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Essays and Perspectives

The ecosystem service approach and its application as a tool for integrated coastal management

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ABSTRACT

Ecosystem services are the benefits that natural environments supply to human beings. Due to the immense diversity of ecosystems and objectives for which their services are being assessed, there are no standard methodologies for this type of evaluation. The high biodiversity and geodiversity of the coastal zone allow a wide range of services. However, deleterious impacts to the environment threaten the delivery of these services and, consequently, the human well-being they lead to. The coastal zone, with its multiple users and impacts, is a case in which an ecosystem-based approach would bring many benefits within the scope of an integrated coastal management strategy. By considering the ecosystem services supplied by the coastal zone, it is possible to make well-informed decisions. The objective of the present study was to carry out a revision on ecosystem services and their application within the context of coastal management.

Introduction

Ecosystem services can be defined simply as the benefits natural ecosystems supply to guarantee human well-being. Although the human species presents a certain level of detachment from the direct relationships with the environment, especially due to cultural and technological issues, we are still fundamentally dependent on the flow of ecosystem services. For instance, a car can only move with fuel (gas, electricity, biodiesel, etc.), constructions are only possible with raw material, our breathing depends on the production of oxygen by photosynthesizing organisms, and so forth.

The study of ecosystem services can be included in what is called "ecological economics", a transdisciplinary science through which different fields of knowledge seek to communicate by means of a common language (Daly and Farley, 2004). For example, in an environmental impact study on the construction of a coastal enterprise, how is it possible to clearly separate the areas of influence of oceanography, geology, and biology, among others? The flow of services is very interactive. More than one service can be delivered by the same ecosystem, while the same service may be delivered by different ecosystems. Thus, by considering this interactivity, by means of including multidisciplinary teams in decision-making processes and taking an integrated view

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of the environment, it is possible to understand the limits of the environment and its resources, creating policies that allow for sustainable development.

Malone et al. (2014) defend a holistic and integrated approach when addressing ecosystem services and sustainable development. These authors consider that sustainable development involves three dimensions: economic development, social development and environmental sustainability. However, while public policies have treated these dimensions as interactive, these are not always seen as being interdependent. From an ecological economics standpoint, economic activity occurs within a system of social relationships, which is limited by environmental parameters and, thus, should respect the carrying capacity limits of natural environments (Costanza et al., 1997; Daly and Farley, 2004; Malone et al., 2014).

By integrating the ecosystem service approach and the decision-making process, ecosystem-based management strategies can be developed (Fig. 1). While isolated, the decision-making process considers social preferences and human activities without necessarily accounting for the inherent value of nature or the benefits provided by ecosystem services. However, by striving for more sustainable and resilient policies, managers may then understand that an ecosystem-based management strategy would allow an integrative approach toward the issue at hand, valuing the natural capital of the area, respecting the environment's carrying capacity and reaching long-term and fair benefits to all involved.

Thus, the objective of the present study was to carry out a review on the ecosystem service approach and its applicability in integrated coastal management strategies.

Historic background

The explicit recognition of the term "ecosystem services" is fairly recent, but the general notion that natural ecosystems support human society is ancient. Daly and Farley (2004) exemplify this condition with the nomad behavior of prehistoric man, always searching for resources for survival. Mooney and Ehrlich (1997) mention how Plato, the Greek philosopher (c. 400 BC), understood that the soil erosion and dying rivers in the region of Attica were a consequence of deforestation in a farther upstream area. These same authors also state that the modern understanding of ecosystem services probably began with the book Man and Nature, by George Perkins Marsh, in 1864, in which the erroneous concept that our planet's resources are infinite was contested for the first time in a high-impact publication.

After a period of hiatus, in which Marsh's work was not greatly recognized, undoubtedly due to the influence of the 1st and 2nd World Wars, three authors resumed the themes he had addressed during the 1940s. These were Fairfield Osborn, William Vogt and Aldo Leopold, whose publications reignited the discussions on human reliance on the environment, adopting the concept of "natural capital" (Mooney and Ehrlich, 1997). Natural capital can be understood as all natural resources, in other words, the stock of material and information that exists in a given moment originated from natural environments, such as solar energy, soils, trees, minerals, fossil fuels, ecosystems and atmosphere (Costanza et al., 1997; Daly and Farley, 2004). This is the starting point for the flow of ecosystem services.

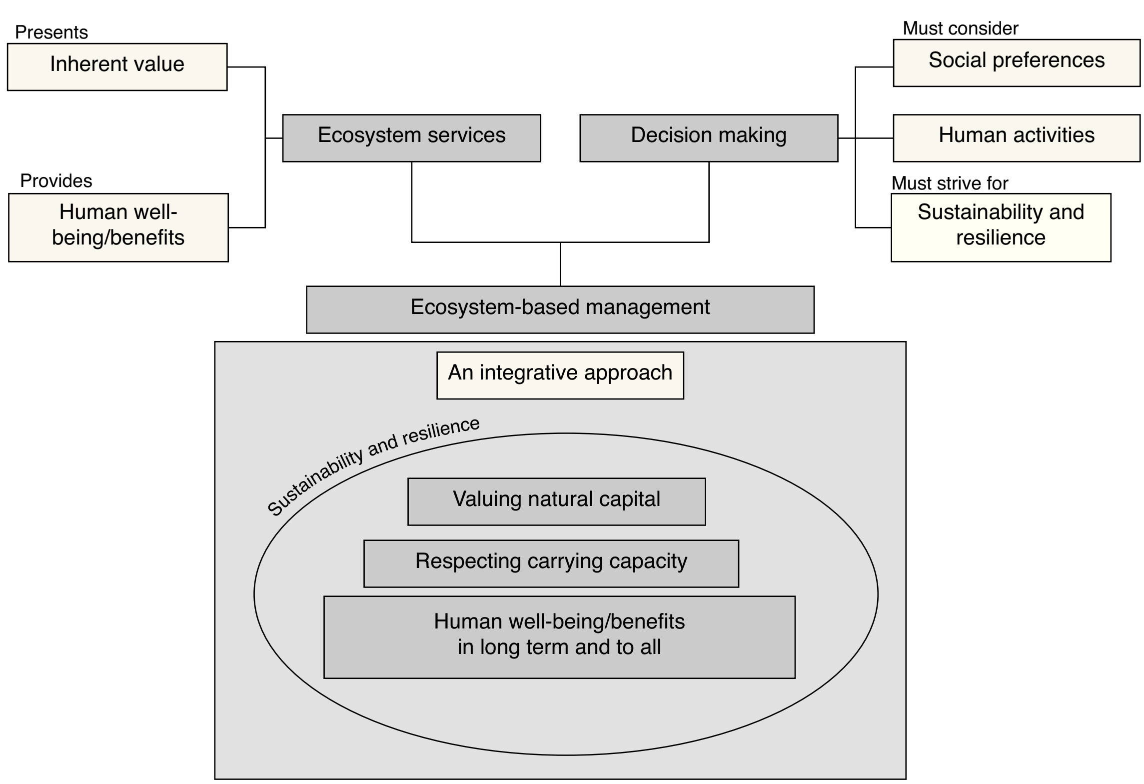

Fig. 1 – Schematic representation of how the ecosystem service approach and the decision-making process can be integrated to create an ecosystem-based management strategy.

The first record of the use of the term "environmental services" was in 1970 in the report Study of Critical Environmental Problems, a study on the global effect of climate and ecosystems on human activities, which included researchers from the fields of meteorology, oceanography, ecology, chemistry, physics, biology, geology, engineering, economics, social sciences and law, sponsored by the Massachusetts Institute of Technology (SCEP 1970 *apud* Mooney and Ehrlich, 1997). However, the term "ecosystem services" only became the standard in the scientific literature after the publication by Ehrlich and Ehrlich (1981).

Costanza et al. (1997) carried out the first global effort for economically valuing ecosystem services and natural capital. These authors considered that a way to think of ecosystem service valuation was to determine how much it would cost to replicate them in an artificial biosphere. However, the authors clearly expressed that there was (and still is) great debate over the complexity in valuing an ecosystem, considering that there is no sense in investigating the total value of all natural capital for human well-being, because if there is no natural capital there is no human well-being.

Nevertheless, economic valuation can highlight natural attributes that are not usually considered in traditional markets. Considering that the study only assessed 17 services in 16 biomes, including only renewable resources, in addition to other possible limitations, the total value of global ecosystem services was calculated as at least US$ 33 trillion/year (varying between US$ 16 trillion to US$ 54 trillion depending on the ecosystem in question), clearly demonstrating the importance and human reliance on these ecosystems.

After this milestone in the study of ecosystem services, an exponential increase was observed in the number of publications on the subject, as demonstrated by Fisher et al. (2009). These authors accredit the popularization of this theme as partly due to the publication of the Millennium Ecosystem Assessment in 2005. This initiative from the United Nations Organization (UNO) combined the scientific effort of over 1360 researchers all around the world. The main goal of the project was to evaluate the consequences of environmental changes to human well-being and the scientific base for taking the necessary actions to improve the conservation and the sustainable use of these ecosystems, as well as assess their contribution to human well-being.

Classifications

According to Fisher et al. (2009), one of the most used classifications in the study of ecosystem services is the one proposed by the Millennium Ecosystem Assessment (2005), which divides the services in four groups: provisioning, regulating, supporting and cultural services.

Provisioning services regard the goods we take from the environment, such as food, minerals and genetic resources that can be used in the production of drugs and other biotechnologies. Regulating services, on the other hand, are those that maintain the balance in ecosystem functions, by means of climate regulation, or water and erosion regulation, for example. Supporting services play a similar role to the regulating services, but they maintain the ecosystem in balance by means of supporting ecosystem services themselves, for example by means of soil formation and nutrient cycling. Finally, cultural services present the most abstract character, because they do not concern a physical good, and they are much more connected to human well-being in an immaterial way. For example, recreational activities, scenic quality and spirituality are cultural services and promote a sense of place and well-being to mankind that is only possible through a healthy environment.

Another way of understanding the supply of ecosystem services is to classify them as intermediate and final services, depending on the service in question that is being evaluated (Boyd and Banzhafa, 2007; Fisher et al., 2009). For example, clean water would be the benefit (final service) that we receive from the purification of water (intermediate service) performed by coastal dunes. Another example, considering an assessment of recreational quality in beaches, the final service would be the creation of the beach itself, while the intermediate service would be the geodynamics that allowed for the beach creation.

However, still according to Boyd and Banzhafa (2007) and Fisher et al. (2009), depending on the objective of the study, classifications should be adapted, especially in the case of economic valuations, so as to avoid valuing the same service more than once. Moreover, Daily et al. (1997) suggest that due to the interconnectivity of services, any type of classification is quite arbitrary and, therefore, researchers should not limit themselves on this issue.

Methodologies for surveying and analyzing ecosystem services

The greatest challenge currently faced in the study of ecosystem services is the difficulty in standardizing methodologies and terminology, which frequently represents an obstacle for carrying out more robust analyses. Bockstael et al. (2000) attribute this difficulty to the lack of collaborative studies between scientists from different fields, so as to encompass all the relevant issues involved in the subject. However, there have been several efforts to establish some type of standardization in these studies (e.g. De Groot et al., 2002; Barbier, 2012; Jungwiwattanaporn, 2012; Seppelt et al., 2012).

According to Chan and Ruckelshaus (2010), early studies, such as that by Costanza et al. (1997), were based on "transference of benefits/values" approaches, in which previous studies that evaluated the value of benefits of ecosystems were applied to other sites. However, although this is an easy and low-cost method, the authors emphasize that this method demonstrates a static vision of the ecosystem, which is not suitable for management situations, as well as presenting difficulties in the comparison of areas that are frequently relatively incomparable (scale, local reality, etc.). Thus, it is more interesting if the methodological approach does not follow a single format to fit all situations and, instead, should be only guided by a set of recommendations to optimize scientific effort (Troy and Wilson, 2006).

To carry out the initial survey of ecosystem services in a coastal area, Santos and Silva (2012) walked along the study site identifying and evaluating which services were delivered in greater or lower scale, creating a sort of inventory based on environmental and geological indicators. Following the same procedure, Seppelt et al. (2012) elaborated a form seeking to standardize attributes observed during these primary surveys. This was later redrafted by Crossman et al. (2013) based on the professional experience of the participants of the 6th Annual International Conference of the Ecosystem Services Partnership. In this new version, the service evaluated should be described according to its indicators, quantification unit (e.g. mass, area, time), and scale (local, regional, global), among other attributes, so as to allow more robust and comparable analyses.

With this primary information, researchers can then carry out modeling, mapping and valuation studies.

Regarding economic valuation of ecosystem services, Bockstael et al. (2000) explain that a valuation estimate of this sort is, in reality, an answer to a carefully formulated question to which there are two alternatives: was it better (was there more value) before or will it be better after? Moreover, as stated by Boyd and Banzhafa (2007), in cases of economic valuation, it might be best to apply the classification of final and intermediate services, or else the value of intermediate products can be accounted for multiple times, since their values are already incorporated into the value of the final product.

However, the ecosystem service approach applied to decision-making does not necessarily have to include economic valuations. In fact, Ruckelshaus et al. (2013a), evaluating 20 pilot studies in the application of ecosystem services, observed that many decision makers wished to examine the consequence of their actions to traditional market commodities in monetary terms and, also, the non-economic benefits, described in biophysical units, which include cultural and biodiversity values. Moreover, these authors identified that the erroneous concept that an ecosystem service assessment requires economic valuation was considered to be a barrier both for scientific development (e.g. to those who believe their work becomes irrelevant if they are not interested in a formal monetary valuation) and for the people who apply the concept (e.g. to those who believe that an ecosystem service approach excludes consideration toward the inherent value of natural factors such as biodiversity and geodiversity).

Chan and Ruckelshaus (2010) listed some recent efforts to model and map ecosystem services, including in coastal and marine environments: Multiscale Integrated Models of Ecosystem Services (MIMES), Artificial Intelligence for Ecosystem Services (ARIES) and the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST). However, as these authors report, these models are recent and there are few published studies demonstrating the applicability of these tools, which are continuously updated and improved.

Among these models, InVEST, developed by the Natural Capital Project, has been used in an array of terrestrial and aquatic studies, with publications already demonstrating its application and success in management strategies (e.g. Arkema et al., 2013; Kovacs et al., 2013; Ruckelshaus et al., 2013a; Bhagabati et al., 2014). This tool is particularly interesting because it delivers results in monetary values, non-monetary values (e.g. high, medium or low supply of the service) and also in biophysical values (e.g. meters of shoreline protected by coral reefs) (Guerry et al., 2012). Moreover, InVEST allows modeling how climate change scenarios or scenarios of change in management and public policies can influence the delivery of ecosystem services such as the provision of food, recreation, tourism, and shoreline protection against erosion and coastal flooding, by abiotic and biogenic environments (Chan and Ruckelshaus, 2010).

Discussion

Coastal ecosystem services

Coastal regions can be considered as the areas of greatest exchange of energy and matter in the whole Earth system, particularly due to their interconnection with components of the geo-, hydro- and atmosphere (Brandão, 2008). As described by Gray (2004), this dynamicity and the geological history of the coastal zone itself is what allowed for this region to develop such high geodiversity, meaning a great richness of geological features, which in turn molded the evolution of this region regarding the uses of the area and, consequently, the ecosystem services delivered. Gordon and Barron (2013) stated that most of the ecosystem services listed by the Millennium Ecosystem Assessment (2005) are either directly or indirectly influenced by geological, hydrogeological and geomorphological processes and factors, since the geosphere represents the base upon which the whole biosphere is sustained.

According to the study performed by Costanza et al. (1997), (63)% of all economic value found for global natural capital and ecosystem services come from the marine environment, of which a large portion of this percentage is attributable to the coastal zone. Martínez et al. (2007), in a more recent study, estimated that the coastal zone (considered as up to 100 km from the shoreline), including both natural terrestrial and aquatic environments and also human-altered environments, was responsible for 77% of the global value calculated by Costanza et al. (1997).

Several ecosystems compose the coastal zone, such as beaches, mangroves, coral reefs, seagrass beds, estuaries, deltas, bays, among others. Thus, the list of all services delivered by these environments is very extensive. A synthesis of the main ecosystem services delivered by some coastal ecosystems is presented in Table 1, based on the surveys by UNEP (2006) and Santos and Silva (2012).

Application in coastal management

One-third of the human population lives in coastal regions (UNEP, 2006). Moreover, 84% of all countries have coastlines, while 21 of the 33 megacities in the world are within a range of 100 km of the shore (Martínez et al., 2007). Thus, to maintain and improve the multiple benefits available through coastal and marine ecosystems these systems must be managed considering their multiple uses, so to take into account the various services delivered (Guerry et al., 2012). However, despite their remarkable importance, ecosystem services are rarely weighed accordingly or even considered during decision making and elaboration of public policies (Costanza et al., 1997).

As mentioned previously, the concept of ecosystem services is fairly recent and their application is beginning to show

Table 1 – Examples of ecosystem services delivered in the coastal zone.

Ecosystem service	Description	Coastal ecosystem
Provisioning services		
Food provision	Fisheries, aquaculture, plant production	Estuaries, mangroves, coastal lagoons, intertidal, Kelp forests, coral reefs, rocky shores, seagrass
Water resources	Freshwater for human use	Rivers, lakes, aquifers
Ornamental resources	Resources that can be used for ornamental purposes (e.g. seashells, minerals, tilapia leather)	Beaches, estuaries, coral reefs
Genetic resources	High genetic flow associated to heterogeneous environments (important for the development of biotechnologies, for example)	Coral reefs, estuaries, mangroves, inner continental shelf
Regulation services		
Erosion control	Natural retention of sediments, wave energy attenuation	Beaches, estuaries, mangroves, coastal lagoons, seagrass, coral reefs
Aquifer recharge and hydric balance	Associated with permeable geological units and areas of freshwater retention	Marine terraces, estuaries, coastal lagoons
Biological regulation	Associated with environments that regulate the interaction between species, primary productivity	Estuaries, mangroves, coastal lagoons, intertidal, rocky shores, coral reefs
Atmospheric and climatic regulation	Associated with the carbon cycle and other gases	Estuaries, mangroves, coastal lagoons, intertidal, rocky shores, seagrass, coral reefs, continental shelf
Waste processing	Natural depuration of pollutants and other waste	Estuaries, mangroves, coastal lagoons, wetlands, seagrass, coral reefs
Flood and storm protection	Associated with wave energy attenuation and natural shoreline protection	Beaches, estuaries, mangroves, coastal lagoons, intertidal, Kelp forests, rocky shores, seagrass, coral reefs
Supporting services		
Ecosystem maintenance	Associated with environments that allow the maintenance of adjacent ecosystems, supporting the biological community	Beaches, estuaries, mangroves, coastal lagoons, intertidal, rocky shores, seagrass, coral reefs
Nutrient cycling	Allows greater productivity and fertility to environments	Estuaries, mangroves, coastal lagoons, intertidal, Kelp forests, rocky shores, coral reefs, inner continental shelf
Cultural services		
Recreation and tourism	Use of natural environments for leisure activities	Beaches, estuaries, mangroves, coastal lagoons, Kelp forests, rocky shores, coral reefs
Scenic quality	Associated with the presence of natural attributes that stimulate visitation	Beaches, estuaries, mangroves, coastal lagoons, Kelp forests, rocky shores, coral reefs
Education and research	Environments that offer the opportunity of education and research	Beaches, estuaries, mangroves, coastal lagoons, Kelp forests, rocky shores, seagrass, coral reefs, inner continental shelf

potential from an ecosystem-based approach toward issues observed in the coastal zone and other natural environments. Although this scenario is changing, traditional coastal management strategies tend to address one issue at a time in a very non-interactive and non-transdisciplinary way (Clarke et al., 2013). For example, as presented by Ruckelshaus et al. (2013b), the construction of a coastal protection structure may be interesting when the sole objective is to protect coastal properties; however, if we consider the impacts that this construction would have on local fisheries and tourism/recreation, it may lose its potential, demonstrating why the multiple uses and vocation of the area should always be considered.

In a recent study, Ido and Shimrit (2015) reported a practical experience of a similar situation. The use of an eco-design concrete-based coastal and marine infrastructure was compared to a standard traditional design in a boat basin in the Haifa Bay, Israel. The eco-design showed a positive influence on the biological and ecological performances of the structure, without hampering structural performance. The authors emphasize the need to integrate this sort of environmentally sensitive technology, which increases the provision of ecosystem services, into future coastal development projects. Thus, by taking an ecosystem-based approach and considering the inherent value of the ecosystem services provided by a more complex structure (eco-design vs. standard), this coastal management project was able to efficiently solve the issue at hand with a more sustainable and resilient solution.

According to Turner (2009), coastal management strategies as a whole should be based on the principles of adaptive management, in other words, "learning with the process". An ecosystem-based approach (by means of evaluating ecosystem services) allows for this strategy to be broad and flexible, so as to better understand how we can make the most of the natural resources that are already available and also obtain the most efficient solutions for the situations at hand. For example, Arkema et al. (2013) studied coastal vulnerability in the USA by means of the InVEST suite of models and identified that, if the current trend of climate change continues, there will be an increase between 30 and 60% of the amount of people and properties at a high risk level on the coast. Moreover, the authors estimated that 67% of the coastline is currently protected by natural ecosystems (coral reefs, seagrass beds, etc.), but if these environments lose their ability to deliver their regulating and supporting services, the extent of highly vulnerable coastline to storm surges and sea level rise will double. Thus, the study suggests that instead of investing only in the construction of physical structures for shoreline protection, investments are also required toward the conservation of coastal ecosystems, which already provide this service (and others) at no cost.

In addition, the question made by Bockstael et al. (2000) (was there more value before or will there be more after the intervention?) is one that is frequently asked to and by environmental managers when facing decisions and working with conflicts between users. Bockstael et al. (2000) illustrate this concept applied to a management situation by giving an example of the construction of an electrical power plant in a location that would eliminate the use of a beach for recreation. Each person considered in this case may present very different personal values, depending on if this person is a regular beachgoer, if he/she would benefit from the electricity generated, or even both. Thus, an economic valuation in this situation could measure how much a person would be willing to pay or should receive as compensation to attain the same level of benefits and well-being as before the construction. This example is of course an oversimplification of a real situation, considering only one class of services. If we were to take this example further, supposing that this beach also presented a well-established dune field, services delivered by the dunes, such as shoreline protection, aquifer recharge and water depuration, should also be taken into account in the valuation. This way the study can define more precisely where is it best to place the power plant without compromising essential services, which are often not incorporated at a first moment.

Clarke et al. (2013) indicated that the main challenges faced by effective coastal management are the natural complexity of the coastal systems, the multiple uses of the region, different jurisdictions, administrative organs with responsibilities over the coast, different ways to understand and enjoy the coast, and the divergence of perspectives on how the area should be management, governed and used. Added to these challenges are the current threats toward coastal geodiversity and biodiversity, such as inordinate coastal development (Brilha, 2005; Silva et al., 2009), which result in a scenario where the current management policies are not adequate.

These issues demonstrate how the use of an ecosystem service approach can be beneficial and optimize coastal management strategies. Ruckelshaus et al. (2013a) evaluated 20 pilot-studies that applied the ecosystem service approach to guide public policy decisions in real situations. The authors concluded, based on these real field experiences, that there is great potential for widely incorporating the ecosystem service approach in various decision-making contexts, such as spatial planning, environmental impact evaluations and payments for ecosystem services.

A good example of coastal ecosystem services being incorporated into management decisions was reported by Arkema et al. (2014). In this study the authors describe the use of the habitat risk assessment tool of the InVEST suite of models to generate three possible management scenarios for the government of Belize. Risk, in this case, regards both the presence of the assessed habitats (e.g. coral reefs and mangroves) and the ability of these habitats to deliver services under the input conditions. The results composed the country's first Integrated Coastal Zone Management Plan and allowed a decrease of habitats in high-risk areas to less than 20%, while still increasing the extent of several ocean uses (e.g. coastal development and aquaculture). This clearly demonstrates the potential for more sustainable decision-making when incorporating the ecosystem service approach in coastal management.

Conclusions

The dependent relationship between human communities and coastal ecosystems is very clear. However, this relationship does not always respect the resilience and carrying capacity limits of these ecosystems, which places the delivery of essential ecosystem services in risk. Local issues such as pollution, overfishing and environmental degradation in the coastal zone require immediate action to guarantee ecosystem integrity. Moreover, basic challenges, such as lack of monitoring effort, lack of information and use conflicts, must be overcome in coastal management strategies.

Coastal management is beginning to encompass more integrated strategies, but more holistic and transdisciplinary strategies are also necessary. The ecosystem services approach is a participative and iterative process, which seeks to improve decision-making over a particular issue, with a variety of measurement units (biophysical, monetary or non-monetary) depending on each case, and recognizes that the context in which the environmental assessment is inserted is important, as well as the demand for services.

Changing the current scenario is a difficult process, which includes changes in current public policies, public awareness and repeatedly producing results that support decisions. However, important first steps have already been taken through simple spatial and quantitative tools, providing clear subsidies that can be used by decision makers.

By understanding how the coastal environment works and how we can make the most of it without compromising the delivery of these benefits to other people (either same generation or future ones), we will be heading toward a more sustainable life style and will become more able to adapt in face of future global changes.

Conflicts of interest

The authors declare no conflicts of interest.

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