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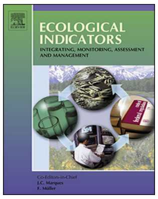

Review

Trait-based approaches in rapidly changing ecosystems: A roadmap to the future polar oceans

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ABSTRACT

Polar marine regions are facing rapid changes induced by climate change, with consequences for local faunal populations, but also for overall ecosystem functioning, goods and services. Yet given the complexity of polar marine ecosystems, predicting the mode, direction and extent of these consequences remains challenging. Trait-based approaches are increasingly adopted as a tool by which to explore changes in functioning, but trait information is largely absent for the high latitudes. Some understanding of trait–function relationships can be gathered from studies at lower latitudes, but given the uniqueness of polar ecosystems it is questionable whether these relationships can be directly transferred. Here we discuss the challenges of using trait-based approaches in polar regions and present a roadmap of how to overcome them by following six interlinked steps: (1) forming an active, international research network, (2) standardizing terminology and methodology, (3) building and crosslinking trait databases, (4) conducting coordinated trait-function experiments, (5) implementing traits into models, and finally, (6) providing advice to management and stakeholders. The application of trait-based approaches in addition to traditional species-based methods will enable us to assess the effects of rapid ongoing changes on the functioning of marine polar ecosystems. Implementing our roadmap will make these approaches more easily accessible to a broad community of users and consequently aid understanding of the future polar oceans.

1. Introduction

Climate change is a serious threat to humanity, in particular the rapid changes observed in polar regions have global implications (Hassol, 2005; IPCC, 2014; Sunday et al., 2015). Although we have gained insights into how certain polar marine species, taxon groups and local assemblages were affected by climate change (Gutt et al., 2013; Kortsch et al., 2015; Matishov et al., 2012; Montes-Hugo et al., 2009;

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Table 1
Glossary in alphabetic order. If terms within the explanation occur also as entries themselves, they are given in italics.

Biological trait	A well-defined, measurable property of organisms, usually at the individual level and used comparatively across species (McGill et al., 2006; Reiss et al., 2009; Violle et al., 2007). Examples of frequently used biological traits in the marine realm are body size, mobility, and feeding habit
Biological Trait Analysis (BTA)	An approach that considers a range of *biological traits* of organisms to assess how functioning varies between assemblages (Bremner et al., 2003). Also, it may explore potential relationships between community biology and environmental characteristics, including human activities (Beauchard et al., 2017)
Ecosystem function	Comprises the stocks and fluxes of energy and materials in the system, and the relative stability over time (Paterson et al., 2012). Examples are primary production, nutrient cycling, or sediment stability. Absolute separation of *ecosystem functions* and *ecosystem processes* is not always possible, and in literature terms are often used synonymously (Paterson et al., 2012; Reiss et al., 2009).
Ecosystem functioning	The joint effects of all processes that sustain an ecosystem (Reiss et al., 2009)
Ecosystem goods and services	Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life. They maintain biodiversity and the production of ecosystems goods such as seafood, forage, timber, biomass fuels, natural fiber, and many pharmaceuticals, industrial products, and their precursors (Daily, 1997)
Ecosystem process	Mostly small-scale transformation and translocation of energy and material within the ecosystem, due to physical, chemical or biological action; in sum regulating the observed level of *ecosystem functions* (Paterson et al., 2012). Examples are electron transport pathways of photosynthesis or shell formation in bivalves
Effect traits	Those *functional traits* that determine how an organism affects ecosystem properties (Hooper et al., 2005; Lavorel and Garnier, 2002). An example are traits related to bioturbation, which affect sediment biogeochemistry
Functional trait	Component of an organism's phenotype that influences *ecosystem processes* and its response to environmental factors (Naeem and Wright, 2003; Petchey and Gaston, 2006)
Functional diversity	The range and value of those traits that influence *ecosystem functioning* (Tilman, 2001). Functional diversity indices usually describe two broad aspects of functional diversity: (1) how much of the functional niche space is filled by the existing species (functional richness) and (2) how this space is filled (functional evenness, functional divergence/variance) (Schleuter et al., 2010; Villéger et al., 2008)
Fuzzy coding	A coding procedure allowing organisms to exhibit *trait categories* to different degrees, to reflect its biology, or our uncertainty of its biology (Chevenet et al., 1994; Frid et al., 2008)
Response traits	Those *functional traits* that determine how organisms respond to a disturbance or change in the environment (Hooper et al., 2005). An example is life span: in highly disturbed environments species with short life span and high turnover prevail
Trait-based approach	Here used for any framework in community ecology that considers organism traits rather than individual species, including studies that focus only on a single trait
Trait categories	Traits can be subdivided into categories (often also called modalities). For example, the trait 'feeding habit' can be split up into the categories deposit feeder, filter/suspension feeder, opportunist/scavenger and predator (Bremner et al., 2006b)

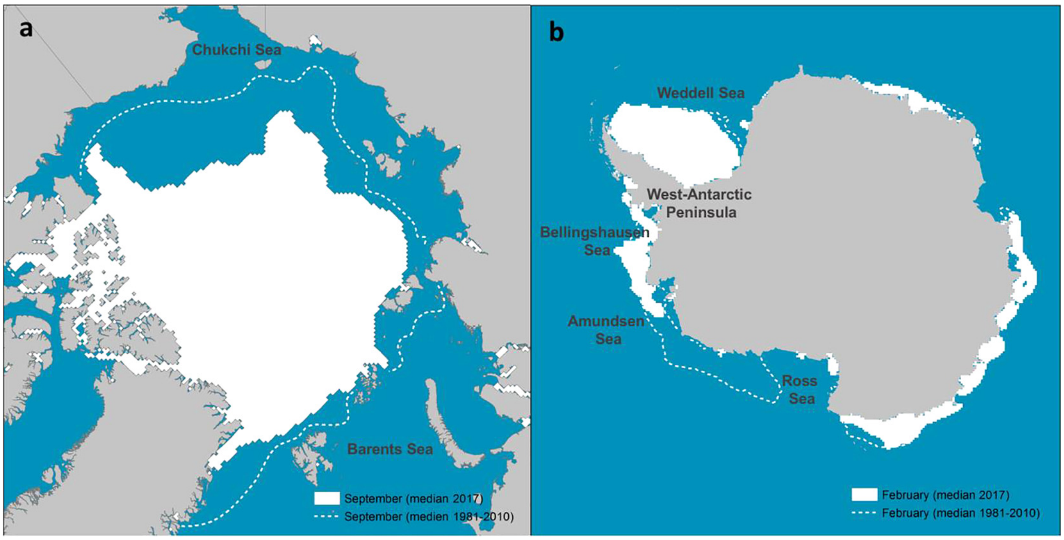

Fig. 1. Arctic and Antarctic study region and sea ice extent. Mean Arctic sea ice extent of September 2017 compared to the September median of 1981–2010 (a) and mean Antarctic sea ice extent of February 2017 compared to the February mean of 1981–2010 (b). Shapefiles by NSIDC (http://nsidc.org/data/; Fetterer et al. 2002).

Nahrgang et al., 2014; Sahade et al., 2015), we have considerably less understanding of how certain ecosystem processes, let alone overall ecosystem functioning (see Table 1 – Glossary for definitions) will be affected. A major reason for this uncertainty is that we lack knowledge of community structure-function relationships that could be related to (changing) environmental parameters in large-scale approaches (Worm et al., 2006). Animals, plants and microbes shape ecosystem functions via their collective life activities or traits; accordingly, we infer that stressor-induced changes in community structure will alter certain functions (Naeem et al., 1999). Today, polar marine communities are facing drastic changes. The Arctic is warming at twice the rate of the global average (Pachauri et al., 2014), most visibly reflected in the drastic decrease of Arctic sea ice thickness and extent within the last decades (Comiso, 2016) (Fig. 1a). The Antarctic shows a different trend and stronger natural variability than the Arctic (Turner and Overland, 2009). This variability is reflected in the long-term decline of sea ice in the Bellingshausen Sea, and in the increase of sea ice in the adjacent Ross Sea (Stammerjohn et al., 2008). In austral spring 2016, overall Antarctic sea ice decreased at a record rate, leading to a decrease of sea ice 28% greater than the mean (Turner et al., 2017). Sea ice is the central structuring force in polar ecosystems: it serves as a habitat for a variety of taxa (Loeb et al., 1997; Moore and Huntington, 2008), while its seasonal growth and melt rhythms control the stratification of the water column and light availability, and thus the availability of nutrients and the onset of the productive season (Leu et al., 2015, 2011; Turner et al., 2009). Consequently, drastic changes in sea ice affect the