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Plankton as prevailing conditions: A surveillance role for plankton indicators within the Marine Strategy Framework Directive

Jacob Bedford[a,*], David Johns[b], Simon Greenstreet[c], Abigail McQuatters-Gollop[a]

[a] Centre for Marine Conservation and Policy Research, Plymouth University, Drake Circus, PL4 8AA Plymouth, UK
[b] Sir Alister Hardy Foundation for Ocean Science, The Laboratory, Citadel Hill, PL1 2PB Plymouth, UK
[c] Marine Scotland – Science, Marine Laboratory, 375 Victoria Road, AB11 9DB Aberdeen, UK

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ABSTRACT

The Marine Strategy Framework Directive (MSFD) uses an indicator-based approach for ecosystem assessment; indicators of the state of ecosystem components ('state indicators') are used to determine whether, or not, these ecosystem components are at 'Good Environmental Status' relative to prevailing oceanographic conditions. Here, it is illustrated that metrics of change in plankton communities frequently provide indications of changing prevailing oceanographic conditions. Plankton indicators can therefore provide useful diagnostic information when interpreting results and determining assessment outcomes for analyses of state indicators across the food web. They can also perform a strategic role in assessing these state indicators by influencing target setting and management measures. In addition to their primary role of assessing the state of pelagic habitats against direct anthropogenic pressures, plankton community indicators can therefore also fulfil an important 'surveillance' role for other state indicators used to formally assess biodiversity status under the MSFD.

1. Introduction

An ecosystem-based approach is increasingly adopted for the management of marine ecosystems [1,2]. Whilst previous management strategies focused on key species and habitats, they neglected the interactions and linkages between ecosystem components, as well as between ecological and social systems [3,4]. Ecosystem-based management on the other hand, considers humans as part of the ecosystem, and aims to manage the impact of multiple anthropogenic activities to achieve a healthy ecosystem state with a sustained flow of ecosystem services to humans [4,5]. The EU Marine Strategy Framework Directive (MSFD) takes an ecosystem approach to the management of European seas, supported by Integrated Ecosystem Assessments, where indicators are required to synthesize scientific information and formally assess progress towards the overall ecosystem objective of 'Good Environmental Status' (GES) [6,7]. Out of the 11 qualitative descriptors that comprise the MSFD [8], the descriptors, 'Biodiversity', 'Food webs' and 'Sea Floor Integrity', describe ecosystem state [9].

As a directive concerning direct, manageable anthropogenic pressures on the marine environment, the development of MSFD biodiversity state indicators for formal assessment initially focused on indicators with clear pressure-state relationships and associations with defined thresholds and targets. An example is a fish stock size controlled by levels of fishing pressure [10,11]. These state indicators can follow an 'Activity'-'Pressure'-'State'-'Response' (APSR) framework of marine management, where a human activity applies a defined pressure on the system. This pressure causes a change in the state of the indicator, which can trigger a management response [12]. However, Shephard et al. [12] argue that a separate class of indicators called 'surveillance indicators', where the links to defined anthropogenic pressures are not well understood and where target setting is difficult, can also contribute to ecosystem assessments under the MSFD. Surveillance indicators do not have a direct influence on the formal assessment of Good Environmental Status, but their 'surveillance' can provide information on wider ecosystem impacts of anthropogenic pressures as well as changing environmental conditions. Therefore, surveillance indicators can also result in triggering management action when pre-defined bounds are passed.

Indicators that describe the structure and functioning of plankton communities have been developed to formally assess the state of 'pelagic habitats' within the MSFD. These include indicators of bulk properties such as primary production as well as indicators of change in plankton functional groups [13]. Plankton indicator change may be driven by a multitude of direct anthropogenic pressures, most notably eutrophication resulting from anthropogenic nutrient pollution [14]. The assessment of these MSFD plankton indicators, therefore, can

* Corresponding author.
E-mail address: jacob.bedford@plymouth.ac.uk (J. Bedford).

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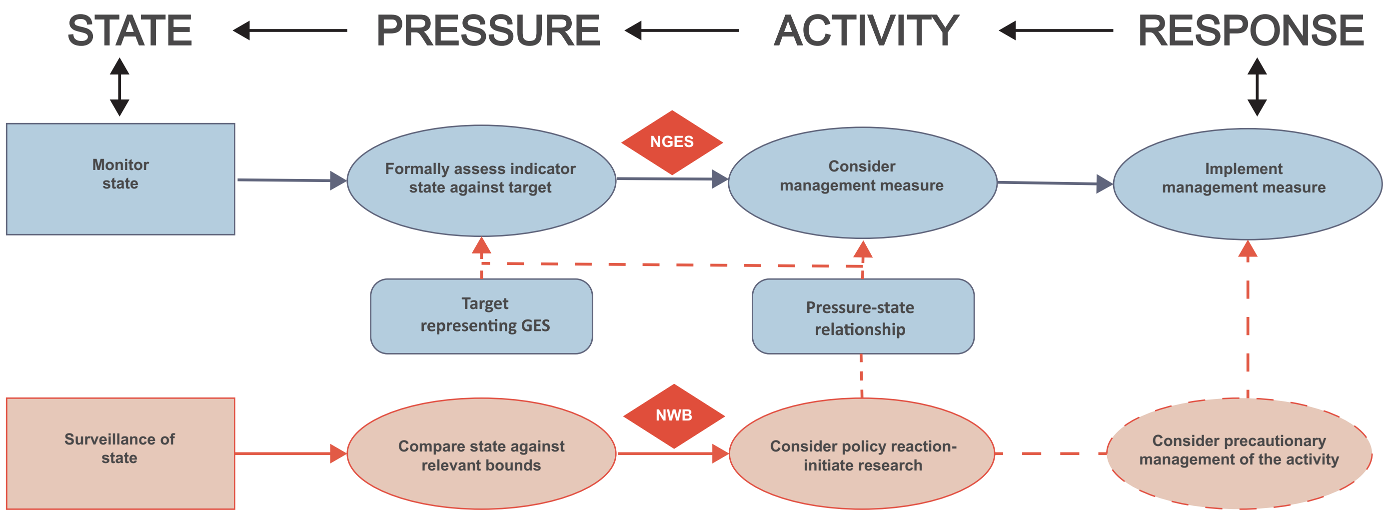

Fig. 1. The 'surveillance indicator' framework used here. Diagram adapted from Shephard, Greenstreet, Piet, Rindorf and Dickey-Collas [12]. Formally assessed indicator change is detected (top rows process). If indicator moves to being not in GES (NGES), a management measure is considered, based on the pressure-state relationship of the assessed indicator with a direct pressure. Surveillance indicators are monitored simultaneously (bottom row process) to the assessed indicator, and surveillance indicator change is detected when the surveillance indicator moves out of predefined bounds (not within bounds: NWB). This surveillance indicator change triggers research targeted at the pressure-state relationships and GES targets of associated formally assessed indicators.

directly contribute to the design of the programme of management measures needed to ensure marine ecosystems are in Good Environmental Status under the MSFD, should a change in the plankton indicators be detected during assessment, and linked to direct anthropogenic pressure.

Plankton dynamics, however, are largely driven by climate [15], particularly at the regional scale which is the focus of the MSFD. Consequently, both climate variability and anthropogenic climate change can cause widespread changes in the plankton [16] which are likely to manifest through changes in plankton indicators. The MSFD [8] refers to these drivers of change as 'prevailing conditions' and mandates that "*the quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions*". Changes in the plankton driven by climate change and environmental variability, therefore, would be considered in line with Good Environmental Status, with no management impetus through the MSFD.

Because plankton are sensitive to changes in climatic and physical oceanographic conditions however, and have been shown to amplify weak climatic signals [17], they can be useful indicators for large scale changes in prevailing conditions. For example, indicators of variability in volume of Atlantic inflow into the North Sea, a key forcing variable for the North Sea ecosystem, can be derived from zooplankton communities [18]. Furthermore, due to the key role of phytoplankton as primary producers in the marine food web, and the key role of zooplankton as prey for higher trophic levels such as fish, climate-induced changes in plankton themselves may be considered as prevailing conditions for other biodiversity components [19]. In this way, in addition to their use in directly assessing for Good Environmental Status, plankton indicators can also be considered surveillance indicators, reflecting change in prevailing conditions that can aid in the interpretation of formal biodiversity indicator assessments. Plankton indicators can therefore have an additional 'surveillance role' even when the plankton indicator changes are not linked to direct anthropogenic pressures.

The surveillance role of plankton indicators is not limited to the formally assessed MSFD plankton indicators however, and can extend to the wider climate change trends identified from time-series datasets that aren't formally assessed within the MSFD. For example a trend for a decrease in *Calanus finmarchicus* and an increase in its congeneric warmer-water species *Calanus helgolandicus* was identified in the North Atlantic and is an indicator of climate change [20]. Similarly, changes in the phenology of phytoplankton bloom dynamics, linked to the efficiency of energy transfer from phytoplankton to higher trophic levels, have been identified and attributed to climate change [21]. These trends are not formally assessed within the MSFD, but are derived from the same time-series datasets as the assessed MSFD plankton indicators, providing useful supplementary information with no additional monitoring effort.

Here, the surveillance indicator framework presented by Shephard, Greenstreet, Piet, Rindorf and Dickey-Collas [12] is used to demonstrate the utility of plankton indicators in the surveillance role of informing on changing prevailing conditions. This framework illustrates how surveillance indicators can add contextual information to formal state indicator assessments within the MSFD, aiding in assessment interpretation. Specifically, here the contextual information gained from the surveillance of plankton indicators is classified as 'diagnostic', which helps diagnose the drivers of changes within the ecosystem, and 'strategic' which aids in setting targets and management measures for Good Environmental Status.

1.1. The surveillance indicator framework

The surveillance indicator framework described by Shephard et al. [12] provides a conceptual tool for integrating changes in prevailing conditions into the formal biodiversity indicator assessment process. Due to their lack of clear pressure-state relationships, surveillance indicators cannot follow directly an Activity-Pressure-State-Response framework. Therefore, Shephard et al. modified the traditional APSR framework to include surveillance indicators (Fig. 1). A key feature of their surveillance indicator framework is that there are no GES targets for surveillance indicators. Instead, when a surveillance indicator moves outside of a defined bound, new research is triggered as the potential implication of this indicator change may not be clear. This research focuses on addressing whether the change in surveillance indicators means that the targets and management measures for associated assessed indicators need to be re-evaluated. Precautionary management may be implemented as a result of surveillance indicator change, in respect to the management responses to changes in associated formally assessed indicators.

When applying plankton to this surveillance indicator framework, time-series data can be used for setting surveillance bounds [12,22], for