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Linking biodiversity indicators, ecosystem functioning, provision of services and human well-being in estuarine systems: Application of a conceptual framework

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ABSTRACT

Assuming that human well-being strongly relies on the services provided by well-functioning ecosystems, changes in the ecological functioning of any system can have direct and indirect effects on human welfare. Intensive land use and tourism have expanded in recent decades along coastal ecosystems, together with increasing demands for water, food and energy; all of these factors intensify the exploitation of natural resources. Many of the interrelations between ecosystem functioning and the provision of ecosystem services (ES) still require quantification in estuarine systems. A conceptual framework to assess such links in a spatially and temporally explicit manner is proposed and applied to the Mondego estuary (Portugal). This framework relies on three consecutive steps and discriminates among biodiversity structural components, ecosystem functioning and stability and the services provided by the ecosystem.

Disturbances in abiotic factors were found to have a direct effect on biodiversity, ecosystem functioning and the provision of ES. The observed changes in the species composition of communities had a positive effect on the ecosystem's productivity and stability. Moreover, the observed changes in the estuarine ES provision are likely to arise from changing structural and abiotic factors and in the present case from the loss or decline of locally abundant species. This study also indicates that linear relationships between biodiversity, ecosystem functioning and services provision are unlikely to occur in estuarine systems. Instead, cumulative and complex relations are observed between factors on both temporal and spatial scales. In this context, the results suggest several additional conclusions: (1) biodiversity and ecosystem functioning interaction with human well-being need to be incorporated into decision-making processes aimed at the conservative management of systems; (2) the institutional use of research results must be part of the design and implementation of sustainable management activities; and (3) more integrative tools/studies are required to account for the interactions of estuarine ecosystems with surrounding socio-economic activities. Therefore, when performing integrated assessments of ecosystem dynamics, it becomes essential to consider not only the effects of biodiversity and ecosystem functioning on services provision but also the effects that human well-being and ES provision may have on estuarine biodiversity and ecosystem functioning.

The proposed framework implies taking into account both the functional and the commodities points of view upon natural ecosystems and by this representing a line of thought which will deserve further research to explore more in detail the conceptual links between biodiversity–ecosystem functioning–services provided.

1. Introduction

Ecosystems deliver services of great value to human society (Pearce and Moran, 1994; Costanza et al., 1997; Daily, 1997; Barbier et al., 2011; Burkhard et al., 2012). However, increasing anthropogenic pressures have led to a growing loss of biodiversity and changes in the internal functioning of ecosystems, reflected in the variation of benefits provided to human societies (Hooper et al., 2005). In 2005, the Millennium Ecosystem Assessment (MEA, 2005) published the status of ecosystems and their capacity to benefit humans, concluding that most of the world's wetlands have been destroyed or degraded during the 20th century, thereby creating the need for integrative frameworks to consider the dynamics of whole systems. The central framework

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for this assessment (MEA, 2003) was a simple conceptual guiding principle:

biodiversity → ecosystem functioning → ecosystem services → human well-being

where each arrow represents a causal relationship (Naeem et al., 2009) and where ecosystem services (hereafter ES) may be seen as functions that ultimately benefit humans (Costanza et al., 1997; Daily, 1997; Naeem et al., 2009). This framework relies on the assumption that increased biodiversity augments, at least to a certain extent, ecosystem functioning, which improves ES and may eventually improve human well-being, depending on the elements involved. A number of studies have attempted to link explicitly or implicitly the biological composition of ecosystems, given by biodiversity proxies, to the stability of ecosystem functioning (e.g., Remane, 1934; MacArthur, 1955; Odum, 1959; May, 1972; de Jonge, 1974; Pimm, 1984; Ives et al., 1999; Loreau et al., 2001; Balvanera et al., 2006; Isbell et al., 2009; Godbold et al., 2011). These studies assumed that such links may have a determinant role in ES delivery (e.g., Costanza et al., 1997; Turner et al., 2003; Srivastava and Vellend, 2005; Tilman et al., 2006; Díaz et al., 2007; Haines-Young and Potschin, 2010). Typically, researchers have considered that if ecosystem biodiversity could be linked with functioning then it would follow that ES are directly related to human well-being (Naeem et al., 2009).

Although most of the considerations of ES focus on the link between ecological functions and human well-being, it is also important to consider the prior link between biodiversity and ecosystem functioning (Morling et al., 2010). Several studies have tried to demonstrate the biodiversity role in ES provision (Mace and Bateman, 2011), through: (1) biodiversity supports the delivery of ES (Díaz et al., 2006), acting as insurance against change (increased redundancy associated with higher diversity may buffer ecosystems against change, contributing to higher system resilience) (Ulanowicz, 1979; Hooper et al., 2005) and offering more options for the future (Yachi and Loreau, 1999); (2) genetic and biological species diversity may directly supply some goods, such as animal and plant breeds (MEA, 2003); and (3) many components of biodiversity are valued by people for altruistic reasons (e.g., appreciation of wildlife, contribution to spiritual or educational motifs and recreational experiences), although biodiversity, per se, is not considered to be a service by everyone (Haines-Young and Potschin, 2010). Thus, when addressing natural resources management, the challenging issues are determining the nature and sensitivity of the relationship between environmental quality/biodiversity assets and the provision of services. Most of this discussion regards the links between biodiversity assets and ecosystem functioning and stability, which can be used as a proxy to the supporting services classes from the MEA, or intermediate services. Several studies have been conducted to address the relation between biodiversity assets and ecosystem productivity and stability (e.g., Pimm, 1984; Schwartz et al., 2000; Loreau et al., 2001; Tilman et al., 2005; Balvanera et al., 2006); nevertheless, the controversy persists.

To address these complex relations, the Convention for Biological Diversity (2004) suggested the use of the ecosystem approach (EA) to provide a clear integration into a holistic framework of all services provided to people by biodiversity and ecosystems. This approach defends an integration of the ecological, economic, and socio-cultural perspectives when evaluating an ecosystem (de Groot et al., 2002; Farber et al., 2002; MEA, 2005; Carpenter et al., 2009), thus providing a methodological framework for wetland management (de Jonge, 2007). In fact, ES clearly have ecological and socio-economic aspects whose interdependencies need to be clarified (Mace and Bateman, 2011) and described (de Jonge et al., 2012). Therefore, it is crucial to understand the role and effects of biodiversity in both an ecological as well as a socio-ecological context (Carpenter et al., 2009). Despite the attempts to identify the potential relationships between biodiversity and the delivery of services, adequate quantitative data are not available (Norris et al., 2010). Despite the few data there is some evidence for a weak correlation between areas rich in biodiversity (according to nature conservation designations) and those high in ES delivery (Naidoo et al., 2008; Anderson et al., 2009). A study by Norris et al. (2010) supports the idea that microorganisms, fungi and plants play a major role in supporting and regulating services, whereas vertebrates are more important for cultural services, described as the 'cute and cuddling' services in de Jonge et al. (2012). Because of the increasing pressures on natural resources, trade-offs among services have to be verified. The general increase in provisioning services over the past century has been achieved through decreases in regulating and cultural services and in biodiversity (MEA, 2005; Bennett and Balvanera, 2007; Carpenter et al., 2009). In this context, it is essential that such trade-offs are recognised in future ecosystem assessments (Carpenter et al., 2009). The suggestion to further clarify the relations between habitats, food web functioning via ecological network analysis (ENA) and the Driver-Pressure-State Change-Impact-Response (DPSIR) approach as performed by de Jonge et al. (2012) may be seen as a step in that direction.

Because of the complexity and integration of concepts and methodologies, it is essential to clearly define the terms used in the present work:

(a) *Biodiversity* is the variability among living organisms and their habitats from all sources, including diversity within species, between species and within entire ecosystems (Heywood, 1995). Because of data limitations in the present case, diversity measures were used to estimate biodiversity (according to Marques, 2001);
(b) *Ecosystem functioning* refers to all of the biogeochemical processes occurring within an ecosystem, such as the cycling of nutrients, matter or energy (Naeem, 1998);
(c) *Ecological condition* refers to the integrity of the ecosystem (Jorgensen et al., 2010); in the present study, ecological condition was expressed as the ecological quality status *sensu* the European Union Water Framework Directive (EC, 2000);
(d) *Stability* is a collective notion defined by three properties (constancy, resilience and persistence) (*sensu* Grimm and Wissel, 1997); in the present study, stability was expressed as temporal stability (see Pinto et al., 2013a);
(e) *Ecosystem services* can be defined as the functions of ecosystems having value for human welfare (Fisher et al., 2009). According to the MEA (2005), ES can be classified into one of four categories: regulating (e.g., water purification); supporting (e.g., nutrient cycling); provisioning (e.g., food production); and cultural (e.g., opportunities for recreation); and
(f) *Human well-being* can be defined as the human experiences that include the basic materials for human lives, freedom of choice, health, good social relations, a sense of 'cultural identity' and security (MEA, 2005; Díaz et al., 2006).

The present work discusses the links between biodiversity proxies and ecosystem functioning in estuarine ecosystems, the role of macro-invertebrates in the provision of ES, and the use of ES as a tool to address the exploitation and conservation of natural resources. Therefore, the present work provides clues regarding the changes in estuarine biodiversity that are expected to have consequences for human well-being. In a first step, the effect of biodiversity assets on several ecosystem processes was analysed. In a second step, the relation between those processes and the capacity of the system to provide services (as a link to the socio-economic system) was considered. Finally, recommendations based on this