OSPAR COMMISSION

Primary Productivity

Pilot Assessment

OSPAR

QUALITY STATUS REPORT 2023

2023

OSPAR's Quality Status Report 2023

Pilot Assessment of Primary Productivity

Contributor

Authors: Arnaud Louchart, Fabrice Lizon, Pascal Claquin, Felipe Artigas

Delivered by

This work was co-funded by the European Maritime and Fisheries Fund through the project: "North-east Atlantic project on biodiversity and eutrophication assessment integration and creation of effective measures (NEA PANACEA)", financed by the European Union's DG ENV/MSFD 2020, under agreement No. 110661/2020/839628/SUB/ENV.C.2.

Citation

Louchart, A., Lizon, F., Claquin, P., Artigas, L. F., 2022. *Pilot assessment on primary production*. In: OSPAR, 2023: The 2023 Quality Status Report for the North-East Atlantic. OSPAR Commission, London. Available at: https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/primary-prod-pilot-assessment/

Contents

Key Message

Primary production sustains the functioning of marine food webs. Over the long-term (1997-2019) primary production was stable in the Greater North Sea, Celtic Seas and Bay of Biscay and Iberian Coast. Significant decreases occurred 2015-2019, likely driven by reduced nutrient availability and climate change, which may disturb higher trophic levels.

Message clé

La production primaire assure le fonctionnement des réseaux trophiques marins. Sur le long terme (1997-2019), la production primaire est restée stable dans l'ensemble de la mer du Nord, les mers celtiques, le golfe de Gascogne et la côte ibérique. Des baisses significatives ont eu lieu entre 2015 et 2019, probablement dues à la réduction de la disponibilité des nutriments et au changement climatique, qui peuvent perturber les niveaux trophiques supérieurs.

Background

Phytoplankton comprises photosynthetic microscopic organisms. The major groups in coastal systems are diatoms and dinoflagellates and, in some coastal and shelf systems, haptophytes. Phytoplankton primary production is fundamental to the marine ecosystems and represents the first available flow of energy through the ecosystem (**Figure 1**).

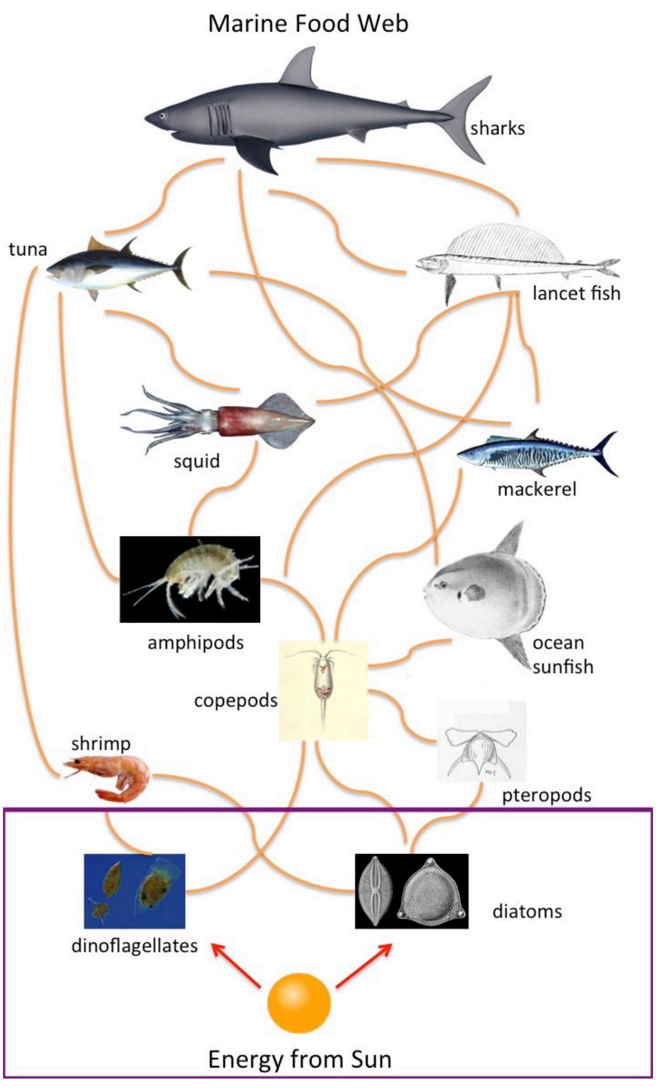

Figure 1: Representation of a marine food web (purple box represents phytoplankton primary production).

Phytoplankton primary production (i.e., organic matter formation) can be assessed *in-situ* using oxygen and carbon dioxide tracers or various fluorometric techniques.

Phytoplankton primary production is directly affected by various pressures, including nutrient enrichment, light availability, contaminants, hydrodynamics and climate change and indirectly by grazing pressure. Phytoplankton primary production is useful as an indicator of the structure and functioning of marine food webs more or less sensitive to pressures. The ability of an ecosystem to recover from disturbance is a complex process; information on phytoplankton primary production, together with pelagic habitats indicators (e.g., plankton biomass, abundance and diversity) can help understanding of this process. This indicator is in development and the current assessment is a demonstration of how it could work, using available data.

Background (extended)

Primary production is the synthesis of organic matter from inorganic compounds – carbon dioxide (CO_2) and water (H_2O) – with light as the energy source. Primary production principally occurs through the process of photosynthesis:

$$6\,CO_2 + 6\,H_2O + light \rightarrow C_6H_{12}O_6 + 6\,O_2$$

Phytoplankton primary production represents the main production source of organic matter in the oceans. This production is a key process in the marine food webs since it represents the first input/flux of organic matter in the food web and fuels the microbial loop.

Moreover, by the uptake of essential nutrients (e.g., nitrates, ammonia and phosphates), phytoplankton micro-organisms are able to synthesise lipids, proteins, nucleic acids and other major compounds.

In the marine environment, primary producers are represented by microalgae such as unicellular phytoplankton and phytobenthos, macroalgae and phanerogams (Houliez, 2012; Napoléon, 2012). Phytoplankton do not fit neatly into one taxonomic group and represent at least ten different classes from five to eight different eukaryotic kingdoms and two domains (Eukarya and Bacteria). Unicellular phytoplankton varies in size from less than one micrometre (µm) to approximately one millimetre in length or more (colonial forms). There is also diversity in the shape, pigments, storage products, motility and cell wall and external protection of phytoplankton. The two major groups in coastal systems are diatoms and dinoflagellates and, in some coastal and shelf systems, haptophytes.

Phytoplankton primary production is an important indicator in ecosystem assessment (Tett et al., 2007; Gaichas et al., 2009) and varies from area to area (e.g., coastal versus offshore). Technical advice from the International Council for the Exploration of the Sea (ICES) recognises phytoplankton primary production as a promising indicator in ecosystem assessment for implementing the European Union Marine Strategy Framework Directive (MSFD) (Rogers et al., 2010). In 2004, ICES held a workshop on the revision of the 2010 European Union Commission Decision on criteria and methodological standards on good environmental status (GES) of marine waters; advice from the workshop included using phytoplankton primary production as an indicator for food webs.

Phytoplankton primary production is a highly sensitive indicator that may respond to multiple pressures. For example, (in no order of priority): changes in the physical conditions of the water column, such as hydrodynamics, light, and climate (Cole and Cloern, 1987), anthropogenic nutrient enrichment (e.g., eutrophication, Cadée and Hegeman, 2002; land-use management), contaminants (e.g., wastewater, herbicides, anti-foulants, and heavy metals) and climate change. Grazing (e.g., marine aquaculture, Prins et al., 1997) and non-indigenous species (e.g., the Ctenophora *Mnemiopsis leidyi*, Oguz et al., 2001) also affect indirectly primary production. As phytoplankton can grow and reproduce quickly, they can respond and acclimate their productivity in response to natural and human-induced pressures. Indeed, the large plasticity of phytoplankton physiology could lead to high variations in carbon fixation efficiency (Ayata et al., 2014). Hence, phytoplankton primary production can act as a warning signal providing complementary information to other indicators, and allowing for a broader and more holistic view of the state of the ecosystem, as well as informing and supporting science, policy, and management (Shephard et al., 2015). However, ascribing changes in phytoplankton primary production directly to anthropogenic pressures is difficult.

Phytoplankton primary production can be measured *in-situ* using oxygen and carbon dioxide tracers by incubation or bulk changes that can be monitored at diverse scales or various fluorometric techniques. On a global scale, phytoplankton primary production can be estimated with models calibrated with *in-situ* data and using satellite data. The case studies used for the scientific development of this assessment are based on these different methods. Although primary production estimates can vary between methods, Regaudie-de-Gioux et al,. (2014) have shown that estimates of production obtained from different techniques can, to some extent, be converted one into another and integrated.

As primary production is affected by different environmental conditions, it is expected to vary from one region to another (Gaichas et al., 2009; OSPAR, 2000; Cloern et al., 2014). Therefore, assessment values should be specifically defined for each pilot area.

Assessment Method

The methodology was adapted since IA 2017 to spatially assessing the primary production. An updated version of the methodology will be delivered soon in the OSPAR's Coordinated Environmental Monitoring Programme (CEMP) for the FW2. First, the type of data is considered separately: time series collected at fixed (mainly coastal) stations, data from semi-autonomous collecting devices that regularly cover large spatial domains, such as the cruise data set, and satellite primary production that provide a monthly synoptic view of the OSPAR Regions. Then, primary production indicator is computed on the basis of the Pelagic Habitat indicator 'Changes in phytoplankton biomass and zooplankton abundance'.

Pre-analysis Steps: Specificities related to data type

Phytoplankton primary production can be measured using different methods, sampling strategies and sampling designs (see OSPAR CEMP, in prep. and Kromkamp et al., 2017). The method adopted to measure production should not affect the assessment as long as the result (Annual Primary Production-APP) is expressed in common units (i.e., $gC/m^2/y$).

Phytoplankton primary production is monitored at different scales:

- spatial scale: local (fixed stations), along lines (transects, mobile data collection), large area (satellites, models)
- temporal scale: daily, monthly, seasonal, annual and multiannual, long time series.

Therefore, the different type of monitoring should be treated separately.

Fixed monitoring station data

When the data are collected from a fixed monitoring station, the pre-analysis step is simple. The data should be acquired at the highest temporal resolution as possible to capture the variability of primary production. Then, because the computation of the indicator needs a monthly frequency, data with higher frequency must be averaged for each month. The next step is the pre-ingestion consisting of the investigation of the whole time-series. It consists of checking the consistency of the time-series. For example, years with less than 8 months of observation will be removed from the analysis. If a year has some missing months, data can be interpolated with a maximum gap of 3 months. Dataset of productivity integrated along the water column (expressed in $gC/m^3/y$) and at a given depth (expressed in gC/m2/y) should be analysed separately unless primary production of several depths can be used to integrate in the whole water column.

Non-station data

Large spatiotemporal primary production datasets originated from satellite. The satellite data provided by Plymouth Marine Laboratory (PML) originated from the European Space Agency Ocean Colour Climate Change Initiative using the OC5CI Chla algorithm. The OC5CI algorithm can be applied in case 1 open ocean regions as well as case 2 coastal regions (Tilstone et al., 2022). The first step is a space-time aggregation of the data to pixel of 0,5 degree (of latitude and longitude) for each month to better assess the study area. If several sites within a pixel of the grid were acquired during the same month, the average value was calculated as for fixed station data. The second step consists of a temporal extrapolation of the pixels of the grid. A minimum of 8 months within a year allow the temporal extrapolation of a pixel. Thus, if more than 4 months were missing in a year, the whole year was removed from the time-series. The temporal extrapolation was especially useful for completion of satellite data of the Northern North Sea which are often missing during the winter months due to cloud cover (November to February).

Methodology and concept

This indicator is based on identification of trends in anomalies of primary production within time-series. As primary production is closely related to phytoplankton biomass, we used the same methodology as for the Pelagic Habitat indicator 2 'Changes in phytoplankton biomass/zooplankton abundance'. Anomalies represent deviations from the assumed natural variability of a time-series. Thus, the greater the magnitude of the anomaly (in terms of absolute value, since anomalies can be positive or negative), the greater the change. An anomaly value of zero indicates no difference from the time-series mean trend (which must be de-seasonalised). To understand the changes presented (i.e., annual anomalies) and to be most useful for decision makers, the annual anomalies must be considered using details given by the monthly anomalies (since an early warning indicator should be assessed at the best temporal resolution possible). An R script for the plankton time series was first developed by Ibanez (reported in Berline et al., 2009), and then adapted for this assessment.

Previous assessment

The previous assessment (OSPAR Intermediate Assessment; IA 2017) was based on the description of the annual variability of primary production. This assessment was conducted on 9 stations / areas which limited mostly the spatial representativeness of the indicator. The temporal representativeness was less affected as trends could be characterised for 8 out of 9 stations/areas. In addition, a statistical test was conducted to report the significance of the trends. Finally, the link between the variation in trend and pressures (mainly nutrients) on the ecosystem was addressed to some stations/areas but could not be generalised across the sites included in the pilot assessment.

Temporal trend analysis of primary productivity

When the data are in the format of monthly mean values, they can be fitted to the COMP4 assessment units (see the subsection **Spatial scales**). Following these steps, the time-series analysis can be run. Primary production time-series analyses are run using the same R script for both discrete-station data and non-station data, after the pre-analysis steps have been followed. The first step consists of removing mean seasonal cycle (which is called seasonality in this assessment) from the time series. Removing the seasonality is required in order to analyse the variations of primary production beyond its natural cycle. This step produced monthly anomalies of the time-series. The second step consists in obtaining anomalies by subtracting this seasonality from the original time-series. The method used is the seasonal differentiation by the seasonal deviation methods. Finally, the cumulative sum of these anomalies was produced to detect regime shifts in the time-series. A Spearman rank correlation test is then implemented to test the anomalies of the assessment period against the anomalies of the reference period. The correlation can move toward a significant ($p \leq 0{,}05$)

increase in primary production (0 to 1), no changes (=0) or decrease in primary production (-1 to 0). The results of the Spearman rank correlation provided an indication of changes. A t-test against the cumulative sum of the anomalies of the comparison period and the reference period provide information whether the trends are significantly different or not.
For the QSR2023, the reference period included all data prior to 2015 and the assessment period was set from 2015 to 2016, due to post-2016 data not yet being available in satellite primary production datasets. For station data, the assessment period was set from 2015 to 2019 when data are available.

Spatial scales
Because plankton community composition, distribution, and dynamics are closely linked to their environment, the analysis was performed at the scale of the 'COMP4 assessment units' (COMP4 v8a; **Figure a, Table a**). Assessment units within the Greater North Sea and Celtic Seas (OSPAR Regions II and III, respectively) were initially developed by Deltares and partner institutes as part of the EU Joint Monitoring Programme of the Eutrophication of the North Sea with Satellite data (JMP-EUNOSAT; Enserink et al., 2019) and further refined in the revision process of the eutrophication assessment by OSPAR expert groups ICG-EMO and TG-COMP. Assessment units with similar phytoplankton dynamics were derived from cluster analysis of satellite data for chlorophyll *a* and primary production. Boundaries between assessment units were derived by relating clustering results to the best-matching gradients in environmental variables obtained from the three-dimensional hydrodynamic Dutch Continental Shelf model version 6 (DCSMv6 FM). The variables which best matched the divisions highlighted by clustering were depth, salinity, and stratification regime. Additional geographic areas were added such as the Channel, Irish Sea and Kattegat. These assessment units are a geographical representation of the conditions which best suit plankton distribution, dynamics, and community composition.

Because the Bay of Biscay and Iberian Coast (OSPAR Region IV) extended beyond the boundaries of the DCSMv6 FM, assessment units within this region were developed using a different methodology, based on phytoplankton dynamics (Spain) and salinity dynamics (Portugal). To delineate assessment units for the Spanish coast, a polygon was created to extend from the coast to the exclusive economic zone (EEZ) boundary. Daily MODIS-Aqua Level-2 satellite images were used to calculate climatological mean values of chlorophyll *a* for each pixel. K-means clustering was then used to group pixels with similar dynamics, resulting in six distinct groupings within the main Spanish polygon. Portugal's three Water Framework Directive assessment units were extended to the boundaries of the Portuguese EEZ. These assessment units were further divided longitudinally to separate pelagic waters from coastal waters more subject to eutrophication from river influence by applying a salinity threshold, followed by a bathymetry threshold.

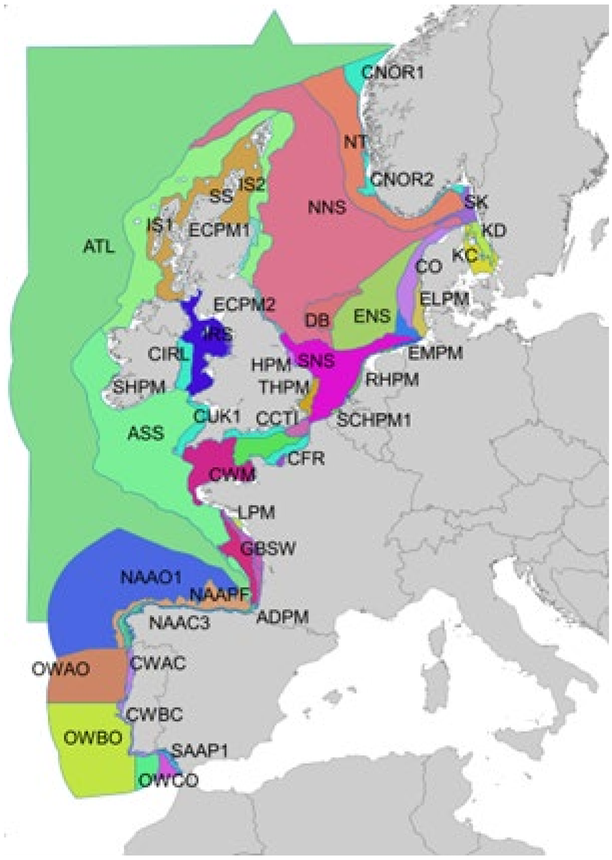

Figure a: COMP4 assessment units developed by JMP-EUNOSAT and OSPAR.

Classification of the pelagic habitats

Following the European Commission (2017) outlining criteria and methodological standards on good environmental status of marine waters, the COMP4 assessment units and the fixed-point stations are associated with a habitat type within their corresponding OSPAR Region (**table a**). Habitat identifications were processed following strict criteria according to surface mean salinity and mean depth. Four habitats were identified: variable salinity (corresponding to river plumes and regions of freshwater influence (ROFI)), coastal habitat (nearshore areas adjacent to ROFIs with mean salinity < 34,5), shelf habitat (corresponding to offshore areas with mean depth less than 200 m and mean salinity > 34,5) and oceanic/beyond shelf habitats (corresponding to offshore areas with mean depth greater than 200 m).

Table a: classification of the COMP4 assessment units and monitoring fixed-point stations by habitat type within OSPAR Regions.

Area code	Area name	Salinity (surface mean)	Depth (mean)	Habitat type	OSPAR region
ADPM	Adour plume	34,4	87	Variable salinity	IV
ELPM	Elbe plume	30,8	18		II
EMPM	Ems plume	31,4	19		II
GDPM	Gironde plume	33,5	34		IV
HPM	Humber plume	33,5	16		II
LBPM	Liverpool Bay plume	30,6	15		III
LPM	Loire plume	33,8	38		IV
MPM	Meuse plume	29,3	16		II
RHPM	Rhine plume	31,0	17		II
SCHPM1	Scheldt plume 1	31,4	13		II
SCHPM2	Scheldt plume 2	30,9	15		II

SHPM	Shannon plume	34,1	61		III
SPM	Seine plume	31,8	25		II
THPM	Thames plume	34,4	22		II
CER	Coastal FR Channel	34,2	33	Coastal	II
CIRL	Coastal IRL 3	34,0	65		III
CNOR1	Coastal NOR 1	34,3	190		II
CNOR2	Coastal NOR 2	34,0	217		II
CNOR3	Coastal NOR 3	32,4	171		II
CUK1	Coastal UK 1	34,5	60		III
CUCK	Coastal UK Channel	34,8	37		II
CWAC	Coastal Waters AC	No information	No information		IV
CWBC	Coastal Waters BC	No information	No information		IV
CWCC	Coastal Waters CC	No information	No information		IV
ECPM1	East Coast (permanently mixed) 1	34,8	73		II
ECPM2	East Coast (permanently mixed) 2	34,5	43		II
GBC	German Bight Central	33,4	39		II
IRS	Irish Sea	33,7	65		III
KC	Kattegat Coastal	25,7	21		II
KD	Kattegat Deep	27,6	50		II
NAAC1A	NorAtlantic Area NOR-NorC1	No information	No information		IV
NAAC1B	NorAtlantic Area NOR-NorC1	No information	No information		IV
NAAC1C	NorAtlantic Area NOR-NorC1	No information	No information		IV
NAAC1D	NorAtlantic Area NOR-NorC1	No information	No information		IV
NAAC2	NorAtlantic Area NOR-NorC2	No information	No information		IV
NAAC3	NorAtlantic Area NOR-NorC3	No information	No information		IV
OC	Outer Coastal DEDK	33,4	27		II
SAAC1	SudAtlantic Area SUD-C1	No information	No information		IV
SAAC2	SudAtlantic Area SUD-C2	No information	No information		IV
SAAP2	SudAtlantic Area SUD-P2	No information	No information		IV

SNS	Southern North Sea	34,3	32		II
ASS	Atlantic Seasonally Stratified	35,2	134	Shelf	III, IV
CCTI	Channel Coastal shelf tidal influenced	34,8	40		II
CWM	Channel well mixed	35,1	77		II, III
CWMTI	Channel well mixed tidal influenced	35,0	59		II
DB	Dogger Bank	35,1	28		II
ENS	Eastern North Sea	34,8	43		II
GBCW	Gulf of Biscay coastal waters	34,6	53		IV
GBSW	Gulf of Biscay shelf waters	34,9	107		IV
IS1	Intermittently stratified 1	35,3	138		II, III
IS2	Intermittently stratified 2	35,1	102		II
NAAP2	NorAtlantic Area NOR-NorP2	No information	No information		IV
NAAPF	NorAtlantic Area NOR-Plataforma	No information	No information		IV
NNS	Northen North Sea	35,0	121		II
NT	Norwegian Trench	34,1	349		II
SAAP1	SudAtlantic Area SUD-P1	No information	No information		IV
SK	Skagerrak	31,8	134		II
SS	Scottish Sea	35,1	89		II, III
ATL	Atlantic	35,3	2 291	Oceanic / Beyond shelf	II, IV, V
NAAO1	NorAtlantic Area NOR-NorO1	No information	No information		IV
OWAO	Ocean Waters AO	No information	No information		IV
OWBO	Ocean Waters BO	No information	No information		IV
OWCO	Ocean Waters CO	No information	No information		IV
SAAOC	Sudatlantic Area SUD-OCEAN	No information	No information		IV
Kristineberg		No information	No information	Coastal	II
FYN6300043		19,23	35	Coastal	II
FYN6500051		17,26	20	Coastal	II
FYN6900017		19,64	8,35	Coastal	II
FYN6700053		23,35	32	Coastal	II
VEJ0006870		23,29	19	Coastal	II
ROS60		13,09	4.8	Coastal	II
KBH431		26,68	50	Coastal	II
RKB1		8,91	3,2	Coastal	II

VSJ20925		27,91	43	Coastal	II
ARH170006		23,97	16,4	Coastal	II
NOR5503		17,30	27	Coastal	II
NOR409		24,69	14,5	Shelf	II

Data provided and used in this assessment

The datasets used for this pilot assessment have been collated from different research projects carried out by experts from the OSPAR food web expert group and from peer-reviewed scientific publications. The techniques that were used to estimate primary production varied, for example carbon or oxygen isotope techniques (DK, UK and SW) or fluorometric techniques (NL). The datasets have different temporal and spatial scales, some representing time series of regular phytoplankton primary production measurements carried out at specific sites, with others based on annual, seasonal or episodic studies (**Table b**).

The assessment method has been developed to integrate heterogeneous datasets from scientific case studies through a step-by-step approach (OSPAR CEMP, in prep.). There was a need to identify existing monitoring and to propose a coordinated approach for OSPAR in order to progress toward a full assessment for the next cycle.

Table b: Contracting Parties and institutes that provided the datasets for the primary production assessment.

Contracting Party	Institute	Dataset name	Sampling design	Date range
United-Kingdom	PML	In_situ_14C_PP_PML	Station and Transect	1998-2019
		Satellite_PP_PML	Remote sensing	1997-2016
Denmark	Aarhus University	PP NOVANA	Station	1975-2020
Netherlands	RWS	MONEOS_2016	Transect	2016
Sweden	SMHI	National Data_SMHI	Station	1985-2020

Relationship between environmental pressures and phytoplankton biomass / zooplankton abundance

Environmental variables were selected according to their relevance for plankton to determine the most important pressure in primary production changes. The set of environmental variables used originated from different models targeting the North-East Atlantic area (**Table c**).

The first step consisted of evaluating long-term links to pressures and to avoid excluding the first several decades of many plankton time-series due to missing values. To achieve this, the method used multiple random forest regressions to impute missing values based on collinearities among observed values in the predictors. For each variable containing missing values the algorithm generated a separate regression model based on all the other predictors. To improve imputation performance, a numeric variable representing 'month' was included in this step to better predict the consistent seasonal patterns in some variables. This step was performed using 'missRanger' R package (Mayer and Mayer 2019).

Then, values for each environmental variable were calculated as the mean of monthly mean gridded values (modelled and remotely sensed) within each COMP4 assessment unit. For fixed-point stations, mean values were calculated from all measurements within a 5-nautical mile radius of the station. Where in-situ data were available (total nitrogen, nitrate, phosphate, total phosphorous, silicate) they were evaluated instead of the modelled environmental variables. For Atlantic Multidecadal Oscillation (AMO) and North Atlantic Oscillation

(NAO), monthly values were applied identically across all assessment units since these variables have basin-scale influence likely to cover the entire assessment region.

Finally, random forest algorithm was applied to evaluate which was the best combination of environmental variable for primary production prediction. The algorithm is based on the combination of predictions made by multiple regression trees (here, k = 1000 trees) with the optimal tree (defined as the best combination of variables) obtained by majority voting.

Prior to analysis, the original datasets were split into two subsets resulting in a training set and a test set. The training set was used for the selection of the best combination while the test set was used to validate the predictions. The training set consisted of data from the comparison period (prior to 2015) while the test set consisted of data from the assessment period (from 2015 to 2019).

For map visualisation, some variables were aggregated together. Total nitrogen, nitrate, phosphate, total phosphorus, N:P ratio and silicates were pooled under the term "nutrient". The same procedure was applied for AMO and NAO which were pooled under the term "Climate indices".

Table c: list of environmental variables used as pressures.

Variable name	Description	Abbreviation	Source
Sea surface temperature	Temperature of surface layer, as measured by satellite	sst	International Comprehensive Ocean-Atmosphere Data Set (ICOADS): https://psl.noaa.gov/data/gridded/data.coads.1deg.html
Salinity	Salinity of the surface layer	sal	European Regional Seas Ecosystem Model (ERSEM; NWSHELF_MULTIYEAR_PHY_004_009; https://doi.org/10.48670/moi-00059)
Total nitrogen	Total nitrogen concentration of the surface layer	totn	*In-situ* data from Marine Scotland Science (MSS): https://doi.org/10.7489/1881-1
Nitrate	Nitrate concentration of the surface layer	ntra	European Regional Seas Ecosystem Model (ERSEM; NWSHELF_MULTIYEAR_BGC_004_011): https://doi.org/10.48670/moi-00058); *In-situ* data from Plymouth Marine Laboratory (PML): https://www.westernchannelobservatory.org.uk/l4_nutrients.php
Phosphate	Dissolved inorganic phosphate concentration of the surface layer	phos	European Regional Seas Ecosystem Model (ERSEM; NWSHELF_MULTIYEAR_BGC_004_011): https://doi.org/10.48670/moi-00058); *In-situ* data from Plymouth Marine Laboratory (PML): https://www.westernchannelobservatory.org.uk/l4_nutrients.php
Total phosphorus	Total phosphorus concentration of the surface layer	totp	*In-situ* data from Aarhus University (Svendsen et al. 2005)
N:P ratio	The ration of molar nitrogen concentration to molar	np	Derived from: European Regional Seas Ecosystem Model (ERSEM; NWSHELF_MULTIYEAR_BGC_004_011): https://doi.org/10.48670/moi-00058);

	phosphorus concentration		*In-situ* data from Plymouth Marine Laboratory (PML): https://www.westernchannelobservatory.org.uk/l4_nutrients.php and Marine Scotland Science (MSS): https://doi.org/10.7489/1881-1
Silicates	Dissolved silicates concentration of the surface layer	Si	*In-situ* data from Marine Scotland Science (MSS): https://doi.org/10.7489/1881-1; Plymouth Marine Laboratory (PML): https://www.westernchannelobservatory.org.uk/l4_nutrients.php; *In-situ* data from Aarhus University (Svendsen et al., 2005)
Wind speed	Wind speed (proxy of turbulence)	wspd	International Comprehensive Ocean-Atmosphere Data Set (ICOADS); https://psl.noaa.gov/data/gridded/data.coads.1deg.html
Mixed layer depth	Surface layer in which density is nearly homogeneous with depth	mld	European Regional Seas Ecosystem Model (ERSEM; NWSHELF_MULTIYEAR_PHY_004_009; https://doi.org/10.48670/moi-00059)
Light attenuation	The extinction coefficient for the visible light in the water column	attn	European Regional Seas Ecosystem Model (ERSEM; NWSHELF_MULTIYEAR_BGC_004_011): https://doi.org/10.48670/moi-00058)
Precipitation	Rate of precipitation	precip	International Comprehensive Ocean-Atmosphere Data Set (ICOADS); https://psl.noaa.gov/data/gridded/data.coads.1deg.html
Current velocity	Current velocity in the surface layer	cvel	European Regional Seas Ecosystem Model (ERSEM; NWSHELF_MULTIYEAR_PHY_004_009; https://doi.org/10.48670/moi-00059)
pH	Alkalinity of the surface layer	pH	European Regional Seas Ecosystem Model (ERSEM; NWSHELF_MULTIYEAR_BGC_004_011): https://doi.org/10.48670/moi-00058)
NAO	The North Atlantic Oscillation is a weather phenomenon over the North Atlantic Ocean of fluctuations in the difference of atmospheric pressure at sea level between the Icelandic Low	nao	National Oceanic and Atmospheric Administration (NOAA): https://www.ncdc.noaa.gov/teleconnections/nao/

	and the Azores High		
AMO	The Atlantic Multidecadal Oscillation is the theorised variability of the sea surface temperature of the North Atlantic Ocean on the timescale of several decades	amo	National Oceanic and Atmospheric Administration (NOAA); https://psl.noaa.gov/data/timeseries/AMO/

Integration of indicator results:
A primary objective of this indicator assessment was to integrate results to facilitate an understanding of changes occurring across pelagic habitat types within the Greater North Sea (OSPAR Region II), the Celtic Seas (OSPAR Region III) and the Bay of Biscay and Iberian Coast (OSPAR Region IV). This required indicator results for each OSPAR Region to be integrated according to the following pelagic habitat categories: variable salinity, coastal, shelf, and oceanic / beyond shelf. This categorisation of COMP4 assessment units and fixed-point stations is described in **Table a.** To meet this objective, we focused on the primary direction of change detected across assessment units and fixed-point stations within each pelagic habitat category for each of the 2 plankton components highlighted in this assessment. We then reported the mean confidence, spatial representativeness, and most likely links to environmental pressures.

As an example, changes in primary production were assessed across 6 COMP4 areas and 4 fixed-point stations representing coastal habitats within the Greater North Sea (OSPAR Region II). If 4 decreasing trend, 3 increasing trends, and 3 instances of no trend were detected across these locations, we would report a decreasing net trend and the proportion of assessment units studied where this trend was detected, in this case 0,4.

The spatial representativeness of the result corresponds the proportion of the total number of COMP4 assessment units considered in the analysis, in this case 6, out of the total number of possible COMP4 assessment units representing coastal habitats within the OSPAR Region, in this case 12. Therefore, the spatial representativeness of the result would be 0,5. Note that fixed-point station datasets do not contribute to this score.

Finally, to report links to environmental pressures which can drive changes in PH2 components for the net trend, we ranked environmental variables for each location based on their relative variable importance, with 1 assigned to the variable with highest importance, 2 to the variable with second highest importance and so on. For locations where the net trend was increasing, we calculated the mean rank of each environmental variable and reported the variable with the lowest mean rank.

Addressing FW2 quality status
In order to deliver a clear and comprehensive message to the scientific and non-scientific community, the results of the indicator were summarised by their quality status. The quality status had been defined by the change in indicator value according to assessment threshold and / or the impact of anthropogenic pressures and climate change on the indicator change (McQuatters-Gollop et al., 2022). Thus, the quality status resulted in 4 categories: Not good, Unknown, Good, and Not assessed. **Table d** gives the detailed explanation of the different categories.

Table d: Categorization of the quality status and their associated narratives.

Quality status categories	
Not good	Indicator value is below assessment threshold, or change in indicator represents a declining state, or indicator change is linked to increasing impact of anthropogenic pressures (including climate change), or indicator shows no change but state is considered unsatisfactory
Unknown	No assessment threshold and/or unclear if change represents declining or improving state, or indicator shows no change but unknown if state represented is satisfactory
Good	Indicator value is above assessment threshold, or indicator represents improving state, or indicator shows no change but state is satisfactory
Not assessed	Indicator was not assessed in a region due to lack of data, lack of expert resource, or lack of policy support.

Results

This pilot assessment identified changes in primary production at regional and local scales in the Greater North Sea and the Celtic Seas (OSPAR Regions II and III) and in some areas of the Bay of Biscay and Iberian Coast (OSPAR Region IV). The regional scale is represented by the COMP4 assessment units and the local scale is represented by monitoring fixed stations. Assessment of primary production was possible for 38 areas. Within the COMP4 assessment units, long-term changes (1997-2016) were significant (**Figure 2**). Depending on the length of the time-series, changes were also observed at local scale (**Figure 2**), located in the Greater North Sea.

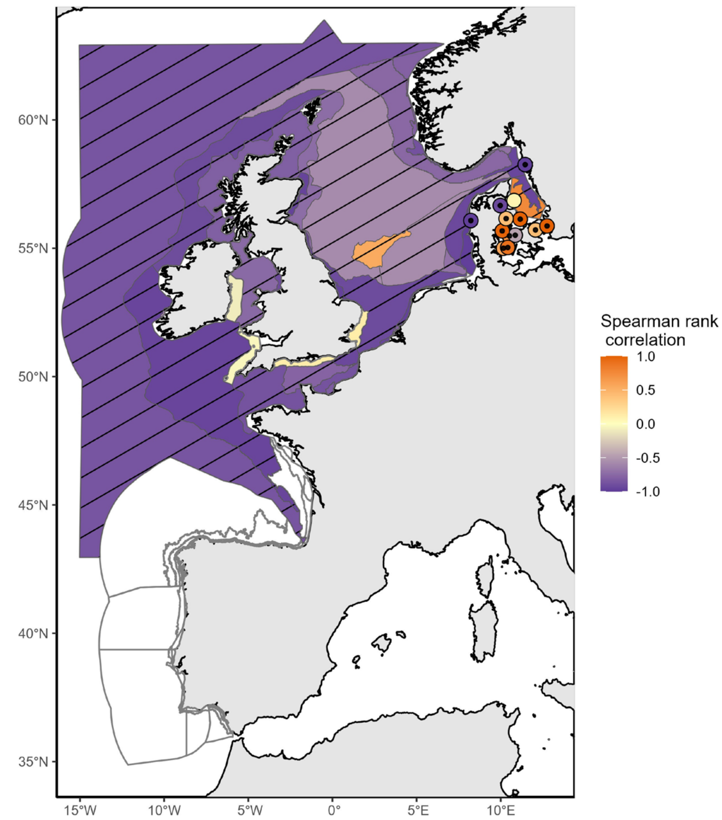

Figure 2: Trend in primary production between the assessment period (2015–2016) and the reference period (station data: 1992–2014; non-station data: 1997–2014). Hatched areas were characterised by significant changes in primary production between the reference and the assessment periods. Black dots represent significant trend for stations. White areas indicate no data or insufficient data to assess the area.

Spearman rank correlation indicated that primary production were generally decreasing across the majority of COMP4 areas assessed during the assessment periods with significant different trends between the reference and assessment period. Strong negative trends in primary production occurred across 32 assessment units while increases were documented in only 2 areas (Kattegat coastal and Dogger Bank). No significant changes were observed in 4 assessment units (in southern and western coastal UK areas, in the coastal Irish waters and in the Thames Plume). Despite the fact that long-term trends did not provide strong evidence for changes in primary production (see **Results (extended)**; **Figure b**), comparison between the trend of the cumulative sum of the assessment period and trend of the cumulative sum of the reference period showed clearly changes in primary production, supporting our main result (see **Results (extended)**; **Figure c**).

Links between primary production (**Figure 3**) and pressures under climate change were evident in the Celtic Seas and Bay of Biscay and Iberian Coast (OSPAR Region III and IV) and in the coastal habitat of the Greater North Sea (OSPAR Region II). Sinking mixed layer depth (16%), increasing SST (13%), decreasing pH (13%) and decreasing wind speed (11%) were among the most important variables linked to decrease of primary production. Decrease of salinity (8%), precipitation (5%) and light attenuation (3%) were also important. In the variable salinity and shelf habitats of the Greater North Sea (OSPAR Region II), nutrients (nitrate, phosphorus, N:P ratio and silicate), considered as a proxy of eutrophication, were the most important variables in primary production changes (29% of COMP4 areas). As was observed in the PH2 indicator, the impact of eutrophication may be significant in this Region and further works must be carried out with the ICG-Eut group to better understand the underlying relationships. The remaining 2% of COMP4 areas are impacted by natural climatic variation (AMO). Regarding these relationships, quality status of most habitats within the OSPAR Regions was “Not good". Only variable salinity habitat in the Greater North Sea (OSPAR Region II) had an "Unknown” quality status. Further details can be found in the **Results (extended)**.

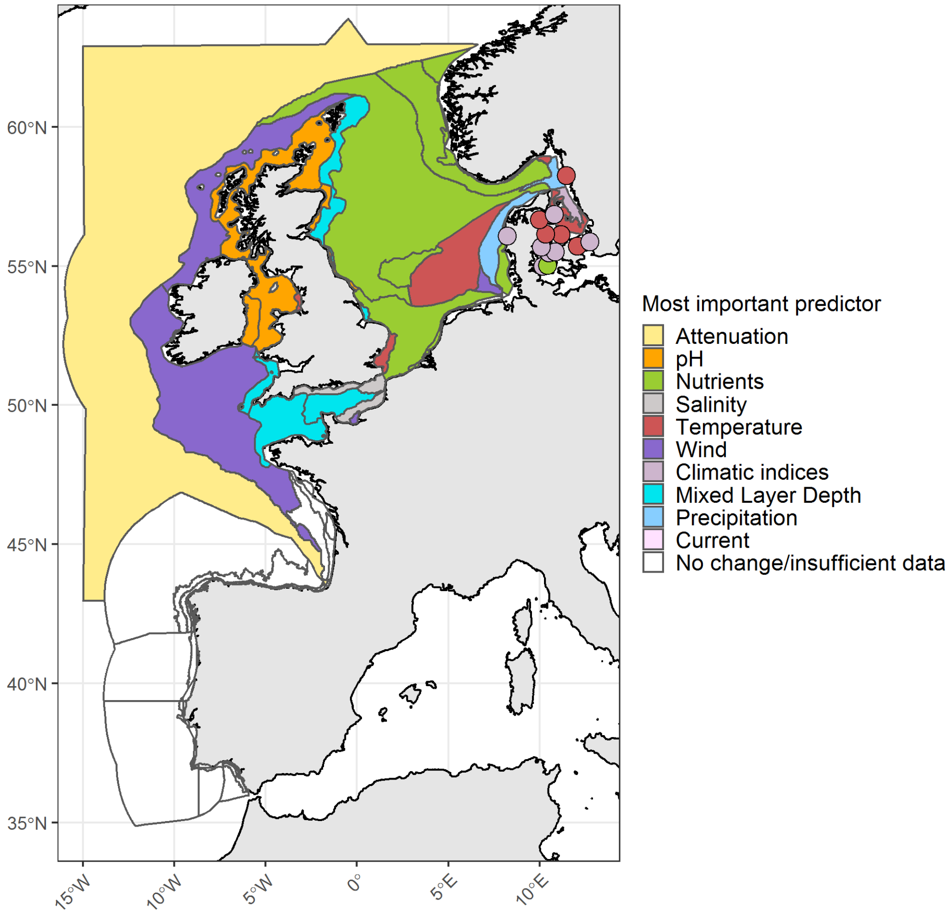

Figure 3: Most important variables addressing changes in primary production within the COMP4 assessment units.

Results (extended)

Detailed computation

The current section aims at presenting the detailed results. Long-term trends (1997-2016; **Figure b**) indicated that primary production has been steadily unchanged throughout the North-East Atlantic. Considering the de-seasonalised time-series, the long-term trends (**Figure c**) showed globally to have stronger increasing or decreasing trends (black regression) than the raw data. When considering two distinct periods to compare, the reference period (red regression) and the whole time-series had similar trend. Contrariwise, the trends of the assessment period (blue regression) were quite different revealing a decreasing primary production in most of the case over the last two years.

Although changes could be characterised for long-term trends and short period, the data available limit the assessment period to two years for the COMP4 areas. This element may limit the comparison with other relevant pelagic and food web indicators. Consequently, longer data availability for the assessment period is required to address adequately the study of the assessment period and increase the reliability of the results. Furthermore, the contribution of the assessment period to long-term changes will be explored in the future.

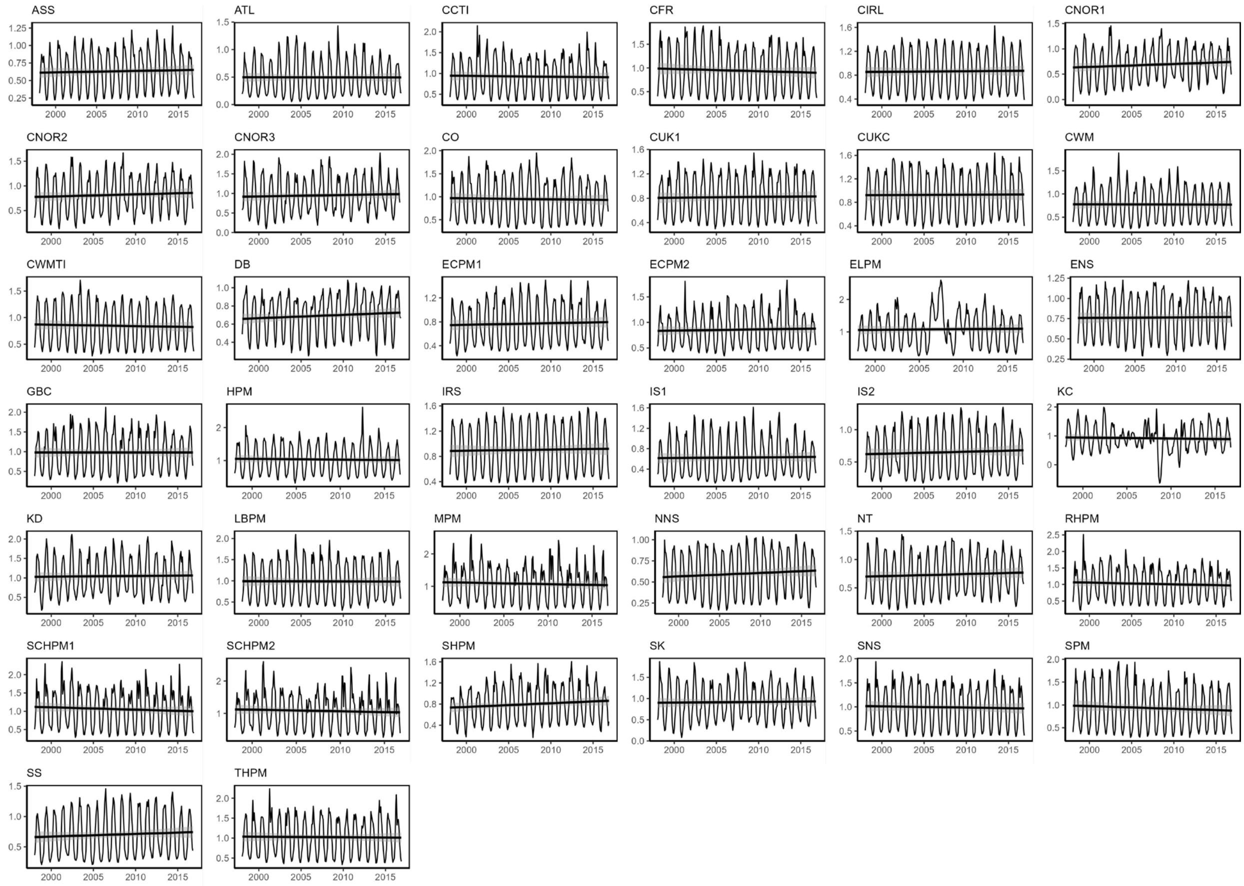

Figure b: Time-series (1997-2016) of primary production and their trends within each assessment unit.

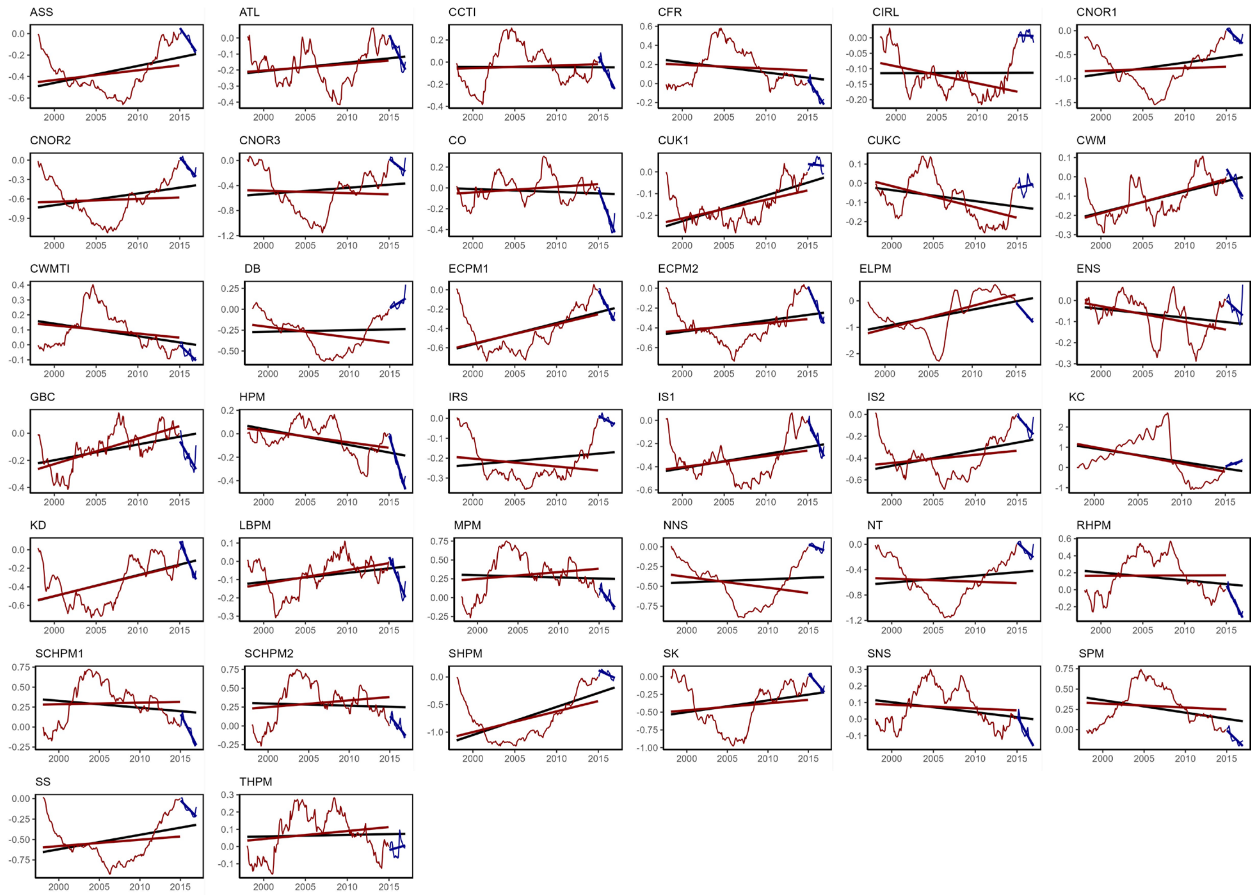

Figure c: Cumulative sum of the primary production monthly anomalies. The line in red represents the anomalies of the reference period. The line in blue represents the anomalies of the assessment period.

Regression lines materialised the trends (i) of the whole time-series (black), (ii) of the reference period (red) and (iii) of the assessment period (in blue).

Relation between pressures and indicator

In the Greater North Sea (OSPAR Region II), the multiple regression results have revealed nutrients (phosphorous and the balance between nitrogen and phosphorous) as the most important pressures affecting changes in primary production for variable salinity and shelf habitats. A decrease of phosphorus was linked to decrease in primary production for variable salinity habitats whereas increasing N:P ratio, due to better mitigation effort of phosphorous than nitrogen over the last decades, in shelf habitat was linked to decrease in primary production. Finally, in the coastal habitat surface warming was the most important pressure linked to decline of primary production at broad scale.

In the Celtic Seas (OSPAR Region III), decreasing pH was linked to the decline of primary production in variable salinity and coastal habitats. However, downward trend of primary production was insignificant. This relationship between pH and primary production should be evaluated cautiously as phytoplankton impact directly pH through the ingestion of DIC to fuel growth and reproduction. Further analysis is necessary to quantify phytoplankton's contribution to pH variability. Indicator results in shelf habitat also reflected a reduction of primary production linked to decreasing mixed layer depth, probably in relation to increasing stratification and surface warming.

In the Bay of Biscay and Iberian Coast (OSPAR Region IV), changes in primary production were strongly linked to climatic pressures. While primary production decrease in the shelf habitat was related to decreasing wind speed, increasing light attenuation was associated with the downward of primary production. Climate change has been evidenced as the cause of decreasing wind speed. Concerning increasing light attenuation (i.e., decrease of water clarity), PH2 revealed that phytoplankton biomass was decreasing in oceanic habitat which was also the same pattern of primary production. The nature of increasing light attenuation seems of abiotic origin but further investigations should be carried out to validate this hypothesis.

The quality status of the food webs within OSPAR Regions was addressed following the links between pressures and FW2 indicator's results (**Table e**). Despite relationships with environmental variables remaining unclear, climate change and decreasing pH have been linked with the indicators within coastal habitat of the Greater North Sea (OSPAR Region II), within variables salinity, coastal and shelf habitats of the Celtic Seas (OSPAR Region III) and within shelf and oceanic / Beyond shelf habitats of the Bay of Biscay and Iberian Coast (OSPAR Region IV). Consequently, the quality status within these habitats is "Not good". There is also evidence that the N:P ratio has impacted the primary production. This was the case for shelf habitat of the Greater North Sea (OSPAR Region II). As a consequence of the imbalance between nitrate and phosphorus which might be related to eutrophication, the quality status of the habitat was also determined to be "Not good". Finally, where other parameters were linked with changes in primary production (e.g., variable salinity habitats of the Greater North Sea), it was more difficult to establish the origin of the pressure. In this case, quality status of the habitat was categorised as "Unknown".

Table e: Integration of the indicator results of the Greater North Sea, the Celtic Seas and the Bay of Biscay and Iberian Coast (OSPAR Region II, III and IV respectively). Column names are described as follows: Dir:

the net direction of change in the primary production (upward arrow: increasing trend, equality sign: no trend, downward arrow: decreasing trend), Trend: the percentage of assessment units exhibiting the respective trend (if no results were reported for assessment units, stations are used), Change: a logical variable (TRUE/FALSE) to report whether a net trend is likely given the significance of the results, Pressure: the environmental pressure with the greatest mean rank for the respective trend, Rank: the mean rank of the environmental pressure indicated under Pressure, nSt: the total number of fixed-point stations considered, nCOMP4: The total number of COMP4 assessment units considered, totCOMP4: The total number of potential COMP4 assessment units for the habitat category, spatialRep: the spatial representativeness score of the analysis.

OSPAR Region	Habitat	Dir	Trend	Change	Pressure	Rank	nSt	nCOMP4	totCOMP4	Spatial Rep
The Greater North Sea	Variable salinity	↓	88%	TRUE	phosp	2,8	0	8	9	89%
	Coastal	↓	83%	TRUE	sst	4,2	12	12	12	100%
	Shelf	↓	88%	TRUE	np	4,1	1	8	11	72%
	Oceanic	NA								
The Celtic Seas	Variable salinity	↓	100%	TRUE	pH	2,0	0	2	2	100%
	Coastal	=	100%	FALSE	pH	2,3	0	3	3	100%
	Shelf	↓	100%	TRUE	mld	3,0	0	4	4	100%
	Oceanic	NA								
The Bay of Biscay and Iberian Coast	Variable salinity	NA								
	Coastal	NA								
	Shelf	↓	17%	TRUE	wspd	1,0	0	1	6	17%
	Oceanic	↓	17%	TRUE	attn	1,0	0	1	6	17%

Conclusion

This pilot assessment illustrates the potential for the indicator to show changes in phytoplankton primary production at regional (COMP4 assessment units) and local (discrete monitoring stations) scales and provides key information on the dynamics of primary production. This pilot assessment demonstrates inter-annual variability within study sites and variability between them indicating the importance of collecting enough years of data to understand the range in variability and the likely causes. The results bring to light a general decline in primary production at the regional scale. The different sampling strategy and sampling design used for this assessment showed similar results which allow flexibility for contracting parties to have differing monitoring programmes. Although, remote sensing provides regular and synoptic view, more *in-situ* primary production measurements are required by any means (carbon isotope, O2 or CO2 bulk changes, FRRf, PAM) as most of the assessment is based on models (including remote sensing). Possible links with climate change were reported especially in the Celtic Seas and the Bay of Biscay and Iberian Coast and in coastal habitat of the Greater North Sea. Eutrophication had been linked to the indicator especially in variable salinity and shelf habitats of the Greater North Sea. Finally, future investigations will report the cause of the changes and explore connections with relevant pelagic habitats and food web indicators.

Conclusion (extended)

This pilot assessment demonstrates the potential for this indicator to show changes in phytoplankton primary production. Results indicate spatial and temporal variability of primary production at regional (COMP4 assessment units) and local (discrete monitoring stations) scale and allows the comparison of assessment units between them. In accordance with peer-reviewed literature (e.g., Capuzzo et al., 2017), an overall decrease of primary production occurred in the North Sea but also in the Celtic Seas and the Bay of Biscay and Iberian Coast. Furthermore, future investigations should interpret the results in the light of other indicators (pelagic habitats, eutrophication, food web indicators).

Key information on the trend of phytoplankton primary production during the assessment period was provided. The method used here attempted to link primary production (significant decrease / increase or no change) and climate change and anthropogenic pressures. Despite a consistent pattern of change across the assessment units, the results indicated that no single environmental variable was responsible for the change in primary production. It appears that the factors driving this variability are likely to be site-specific.

Finally, the different sampling strategy and sampling design used for this assessment showed similar results which allow flexibility for Contracting Parties to have differing monitoring programmes. Although, remote sensing provides regular and synoptic view of the Greater North Sea, the Celtic Seas and the Bay of Biscay and Iberian Coast (OSPAR Regions II, III and IV respectively), more *in-situ* primary production measurements are required by any means (carbon isotope, O2 or CO_2 bulk changes, FRRf, PAM) as most of the assessment is based on models (including remote sensing).

Knowledge Gaps

Further work recommendations are as follows: 1. Methodology improvement must be carried out to define more precisely the natural cycle of primary production; 2. Multiple regimes shifts instead of a single long-term trend should be considered; 3. Comparison should be made to relevant pelagic habitat and food web indicators to better address the extent of changes; 4. *In-situ* measurements of primary production should be reinforced; 5. More time-series of real primary production estimations in the field should be included; 6. Additional datasets particularly for the Bay of Biscay and Iberian Coast should be included; 7. An index for spatial and temporal confidence of the results should be proposed; and 8. The links between FW2 and pressures should be refined.

Knowledge Gaps (extended)

Further development of this indicator is needed, particularly on the following points:

- Improvement of the methodology for defining the natural cycle and then for trend characterisation
- Comparison to relevant Pelagic Habitat and Food Web indicators as well as relevant indicators within ICG-Eut.
- Reinforcement of *in-situ* measurements of primary production
- Inclusion of additional datasets from field estimation
- Inclusion of additional datasets to improve the confidence of the indicator's result especially for the Bay of Biscay and Iberian Coast (OSPAR Region IV).
- Refinement of the use of remote sensing data within estuaries, plumes and coastal habitats
- Improvement of the methodology for defining spatial and temporal confidence of the results;
- Refinement of the links between FW2 and pressures to identify the origin of the pressures.

Methodology improvement and multiple regimes shifts

The current assessment is built on the assumption that primary production fluctuates over a consistent annual cycle. However, primary production has large year-to-year variability, and this pattern of variability differs across ecosystems and habitats. For example, periodicities of 12 or 6 months or less have been reported. Shifts in the typical annual cycle have also been detected in the past. Future development should therefore focus on investigating the annual cycle for non-stationary datasets (e.g., Winder and Cloern, 2010) and applying this information to de-trend time-series data. It is also important to note that longer cycles than 12 months (e.g., Schwabe sunspot cycle) also impact primary production.

Once the annual mean cycle has been removed, the trend analysis can be conducted using linear modelling. Although this methodology is widely accepted, this does not always match with the dataset. Trends can be linear, cubic, quadratic or absent. Consequently, it is necessary to propose an evaluation tool to define more accurately the type of relationship of the de-trended data over time.

Comparison to relevant Pelagic Habitat and Food Web indicators

Comparison between FW2 'Pilot assessment of Primary Production' and PH2 'Changes in Phytoplankton Biomass and Zooplankton Abundance' indicator should be carried out as primary production and phytoplankton biomass are related.

Reinforcement of *in-situ* measurements of primary production

Satellite requires *in-situ* measurements (e.g., oxygen, C14, FRRf, PAM) for validation of their algorithms. There is a crucial need to maintain existing monitoring and to reinforce the acquisition of *in-situ* measurement for the different habitats within the different OSPAR Regions.

Inclusion of additional datasets from field estimation

The inclusion of additional datasets will also allow comparison between data originating from different monitoring strategies to define which monitoring strategy is the most suitable per habitat.

Inclusion of additional datasets for the Bay of Biscay and Iberian Coast

Inclusion of additional datasets in the Bay of Biscay and Iberian Coast (OSPAR Region IV) will allow the computation of the indicator within variable salinity habitats and improve the spatial and temporal confidence of the FW2 indicator for the variable salinity, coastal, shelf and oceanic habitats. Changes in primary production may also result in shifts between pairs of lifeforms (e.g., from diatoms to dinoflagellates). Links with the PH1/FW5 'changes in Phytoplankton and Zooplankton Communities' should also be carried out.

Refinement of the use of remote sensing data within estuaries, plumes and coastal habitats

Examine satellite data at finer spatial scale and improve assessment from remote sensing for turbid and eutrophic water bodies, in particular in variable salinity and coastal habitats of the Greater North Sea (OSPAR Region II).

Spatial and temporal confidence of the results
The confidence of the results depends strongly on the homogeneity of sampling in space and time. Spatial and temporal confidence indices will address the sampling effort in the pelagic habitats within OSPAR Regions. These spatial and temporal confidence indices will be implemented in future assessments.

Refine the pressure-FW2 relationship
The origin of the different pressure is unclear at this stage. Despite evidence from literature, future work should make the distinction between natural versus human induced pressure as well as the origin of natural pressures (e.g., nutrient originating from river run-off or benthic origin or Atlantic flow).
In addition, introduction of a lag into the variable selection is needed to test for delayed effects of environmental pressures on primary production (e.g., the effects of winter nutrient concentrations on primary production during the growing season).

References

Ayata, S.D., Lévy, M., Aumont, O., Resplandy, L., Tagliabue, A., Sciandra, A., and Bernard, O. (2014). Phytoplankton plasticity drives large variability in carbon fixation efficiency. Geophysical Research Letters, 41(24), 8994-9000.

Berline L., Ibanez F., and Grosjean P. (2009). Roadmap for zooplankton time series analysis. SESAME WP1 report. 20p.

Cadée, G.C., and Hegeman, J. (2002). Phytoplankton in the Marsdiep at the end of the 20th century; 30 years monitoring biomass, primary production, and Phaeocystis blooms. Journal of Sea Research, 48(2), 97-110.

Capuzzo, E., Lynam, C. P., Barry, J., Stephens, D., Forster, R. M., Greenwood, N., McQuatters-Gollop, A., Silva, T., van Leeuwen, S.M., and Engelhard, G. H. (2018). A decline in primary production in the North Sea over 25 years, associated with reductions in zooplankton abundance and fish stock recruitment. Global change biology, 24(1), e352-e364.

Cloern, J.E., Foster, S.Q., & Kleckner, A.E. (2014). Phytoplankton primary production in the world's estuarine-coastal ecosystems. Biogeosciences, 11(9), 2477-2501.

Cole, B. E., and Cloern, J. E. (1987). An empirical model for estimating phytoplankton productivity in estuaries. Marine Ecology Progress Series, 36(1), 299-305.

Enserink, L., Blauw, A., van der Zande, D., and Markager S. (2019). Summary report of the EU project 'Joint monitoring programme of the eutrophication of the North Sea with satellite data' (Ref: DG ENV/MSFD Second Cycle/2016). 21 pp.

Gaichas, S., Skaret, G., Falk-Petersen, J., Link, J.S., Overholtz, W., Megrey, B.A., Gjøsæter, H., Stockhausen, W.T., Dommasnes, A., Friedland, K.D., and Aydin, K. (2009). A comparison of community and trophic structure in five marine ecosystems based on energy budgets and system metrics. Progress in Oceanography, 81(1-4), 47-62.

Houliez, E., Lizon, F., Thyssen, M., Artigas, L.F. and Schmitt F.G. (2012). Spectral fluorometric characterization of Haptophyte dynamics using the FluoroProbe: an application in the eastern English Channel for monitoring Phaeocystis globosa. J. Plankton Res.34:136-151

Kromkamp, J., Capuzzo, E., Philippart, C.J.M. (2017). Measuring phytoplankton primary production: review of existing methodologies and suggestions for a common approach. EcApRHA Delivrable WP3.2. 29pp.

Mayer, M., and Mayer, M. M. (2019). Package 'missRanger'. R Package.

McQuatters-Gollop, A., Guérin, L., Arroyo, N.L., Aubert, A., Artigas, L.F., Bedford, J., Corcoran, E., Dierschke, V., Elliott, S.A.M., Geelhoed, S.C.V., Gilles, A., Gonzalez-Irusta, J.M., Haelters, J., Johansen, M., Le Loc'h, F., Lynam, C.P., Niquil, N., Meakins, B., Mitchell, I., Padegimas, B., Pesch, R., Preciado, I., Rombouts, I., Safi, G., Schmitt, P., Schückel, U., Serrano, A., Stebbing, P., De la Torriente, A., Vina-Herbon, C. (2022). Assessing the state of marine biodiversity in the Northeast Atlantic. Ecological Indicators, 141, 109148.

Napoléon, C., and Claquin, P. (2012). Multi-parametric relationships between PAM measurements and carbon incorporation, an *in-situ* approach. PloS one, 7(7), e40284.

Oguz, T., Ducklow, H.W., Purcell, J.E., and Malanotte-Rizzoli, P. (2001). Modeling the response of top-down control exerted by gelatinous carnivores on the Black Sea pelagic food web. Journal of Geophysical Research: Oceans, 106(C3), 4543-4564.

OSPAR. OSPAR Agreement 2019-06 (2023 Update). Coordinated Environmental Monitoring and Assessment Programme Guidelines for assessing Changes in Phytoplankton Biomass and Zooplankton Abundance. https://www.ospar.org/documents?v=40972

Prins, T.C., Smaal, A.C., and Dame, R.F. (1997). A review of the feedbacks between bivalve grazing and ecosystem processes. Aquatic Ecology, 31(4), 349-359.

Regaudie-de-Gioux, A., Lasternas, S., Agustí, S., and Duarte, C.M. (2014). Comparing marine primary production estimates through different methods and development of conversion equations. Frontiers in Marine Science, 1, 19.

Rogers, S., Casini, M., Cury, P., Heath, M., Irigoien, X., and Kuosa, H. (2010). MSFD, Task Group 4 Report, Food webs. European Commission Joint Research Center and ICES.

Shephard, S., van Hal, R., de Boois, I., Birchenough, S.N., Foden, J., O'Connor, J., Geelhoed, S.C.V. Van Hoey, G., Marco-Rius, F., Reid, D.G. and Schaber, M. (2015). Making progress towards integration of existing sampling activities to establish Joint Monitoring Programmes in support of the MSFD. Marine Policy, 59, 105-111.

Svendsen, L., L. van der Bijl, S. Boutrup, and B. Norup. 2005. NOVANA. National Monitoring and Assessment Programme for the Aquatic and Terrestrial. and number: NERI Technical Report.

Tett, P., Gowen, R., Mills, D., Fernandes, T., Gilpin, L., Huxham, M., Kennington, K., Read, P., Service, M., Wilkinson, M., and Malcolm, S. (2007). Defining and detecting undesirable disturbance in the context of marine eutrophication. Marine pollution bulletin, 55(1-6), 282-297.

Tilstone, G. H., Land, P. E., Pardo, S., Kerimoglu, O., & Van der Zande, D. (2022). Threshold indicators of primary production in the north-east Atlantic for assessing environmental disturbances using 21 years of satellite ocean colour. *Science of The Total Environment*, 158757.

Winder, M., and Cloern, J. E. (2010). The annual cycles of phytoplankton biomass. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1555), 3215-3226.

Assessment Metadata

Field	Data Type	
Assessment type	List	Pilot Assessment
SDG Indicator	List	13.2 Integrate climate change measures into national policies, strategies and planning 14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans
Thematic Activity	List	Biological Diversity and Ecosystems
Relevant OSPAR Documentation	Text	OSPAR Agreement 2010-03 The North-East Atlantic Environment Strategy. Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2010–2020 OSPAR Agreement 2016-01 OSPAR Coordinated Environmental Monitoring Programme (CEMP), as amended OSPAR Agreement 2021-01 Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2030
Contributor	Text	Louchart, A., Lizon, F., Claquin, P., Artigas, L. F., 2022. *Pilot assessment on primary production*. In: OSPAR, 2023: The 2023 Quality Status Report for the North-East Atlantic. OSPAR Commission, London. OSPAR Food web expert group, ICG-COBAM, BDC.
Date of publication	Date	2023-06-30
Conditions applying to access and use	URL	https://oap.ospar.org/en/data-policy/

OSPAR's Quality Status Report 2023

OSPAR COMMISSION

OSPAR Secretariat
The Aspect
12 Finsbury Square
London
EC2A 1AS
United Kingdom

t: +44 (0)20 7430 5200
f: +44 (0)20 7242 3737
e: secretariat@ospar.org
www.ospar.org

Our vision is a clean, healthy and biologically diverse North-East Atlantic Ocean, which is productive, used sustainably and resilient to climate change and ocean acidification.

Publication Number: 950/2023