The Western Channel Observatory: a century of physical, chemical and biological data compiled from pelagic and benthic habitats in the Western English Channel

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Abstract

The Western Channel Observatory (WCO) comprises a series of pelagic, benthic and atmospheric sampling sites within 40 km of Plymouth UK, which have been sampled by the Plymouth Institutes on a regular basis since 1903. This longevity of recording and the high frequency of observations provide a unique combination of data; for example temperature data were first collected in 1903 and the reference station L4 has been sampled on a weekly basis since 1988 where nearly 400 planktonic taxa have been enumerated. While the component datasets have been archived, here we provide the first summary database bringing together a wide suite of the observations. This provides monthly average values of some of the key pelagic and benthic measurements for the inshore site L4 (50° 15.00' N, 4° 13.02' W approx depth 55 m), the offshore site E1 (50° 02.00' N, 4° 22.00' W approx depth 75 m) and the intermediate L5 site (50° 10.80' N, 4° 18.00' W approx depth 58 m). In brief, the data include: water temperature (from 1903); macronutrients (from 1934); dissolved inorganic carbon and total alkalinity (from 2008); methane and nitrous oxide (from 2011); chlorophyll *a* (from 1992); HPLC-derived pigments (from 1999); <20 µm plankton by flow cytometry including bacteria (8 functional groups from 2007); phytoplankton by microscopy (6 functional groups from 1992); microplankton and mesozooplankton from FlowCam (6 groups from 2012), *Noctiluca* sp. dinoflagellate (from 1997); mesozooplankton by microscopy (8 groups from 1988); *Calanus helgolandicus* egg production rates (from 1992); fish larvae from Young Fish Trawl survey (4 groups from 1924); benthic macrofauna (4 groups from 2008); demersal fish (19 families from 2008); blue shark, *Prionace glauca* (from 1958); 16S alpha diversity for

sediment and water column (from 2012). These data have varying coverage in time and depth resolution. The metadata tables describe each data set, provide pointers to the source data and other related Western Channel Observatory data sets and outputs not compiled here. We provide summaries of the main trends in seasonality and some major, climate related shifts that have been revealed over the last century. The data are available from Data Archive for Seabed Species and Habitats (DASSH) via the link https://doi.org/10.17031/645110fb81749 (McEvoy and Atkinson, 2023). Making the data fully accessible and including units of both abundance and biomass will stimulate a variety of uptakes. These may include uses as an educational resource for projects, for models and budgets or for analysis of seasonality and long-term change in a coupled benthic-pelagic system and for supporting UK and Northeast Atlantic policy and management.

1 History

Sustained observations of the marine environment are vital to understand marine ecosystem functioning and climate change responses (O'Brien et al., 2017; Richardson, 2008). Over seasonal timescales, high resolution observations allow the understanding of community succession and seasonality (Smyth et al., 2014) and over multiple decades they allow us to tease out the effects of local variability and anthropogenic stressors from the longer-term signal of climate change (Edwards and Richardson, 2004; Ratnarajah et al., 2023). Paradoxically, however, many sampling programs are funded for only 3-4 years and despite the urgency of understanding climate change responses, time series globally are threatened (Vucetich et al., 2020). This makes it even more important to make data from existing long time series findable, reusable and as well documented as possible.

The Western Channel Observatory (WCO) data contains an unprecedented collection of parameters both in terms of longevity and variety. Investigation of the marine environment in the western English Channel off Plymouth began with the opening of the Marine Biological Association (MBA) laboratory in 1888. Given the importance in the area of the pelagic fishery the remit focused strongly on research in applied fisheries. Initial studies centered on the eggs and larvae of commercially important fish. With the advent of the International Council for the Exploration of the Sea (ICES) and a growing realisation that hydrography had an influence on biological communities, plankton surveys and hydrographical measurements were soon added (Southward et al., 2005; Southward and Roberts, 1987). In the decades that followed, observations were expanded with the creation of stations E1 (50° 02.00' N, 4° 22.00' W) and L5 (50° 10.80' N, 4° 18.00' W). Sampling was interrupted during both World War I (1914-1918) and World War II (1939-1945). Funding priorities and organisational changes in the 1970s and 1980s threatened the future of long-term time series, and sampling at L5 and E1 was consequently stopped until 2002. However, in 1988 Plymouth Marine Laboratory (PML) established weekly zooplankton sampling at station L4 (50° 15.00' N, 4° 13.02' W), with ad-hoc funding and no formal support. Sampling for phytoplankton community composition and abundance, egg production and environmental variables followed from 1992 onwards. The WCO was founded in 2005 to bring these valuable time series together. The WCO provided a platform for a wider array of parameters to be initiated, for example the benthic survey from 2007, *in-situ* automated buoys at L4 and E1 (supported initially by Natural Environmental Research Council (NERC) and then the Met Office), the Penlee Point Atmospheric Observatory (PPAO) from 2014 and Smart Sound Plymouth from 2021 (**Fig 1**).

The stations around Plymouth now known as the Western Channel Observatory have supported major innovative work, for example pioneering work on plankton as indicators (Russell, 1935), the measurement of nutrients and primary production (Boalch et al., 1978), early work on fatty acids and the importance of food quality for zooplankton (Conover and Corner, 1968; Pond et al., 1996) and the use of molecular biology tools to provide insight into the seasonal dynamics of viral and bacterial plankton (Lindeque, 2023; Gilbert et al., 2009; Schroeder et al., 2003). These works, including the development of intertidal research and data not covered here can be found in the historical review of Southward et al. (2005). Later Special journal issues cover the 20th and 25th anniversaries of regular sampling at L4 and are described respectively in Harris (2010) and Smyth et al., (2015). We refer the reader to these for the historical context of the observations we summarise here.

Figure 1: Location of Western Channel Observatory (WCO) sampling stations.

2 The WCO environment

The two main marine stations of L4 and E1 both exhibit strong seasonal signals and are tidally influenced (Smyth et al., 2015). Both become stratified typically after April, continuing through the summer months and lasting until late September. Station L4 is classified as a coastal site and is periodically influenced by flood water discharge from the rivers Tamar and Plym (Rees et al., 2009). However, at a depth of approx. 55 m and 13 km offshore it is not as prone to localized inshore effects and is classified as “transitionally stratified” (Pingree, 1980). The deeper station E1, 40 km offshore and approx. 75 m deep, is less influenced by coastal water influx and is classified as an open shelf station that is seasonally stratified. The intermediate station, L5, was much sampled in early years and is just west of Eddystone reef. These stations experience classic, albeit highly variable seasonal production cycles with spring and autumn phytoplankton blooms. Figure 2 compares the key WCO sites in relation to the wider summer pattern of stratification (**Fig. 2a**) and to the longer trend of climatic cycles across the North Atlantic (Bode, 2023) highlighting a recent phase of intense warming over the last 4 decades (**Fig. 2b**). These environmental changes, and the response of the biota, are described more fully in Section 5 using plots derived from our summary database.

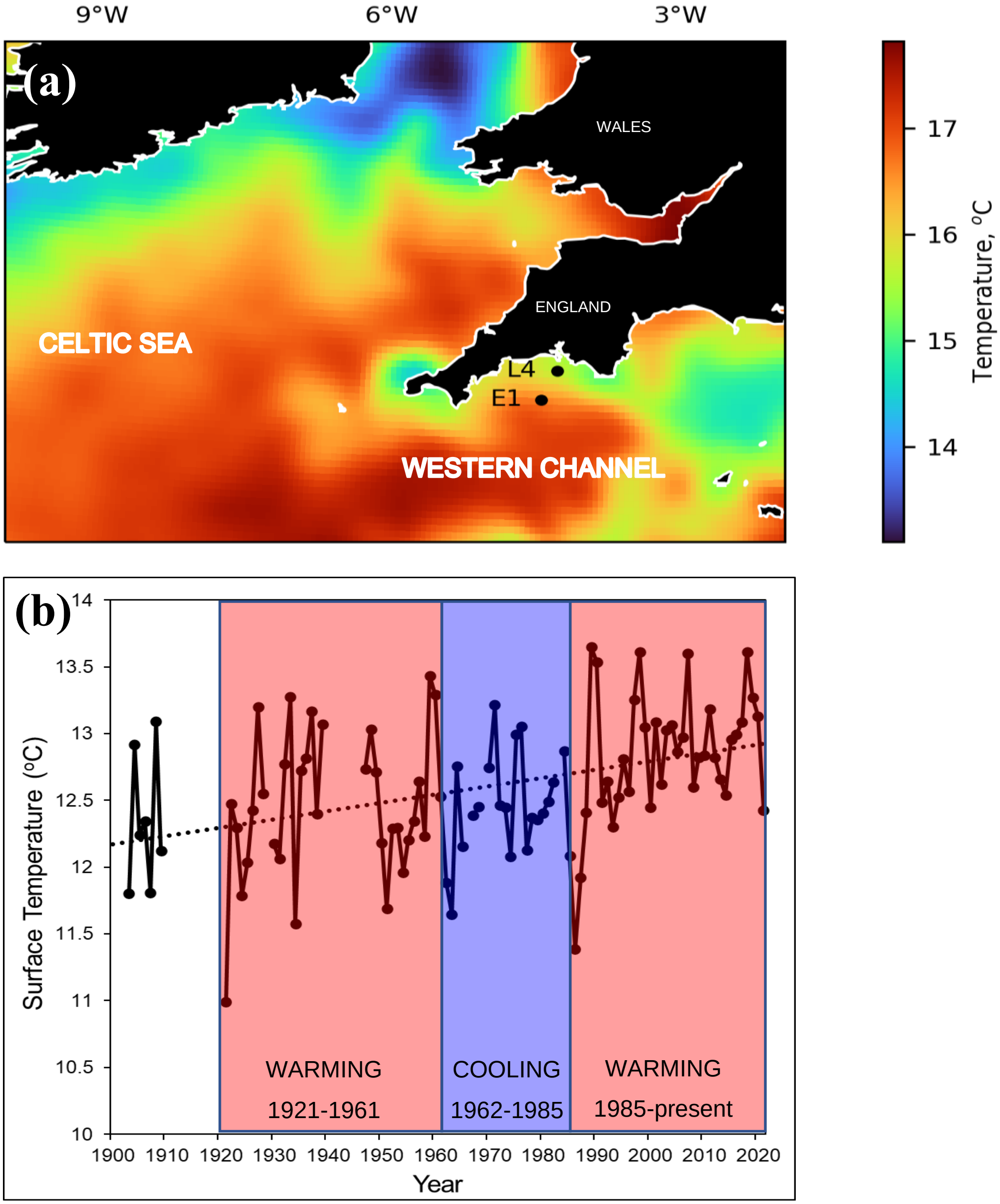


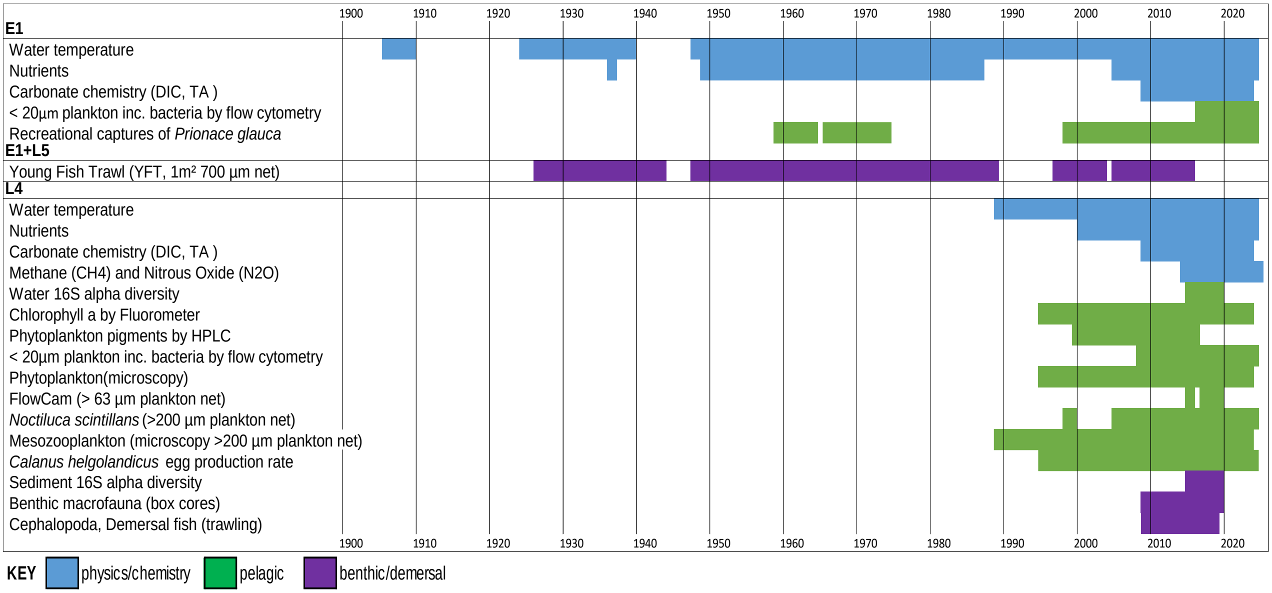
Figure 2: Wider-scale spatial and temporal context for the Western Channel Observatory. (a) The wider setting of the L4 and E1 stations in the Western English Channel, in relation to summer sea surface temperature July 2016 (Merchant et al., 2019). Cold colours represent tidally mixed areas, warm colours represent summer stratifying areas with seasonal summer thermocline. L4 stratifies in summer and is defined as transitionally stratified, whereas E1 is open shelf and defined as seasonally stratified (Pingree, 1980). (b) Annual surface temperature records at station E1 spanning 1903-2021. Due to missing data in some months of the early years, annual means were calculated here as averages of February, May, August and November. Missing months were interpolated as mean respective month over the whole timespan. Years with more than 2 of the four missing months are not plotted here. Dotted line is least squares linear regression over the whole timespan. Three thermal epochs are coloured here based on the interpretation of Southward et al., (2005). They defined periods of warming from 1921-1961, followed by a cooling era from 1962-1985 and then a warming period from 1986.

3 Objectives

The individual data sets of the WCO are valuable, but differing levels of reporting and formatting hamper their use and prevent integration. Many are currently available through data repositories such as British Oceanographic Data Centre, https://www.bodc.ac.uk/data/ and Data Archive for Seabed Species and Habitats, https://www.dassh.ac.uk/, however, some are lodged with individual scientists. To improve their overall utility, the various component data sets need to be brought together into a single format. We have done this here for the first time, but to make this project tractable we have summarized the core datasets as monthly averages, and for broad functional groups. This level of resolution (coarser than some of the measurements, which can be weekly and for individual species), was chosen as a first step to allow timely completion of this initiative, to provide a summary database that combines many diverse data sources. This data paper combines in a single spreadsheet most of the key variables which have good seasonal or longer-term coverage (**Table 1**). Specialists who wish to access the underlying high-resolution observations, data for individual species, who require the most recent data available, or require other data sets not summarized here are directed to our WCO data catalogue: https://www.westernchannelobservatory.org.uk/data.php. This catalogue provides sampling details, doi's of the most recent versions, and points of contact for specific data sets. Additional information is also available in Table A1 and Table A2.

This data paper is aimed towards scientists who may not need weekly resolution or species-specific data, but who wish to compare the monthly-averaged physical, chemical and biological data. Biological data are provided in units of both abundance and biomass, to enhance their utility for modelling. We have also made the spreadsheets as user-friendly and simple as possible to be of help as an educational resource at the undergraduate level. This data paper describes the database (**Section 4**); illustrates its utility to examine seasonality and longer-term trends while summarizing previous work on these topics (**Section 5**); provides a broader-scale context for the WCO (**Section 6**) and finally provides practical advice on the strengths, limitations and how to use and cite this database (**Sections 7 and 8**).

Table 1: Data combined in this data paper, showing the timespan of each.



4 Data processing

This paper consolidates 22 individual and diverse data sets using monthly averages. Data with comprehensive seasonal coverage which span at least two years are included. Detailed information on sampling and analysis protocols plus data coverage can be found in the Appendices (**Table A1 and A2).** It is essential to read these appendices before extracting data to avoid errors, for example in distinguishing between zeros and absent data. A zero represents a parameter that was either looked for and not found (for plankton data) or was below the detection limit (nutrient data). A blank cell, by contrast, indicates there are no data available for that particular month. Most biotic data are reported both in units of abundance and biomass. The smallest plankton (>20 µm) measured by flow cytometry is an exception. These use fixed conversion factors for the whole functional group, and have multiple groups and depths. Therefore to remove the complexity of having many data fields that are simple multiples of others, these are reported only as abundance per millilitre. Median cell diameters are provided, which enables estimation of biomass based on the volume of a sphere and carbon values from the literature (**Table 2**). Median cell diameters were derived by collecting seawater samples, filtering them sequentially through a series of membrane filters, analysing the filtrates by flow cytometry and the percentage of cells remaining plotted as a percentage of unfiltered seawater against filter pore size (Burkill et al., 1993). The FlowCam analysis of the 63µm mesh plankton net reports biomass only. Here along with the microscopy analysis of lugols and formalin preserved phytoplankton biomass estimation is based on mean cell dimensions and taxa specific biovolumes (**Table A1**). Biomass calculations for the mesozooplankton are based on measured body lengths of material from L4 and applied literature values of length-mass regressions to convert to individual biomass. These were then multiplied by numerical abundances to derive biomass densities (McEvoy et al., 2022). The benthic fauna data biomass are derived from blotted wet weight and Cephalopoda and demersal fish families by wet weight on board.

Table 2: Median cell diameters for plankton groups quantified by flow cytometry. $^{\$}$from Station L4, approximately monthly over an annual cycle 2013-2014 (unpublished); $^{\wedge}$ from the Celtic Sea, April 2002 (unpublished). $^{£}$ (Heywood et al., 2006). *Carbon conversion factor 0.22 pg C per µm^3 (Booth, 1988), $^{\#}$carbon conversion factor 0.285 pg C per µm^3 (unpublished).

Group	***Synechococcus* sp.**$^{\$}$	**Picoeukaryotes**$^{\$}$	**Nanoeukaryotes**$^{\$}$	**Cocco-lithophores**$^{\wedge}$	**Crypto-phytes**$^{\$}$	**Bacteria**$^{£}$
Median diameter (µm) ±1 SD	1.72 ± 0.70	1.83 ± 0.58	5.40 ± 2.04	7.68 ± 0.89	5.48 ± 1.33	-
Spherical volume (µm^3)	2.66	3.20	82.50	236.87	86.36	-
Carbon per cell (pg)	0.59*	0.70*	18.15*	67.51$^{\#}$	19.00*	0.019

5 Results and Discussion

In this section we briefly showcase some of the key data sets, by outlining the seasonality and environmental variability, illustrating the coverage of all of the component data series at L4 (**Fig. 3**) and E1 and L5 (**Fig. 4**). We then show selected examples of the time series data coverage, including longer term trends at L4 (**Fig. 5**) and E1 and L5 (**Fig. 6**). A few other key example results are shown, including the *Calanus* spp. egg production experiments (**Fig. 7**) and the time-depth resolution of sampling for carbonate chemistry (**Fig. 8**).

5.1 Overall seasonality: L4 pelagic system

The high resolution sampling of multiple parameters at L4 makes it an ideal site for improving understanding of the drivers of seasonality. Figure 3 summarises some of the key aspects of this seasonality. In brief, L4 is a transitionally stratified site (Pingree, 1980) that stratifies typically from around May to September with surface temperatures ranging from about 9°C in March to around 16°C in August. This stratification cycle drives much of the pelagic dynamics with nutrient (especially nitrate) depletion to near-limiting levels in the upper water column during the stratified period, as well as progressive reductions in DIC, Methane and Nitrous Oxide typically until about August (Kitidis et al., 2012).

The combination of nutrients, light and grazing causes the conditions for a “classic” temperate shelf sea production cycle (Irigoien et al., 2005). Thus there is typically a spring bloom around April-May dominated by diatoms and the prymnesiophyte *Phaocystis*, followed by a dinoflagellate bloom in late summer and often diatoms in autumn. Importantly however, the monthly mean values of the phytoplankton functional groups in Fig. 3 disguise the substantial inter-annual variability in their magnitude or floristic composition over the time-series (Widdicombe et al., 2010). The pico- and nano fractions follow slightly different dynamics, with highest biomasses building up in the summer stratified period with maxima often in August-September (Tarran and Bruun, 2015). The FlowCam biomass estimates based on 63 µm mesh, full-depth net hauls show the contributions of copepod nauplii and the larger diatoms, dinoflagellates and ciliates, some of which are not statistically quantified in the Lugol's based counts due to their rarity. Conversely the copepod nauplii are too small to be quantitatively retained by the 200 µm mesozooplankton WP2 net. Rare seasonal profile data of the copepod *Oithona* spp. based on bottle sampling is provided by Cornwell et al., (2020).

The mesozooplankton grazers from the full depth 200 µm net hauls tend to increase substantially as early as March, before the spring bloom (Atkinson et al., 2015). The peak is typically in the early summer, dominated by copepods both numerically (Eloire et al., 2010) and in terms of biomass, but also having a substantial contribution in spring from meroplankton (Highfield et al., 2010). More predatory taxa (often gelatinous or semi-gelatinous forms such as chaetognaths) then become important later in summer. Egg production rate of *Calanus helgolandicus* has for most of the time series been highest in the April-June spring bloom months (Irigoien and Harris, 2003; Maud et al., 2015; Maud et al., 2018) although as described in section 5.6 this is changing. This copepod species alongside other zooplankton such as appendicularians (López-Urrutia et al., 2003), decapods (Fileman et al., 2014), bivalve larvae (Lindeque et al., 2015) and *Oithona similis* (Castellani et al., 2016; Cornwell et al., 2018; Cornwell et al., 2020) has been the focus of a series of detailed studies at L4 (Bonnet et al., 2005; Hirst et al., 2007; Irigoien and Harris, 2003).

While Fig. 3 describes a classic textbook shelf sea production cycle (Kiørboe, 2009), a wide suite of alternative mechanisms have been proposed to drive plankton seasonality (Atkinson et al., 2018). These include: the roles of phytoplankton photophysiology (Edwards et al., 2013; Polimene et al., 2014); net heat flux (Smyth et al., 2014); variable temperaure dependence of phenology (Mackas et al., 2012; Atkinson et al., 2015); mortality-controlled zooplankton phenology (Irigoien and Harris, 2003, Cornwell et al., 2018); and various predatory-prey dyanamic models invoking stoichiometry (Polimene et al., 2015), grazing loopholes (Irigoien et al., 2005), grazer traits (Sailley et al., 2015) and the coupling of predator and prey traits (Kenitz et al., 2017). While these mechanisms are not necessarily mutually exclusive, the high resolution sampling of the whole food web over multiple years provides a good testbed for numerical- and conceptual models of the factors driving seasonality.

5.2 Overall seasonality: L4 benthic system

In contrast to the plankton, the benthic and demersal taxa have more varied seasonal dynamics. Macrofauna biomass is dominated at L4 by suspension feeders with similar biomass for most of the year (**Fig. 3**) except for low values in early winter. Potentially reflecting seasonal variation in water column food supply, species richness of infauna peaks throughout the summer in surface sediments and is lowest in late autumn. Higher numbers of species are also found in deeper sediment layers during warmer months, with the community seemingly shallowing over winter (Queirós et al., 2019). An assessment of particulate carbon sources to the seabed at L4 (Queirós et al., 2019) also suggested that fauna in shallow sediment layers exhibit strong signals of suspension and deposit feeding reliant on planktonic food sources, with carnivory increasing with sediment depth, and reliance on water column food diminishing in tandem. Demersal fish are dominated by gadoids with seasonal minima both in December and March-April. In the benthos there is no distinguishable seasonal signature to prokaryote diversity, in contrast to the water column, where it is lowest in the summer months.

While the detail of the seasonality of L4's pelagic and benthic component differs, there is strong connectivity between the pelagic and benthic systems, even during stratified periods. This is illustrated in the peaks and troughs of diversity linked to availability of food sources (see seasonal productivity peaks in Fig. 3 e) - j)**,** Queirós et al., 2019; Tait et al., 2015; Talbot et al., 2019), and also reflected by pigment data and stable isotopic signatures of both dissolved inorganic carbon (DIC) and particulate organic carbon and nitrogen (Queirós et al., 2019; Tait et al., 2015). Bentho-pelagic connectivity has been found to be seasonally variable in terms of the origin of the suspended and dissolved matter fluctuating between the two ecospheres, as well as the dominant flux directions (Queirós et al., 2015; Rühl et al., 2020; Tait et al., 2015). Strong seasonality is also observed in the dynamics of ecosystem processes mediated by macrofauna in L4 sediments i.e. bioturbation and bio irrigation (Kristensen et al., 2012) which have strong mediation effects on the rates of biogeochemical processes at the sediment water interface, such as community respiration, and net carbon sequestration (Queirós et al., 2015; Queirós et al., 2019).

Broader analyses of the seafloor time-series at L4 have also demonstrated that these dynamics are highly variable on an interannual basis, with the effects of extreme events being particularly important (Rühl et al., 2021). Net vertical flux directions of suspended and particulate matter vary throughout the year, switching in direction and respective importance for the overall flow of matter throughout the system. In summary, the benthic system at L4 is not so intensively sampled as the pelagic, but the site still provides an excellent opportunity to better understand benthic-pelagic coupling in a shallow shelf sea.

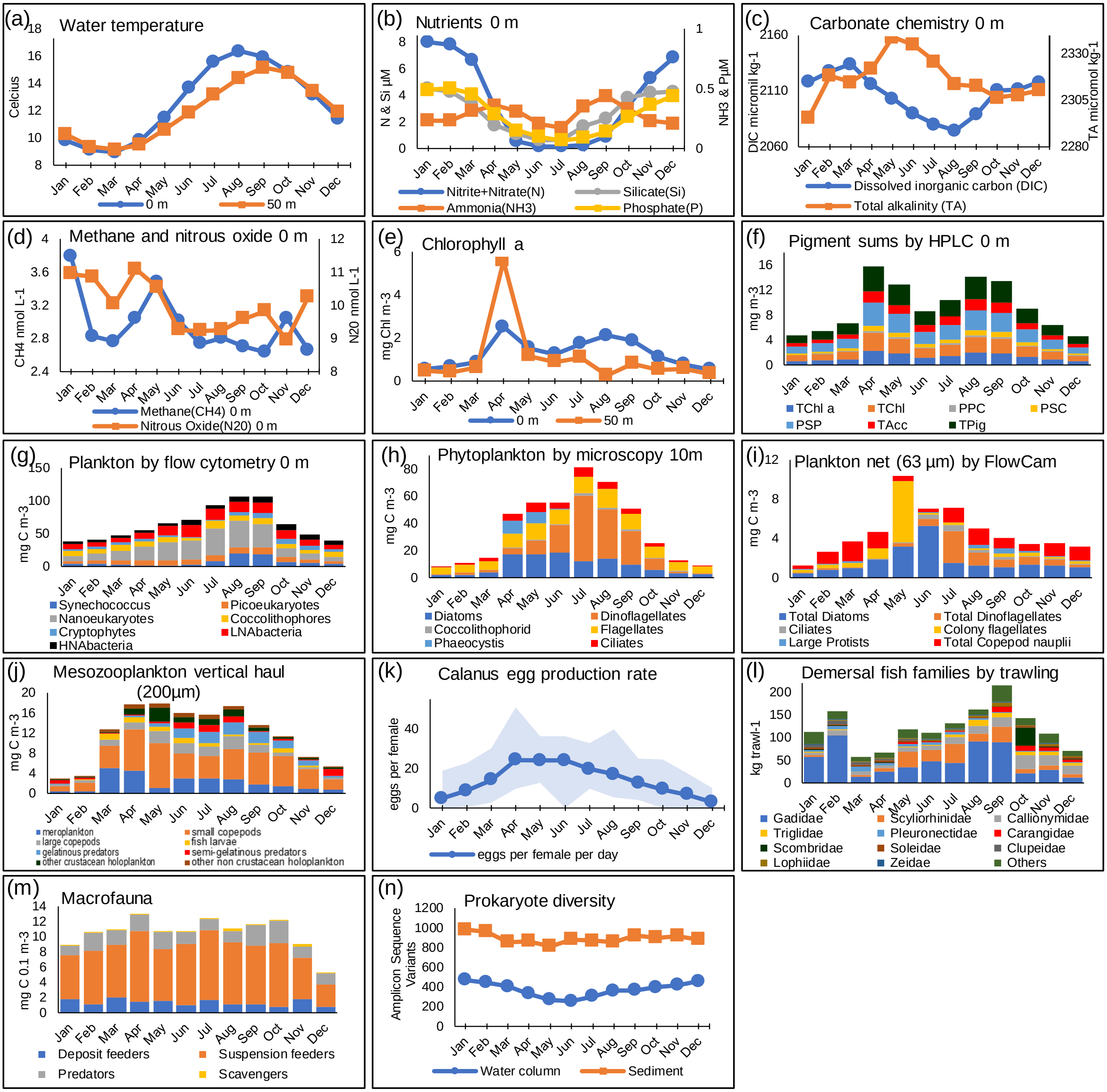


Figure 3: Seasonal patterns at station L4. Monthly mean values calculated across all years of available data, presented for surface (0 m) unless stated. For explanations of all data fields see Table A1. (f) categories show different pigment sums (see Table A1); (g) Biomass of plankton by flow cytometry derived using conversion factors from Table 2; (k) *Calanus* spp. females collected from net samples (l) Fish families plotted here are for the 11 top ranking groups based on annual mean biomass with remaining groups (including Cephalopoda) summed here as “others”.

5.3 Overall seasonality: E1 and L5 in comparison to L4

Figure 4 summarises the data available for the E1 and L5, sites further offshore than L4. All measurements except those from the Young Fish Trawl and the shark catch data pertain to the E1 site. The Young Fish Trawl data are from site E1 and L5 combined. The shark data are from angling vessels from Looe and within 10 miles of E1.

The E1 site is more strongly stratified than L4, as evidenced by slightly higher surface temperatures and a bigger summer temperature difference between surface and depth. Being further offshore than L4 and receiving less riverine nutrient input from the rivers Tamar and Plym macronutrient concentrations are more severely limiting in summer and indeed, iron stress in some seasons has been suggested (Schmidt et al., 2020). This is also reflected in the stronger reduction in dissolved inorganic carbon (DIC) during the stratified period, resulting in an average seasonal amplitude of 83 µmol kg^{-1} at E1 compared to around 55 µmol kg^{-1} at L4. Total alkalinity (TA) in contrast shows little seasonal cycle at E1 (average seasonal amplitude = 29 µmol kg^{-1}), compared to a slight increase in spring at L4 (average seasonal amplitude = 40 µmol kg^{-1}). Both L4 and E1 show a seasonal pattern of seawater CO_2 undersaturation between January and August, followed by supersaturation in September and October, returning to near equilibrium with the atmosphere for the remainder of the year (Kitidis et al., 2012). The subsurface chlorophyll *a* maxima has been shown to be important for controlling carbon fluxes at these sites, as well as the mixing of freshwater, which is evident by the difference between L4 and E1 conditions (Kitidis et al., 2012). The flow cytometry data reflect this (**Fig. 4)** with increased contribution of coccolithophores compared to L4, albeit with pronounced inter-annual variability and large blooms in some years but not others.

Although phytoplankton and zooplankton samples are currently collected at E1 we have not summarised them in this paper because the available time series data do not cover as long a period as L4. However, a summary of phyto- and zooplankton seasonality at E1 is presented and compared with that of L4 by Djeghri et al., (2018). These authors showed that mesozooplankton biomass at E1 is lower than at L4 and at deeper, offshore sites in the Celtic Sea (Giering et al., 2019). Also in the context of these Celtic sea stations, Schmidt (2020) examined nutrient dynamics at E1 in relation to pico- and nanoplankton, and found that late season dominance of the picocyanobacterium S*ynechococcus* (including intense blooms in some years) tended to follow summers of particularly severe nitrate stress.

Data compiled here from the Young Fish Trawl (**Fig. 4d**) show strong summer and autumn increases in sardine (hereafter called by their more locally common name "pilchard") eggs. The later autumn spawning period has become more dominant in recent years (Coombs et al., 2010). Fish eggs of other species, by contrast, are more abundant in early spring. *Calanus* spp. are not quantitatively sampled by the 700 µm mesh of the Young Fish Trawl but Fig. 4d shows an increase in mid-summer, which is in line with Fig. 3j, where the biomass of the large copepod fraction is dominated by *Calanus* spp. This genus comprises mainly *C. helgolandicus* in this area (Lindeque et al., 2013; Maud et al., 2015, 2018) and are important food for pelagic fish. Success in catching blue sharks *Prionace glauca* increases rapidly until late summer.

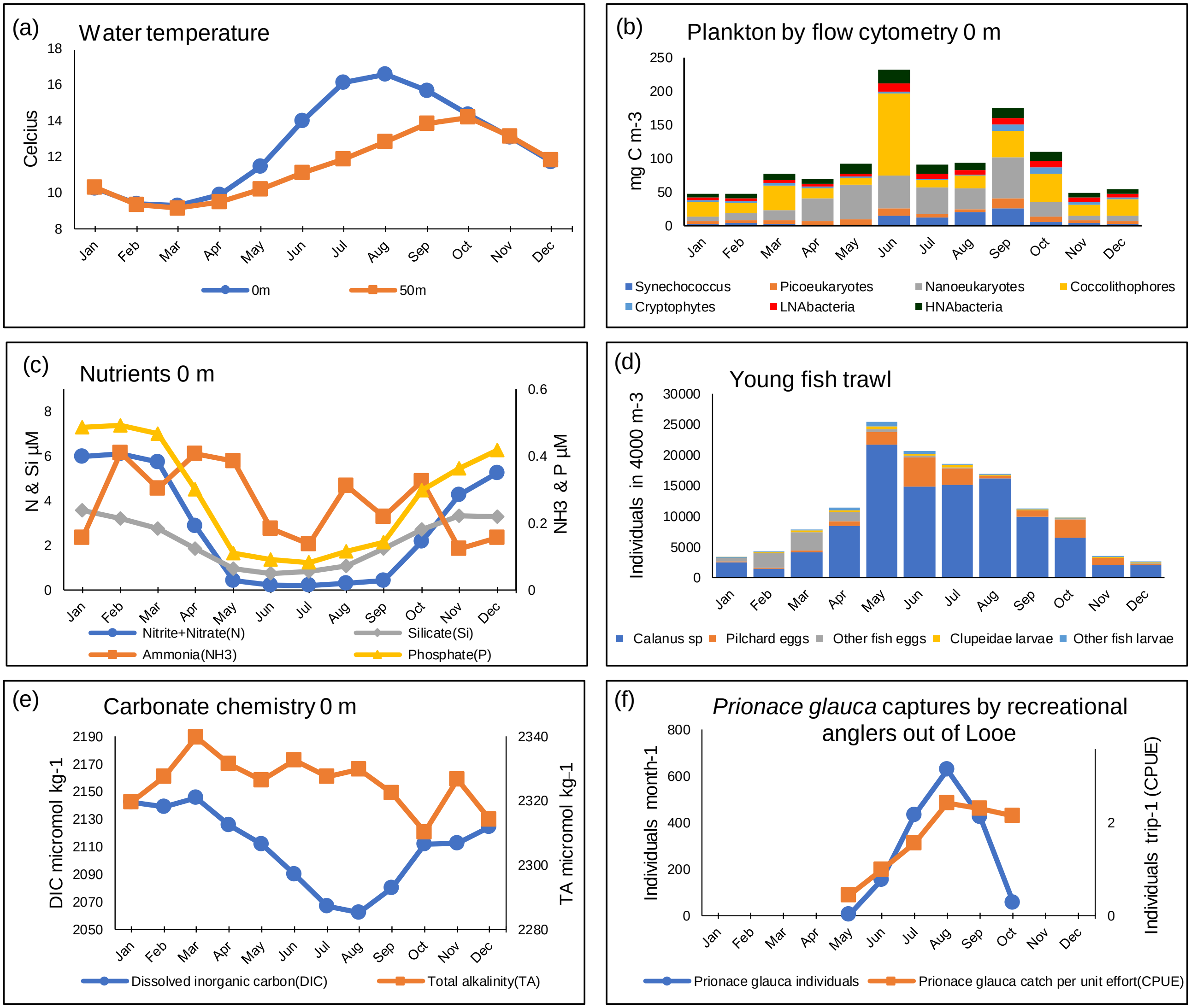


Figure 4: Seasonal patterns at station E1+L5 (1903-2021): Monthly mean values calculated across all years of available data. Illustration shows surface (0 m) data unless stated. For explanations of all data fields see Table A2. (b) Biomass of plankton by flow cytometry derived using conversion factors from Table 2; (d) Young fish trawl oblique tow to a depth of 5m above the seabed.

5.4 Annual time trends: L4

The regular, weekly-resolved measurements at L4 cover the most recent era of rapid warming (**Fig. 2**) and both the sampling intensity and the number of planktonic taxa measured allows observation of systematic change and its driving factors. We cannot review all the literature on change here, but instead Fig. 5 illustrates some of the key trends.

Because stratification is such a major factor driving seasonality at the WCO, Fig. 5 compares trends separately between the most stratified quarter of the year with lowest average nutrients (May-August) and the rest of the year. The temperature rise during the warm stratified period over the last 30 years is more pronounced than in the other months, and is well over 1ºC. The sharp rise in temperature at this time of year coincides with a major decline in nitrate concentrations and DIC, pointing to the effects of enhanced stratification retarding nutrient and carbon supply (**Fig. 5a**).

Figure 5b compares the trends for surface Chlorophyll *a* concentrations and the biomass-dominant functional groups of phytoplankton, that together dominate estimated biomass of cells counted in Lugol's preserved water samples from 10m depth, namely diatoms, dinoflagellates and nanoflagellates (ca. 15µm). Flagellates (ca. 2-15µm) are also counted more quantitatively and with full water column resolution by flow cytometry (since 2007) and the component fluorescing and non-fluorescing groups (termed nanoflagellates and heterotrophic nanoflagellates) are major contributors to community dynamics (Atkinson et al., 2021; Tarran and Bruun, 2015). The larger phytoplankton, namely diatoms, dinoflagellates and the subset of larger nanoflagellates decline strongly during the summer stratified period, with Chlorophyll *a* concentration declining overall by about 50 % over 30 years.

In parallel with these summer declines in phytoplankton, there have been declines at the same time of year in the crustacean mesozooplankton functional groups, namely large and small copepods, other crustacean holoplankton (dominated by *Podon* spp. and *Evadne* spp.) and fish larvae (**Fig. 5c**). The large copepod category (defined here as adult total body length over 2 mm) is strongly dominated by *Calanus helgolandicus*. From 1988 to around 2015 annual abundances of *C. helgolandicus* were fairly stable, only oscillating about four-fold between years (Atkinson et al., 2015; Maud et al., 2015). However, in recent years numbers in summer have started to decline substantially, making it hard to obtain sufficient individuals for egg production experiments. This sudden shift supports the concept of abrupt step changes that "reorganise" assemblages both at this site (Reygondeau et al., 2015) and more widely (Bode, 2023).

Outside of summer, these declines in the crustacean groups were not seen, or were not so prevalent in other months, and there was only a weak phenological shift observed at L4 (Atkinson et al., 2015; Uriarte et al., 2021) which does not explain the differential trends between the summer and the rest of the year.

Other taxa, by contrast, have tended to increase at L4. Only a minority of major crustaceans have shown signs of an increase, notably the more carnivorous, late summer copepod *Centropages typicus* (Corona et al., 2021). The main increases are among meroplankton taxa, fine mesh filter feeders such as appendicularians (which dominate the "other non-crustacean zooplankton" category) as well as the gelatinous predators (dominated by cnidarians) and semi-gelatinous predators (dominated by chaetognaths). Together, this suggests a shift in the balance of the mesozooplankton, from copepod domination towards a diversity of mero- and holoplankton that are fine particle feeders, more gelatinous or more carnivorous.

These trends seen at L4 conform to much wider-scale, long-term trends that are coherent across the NE Atlantic and NW European shelf. They are even broadly similar to those at the Naples Bay monitoring site over a similar timescale (Mazzocchi et al., 2023). As an example, the meroplankton increase is widespread across the NW European shelf and NE Atlantic (Bedford et al., 2020; Holland et al., 2023) and overall, the trends seen at L4 in summer resemble the wider trends seen particularly to the west of the UK (Schmidt et al., 2020; Holland et al., 2023). As a cause, one recent hypothesis involves a bottom-up mechanism whereby increased summer nutrient stress favours pico-size cells and cyanobacteria such as S*ynechococcus* which have low polyunsaturated fatty acid (PUFA) content and poor nutritional quality. This was suggested to cause a mismatch with the energy demands of crustacean zooplankton grazers at the warmest time of year when their metabolic rates are highest (Schmidt et al., 2020). However, this does not explain the increasing abundance of carnivores or meroplankton, and to fully understand the causes of these trends, time series such as these need to be networked with those from other sites (O’Brien et al., 2017).

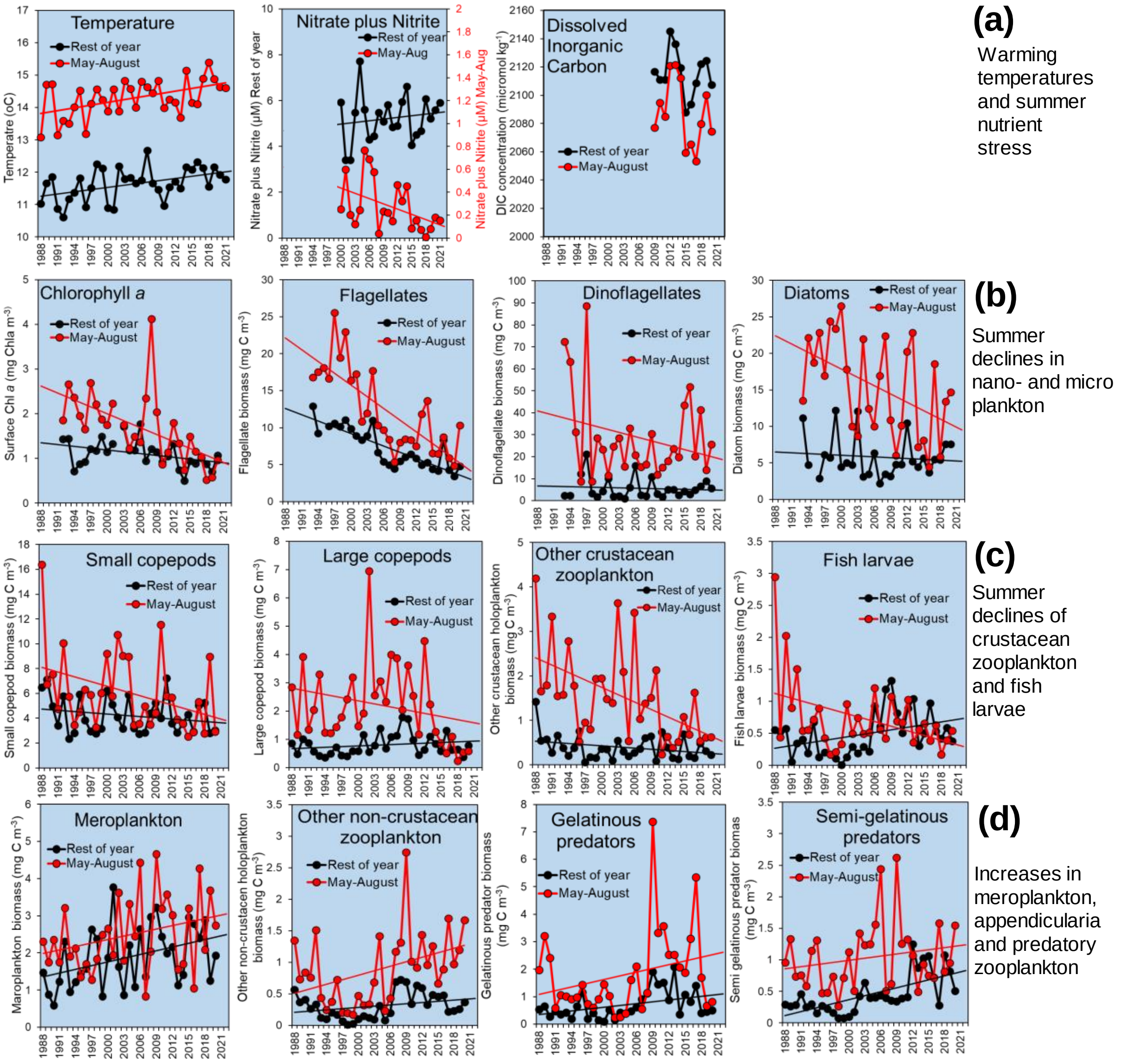


Figure 5: Example plots of L4 time series showing major changes. Each data point represents an annual mean of the monthly values, averaging the main summer stratified period (May-August: red) and the rest of the year (black); (a) Temperature, surface Nitrate plus Nitrite and DIC; (b) Phytoplankton, including surface Chl *a* concentrations and biomass of the dominant phytoplankton functional groups counted in Lugol's-preserved water samples from 10m depth; (c) Mesozooplankton of the "classical food web" that have declined in summer, namely crustaceans (dominated by Copepoda) and fish larvae; (d) biomass of key taxa that have increased, including meroplankton, other holoplankton (dominated by Appendicularia), semi-gelatinous predators (dominated by Chaetognatha) and gelatinous predators (dominated by Cnidaria). Missing months within these time series have been replaced by overall long term mean values for the missing month. Trend lines (drawn for data with >20 year timespans) are illustrative linear regressions and do not necessarily imply statistical significance.

5.5 Overall time trends: E1

The E1 site has the longest history of measurements at the WCO and has exemplified progressive technological advances in measuring macro-nutrients and primary production (Southward et al., 2005). It has also been a testing ground for theories of how climatic variability impacts on nutrients and thereby on phytoplankton, cascading up to fish. The "Russell Cycle" (Cushing, 1977) was a good example of these progressive ideas, where reduced Atlantic inflows of limiting nutrients (Kemp, 1938) were suggested to reduce primary production and shifting from a herring dominated ecosystem in the first few decades of last century to one dominated in the mid-1930s by pilchards. Some of these ideas about the mechanism of the Russell cycle have since been revised (Southward et al., 2005) but nevertheless a degree of cyclicity in temperature and nutrients is clear in Fig. 6a, and this is manifested in major cycles of higher trophic levels (**Fig. 6b, c**).

A major problem when interpreting these long time series is the attribution of cause from correlative-type analyses (Bedford et al., 2020). However, the rapid rise of pilchards after the collapse of the herring fishery may be due to a combination of overfishing and climatic factors (Southward et al., 2005). Similarly, the intensive industrialised pelagic fishing for mackerel and pilchards in the 1970s and its sudden collapse due to overfishing in the 1980s has unknown effects on the trajectories of fish illustrated in Fig. 6c.

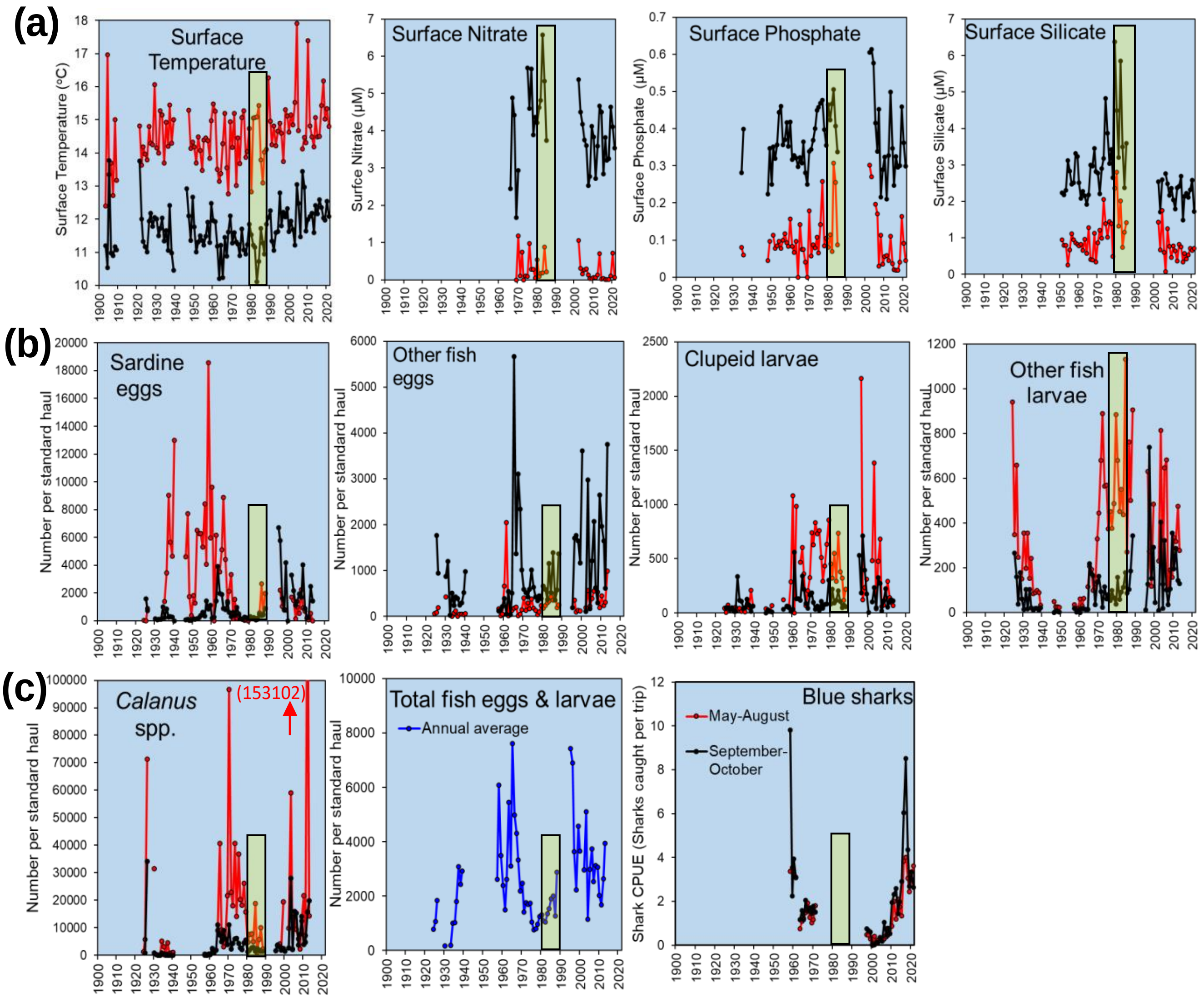


Figure 6: Examples of long time series from stations L5 and E1 from the Western Channel Observatory. Points represent averages of monthly values from the main stratified months (May-August: red) and the rest of the year (black); (a) Temperature and nutrients; (b) Catches per "standard haul" of the Young Fish Trawl, showing four categories of fish eggs and larvae with standard haul volumes, standardised to a filtration volume of 4000 m^3; (c) Respective panels showing: catches of *Calanus* spp. from the Young Fish Trawl; annual mean values for total fish caught in the Young Fish Trawl (all four categories in panel b, but screened such that records with absent data for any of the four categories were removed) and then annual means calculated based on a mean of all available monthly data; Blue shark *Prionace glauca* catch per unit effort (mean catch per trip from angling boats from Looe fishing within 10 nautical miles of E1). Yellow bars mark the 1980s for ease of cross referencing between plots. The 1980s marked major changes, including the onset of rapid warming, the end of a period of intense pelagic trawling off Plymouth and cessation of funding for many monitoring programs including the WCO.

5.6 *Calanus* spp. egg production experiments at L4

Although rate measurements have periodically been made at the WCO, such as primary production (Barnes et al., 2015) and grazing (Bautista and Harris, 1992; Fileman et al., 2010), measurements of *Calanus* spp. egg production rate have been made fairly consistently since 1992 (**Fig. 7**). This makes it one of the longest zooplankton production time series of its kind (Harris, 2010) and offers a valuable insight both into food quantity and quality for grazers and into the population dynamics of *Calanus helgolandicus* (Green et al., 1993; Irigoien et al., 2000). While the original weekly data are archived at BODC, the monthly values averaged here (i.e. a mean of the weekly average rates) provide a good seasonal and long-term comparison with the respective monthly average water temperature and functional groups of phytoplankton.

A series of publications have used these *Calanus* spp. egg production data and have supplied extra supporting information. Examples include the linking of egg and female condition to nutritional quality of food during the 1994 season via the use of fatty acids (Pond et al., 1996); understanding population dynamics based on the timing of egg production and the onset of stratified conditions suggested to retard egg sinking (Irigoien and Harris, 2003) and *Calanus* spp. population dynamics in relation to food and temperature, also including measurements of hatching success (Bonnet et al., 2005; Cornwell et al., 2018; Maud et al., 2015; Maud et al., 2018). Long term changes in the phenology and rates of *Calanus helgolandicus* egg production have not been studied recently but these show some interesting patterns (**Fig. 7**). Until roughly 2006 there was a clear maximum of egg production per female during the spring bloom months, but over the following 15 years this moved later into the summer and autumn months, with a general decline in maximum rates. In the last couple of years, however, there are suggestions that a pattern of high egg output in spring may be re-asserting itself.

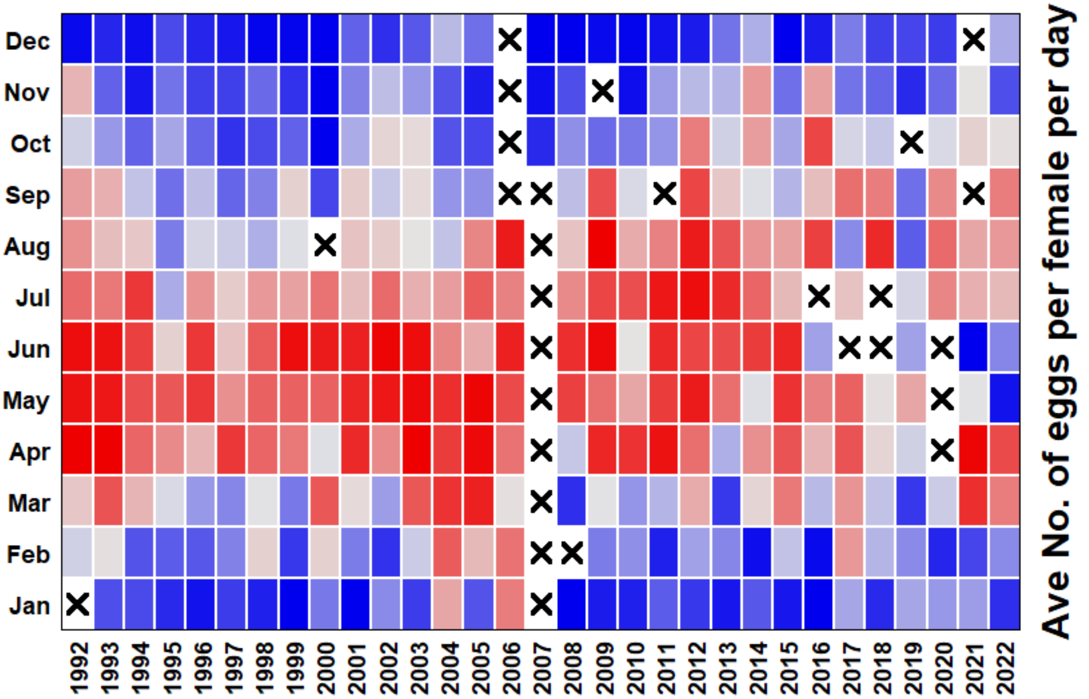


Figure 7: Heatmap of mean egg production rate of *Calanus helgolandicus.* Pending suitable weather conditions for L4 sampling and enough adult females to incubate, experiments are run weekly with 25 female *Calanus helgolandicus* incubated for 1 day in egg production chambers and eggs then counted. Red cells: highest egg production; blue cells: lowest egg production; Cells with crosses: no data available.

5.7 Carbonate chemistry measurements

Over a decade worth of data is now available for the carbonate chemistry at both L4 and E1, which has been used to provide evidence for a number of assessments relating to ocean acidification, including the OSPAR QSR2023 OA Assessment (McGovern et al., 2023) and the recent Marine Climatic Change Impacts Partnership (MCCIP) 2022 Status on Ocean Acidification around the UK and Ireland (Findlay et al., 2022). The data series are one of just two time-series stations that record carbonate chemistry parameters in the UK at this frequency, and are submitted as part of the UK's contribution to the UN Sustainable Development Goal 14.3.1 Indicator for ocean acidification.

Over the full time-series for L4 there has been an overall decline in both total alkalinity (TA) and dissolved inorganic carbon (DIC), which has resulted in an increase in CO_2 fugacity (fCO_2) of 6.4 µatm yr^{-1} and a decrease in pH of -0.0126 ± 0.0022 yr^{-1}. If the 2021 data is excluded, the decrease in pH is slightly slower at -0.006 yr^{-1} (Findlay et al., 2022), demonstrating a significant lowering of pH in 2021, a result of a decrease in alkalinity and a large reduction in salinity (Gonzalez-Pola et al., 2022 monthly analysis from same sampling points as carbonate chemistry gives a decline over the time-series of -0.01 ± 0.005 psu y^{-1}). This rate of pH decline is faster than rates observed in the open ocean, but is similar to rates found in other near-shore locations off the French coast in the Western English Channel and Bay of Biscay (McGovern et al., 2023). Interestingly, aragonite saturation state shows no significant trend at L4, most likely resulting from the concomitant decline in both DIC and TA, but also the high level of variability in TA caused by organic alkalinity inputs from local rivers. At station E1, there has been a greater decline in DIC, similar decline in TA and a slightly slower decline in pH (when including 2021 data: -0.008 ± 0.0022 yr^{-1}).

Since autumn 2017 additional water column measurements have been taken at L4, which provides a profile view of the carbon dynamics. As a case study, we show here the profiles between 2018 and 2020, inclusive (**Fig. 8**). There is a clear relationship between in situ density anomaly (σt) and both DIC (DIC ($\mu mol\ kg^{-1}$) = 38.79.σt + 1086, r = 0.7184, n=144, $p < 0.0001$) and TA (TA ($\mu mol\ kg^{-1}$) = 18.36.σt +1814, r = 0.4118, n = 144, $p < 0.0001$). The in situ density anomaly at L4 is primarily driven by temperature, although salinity is important for the dilution of carbonate parameters at this site. The σt represents the seasonal cycle of winter mixing followed by stratification through the spring and summer and breakdown of stratification again in the autumn. Both DIC and TA are generally at similar concentrations throughout the water column, with DIC being reduced in the upper mixed layer during stratification and corresponding to the sub-surface chlorophyll blooms (**Fig. 8**). TA has much higher variability as a result of organic alkalinity contributions.

Data on suspended matter and particulate carbon compounds have also been collected at the WCO during different times over the years. As shown in (Rühl et al., 2021), the concentration of particulate organic carbon (POC) at a depth of 10 m at L4, measured between 2013 and 2017, is highly seasonally variable, but overall decreasing over the four-year period. It is unclear whether this is part of a more long-term cyclical pattern, or a true temporal trend in the data. Variability in particulate suspended matter concentration in general is less seasonal and does not conform to any clear trend throughout the same time period (Rühl et al., 2021).

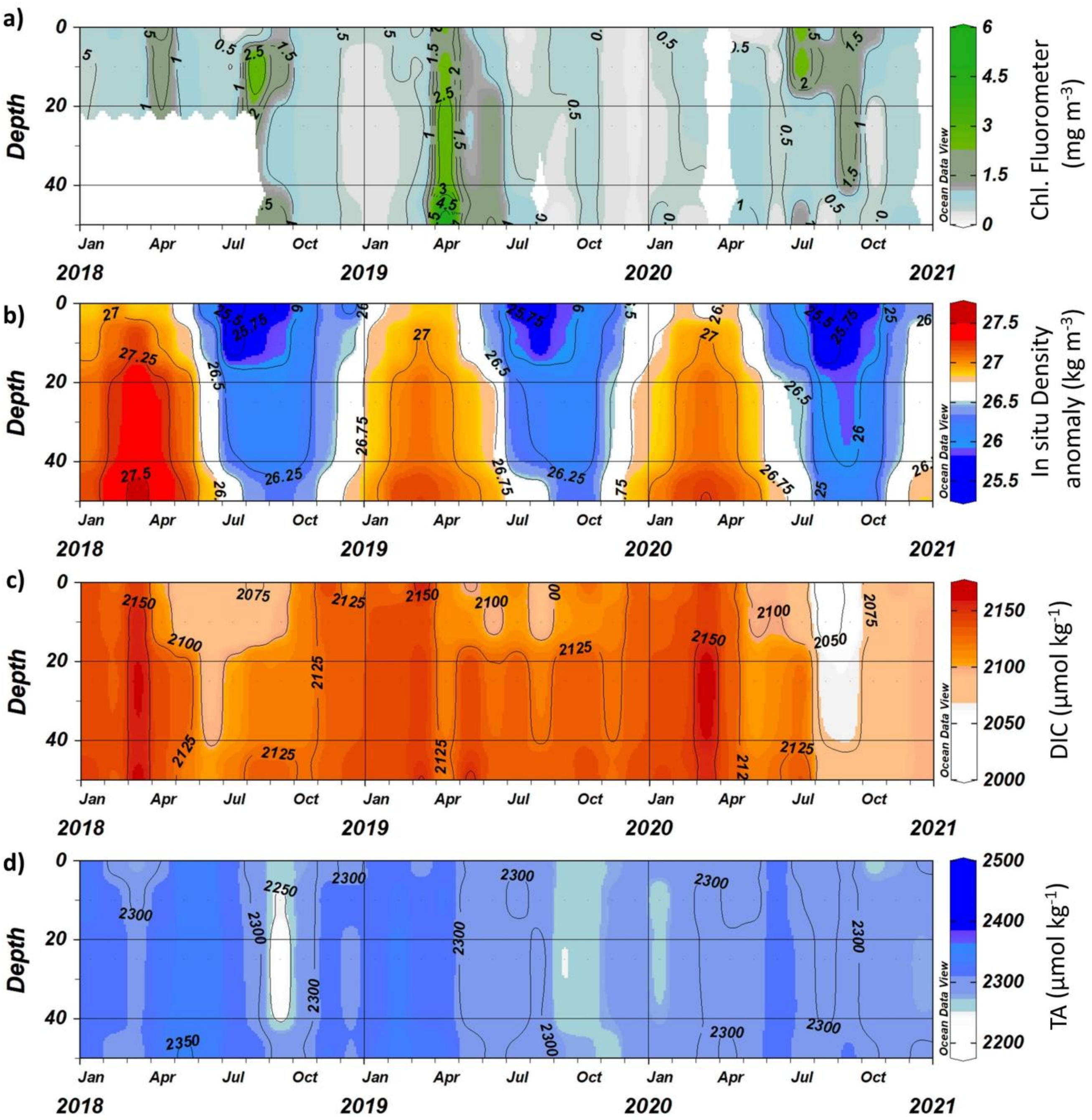


Figure 8: Depth profiles at station L4 through time between 2018 and 2021 of a) Chlorophyll, b) density, c) dissolved inorganic carbon (DIC), and d) total alkalinity (TA).

6 Wider context

6.1 Numerical Modelling

Long-term time series like the ones reported here have been paramount in shaping our understanding of biogeochemical cycling and plankton dynamics (Benway et al., 2019). Not only have they provided the necessary data consistency to generate hypotheses to progress our understanding of marine ecosystems, they have also been critical to the advancement of our capacity to model the complex interactions between environmental and plankton dynamics. The breadth of ecosystem components that are measured routinely at the WCO has enabled a form of digital hypothesis testing using biogeochemical and plankton models (Polimene et al., 2014) comparable to the more traditional approach to hypothesis testing through experimental work under controlled laboratory conditions. The WCO timeseries have contributed to a broad range of developments of European Regional Seas Ecosystem Model (ERSEM) originating from testable hypotheses. These range from photophysiology control of plankton succession (Atkinson et al., 2018), the role of food quality on plankton blooms (Polimene et al., 2015), bacteria carbon pump (Polimene et al., 2017) or the role of mixoplankton in plankton succession dynamics (Leles et al., 2021). Models can also represent a key source of information (a concept generally referred to as data augmentation) for the interpretation of time series. For example, operational models such as the Western Channel Observatory Operational Forecast model (WCOOF) (Torres and Uncles, 2011), can be used to reconstruct back trajectories of plankton samples to explain community variations or assist in the evaluation of carbon sequestration estimates (Queirós et al., 2023). Models like WCOOF can also be used to interpolate environmental conditions to explain observed plankton shifts (e.g. rapid changes to weak stratification not captured by the time-series sampling frequency) or to interpolate sparse measurements (Sims et al., 2022). Ultimately, models can also inform and optimize observational approaches e.g. primary production estimation from Oxygen/Argon ratios and oxygen isotopes.

6.2 The WCO contribution to wider observing networks to report on ocean health

Marine time series such as those provided by the WCO form an important component to a series of wider networks for reporting on pelagic and benthic ecosystem status, and these networks span a range of scales. At the smallest scale of the SW UK, the Western Channel Observatory observations form important contributions to the annual Southwest Marine Ecosystems Annual Reports (Smyth 2022, Atkinson et al., 2022). At the UK scale WCO data inform on regional-scale trends in plankton on the Marine Climate Change Impacts Partnership (Edwards et al., 2020; Findlay et al., 2022) and the plankton data contribute to indicator C5 within the UK’s 25 Year Environment Plan. At a slightly wider scale (NW European shelf and NE Atlantic) the WCO data form part of the policy reporting to meet statutory UK policy obligations under the UK Marine Strategy and OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic), for example in relation to carbonate chemistry (McGovern et al., 2023), or pelagic habitats (Ostle et al., 2021; Holland et al., 2023).

One advantage of the WCO plankton data is that they are both relatively complete in terms of taxonomic resolution and that they span multiple decades, which has enabled their use as a testbed dataset for developing indicators (McQuatters-Gollop et al., 2019), to examine how representative single sampling stations are of wider areas (Ostle et al., 2017) and to develop indicators that include the full suite of plankton, including major groups such as gelatinous species and picoplankton, which are not included as indicators from other longer term monitoring programmes such as the Continuous Plankton Recorder. At wider ocean basin scales the Western Channel Observatory data contribute to a series of reporting networks, for example oceanography through ICES reports on ocean climate (IROC) (Gonzalez-Pola et al., 2022) or plankton through the International Group of Marine Ecological Time series (IGMETS) (O'Brien et al., 2017). Because the WCO spans a small area, building these wider networks of time series is a vital tool to understand the spatial-temporal imprint of climate change amid other, more acute and localised stressors (Ratnarajah et al., 2023).

6.3 The future: melding new technological developments with existing long time series

Most of the longer time series data that we provide here have been collected with traditional techniques that require direct collection of samples, their transport to the laboratory followed by expert chemical or taxonomic analysis. These methods are expensive and time consuming and for this reason, time series worldwide are under threat from funding cuts and loss of expert taxonomists (Vucetich et al., 2020). Concurrent with this, new techniques are being developed for time series, for example, underway autonomous vehicles or remote collection of data with acoustic methods, or moorings data are processed by automated particle imaging using machine learning particle classification. Likewise, there is much interest in the development of molecular (e.g. eDNA) approaches to observing plankton.

Some of these newer, “big data” approaches are now being developed at the WCO. The NERC-funded Automated in-situ plankton imaging and classification system (APICS) project represents the first in-situ co-deployment of an Imaging FlowCytobot (McLane Research Laboratories, Inc.) and a Plankton Imager (Pi-10; Plankton Analytics Ltd.) in the world. APICS will generate abundance and diversity data for organisms spanning 3-4 orders of magnitude in size, i.e. 5 µm – 20 mm, on hourly time-scales, which will allow a ca. 100-fold increase in phyto- and zooplankton sampling frequency at Station L4 in 2024. APICS will allow critical plankton data to be collected at the same temporal resolution as physical and chemical variables. The establishment of an in-situ imaging time-series of plankton and particles at station L4 will also facilitate the collection of highly temporally resolved pelagic suspended particulate matter / particulate organic carbon (POC) concentration data, using image-based POC estimation methods that are currently being refined (Giering et al., 2020; Rühl, unpublished data). Likewise, molecular metabarcoding approaches are being developed and tested alongside traditional techniques (Lindeque et al., 2013; Parry et al., 2021), with eDNA time series being run alongside conventional sampling (Karen Tait, unpublished data).

The WCO's rich background of contextual data, relative ease of accessibility yet at the same time its exposure to large wave amplitudes from the SW weather systems, also make it an ideal testing ground for new technology and this development is currently highly active, with Smart Sound Plymouth (https://www.smartsoundplymouth.co.uk) providing ambitious new directions in this area.

A common conception of funders and policy makers is that new moored and autonomous instrumentation will provide a substitute for traditional monitoring that involves the collection of samples and analysis by skilled humans in a land-based laboratory. This may seem an attractive way of reducing a whole suite of costs including those for staff time, training of taxonomic skills, ship time and fuel, as well as the carbon footprint. These new methods, however, produce fundamentally different types of data to traditional approaches. This presents difficulties when melding the data together. This is a key detail, because the detection of climate change responses usually requires multiple decades of data collected in consistent fashion to have sufficient statistical power to detect change. Instead, the new approaches provide novel insights, often at much higher temporal and spatial resolution than traditional methods, better suited to capturing delicate organisms (Cross et al., 2015), vertical structure (Cornwell et al., 2020) or revealing the "hidden" diversity of assemblages through molecular metabarcoding (Lindeque et al., 2013; Parry et al., 2021). These are complementary, rather than alternatives to ongoing monitoring and provide fresh views on how these ecosystems function. These new technologies provide far more data than can be processed manually and currently traditional methods are essential for ground-truthing the new data. We hope that sustained observations such as the WCO will embrace the strengths of both traditional and new approaches in the following decades.

7. Data availability and how to cite them

The full data and metadata are stored in a reputable UK repository known as DASSH (The Data Archive for Marine Species and Habitats) at the Marine Biological Association, Plymouth, https://www.dassh.ac.uk. The data are available via the link https://doi.org/10.17031/645110fb81749 (McEvoy and Atkinson, 2023). On using this particular version, we kindly request to cite both the actual data citation (McEvoy and Atkinson, 2023) and to cite this paper in Earth System Science Data. This paper gives a full description of the methods and correctly citing it gives due credit to the authors who contributed the datasets. Citing the present paper when the data are used also allows standard literature searches to reveal data usage, and this provides valuable evidence to warrant continued funding of the WCO.

In future, we aim to produce more WCO data papers with updated, doi'd time series, corrections of any errors and extended data fields. Importantly, some of the older (pre-1988) time series datasets and metadata held by the MBA were not available for this data paper. We anticipate that later doi'd versions of the data will be able to include more complete historical data as well as their metadata.

8. Potential uses and limitations of these data

The dataset we provide here has both strengths and limitations. Its main strength is that it combines, for the first time, data that span from oceanography to sharks and from microbial diversity up to benthic macrofauna and fish. We hope that this is particularly valuable for education purposes: for example student projects, where the student will spend less time trying to hunt down scattered datasets and melding them together, and more time analysing them. We have also, where we could, presented the data in units of mass as well as abundance since this is particularly amenable to carbon budgets (Queirós et al., 2019), biogeochemical studies (Barnes et al., 2015) or models (Kenitz et al., 2017; Polimene et al., 2014). This study also represents the first attempt to put benthic and pelagic data sets together, and we hope this helps to make the WCO a natural laboratory to study benthic-pelagic coupling. Another advantage of this summary version of the dataset is that it spans over 100 years, with over three decades of high-quality data from multiple trophic levels. Because the WCO has witnessed substantial warming and broadly responded in a manner similar to the wider NW European shelf (Bedford et al., 2020; Schmidt et al., 2020) our summary dataset provides a test-bed to study the mechanisms that control seasonality and climate change response across multiple trophic levels.

Our data summary also has a series of key limitations, the first one being its taxonomic resolution. To make our database manageable in size, we have condensed large species lists (over 400 planktonic taxa alone) into a just a few dozen functional groups. Users wishing to estimate diversity changes, or responses of individual key species, will need to source the original data sets via the points of contact listed on the WCO data catalogue https://westernchannelobservatory.org.uk/pelagic_TS.php . Likewise, those studying short-term dynamics or “events”, for instance phenology shifts, bloom dynamics or extreme weather may prefer to access the individual timepoints which are typically weekly at L4. Despite this proviso and recommendations that <20 day resolution are needed to reveal phenology shifts (Henson et al., 2018), long-term studies of such phenomena have tended to take the pragmatic approach by averaging irregularly-spaced timepoints into monthly blocks to improve precision, data coverage and to fill data gaps (Atkinson et al., 2021; Barton et al., 2020; Edwards and Richardson, 2004; Fanjul et al., 2018; Uriarte et al., 2021).

A final three requests to users are first: to let us know if you find any errors; second: suggest any improvements for the next version; third, please let us know if you want to incorporate this data set into a wider data networking or databasing initiative. This is to ensure that data do not become separated from metadata and that old, outdated legacy versions of the data do not linger on data portals.

9 Author contribution

AJMc and AA co-ordinated the project. AJMc compiled the monthly database from the component datasets. AA, RA, RB, IB, EF, HF, CM, AJMc, CO, PS, TS, GT, KT, ST and CW submitted the individual datasets. AJMc and AA prepared the manuscript with contributions from HF, GT, CW, SR, RT, AQ, RA, RB, EF, TS, KT, CO. All authors are either current or previous producers of the component data sets.

10 Acknowledgements

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11 Competing interests

The authors have no competing interests

12 Appendices

Table A1: L4 metadata for WCO monthly time-series 1988-2022. Includes sampling and analysis protocols pus data coverage and links for availability of full data sets. Column numbers reference the data sheet available via doi: 10.17031/645110fb81749

Data type **Column headings**	**Sampling and Analysis method**	**Data coverage** **Availability of full data**
L4: Water temperature L4_Temp_0m_degC L4_Temp_10m_degC L4_Temp_25m_degC L4_Temp_50m_degC Columns 3-6	Taken weekly where conditions allow. March 1988 to April 1993 surface temperature (0m) measured using a mercury thermometer in a stainless-steel bucket of freshly collected seawater. May 1993 to Dec 2001 a PML CTD was also used concurrently with the bucket method. Jan 2002 this PML CTD was replaced by a SeaBird SBE19+ CTD. Bucket temperatures were adjusted to CTD equivalents using a regression equation for parallel determinations. For surface values, we obtained a value for each sampling week based on this adjusted bucket temperature if only this was available. If both bucket and CTD data were available, we used the CTD temperature. We then derived arithmetic mean temperatures for each month.	March 1988 to Dec 2021 monthly data derived from 1491 sampling points. May 1993 onwards CTD was used providing 1142, 1140 and 977 weekly timepoints for 10m, 25m and 50m respectively. https://www.westernchannelobservatory.org.uk/data.php
L4: Nutrients L4_Nitrite_0m_µM L4_Nitrite_10m_µM L4_Nitrite_25m_µM L4_Nitrite_50m_µM L4_Nitrite+Nitrate_0m_µM L4_Nitrite+Nitrate_10m_µM L4_Nitrite+Nitrate_25m_µM L4_Nitrite+Nitrate_50m_µM L4_Ammonia_0m_µM L4_Ammonia_10m_µM L4_Ammonia_25m_µM L4_Ammonia_50m_µM L4_Silicate_0m_µM L4_Silicate_10m_µM L4_Silicate_25m_µM L4_Silicate_50m_µM L4_Phosphate_0m_µM L4_Phosphate_10m_µM L4_Phosphate_25m_µM L4_Phosphate_50m_µM Columns 7-26	Taken weekly where conditions allow. Samples returned in the cool and dark to the laboratory in Plymouth as soon as possible. Triplicate samples are analysed using 0.2µm Millipore Fluoropore filtered and non-filtered water. Analyser is a 5-channel Bran+Luebbe segmented flow system. Methodology standardised according to PML protocols. Since 2007 samples analysed as soon as possible after collection. Prior to this samples were frozen and analysed in batches. Due to storage method concentrations of ammonia should be treated with care. More appropriate to consider trends rather than accurate concentrations. Quality control procedures carried out using KANSO certified reference material. Scientists participate in QUASIMEME programme. This summary data set provides a mean value of all available determinations within any given calendar month. In the original data set the symbol "<" refers to concentrations below detection limit. These have been assigned a value of zero before averaging	Surface (0m) Jan 2000 to Dec 2021 Profile (10m 25m 50m) Jan 2012 to Dec 2021 Full data lists individual replicate measurements from the weekly resolution sampling. Publicly-accessible nutrient data accessed on 14 Jul 2022 from https://www.westernchannelobservatory.org.uk/data.php
L4: Carbonate chemistry DIC (dissolved inorganic carbon) and TA (total alkalinity) L4_DIC_0m_µmol kg-1 L4_DIC_10m_µmol kg-1 L4_DIC_25m_µmol kg-1 L4_DIC_50m_µmol kg-1 L4_TA_0m_µmol kg-1 L4_TA_10m_µmol kg-1 L4_TA_25m_µmol kg-1 L4_TA_50m_µmol kg-1 Columns 27-34	Taken weekly where conditions allow. Borosilicate glass bottles with ground glass stoppers were used to collect seawater from the Niskin bottles. Sample bottles were rinsed, filled and poisoned with mercuric chloride according to standard procedures detailed in Dickson et al. (2007). Samples were returned to PML for analysis. DIC was measured using a Dissolved Inorganic Carbon Analyser (Apollo SciTech, Model AS-C3). The analyser adds a strong acid (10% H3PO4 plus 10% NaCl solution) causing carbon species within the seawater to be converted to CO2 gas, which is purged from the sample by pure nitrogen (N2) carrier gas, is dried and cooled to reduce water vapour. The concentration of the dried CO2 gas is measured with a LICOR LI-7000 CO2 analyser. The total amount of CO2 is quantified as the integrated area under the concentration-time curve, and converted to DIC using a standard curve created by analysing known concentrations of the Certified Reference Materials (Dickson CO2 CRMs). A measurement volume of 0.75 mL was used, with up to 5 measurements made from each sample. Values outside a 0.1 % range were excluded from the final result. Duplicate measurements provided an estimate of measurement error < 0.1 %. DIC was corrected for the addition of mercuric chloride. TA was measured using the open-cell potentiometric titration	Surface, 0m and 50m Oct 2008 to Dec 2020 10m and 25m Sep 2017 to Dec 2020 Data are available from British Oceanographic Data Centre (BODC) and are citable via doi:10.5285/1ec0cae5-071d-16e1-e053-6c86abc07d47 https://www.westernchannelobservatory.org.uk/C_chem.php

	method (Dickson et al. 2007) on 12 mL sample volumes using an automated titrator (Apollo SciTech Alkalinity Titrator Model AS-ALK2). Calibration was made using Certified Reference Materials (Dickson CO2 CRMs). Duplicate measurements were made for each sample, and the estimate of measurement error < 0.5 %. TA was corrected for the addition of mercuric chloride.	
L4: Methane (CH4) and Nitrous Oxide (N2O) concentrations L4_Ch4_0m nmol L-1 L4_Ch4_10m nmol L-1 L4_Ch4_25m nmol L-1 L4_Ch4_50m nmol L-1 L4_N2O_0m nmol L-1 L4_N2O_10m nmol L-1 L4_N2O_25m nmol L-1 L4_N2O_50m nmol L-1 Columns 35-42	Borosilicate glass bottles with ground glass stoppers were used to collect seawater from the Niskin bottles for the methane and nitrous oxide, both gasses were determined from the same bottle. Prior to all depths being collected in 2019 samples were collected in triplicate. Sample bottles were rinsed, filled and poisoned with mercuric chloride according to standard procedures detailed in Dickson et al. (2007). Samples were returned to PML for analysis. All samples were analysed within 3 months of collection Samples were placed into a water bath at 25°C and temperature equilibrated for a minimum of one hour before analysis. Samples were analysed by single-phase equilibration gas chromatography using a Flame Ionisation Detector for CH4, and electron capture detector for N2O and similar to that described by (Upstill-Goddard 1996). Samples were calibrated against three certified (±5%) reference standards (Air Products Ltd) which are traceable to NOAA WMO-N2O-X2006A. Concentrations in seawater at equilibration temperature (~25°C) and salinity were calculated from solubility tables of Weiss and Price(1980).	Surface N2O coverage is from 2011 and CH4 from 2013 All 4 depths were sampled from 2019. https://www.westernchannelobservatory.org.uk/data.php
L4: Water 16S alpha diversity L4_water_prokaryote_diversity_S_0m_16s SEQ L4_water_prokaryote_diversity_Pielou_0m_16s SEQ L4_water_prokaryote_diversity_Shannon_0m_16s SEQ Columns 43-45	Taken weekly where conditions allow. On each sampling date, 5L of seawater was collected from the surface and filtered immediately (on board) through a 0.22mm Sterivex cartridge (Millipore). This was then stored at -80°C at PML before further processing. Nucleic acids were extracted using the Qiagen AllPrep DNA/RNA Mini Kit. The sterivex barrel was first filled with RLT lysis buffer and heated to 65°C for 30 mins. DNA and RNA was then extracted from the lysate following the manufacturer's instructions. DNA samples were used for microbiome analyses by sequencing of 16S rRNA genes using the Earthmicrobiome V4 PCR primers 515F (GTGYCAGCMGCCGCGGTAA) and 806R (GGACTACNVGGGTWTCTAAT). Sequencing was performed on the MiSeq Personal Sequencer (Illumina, San Diego, CA, USA) using the V2 500 reagent kit by commercial contract (NU_OMICS, UK). Demultiplexed paired end FASTQ files were analysed using QIIME2 and amplicon sequence variants (ASVs) generated using DADA2. For each sample, the number of ASVs (S), Pielou evenness and Shannon diversity were calculated.	Feb 2012 to Nov 2019. Data are available from PML Karen Tait. https://www.westernchannelobservatory.org.uk/data.php
L4: Fluorometer-derived Chlorophyll *a* concentrations L4_Chl_0m_Fluorom_mgChl m-3 L4_Chl_10m_Fluorom_mgChl m-3 L4_Chl_25m_Fluorom_mgChl m-3 L4_Chl_50m_Fluorom_mgChl m-3 Columns 46-49	Taken weekly where conditions allow Triplicate 100 ml water samples filtered onto 25 mm GFF filters. Extracted overnight at 4 deg C and analysed on a Turner Fluorometer according to Welshmeyer 1994.	Surface (0m) and 10m Feb 1992 to 2020 with 1110 and 568 weekly resolution samples respectively. All depths sampled from 2018 Publicly-accessible nutrient data accessed from https://www.westernchannelobservatory.org.uk/data.php
L4: Pigment sums generated from primary pigment data, determined by HPLC L4_[TChl a]_0m_HPLC_mgm-3 L4_[TChl]_0m_HPLC_mgm-3 L4_[PPC]_0m_HPLC_mgm-3 L4_[PSC]_0m_HPLC_mgm-3 L4_[PSP]_0m_HPLC_mgm-3 L4_[TAcc]_0m_HPLC_mgm-3 L4_[TPig]_0m_HPLC_mgm-3 L4_[TChl a]_10m_HPLC_mgm-3 L4_[TChl]_10m_HPLC_mgm-3 L4_[PPC]_10m_HPLC_mgm-3 L4_[PSC]_10m_HPLC_mgm-3 L4_[PSP]_10m_HPLC_mgm-3 L4_[TAcc]_10m_HPLC_mgm-3 L4_[TPig]_10m_HPLC_mgm-3	Taken weekly where conditions allow Parameter Names (if shortened versions used in column titles): [TChl a] = Total chlorophyll a = [Chlide a] + [DVChl a] + [Chl a]; [TChl] = Total chlorophyll = [TChl a] + [TChl b] + [TChl c]; [PPC] = Photoprotective carotenoids = [Allo]+[Diad]+[Diato]+[Zea]+[Caro]; [PSC] = Photosynthetic carotenoids = [But]+[Fuco]+[Hex fuco]+Perid]; [PSP] = Photosynthetic pigments = [PSC]+[TChl]; [TAcc] = Total accessory pigments = [PPC]+[PSC]+[TChl b]+[TChl c]; [TPig] = Total pigments = [TAcc]+[TChl a]. Total chlorophyll a = chlorophyllide a + divinyl chlorophyll a + chlorophyll a. May be underestimated if chlorophyllide a is not quantified. Total chlorophyll b = chlorophyll b + divinyl chlorophyll b.	Surface coverage is from March 1999 to Dec 2014 10, 25 and 50 m from 2009 onwards (some gaps in data) until 2014 Source data accessed via https://www.westernchannelobservatory.org.uk/data.php

L4_[TChl a]_25m_HPLC_mgm-3 L4_[TChl]_25m_HPLC_mgm-3 L4_[PPC]_25m_HPLC_mgm-3 L4_[PSC]_25m_HPLC_mgm-3 L4_[PSP]_25m_HPLC_mgm-3 L4_[TAcc]_25m_HPLC_mgm-3 L4_[TPig]_25m_HPLC_mgm-3 L4_[TChl a]_50m_HPLC_mgm-3 L4_[TChl]_50m_HPLC_mgm-3 L4_[PPC]_50m_HPLC_mgm-3 L4_[PSC]_50m_HPLC_mgm-3 L4_[PSP]_50m_HPLC_mgm-3 L4_[TAcc]_50m_HPLC_mgm-3 L4_[TPig]_50m_HPLC_mgm-3 Columns 50-77	Divinyl chlorophyll b coelutes with chlorophyll b under HPLC conditions used to generate these data, so were not quantified separately. Divinyl chlorophyll b is not expected to be present in UK waters. Total chlorophyll c = chlorophyll c1 + chlorophyll c2 + chlorophyll c3 Carotenes = βε-Carotene + ββ-Carotene Alloxanthin: quantified by both HPLC methods used to generate L4 pigment data 19'-butanoyloxyfucoxanthin: quantified by both HPLC methods used to generate L4 pigment data Diadinoxanthin: quantified by both HPLC methods used to generate L4 pigment data Diatoxanthin: quantified by both HPLC methods used to generate L4 pigment data Fucoxanthin: quantified by both HPLC methods used to generate L4 pigment data 19'-hexanoloxyfucoxanthin: quantified by both HPLC methods used to generate L4 pigment data. May include prasinoxanthin (when present) for data generated using Barlow HPLC method (1999-2011) Peridinin: quantified by both HPLC methods used to generate L4 pigment data Zeaxanthin: quantified by both HPLC methods used to generate L4 pigment data Chlorophyll a: includes allomers and epimers: quantified by both HPLC methods used to generate L4 pigment data Divinyl chlorophyll a: quantified by both HPLC methods used to generate L4 pigment data Chlorophyllide a: quantified in 2002; 2004-5 and May 2011 onwards Chlorophyll b and divinyl chlorophyll b: Divinyl chlorophyll b coelutes with chlorophyll b under HPLC conditions used to generate these data, so were not quantified separately. Dinvinyl chlorophyll b is not expected to be present in UK waters. Chlorophyll c1: Quantified separately from chlorophyll c2 from May 2011 onwards. Chlorophyll c2: Includes chlorophyll c1 for data from 1999-April 2011 Chlorophyll c3: quantified by both HPLC methods used to generate L4 pigment data βε-carotene (alpha-carotene): quantified separately from ββ-carotene from May 2011 onwards. ββ-carotene (beta-carotene): includes βε-carotene for data from 1999-April 2011. Barlow HPLC Method reference: Barlow RG et al. (1997) Column: MOS-2 Hypersil; 100x4.6mm; 3um particle size Flow rate: 1mL/min Mobile phase: Barlow et al. 1997 Extraction solvent and volume: 90% acetone; 2mL Internal standard used?: Yes, Trans-B-Apo-8'-carotenal used until 2008. Disruption method and time: Sonication (probe), 35s Soak time: 1 hr Clarification procedure: Centrifugation Injection procedure and volume: Autosampler mixes sample with ammonium acetate (1 M) in 50/50 ratio by volume. Injects 50 uL Calibration Procedure: Single point Source of standards: DHI, Denmark Absorption coefficients used: Those provided with standards by DHI Expected capability of method: Not recorded Quality assurance protocols: Up to 20 samples were analysed per day, so maximum time of samples in autosampler is 24 h. Autosampler is maintained at 4oC. Zapata HPLC Method reference: Zapata M et al. (2000) Column: Waters C8 Symmetry; 150x2.1 mm; 3.5um particle size Flow rate: 200uL/min Mobile phase: As described by Zapata et al. 2000 Extraction solvent and volume: 90% acetone; 2mL Internal standard used?No Disruption method and time: Sonication (probe), 35s Soak time: 1 hr Clarification procedure: Centrifugation and filtration (0.45 um Teflon syringe filter) Injection procedure and volume: Autosampler mixes 200 uL sample and 80 uL water in a vial. 25 uL of this mixture is injected (actual injection volume of sample = 17.86	

	uL Calibration Procedure:Multipoint; three solutions bracketing the LOQ, and three bracketing the expected sample concentration Source of standards: DHI, Denmark Absorption coefficients used: Those provided with standards by DHI Expected capability of method: Average precision and accuracy for chl a (standards) was 1.44 and 2.01%, respectively Quality assurance protocols: First run of the day was discarded. A sample of mixed pigments was run prior to any samples to check retention times and resolution of critical pairs. Three samples of chlorophyll standard were analysed with each sample set to check response factor is within 5% of calibration value. Up to 20 samples are analysed per day, so maximum time of samples in autosampler is 24 h. Autosampler was maintained at 4oC. Pipette accuracy determined daily by weighing.	
L4: <20 µm plankton abundance profiles measured by flow cytometry L4_Syn_0m_FCM_cells mL-1 L4_Picoeuk_0m_FCM_cells mL-1 L4_Nanoeuk_0m_FCM_cells mL-1 L4_Cocco_0m_FCM_cells mL-1 L4_Crypto_0m_FCM_cells mL-1 L4_HNan_0m_FCM_cells mL-1 L4_HNAbacteria_0m_FCM_cells mL-1 L4_LNAbacteria_0m_FCM_cells mL-1 L4_Syn_10m_FCM_cells mL-1 L4_Picoeuk_10m_FCM_cells mL-1 L4_Nanoeuk_10m_FCM_cells mL-1 L4_Cocco_10m_FCM_cells mL-1 L4_Crypto_10m_FCM_cells mL-1 L4_HNan_10m_FCM_cells mL-1 L4_HNAbacteria_10m_FCM_cells mL-1 L4_LNAbacteria_10m_FCM_cells mL-1 L4_Syn_25m_FCM_cells mL-1 L4_Picoeuk_25m_FCM_cells mL-1 L4_Nanoeuk_25m_FCM_cells mL-1 L4_Cocco_25m_FCM_cells mL-1 L4_Crypto_25m_FCM_cells mL-1 L4_HNan_25m_FCM_cells mL-1 L4_HNAbacteria_25m_FCM_cells mL-1 L4_LNAbacteria_25m_FCM_cells mL-1 L4_Syn_50m_FCM_cells mL-1 L4_Picoeuk_50m_FCM_cells mL-1 L4_Nanoeuk_50m_FCM_cells mL-1 L4_Cocco_50m_FCM_cells mL-1 L4_Crypto_50m_FCM_cells mL-1 L4_HNan_50m_FCM_cells mL-1 L4_HNAbacteria_50m_FCM_cells mL-1 L4_LNAbacteria_50m_FCM_cells mL-1 Columns 78-109	Taken weekly where conditions allow Analysed in triplicate (phytoplankton and bacteria) or duplicate (heterotrophic nanoflagellates). Vertical profiles of the mean abundance of groups of microbial plankton as cells per millilitre, measured using flow cytometry (BD Accuri C6 flow cytometer) The groups quantified are divided into phytoplankton and heterotrophs. Phytoplankton groups quantified are: Syn Synechococcus sp. (cyanobacteria) Picoeuk Picoeukaryotes (smaller than 3 µm) Crypto Cryptophytes Cocco Coccolithophores Nanoeuk Nanoeukaryotes not already mentioned (2-20 µm). Heterotrophs quantified are: HNan heterotrophic nanoflagellates HNAbacteria heterotrophic bacteria with relatively high nucleic acid content LNAbacteria heterotrophic bacteria with relatively low nucleic acid content.	April 2007 to Dec 2021 Source data accessed via https://www.westernchannelobservatory.org.uk/data.php
L4: Microscopy analysis of lugols and formalin preserved phytoplankton L4_Diatoms_10m_microscopy_cells ml-1 L4_Dinoflagellates_10m_microscopy_cells ml-1 L4_Coccolithophores_10m_microscopy_cells ml-1 L4_Flagellates_10m_microscopy_cells ml-1 L4_Phaeocystis_10m_microscopy_cells ml-1 L4_Ciliates_10m_microscopy_cells ml-1 L4_Diatoms_10m_microscopy_mgC m-3 L4_Dinoflagellates_10m_microscopy_mgC m-3 L4_Coccolithophorid_10m_microscopy_mgC m-3 L4_Flagellates_10m_microscopy_mgC m-3 L4_Phaeocystis_10m_microscopy_mgC m-3 L4_Ciliates_10m_microscopy_mgC m-3 Columns 110-121	Taken weekly where conditions allow Paired 200mL water samples collected from 10m depth using Niskin bottle attached to the CTD are immediately fixed in 1) acid Lugol's iodine (for all taxa except coccolithophores) and 2) neutral formaldehyde for coccolithophores. Sub samples are analysed by light microscopy using the settlement technique (Utermohl, 1958) and identified to species level where possible. Organised into six functional groups. Mean cell dimensions of each taxa are used to calculate species-specific biovolumes which are converted to carbon biomass using the equations of (Menden-Deuer and Lessard, 2000) Abundance data are presented as cells per mL and biomass as mgC per m3.	Single depth (10m) October 1992 – December 2020, except for gaps in sampling between October 1994 – May 1995 and December 2011 Data are available from British Oceanographic Data Centre (BODC) and are citable via doi:10.5285/c9386b5c-b459-782f-e053-6c86abc0d129 https://www.westernchannelobservatory.org.uk/data.php

	Note: In 2005 sample collection was via a deck hose. This caused damage to the fragile ciliates hence the count is much lower for that year.	
L4: FlowCam analysis of 63µm mesh plankton net hauls (50-0m) L4_Total Diatoms_FlowCam_mgCm-3 L4_Total Dinoflagellates_FlowCam_mgCm-3 L4_Ciliates_FlowCam_mgCm-3 L4_Colony flagellates_FlowCam_mgCm-3 L4_Large Protists_FlowCam_mgCm-3 L4_Total Copepod nauplii_FlowCam_mgCm-3 Columns 122-127	Taken weekly where conditions allow Water samples collected from a 0-50m vertical haul using a 63µm mesh WP2 style net (UNESCO, 1968, p. 153–157). Mesh change in July 2019 from 63µm to 50µm. Prior to analysis samples are pre-screened using a 300µm mesh. However, net samples collected between June 2015 and May 2016 were pre-screened using a 200µm mesh. Sample analysed live whenever possible using a FlowCam VS IV model fitted with a 300µm flowcell. Analysis carried out using x4 magnification using auto-image mode. Classification of acquired images carried out using Visualspreadsheet (2012-2016) and Ecotaxa (2017-2019). Taxa were then assigned to six broad functional groups. Mean cell dimensions of each taxa were used to calculate species-specific biovolumes which were converted to carbon biomass using suitable C conversion equations. Biomass is presented as mgC per m3. For Diatoms, Dinoflagellates (excluding Noctiluca, and Neoceratium spp) and Ciliates, morphological information and shape assignment was used to calculate biovolume (Alvarez et al 2012 Table 1.). For Noctiluca and Neoceratium spp., mean cell volumes were taken from Widdicombe et al (2010). For all other Dinoflagellates, Diatoms and Ciliates, cell biovolumes were converted to carbon biomass using the equations of Menden-Deuer and Lessard (2000). For large protists mostly Radiolaria, the C conversion in Michaels et al (1995) was used. Colonial flagellates were converted to C according to Børsheim and Bratbak, (1987). Biomass of Copepod nauplii was calculated using the equations of Uye et al (1996).	Sept 2012 to Dec 2013 are from 43 time points June 2015 to Dec 2019 are from 163 time points Abundance data are also available for meroplankton taxa, these have not been converted to biomass to date. Source data accessed via https://www.westernchannelobservatory.org.uk/data.php
L4: *Noctiluca scintillans* microscopy analysis of WP2 net hauls (50-0m) L4_*Noctiluca scintillans*_WP2net_no.m-3 L4_*Noctiluca scintillans*_WP2net_mcgC.m-3 Columns 128-129	Taken weekly where conditions allow. Two vertical hauls (50-0m) are taken using 200 micron WP2 nets (UNESCO, 1968, p. 153–157) Both replicates samples are analysed by subsampling, enumerated and identified, currently using an Olympus SZX16 stereo microscope fitted with a SZX2-ILLT LED transmitted light illuminator stand. Source data represents weekly average abundance across the two replicates and converted to numbers in a m3. Monthly abundance represent an arithmetic mean value from between 1 and 5 visits in any given month and on a weekly basis. Biomass calculations derived from abundance data using a conversion factor of 0.020375mcgC per cell using the equations of (Menden-Deuer and Lessard, 2000). Be aware that zeros are present from 2009 onwards where there is confidence in the data. A zero represents looked for but not present in the sample analysed. Data prior to this is less certain so zeros have been omitted.	July 1997-2021. McEvoy A.; Atkinson A.; Beesley A.(2022). Zooplankton abundance time series from net hauls at site L4 off Plymouth, UK between 1988-2021. Data are available from British Oceanographic Data Centre (BODC) and are citable via doi:10.5285/e785f2f7-05d5-2f47-e053-6c86abc08bee https://www.westernchannelobservatory.org.uk/data.php

L4: Zooplankton microscopy analysis of WP2 net hauls (50-0m) L4_meroplankton_WP2net_no.m-3 L4_small_copepods_WP2net_no.m-3 L4_large_copepods_WP2net_no.m-3 L4_fish_larvae_WP2net_no.m-3 L4_gelatinous_predators_WP2net_no.m-3 L4_semi-gelatinous_predators_WP2net_no.m-3 L4_other_crustacean_holoplankton_WP2net_no.m-3 L4_other_non-crustacean_holoplankton_WP2net_no.m-3 L4_meroplankton_WP2net_mgCm-3 L4_small_copepods_WP2net_mgCm-3 L4_large_copepods_WP2net_mgCm-3 L4_fish_larvae_WP2net_mgCm-3 L4_gelatinous_predators_WP2net_mgCm-3 L4_semi-gelatinous_predators_WP2net_mgCm-3 L4_other_crustacean_holoplankton_WP2net_mgCm-3 L4_other_non_crustacean_holoplankton_WP2net_mgCm-3 Columns 130-145	Taken weekly where conditions allow. Two vertical hauls (50-0m) are taken using 200-micron WP2 nets (UNESCO, 1968) Both replicates' samples are analysed by subsampling, enumerated and identified currently using an Olympus SZX16 stereo microscope fitted with a SZX2-ILLT LED transmitted light illuminator stand. More details are provided in Atkinson et al (2015). Source data comprises average abundance of the taxa that have been consistently identified since 1988. These source data are weekly averages across the two replicates, converted to numbers per m3 and biomass estimated. Data presented here have been aggregated into functional groups broadly based on the lifeforms for policy reporting in Ostle et al (2021). There has, however, been a few further subdivisions to better reflect trophic mode. These functional group allocations are coded, and numbers-to-biomass conversion factors are provided within the “trait” header bar data from the source dataset. Therefore there are 8 functional groups based partly on size, taxonomy and trophic mode, and with separate columns for abundance and estimated biomass. Because biomass is a derived property, often with different conversion factors between the four seasons (see data source doi), it is best to use numerical abundance data for population dynamics studies and biomass data for models, carbon budgets etc. As previously stated the groups comprise the whole of the consistently identified zooplankton so adding them will give a good estimate of total metazoan zooplankton with the exception of Ctenophores (see below). MEROPLANKTON: All 14 taxa with code no. 38. They are numerically dominated by Cirripedia larvae. The biomass is strongly dominated by the larvae of Cirripedia, Decapoda and Polychaeta plus Gammaridea amphipods. Fish and Cnidarians are excluded, some of whom are meroplanktonic, but which are all pooled within the fish larvae and gelatinous predator lifeforms instead. SMALL COPEPODS: Excluding nauplii, code no. 36 with the addition of the uncoded harpacticoid copepods. They are species with total adult body length under 2mm. They comprise 20 taxa dominated numerically by the genera *Oithona, Oncaea, Paracalanus* and *Pseudocalanus* and in biomass by *Pseudocalanus, Temora* and *Paracalanus.* LARGE COPEPODS: They comprise 8 taxa with code no. 36 and are species with total body length 2mm or over. Their numbers and biomass are strongly dominated by *Calanus helgolandicus*. FISH LARVAE: Note the lifeforms group for plankton reporting in Ostle et al. (2021) includes eggs and larvae pooled, but here the fish eggs have been omitted to better describe the abundance of actively carnivorous groups. GELATINOUS PREDATORS: Cnidarians only, dominated in terms of numbers and biomass by Siphonophores. A notable taxon not included is Ctenophores, due to potential inconsistency in counting in early years and due to preservation issues, which we are in the process of resolving. SEMI-GELATINOUS PREDATORS: Chaetognaths and *Tomopteris* spp., with numbers and biomass strongly dominated by the former. OTHER CRUSTACEAN HOLOPLANKTON: These are the remaining groups of crustacean holoplankton not covered above, namely *Evadne* spp. *Podon* spp., Hyperiidae amphipods, mysids, and the various nauplii to adult stages of Euphausiids. They are strongly dominated numerically and in terms of biomass by the Cladocerans (miscoded as non-crustaceans in the source file). OTHER NON-CRUSTACEAN HOLOPLANKTON: These are the remaining groups of crustacean holoplankton not covered above, namely Appendicularians, *Limacina* spp., Doliolids and *Clione* spp. They are strongly dominated numerically and in terms of biomass by Appendicularians.	March 1988 to Dec 2020. Derived from 1452 sampling timepoints with a weekly resolution. Monthly mean data are available for each intervening month except August 2000 and typically represent an arithmetic mean value across between 1 and 5 weekly visits in any given month. McEvoy, A., Beesley, A., and Atkinson, A. (2022). Subset of zooplankton abundance and biomass time series from net hauls at site L4 off Plymouth, UK between 1988-2020. (Version 1) Data are available from British Oceanographic Data Centre (BODC) and are citable via doi:10.5285/d7fb6ce3-7bc9-307b-e053-6c86abc0671b https://www.westernchannelobservatory.org.uk/l4_zooplankton.php
L4: Calanus helgolandicus weekly egg production using females from the Western English Channel site L4 L4_Calanus eggs_watercolumn_expt_eggs per female per day Column 146	Taken weekly where conditions allow A live sample is collected and returned in the cool and dark to the laboratory in Plymouth as soon as possible. Sample is gently poured through a 200-micron mesh sieve *Calanus sp* females in healthy condition are picked out gently using stork-billed forceps under a microscope as quickly as possible. Five replicates each containing 5 female *Calanus* sp are	Feb 1992 to Nov 2021 where availability of *Calanus* females allow. Data represents Mean No eggs per female per day. McEvoy A.; Beesley A.; Atkinson A.(2022). Calanus helgolandicus weekly egg production time series between 1992-2021, using females from the Western English Channel

	incubated in the dark in filtered seawater for 24 hours. Each beaker contains an egg collector. Temperature follows ambient conditions at L4 surface. The eggs produced are collected and counted. Females are identified for species. Eggs retained for hatching success.	site L4. Data are available from British Oceanographic Data Centre (BODC) and are citable via doi:10.5285/e28496a4-0c72-0e7a-e053-6c86abc0d7c7 https://www.westernchannelobservatory.org.uk/calanus_egg_production.php
L4: Sediment 16S alpha diversity L4_sediment_prokayote_diversity_S_0m_16S SEQ L4_sediment_prokayote_diversity_Pielou_0m_16s SEQ L4_sediment_prokayote_diversity_Shannon_0m_16s SEQ Columns 147-149	Sediments are collected using a box corer and the uppermost 0 - 1cm carefully sampled by scraping into a sterile 2mL tube. Eight replicate samples are taken for each sampling time, and four of these are used for DNA extraction using 0.5g sediment and Qiagen's DNeasy PowerSoil Kit according to the manufacturer's instructions. 16S rRNA genes were sequenced using the Earthmicrobiome V4 PCR primers 515F (GTGYCAGCMGCCGCGGTAA) and 806R (GGACTACNVGGGTWTCTAAT). Sequencing was performed on the MiSeq Personal Sequencer (Illumina, San Diego, CA, USA) using the V2 500 reagent kit by commercial contract (NU_OMICS, UK). Demultiplexed paired end FASTQ files were analysed using QIIME2 and amplicon sequence variants (ASVs) generated using DADA2. For each sampling occasion, the mean number of ASVs for the four replicates is calculated (S), along with Pielou evenness and Shannon diversity.	Feb 2012 to 2019. In 2012 and from 2014 to 2019, the aim was to sample monthly when possible. In 2013 samples were collected in February and September only. Data are available from PML Karen Tait. https://www.westernchannelobservatory.org.uk/data.php
L4: Benthic fauna from box cores L4_Macrofaunal Deposit Feeders_50m_0.1m3 Box Core_Average abundance of individual taxa per month L4_Macrofaunal Suspension Feeders_50m_0.1m3 Box Core_Average abundance of individual taxa per month L4_Macrofaunal Predators_50m_0.1m3 Box Core_Average abundance of individual taxa per month L4_Macrofaunal Scavengers_50m_0.1m3 Box Core_Average abundance of individual taxa per month L4_Macrofaunal Deposit Feeders_50m_0.1m3 Box Core_Average biomass of individual taxa per month L4_Macrofaunal Suspension Feeders_50m_0.1m3 Box Core_Average biomass of individual taxa per month L4_Macrofaunal Predators_50m_0.1m3 Box Core_Average biomass of individual taxa per month L4_Macrofaunal Scavengers_50m_0.1m3 Box Core_Average biomass of individual taxa per month Columns 150-157	Taken monthly where conditions allow. 4 or 5 replicate 0.1m3 box cores of sediment collected from 50m depth. All sediment collected is sieved over a 0.5mm mesh and retained fauna preserved in 10% formaldehyde solution. Source taxa are identified and counted using stereo and compound microscopy to species level or lowest possible taxonomic resolution. Abundance and blotted wet weight (0.00000g) per taxa is recorded per 0.1m3 box core sample. From 4 principle feeding traits, based on information primarily gathered from the BIOTIC database, 1 unique principle trait was assigned per taxa; calculated using algorithms based upon body composition, maximum length and body mass. (MarLIN 2006)	July 2008 to July 2019. Abundance and biomass data from 65 time points is presented as monthly averages per corresponding feeding trait; suspension feeders, deposit feeders, scavengers, carnivores. Mesher T., McNeill C.L. (2022). Benthic Survey Macrofauna Abundance and Biomass Data, as part of the Western Channel Observatory, UK, between 2008 and 2019. Data are available from British Oceanographic Data Centre (BODC) and are citable via doi:10.5285/d9f44202-b0d4-646c-e053-6c86abc018c6 https://www.westernchannelobservatory.org.uk/data.php
L4: Cephalopoda and Demersal fish families by trawling L4_Cephalopoda abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Bothidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Soleidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Callionymidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Caproidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Cepolidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Triglidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Clupeidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Engraulidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Pleuronectidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Gadidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Merlucciidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Mullidae abundance_50-60m_Standard	Standard hauls were collected using a large otter trawl (2008-June 2014), a Channel Hunter box trawl (July 2014-March 2015) deployed from Plymouth Quest, then a modified Channel Hunter box trawl (April 2015-September 2018) deployed from MBA Sepia. Trawl duration was approximately 40 minutes. Only trawls from 50-60m are included. Individuals were identified to species, measured (mm) and weighed (g) on-board. Where a species was abundant a subsample was weighed and total biomass extrapolated. Abundances and biomass are reported at the family level, and only families comprising at least 1% contribution in at least one month are included.	April 2008 to Sept 2018. Between 1 and 7 trawls were collected per month sampled (total 282, average 2.88) Source data for 2015-2018 available from Data Archive for Seabed Species (DASSH) via doi:10.17031/1802

Haul_individuals.trawl-1 L4_Carangidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Zeidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Gobiidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Scombridae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Scyliorhinidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Scophthalmidae abundance_50-60m_Standard Haul_individuals.trawl-1 L4_Cephalopoda biomass_50-60m_Standard Haul_g.trawl-1 L4_Bothidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Soleidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Callionymidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Cepolidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Triglidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Clupeidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Engraulidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Pleuronectidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Gadidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Merlucciidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Mullidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Carangidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Zeidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Scombridae biomass_50-60m_Standard Haul_g.trawl-1 L4_Scyliorhinidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Lophiidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Triakidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Scophthalmidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Rajidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Lotidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Moronidae biomass_50-60m_Standard Haul_g.trawl-1 L4_Congridae biomass_50-60m_Standard Haul_g.trawl-1 L4_Squalidae biomass_50-60m_Standard Haul_g.trawl-1 Columns 158-200		

Table A2: E1 metadata for WCO monthly time-series 1903-2021. Includes sampling and analysis protocols pus data coverage and links for availability of full data sets. Column numbers reference the data sheet available via doi :10.17031/645110fb81749

Data type Column headings	Sampling and Analysis method	Data coverage Availability of full data
E1: Water temperature E1_Temp_0m_DegC E1_Temp_10m_DegC E1_Temp_20m_DegC E1_Temp_30m_DegC E1_Temp_40m_DegC E1_Temp_50m_DegC E1_Temp_60m_DegC E1_Temp_70m_DegC Columns 3-10	For the early period of the E1 time-series reversing thermometers were used. Values are derived from Niskin bottles and CTD except for the period December 1985 to April 2002 when no in situ sampling was undertaken and satellite sea surface temperature data pertaining to the middle of each month were used instead . Where multiple sampling timepoints existed for a calendar month we used the arithmetic mean value. Post 2002 a SeaBird SBE19+ was used.	1903 data begins 1910 to 1920 no data 1939 to 1945 no data Surface data are most extensive. For each depth, number of sampling timepoints were 1146, 954, 892, 609, 740, 908, 262, and 815 respectively. Source dataset was produced for the ICES Report on Ocean by Tim Smyth https://ocean.ices.dk/core/iroc https://www.westernchannelobservatory.org.uk/data.php
E1: Nutrients E1_Nitrite_0m_µm E1_Nitrite_10m_µm E1_Nitrite_20m_µm E1_Nitrite_30m_µm E1_Nitrite_40m_µm E1_Nitrite_60m_µm E1_Nitrite+Nitrate_0m_µm E1_Nitrite+Nitrate_10m_µm E1_Nitrite+Nitrate_20m_µm E1_Nitrite+Nitrate_30m_µm E1_Nitrite+Nitrate_40m_µm E1_Nitrite+Nitrate_60m_µm E1_Ammonia_0m_µm E1_Ammonia_10m_µm E1_Ammonia_20m_µm E1 Ammonia_30m_µm E1_Ammonia_40m_µm E1_Ammonia_60m_µm E1_Silicate_0m_µm E1_Silicate_10m_µm E1_Silicate_20m_µm E1_Silicate_30m_µm E1_Silicate_40m_µm E1_Silicate_60m_µm E1_Phosphate_0m_µm E1_Phosphate_10m_µm E1_Phosphate_20m_µm E1_Phosphate_30m_µm E1_Phosphate_40m_µm E1_Phosphate_60m_µm Columns 11-40	Taken fortnightly where conditions allow. Data from 2002: Samples returned in the cool and dark to the laboratory in Plymouth. Samples are stored for 2-3 hours before returning for analysis and sometimes frozen. Triplicate samples are analysed using 0.2µm Millipore Fluoropore filtered and non-filtered water. Analyser is a 5-channel Bran+Luebbe segmented flow system. Methodology standardised according to PML protocols. Due to storage method concentrations of Ammonia should be treated with care. More appropriate to consider trends rather than accurate concentrations. Quality control procedures carried out using KANSO certified reference material. Scientists participate in QUASIMEME programme Data from last century: Data obtained from the link on the data page of the Western Channel Observatory website and extracted from the NOWESP (North West European Shelf Program) database for the period 1934-1987. Source data includes profile data from 0-80m. This monthly data uses depths 0, 10 and 20m because these are compatible with post 2002 records. Nitrite+Nitrate column header describes post 2002 records. It is unclear if the last century values refer strictly to Nitrate only or Nitrite+Nitrate. This summary data set provides a mean value of all available determinations within any given calendar month. In the original data set the symbol "<" refers to concentrations below detection limit. These have been assigned a value of zero before averaging.	Jan 1934 a few records for Phosphate April 1948 records begin again for Phosphate Jan 1951 records begin for Silicate Jan 1966 records begin again for Nitrite+Nitrate Jan 1986 to Dec 2001 no data Jan 2002 to Oct 2021 all covered Full data lists individual replicate measurements from the weekly resolution sampling Publicly-accessible nutrient data accessed on 14 Jul 2022 from https://www.westernchannelobservatory.org.uk/data.php
E1: Carbonate chemistry DIC (dissolved inorganic carbon) and TA (total alkalinity) E1_DIC_0m_micromol kg-1 E1_DIC_60m_micromol kg-1 E1_TA_0m_micromol kg-1 E1_TA_60m_micromol kg-1 Columns 41-44	Taken fortnightly where conditions allow. Borosilicate glass bottles with ground glass stoppers were used to collect seawater from the Niskin bottles. Sample bottles were rinsed, filled and poisoned with mercuric chloride according to standard procedures detailed in Dickson et al. (2007). Samples were returned to PML for analysis. DIC was measured using a Dissolved Inorganic Carbon Analyser (Apollo SciTech, Model AS-C3). The analyser adds a strong acid (10% H3PO4 plus 10% NaCl solution) causing carbon species within the seawater to be converted to CO2 gas, which is purged from the sample by pure nitrogen (N2) carrier gas, is dried and cooled to reduce water vapour. The concentration of the dried CO2 gas is measured with a LICOR LI-7000 CO2 analyser. The total amount of CO2 is quantified as the integrated area under the concentration-time curve and converted to DIC using a standard curve created by analysing known concentrations of the Certified Reference Materials (Dickson CO2 CRMs). A measurement volume of 0.75 mL was used, with up to 5 measurements made from each sample. Values outside a 0.1 % range were excluded from the final result.	Surface 0m and 60 m depth coverage from October 2008 to December 2020. Data are available from British Oceanographic Data Centre (BODC) and are citable via doi:10.5285/50bb1181-960e-58b4-e053-6c86abc0e44f https://www.westernchannelobservatory.org.uk/C_chem.php

	Duplicate measurements provided an estimate of measurement error < 0.1 %. DIC was corrected for the addition of mercuric chloride. TA was measured using the open-cell potentiometric titration method (Dickson et al. 2007) on 12 mL sample volumes using an automated titrator (Apollo SciTech Alkalinity Titrator Model AS-ALK2). Calibration was made using Certified Reference Materials (Dickson CO2 CRMs). Duplicate measurements were made for each sample, and the estimate of measurement error < 0.5 %. TA was corrected for the addition of mercuric chloride.	
E1: <20 µm plankton abundance profiles measured by flow cytometry E1_Syn_0m_FCM_ cells mL-1 E1_Picoeuk_0m_FCM_cells mL-1 E1_Nanoeuk_0m_FCM_cells mL-1 E1_Cocco_0m_FCM_cells mL-1 E1_Crypto_0m_FCM_cells mL-1 E1_HNAbacteria_0m_FCM_cells mL-1 E1_LNAbacteria_0m_FCM_cells mL-1 E1_Syn_10m_FCM_cells mL-1 E1_Picoeuk_10m_FCM_cells mL-1 E1_Nanoeuk_10m_FCM_cells mL-1 E1_Cocco_10m_FCM_cells mL-1 E1_Crypto_10m_FCM_cells mL-1 E1_HNAbacteria_10m_FCM_cells mL-1 E1_LNAbacteria_10m_FCM_cells mL-1 E1_Syn_20m_FCM_cells mL-1 E1_Picoeuk_20m_FCM_cells mL-1 E1_Nanoeuk_20m_FCM_cells mL-1 E1_Cocco_20m_FCM_cells mL-1 E1_Crypto_20m_FCM_cells mL-1 E1_HNAbacteria_20m_FCM_cells mL-1 E1_LNAbacteria_20m_FCM_cells mL-1 E1_Syn_30m_FCM_cells mL-1 E1_Picoeuk_30m_FCM_cells mL-1 E1_Nanoeuk_30m_FCM_cells mL-1 E1_Cocco_30m_FCM_cells mL-1 E1_Crypto_30m_FCM_cells mL-1 E1_HNAbacteria_30m_FCM_cells mL-1 E1_LNAbacteria_30m_FCM_cells mL-1 E1_Syn_40m_FCM_cells mL-1 E1_Picoeuk_40m_FCM_cells mL-1 E1_Nanoeuk_40m_FCM_cells mL-1 E1_Cocco_40m_FCM_cells mL-1 E1_Crypto_40m_FCM_cells mL-1 E1_HNAbacteria_40m_FCM_cells mL-1 E1_LNAbacteria_40m_FCM_cells mL-1 E1_Syn_60m_FCM_cells mL-1 E1_Picoeuk_60m_FCM_cells mL-1 E1_Nanoeuk_60m_FCM_cells mL-1 E1_Cocco_60m_FCM_cells mL-1 E1_Crypto_60m_FCM_cells mL-1 E1_HNAbacteria_60m_FCM_cells mL-1 E1_LNAbacteria_60m_FCM_cells mL-1 Columns 45-86	Taken fortnightly where conditions allow Most analysed in triplicate (phytoplankton and bacteria) for surface (0m) and single samples for all other depths. Vertical profiles of the mean abundance of groups of microbial plankton as cells per millilitre, measured using flow cytometry. (BD Accuri C6 flow cytometer) The groups quantified are divided into phytoplankton and heterotrophs. Phytoplankton groups quantified are: Syn: Synechococcus sp. (cyanobacteria) Picoeuk: Picoeukaryotes (smaller than 3 µm) Crypto: Cryptophytes Cocco: Coccolithophores Nanoeuk: Nanoeukaryotes not already mentioned (2-20 µm). Heterotrophs quantified are: HNAbacteria: heterotrophic bacteria with relatively high nucleic acid content LNAbacteria: heterotrophic bacteria with relatively low nucleic acid content.	March 2014 to Oct 2021 Source data set available via https://www.westernchannelobservatory.org.uk/data.php
E1+L5: combined Young Fish Trawl (YFT) E1+L5_ Calanus sp_YFT_No.4000m-3 E1+L5_ Pilchard eggs_YFT_No.4000m-3 E1+L5_ Other fish eggs_YFT_No.4000m-3 E1+L5_ Clupeidae larvae_YFT_No.4000m-3 E1+L5_Other fish larvae_No.4000m-3 Columns 87-91	Although net design and methods of deployment have changed on several occasions, care has been taken to ensure that sampling characteristics have not altered appreciably. The $1m^2$ Young Fish Trawl (YFT) fitted with a 700µm knitted mesh is hauled for 20 min in an oblique profile to an ideal depth of∼5m above the seabed.(Ostle et al., 2021) The samples are preserved in 4% buffered formalin and analysed as soon as possible after collection using a WILD M5 binocular microscope. The volume of filtered water is calculated using flow data recorded by a flowmeter fitted across the net mouth. Results are standardised to the number of individuals per 4000m3 in order to mitigate historical changes in sampling gear and deployment. A comprehensive summary of these macroplankton sampling methods and analysis is given in Southward et al. (2005) Note: Please be aware of zero values within this dataset, generally these are true zeros but not necessarily for all. This is being checked and will be addressed in future versions of the dataset.	1924–1940 1945–1987 2001–2013 Source data available from Data Archive for Seabed Species (DASSH) via doi:10.17031/1636

E1: Recreational captures of blue shark (*Prionace glauca*) E1_Prionace glauca captures_recreational anglers out of Looe_individuals E1_Prionace glauca catch per unit effort_recreational anglers out of Looe_captures.trip^-1 Columns 92-93	The Pat Smith database is a collaboration between the Shark Angling Club of Great Britain (SACGB) and the Sportfishing Club of the British Isles (SCBI). It is a collation of information records kept by the SACGB. Recreational angling trips from the port of Looe, Cornwall, within 10nm radius of E1. The data presented here are for years when monthly log-book information is currently available. The data record 64287 captures from 32906 trips from the port in 200 monthly periods between 1958 and 2021. Since 1998 all captures have been released. Data presented are the total number of captures in a given month, and the average catch per unit effort (as captures per trip).	1958- 1971 1997-2021 Annual data are available for all years 1953-2022 from Simon Thomas https://www.researchgate.net/publication/372251839

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