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Annex 5: 2018 options for monitoring UK pelagic habitats

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Foreword

Yessica Griffiths and Dr Karen Webb, JNCC (2024)

This historical paper is part of an archival report series, produced between 2016 and 2018, which collectively presents options for monitoring UK marine biodiversity. These options for monitoring were evaluated at a series of workshops in 2017 and 2018, by scientific experts from the Healthy and Biologically Diverse Evidence Group (HBDSEG) and policy advisors from the four governments of the UK. The initial set of workshops provided a steer on political ambitions for monitoring specific aspects of marine biodiversity, while a final workshop garnered advice from scientific experts on the proposed monitoring across UK marine biodiversity. In 2019, the combined outcomes of these workshops formed advice for UK Governments on monitoring of UK marine biodiversity. The process for developing this advice is outlined in the summary paper (Webb *et al.* 2024).

Publication of this historical report series provides a publicly available audit of the information underpinning the 2019 advice to UK Governments on proposed marine biodiversity monitoring in UK waters. This information provides a solid foundation for developing updated future advice. At the time of publication (2024), many of the evidence gaps which have been highlighted remain and, in some instances, have increased.

This paper provides a snapshot in time of the government funded UK pelagic habitat monitoring in 2017 and the collated viewpoints, on proposed monitoring, of HBDSEG and policy representatives in 2018. These viewpoints are historical and do not necessarily reflect viewpoints at the time of publication in 2024. All monitoring options developed and presented in this paper were dependent on the assumption that core UK monitoring programmes would continue at the same level of funding. However, in parallel with decreasing resources, inflation has significantly increased the costs of marine monitoring, particularly those that were vessel based and as a result there has been ongoing, yearly erosion of core monitoring.

Greater understanding of pelagic community changes is required to provide evidence for tackling the biodiversity loss and climate crisis (temperature, ocean acidity, changes in stratifying layers, and hydrodynamics), food web changes, coastal darkening, and changes in the pelagic community and its lifeforms (e.g. prevalence of harmful algal blooms). Biodiversity is intricately and complexly linked to many other issues such as food supply via various food webs. The plankton time series are important for detecting rapid changes brought on by climate change and other anthropogenic pressures. Without adequate plankton monitoring, the approaching “tipping points” are likely to be missed, as will the opportunity to take preventative measures.

It should be noted that some of the legislative drivers which have been referenced in this report have been updated or superseded since 2017. In addition, new legislation and obligations have been introduced since 2017. For clarity, ‘[2017]’ has been included alongside all occurrences of the term ‘current’ (and its derivatives) and within all table and figure captions and headings, throughout this paper.

Contents

1 Submission: Decision on options for monitoring of UK pelagic habitats

1.1 Issue

The UK Marine Biodiversity Monitoring R&D Programme has been tasked by UK Governments with developing recommendations for an integrated monitoring scheme for all marine biodiversity across all UK waters. The monitoring options included will help the UK fulfil our nature conservation obligations for monitoring and assessment in a coordinated and cost-effective manner and enable us to provide robust evidence for marine management purposes. A decision is now required on which option to select for the monitoring of UK pelagic habitats and their associated biological communities.

1.2 Recommendation

That governments jointly decide on a preferred option for UK pelagic habitats monitoring.

1.3 Background

The pelagic habitats expert group have been asked by the Governments of the UK for advice on options for marine biodiversity monitoring for the waters of the UK. This work forms part of the UK Marine Monitoring and Assessment Strategy (UKMMAS) and is being undertaken in partnership with the UK's Healthy and Biologically Diverse Seas Evidence Group (HBDSEG). The advice aims to cost-effectively encompass the UK's significant policy and statutory obligations, such as the:

- High Level Marine Objectives
- UK Biodiversity Action Plan
- OSPAR Convention
- EU Urban Waste Water Treatment Directive
- EU Nitrates Directive
- EU Habitats Directive
- EU Water Framework Directive
- EU Marine Strategy Framework Directive
- Convention for Biological Diversity (CBD)

1.4 Objective

This policy decision will begin to enable UK Governments to meet their national and international obligations for biodiversity monitoring, assessment and reporting of pelagic habitats in a cost-effective manner, and to robustly inform advice on management of human activities in the marine environment that are related to pelagic diversity.

1.4.1 Criteria

The criteria used to evaluate the effectiveness of each potential monitoring option are as follows:

1. Meeting legislative obligations for monitoring and/or assessment related to plankton diversity.
2. Establishing a long-term, wide-scale monitoring network across pelagic habitat types (ecohydrodynamic zones) to provide an understanding of change due to natural variation and climate change, thereby allowing the interpretation of superimposed anthropogenic of changes detected through monitoring activities. This is to ensure that the monitoring is viable in informing the UK's responses in the long term.
3. Undertaking targeted pressure – state relationship studies and management effectiveness monitoring for habitat \ pressure \ management measure relationships.

1.4.2 Why monitor plankton?

Plankton form the base of the marine food chain and are at the foundation of pelagic and benthic food webs, supporting a range of key ecosystem functions including carbon sequestration, benthic-pelagic coupling, and energy flow to higher trophic levels such as fish, birds, and cetaceans. As well as being extremely biologically diverse (150,000 + eukaryotic taxa, over two million prokaryotic taxa), plankton provide several key environmental functions. Phytoplankton generate 50% of global O_2; fix 50% of the carbon (sequestering 25% of excess anthropogenic carbon), produce dimethylsulfide (DMS) which is important for cloud generation (and consequent climate moderation), and are important in the eutrophication process. Plankton's quick growth and reproduction means that they rapidly respond to changes in the system, often long before response is seen in higher trophic levels. This sensitivity is particularly important if the timing of algal blooms or zooplankton appearance changes (i.e. phenology) as it impacts other trophic levels in the marine ecosystem, including commercially valuable fish. A misbalance of plankton can lead to, for example, poor recruitment of juvenile cod (due to the "wrong copepod" zooplankton); excessive jellyfish production; more energy funnelled into microbial loops than into food webs supporting fish; or toxic blooms that impact on aquaculture, shellfish, and human health.

Because of the above features plankton are key indicators for:

- **Early warning of change** - rapid response to changes before they are seen elsewhere in the system because of rapid turnover of plankton, and presence at the base of the food web linking them closely to other ecosystem components.

- **Help to explain causes of ecosystem change** - Plankton are widely connected to the wider ecosystem (e.g. copepod zooplankton to fish recruitment; phytoplankton to eutrophication) and close coupling exists between the pelagic water column and the benthos. Plankton also have strong relationships with pressures and climate variability (e.g. climate change, currents, fronts, nutrients, invasive species), but near shore and offshore patterns in plankton dynamics differ.

- **Detect and predict "regime shifts"** – Plankton are sensitive to changes in their environment and long-term indicator time-series can be used for early detection of stepwise changes in marine ecosystems, known as regime shifts. These alterations

reflect changes and timing in proportions of plankton lifeforms and different trophic levels, as well as keystone trophic indicators (e.g. jellyfish).

- **Inshore indicators** – Phytoplankton are strong indicators of anthropogenic eutrophication. Plankton lifeforms also indicate changes in nearshore trophic webs which link to fish and seabird health, while benthic pelagic coupling indicates health of energy and carbon flows through seabed/shore habitats.

- **Offshore indicators** - Plankton indicators can distinguish between prevailing conditions (including climate change) and anthropogenic issues (e.g. fishing and offshore developments). Plankton rapidly respond to changes in frontal systems, ecohydrodynamics, ocean acidification, and temperatures changes with changes in timing and seasonality of plankton blooms and zooplankton assemblages rippling further through the food web (e.g. to fish, birds, and cetaceans).

- **Disruption of physical processes (coastal to offshore coupling / links between ecohydrodynamic regions)** - Under “normal conditions” distinct plankton assemblages are associated with different regions and hydrodynamic conditions; gradations or sharp breaks in indicator time-series indicate hydromorphological changes or anthropogenic impacts.

- **Biogeophysical indicators** – Plankton indicators are indicative of carbon sequestration and distribution, and sulphur cycle and climate change moderation. Plankton trophic levels and key taxa (e.g. microbial loops, jelly fish shunts and benthic-pelagic coupling) indicate the potential strength and direction of carbon sequestration, distribution, or burial in levels of the food web. Key plankton taxa indicate activity in the sulphur cycle and climate change moderation through DMS.

1.4.3 Meeting the obligations

Plankton cover a few different policy areas and obligations and as a result have a significant policy involvement (Table 1). Those obligations which are legally binding and explicit in their requirement for monitoring are considered the principal policy drivers for monitoring. The key instruments identified as requiring monitoring of pelagic habitats are the EU Water Framework and Marine Strategy Framework Directives and OSPAR. Both include explicit requirements for monitoring habitats to inform periodic assessment and reporting of environmental status. The Directives are also likely to bear the largest risk of legal challenge if implementation is assessed as being insufficient, although this may change following the UK’s exit from the EU.

In addition to the biodiversity assessment obligations, there are various assessment and reporting requirements that must be met by Competent Authorities and developers for proposed plans or projects in the marine environment. These requirements include those under the EU Strategic Environmental Assessment (SEA) Directive, the EU Environmental Impact Assessment (EIA) Directive, EU Habitats Directive, Urban Waste Water Treatment Directive (UWWTD); Nitrates Directive (ND); UK & OSPAR Eutrophication & biodiversity strategies; impacts on aquaculture welfare, shellfish and human health (via food standards agencies); UN sustainable development goals; the Convention on Biological Diversity; and the local, national and international issues on bird, fish and cetacean policy as well as the relevant UK regulations that transpose these requirements into UK law (Hinchen 2014).

1.4.4 Developing a monitoring programme to meet all needs

To develop a scientifically robust monitoring programme for UK pelagic habitats that can meet all relevant Government obligations without being specifically designed for any

particular one, it is necessary to consider what monitoring is needed without being constrained by what is specified in individual policy obligations. Rather, considering the ecology of the pelagic habitats in the UK and the human pressures and impacts which they are subject to will allow the needs for pelagic habitats monitoring to be identified in an objective and repeatable manner, as well as any gaps in what is existing or proposed for monitoring under currently [2017] developing obligations, such as the MSFD.

As described above, plankton data are versatile and can be used to answer multiple questions. Once collected and analysed, plankton data can be used to investigate three aspects of pelagic habitats related to biodiversity (collect once, use many times):

- **Sentinel monitoring of long-term trends (Type 1 monitoring)**

  Objective: to measure rate and direction of long-term change.

  To achieve this objective efficiently, a long-term, regular, and consistent data collection is necessary as time-series have greater power in identifying trends than any combination of independent studies.

- **Operational monitoring of pressure-state relationships (Type 2 monitoring)**

  Objective: to measure state and relate observed change to possible causes.

  This objective considers the likely impacts of pressures on habitats and species and identifies emerging problems. It relies on finding relationships between observed changes in biodiversity and observed variability in pressures and environmental factors. It provides inference but it is not proof of cause and effect.

- **Investigative analysis to determine management needs and effectiveness (links to Type 3 monitoring)**

  Objective: to investigate the cause of change.

  This analysis type provides evidence of causality. It complements the above types by testing specific hypothesis through targeted manipulative studies. The design and statistical approach that can be used in these cases gives confidence in identifying cause and effect. It is best suited to test state/pressure relationships and the efficacy of management measures.

1.4.5 Country preference regarding a monitoring option

Policy representatives within the Devolved Administrations (DAs) were given opportunity to review the suite of options for monitoring pelagic habitats and asked to consider which monitoring option, or combination of monitoring activities across different options, currently represents their position on future monitoring activities for pelagic habitats. A discussion was held via teleconference Thursday 27 February with representatives from Welsh Government and Department of Agriculture, Environment and Rural Affairs, Northern Ireland (DAERA). Marine Scotland and Department of Environment, Food and Rural Affairs, England (DEFRA) communicated their preference via individual telephone meetings.

The outcome of policy discussions was a range in the individual option preferences expressed with one DA preferring Option 1 (“status quo”), one DA preferring Option 2 (“maintaining current monitoring and making the best of all data”) and two DAs expressing interest in an Option 2+ scenario by strengthening Option 2 with some of the prioritised monitoring included in Option 3 (“filling in some of the gaps”). Specifically, expanding

existing coastal phytoplankton programs to include zooplankton sampling and re-instalment of the recently lost Continuous Plankton Recorder (CPR) routes.

As three of the four DAs agreed that as a minimum, we should enable capacity to optimise and incorporate all data currently collected across all UK monitoring programs into biodiversity assessments, Option 2 has been identified as the ***majority*** option preference.

It was identified that for the Option 2 and Option 2+ scenarios, further consideration would need to be given to how these would be funded.

1.4.6 HBDSEG review of policy preferred option

The preferred option selected by policy was reviewed by HBDSEG, alongside the remaining biodiversity components, at a two-day workshop, 27 to 28 March 2018. Participants provided advice on whether an adequate level of evidence would be achieved by the policy option preference and, if inadequate, what it would take to bring the option to a level of adequacy that would fulfil the following monitoring objectives:

- Understanding the natural variability of the biodiversity component and its role within ecosystem processes and functions.
- Understanding pressure-state relationships and facilitating the development of pressure-based monitoring to enable the sustainable management of human activities.
- Undertake robust assessments of conservation status and site condition at required scales and temporal frequencies to fulfil national and international reporting obligations.

HBDSEG developed advice on how best to address the key inadequacies identified within the policy preference and made recommendations on the minimum acceptable level of monitoring.

1.4.7 HBDSEG advice

HBSEG concluded that the majority policy option preference (Option 2) for monitoring pelagic habitats would provide a limited evidence base which would not be able to sufficiently meet our conservation and wider policy needs. Plankton are key components of marine food webs; energy, carbon, sulphate, and nutrient cycles; and benthic-pelagic, and inshore-offshore links. Consequently, the balance of organisms in the plankton indicate climate change, impact on the other elements (fish, shellfish, birds, marine mammals), and can influence tourism, aquaculture, and energy sectors.

HBDSEG advised that the following residual risks were associated with the majority policy option preference:

a. Missing lifeforms and trophic levels (particularly inshore zooplankton, and microbes more generally).

b. Inability to distinguish climate change signals in inshore waters from other signals (e.g. eutrophication).

c. Lacking the ability to adequately investigate benthic/pelagic coupling.

d. Lacking the ability to adequately investigate inshore/offshore coupling.

e. Weak datasets for critical ecohydrodynamic regions.

f. Unknown oceanographic boundary conditions (especially in the South West).

1.4.8 Inclusion of HBDSEG advice in policy option preference

HBDSEG advised that the majority option preference needed to be strengthened to improve the evidence base provided and significantly reduce the identified risks. This includes expansion of existing coastal phytoplankton programs to include zooplankton sampling (mitigating risks a-d) and the reinstatement of the recently lost Continuous Plankton Recorder (CPR) route (mitigating risks e–f).

HBDSEG advised that these additions to the monitoring programme would provide an integrated plankton monitoring program with interpretive ability across a large range of temporal, geographic and lifeform dimensions. This would allow us to have a consolidated assessment of plankton health with respect to human, climatic, and cross-element impacts that can be resolved at various scales.

An outline of the estimated costs are provided in Table 3. A summary of the costs, benefits and risks associated with the policy option and HBDSEG amended policy option, are provided in Table 4.

Table 1: Principal policy drivers of national and international obligations for biodiversity monitoring of pelagic habitats [table created in 2017].

International & national obligations	Biodiversity monitoring requirement	Explanation
Water Framework Directive (WFD 2000)	Implicit	Annex V, section 1.4.2 of the Directive describes the presentation of monitoring results and classification of ecological status and ecological potential. The monitoring systems in place under WFD should inform the values of the biological quality elements specified for each surface-water category. Annex V section 1.3 states that 'Member States shall monitor parameters which are indicative of the status of each relevant quality element. In selecting parameters for biological quality elements Member States shall identify the appropriate taxonomic level required to achieve adequate confidence and precision in the classification of the quality elements'. UK TAG recommends monitoring of phytoplankton taxa and biomass. Note – there is no requirement to monitor zooplankton, ciliates, marine bacteria, or viruses under this directive.
Marine Strategy Framework Directive (MSFD 2008)	Explicit	Article 11 of the MSFD provides explicit requirements for Member States to establish and implement coordinated monitoring programmes to support the ongoing assessment of the environmental status and the progress in achieving related environmental targets. Monitoring programmes shall be compatible within marine regions or sub-regions and shall build upon, and be compatible with, relevant provisions for assessment and monitoring laid down by Community legislation, including the Habitats and Birds Directives, or under international agreements.
Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR 1998)	Explicit	As a signatory to the OSPAR convention, delivery of the work programmes agreed under the convention is mandatory for the UK. Article 6 in conjunction with Annex IV (Article 2a) explicitly requires Contracting Parties to cooperate in carrying out monitoring programmes to support joint assessments of the quality status of the marine environment and to evaluate the effectiveness of the measures taken and planned for the protection of the marine environment. The work carried out under OSPAR on monitoring and assessment has become legally underpinned by the MSFD. Failings in delivering the MSFD will lead to failings in delivering OSPAR commitments. Currently [2017] there is no coordination between MSFD D1 and OSPAR biodiversity indicators which come under HBDSEG and MSFD D5 and OSPAR eutrophication indicators which falls under CSEG's remit.

International & national obligations	Biodiversity monitoring requirement	Explanation
Convention on Biological Diversity (CBD 1992)	Explicit	As a signatory to the CBD, delivery of the work programmes agreed under the convention is mandatory for the UK. Article 7 explicitly requires Contracting Parties to monitor biological components important for the conservation of biological diversity and sustainable use, particularly for the purposes of delivering the provisions set out in Articles 8 to 10 (e.g. to support the regulation and management of biological resources within or outside MPAs).
United Nations Convention on the Law of the Sea (UNCLOS 1994)	Explicit	As a signatory of UNCLOS, delivery of the work programmes agreed under the convention is mandatory for the UK. Part XI (Section 4, Subsection C, Article 165, 2h) together with Part XII (Section 4, Article 204), explicitly requires Contracting Parties to establish a monitoring programme to observe, measure, evaluate and analyse, on a regular basis, the risks, or effects of pollution on the marine environment, in particular undertaking surveillance of the effects of those activities which are permitted.
Urban Waste Water Treatment Directive (UWWT 1991) & Nitrate Directive (ND 1991)	Implicit	The Urban Waste Water Treatment Directive (UWWT) (Council Directive 91/271/EEC) and Nitrates Directive (ND) were adopted in 1991. The Directives concern the collection, treatment and discharge of urban wastewater, the treatment and discharge of certain industrial and agricultural waste waters. Their aims are to protect the environment from the adverse effects of insufficiently treated urban wastewater discharges and discharges of industrial and agricultural waste waters. Amendments clarify the requirements for discharges to sensitive areas which are subject to eutrophication – the assessments of sensitivity can include biodiversity measurements of phytoplankton

1.4.9 Current [2017] status of UK plankton monitoring

UK monitoring of plankton is currently [2017] designed to meet the following needs:

1. Research (CPR, PML, MSS)
2. Status assessments (e.g. WFD and MSFD (EA, SEPA, MSS))
3. Climate change (PML, CPR, MSS, Cefas)
4. OSPAR obligations (PML, CPR, MSS)
5. Fisheries and aquaculture (CPR, Cefas, MSS)
6. Marine Climate Change Impact Partnership (CPR, PML)
7. Decommissioning (CPR)
8. Other policy drivers (EA, MSS, CPR)

UK plankton monitoring consists of:

1. 13 fixed point stations:
    - 3 monitor all phyto and zooplankton at frequency required for biodiversity assessment (monthly):
        - 1 also monitors bacteria.
    - 10 only monitor phytoplankton:
        - 3 of these monitor too infrequently to capture intra-annual change.
        - 1 collects zooplankton but samples not analysed.
2. 10 CPR routes:
    - Robust zooplankton, robust and large phytoplankton, and phytoplankton biomass are monitored.

Although the MSFD is the current [2017] focus of pelagic biodiversity monitoring in UK, the data used for the MSFD is therefore coming from previously existing time-series established for other purposes such as WFD, institutional monitoring, or research projects. Most of these are funded by the governments and research councils, and the good will of ships of opportunity to collect these monitoring samples.

The UK's current [2017] plankton monitoring programme is both valuable to policy and cost efficient. Plankton biodiversity monitoring is entangled with a variety of research and policy drivers. Consequently, plankton are integrated into wider ecosystem monitoring programs throughout the UK and are usually sampled in tandem with other monitoring such as for fish, abiotic factors, or benthic habitats. This approach saves money on ship time and supports integrated analysis of multiple trophic levels, and this interconnectivity is a demonstration of the ecosystem approach required by the MSFD. When plankton are sampled, all organisms are identified and enumerated, allowing biodiversity aspects of the data to be analysed in multiple ways, resulting in a cost effective mechanism to increase the robustness of information, evidence, and advice. In other words, plankton data collected for one policy driver can be re-used to inform on other drivers.

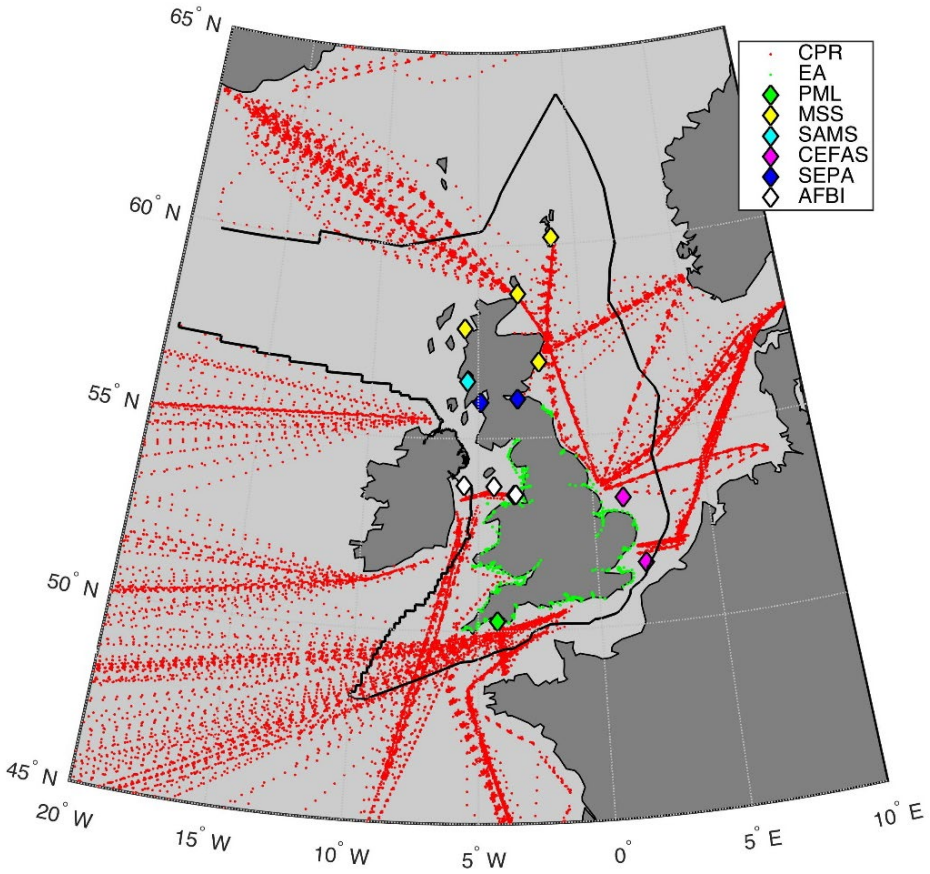

Figure 1: The UK plankton monitoring programmes [2017] consists of disparate but complementary surveys. Samples from the Continuous Plankton Recorder (CPR) are displayed as red dots along routes. The other surveys operate fixed-point sampling schemes. Abbreviations: EA – Environment Agency; PML – Plymouth Marine Laboratory; MSS – Marine Scotland Science; SAMS – Scottish Association for Marine Science; Cefas - Centre for Environment, Fisheries and Aquaculture Science; AFBI – Agri Food and Biosciences Institute, Northern Ireland; and SEPA – Scottish Environmental Protection Agency.

Table 2: Current [2017] status of UK plankton monitoring programme.

Plankton survey	Current [2017] policy drivers	Plankton component available		Sampling years	Sampling frequency	Spatial extent
		Phytoplankton	Zooplankton			
Environment Agency (EA)	Water Framework Directive Urban Waste Water Treatment Directive Nitrates Directive OSPAR comprehensive studies OSPAR eutrophication strategy	√	-	2000 to present	monthly	fixed point, coastal
Centre for Environment, Fisheries and Aquaculture Science (Cefas)	-	-				
Dowsing Smartbuoy	-	√	-	2017 to present	monthly	fixed point, coastal
Liverpool Bay Smartbuoy	-	√	-	-	monthly	fixed point, coastal
West Gabbard Smartbuoy	-	√ (quarterly)	√ (monthly)	2016 to present	monthly	fixed point, coastal

Plankton survey	Current [2017] policy drivers	Plankton component available		Sampling years	Sampling frequency	Spatial extent
		Phytoplankton	Zooplankton			
Marine Scotland Science (MSS)	WFD, MSFD, OSPAR biodiversity and eutrophication, climate change, aquaculture advice, HABs, ocean acidification, specific research projects	-				
Loch Ewe	-	√	√	-	weekly	fixed point, coastal
Stonehaven	-	√	√	-	weekly	fixed point, coastal
Scapa, Orkney	-	√	-	-	weekly	fixed point, coastal
Scalloway, Shetland	-	√	-	-	weekly	fixed point, coastal
Plymouth Marine Laboratory (PML) L4	MSFD and OSPAR Marine Climate Change Impact Partnership, ICES, specific research projects	√	√	1988 to present for zooplankton; 1992 to present for phytoplankton	weekly	fixed point, coastal
Scottish Association for Marine Science (SAMS) Lorne Pelagic Observatory	-	√*	?*	2011 to present	monthly	fixed point, coastal
Scottish Environmental Protection Agency (SEPA)	-	-				

Plankton survey	Current [2017] policy drivers	Plankton component available		Sampling years	Sampling frequency	Spatial extent
		Phytoplankton	Zooplankton			
Clyde	-	√	-	-	monthly	fixed point, coastal
Firth of Forth	-	√	-	-	monthly	fixed point, coastal
Continuous Plankton Recorder (CPR)	Fisheries (ICES and DFO Canada), MSFD (National, International and OSPAR) Marine Climate Change Impact Partnership Marine pollution Decommissioning	√	√	1958 to present	monthly	CPR routes, offshore
AFBI NI	-	-				
Western Irish Sea mooring (38a)	-	√	√	2015 to present	monthly	fixed point, coastal
AFBI LB 06 station	-	√	√	2015 to present	monthly	fixed point, coastal

Plankton survey	Current [2017] policy drivers	Plankton component available		Sampling years	Sampling frequency	Spatial extent
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DAERA	Water Framework Directive Urban Waste Water Treatment Directive Nitrates Directive OSPAR comprehensive studies OSPAR eutrophication strategy	√	-	2011 to present	Monthly or quarterly.	Fixed point, coastal

* Phytoplankton analysis intermittent from 1970, continuous from 2000 (some work still needed to get data pre-2007 in usable form); zooplankton sampling started 2011 and continues but awaiting funding for analysis.

1.4.10 Monitoring options for pelagic habitats

The four proposed options for monitoring UK pelagic habitats are outlined below in Table 3, along with the types of monitoring activities that each option would comprise, and the pros and cons of that monitoring approach. The pelagic team constructed these options in 2017 as part of a Monitoring Options Workshop, funded by Defra. As stated above, here we focus on biodiversity monitoring for pelagic habitats. The options are then related to the reasons for monitoring in Table 4. This shows the strength of information against each policy area.

Greater detail for each option is provided in Appendix 1.

None of the proposals recommend establishing new monitoring stations. Instead, they focus on the greater benefits that will accrue from:

- preventing the further loss of stations;
- making much better use of the existing data and knowledge;
- reversing some recently lost sampling (this is value for money as we already know the power of the data); and
- expanding the life-forms monitored at existing stations.

In addition, an R&D element is proposed that continually evaluates new technologies and analytical methods (Table 3).

In some instances, the UK pelagic habitats monitoring programs and datasets that can provide data for this purpose were not originally instigated for biodiversity monitoring. Instead, their primary missions, are non-biodiversity related, such as, for example, eutrophication strategy or human health. Many of these UK plankton monitoring programs are currently [2017] undergoing their own independent review and rationalisations and it is critical that all reviews are considered with a joined-up perspective. Further detail can be found in Appendix 1. In addition to funding the sampling portion of monitoring programs, there also needs to be commitment to fund the ongoing data analysis work to use UK plankton data to their full potential, to improve the confidence of assessments, and detect and understand climate-driven changes in plankton indicators. This analysis stage of monitoring is just as important as the sampling stage and will allow maximum use of plankton information for policy. Governments need to develop capacity to draw in expertise from the wider pelagic community as in-house expertise in pelagic habitats is currently [2017] lacking. For example, there is no mechanism to fund regular meetings of the Pelagic Habitats Working Group (WG) whose members carry out the integration, analysis, and assessment stages of pelagic monitoring. In particular, the funding to allow institutes to interpret their data and assess GES is in many cases missing. In many cases, the WG is reliant on voluntarily commitment, which can be intermittent as workloads allow. Additionally, there are no consistent resources to enable the analysis and interpretation of data, restraining the utility of collected data; this capacity needs to be resourced as part of the UK pelagic habitats monitoring programme. Without this capability, data are being generated which are not being optimized due to a lack of resources in some institutes.

Country preference regarding a monitoring option

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As three of the four DAs agreed that as a minimum, we should enable capacity to optimise and incorporate all data currently collected across all UK monitoring programs into biodiversity assessments, Option 2 has been identified as the *majority* option preference.

It was identified that for the Option 2 and Option 2+ scenarios, further consideration would need to be given to how these would be funded.

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- Understanding the natural variability of the biodiversity component and its role within ecosystem processes and functions.
- Understanding pressure-state relationships and facilitating the development of pressure-based monitoring to enable the sustainable management of human activities.
- Undertake robust assessments of conservation status and site condition at required scales and temporal frequencies to fulfil national and international reporting obligations.

HBDSEG developed advice on how best to address the key inadequacies identified within the policy preference and made recommendations on the minimum acceptable level of monitoring.

HBDSEG advice

HBSEG concluded that the majority policy option preference (Option 2) for monitoring pelagic habitats would provide a limited evidence base which would not be able to sufficiently meet our conservation and wider policy needs. Plankton are key components of marine food webs; energy, carbon, sulphate, and nutrient cycles; and benthic-pelagic, and inshore-offshore links. Consequently, the balance of organisms in the plankton indicate climate change, impact on the other elements (fish, shellfish, birds, marine mammals), and can influence tourism, aquaculture, and energy sectors.

HBDSEG advised that the following residual risks were associated with the majority policy option preference:

g. Missing lifeforms and trophic levels (particularly inshore zooplankton, and microbes more generally).

h. Inability to distinguish climate change signals in inshore waters from other signals (e.g. eutrophication).

i. Lacking the ability to adequately investigate benthic/pelagic coupling.

j. Lacking the ability to adequately investigate inshore/offshore coupling.

k. Weak datasets for critical ecohydrodynamic regions.

l. Unknown oceanographic boundary conditions (especially in the South West).

Inclusion of HBDSEG advice in policy option preference

HBDSEG advised that the majority option preference needed to be strengthened to improve the evidence base provided and significantly reduce the identified risks. This includes expansion of existing coastal phytoplankton programs to include zooplankton sampling (mitigating risks a-d) and the reinstatement of the recently lost Continuous Plankton Recorder (CPR) route (mitigating risks e–f).

HBDSEG advised that these additions to the monitoring programme would provide an integrated plankton monitoring program with interpretive ability across a large range of temporal, geographic and lifeform dimensions. This would allow us to have a consolidated assessment of plankton health with respect to human, climatic, and cross-element impacts that can be resolved at various scales.

An outline of the estimated costs are provided in Table 3. A summary of the costs, benefits and risks associated with the policy option and HBDSEG amended policy option, are provided in Table 4.

Table 3. Estimated costs for modular options [table created in 2017].

Option	Detail	£k			
		Year 1	**Year 2**	**Year 3**	**etc.**
Original	Addresses lack of co-ordination, data analysis, and interpretation	**285**	**285**	**285**	**235**
Improved at workshop	Add in missing Zooplankton	450	400	400	400
	Add in missing UK waters CPR coverage	30	30	30	30
	Sub total: "Near UK" waters	**765**	**715**	**715**	**665**
	Add in missing EU waters CPR coverage	137	137	137	137
	Sub total: "UK & UK influenced EU" waters	**902**	**852**	**852**	**802**
	Add in missing International waters CPR coverage (all OSPAR regions)	191	191	191	191
	Total: "UK & UK influenced EU & international" waters	**1093**	**1043**	**1043**	**993**

Table 4. Comparison of costs, benefits and risks associated with policy option and HBDSEG amended policy option [table created in 2017]

	Key monitoring elements	Average annual cost (£Mill))	Risk	Benefits
Policy preference	Continuation of current 15 monitoring programs undertaken by several regulatory agencies. Use of all data currently acquired optimised by including all data in any indicator assessments and improving the data presentation, accessibility, and analysis.	+0.3[1]	Limited capacity to provide information on changes in ecosystem function, changes in ecosystem services or impacts of a changing climate. Does not include all lifeforms and trophic levels, particularly inshore zooplankton, and microbes more generally. Some gaps in spatial and temporal sampling will remain.	Improved ability, compared to current monitoring, to assess the two UK MSFD indicators: changes in plankton communities and changes in plankton biomass and abundance. Improved ability, compared to current monitoring, to identify key pressures and their responses. Stabilisation of resources to support current monitoring and analysis activities (i.e. no further loss). Continues to make best use of many programmes, with one sample serving multiple purposes and drivers. Data provides an increasingly holistic biodiversity assessment for UK waters, resulting in improved confidence compared to current monitoring.

[1] This is 'additional' cost only, round up to the nearest £100k. Current costs not well defined.

	Key monitoring elements	Average annual cost (£Mill))	Risk	Benefits
HBDSEG advice	Continuation of current 15 monitoring programs undertaken by several regulatory agencies. Use of all data currently acquired optimised by including all data in any indicator assessments and improving the data presentation, accessibility, and analysis. Expansion of existing coastal phytoplankton programs to include zooplankton sampling. Re-instalment of the recently lost Continuous Plankton Recorder (CPR) routes.	+0.8 - 1.1[2]	Will not provide comprehensive spatial and temporal coverage in sampling. Some plankton groups remain inadequately collected resulting in partial community representation and poor understanding of ecosystem function. Costs do not include the evaluation and adoption of new technologies for sampling, and new methods for analysis and assessment, to increase the power and reduce the cost of the adopted scheme.	An integrated plankton monitoring programme with interpretive ability across a large range of temporal, geographic and lifeform dimensions enabling a consolidated assessment of plankton health with respect to human, climatic, and cross-element impacts that can be resolved at various scales. Further improvements to all the benefits associated with the preferred policy option.

[2] This is 'additional' cost only, round up to the nearest £100k. Current [2017] costs not well defined. The minimum is for additional sampling in UK waters and the maximum is for additional sampling in UK, EU and international waters.

References

Webb, K., Griffiths, Y. & Proudfoot, R. 2024. The U.K. Marine Biodiversity Monitoring Programme: Development of advice on future monitoring (2019). *JNCC Report 765*, JNCC, Peterborough, ISSN 0963-8091.
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Appendices

Appendix 1

Table A1.1: Further detail on pelagic habitats monitoring options [table created in 2017].

Option	Current status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 1: Status quo Use of existing plankton time series, but with little continuity or reliability in our ability to report for policy	**Infrastructure:** Datasets are collected independently, and resources are required to coordinate and manipulate master database and assessment. No holistic assessment infrastructure exists. No British institute maintains master species list – it is currently stored by OSPAR and already out of date. No reliable mechanism for meeting of pelagic habitats expert group which would improve coordination of plankton monitoring and analysis.	**Infrastructure:** Lack of assessment infrastructure means that individual institutes perform own assessments, and the UK assessments are not holistic and integrated and therefore lack robustness. No clear definition of GES, which are defined separately and possibly subjectively for each data set. Lack of maintenance of UK master species list means that some UK plankton monitoring data are not incorporated in UK assessments and assessment accuracy will drastically decrease with time as species list gets out of date. Hindrance of continuity due to lack of	**Risks:** i) Lack of zooplankton sampling in coastal regions and spatial gaps in sampling in some offshore areas result in failure to properly assess changes in the plankton community including those involving changes in the "balance of total abundance between the trophic guilds" (COM (EU) 2017/848) (i.e. lifeforms). ii) Robustness of MSFD lifeforms indicator is limited due to spatial gaps in data, lack of coastal zooplankton data, partial sampling of plankton community, and lack of data management infrastructure. iii) Limited capacity to link changes in plankton to anthropogenic pressures. iv) The above limits robustness of advice available for decision	Current programme is at risk due to funding cuts.

Option	Current status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 1: Status quo Use of existing plankton time series, but with little continuity or reliability in our ability to report for policy	**Spatial:** Coastal: phytoplankton sampled well in most areas, but zoo under-sampled. Offshore: Most phyto and zooplankton sampled on existing CPR routes, but small and fragile species not sampled well by this method. Spatial gaps exist and not all taxa sampled. **Temporally**: Not all UK time-series included in MSFD assessment since they don't all have data during starting conditions period. **Community level:** Time-series sample only a portion of the plankton community. **Funding:** increased concern about temporal sustainability of UK wide monitoring due to funding cuts and some programmes	resource for pelagic expert group to meeting. **Funding:** Not all plankton monitoring covered by Defra. Some sampling regimes reliant on goodwill of individuals and shipping industry. Annually, Defra pays xx% of monitoring – incl citizen science and in kind costs. **Spatial:** Spatial gaps exist offshore; zooplankton community gaps in coastal waters. **Temporally:** Time-series of different lengths with continuity at risk due to funding cuts for some time-series, decreasing robustness of evidence provided by time-series. **Community level**: Only a few fixed point stations can assess all MSFD indicator life forms and some parts of plankton not monitored at all.	making around policy obligations. v) Lack of basic knowledge and information about change in small taxa, bacteria, and viruses (< 5 um). vi) Low confidence around some MSFD indicator lifeforms pairs due to lack of biological information about functional traits. vii) Lack of continuity and low quality control of pelagic data analysis due to ad hoc meeting schedule and membership of pelagic group. viii) Unable to demonstrate UK waters in GES with adequate confidence as GES conditions have not been defined for each EHD. ix) risk of not being able to detect change at UK scale due to spatial and temporal gaps in data and as only three sites monitor all lifeforms. x) increased concern about temporal sustainability of UK wide monitoring due to funding	

Option	Current status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 1: Status quo Use of existing plankton time series, but with little continuity or reliability in our ability to report for policy)	have already had to cut routes/sampling. Not all UK plankton sampling is funded by Defra – some is by projects or NERC NC or Das.		cuts and some programmes have already had to cut routes/sampling. Not all UK plankton sampling is funded by Defra – some is by projects or NERC NC or Das. **Benefits:** i) Partial delivery of MSFD lifeforms indicator in UK waters. ii) Spatial coverage is good but spatial and community sampling gaps decrease confidence in assessments and advice. iii) The MSFD plankton lifeforms indicator approach is flexible enough to include data from disparate plankton datasets, potentially adding confidence to assessments over wide geographic areas. iv) Data from inshore areas can provide robust advice for some pressures such as nutrient enrichment and pollution (though this is mostly D5, rather than D1, D4, D6).	

Option	Current status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 2: Use of existing time series with enhanced development of interpretation and reporting	Same coverage of indicator data as above, but greatly increased confidence in how GES is assessed and in the attribution of cause to any observed changes.	All of Option 1 for data coverage issues but Option 2 provides better understanding of ecosystem including detecting long term change in plankton communities to endogenous pressures and to exogenous pressures such as climate change. Legislative obligation: MSFD and OSPAR and CBD. Analysis of current data to increase robustness of interpretation and assessment and incorporate all available UK plankton datasets: sort out reference conditions, define GES, interpret change in Plankton Index, understand spatial representivity – see list above. Data management infrastructure in place to support and maintain pelagic habitats master list and database.	**Risks:** Risks i) to iii), v) and iX and x) above remain. The others are reduced: **Benefits:** Benefits i-iV. Improved confidence in GES assessment. Better value for money spent on collection and analysis of samples.	This should include time and resources for contributors of time series to attend meetings format the data, assess GES, and interpret what trends mean, as local experts all contributing to the reports. (as well as the dedicated central person that we all agree is needed).

Option	Current status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 2: Use of existing time series with enhanced development of interpretation and reporting		Consistent resources to support pelagic expert group meeting and working. Formal mechanism requested for funding of work and meetings of members of pelagic habitats expert group.		
Option 3: Use of existing time series with enhanced development of interpretation and reporting coupled to Upgraded sampling at existing stations.	Not being implemented.	All of option 2 plus: Zooplankton sampling added to coastal phytoplankton programs (MSS, EA). Cefas and AFBI supported to increase sampling of zooplankton to at least monthly so data can be used for MSFD. Reinstatement of recently (2017) cut CPR routes to resolve some spatial gaps in offshore waters. Analysis of already-collected zooplankton samples by SAMS and Sepa. Analysis of current data to increase robustness of	**Risks:** i) Lack of basic knowledge and information about change in small taxa (< 5 um). ii) Lack of zooplankton sampling in some coastal regions and gaps in sampling in some offshore areas result in failure to properly assess changes the plankton community (not all lifeforms addressed in all locations). iii) Robustness of MSFD lifeforms indicator is limited due to spatial gaps in data, lack of coastal zooplankton data. iv) The above limits robustness of advice available for decision making around policy obligations.	Assuming continuation of Options 1 and 2, additional costs include: **Total: £492 k - £820 k for first year, £443 k - £771 k per year thereafter** **Inshore zooplankton:** SAMS: First year: 22k for back log plus 21k annual cost; subsequent years: 21k. SEPA: 9.3k per year for two sites. Addition of missing zooplankton and chlorophyll components: MSS chlorophyll and zooplankton: First year: £7.3 set up costs plus £46.5 annual cost for two sites Scapa and

Option	Current status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 3: Use of existing time series with enhanced development of interpretation and reporting coupled to Upgraded sampling at existing stations.		interpretation and assessment and incorporate all available UK plankton datasets: sort out reference conditions, define GES, interpret change in Plankton Index, understand spatial representivity – see list above. Data management infrastructure in place to support and maintain pelagic habitats master list and database. Consistent resources to support pelagic expert group meeting and working. Formal mechanism requested for funding of meeting of pelagic habitats group.	**Benefits:** i) Increased sampling increases ability to assess change in UK plankton community. ii) Partial delivery of zooplankton aspects of MSFD lifeforms indicator possible in coastal waters, leading to more robust advice for policy. iii) Increased confidence of MSFD lifeforms indicator results in more robust assessments and better management advice. iv) Improved confidence around some MSFD indicator lifeforms pairs. v) Data infrastructure inclusive of more plankton datasets than in option 1 improving data security and assessment robustness. vi) Increased continuity and quality control of pelagic data analysis due to a regular meeting schedule of pelagic group. viii) Able to demonstrate UK waters in GES.	Scalloway; Subsequent years: £46.5k annually for two sites. EA: Annually: £15k per site (across 20 sentinel sites = £300k). AFBI: Annually: £10k per site (1 site). Cefas: First year: £10k for zooplankton backlog plus £20.5k annual cost for phyto and zoo; Subsequent years: £20.5 annually per Smartbuoy site (1 site). Reinstatement of CPR routes: SAHFOS: Annually (includes reinstatement costs) UK waters: 132 samples, phytoplankton, and zooplankton, per year, £30k; EU waters: 540 samples, phytoplankton, and zooplankton, per year £137k; International waters: 804 samples, phytoplankton and zooplankton, per year £191k.

Option	Current status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 4: All above plus upgrading at-sea monitoring to fill gaps in spatial coverage	Not being implemented.	Zooplankton sampling added to coastal WFD programs and selected MSS programs. Cefas supported to sample monthly so data can be used for MSFD. New fixed-point sites at Bristol Channel, Firth of Lorne, and Liverpool Bay cover all main ecoyhydrodynamic types. Three new CPR routes around Bristol Channel and Irish Sea, routes to fill spatial gaps. Discuss inclusion of innovative new technology. Flow cyto.	**Risks:** i) none. **Benefits:** i) Comprehensive sampling increases ability to assess change in UK plankton community. ii) Delivery of zooplankton aspects of MSFD lifeforms indicator possible in coastal waters. iii) Increased confidence of MSFD lifeforms indicator results in more robust assessments and better management advice. allowing replicability of assessments and integration of data for more robust advice.	See table 3 for costs.

Table A1.2: Pelagic habitats monitoring options [table created in 2017]. This table summaries options to confidently detect and understand changes in pelagic habitats and determine the status of UK pelagic habitat biodiversity (MSFD D1, D4, and OSPAR biodiversity obligations).

Option number	Option background	Pros	Cons	Estimated cost/value per annum
1.[1]	**Current [2017] Monitoring Programs** Several monitoring programs as part of their own delivery to policy drivers and Directives (Table 1) can provide plankton data that could be used for a UK seas wide biodiversity assessment. These programs have not been designed with specific biodiversity assessment in mind and deliver to their own priorities to a greater or lesser degree of effectiveness. Only 2 of approximately 15 plankton monitoring programs are fully funded by DEFRA, but DEFRA funding receives good non-governmental financial support (e.g. Ships of opportunity provide about £3 million of "free boat time" for CPR per year).	• Many programs deliver for multiple drivers and needs. • Many are highly integrated and optimised, with one sample serving multiple purposes and drivers. • Provision of local and limited biodiversity assessment such as for MSFD GES and OSPAR obligation completed under previous funding climate. • Existing programs provide a critical baseline dataset and scientific expertise to understand and interpret changes due to climate change and anthropogenic pressures.	• Some time series recently lost. • Monitoring programs at risk from review and rationalisation resulting in loss of plankton data and expertise. • Spatial and temporal gaps in sampling. • Data do not provide a holistic biodiversity assessment for UK waters, resulting in low confidence advice. • Inconsistent resourcing is a challenge to producing holistic biodiversity assessment across programs. • Limited capacity to link changes in plankton to changes in climate change and anthropogenic pressures, resulting in low confidence.	To establish the cost of pelagic habitat monitoring is complex. UK pelagic habitats monitoring is a set of dispersed programs with multiple funding streams, some of which are non-governmental. The objectives of these programs range from fulfilling non-biodiversity policy obligations and directives to R&D to wider science programmes. Pelagic habitats monitoring for biodiversity depends on the continuation of plankton monitoring in support of other drivers such as those mentioned above. Pelagic habitat monitoring for biodiversity therefore is entwined with wider ecosystem research, and the costing related to the plankton component cannot easily be disentangled.

Option number	Option background	Pros	Cons	Estimated cost/value per annum
1.			• Some plankton groups inadequately collected resulting in partial community representation and poor understanding of ecosystem function	
2.	**Optimisation of current [2017] data and knowledge** - Requires maintenance of current [2017] levels of UK pelagic habitats monitoring. - expand application of MSFD indicator to all UK plankton monitoring programs, and maintain capacity required for biodiversity assessment. - integrate monitoring data across plankton programs for biodiversity assessment and increased understanding of climate change responses. - Facilitate use of knowledge across the research and statutory community.	• Increased ability to provide biodiversity assessment such as for MSFD GES and OSPAR obligation. • Many programs deliver for multiple drivers and needs. • Many are highly integrated and optimised, with one sample serving multiple purposes and drivers. • Existing programs provide a critical baseline dataset and scientific expertise to understand and interpret changes due to climate change and anthropogenic pressures. • Data provide an increasingly holistic biodiversity assessment	• Spatial and temporal gaps in sampling. • Some plankton groups inadequately collected resulting in partial community representation and poor understanding of ecosystem function.	Assuming continuation of Option 1, additional costs include: Total: First three years: £285k per year; Subsequent years: £235k per year. For three years: £50kpa (total £150k) to address issues of representivity, starting conditions, data integration, taxa reconciliation. Annually: Nominally £25 k (or equivalent from internal mechanisms) per institute for engagement in pelagic habitats expert group, data extraction and preparation, and assessment and interpretation of results (Cefas, MSS, AFBI, SEPA, EA, SAHFOS, PML, SAMS, Plym Uni).

Option number	Option background	Pros	Cons	Estimated cost/value per annum
2.		for UK waters, resulting in improved confidence. • Capacity to link changes in plankton to changes in anthropogenic pressures and climate change, resulting in increased confidence.		Annually: £10k for data management and maintenance (pilot project with Medin currently [2017] underway may reduce cost).
3.	**Enhancement of current [2017] programs** This requires Option 2 above, and: - Filling prioritised biological gaps (e.g. inshore zooplankton). - Zooplankton sampling and analysis added to existing coastal (e.g. MSS, EA) and non-coastal (e.g. AFBI and Cefas) phytoplankton programs. - Reinstatement of recently (2017) cut CPR routes to resolve some spatial gaps in offshore waters.	• Increased ability to provide biodiversity assessment such as for MSFD GES and OSPAR obligation. • Many programs deliver for multiple drivers and needs. • Many are highly integrated and optimised, with one sample serving multiple purposes and drivers. • Existing programs provide a critical baseline dataset and scientific expertise to understand and interpret changes due to climate change and anthropogenic pressures.	• Reduced spatial and temporal gaps in sampling. • Some plankton groups remain inadequately collected resulting in partial community representation and poor understanding of ecosystem function.	Assuming continuation of Options 1 and 2, additional costs include (components are modular): Component 1 - Inshore zooplankton, per year: 1st year: appx £450 Additional years: appx £400 Component 2 - Reinstatement of CPR routes: Annually (includes reinstatement costs, options are modular): - UK waters: 132 samples, phytoplankton, and zooplankton, per year, £30k.

Option number	Option background	Pros	Cons	Estimated cost/value per annum
3.		• Data provide an increasingly holistic biodiversity assessment for UK waters, resulting in improved confidence. • Capacity to link changes in plankton to changes in anthropogenic pressures and climate change, resulting in increased confidence. • Resurrection of recently lost time series improves assessment confidence. • Improved spatial and temporal coverage. • More plankton groups adequately collected resulting in better community representation and improved understanding of ecosystem function.		- EU waters: 540 samples, phytoplankton, and zooplankton, per year £137k. - International waters: 804 samples, phytoplankton, and zooplankton, per year £191k.

Option number	Option background	Pros	Cons	Estimated cost/value per annum
R&D	**A. Evaluating and adopting new technologies for sampling, and new methods for analysis and assessment, to increase the power and reduce the cost of the adopted scheme.** **B. Working towards Full temporal, spatial and biological coverage.** This requires options 2 and 3 above and: - Most UK waters covered by adequate monitoring of plankton. - Increased resolution of pelagic community taxa sampled using new technology which will capture a significantly broader component of the pelagic community to fill knowledge gaps (picoplankton, viruses, bacteria) unaddressed in biodiversity assessments (e.g. flow cytometry for phytoplankton and Plankton Image Analysis for zooplankton. Both	• Increased ability to provide biodiversity assessment such as for MSFD GES and OSPAR obligation. • Many programs deliver for multiple drivers and needs. • Many are highly integrated and optimised, one sample serving multiple purposes and drivers. • Existing programs provide a critical baseline dataset and scientific expertise to understand and interpret changes due to climate change and anthropogenic pressures. • Data provide an increasingly holistic biodiversity assessment for UK waters, resulting in improved confidence. • Capacity to confidently link changes in plankton to changes in anthropogenic pressures and climate change,	Increased use of automated technologies results in large datasets that require more processing power.	Assuming continuation of Options 1, 2, and 3, additional costs include: Start-up costs depending on options chosen: £500k to £2,000,000 And £500k per year

Option number	Option background	Pros	Cons	Estimated cost/value per annum
R&D	systems are currently [2017] in development by CEFAS for use underway during various surveys by Cefas Endeavour). - Harmonising and cross-calibrating developing technologies with existing time-series.	resulting in increased confidence. • Resurrection of recently lost time series improves assessment confidence. • Comprehensive spatial and temporal coverage in sampling. • Improved sampling of pelagic community resulting in better community representation and understanding of ecosystem function. • Use of automated technologies allows for high frequency data to be collected to complement other monitoring programmes.		

[1] *There is a serious and real risk to the continuation of existing monitoring within the UK*. Recent funding cuts in the allocated NERC National Capability funding have left several plankton surveys in the UK in a deficit situation, resulting in loss of sampling. There needs to be continued support for long-term monitoring within the UK, and without that commitment all options below must be considered at risk.

Table A1.3: The benefits of plankton monitoring is linked to each monitoring options [table created in 2017]. The strength of evidence provided, and the policy value is also included.

Benefits of Plankton Monitoring	Options	Strength	Policy links to:
Early warning of change Rapid response to changes before they are seen elsewhere in the system because of rapid turnover of plankton, and presence at the base of the food web linking them closely to other ecosystem components.	Option 1 ("status quo")	Limited	Regime change; Eutrophication; Inshore / offshore fisheries; Aquaculture and shellfisheries; Food webs (seabirds, fish, marine mammals, benthic habitats); Recreation / Tourism (bathing beaches, angling).
	Option 2 (1+data optimisation)	Moderate	
	Option 3 (2+ added monitoring)	Moderate	
	R&D (3+Development)*	≥ Moderate	
Help to explain causes of Ecosystem change Plankton are widely connected to the wider ecosystem (e.g. copepod zooplankton to fish recruitment; phytoplankton to eutrophication) and close coupling exists between the pelagic water column and the benthos. Plankton also have strong relationships with pressures and climate variability (e.g. climate change, currents, fronts, nutrients, invasive species), but near shore and offshore patterns in plankton dynamics differ.	Option 1 ("status quo")	Limited	Biodiversity; Regime change; Eutrophication; Inshore / offshore fisheries; Aquaculture and shellfisheries; Food webs (seabirds, fish, marine mammals, benthic habitats); Benthic/pelagic coupling.
	Option 2 (1+data optimisation)	Moderate	
	Option 3 (2+ added monitoring)	Moderate+	
	R&D (3+Development)*	≥ Moderate ++	
Detect and predict "regime change" Plankton are sensitive to changes in their environment and long-term indicator time-series can be used for early detection of stepwise changes in marine ecosystems, known as regime shifts. These alterations reflect changes and timing in proportions of plankton lifeforms and different trophic levels, as well as keystone trophic indicators (e.g. jellyfish).	Option 1 ("status quo")	Limited	Regime change; Biodiversity; Inshore / offshore fisheries. Food webs (seabirds, fish, marine mammals, benthic habitats); Biodiversity.
	Option 2 (1+data optimisation)	Moderate	
	Option 3 (2+ added monitoring	Moderate+	
	R&D (3+Development)*	≥ Moderate+	

Benefits of Plankton Monitoring	Options	Strength	Policy links to:
Inshore indicators Phytoplankton are strong indicators of anthropogenic eutrophication. Plankton lifeforms also indicate changes in nearshore trophic webs which link to fish and seabird health, while benthic pelagic coupling indicates health of energy and carbon flows through seabed/shore habitats.	Option 1 ("status quo")	Limited	Eutrophication; Inshore / offshore fisheries; Aquaculture and shellfisheries; Food webs (seabirds, fish, marine mammals, benthic habitats); Recreation / Tourism; Biodiversity
	Option 2 (1+"data optimisation)	Moderate	
	Option 3 (2+ added monitoring)	Moderate+	
	R&D (3+Development)*	≥ Moderate+	
Offshore indicators Plankton indicators can distinguish between prevailing conditions (including climate change) and anthropogenic issues (e.g. fishing and offshore developments). Plankton rapidly respond to changes in frontal systems, ecohydrodynamics, ocean acidification, and temperatures changes with changes in timing and seasonality of plankton blooms and zooplankton assemblages rippling further through the food web (e.g. to fish, birds, and cetaceans).	Option 1 ("status quo")	Limited	Biodiversity; Regime change; Inshore / offshore fisheries Aquaculture and shellfisheries; Food webs (seabirds, fish, marine mammals, benthic habitats); Climate change & carbon sequestration; Energy sector, Development & extraction.
	Option 2 (1+"data optimisation)	Moderate+	
	Option 3 (2+ added monitoring	Moderate++	
	R&D (3+Development)*	≥ Moderate++	
Disruption of ecosystem dynamics (Coastal to offshore coupling / linkages between ecohydrodynamic regions) Under "normal conditions" distinct plankton assemblages are associated with different regions and hydrodynamic conditions; gradations or sharp breaks in indicator time-series indicate hydromorphological changes or anthropogenic impacts.	Option 1 ("status quo")	Limited	Climate change (changes in timing and position of frontal systems and currents); Energy (extractable, renewable, nuclear, other); Development (ports /harbours / aggregate extraction); Recreation / Tourism (bathing beaches, angling, sailing); Eutrophication; Inshore / offshore fisheries; Aquaculture and shellfisheries; Food webs (seabirds, fish, marine mammals, benthic habitats).
	Option 2 (1+"data optimisation)	Limited	
	Option 3 (2+ added monitoring	Moderate	
	R&D (3+Development)*	≥ Moderate	

Benefits of Plankton Monitoring	Options	Strength	Policy links to:
Biogeophysical indicators Plankton indicators are indicative of carbon sequestration and distribution, and sulphur cycle and climate change moderation. Plankton trophic levels and key taxa (e.g. microbial loops, jelly fish shunts and benthic-pelagic coupling) indicate the potential strength and direction of carbon sequestration, distribution, or burial in levels of the food web. Key plankton taxa indicate activity in the sulphur cycle and climate change moderation through DMS.	Option 1 (“status quo”)	Limited	Climate change, carbon sequestration & sulphur cycle (DMS); Regime change (Jellies and microbial carbon); seafloor integrity.
	Option 2 (1+“data optimisation)	Limited	
	Option 3 (2+ added monitoring	Limited+	
	R&D (3+Development)*	≥ Limited+	

Appendix 2

Table A2.1: Further detail on pelagic habitats monitoring options [developed in 2017].

Option	Current [2017] status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 1: Status quo (Use of existing plankton time series, but with little continuity or reliability in our ability to report for policy.	Infrastructure: Datasets are collected independently, and resources are required to coordinate and manipulate master database and assessment. No holistic assessment infrastructure exists. No British institute maintains master species list – it is currently [2017] stored by OSPAR and already out of date. No reliable mechanism for meeting of pelagic habitats expert group which would improve coordination of plankton monitoring and analysis.	Infrastructure: Lack of assessment infrastructure means that individual institutes perform own assessments, and the UK assessments are not holistic and integrated and therefore lack robustness. No clear definition of GES, which are defined separately and possibly subjectively for each data set. Lack of maintenance of UK master species list means that some UK plankton monitoring data are not incorporated in UK assessments and assessment accuracy will drastically decrease with time as species list gets out of date. Hindrance of continuity due to lack of resource for pelagic expert group to meeting.	**Risks:** i) Lack of zooplankton sampling in coastal regions and spatial gaps in sampling in some offshore areas result in failure to properly assess changes in the plankton community including those involving changes in the "balance of total abundance between the trophic guilds" (COM (EU) 2017/848) (i.e. lifeforms). ii) Robustness of MSFD lifeforms indicator is limited due to spatial gaps in data, lack of coastal zooplankton data, partial sampling of plankton community, and lack of data management infrastructure. iii) Limited capacity to link changes in plankton to anthropogenic pressures. iv) The above limits robustness of advice available for decision making around policy obligations. v) Lack of basic knowledge and information about change in small taxa, bacteria, and viruses (< 5 um).	Current [2017] programme is at risk due to funding cuts.

Option	Current [2017] status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 1: Status quo (Use of existing plankton time series, but with little continuity or reliability in our ability to report for policy.	Spatial: Coastal: phytoplankton sampled well in most areas, but zoo under-sampled. Offshore: Most phyto and zooplankton sampled on existing CPR routes, but small and fragile species not sampled well by this method. Spatial gaps exist and not all taxa sampled. Temporally: Not all UK time-series included in MSFD assessment since they don't all have data during starting conditions period. Community level: Time-series sample only a portion of the plankton community.	Funding: Not all plankton monitoring covered by Defra. Some sampling regimes reliant on goodwill of individuals and shipping industry. Annually, Defra pays xx% of monitoring – including citizen science and in-kind costs. Spatial: Spatial gaps exist offshore; zooplankton community gaps in coastal waters. Temporally: Time-series of different lengths with continuity at risk due to funding cuts for some time-series, decreasing robustness of evidence provided by time-series. Community level: Only a few fixed-point stations can assess all MSFD indicator life forms and some parts of plankton not monitored at all.	vi) Low confidence around some MSFD indicator lifeforms pairs due to lack of biological information about functional traits. vii) Lack of continuity and low quality control of pelagic data analysis due to ad hoc meeting schedule and membership of pelagic group. viii) Unable to demonstrate UK waters in GES with adequate confidence as GES conditions have not been defined for each EHD. ix) risk of not being able to detect change at UK scale due to spatial and temporal gaps in data and as only 3 sites monitor all lifeforms. x) increased concern about temporal sustainability of UK wide monitoring due to funding cuts and some programmes have already had to cut routes/sampling. Not all UK plankton sampling is funded by Defra – some is by projects or NERC NC or Das.	

Option	Current [2017] status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 1: Status quo (Use of existing plankton time series, but with little continuity or reliability in our ability to report for policy.	Funding: increased concern about temporal sustainability of UK wide monitoring due to funding cuts and some programmes have already had to cut routes/sampling. Not all UK plankton sampling is funded by Defra – some is by projects or NERC NC or Das.		**Benefits:** i) Partial delivery of MSFD lifeforms indicator in UK waters. ii) Spatial coverage is good but spatial and community sampling gaps decrease confidence in assessments and advice. iii) The MSFD plankton lifeforms indicator approach is flexible enough to include data from disparate plankton datasets, potentially adding confidence to assessments over wide geographic areas. iv) Data from inshore areas can provide robust advice for some pressures such as nutrient enrichment and pollution (though this is mostly D5, rather than D1, D4, D6).	
Option 2: Use of existing time series with enhanced development of interpretation and reporting.	Same coverage of indicator data as above, but greatly increased confidence in how GES is assessed and in the attribution of cause to any observed changes.	All of option 1 for data coverage issues but Option 2 provides better understanding of ecosystem including detecting long term change in plankton communities to endogenous pressures and to exogenous pressures such as climate change.	**Risks:** Risks i) to iii), v) and iX and x) above remain. The others are reduced. **Benefits:** Benefits i-iV. Improved confidence in GES assessment.	This should include time and resources for contributors of time series to attend meetings format the data, assess GES, and interpret what trends mean, as local experts all contributing to the reports (as well as the dedicated central person that we all agree is needed).

Option	Current [2017] status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 2: Use of existing time series with enhanced development of interpretation and reporting.		Legislative obligation: MSFD and OSPAR and CBD. Analysis of current data to increase robustness of interpretation and assessment and incorporate all available UK plankton datasets: sort out reference conditions, define GES, interpret change in Plankton Index, understand spatial representivity – see list above. Data management infrastructure in place to support and maintain pelagic habitats master list and database. Consistent resources to support pelagic expert group meeting and working. Formal mechanism requested for funding of work and meetings of members of pelagic habitats expert group.	Better value for money spent on collection and analysis of samples.	

Option	Current [2017] status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 3: Use of existing time series with enhanced development of interpretation and reporting coupled to Upgraded sampling at existing stations.	Not being implemented.	All of Option 2 plus: Zooplankton sampling added to coastal phytoplankton programs (MSS, EA). Cefas and AFBI supported to increase sampling of zooplankton to at least monthly so data can be used for MSFD. Reinstatement of recently (2017) cut CPR routes to resolve some spatial gaps in offshore waters. Analysis of already-collected zooplankton samples by SAMS and Sepa. Analysis of current data to increase robustness of interpretation and assessment and incorporate all available UK plankton datasets: sort out reference conditions, define GES, interpret change in Plankton Index, understand spatial representivity – see list above.	**Risks:** i) Lack of basic knowledge and information about change in small taxa (< 5 um). ii) Lack of zooplankton sampling in some coastal regions and gaps in sampling in some offshore areas result in failure to properly assess changes the plankton community (not all lifeforms addressed in all locations). iii) Robustness of MSFD lifeforms indicator is limited due to spatial gaps in data, lack of coastal zooplankton data. iv) The above limits robustness of advice available for decision making around policy obligations. **Benefits:** i) Increased sampling increases ability to assess change in UK plankton community. ii) Partial delivery of zooplankton aspects of MSFD lifeforms indicator possible in coastal waters, leading to more robust advice for policy.	Assuming continuation of Options 1 and 2, additional costs include: Total: £492 k - £820 k for first year, £443 k - £771 k per year thereafter. Inshore zooplankton: SAMS: First year: 22k for back log plus 21k annual cost; subsequent years: 21k. SEPA: 9.3k per year for two sites. Addition of missing zooplankton and chlorophyll components: MSS chlorophyll and zooplankton: First year: £7.3 set up costs plus £46.5 annual cost for two sites Scapa and Scalloway; Subsequent years: £46.5k annually for two sites. EA: Annually: £15k per site (across 20 sentinel sites = £300k). AFBI: Annually: £10k per site (1 site).

Option	Current [2017] status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 3: Use of existing time series with enhanced development of interpretation and reporting coupled to Upgraded sampling at existing stations.		Data management infrastructure in place to support and maintain pelagic habitats master list and database. Consistent resources to support pelagic expert group meeting and working. Formal mechanism requested for funding of meeting of pelagic habitats group.	iii) Increased confidence of MSFD lifeforms indicator results in more robust assessments and better management advice. iv) Improved confidence around some MSFD indicator lifeforms pairs. v) Data infrastructure inclusive of more plankton datasets than in Option 1 improving data security and assessment robustness. vi) Increased continuity and quality control of pelagic data analysis due to a regular meeting schedule of pelagic group. viii) Able to demonstrate UK waters in GES.	Cefas: First year: £10k for zooplankton backlog plus £20.5k annual cost for phyto and xoo; Subsequent years: £20.5 annually per Smartbuoy site (one site). Reinstatement of CPR routes: SAHFOS: Annually (includes reinstatement costs) UK waters: 132 samples, phytoplankton, and zooplankton, per year, £30k; EU waters: 540 samples, phytoplankton, and zooplankton, per year £137k; International waters: 804 samples, phytoplankton, and zooplankton, per year £191k.
Option 4: All above plus upgrading at-sea monitoring to fill gaps in spatial coverage.	Not being implemented.	Zooplankton sampling added to coastal WFD programs and selected MSS programs. Cefas supported to sample monthly so data can be used for MSFD.	**Risks:** i) none. **Benefits:** i) Comprehensive sampling increases ability to assess change in UK plankton community. ii) Delivery of zooplankton aspects of MSFD lifeforms indicator possible in coastal waters.	See table 3 for costs.

Option	Current [2017] status	Limitations of option	Risks and benefits	Detailed cost per year of implementing option (where needed)
Option 4: All above plus upgrading at-sea monitoring to fill gaps in spatial coverage.		New fixed-point sites at Bristol Channel, Firth of Lorne, and Liverpool Bay cover all main ecoyhydrodynamic types. Three new CPR routes around Bristol Channel and Irish Sea, routes to fill spatial gaps. Discuss inclusion of innovative new tech. Flow cyto.	iii) Increased confidence of MSFD lifeforms indicator results in more robust assessments and better management advice, allowing replicability of assessments and integration of data for more robust advice.	