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

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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

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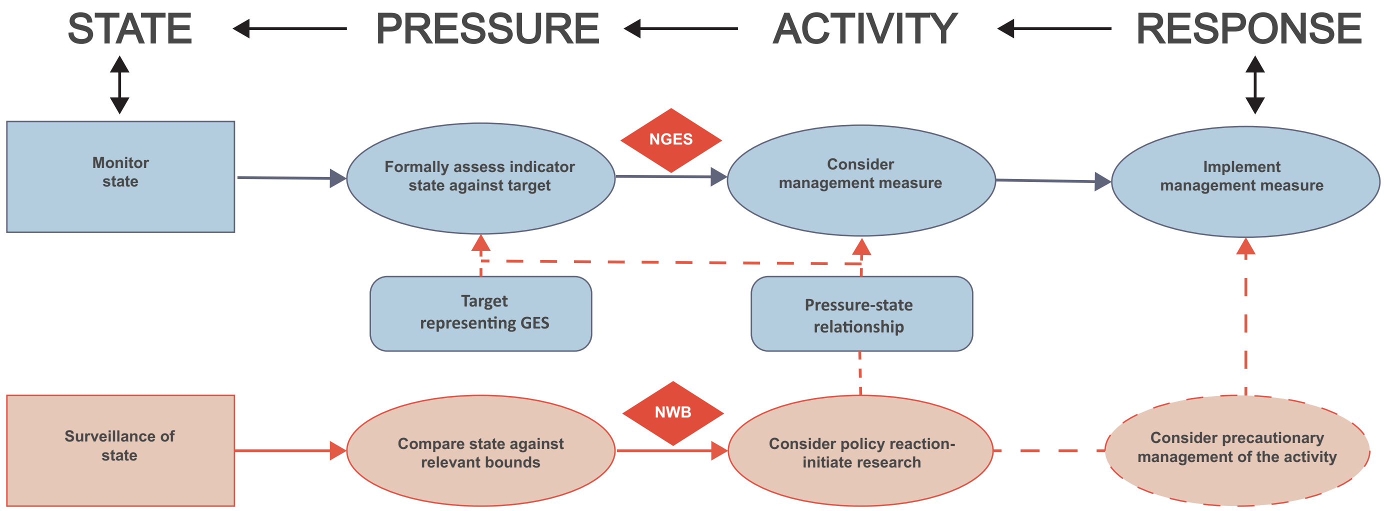

Fig. 1. The 'surveillance indicator' framework used here. Diagram adapted from Shephard, Greenstreet, Piet, Rindorf and Dickey-Collas [12]. Formally assessed indicator change is detected (top rows process). If indicator moves to being not in GES (NGES), a management measure is considered, based on the 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 example based on past ranges of indicator values, or using past variability to categorize different magnitudes of change. This is because long term time-series aid in contextualising any indicator changes identified, in terms of the indicated changes in prevailing conditions. An example is the use of time-series data in the detection of regime shifts, such as the 1980s climate-driven regime shift detected in Continuous Plankton Recorder (CPR) survey data that caused widespread changes in both phytoplankton and zooplankton communities, coinciding with changes across the wider food web [23–25]. Time series data can also aid in identifying whether observed changes are the continuation of longer term trends by identifying any existing trajectories of indicator change [26].

Often, however, the strength of coupling between hydro-climatic variation, plankton, and other food web components may not be clear and instead obscured by natural variability. Thus, covariation between a plankton indicator and assessed indicators at higher trophic levels would not be sufficient to trigger precautionary management alone within the framework. Furthermore, the use of correlations to derive links between environmental variation and higher trophic levels has been criticised [27]. Instead, within the framework, any covariation identified would highlight questions that could be considered when interpreting the results of formal state indicator assessments, often requiring further research and analysis. Examples of how information on prevailing conditions gained through plankton surveillance provides evidence for the interpretation of formal biodiversity indicator assessments are given below.

2. Diagnostic role in identifying drivers of change in formally assessed biodiversity indicators

A key challenge in assessing any biodiversity state indicator within the Marine Strategy Framework Directive is in the attribution of observed indicator changes to either direct anthropogenic pressure or prevailing conditions [28], thus 'diagnosing' the cause of indicator change (Fig. 2) [29]. Within pelagic habitats, it is established that an understanding of climate-driven plankton trends is essential for disentangling any effect of direct pressures from wider climatic influences [30]. For example, an indicator for phytoplankton community structure using functional groups is formally assessed at the OSPAR level [31]. This indicator may reveal changes in phytoplankton community structure as a result of human pressures, such as, for example, the effects of anthropogenic nutrient loading altering the proportions of dinoflagellates and diatoms within phytoplankton communities [14]. Phytoplankton community structure, however, is also influenced by climate. For example, the CPR survey reveals multi-decadal range changes in multiple phytoplankton taxa in response to climate change. These responses to climate are not uniform across taxa, with some taxa tracking northward movements of thermoclines closer than others, causing restructuring of phytoplankton communities [32]. Understanding the climate contribution to changes in plankton communities, therefore, helps diagnose the drivers of change in the assessed MSFD plankton indicators (Fig. 3A).

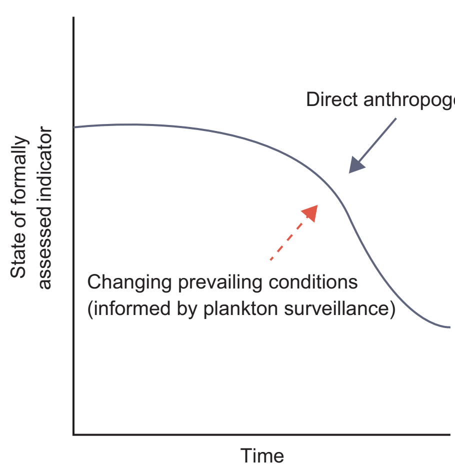

Fig. 2. Schematic diagram of the diagnostic role for plankton surveillance information. Change in the state of a formally assessed biodiversity state indicator can be influenced by both direct anthropogenic pressures and prevailing conditions. Plankton surveillance can aid in understanding the relative influence of prevailing conditions.

As well as performing this diagnostic role in the interpretation of formally assessed pelagic habitat indicators however, plankton surveillance information can also be useful for interpreting changes in assessed indicators within other habitats and trophic levels. Similarly to plankton, MSFD indicators from these other components may be driven by both direct anthropogenic pressures as well as changes in prevailing conditions, requiring a degree of attribution of the different drivers when interpreting indicator change. Plankton indicator surveillance could inform on changes in prevailing conditions affecting these assessed indicators, and therefore help diagnose when changes are not driven by direct anthropogenic pressures alone. For example, under the MSFD, benthic habitat condition is assessed at the OSPAR level for the 'Biodiversity' and 'Seafloor integrity' descriptors [33]. Multi-metric indices are used to compare the condition of benthic habitat communities over intensity gradients of different anthropogenic pressures, resulting from a range of human activities including bottom-trawling and sediment extraction allowing for the determination of the degree to which the pressures causes change in benthic condition [33].

Benthic communities, however, are also impacted by large scale climate variability, and regime shifts detected in plankton communities have coincided with changes in the benthos [34]. Changes in the abundance of the larval stages of different benthic invertebrate groups (meroplankton) in relation to climate have also been detected from plankton time-series surveys [35]. Furthermore, particularly in coastal regions, there is often tight benthic-pelagic coupling as phytoplankton production is the main source of organic supply to benthic faunal communities [36]. Phytoplankton bloom dynamics may therefore control benthic community structure by influencing food availability and levels of environmental hypoxia [37]. Clare et al. [38] showed that abrupt shifts in the temporal trends of large and long-lived taxa within a benthic community time-series were attributed to increased detrital input from pelagic primary production. Increasing frequency of Harmful Algal Bloom events as a result of climate change [39,40] may also influence benthic communities through selectively impacting both larval and post-larval survival of benthic invertebrates [41]. As the MSFD benthic condition assessment is based on quantifying pressure state relationships, changes in benthic state indicators influenced by changes in prevailing conditions may result in the influence of direct pressures being misinterpreted [42]. The surveillance of plankton indicators including bulk primary productivity and HAB dynamics (Fig. 3B), can therefore aid in the interpretation of the assessment of benthic habitat condition.

3. Strategic role in influencing targets and management measures for formally assessed biodiversity indicators

In addition to diagnosing the drivers of change in MSFD biodiversity indicators during formal assessments, plankton surveillance information could contribute to the determination of GES targets (Fig. 4). For example, an indicator for recovery in the population abundance of sensitive fish species has been developed for formal assessment at the OSPAR level [43]. However, the influence of changing prevailing oceanographic conditions on population growth is required to determine the scope for population recovery [43]. Changes in plankton indicators can track trends in physical oceanographic conditions that may affect recovery, and changes in plankton community composition and phenology may affect fish recruitment independently of the size of the spawning stock biomass [44]. For example, directly after the 1980s

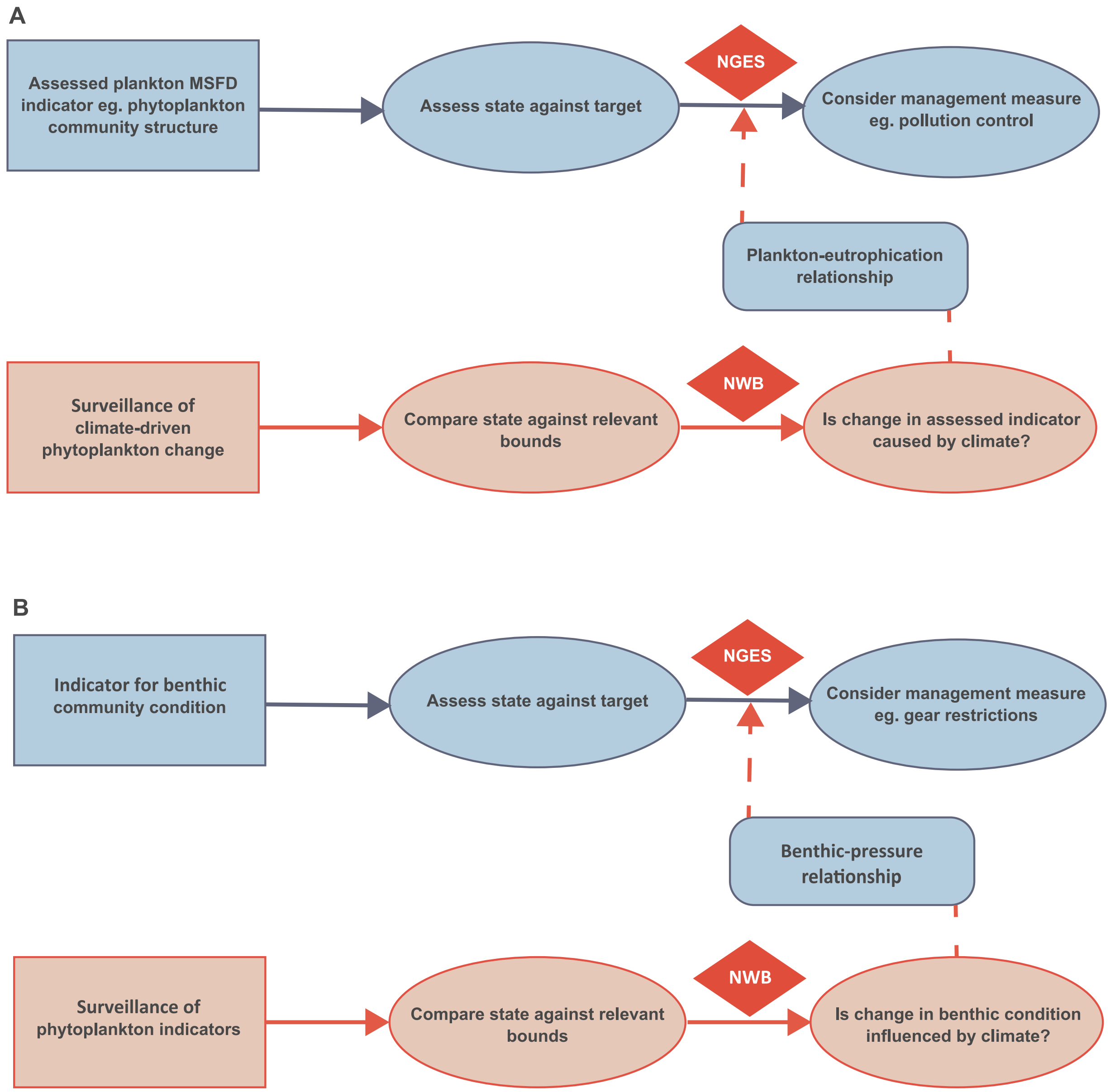

Fig. 3. Examples of the diagnostic role of plankton surveillance information in MSFD implementation using the surveillance indicator framework from Shephard et al. A) The role of plankton surveillance information in diagnosing drivers of change in pelagic habitat MSFD indicators. Here, surveillance of climate-driven plankton change triggers research targeted at the pressure-state relationship between phytoplankton GES indicator and eutrophication pressure - 'Is change in plankton GES indicator driven by climate induced range shifts?' **B)** The potential role of plankton surveillance information in diagnosing the drivers of change in assessed indicators within other habitats and ecosystem components. Here, surveillance of phytoplankton indicators triggers research targeted at the benthic pressure-state relationship, and therefore assessment of GES, between benthic community composition and anthropogenic benthic disturbance- 'Is change in benthic condition indicator influenced by climate?'.

plankton regime shift North Sea cod populations fell to historically low levels and showed weak signs of recovery [45]. Furthermore, a regime shift that occurred in the North Sea in the early 2000s was suggested as the leading candidate mechanism to explain the low herring recruitment observed between 2002 and 2007, with plankton shifts providing more explanatory power than the effects of physical variables alone [46]. Although the linking of fish recruitment dynamics to environmental variability is challenging [47], surveillance of plankton indicators provides information on any influence of plankton on fish recovery potential [48].

The method for assessing GES in respect to fish population recovery is outlined by [49]. First, targets for a given indicator are set at the individual species level, based on the indicator metric falling in the upper 25 percentile of all values in the species' reference period. These species-level indicator assessments are then aggregated to the community level by comparing the number of different species achieving their target for the given indicator. Therefore, changes in prevailing conditions that affect the recovery potential of stocks, despite a reduction in anthropogenic pressure, may mean the GES targets may no longer be realistic. Instead, the permitted range in which individual species metrics can fall may need to be increased, or the number of species required to be in GES at the community level may need to be reduced [50]. In this way, plankton indicator surveillance can contribute to the setting of realistic targets for the assessment of fish state indicators [51] (Fig. 5A).

As well as affecting the feasibility of reaching a specified state target, changes in prevailing conditions detected through plankton surveillance may alter the sensitivity of an ecosystem component to a specified anthropogenic pressure, thus affecting the amount of pressure that will cause an assessed biodiversity indicator to move away from Good Environmental Status. (Fig. 4) For example, indicators of seabird population size and breeding success are formally assessed at the

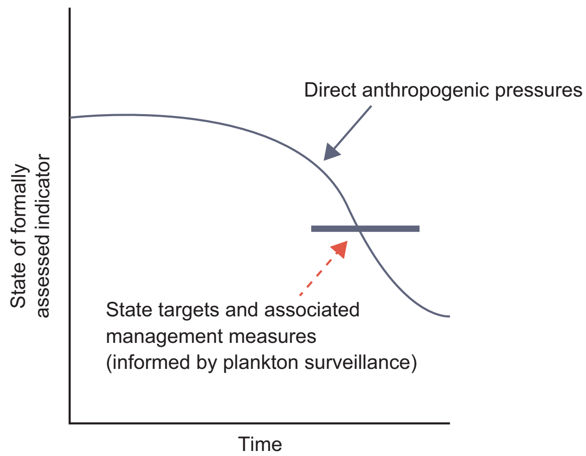

Fig. 4. Schematic diagram of the 'strategic' role for plankton surveillance information. Targets, and associated management measures, for a formally assessed state indicator can be adapted to changing prevailing conditions. Plankton surveillance information can inform appropriate target setting and management measures.

OSPAR level within the MSFD [52,53] and are useful indicators of the food web repercussions of direct pressures targeted at the lower levels of the food web, such as fishing pressure on forage fish prey [54,55]. For effective ecosystem-based management, management of forage fish exploitation must account for the need to sustain top predators and as forage fish biomass and productivity is highly variable, the setting of acceptable fishing levels must remain adaptive [56,57]. With a reduction in the recruitment success of key forage fish species such as sandeel predicted under climate change [58], reducing fishing pressure on forage fish through precautionary management measures may be needed to maintain Good Environmental Status of seabirds under future climate conditions [59].

Forage fish abundance has been linked to phytoplankton production [60] and zooplankton community composition through changes in the distribution of copepods both indicating changes in physical oceanographic conditions and influencing recruitment [61]. There can also be direct trophic links between zooplankton and seabirds, especially in the non-breeding season [62,63]. In these ways, climate-driven plankton shifts may place an additional pressure on seabirds, influencing the outcome of seabird state indicator assessments, and could therefore indicate relevant prevailing conditions when setting management

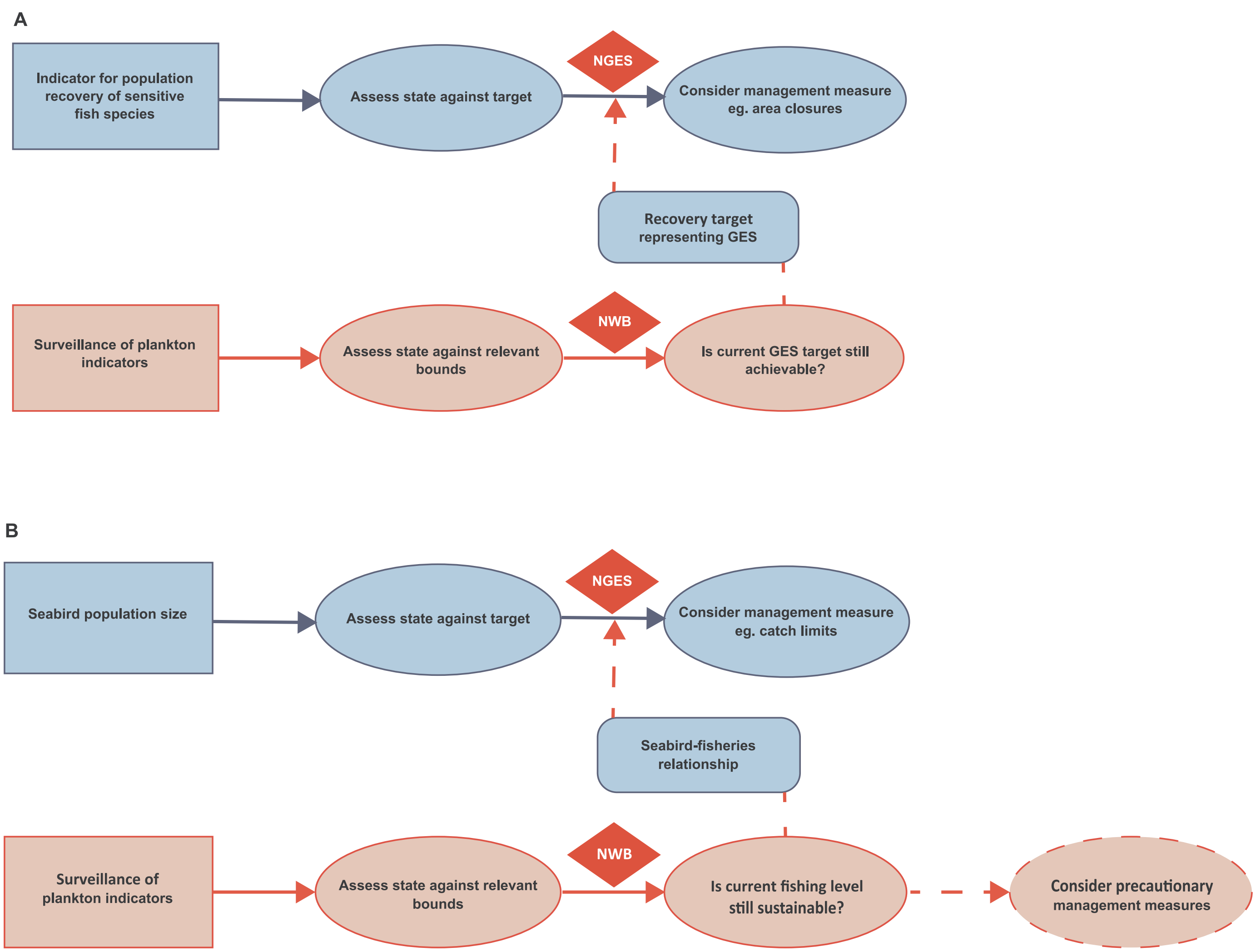

Fig. 5. Examples of the strategic role of plankton surveillance information in MSFD implementation using the surveillance indicator framework from Shephard, Greenstreet, Piet, Rindorf and Dickey-Collas [12]. A) The potential role of plankton surveillance information in setting targets for other components and descriptors. Here, plankton indicator surveillance triggers research around the target representing GES for the recovery of sensitive fish communities -'Is the current GES target still achievable under the new climate conditions?'. This research could lead to the adjustment of GES state targets. B) The potential role of plankton surveillance information in influencing the programme of measures. Here, plankton indicator changes linked to prevailing conditions trigger research targeted at the pressure-state relationship between forage fish fisheries and seabird breeding success- 'Is the current threshold level of fishing still sustainable, considering the changed prey landscape?' This research could lead to more precautionary management measures being implemented.

measures (Fig. 5B). Within MSFD assessment cycles, management of direct pressures could be altered to take into account trends in climatic (non-manageable) drivers [64], informed by plankton surveillance. In this way, although the drivers of climate induced changes cannot be addressed by the MSFD, adaptive management of direct pressures could increase the likelihood of an indicator remaining in Good Environmental Status in relation to manageable pressures, as well as help increase the resilience of the ecosystem component to climate change [65–67].

4. Summary and conclusions

In this paper, we have illustrated a surveillance role of plankton indicators within the Marine Strategy Framework Directive in addition to their primary role in formally assessing pelagic habitats for influences of direct anthropogenic pressures. Plankton indicators are useful early-warning indicators of physical hydro-climatic changes and can therefore inform on changes in the underlying prevailing conditions in which MSFD biodiversity indicators are formally assessed. Furthermore, changes in plankton can be important prevailing conditions to consider themselves. The importance of including biotic ecosystem drivers, such as changes in plankton, within marine monitoring programmes has been acknowledged by the Framework for Ocean Observing (FOO) with the development of 'ecosystem Essential Ocean Variables (eEOVs)', which are defined biological or ecological quantities derived from field observations [68]. The surveillance indicator framework presented by Shephard [12], is a useful tool in translating this established monitoring need into the MSFD implementation process.

This surveillance of plankton indicators provides two, newly-defined, types of contextual information for the assessment of biodiversity within the MSFD. 'Diagnostic' plankton surveillance information can help disentangle the influence of direct anthropogenic pressure from the influence of prevailing conditions, both within pelagic habitats, and within other habitats and ecosystem components. On the other hand, plankton surveillance information can have a 'strategic' role by indicating when the climate influence on the ecosystem may mean targets and management measures need to be altered. Due to the highly variable nature of coupling between changes in the plankton and changes in the wider marine ecosystem, both diagnostic and strategic roles of plankton surveillance information are based on the triggering of targeted research questions for consideration during assessments, following the observation of a change in plankton indicators and the detection of trends, thereby making an important evidence contribution to allow the implementation of the MSFD to be adaptive under climate change [69].

Currently, changes in plankton communities linked to climate are considered as being aligned with Good Environmental Status, as the changes are linked to natural variations or exogenous pressures. Limiting the application of these climate-driven indicator changes in this way however, is not using monitoring effort efficiently, when plankton indicators are also useful in a wider surveillance role. Progressing this surveillance role for plankton indicators requires further work on understanding ecosystem interactions between plankton and other formally assessed biodiversity components, as well as the consequences of changes in climatic and oceanographic conditions on both plankton indicators and the wider foodweb. This in turn requires further collaboration between scientists working on these different components. Ultimately, the maintenance of long-term plankton time series has multiple applications for ecosystem-based management of European seas within the Marine Strategy Framework Directive.

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Conflicts of interest

None.

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