Estuarine, Coastal and Shelf Science 161 (2015) 46–64

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Marine biodiversity and ecosystem function relationships: The potential for practical monitoring applications

James Asa Strong [a,*], Eider Andonegi [b], Kemal Can Bizsel [c], Roberto Danovaro [d], Mike Elliott [a], Anita Franco [a], Esther Garces [e], Sally Little [a], Krysia Mazik [a], Snejana Moncheva [f], Nadia Papadopoulou [g], Joana Patrício [h], Ana M. Queirós [i], Chris Smith [g], Kremena Stefanova [f], Oihana Solaun [b]

[a] *The Institute of Estuarine and Coastal Studies, University of Hull, Hull HU6 7RX, UK*
[b] *AZTI – Tecnalia, Astondo Bidea, Edificio 609, Parque Tecnológico de Bizkaia, 48160 Elexalde Derio, Vizcaya, Spain*
[c] *Institute of Marine Sciences and Technology Baku, Blvd. No 100, P.K. 478 Inciralti-Izmir, Turkey*
[d] *CONISMA, Polytechnic University of Marche, Piazza Roma, 22, 60121 Ancona, Italy*
[e] *Institut de Ciències del Mar, CSIC, Spain, Passeig Marítim de la Barceloneta, 37-49, E-08003 Barcelona, Spain*
[f] *Institute of Oceanology-BAS, First May Street 40, P.O.Box 152, Varna 9000, Bulgaria*
[g] *Hellenic Centre of Marine Research, Athens Sounio Ave. P.C., 19013 Anavyssos Attiki, Greece*
[h] *European Commission, Joint Research Centre, E. Fermi 2749, 21027 Ispra (VA), Italy*
[i] *Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH, UK*

ARTICLE INFO

Article history:
Received 20 November 2014
Accepted 25 April 2015
Available online 6 May 2015

Keywords:
biodiversity and ecosystem function relationships
marine
practical applications
operationalization
monitoring

ABSTRACT

There is an increasing demand for environmental assessments of the marine environment to include ecosystem function. However, existing schemes are predominantly based on taxonomic (i.e. structural) measures of biodiversity. Biodiversity and Ecosystem Function (BEF) relationships are suggested to provide a mechanism for converting taxonomic information into surrogates of ecosystem function. This review assesses the evidence for marine BEF relationships and their potential to be used in practical monitoring applications (i.e. operationalized).

Five key requirements were identified for the practical application of BEF relationships: (1) a complete understanding of strength, direction and prevalence of marine BEF relationships, (2) an understanding of which biological components are influential within specific BEF relationships, (3) the biodiversity of the selected biological components can be measured easily, (4) the ecological mechanisms that are the most important for generating marine BEF relationships, i.e. identity effects or complementarity, are known and (5) the proportion of the overall functional variance is explained by biodiversity, and hence BEF relationships, has been established.

Numerous positive and some negative BEF relationships were found within the literature, although many reproduced poorly the natural species richness, trophic structures or multiple functions of real ecosystems (requirement 1). Null relationships were also reported. The consistency of the positive and negative relationships was often low that compromised the ability to generalize BEF relationships and confident application of BEF within marine monitoring. Equally, some biological components and functions have received little or no investigation.

Expert judgement was used to attribute biological components using spatial extent, presence and functional rate criteria (requirement 2). This approach highlighted the main biological components contributing the most to specific ecosystem functions, and that many of the particularly influential components were found to have received the least amount of research attention.

The need for biodiversity to be measureable (requirement 3) is possible for most biological components although difficult within the functionally important microbes. Identity effects underpinned most marine BEF relationships (requirement 4). As such, processes that translated structural biodiversity measures into functional diversity were found to generate better BEF relationships.

* Corresponding author.
E-mail address: j.strong@hull.ac.uk (J.A. Strong).

http://dx.doi.org/10.1016/j.ecss.2015.04.008

The analysis of the contribution made by biodiversity, over abiotic influences, to the total expression of a particular ecosystem function was rarely measured or considered (requirement 5). Hence it is not possible to determine the overall importance of BEF relationships within the total ecosystem functioning observed. In the few studies where abiotic factors had been considered, it was clear that these modified BEF relationships and have their own direct influence on functional rate.

Based on the five requirements, the information required for immediate 'operationalization' of BEF relationships within marine functional monitoring is lacking. However, the concept of BEF inclusion within practical monitoring applications, supported by ecological modelling, shows promise for providing surrogate indicators of functioning.

1. Introduction

The physical, chemical and biological processes that transform and translocate energy or materials in an ecosystem are termed ecosystem functions (Naeem, 1998; Paterson et al., 2012). Ecosystem functioning generally describes the combined effects of individual functions, with the overall rate of functioning being governed by the interplay of abiotic (physical and chemical) and/or biotic factors (Reiss et al., 2009). Of these biotic factors, the influence of biodiversity is widely cited as being influential and is referred to as the 'Biodiversity and Ecosystem Function' relationship (BEF). Furthermore, these ecosystem functions represent a significant component of ecosystem health (Tett et al., 2013) and provide ecosystem services that benefit society (Paterson et al., 2012).

The need to ensure the sustainable functioning of aquatic ecosystems is acknowledged by many marine policy obligations, either explicitly (e.g. the European Marine Strategy Framework Directive, MSFD, 2008/56/EU), or indirectly by addressing structural aspects which can be related to functioning (e.g. Water Framework Directive, 2000/60/EC, and Habitats Directive, 1992/43/EEC). The MSFD aims to achieve Good Environmental Status (GEnS) of European seas by 2020. The MSFD definition of GEnS includes the requirement that 'the structure, functions and processes of the constituent marine ecosystems allow those ecosystems to function fully'. The GEnS assessment can be interpreted as requiring (1) functioning to be considered at all levels of biological organization (i.e. cell, individual, population, community and ecosystem) and (2) the potential to relate these functions to GEnS indicators and overall ecosystem health (Tett et al., 2013). Consequently, this review aims to assessing the evidence for BEF relationships and their potential to be used in the monitoring of ecosystem functions.

Structurally-based biodiversity assessments, such as species richness and abundance (Gray and Elliott, 2009), are extensively used to monitor components of the marine ecosystem. These structural indicators are routinely used because they are well established, cost-effective and provide structural surrogate indicators of ecosystem condition and functional state (Gray and Elliott, 2009). However, using BEF relationships in practical monitoring applications ('operationalizing' BEF) provides a more direct and tangible link by which biological diversity information can be translated into surrogates of ecosystem functionality that ultimately help fulfil monitoring obligations and policy goals. Although direct measurements of specific ecosystem functions are often more straight-forward and cost-effective, the use of biodiversity information and BEF relationships has the following benefits: (1) one biological dataset can provide surrogates of multiple ecosystem functions; (2) combines the analysis of structural and functional status; (3) predictions of ecosystem function can be generated, based on known sensitivity of individual species, within realistic patterns of biodiversity loss; and (4) functional evaluations, based on biodiversity, incorporate the biological apparatus of functional delivery within the same assessment.

This review aims to explore the prevalence and nature of marine BEF relationships and the potential of these relationships to be used in operational monitoring of marine environmental health. The key objectives are to (1) identify what information is required for the consistent and confident application of BEF relationships within ecosystem functioning monitoring; (2) review the evidence for BEF realtionships including details about strength, consistency, direction and the mechanism of delivery (i.e. complementarity and identity effects); (3) identify the relevant biological components (i.e. broad biological groupings, based on either taxonomic or ecological similarity, could include for example microbes, benthic invertebrates, phytoplankton, and fish) for specific ecosystem functions; (4) provide a framework for the incorporation of BEF relationships within marine monitoring; and (5) assess the limitations and future work required to fully implement BEF relationships within functional monitoring. Hence we give: (1) the key requirements for the practical application; (2) a review of the BEF evidence in relation to these requirements and (3) an overall assessment of the potential of BEF relationships to be used in practical applications of ecosystem monitoring and a framework by which this could be achieved.

1.1. Biodiversity and ecosystem functioning relationships

BEF research has recently proliferated in response to scientific and public awareness of the widespread and unprecedented biodiversity turnover (β diversity scale) and loss in many biological components (Pimm et al., 1995; Bulling et al., 2010; Dornelas et al., 2014; Pandolfi and Lovelock, 2014) induced by human activity and climate change (Loreau et al., 2001; Covich et al., 2004). Such changes have potential implications for the provision of ecosystem services and societal benefits (Chapin et al., 1997; Covich et al., 2004; Solan et al., 2004; Worm et al., 2006; Atkins et al., 2011; Cardinale et al., 2012; Hooper et al., 2012; UK National Ecosystem Assessment, 2014). BEF research is increasingly centred on whether altered species diversity affects functions (Loreau et al., 2001; Covich et al., 2004).

The underlying BEF theory postulates that changes in biodiversity will result in altered ecosystem functions, i.e. that higher and more efficient functioning rates come from highly diverse areas. This is presumed to be because diverse communities are more likely to contain a greater range of functional traits and environmental sensitivities (Chapin et al., 1997). High diversity therefore entails opportunities for more efficient resource use as well as providing stability to ecosystem functions in variable environments and in the face of disturbance (Chapin et al., 1997). Alternatively, systems with species-poor communities are theoretically likely to be functionally poorer, less resistant (capacity to resist change) and resilient (capacity to recover from change) to