

# The influence of temporal scale selection on pelagic habitat biodiversity indicators

---

1

2 **Authors and affiliations**

3

4 **Jacob Bedford<sup>1</sup>, Clare Ostle<sup>2</sup>, David G. Johns<sup>2</sup>, Alexandre Budria<sup>3,4,5</sup>, Abigail McQuatters-Gollop<sup>1</sup>**

5

6 <sup>1</sup>Marine Conservation Research Group, University of Plymouth, Drake Circus, Plymouth PL4 8AA, UK

7 <sup>2</sup>The Marine Biological Association, The Laboratory, Citadel Hill, Plymouth PL1 2PB, UK

8 <sup>3</sup>Muséum National d'Histoire Naturelle, CRESCO, Dinard, France 2- UMR 8187 CNRS

9 <sup>4</sup>Laboratoire d'Océanologie et de Géosciences, Université du Littoral Côte d'Opale, Wimereux, France

10 <sup>5</sup>Department of Coastal Systems, NIOZ Royal Netherlands Institute for Sea Research, Den Burg, Texel, The  
11 Netherlands

12

**Corresponding author: Jacob Bedford, [jacob.bedford@plymouth.ac.uk](mailto:jacob.bedford@plymouth.ac.uk)**

**Keywords: biodiversity, ecosystem assessment, climate change, baselines**

13

14 **Funding sources:**

15 This work was supported through the EMFF funded 'ICEGRAPH' project (Increasing Confidence  
16 Evaluating GES for Regional Assessments of Pelagic Habitats). A.M-G was supported by the UK  
17 Natural Environmental Research Council Knowledge Exchange fellowship scheme (NE/ R00273/1).

18 **Conflicts of interest: none**

19

20

21

# 22 The influence of temporal scale selection on 23 pelagic habitat biodiversity indicators

---

24

## 25 **Abstract**

26 The development of biodiversity indicators is an integral component of forming marine strategies  
27 under the European Marine Strategy Framework Directive (MSFD). A key stage in the development  
28 of biodiversity indicators is the selection of an appropriate temporal scale over which to assess  
29 change in indicator state. This presents a particular challenge for the development of plankton  
30 indicators for assessing the state of pelagic habitats, due to the inherent stochasticity of plankton  
31 dynamics and the sensitivity of indicators to both climate-driven change and directly manageable  
32 pressures. Using two plankton indicator metrics, we demonstrate that the outcome of indicator  
33 assessments is inherently influenced by the temporal scale of the time-period over which the  
34 indicators are assessed. For example, we show that the inclusion of data from before a regime shift  
35 that occurred in the 1980s often alters the assessment of change compared to only including data  
36 from after the regime shift. We highlight that ultimately the appropriate temporal scale selected  
37 depends on the policy questions being addressed. We also suggest that reporting indicators over  
38 multiple temporal scales within an assessment helps provide information relevant to contemporary  
39 management, whilst also retaining crucial multi-decadal trends such as those caused by climate  
40 change.

41

42

43

## 44 1 Introduction

45 Monitoring of marine biodiversity underpins the achievement of healthy marine ecosystems by  
46 ensuring that management can be flexible, adaptive and effective (Addison et al., 2017). Across  
47 European seas, cumulative pressures from human activities are causing changes in marine  
48 biodiversity that are being addressed through both national and regional scale management  
49 frameworks (Apitz et al., 2006; Berg et al., 2015). Focusing at a regional scale, the European Union  
50 (EU) Marine Strategy Framework Directive (MSFD) incorporates biodiversity status into ecosystem-  
51 based management strategies, where different components of the marine ecosystem are formally  
52 monitored and assessed against targets representing 'Good Environmental Status' (GES) (Directive  
53 2008/56/EC). As the base of the marine pelagic food web, plankton communities form one of the  
54 key components of these biodiversity assessments, and plankton community indicators are used to  
55 assess the status of 'pelagic habitats'.

56 A suite of indicators for pelagic habitat biodiversity has been identified and developed for formal  
57 assessment under the MSFD, reflecting change in bulk, functional, and compositional aspects of  
58 plankton community structure and ultimately, pelagic habitat state (McQuatters-Gollop et al., 2017).  
59 To quantify changes in these indicators, appropriate metrics have been selected which detect and  
60 measure change in the indicator state from a temporal baseline (McQuatters-Gollop et al., 2019;  
61 Rombouts et al., 2019). As current indicator state is compared to this baseline to evaluate change,  
62 here we refer to this temporal baseline as a 'comparison period'.

63 This temporal comparison period can be selected for a series of years that are considered to best  
64 represent Good Environmental Status, so that deviations away from this period inherently imply the  
65 pelagic habitat is not in GES (Dickey-Collas et al., 2017; Scherer et al., 2016). Plankton communities,  
66 however, are highly dynamic, species rich, and are driven by a multitude of complex ecological  
67 processes. An initial role of indicators therefore, before the evaluation of GES, is in the detection of a  
68 change in plankton community state compared to background variability. A comparison period for  
69 pelagic habitat indicators needs to be suitable for providing an initial flag of change in pelagic habitat

70 state. This flagging process can trigger subsequent investigations as to how that change in state  
71 relates to Good Environmental Status, including identifying the underlying causes of change, and any  
72 implications for management.

73 An inherent challenge in the development of pelagic habitat indicators therefore, is the selection of  
74 an appropriate temporal scale from which to compare current indicator state, i.e. whether to  
75 compare current indicator state to the full extent of a multi-decadal time series, or just a recent  
76 period. For example, it may be important to account for 'shifting baselines syndrome' in ecosystem  
77 state that has been identified within other areas of marine conservation (McClenachan et al., 2015;  
78 Pauly, 1995; Thurstan et al., 2015) . This is the phenomenon where neglecting past changes obscures  
79 the magnitude of change or variability in ecosystem components. Here, plankton data from the  
80 beginning of long-term time-series provide a possibility for setting a comparison period for pelagic  
81 habitat assessments that minimises shifting baselines syndrome. For example, Wasmund (2017)  
82 used historical plankton data to define a threshold value for the ratio for the diatom/dinoflagellate  
83 index, an indicator of plankton community structure used in assessments of the Baltic Sea, arguing  
84 that using pre-eutrophication period from the first half of the 20<sup>th</sup> century in the Baltic Sea provides  
85 a relatively pristine period for comparison. Furthermore, it is well understood that multi-decadal  
86 data are required for detecting climate change signals. For example, a well-documented climate  
87 change-driven regime shift occurred in the late 1980s in the North Sea, associated with a  
88 fundamental restructuring of the food-web (Reid et al., 2015). Including data from before, as well as  
89 after, this regime shift in the comparison period would be required to account for impacts of this  
90 regime shift in the assessment of current biodiversity indicator status. This requirement further  
91 supports the use of long temporal scales when establishing whether the current indicator state  
92 represents a changed or perturbed pelagic habitat (Giron-Nava et al., 2017; Henson et al., 2010).

93 On the other hand, there are arguments against the use of including historic data, e.g. from the  
94 beginning of a long multidecadal time-series, in comparison periods, and instead establishing a

95 comparison period using contemporary data. Firstly, plankton communities are naturally variable at  
96 seasonal, inter-annual and multi-decadal time-scales. The biodiversity of a given ecological  
97 community can be seen as having a temporal component, and turnover in a community occurs  
98 regardless of human pressures, meaning a degree of multidecadal change is to be expected  
99 (Magurran et al., 2010). Secondly, 'legacy' effects, where the state of an ecosystem at a given point  
100 in time (in this case an MSFD assessment period) is representative of previous accumulated human  
101 pressures, as well as the pressures for the period that is being assessed (O'Higgins et al., 2014). A  
102 balance must be drawn as to whether management is focused on contemporary pressures occurring  
103 in the current assessment cycle, or on the reduction and remediation of longer term legacy effects.  
104 Lastly, and arguably the largest challenge for pelagic habitats, is that climate change is outside the  
105 scope of drivers managed under the MSFD, and climate change can obscure the response of  
106 plankton communities to management measures aimed at direct localised pressures. Duarte et al.  
107 (2009) for example show that reduction in nutrient levels did not result in a return of a eutrophic  
108 coastal system to a pristine reference status, due to underlying environmental changes. Climate  
109 change is instead categorised as a 'prevailing condition' by the Directive, and state changes caused  
110 by climate change are not legislatively required to lead to a management response (McQuatters-  
111 Gollop, 2012). These factors together therefore call into question the use of assessing indicators for  
112 certain policy needs over long, multidecadal time-series. For example, is detecting the impacts of a  
113 regime shift in the 1980s relevant for current management? Would it instead be more useful to  
114 assess indicator change over a shorter, more contemporary time-scale?

115 Given these questions, much attention has been drawn to the temporal scale of indicator reporting  
116 within the Marine Strategy Framework Directive. A recent analysis by Machado et al. (2019)  
117 highlighted a lack of consensus on appropriate temporal scale by Member States in their MSFD  
118 reporting, leading to varied time-scales and a lack of comparability across indicators and regions.  
119 They also advise against the use of opportunistic historical data in reporting indicator trends, and  
120 advocate for more structured harmonisation of temporal scales. It is important therefore, to

121 understand how temporal scale influences the outcome of indicator assessments to consolidate an  
122 appropriate temporal scale for reporting between indicators and assessment regions. It is also  
123 important to understand how different temporal scales may give different types of information to  
124 policy for making management decisions.

125 Here we use two plankton indicator metrics developed at the OSPAR level (the regional seas  
126 convention for the North-East Atlantic) to test how different time scale lengths affect the  
127 assessment of an indicator. Underlying these tests is understanding whether including data from  
128 further in the past in the comparison period increases the chances of detecting a state change in the  
129 assessment period (because for example, data from different climate regimes are compared), or  
130 whether including this data decreases the ability of detecting state change because more variability  
131 is encompassed within the comparison period. The first indicator metric aggregates plankton  
132 taxonomic data into broad functional groups, termed 'lifeforms', and compares the current balance  
133 of key plankton functional groups in the system to prior time-points in a time-series (McQuatters-  
134 Gollop et al., 2019). This metric forms the assessment of the OSPAR PH1 indicator 'Change in  
135 Phytoplankton and Zooplankton Communities' (OSPAR, 2017a). The second indicator metric  
136 partitions the total variability in a time-series into the 'Local Contributions' of individual time-points,  
137 to detect whether the current plankton community composition is or anomalous, compared to that  
138 of the wider time-series. This 'Local Contribution to Beta Diversity (LCBD)' metric contributes to a  
139 multi-metric index for assessing the OSPAR indicator PH3 'Changes in plankton diversity' (Budria et  
140 al., 2017; OSPAR, 2017b; Rombouts et al., 2019). Both indicators are reliant on comparison to  
141 previous data in a time-series, and therefore the outcomes of assessing these indicators are  
142 inherently influenced by the temporal scale of the comparison period. We therefore aim to  
143 understand the influence of short, medium and long temporal scales of indicator assessment.

## 144 2 Materials and Methods

145

146 2.1 Plankton community data

147 Plankton community data were obtained from the Continuous Plankton Recorder (CPR) survey (DOI:  
148 10.7487/2019.98.1.1181). The CPR survey has been collecting samples in the North Sea on a routine,  
149 consistent basis since 1958, creating a fully comparable multi-decadal time-series. CPRs consist of a  
150 filtering mechanism housed in an external body that is towed behind ships of opportunity at a depth  
151 of approximately 7-10m, with each sample representing approximately 10 nautical miles (18.5km) of  
152 tow, and approximately 3m<sup>3</sup> of sea (Batten et al., 2003). Both phytoplankton and zooplankton data  
153 are then identified and enumerated on a semi-quantitative scale (Richardson et al., 2006). Focusing  
154 on the North Sea as a case study for indicator assessment, samples were extracted from a 'northern  
155 North Sea' and a 'southern North Sea' bounding box (Figure 1). Only taxa enumerated consistently  
156 throughout the time-series were included in the analysis.

157

158

159

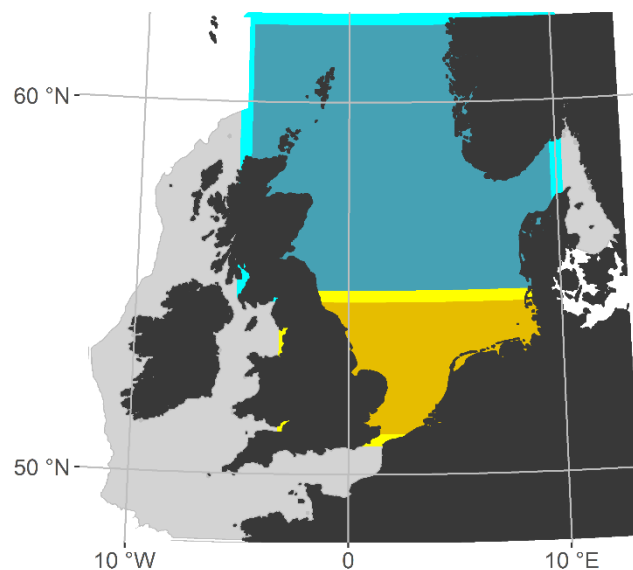
160

161

162

163

164



165

*Figure 1. Northern North Sea (blue), and southern North Sea (yellow) study regions.*

166

167

168

169

170 2.2 Indicator metrics

171

172 2.2.1 Plankton lifeform index

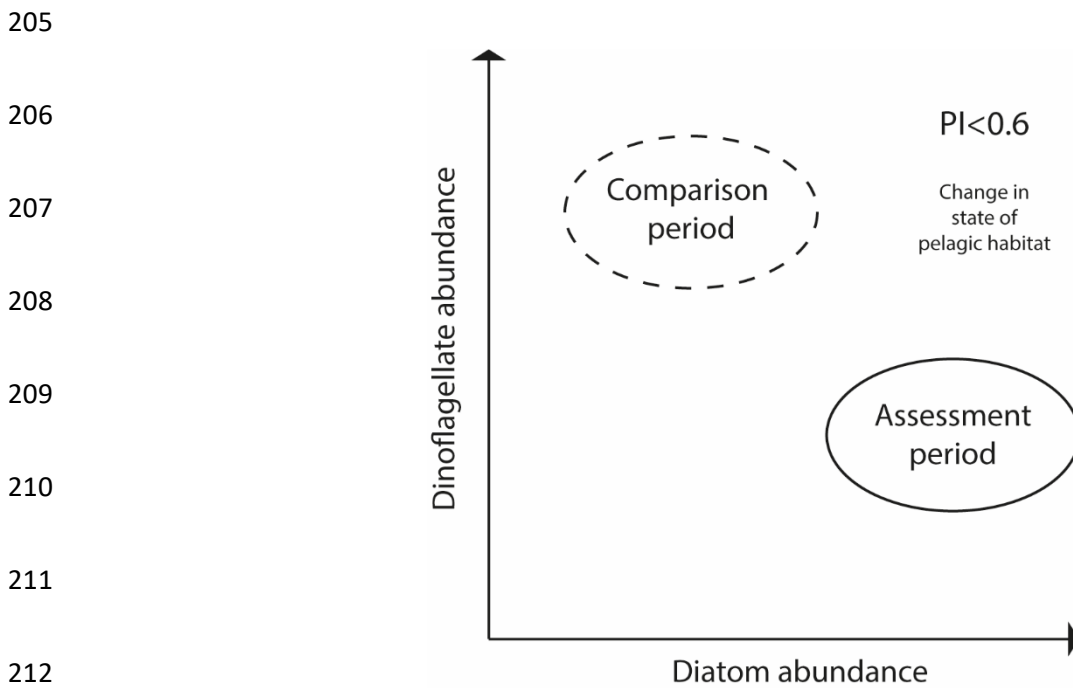
173

174 An indicator based on functional traits has been selected for assessing changes in plankton  
175 community structure under the MSFD (McQuatters-Gollop et al., 2019). The indicator is based on  
176 grouping taxa into their respective 'lifeforms' based on shared functional traits. Lifeforms are groups  
177 of taxa that play the same functional role within an ecosystem (Tett et al., 2013) and are analogous  
178 to functional groups. As ecosystems experience change and are subjected to pressures, the relative  
179 proportions and ratios of different life forms can change. Monitoring the relative abundance of key  
180 lifeforms can therefore help assess change in ecosystem state. The method of aggregating individual  
181 taxa into lifeforms is outlined in McQuatters-Gollop et al. (2019). Here we use five lifeform pairs  
182 included in the OSPAR Intermediate Assessment of 2017 (2017a): Diatoms/Dinoflagellates,  
183 Phytoplankton/ Non-carnivorous zooplankton, Pelagic/Tychopelagic diatoms, Small/Large copepods,  
184 and Holoplankton/Meroplankton.

185 The metric currently employed by OSPAR to quantify changes in the lifeform indicator is the  
186 'Plankton Index', and is based around a 'state-space' approach (Tett et al., 2008). This approach  
187 involves selecting key lifeform pairs, based on their link to ecosystem structure and functioning, then  
188 plotting the abundance of the first lifeform for each month in a time series on the X axis, and the  
189 second lifeform on the Y axis (Tett et al., 2013). For example, in Figure 2 the abundance of diatoms is  
190 plotted on the X axis and the abundance of dinoflagellates on the Y axis, so that monthly plankton  
191 communities are plotted in 'state-space'. As ratios of lifeforms vary naturally, e.g. seasonal variation,  
192 plotting multiple coordinates from months taken throughout a defined time period produces a  
193 'domain' within the plot of ecosystem state. The current plankton community, within the period that  
194 is being assessed, is used to create this domain. We hereby refer to this period as the 'assessment  
195 period'. Previous time periods (i.e. 'comparison periods') can be compared to this assessment period



196 domain by overlaying the months for the previous time period in question. If these points fall within  
197 the domain, it suggests the current state within the assessment period does not represent a change.  
198 If however these points fall outside the domain, it suggests the current state within the assessment  
199 period is different to previous time periods. This change in state is calculated as the proportion of  
200 points falling within the domain, quantified as a standardized 'Plankton Index'. The lower the  
201 proportion of points falling inside the assessment period domain, the lower the Plankton Index  
202 value, and so the greater the change in state. In Figure 2, the assessment period represents a  
203 changed ecosystem state from the comparison period, revealing community change within the  
204 pelagic habitat (Tett et al., 2013).



213 *Figure 2. The Plankton Index approach. Data from the*  
214 *current assessment period is used to create a*  
215 *domain. The comparison period is subsequently*  
216 *overlay and the PI quantifies the proportion of points*  
217 *falling outside of the domain. Here, we use a PI*  
218 *threshold of 0.6 to distinguish a state change from*  
*underlying variability.*

219 In this study, the total for each lifeform was calculated for each CPR sample in each of the two North  
220 Sea regions. These were then aggregated into annual means before being  $\log_{10}(x+1)$  transformed.  
221 Months between 2013 and 2017 were used to create the assessment period domain for each  
222 lifeform pair for each region. This domain is calculated as an envelope that excludes the most  
223 extreme 10% of data points. The PI value is then calculated as the proportion of new points falling  
224 inside the domain, out of the total number of new points. To distinguish a state change from  
225 background variability, for this study we used a threshold of  $PI > 0.6$  (i.e. fewer than 60% of points  
226 falling within the assessment period domain) to represent a state change.. The value of 0.6 was  
227 selected based on expert opinion, to represent a balance between sensitivity of the metric but  
228 allowing the distinguishing of change from background variability. As the selection of thresholds is a  
229 developing area, during future assessments this value may change based on quantitative criteria  
230 such as adjusting for multiple testing.

231

232

233

234

235

### 236 2.2.2 Local Contribution to Beta Diversity

237

238 This indicator metric identifies atypical or unique plankton community composition in a time-series,  
239 compared to other time-points (Legendre and Gauthier, 2014) (without reference as to whether this  
240 composition is 'good' or 'bad' in terms of environmental status). It is based on the concept that the  
241 total variability in community composition between points in a time-series can be viewed as the  
242 temporal 'Beta Diversity' of the time-series, analogous to the more classical use of Beta Diversity as  
243 a spatial concept. This total Beta Diversity can then be partitioned into the contribution each time-  
244 point makes to the total variability. Time-points with significant contributions to the total can be  
245 viewed as contributing disproportionately to total variability, and therefore are atypical, or unique,

246 in community composition, accounting for taxa identity, richness and dominance structures. This  
247 method therefore allows the evaluation as to whether the current assessment period is atypical in  
248 plankton community composition compared to a comparison period of previous time-points in the  
249 time-series. In this way, the evaluation of the assessment period will depend on the length of time-  
250 series used as a comparison period.

251 To calculate the 'Local Contribution to Beta Diversity' (LCBD) metric on annual mean data, first 'Total  
252 Beta Diversity' of both phytoplankton and zooplankton time-series was calculated following  
253 Legendre and Cáceres (2013). Total Beta Diversity ( $BD_{Total}$ ) under this method was calculated as the  
254 total variance of the year-by-species community data, so was calculated without reference to alpha  
255 and gamma diversity as in other metrics of Beta Diversity (Anderson et al., 2011). A matrix of  
256 squared deviations from species means was calculated for each year for each species, so that if the  
257 abundance of a particular species was the same in all years, the values for that species were zero in  
258 each year. The total of these squared deviations were then summed across the species-by-year  
259 abundance data ( $SS_{Total}$ ).  $BD_{Total}$  was then calculated as  $(SS_{Total}/(n-1))$ , where n refers to the number of  
260 years.

261 For this study, the mean monthly abundances of each taxa were  $\log_{10}(x+1)$  transformed, with any  
262 gaps in the monthly mean time-series filled through linear interpolation, before being further  
263 aggregated to annual means (Richardson et al., 2006). These annual means were then chord  
264 transformed prior to analysis to make the data suitable for Beta Diversity analysis and to avoid  
265 putting a large emphasis on rare species (Legendre and Borcard, 2018; Legendre and Gallagher,  
266 2001). Total Beta Diversity was then partitioned into the contribution of each individual year to the  
267  $BD_{Total}$ , so that each year had an associated LCBD value. LCBD indices were tested for significance  
268 through permutation testing.

269 To further interpret variation in the LCBD metric, we then identified the taxa that contribute the  
270 most to total community variability across the time-series. Here  $BD_{Total}$  was partitioned into the

271 contribution each taxa makes, rather than each time-point makes as for LCBD. For each plankton  
272 community time-series, we calculated the 'Species Contributions to Beta Diversity (SCBD)' metric  
273 (Legendre et al., 2005) for each taxon, with taxa with high SCBD values showing the highest variation  
274 across the time-series, i.e. the highest contributions to  $BD_{Total}$ . All calculations and analyses of LCBD  
275 and SCBD were undertaken using the beta.div function in the R package 'adespatial' (Dray et al.,  
276 2016).

277

### 278 2.3 Temporal scale analysis

279

280 For this study, we used 2013-2017 as the focal period for an assessment, i.e. the policy aim is to  
281 characterise the plankton community within this period in relation to previous time periods. These  
282 are the latest 5 years of the CPR time-series included in this study, and represent the period of time  
283 that would be assessed within the latest 6-yearly cycle of the MSFD implementation process. This  
284 current assessment period was then compared to three comparison periods of varying temporal  
285 scale. Firstly, a short-term comparison period going back to 2004 was used. This short-term  
286 comparison period represents the previous policy cycle to the assessment period, so is analogous to  
287 assessing whether there has been a state change since the last policy cycle. Secondly, a medium-  
288 term comparison period going back to 1990 was selected to represent a multi-decadal perspective,  
289 but post the 1980s regime shift. Lastly, we used a long-term comparison period going back to 1958,  
290 which is the start of the consistent CPR time-series. This long-term period represents a multi-decadal  
291 perspective including the time periods before and after the 1980s regime shift.

292 The assessment period of 2013-2017 was assessed at these three temporal scales using each  
293 indicator metric. For the Plankton Index metric, the period 2013-2017 was used to create the  
294 assessment period domain, and then data between 2004 and 2012, 1990 and 2012, and 1958 and  
295 2012, respectively, were overlaid and a Plankton Index value calculated. This analysis therefore  
296 covered both different discreet periods of time within the comparison period, and also different

297 lengths of comparison period. For the LCBD metric, three time-series were created, 2004-2017,  
298 1990-2017, and 1958-2017. The  $BD_{Total}$  was calculated for each time-series and the LCBD values for  
299 each year in each time-series calculated. These time-series of LCBD values were then used to  
300 evaluate whether the assessment period of 2013-2017 was assessed as atypical at each of the three  
301 temporal scales.

302

### 303 3 Results

#### 304 3.1 The effect of temporal scale on the plankton lifeform index

305

306 Outputs of the Plankton Index for the five lifeform pairs included in this study are shown in Table 1.

307 When using a PI threshold of 0.6 to establish whether there has been a change from the comparison

308 period, the southern North Sea appears more stable in terms of plankton community change on the

309 short-term scale compared to the northern North Sea, which experienced change in all lifeforms

310 pairs apart from Pelagic/Tychopelagic diatoms during all three time-scales. Similarly, using the long-

311 term comparison period, two of the lifeform pairs showed a change below the threshold in the

312 southern North Sea, whereas all six lifeform pairs showed a change in the northern North Sea when

313 including long-term data in the comparison period.

314

315

316

317

318

319 *Table 1. Results of the Plankton Index for each lifeform pair in each region. PI<0.6 represents a state*  
 320 *change.*

Lifeform pair	northern North Sea			southern North Sea		
	Short-term (2004-2012)	Medium- term (1990-2012)	Long-term (1958-2012)	Short-term (2004-2012)	Medium- term (1990-2012)	Long-term (1958-2012)
Diatoms/Dinoflagellates	<b>0.54</b>	<b>0.57</b>	<b>0.54</b>	0.64	0.64	<b>0.53</b>
Pelagic/Tychoipelagic diatoms	0.62	<b>0.58</b>	<b>0.55</b>	0.72	0.69	0.62
Phytoplankton/ Non- carnivorous zooplankton	<b>0.52</b>	<b>0.58</b>	<b>0.56</b>	0.69	0.69	0.63
Large/Small copepods	<b>0.52</b>	<b>0.48</b>	<b>0.37</b>	0.8	0.7	0.62
Holoplankton/Meroplankton	<b>0.59</b>	<b>0.46</b>	<b>0.34</b>	0.62	<b>0.55</b>	<b>0.44</b>

321

322

323 There are also differences between lifeform pairs in terms of their assessment outcomes at different  
 324 temporal scales. There is a general trend that as the temporal scale of the comparison period  
 325 increases (i.e. data from further back in time is included in the comparison period), the PI value  
 326 lowers, therefore indicating greater change. For example, the Holoplankton/ Meroplankton pair in  
 327 the northern North Sea showed a change across all temporal scales, with this change getting  
 328 stronger (increasingly smaller PI values) as the temporal scale of the comparison period increased  
 329 (Figure 3A). This pattern suggests this lifeform pair shows a clear trajectory of change over time. A  
 330 similar pattern occurs for the Large/Small copepod pair in the northern North Sea. In contrast,  
 331 Large/Small copepods in the southern North Sea showed stability across all three temporal scales,  
 332 suggesting that little directional change has occurred in this lifeform pair in this area over multi-  
 333 decadal scales (Figure 3B). Stability in the southern North Sea across all three temporal scales is also  
 334 shown in Pelagic/Tychoipelagic diatoms, and Phytoplankton/Non-carnivorous zooplankton.

335 Some lifeform pairs however, show different results depending on temporal scale when using 0.6 as  
 336 a threshold. In the southern North Sea for example, diatoms and dinoflagellates show stability over  
 337 the short and medium time scales, but change over the longer time-scale (Figure 3C). This pattern

338 suggests that a large change in this lifeform pair in the southern North Sea occurred before 1990,  
339 after which it appears more stable.

340

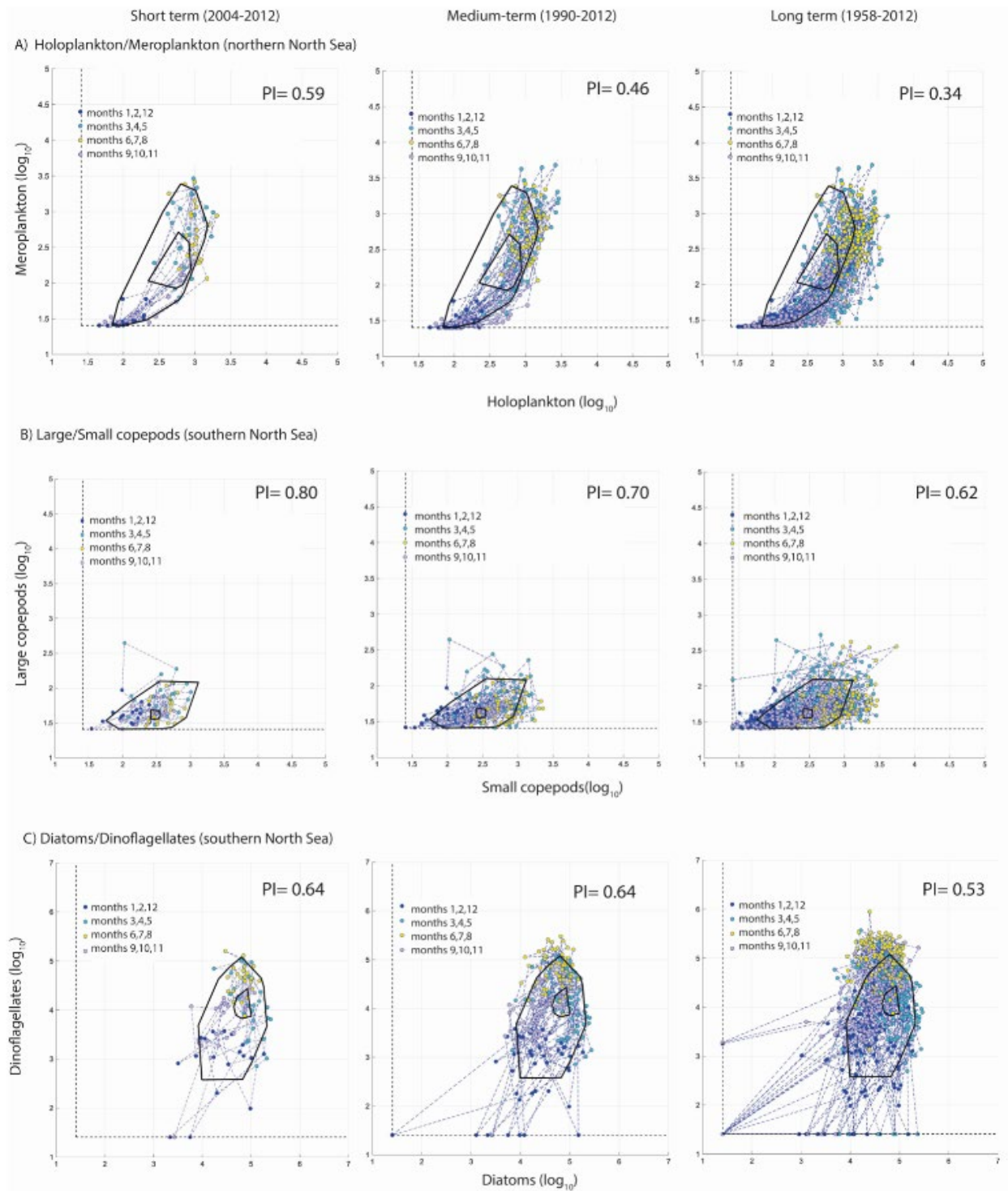
341

342

### 343 3.2 The effect of temporal scale on the LCBD indicator metric

344

345 Results from the analysis of temporal scale on the LCBD metric are shown in Table 2. Similarly to the  
346 PI outputs, results vary between short-term, medium-term and long-term time-scales. Results vary  
347 in two main ways. Firstly, the years that are calculated as having significant Local Contributions to  
348 Beta Diversity vary. For example, in the southern North Sea, 2017 was assessed as having a  
349 significant LCBD for phytoplankton when looking at the short time-scale (Figure 4B). When including  
350 data before 2004, however, 2017 was no longer assessed as significant. Instead, when looking at the  
351 longest time-scale an extended period during the late 1970s and early 1980s was assessed as  
352 significant. When looking at the longest time-frame, therefore, most of the overall time-series  
353 variability ( $BD_{Total}$ ) is driven by this period, rather than the current assessment period. Increasing  
354 temporal scale in this context therefore decreases the likelihood of assessing the current assessment  
355 period as anomalous, as more variability is encompassed in the comparison period than in the  
356 assessment period. This contrasts to the northern North Sea (Figure 4A), where the years 2016 and  
357 2017 were assessed as significant over the long temporal scale, but not under the short or medium-  
358 term scales.



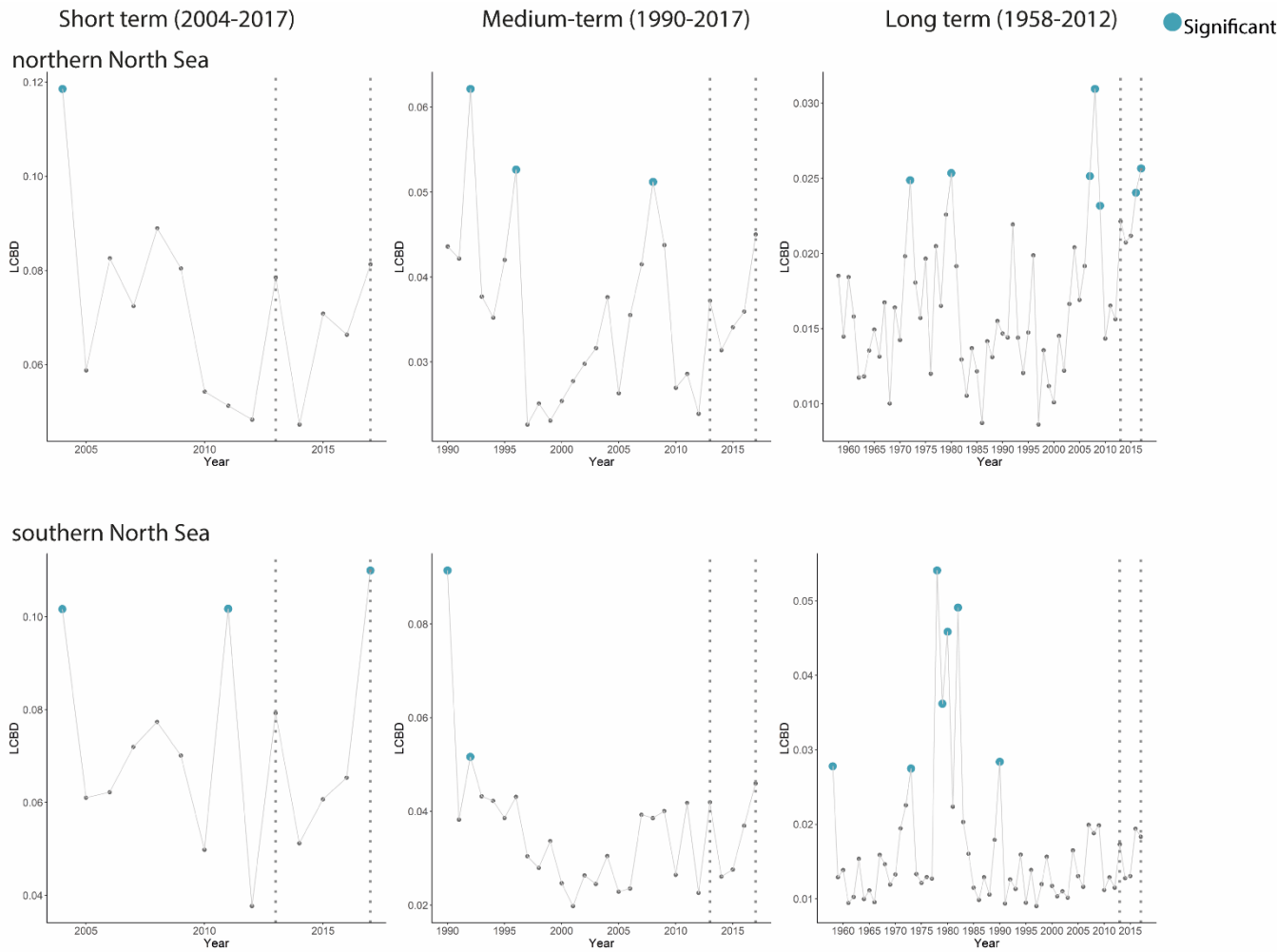
359

360 *Figure 3. Visualisation of the Plankton Index using different temporal scales of comparison periods. A)*  
 361 *Holoplankton/Meroplankton in the northern North Sea. An example of a lifeform pair showing change*  
 362 *over all three temporal scales. B) Large/Small copepods in the southern North Sea. An example of a*  
 363 *lifeform pair showing stability over all three temporal scales. C) Diatoms/Dinoflagellates in southern*  
 364 *North Sea. An example of a lifeform pair showing stability on the short and medium time-scales, but*  
 365 *change over the long-term time-scales.*



Table 2. Outputs of the LCBD metric at different temporal scales. For each community (phytoplankton/zooplankton) in each region (northern/southern North Sea), the years with significant LCBD metrics are shown, with years in the assessment period (2013-2017) highlighted in bold. For each community, the 'top 3' species with the largest SCBD values are listed.

Plankton community	Short-term (2004-2017)		Medium-term (1990-2017)		Long-term (1958-2017)	
	Significant LCBD years	Top three SCBD	Significant LCBD years	Top three SCBD	Significant LCBD years	Top three SCBD
Phytoplankton (northern North Sea)	2004	<b><i>Nitzschia spp. (unidentified)</i></b>	1992,1996,2008	<b><i>Nitzschia spp. (unidentified)</i></b>	1972,1979,1980, 2007,2008,2009, <b>2016,2017</b>	<b><i>Ceratium macroceros</i></b>
		<i>Thalassionema nitzschioides</i>		<i>Ceratium furca</i>		<i>Ceratium furca</i>
		<i>Corethron hystrix</i>		<i>Thalassiothrix longissima</i>		<i>Prorocentrum spp. ('Exuviaella' type)</i>
Phytoplankton (southern North Sea)	2004, 2011, <b>2017</b>	<b><i>Ceratium macroceros</i></b>	1990,1992	<b><i>Ceratium furca</i></b>	1958, 1973,1978,1979, 1980,1982,1990	<b><i>Ceratium macroceros</i></b>
		<i>Nitzschia spp. (unidentified)</i>		<i>Rhaphoneis amphiceros</i>		<i>Ceratium furca</i>
		<i>Thalassionema nitzschioides</i>		<i>Ceratium macroceros</i>		<i>Thalassionema nitzschioides</i>
Zooplankton (northern North Sea)	None	<b><i>Penilia avirostris</i></b>	1991,2009	<b>Bivalve larvae</b>	1961,1965,1978, 1980,1981,2007	<b><i>Calanus finmarchicus</i></b>
		Appendicularia		<i>Penilia avirostris</i>		<i>Centropages typicus</i>
		<i>Centropages spp. (Unidentified)</i>		<i>Para-Pseudocalanus spp.</i>		<i>Echinoderm larvae</i>
Zooplankton (southern North Sea)	2007	<b>Appendicularia</b>	1990,1991,2007	<b><i>Centropages spp. (Unidentified)</i></b>	1958,1979,1982	<b><i>Centropages typicus</i></b>
		<i>Penilia avirostris</i>		<i>Penilia avirostris</i>		<i>Oithona spp.</i>
		<i>Centropages hamatus</i>		Echinoderm larvae		Appendicularia



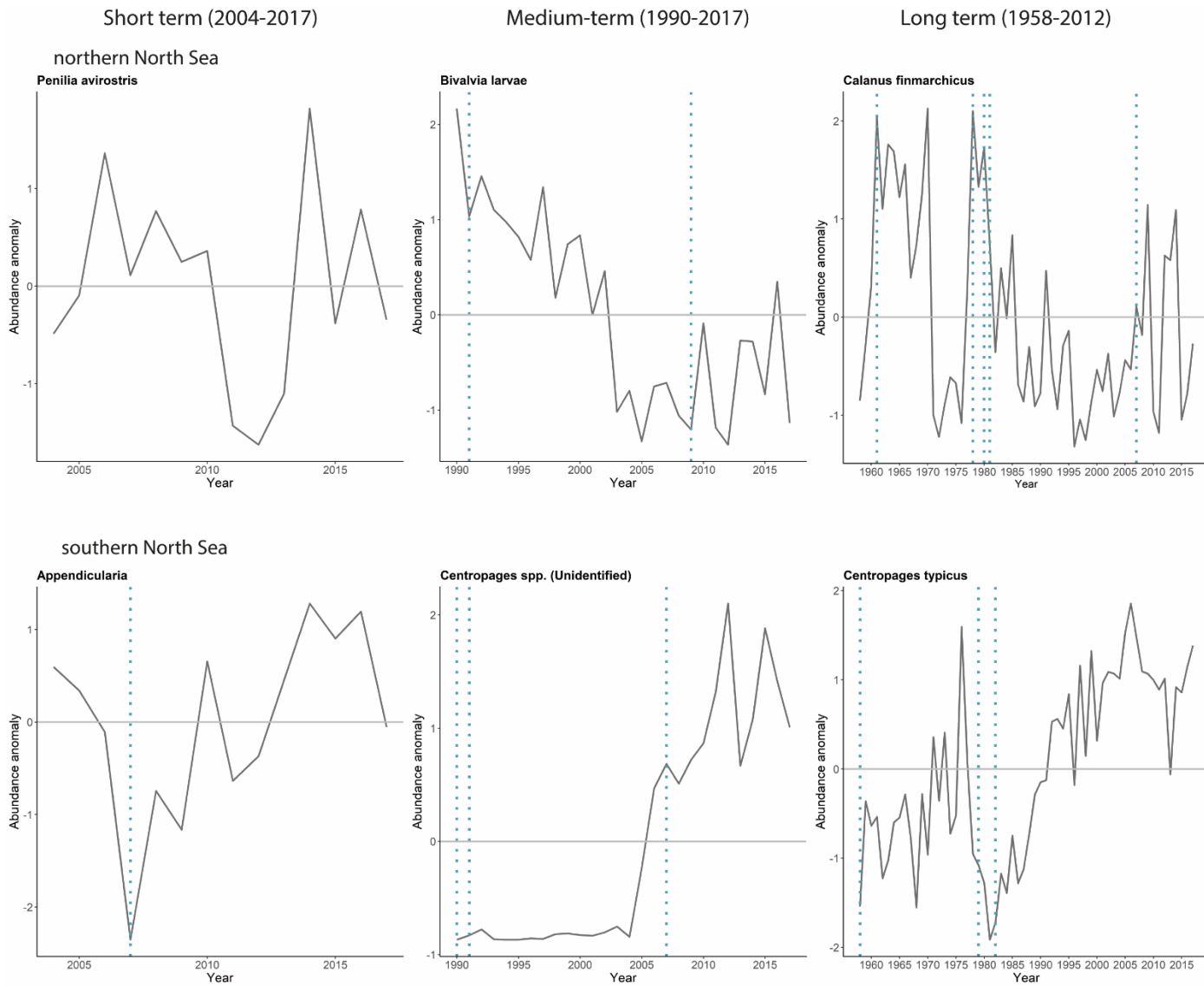
371

Figure 4. LCBD values for phytoplankton communities in the Northern and southern North Sea. Large blue dots indicate years with significant LCBD values at each time-scale. The assessment period of 2013-2017 is shown with vertical dotted lines in each plot.

372

373 As well as different years being assessed as significant, different taxa were identified as the main  
 374 drivers of community variability at different time-scales (i.e., have the highest SCBD values). For  
 375 example, in the northern North Sea region for zooplankton (Figure 5), the invasive cladoceran *Penilia*  
 376 *avirostris* has the highest SCBD in the short-term, although no years had significant LCBD values at  
 377 this time-scale in this region. At the medium time-scale, Bivalve larvae contributed the most to  
 378 community composition variability, but at the long-term scale, *Calanus finmarchicus* contributed the  
 379 highest to variability. This in turn affects the years that are assessed as having significant LCBD values  
 380 (Figure 4). The years 1991 and 2009 are assessed as significant over the medium-term, which frame

381 a period of rapid decline in the abundance of Bivalve larvae, moving from a positive to a negative  
382 abundance anomaly. When looking at the long-time-scale, the years 1980 and 1982, as well as 2007  
383 are assessed as significant, which frame a period of rapid decline in the abundance of *Calanus*  
384 *finmarchcus*. When looking at the short-term, these taxa are relatively stable in abundance and do  
385 not contribute as highly to the total Beta Diversity ( $BD_{Total}$ ). In the southern North Sea for  
386 zooplankton, *Centropages typicus* contributed highly to  $BD_{Total}$  over the longest time-scale, but  
387 unidentified *Centropages* spp. and Appendicularia contributed the most over the medium and short  
388 time-scale, respectively.



389

Figure 5. The taxa with the highest 'Species Contribution to Beta Diversity (SCBD)' values for zooplankton at short, medium and long time scales. Abundance expressed as standardized anomalies of long term mean. For comparison, for each area and time scale the years with significant 'Local Contribution to Beta Diversity (LCBD)' values are shown with a blue dotted line.

390

391

#### 392 4 Discussion

393

394 Distinguishing ecologically-meaningful change in plankton communities from background variability

395 is a key challenge facing the formal assessment of pelagic habitats under policy drivers. However,

396 detection and interpretation of change depends on the years selected for the comparison period,

397 and here we have highlighted that the temporal scale of the comparison period affects the outcome  
398 of indicator assessments. For example, the Plankton Index based on lifeform pairs generally reveals  
399 greater change when including data from further back in time. This supports the concept that  
400 increasing the temporal scale of the comparison period increases the detection of change, because  
401 data from historic environmental conditions are included.

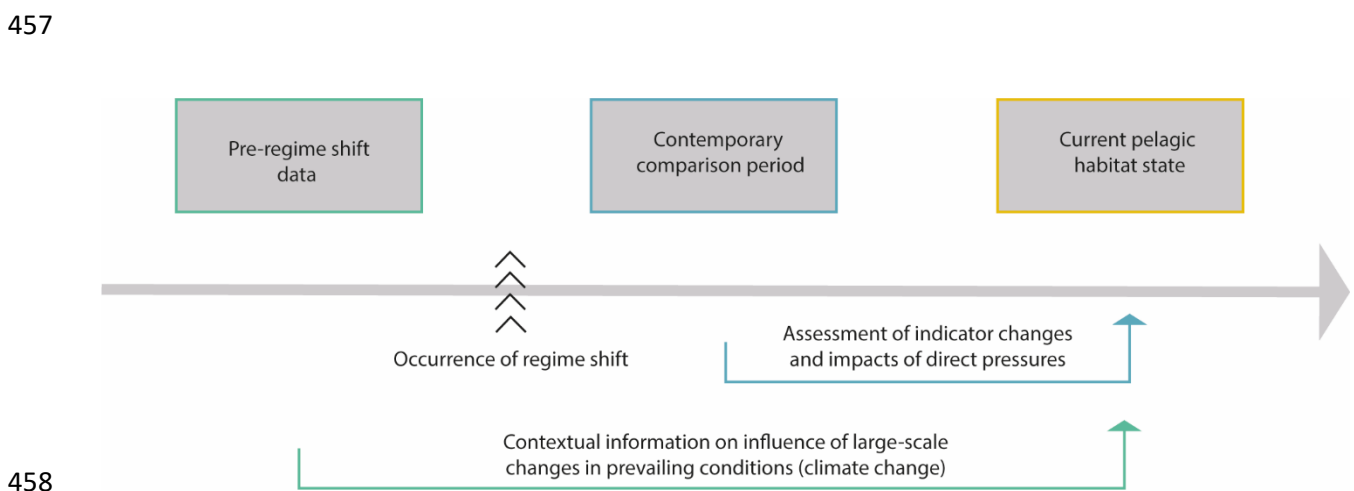
402 This conclusion does not consistently extend to the LCBD indicator metric, however. For example,  
403 the LCBD indices for phytoplankton in the southern North Sea area revealed that 2017 was  
404 anomalous on the short time-scales, but not on the medium or long-term time-scales. Although the  
405 two indicators display non-consistent patterns when assessed over increasing temporal scales, they  
406 provide different, yet complementary ecological information. When assessing over the shorter time  
407 scales therefore, there may be years within the assessment period identified as anomalous in  
408 species-level community composition, even though overall the assessment period doesn't represent  
409 a fundamental change in functional group structure.

410 Most of the long-term time-series variability for southern North Sea phytoplankton was driven by an  
411 anomalous period in the late 1970s, indicated by a period of consistently significant LCBD indices.  
412 This anomalous period in the CPR time series has previously been associated with a pulse of cold,  
413 low salinity water entering the North Sea causing a rapid decrease in SST and salinity (Dickson et al.,  
414 1988; Edwards et al., 2002). This 'Great Salinity anomaly' caused an associated shift in  
415 phytoplankton community composition, most notably a sharp population crash of *Ceratium*  
416 *macroceros*, which here had the highest SCBD value at the long time-scale. Such extreme anomalies  
417 in community composition when looking at the long-temporal scale can mean that any shorter-term  
418 variability is not assessed as significant. In this specific case therefore, increasing the temporal scale  
419 over which the indicator is calculated decreases the likelihood that the current assessment period  
420 represents a change.

421 A large cause of the underlying variability in assessment outcomes at different temporal scales is the  
422 regime shift that occurred in the 1980s; including data from before the regime shift affects the  
423 conclusion of whether the current assessment period represents a change. For example, the PI for  
424 Diatoms/Dinoflagellates in the southern North Sea region was stable over the short- and medium-  
425 term time-scales, but fell below the 0.6 threshold when including pre-regime shift data, indicating a  
426 state change in the community over a long-multidecadal time-scale. This multidecadal pattern in  
427 diatoms and dinoflagellates indicates a shift in trophic pathways within the pelagic ecosystem.  
428 Similarly, when looking at the Species Contributions to Beta Diversity, long-term variability in  
429 southern North Sea zooplankton was largely driven by *Centropages typicus*, which showed a rapid  
430 increase in abundance between 1982 and 2005. Both these years had significant LCBD values,  
431 'framing' this increase in *C. typicus*. *C. typicus* did not have a large contribution to overall variation in  
432 community composition over the short-time-scale, however, suggesting its abundance was stable  
433 over this short temporal scale. The tendency for significant LCBD indices to 'frame' a specific event  
434 as found here was also found by who showed that LCBD values for mollusc assemblages before  
435 nuclear testing events were significant over a long-term-time-series indicating that the intervention  
436 of nuclear testing led to the establishment of a community largely different to what it had previously  
437 been. This highlights the importance of hindsight for this indicator metric; a given year can become  
438 significant once more data are added to the time-series.

439 When a long-term time-series experience a major hydrographic change, such as a regime shift, the  
440 question therefore becomes 'Do we select a comparison period representing 'new conditions' or do  
441 we use the whole time-series as a comparison?'. Given the large influence of climate change, which  
442 is outside the scope of the MSFD, on pelagic habitat biodiversity indicators, it may be appropriate to  
443 first use contemporary data within the current climate regime as a comparison period. For the  
444 assessment of plankton lifeforms for example, this would involve calculating the Plankton Index  
445 between the current assessment period and contemporary data (such as the short- or medium-  
446 time-scale periods used here), rather than comparing all the way back to 1958.

447 The importance of understanding the influence of changing oceanographic and climatic conditions  
448 on biodiversity indicators, however, is increasingly being recognised as important for developing  
449 effective marine strategies (Bedford et al., 2018). This understanding provides a broader perspective  
450 of changing marine ecosystems upon which directly manageable pressures are superimposed.  
451 Crucially, therefore, after assessing over short-temporal scales, long-temporal scale data can then be  
452 used to provide context to the assessment, and inform on multi-decadal changes including any  
453 signals of climate change. By using long temporal scale data in this additional, contextual way, the  
454 assessment process can adapt to ongoing environmental change, whilst also avoiding shifting  
455 baseline syndrome by not losing important information on the influence of prevailing conditions  
456 (Figure 6).



458  
459 *Figure 6. Suggested incorporation of climate regimes into the pelagic habitat assessment process in the North Sea. Contemporary data can be used first as the comparison period for assessments, but, crucially, long temporal scale data should be used as 'contextual data' to inform on the influence of changing prevailing conditions, helping to avoid shifting baselines syndrome.*

460  
461  
462  
463 The LCBD metric is a key example of an indicator that provides different types of information when  
464 assessed over different temporal scales. Whereas over short time-scales the LCBD indicator may  
465 reveal short-term population changes and anomalous phytoplankton blooms (Rombouts et al.,

466 2019), we have highlighted here that over long temporal scales it can reflect large-scale ocean  
467 climate anomalies and climate driven shifts. Similarly, identifying the species contributing the most  
468 to total compositional variability at long time-scales gives insight to large-scale climate-driven shifts.  
469 For example, the copepod species *Calanus finmarchicus* had the highest zooplankton SCBD value in  
470 the northern North Sea over the long-temporal scale, indicating its long-term importance to the  
471 community. *Calanus finmarchicus* is a keystone species in the North Atlantic food-web, and has  
472 undergone a much-documented decline in the North Sea in response to warming, with ramifications  
473 for higher trophic levels (Helaouët and Beaugrand, 2007).

#### 474 4.1 Conclusion

475 Where resources and time-series length allow, assessing indicators over multiple temporal scales  
476 provides different scales of information to policy assessments; from detecting detailed changes  
477 within the current management cycle, to providing broad-scale multi-decadal context to  
478 assessments. Selection of appropriate temporal scales is therefore a key example of the importance  
479 of co-production and dialogue between scientists and policy-makers during the development of  
480 biodiversity indicators.

481

482

## 483 5 Acknowledgements

484 This work was supported through the EMFF funded 'ICEGRAPH' project (Increasing Confidence  
485 Evaluating GES for Regional Assessments of Pelagic Habitats). A.M-G was supported by the UK  
486 Natural Environmental Research Council Knowledge Exchange fellowship scheme (NE/ R00273/1).

487

488

489



490 **References**

- 491 Addison, P., Collins, D., Trebilco, R., Howe, S., Bax, N., Hedge, P., Jones, G., Miloslavich, P.,  
492 Roelfsema, C., Sams, M., 2017. A new wave of marine evidence-based management: emerging  
493 challenges and solutions to transform monitoring, evaluating, and reporting. *ICES Journal of Marine*  
494 *Science* 75, 941-952.
- 495 Anderson, M.J., Crist, T.O., Chase, J.M., Vellend, M., Inouye, B.D., Freestone, A.L., Sanders, N.J.,  
496 Cornell, H.V., Comita, L.S., Davies, K.F., Harrison, S.P., Kraft, N.J., Stegen, J.C., Swenson, N.G., 2011.  
497 Navigating the multiple meanings of beta diversity: a roadmap for the practicing ecologist. *Ecol Lett*  
498 14, 19-28.
- 499 Apitz, S.E., Elliott, M., Fountain, M., Galloway, T.S., 2006. European environmental management:  
500 moving to an ecosystem approach. *Integrated environmental assessment and management* 2, 80-85.
- 501 Batten, S.D., Clark, R., Flinkman, J., Hays, G., John, E., John, A.W.G., Jonas, T., Lindley, J.A., Stevens,  
502 D.P., Walne, A., 2003. CPR sampling: the technical background, materials and methods, consistency  
503 and comparability. *Progress in Oceanography* 58, 193-215.
- 504 Bedford, J., Johns, D., Greenstreet, S., McQuatters-Gollop, A., 2018. Plankton as prevailing  
505 conditions: A surveillance role for plankton indicators within the Marine Strategy Framework  
506 Directive. *Marine Policy* 89, 109-115.
- 507 Berg, T., Furhaupter, K., Teixeira, H., Uusitalo, L., Zampoukas, N., 2015. The Marine Strategy  
508 Framework Directive and the ecosystem-based approach - pitfalls and solutions. *Mar Pollut Bull* 96,  
509 18-28.
- 510 Budria, A., Aubert, A., Rombouts, I., Ostle, C., Atkinson, A., Widdicombe, C., Goberville, E., Artigas, F.,  
511 Johns, D., Padegimas, B., Corcoran, E., McQuatters-Gollop, A., 2017. Cross-linking plankton indicators  
512 to better define GES of pelagic habitats. *EcApRHA Deliverable WP1.4*.
- 513 Dickey-Collas, M., McQuatters-Gollop, A., Bresnan, E., Kraberg, A.C., Manderson, J.P., Nash, R.D.,  
514 Otto, S.A., Sell, A.F., Tweddle, J.F., Trenkel, V.M., 2017. Pelagic habitat: exploring the concept of  
515 good environmental status. *ICES Journal of Marine Science* 74, 1846-1854.
- 516 Dickson, R.R., Meincke, J., Malmberg, S.-A., Lee, A.J., 1988. The "great salinity anomaly" in the  
517 northern North Atlantic 1968–1982. *Progress in Oceanography* 20, 103-151.
- 518 Directive 2008/56/EC, Of the European Parliament and of the Council of 17 June 2008: Establishing a  
519 framework for community action in the field of marine environment policy (Marine Strategy  
520 Framework Directive).
- 521 Dray, S., Blanchet, G., Borcard, D., Guenard, G., Jombart, T., Larocque, G., Legendre, P., Madi, N.,  
522 Wagner, H., 2016. *adespatial: Multivariate Multiscale Spatial Analysis*. R package version 0.0-4.
- 523 Duarte, C.M., Conley, D.J., Carstensen, J., Sánchez-Camacho, M., 2009. Return to Neverland: shifting  
524 baselines affect eutrophication restoration targets. *Estuaries and Coasts* 32, 29-36.
- 525 Edwards, M., Beaugrand, G., Reid, P.C., Rowden, A.A., Jones, M.B., 2002. Ocean climate anomalies  
526 and the ecology of the North Sea. *Marine Ecology Progress Series* 239, 1-10.
- 527 Giron-Nava, A., James, C.C., Johnson, A.F., Dannecker, D., Kolody, B., Lee, A., Nagarkar, M., Pao,  
528 G.M., Ye, H., Johns, D.G., 2017. Quantitative argument for long-term ecological monitoring. *Marine*  
529 *Ecology Progress Series* 572, 269-274.
- 530 Helaouët, P., Beaugrand, G., 2007. Macroecology of *Calanus finmarchicus* and *C. helgolandicus* in the  
531 North Atlantic Ocean and adjacent seas. *Marine Ecology Progress Series* 345, 147-165.
- 532 Henson, S.A., Sarmiento, J.L., Dunne, J.P., Bopp, L., Lima, I.D., Doney, S.C., John, J.G., Beaulieu, C.,  
533 2010. Detection of anthropogenic climate change in satellite records of ocean chlorophyll and  
534 productivity. *Biogeosciences* 7, 621-640.
- 535 Legendre, P., Borcard, D., 2018. Box–Cox–chord transformations for community composition data  
536 prior to beta diversity analysis. *Ecography* 41, 1820-1824.
- 537 Legendre, P., Borcard, D., Peres-Neto, P.R., 2005. Analyzing beta diversity: partitioning the spatial  
538 variation of community composition data. *Ecological Monographs* 75, 435-450.

539 Legendre, P., Cáceres, M., 2013. Beta diversity as the variance of community data: dissimilarity  
540 coefficients and partitioning. *Ecology letters* 16, 951-963.

541 Legendre, P., Gallagher, E.D., 2001. Ecologically meaningful transformations for ordination of species  
542 data. *Oecologia* 129, 271-280.

543 Legendre, P., Gauthier, O., 2014. Statistical methods for temporal and space–time analysis of  
544 community composition data. *Proceedings of the Royal Society of London B: Biological Sciences* 281,  
545 20132728.

546 Legendre, P., Salvat, C., 2015. Thirty-year recovery of mollusc communities after nuclear  
547 experimentations on Fangataufa atoll (Tuamotu, French Polynesia). *Proceedings of the Royal Society*  
548 *of London B: Biological Sciences*, 282, n. 1810, p. 20150750.

549 Machado, I., Costa, J.L., Leal, M.C., Pasquaud, S., Cabral, H., 2019. Assessment level and time scales  
550 of biodiversity indicators in the scope of the Marine Strategy Framework Directive—A case study for  
551 the NE Atlantic. *Ecological Indicators* 105, 242-253.

552 Magurran, A.E., Baillie, S.R., Buckland, S.T., Dick, J.M., Elston, D.A., Scott, E.M., Smith, R.I.,  
553 Somerfield, P.J., Watt, A.D., 2010. Long-term datasets in biodiversity research and monitoring:  
554 assessing change in ecological communities through time. *Trends Ecol Evol* 25, 574-582.

555 McClenachan, L., Cooper, A.B., McKenzie, M.G., Drew, J.A., 2015. The Importance of Surprising  
556 Results and Best Practices in Historical Ecology. *BioScience* 65, 932-939.

557 McQuatters-Gollop, A., 2012. Challenges for implementing the Marine Strategy Framework Directive  
558 in a climate of macroecological change. *Philos Trans A Math Phys Eng Sci* 370, 5636-5655.

559 McQuatters-Gollop, A., Atkinson, A., Aubert, A., Bedford, J., Best, M., Bresnan, E., Cook, K., Devlin,  
560 M., Gowen, R., Johns, D.G., 2019. Plankton lifeforms as a biodiversity indicator for regional-scale  
561 assessment of pelagic habitats for policy. *Ecological Indicators* 101, 913-925.

562 McQuatters-Gollop, A., Johns, D.G., Bresnan, E., Skinner, J., Rombouts, I., Stern, R., Aubert, A.,  
563 Johansen, M., Bedford, J., Knights, A., 2017. From microscope to management: The critical value of  
564 plankton taxonomy to marine policy and biodiversity conservation. *Marine Policy* 83, 1-10.

565 O'Higgins, T., Cooper, P., Roth, E., Newton, A., Farmer, A., Goulding, I.C., Tett, P., 2014. Temporal  
566 constraints on ecosystem management: definitions and examples from Europe's regional seas.  
567 *Ecology and Society* 19.

568 OSPAR, 2017a. Changes in Phytoplankton and Zooplankton Communities. Intermediate Assessment  
569 2017. Available at: <https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017>.

570 OSPAR, 2017b. Pilot assessment of Changes in Plankton Diversity. Intermediate Assessment 2017.  
571 Available at: <https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017>.

572 Pauly, D., 1995. Anecdotes and the shifting baseline syndrome of fisheries. *Trends in ecology &*  
573 *evolution* 10, 430.

574 Reid, P.C., Hari, R.E., Beaugrand, G., Livingstone, D.M., Marty, C., Straile, D., Barichivich, J.,  
575 Goberville, E., Adrian, R., Aono, Y., Brown, R., Foster, J., Groisman, P., Hélaouët, P., Hsu, H.-H., Kirby,  
576 R., Knight, J., Kraberg, A., Li, J., Lo, T.-T., Myneni, R.B., North, R.P., Pounds, J.A., Sparks, T., Stübi, R.,  
577 Tian, Y., Wiltshire, K.H., Xiao, D., Zhu, Z., 2015. Global impacts of the 1980s regime shift. *Global*  
578 *Change Biology* 22, 682-703.

579 Richardson, A., Walne, A., John, A., Jonas, T., Lindley, J., Sims, D., Stevens, D., Witt, M., 2006. Using  
580 continuous plankton recorder data. *Progress in Oceanography* 68, 27-74.

581 Rombouts, I., Simon, N., Aubert, A., Cariou, T., Feunteun, E., Guérin, L., Hoebeke, M., McQuatters-  
582 Gollop, A., Rigaut-Jalabert, F., Artigas, L., 2019. Changes in marine phytoplankton diversity:  
583 Assessment under the Marine Strategy Framework Directive. *Ecological Indicators* 102, 265-277.

584 Scherer, C., Gowen, R.J., Tett, P., 2016. Assessing the State of the Pelagic Habitat: A Case Study of  
585 Plankton and Its Environment in the Western Irish Sea. *Frontiers in Marine Science* 3, 236.

586 Tett, P., Carreira, C., Mills, D.K., van Leeuwen, S., Foden, J., Bresnan, E., Gowen, R.J., 2008. Use of a  
587 Phytoplankton Community Index to assess the health of coastal waters. *Ices Journal of Marine*  
588 *Science* 65, 1475-1482.

589 Tett, P., Gowen, R.J., Painting, S.J., Elliott, M., Forster, R., Mills, D.K., Bresnan, E., Capuzzo, E.,  
590 Fernandes, T.F., Foden, J., Geider, R.J., Gilpin, L.C., Huxham, M., McQuatters-Gollop, A.L., Malcolm,  
591 S.J., Saux-Picart, S., Platt, T., Racault, M.F., Sathyendranath, S., van der Molen, J., Wilkinson, M.,  
592 2013. Framework for understanding marine ecosystem health. *Marine Ecology Progress Series* 494,  
593 1-27.  
594 Thurstan, R.H., McClenachan, L., Crowder, L.B., Drew, J.A., Kittinger, J.N., Levin, P.S., Roberts, C.M.,  
595 Pandolfi, J.M., 2015. Filling historical data gaps to foster solutions in marine conservation. *Ocean &*  
596 *Coastal Management* 115, 31-40.  
597 Wasmund, N., 2017. The diatom/dinoflagellate index as an indicator of ecosystem changes in the  
598 Baltic Sea. 2. Historical data for use in determination of good environmental status. *Frontiers in*  
599 *Marine Science* 4, 153.

600

601

602