forests (Duarte *et al.*, 2013; Alongi *et al.*, 2016). Climate regulation through carbon storage provided by mangroves generates benefits for the entire global population (Pendleton *et al.*, 2012). In the scientific literature, maps of the above-ground biomass (AGB) of mangroves have been used to indicate the carbon sequestration potential of mangrove ecosystems (Hutchison *et al.*, 2014), while more recent research is also taking into account the carbon buried in the sediments (Pendleton *et al.*, 2012; Alongi *et al.*, 2016). Such maps reflect the supply of carbon sequestration services by mangroves without providing any spatial information about who benefits from this ES or how much they benefit. Because carbon sequestration by mangroves reduces the global stock of atmospheric carbon dioxide, the NBs of this service area are distributed globally. Quantifying and mapping the carbon sequestration NBs of mangroves is challenging, given that the impacts of climate change are not homogeneous around the globe. Environmental and socio-economic parameters determine how different areas will be affected by climate change and how they benefit from carbon sequestration. A traditional map depicting such benefits would present either the local benefits associated with carbon sequestration or an aggregated value of global benefits.

As an example, we map the global benefits of climate regulation by mangroves in Mimika Bay, Indonesia (we do not have data on the distribution of opportunity costs). We estimate the total carbon stock in this area and then, applying the "extra-local" approach, assess the benefit of the regulating service this stock can have around the globe. To calculate the amount of carbon stored by mangroves in Mimika Bay, we use biomass estimates [ecosystem (E) in location s_1] by Alongi *et al.* (2016).

$$\text{Total Carbon stock (Mg)} = \text{AGB} + \text{BGB} + \text{Soil C } (>1\text{ m})$$

In the equation, AGB stands for above-ground biomass, BGB for below-ground biomass and Soil C (>1 m), is the carbon stored in the top metre of soil. All units are in Mg of carbon. To assess the economic benefit this carbon stock will have on different regions around the globe (s_N), we use estimates of the foregone Social Cost of Carbon (SCC) per region using the estimates of the RICE-2011 dynamic general-equilibrium model (Nordhaus, 2011). This model takes into account population vulnerability to climate change, GDP and countries' investment regimes. We then calculate and map the impact that Mimika Bay's

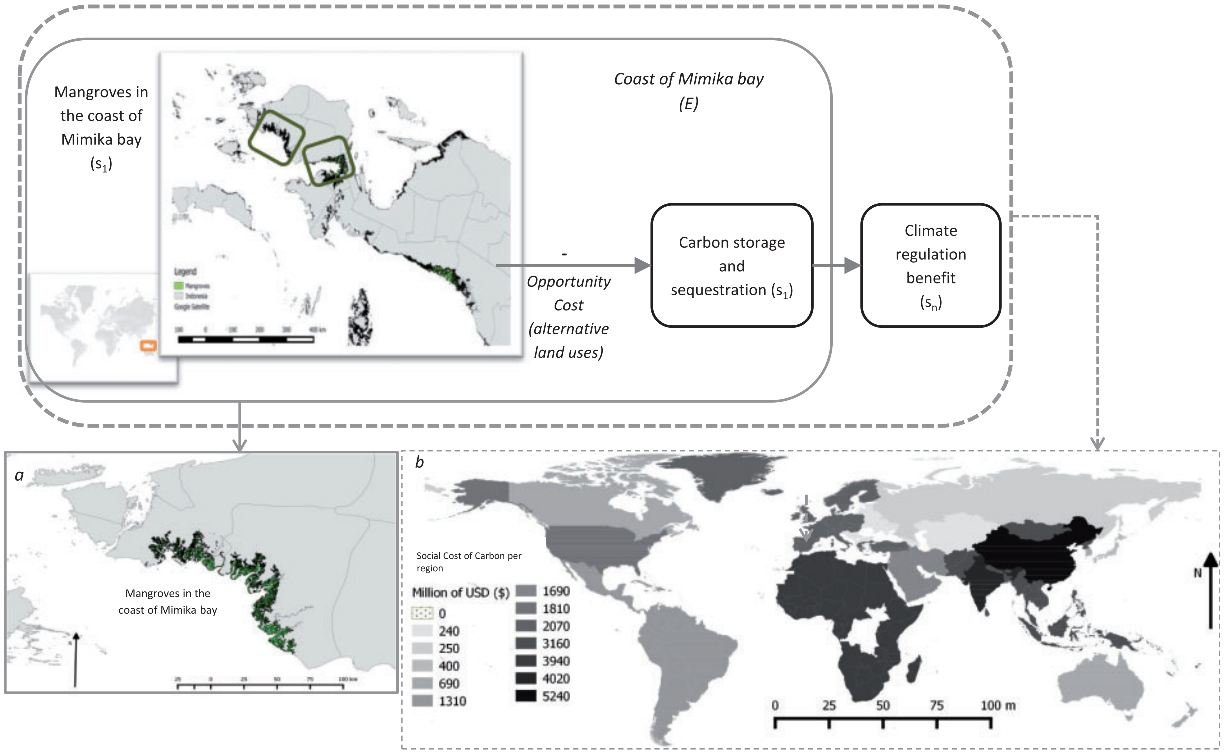

Figure 3. Application of the proposed framework for the climate regulation ES benefits generated by the Mimika bay mangroves. (a) The extent of a map showing the distribution of benefits at the ecosystem level. (b) The extent of a map considering extra-local benefits, depicting a potential impact of the climate regulation benefit to the global population based on regional SCC estimates using the RICE-2011 model (Nordhaus, 2011).

carbon stock will have on the different regions, using their SCC values (Figure 3).

Although regional and global SCC estimates are still a matter of debate (Ackerman and Stanton, 2010; Moore and Diaz, 2015), the major goal of this approach is to illustrate the significance of applying the proposed framework to mapping ES as opposed to the traditional ecosystem-based maps. One major advantage of the extra-local mapping of carbon sequestration ES is that it becomes clear that while Indonesian mangrove ecosystems may be an important supplier of this service, Indonesians are not the only beneficiaries. The map of extra-local benefits shows that both China and Africa may be the principle beneficiaries of carbon storage by mangroves. Although the example focuses on the climate regulation benefits provided by the mangroves in Mimika Bay to demonstrate how the framework can be used for a specific place, other mangroves and coastal ecosystems that sequester or store carbon will support people in similar, geographically disconnected ways.

Discussion

Assessing and mapping the distribution of "extra-local" MES benefits is essential in this era of "blue growth", globalization, population growth, and climate change. In our "crowded" oceans, the expansion of high seas fisheries (Swartz *et al.*, 2010), fossil fuel extraction (including oil, gas, and possibly methane hydrates in the future), and the potential mining of seabed mineral resources will put further pressure on marine ecosystems (Merrie *et al.*, 2014). As exploitation of these resources increasingly expands beyond areas of national jurisdiction, the benefits—and associated negative impacts or costs to human wellbeing—will likely occur in places far beyond the location where extraction occurs (Merrie *et al.*, 2014). For provisioning and cultural services, the global supply chain allows for a distribution of benefits generated by the oceans (like food or raw materials) in which costs and benefits are generated at different locations throughout the chain.

Maps can act as "boundary objects" that can be interpreted by diverse communities in a way that allows communication across sectors and stakeholders (Star and Griesemer, 1989). Maps are used increasingly to connect the often divergent worlds of ES science, policy and practice. Traditional ES maps focus on the ecological spaces we need to manage, restore and protect. Although these maps are useful for place-based conservation decisions, they often obscure the connection between ecosystems and the people they benefit, especially when beneficiaries do not reside in the ecosystem in question. Policy and decision-making require information on the "who", "where", and "what" of the ES provision chain that links the production of ES to the final benefits they produce. Advances in ES mapping allow us to move away from the traditional spatial constraints associated with simply mapping ecosystems. New data standardization and mapping blueprints (Crossman *et al.*, 2013) are being developed, and more sophisticated mapping techniques allow users to visualize a variety of geo-referenced information in ways not previously possible (Villa *et al.*, 2014; Drakou *et al.*, 2015). With the proposed framework for extra-local ES, we urge researchers to use data, scientific knowledge and new mapping technologies to generate more informative maps of local and extra-local benefits generated by marine ecosystems. Maps that include information about the spatial distribution of NBs generated by marine ecosystems are essential to inform ES policy and practice across a range of spatial and administrative scales.

With this article, we illustrate how an extra-local approach to ES assessment can change the spatial representation and extent of ES in mapping. The visualization of extra-local ES through maps offers new types of information that can help shape the direction of ocean governance systems by depicting more accurately the flow of policy-relevant ES.

Mainstreaming this approach contains inherent challenges that vary among different ES types. For provisioning services, data on NBs and beneficiaries are available at the ecosystem and final benefit level but often not for interim steps between ecosystems and beneficiaries. This knowledge gap creates a "black box (Chang, 2014) in the ES provision chain. Interim beneficiaries (those affected by the generation of interim benefits) are especially hard to identify in developing countries, where the level of involvement of local and extra-local actors is not always clear or well-documented (Crow and Carney, 2013). The interim costs are even more difficult to account for, especially for marine ES for which such costs occur in distant locations. For regulating services, like climate regulation or nutrient cycling, the biggest challenge in applying the extra-local approach lies in identifying and assigning often heterogeneous benefits at large spatial scales (e.g. entire regions or the globe). Zhao and Sander (2015) attempted to do this by mapping the spatial distribution of the demand for climate regulation provided by urban forests based on the CO_2 emissions of different regions. In that case, accounting, for instance, for opportunity costs, is something that could be measured at the local scale, but it is still not clear how to measure this for spatially remote areas. For cultural services, most mapping efforts focus on recreational areas or tourists' preferences in those areas (Willemen *et al*., 2015). Maps considering the residence of the beneficiaries would give another dimension for identifying the extent of the distribution of cultural benefits, but data availability remains a challenge.

Using the proposed framework in the marine environment can improve ES research, policy, and practice in a number of ways. Well-established methodologies, developed within industry, trade, economics or information and communication technology sectors (Peppard and Rylander, 2006; Bolwig *et al*., 2010) can be adapted to include such ES assessments. For instance, value chain analysis could be harnessed to show the flow of ecosystem benefits from the ecosystem source. A recent study (Kittinger *et al*., 2015) applied value chain analysis to small-scale fisheries within Hawaii to show the distribution of extra-local benefits. Technological innovations, like the recent "Hapi Fis" (Happy Fish) seafood tracking mobile application by Ecotrust, increase our ability to track fisheries supply chains and collect data on consumption and processing. Villa *et al.* (2014) have created a tool through the ARIES modelling platform that uses artificial intelligence to allow ES practitioners to spatially assess the flows of ES to beneficiaries.

A well-documented accounting of the spatial distribution of the benefits generated by marine ecosystems that goes beyond the ecosystem level could be a step towards more complete and policy-relevant ES assessments. Researchers should focus more on assessing the nature, location and beneficiaries of all the processes occurring throughout the ES provision chain. Although researchers often focus only on final benefits, history has shown that changes throughout the entire production chain may also induce powerful societal changes (Chang, 2014); the human benefits derived from marine ecosystems are no different. Acknowledging, quantifying, and mapping the IPs in the ES provision chain will add another dimension to our understanding of how ES benefits are shared between developing and developed countries. Such knowledge can be also used to build broader constituencies for place-based habitat and ecosystem conservation, to inform regional and international policies and commitments, and identify the kinds of incentive mechanisms that could be employed for more sustainable ecosystems by helping identify who should compensate whom (Convention on Biological Diversity, 2009; Ludwig, 2012).

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