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The Continuous Plankton Recorder survey: How can long-term phytoplankton datasets contribute to the assessment of Good Environmental Status?

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A B S T R A C T

Phytoplankton are crucial to marine ecosystem functioning and are important indicators of environmental change. Phytoplankton data are also essential for informing management and policy, particularly in supporting the new generation of marine legislative drivers, which take a holistic ecosystem approach to management. The Marine Strategy Framework Directive (MSFD) seeks to achieve Good Environmental Status (GES) of European seas through the implementation of such a management approach. This is a regional scale directive which recognises the importance of plankton communities in marine ecosystems; plankton data at the appropriate spatial, temporal and taxonomic scales are therefore required for implementation. The Continuous Plankton Recorder (CPR) survey is a multidecadal, North Atlantic–basin scale programme which routinely records approximately 300 phytoplankton taxa. Because of these attributes, the survey plays a key role in the implementation of the MSFD and the assessment of GES in the Northeast Atlantic region. This paper addresses the role of the CPR's phytoplankton time-series in delivering GES through the development and informing of MSFD indicators, the setting of targets against a background of climate change and the provision of supporting information used to interpret change in non-plankton indicators. We also discuss CPR data in the context of other phytoplankton data types that may contribute to GES, as well as explore future possibilities for the use of new and innovative applications of CPR phytoplankton datasets in delivering GES. Efforts must be made to preserve long-term time series, such as the CPR, which supply vital ecological information used to informed evidence-based environmental policy.

1. Introduction

Phytoplankton are the sea's major marine primary producers, generating 50% of the world's oxygen and playing an important role in ocean carbon cycling (Falkowski et al., 2004). Plankton therefore comprise the base of the marine food web, and alterations to their composition and abundance often have repercussions on higher trophic levels, including those of economic importance, such as fish (Platt et al., 2003; Richardson and Schoeman, 2004). Phytoplankton are also particularly good indicators of marine environmental change (Hays et al., 2005). They are seldom commercially exploited, most individuals are short-lived so populations are only minimally influenced by persistence of individuals from previous years, and they respond rapidly to changes in their environment through range alterations (Hays et al., 2005). Phytoplankton responses to environmental change occur at a variety of spatio-temporal and taxonomic scales, from ephemeral blooms of a single species in a local area to regional-scale decadal changes in community composition.

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Phytoplankton datasets which are 20–30 years in length, spatially extensive and taxonomically detailed are increasingly important in informing the new generation of policy mechanisms which seeks to manage the marine ecosystem holistically. The European Union's Marine Strategy Framework Directive (MSFD) aims to achieve Good Environmental Status (GES) of European seas by 2020 through implementation of an ecosystem approach to marine management. The Directive requires the development of regional sea scale indicators, encompassing both near-shore and off-shore waters, which must be monitored towards environmental targets. Both the Directive and the supporting Commission Decision explicitly acknowledge the ecological importance of achieving GES for multiple aspects of the phytoplankton, including phytoplankton species, communities, functional groups, and biomass (European Commission, 2008, 2010). Under the MSFD, GES must be achieved for 11 qualitative descriptors of the marine ecosystem. Phytoplankton data are required to inform two of these descriptors which are undergoing collective implementation (Descriptor 1: Biodiversity, Descriptor 4: Food webs). Along with Descriptor 6: Seafloor integrity, these three descriptors are collectively known as the 'biodiversity' descriptors as they represent facets of ecosystem state. Phytoplankton data are also required for supporting Descriptor 5: Eutrophication, which is a 'pressure' descriptor undergoing implementation through a slightly different process; for this reason Descriptor 5 is not a focus of this work.

In Europe, the majority of phytoplankton monitoring programmes which collect species-level data are coastal and usually associated with a local laboratory or observatory (e.g. Southward et al., 2005; Wiltshire et al., 2010; Zingone et al., 2010 and Richard Gowen's paper in this special issue), leaving non-coastal areas critically undersampled (Edwards et al., 2010; Koslow and Couture, 2013). Similarly, phytoplankton datasets possessing the minimum 30–40 year time-series, required to determine multidecadal climate-driven trends (Henson et al., 2010), are also scarce. Not surprisingly, plankton monitoring programmes, which are multidecadal, taxonomically detailed and regularly sample the open ocean at a wide spatial scale, are the rarest (Edwards et al., 2010; Koslow and Couture, 2013).

The Continuous Plankton Recorder (CPR) survey, managed by the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) in the UK, routinely monitors the open sea environment, providing a comprehensive picture of epipelagic plankton communities at the regional scale. Approximately 500,000 plankton samples have been collected in the surface waters of the North Atlantic basin on a monthly basis since 1931 (Fig. 1). The collection and taxonomic analysis of CPR samples have been carried out using a consistent methodological approach since 1958 (1948 for the CPR's Phytoplankton Colour Index - PCI), making the CPR survey the longest continuous dataset of its kind in the world (Edwards and Richardson, 2004). CPR taxonomists routinely identify and enumerate over 300 phytoplankton taxa collected by the survey, which has resulted in an 80 + year dataset of comprehensive taxonomic depth. Research using CPR data has advanced the understanding of phytoplankton spatio-temporal dynamics by examining their responses to both natural and anthropogenic components of climate variability, and their links to anthropogenic pressures. CPR data have also contributed to the development of applied indicators that routinely inform UK, European and basin-scale policy and management mechanisms (Edwards et al., 2010; McQuatters-Gollop, 2012). Because of the spatio-temporal scope and taxonomic breadth of the time-series, CPR phytoplankton data are integral to the assessment and delivery of Good Environmental Status through the MSFD.

This paper addresses the role of the CPR's phytoplankton time-series in delivering GES through the development and informing of MSFD indicators, the setting of targets against a background of climate change and the provision of supporting information used to interpret change in non-biodiversity indicators. We also discuss CPR data in the context of other phytoplankton data types that may contribute to GES as well as explore future possibilities for the use of new and innovative applications of CPR phytoplankton datasets in delivering GES.

2. The CPR's methodology: a balance between taxonomic detail and sampling constraints

Taxonomic information provides a crucial understanding of the most basic component of biodiversity: which organisms are present in a region or ecosystem? Fundamental knowledge of phytoplankton taxonomy is necessary to assess diversity, understand plankton community dynamics, gain insights into phytoplankton responses to climate change, detect non-indigenous species, and identify emerging scientific and policy issues. This type of detailed, species level phytoplankton community composition information can only be obtained through analysis by trained taxonomists. Unlike modern analysis techniques (such as automated visual identification, flow cytometry, satellite remote sensing, or fluorometry) which can, for the most part, only discriminate coarse phytoplankton groups, taxonomists can distinguish a wide variety of species relatively efficiently, generating information needed to investigate diversity in complex marine systems. At the wide spatial and multiple decadal scales monitored by the CPR, detailed taxonomic information forms the foundation to understand spatio-temporal changes in global distributions of species and alterations to their community composition (e.g., Beaugrand et al., 2002; Burrows et al., 2014). For a detailed review of the CPR's general methodology and history, which is outside the current remit, please see Batten et al. (2003), Reid et al. (2003) and Richardson et al. (2006).

The CPR most effectively samples phytoplankton which are robust and large in size, particularly diatoms and armoured dinoflagellates; small or delicate phytoplankton taxa are less adequately captured by the CPR for two key reasons. Firstly, the mesh size of the CPR sample silk is relatively large (270 μm) compared to most nets designed for collecting phytoplankton which have a mesh size of <50 μm. As a fisheries ecologist, Alister Hardy originally conceived the CPR as a way to monitor the key food source for larval fish: zooplankton. The mesh size of 270 μm was chosen in order to capture zooplankton yet still provide an indication of phytoplankton bloom conditions without clogging (Hardy, 1939); the CPR was not originally designed as a phytoplankton monitoring tool. Secondly, the sampling method itself can be destructive, with plankton retained on a continuously moving band of filtering silk, which is then wrapped around a storage spool (Batten et al., 2003). Despite these challenges, over 300 North Atlantic phytoplankton taxa are regularly identified, most to species level, and enumerated in CPR samples.

Due to the time demands required to analyse large numbers of CPR samples by light microscopy, there is often insufficient time to identify all taxa to as fine a resolution as scientifically feasible. Consequently, certain groups are simply recorded to genera. The nature of an established time-series over an extended period of time, however, results in a large base of expertise which allows responsive expansion of taxonomic scope with little additional effort. With just a small investment in time and training, the identification to the species level of certain relevant taxa can be implemented. For example, throughout the CPR's history *Dinophysis* was identified only to genus level. In response to increasing interest in harmful algal bloom (HAB) species, since 2004 the twelve most frequently occurring *Dinophysis* species have been