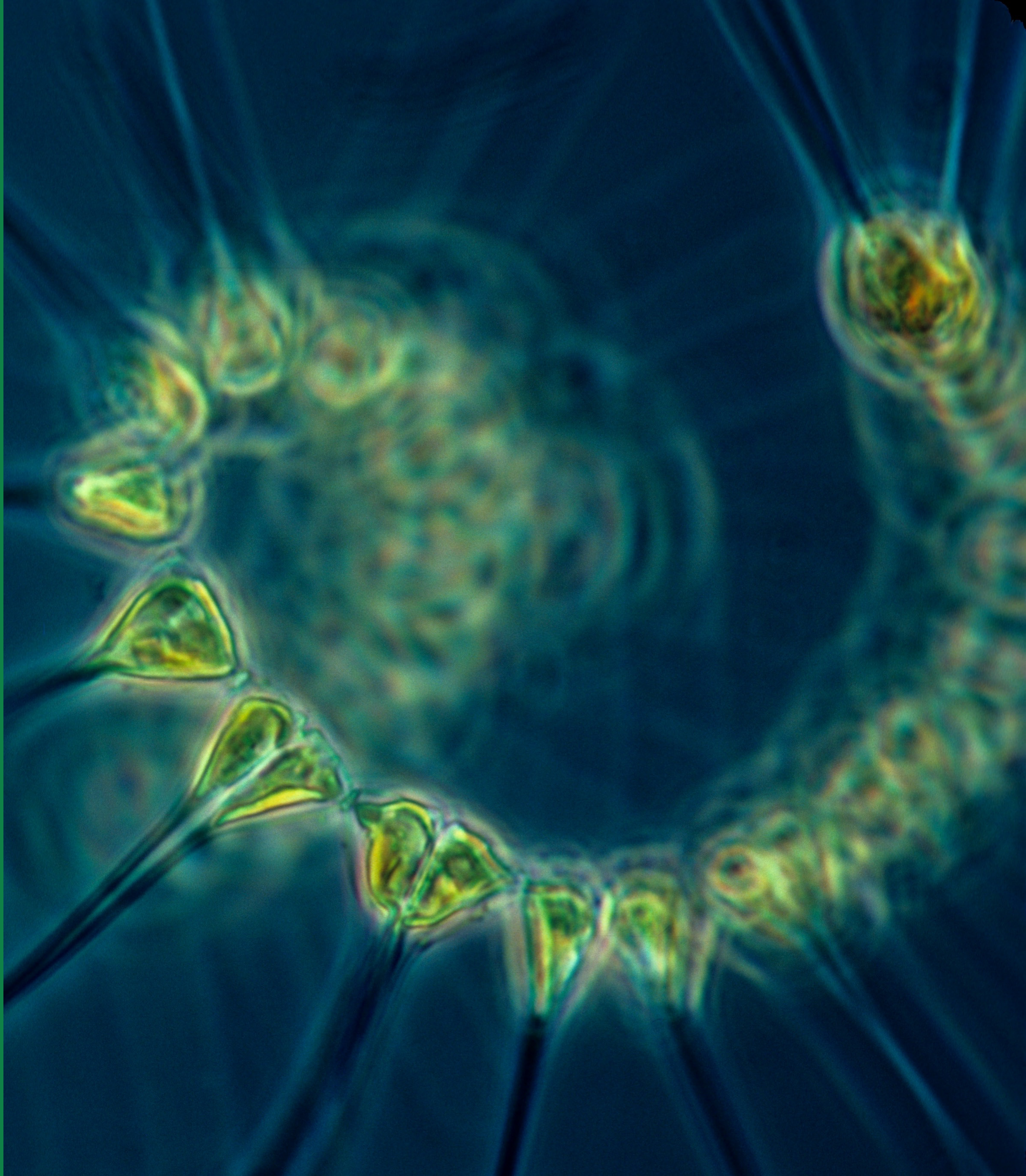

Programming outputs for constructing the plankton lifeform indicator from disparate data types

EcApRHA Deliverable WP1.1

Co-financed by the European Union

EcApRHA
an Ecosystem Approach to Regional Habitat Assessments

2017

EcApRHA

The EcApRHA project (Applying an Ecosystem Approach to (sub) Regional Habitat Assessment) aims to address gaps in the development of biodiversity indicators for the OSPAR Regions. In particular, the project aims to overcome challenges in the development of indicators relating to the MSFD (Marine Strategy Framework Directive 56/2008/EU), such as Descriptor D1 (Biodiversity), D4 (Food webs) and D6 (Seafloor integrity), and to deliver an action plan to OSPAR that will enable monitoring and assessment at the (sub) regional scale, to contribute to OSPAR Intermediate Assessment 2017.

Indicators related to the benthic and pelagic habitats, as well as food webs, are investigated within the project at different levels (from data to indicator; from indicator to habitat assessment; from habitat to ecosystem assessment).

Acknowledgment

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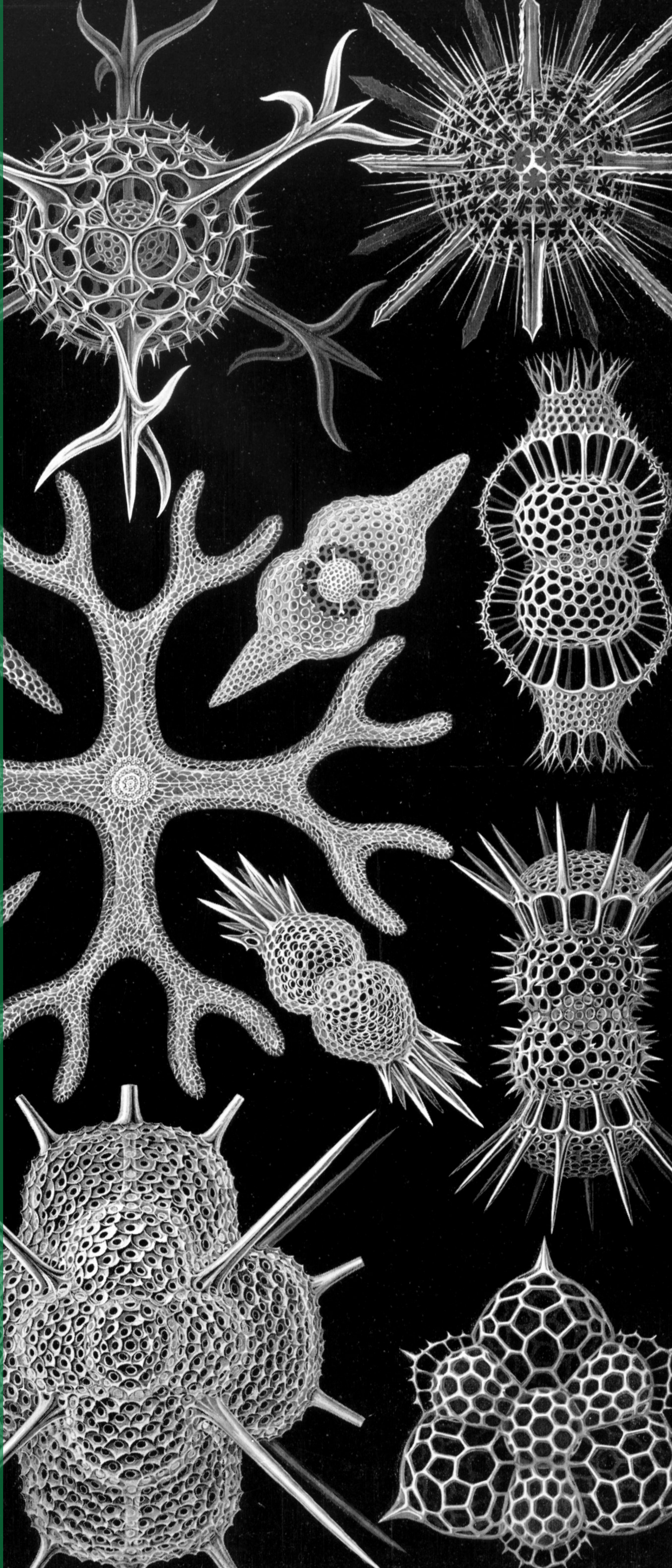
Contents



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Executive summary

The project "applying an ecosystem approach to (sub) regional habitat assessments (EcApRHA)" is centered on addressing gaps in the application of biodiversity indicators in the North-East Atlantic. These gaps have been focused into thematic actions in order to aid the development of such indicators, which are being developed within the OSPAR Commission[1] in response to the Marine Strategy Framework Directive (MSFD). An indicator is a compilation of distinct features that help to quantify descriptors outlined within the MSFD. The indicators support the assessment of moving towards Good Environmental Status (GES). This deliverable is focused around action 1.1, which addresses the need to aggregate disparate forms of plankton data through the integration of regional and local scale plankton datasets. A description is given of the process by which data was acquired, stored and manipulated for the plankton lifeform indicator (PH1). The methodology for PH1 and the outputs of this indicator using three providers of plankton data, which incorporate both local and regional scale data, are also provided.

[1] OSPAR is the mechanism by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic. www.ospar.org

1 Introduction

Indicators based on lifeforms can be used in some hydrographic conditions to assess community response to sewage pollution (Charvet et al., 1998; Tett et al., 2008), anoxia (Rakocinski, 2012), fishing (Bremner et al., 2004), eutrophication (HELCOM, 2012) and climate change (Beaugrand, 2005). Changes in ecologically-meaningful (relevant, see **Table 1** for explanation) pairs of plankton lifeforms, examined together, can provide information on ecosystem structure and energy flow. Combinations of lifeforms comprising lifeform pairs will depend on the habitat and the objective of the indicator, e.g. as a measure for pelagic habitats, food webs, seafloor integrity or eutrophication. An important advantage of these plankton indicators is that the proposed concepts are relatively easily transferable to other European regional seas (Gowen et al., 2011; Rombouts et al., 2013).

In practice, the use of functional types, such as lifeforms (a way of grouping the plankton by role/classification), is often favoured over indicator species since indices of species abundance are frequently subject to large inter-annual variation, often due to natural physical dynamics rather than anthropogenic stressors (de Jonge, 2007). Functional group abundance is often less variable because variability in the abundances of the group's constituent species averages out. Moreover, indicators based on functional groups have been proved relevant for the description of the community's structure and biodiversity, and are more easily intercomparable than taxonomic-based indicators (Estrada et al., 2004; Mouillot et al., 2006; Gallego et al., 2012; Garmendia et al., 2012).

When examined in ecologically-meaningful pairs, lifeforms can provide an indication of changes in: the transfer of energy from primary to secondary producers (changes in phytoplankton and zooplankton); the pathway of energy flow and top predators (changes in gelatinous zooplankton and fish larvae); benthic/pelagic coupling (changes in holoplankton (fully planktonic) and meroplankton (only part of the lifecycle is planktonic, the remainder is benthic)) (**Table 1**; see Gowen et al., 2011; Scherer et al., 2014). Abundance data can be used to inform lifeform pairs, depending on the lifeform in question and data availability from monitoring programmes. As the knowledge base increases, new pairs can be developed as indicators for other pressures than those currently measured.

2 Aims/Rationale

The aims of this deliverable are as follows: Firstly, to describe how disparate datasets (both local and regional) from several Member States were brought together to inform the development of the plankton lifeform indicator (PH1). And secondly, to describe the theory behind the indicator, along with the construction of the outputs of the plankton lifeform indicator.

"PH1 Changes in plankton communities" features a "Plankton Index" of lifeform pairs that have been developed to track changes in the state of the plankton in marine waters over time. The Plankton Index approach is based on work by Tett et al. (2008). Further development of the Plankton Index into an indicator was funded by the UK's Department for Environment, Food, and Rural Affairs (Defra) Contract ME5312 (Gowen et al., 2011; Scherer et al., 2014). Accordingly, much of the critical background technical information included here is based on Gowen et al., 2011 and Scherer et al., 2014; text adapted from these two sources is clearly marked. The main features of the Plankton Index method are: (i) the grouping of planktonic species into functional types or lifeforms (a way of grouping the plankton by role/classification); (ii) the display of changes in the abundance of each of these lifeforms using a state-space approach; (iii) calculating a Plankton Index (PI) to quantify possible changes in the state of the plankton relative to baseline or starting conditions; and (iv) relating trends in the PI to trends in human pressures and climate change indices (Gowen et al., 2011; Scherer et al., 2014).

The OSPAR Quality Status report (QSR) 2010 highlighted the potential impact of climate change and other anthropogenic pressures on plankton communities. Phytoplankton chlorophyll and phytoplankton indicator species are also assessed as parameters under the Common Procedure for eutrophication status assessment in problem and potential problem areas. There was no comparable quantitative assessment of changes in plankton communities to that provided by the plankton lifeforms indicator.

There are two differing but complimentary forms of plankton data currently available for PH1; the use of fixed-point time series data (local scale), and the use of transect time-series data (provided by the Continuous Plankton Recorder (CPR), regional scale). Before the initiation of EcApRHA, PH1 analysis using local scale data was lagging behind the analysis using regional data. This deliverable describes the process of integrating these two different sources of plankton data for use with the plankton lifeform indicator (PH1). By combining these differing datasets, a more complete analysis of the plankton can be conducted, and this resource can be updated as more data is acquired for future assessments/analysis.

3 Methodology

3.1 Lifeform Construction

Each lifeform pair consists of two ecologically-relevant lifeforms, which contain common functional traits (**Table 1;** see also Gowen et al., 2011; Scherer et al., 2014). The rationale for selecting the lifeform pairs and additional criteria containing supplementary information on lifeforms is contained in **Table 1**.

Lifeforms	**Additional criteria**	**Confidence**	**Explanation**
Diatoms v. dinoflagellates		High	Dominance by dinoflagellates may be an indicator of eutrophication or of change in water column stability and may result in less desirable food webs
Gelatinous zooplankton v. fish Larvae/eggs	Ctenophores and cnidaria	High	Indicator of energy flow and possible trophic pathways
Small copepods v. large copepods	Adults <1.9mm (not nauplii or eggs)	High	Size based indicator of food web structure and energy flows
	Adults >2mm		
Carnivorous zooplankton v. non-carnivorous zooplankton		Low	Indicator of energy flow and balance between primary consumers and secondary consumers
Crustaceans v. gelatinous zooplankton		High	Indicator of energy flow and possible trophic pathways
Large microphytoplankton v. small microphytoplankton	>20 µm cells, not colonies.	High	Size-based indicator of the efficiency of energy flow to higher trophic levels
	<20 µm cells, not colonies.		
Microphytoplankton v. non-carnivorous zooplankton	Biomass (example Chl, PCI)	High	Indicator of energy flow and balance between primary producers and primary consumers
	Abundance		
Diatoms v.		Low	Shift in primary producers may indicate

Lifeforms	Additional criteria	Confidence	Explanation
autotrophic and mixotrophic dinoflagellates			eutrophication
Pelagic diatoms v. tychopelagic diatoms		High	Indicator of benthic disturbance and frequency of resuspension events
Nuisance and/or toxin-producing diatoms v. diatoms Or Nuisance and/or toxin-producing dinos v. dinos		Low	Shift in algal community towards nuisance and/or toxic species which have the potential to impact other higher trophic level indicators
Holoplankton v. meroplankton		High	Indicator of strength of benthic-pelagic coupling and reproductive output of benthic versus pelagic faunas
Ciliates v. microflagellates	Including tintinnids	Low	Shift from primarily autotrophic to a more heterotrophic system
	All species < 20 µm		

Table 1: Lifeform pairs consist of two ecologically-relevant lifeforms. The 'Additional criteria' column contains supplementary information regarding particular lifeforms. Table modified from Gowen et al., 2011; Scherer et al., 2014.

A master species list was built by assigning functional traits to each new species then adding additional new datasets to expand the master species list (**Figure 1**). This master species list is provided in the annex file provided with this report, ANNEX>DATA > MERGED_MASTERLIST.xlsx. The species list for each new dataset was assigned a unique Aphia ID via the World Register of Marine Species (WoRMS, **Figure 1**):

http://www.marinespecies.org/aphia.php?p=match

The new dataset's species list was then compared with the plankton database's master species list via Aphia IDs and any new species were identified. This process ensures that each species is only entered in the database once. The new species were then manually assigned functional traits by searching the literature; fields were left blank where functional traits for species were unknown. Once traits were assigned, the new species were added to the master species list. Queries were constructed to build lifeforms from the functional trait information (**Table 2**).

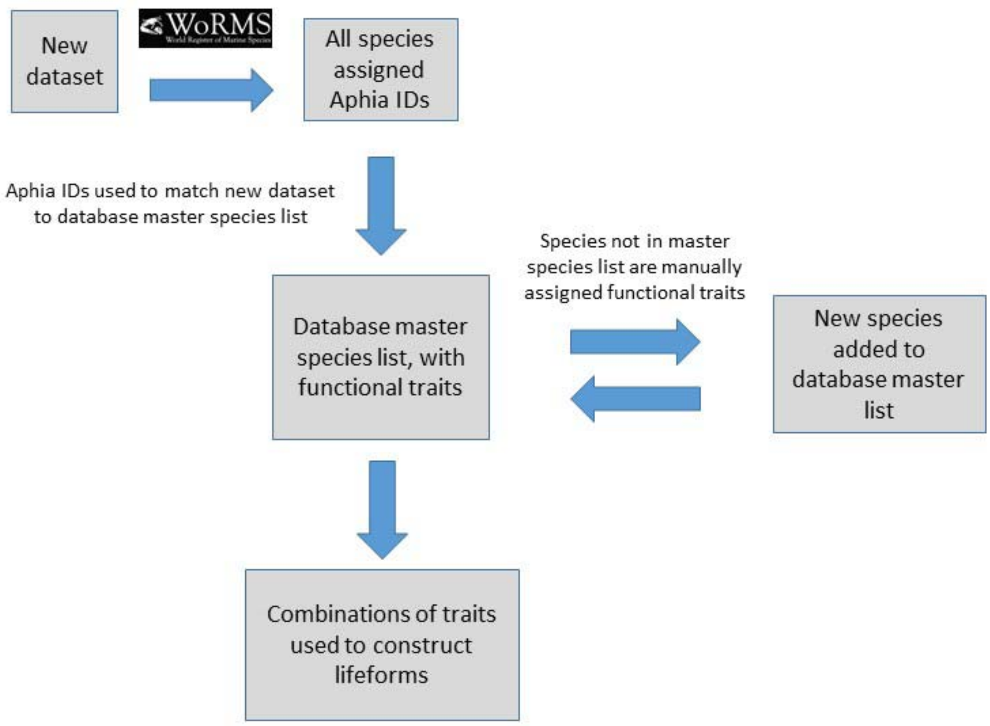

Figure 1: Schematic illustrating process undertaken to assign traits to species, then species to lifeforms. Each species must first be assigned a unique Aphia ID to determine if it is already present in the master species list.

Lifeform	**Traits**	**Criteria**
Diatoms	'Diatom' only	PhytoplanktonType=Diatom
Dinoflagellates	'Dinoflagellate' only	PhytoplanktonType=Dinoflagellate
Gelatinous zooplankton	'Gelatinous' only	PlanktonType=Zooplankton **AND** Gelatinous=Y
Fish larvae	'Fish' only	ZooType=Fish
Carnivorous zooplankton	'Carnivore' only	PlanktonType=Zooplankton **AND** Diet=Carnivore

Lifeform	**Traits**	**Criteria**
Non-carnivorous zooplankton	'Zooplankton' AND either 'Herbivore', 'Omnivore', OR 'Ambiguous'	PlanktonType=Zooplankton **AND** (Diet=Herbivore **OR** Omnivore **OR** Ambiguous)
Crustaceans	'Crustacean' only	Crustacean=Y
Large phytoplankton	'Phytoplankton' AND 'Lg'	PlanktonType=Phytoplankton **AND** PhytoplanktonSize=Lg
Small phytoplankton	'Phytoplankton' AND 'Sm'	PlanktonType=Phytoplankton **AND** PhytoplanktonSize=Sm
Phytoplankton	'Phytoplankton' only	PlanktonType=Phytoplankton
Autotrophic and mixotrophic dinoflagellates	'Dinoflagellate' AND either 'Auto' OR 'Auto/Mixo'	PhytoplanktonType=Dinoflagellate **AND** (FeedingMech=Auto **OR** Auto/Mixo)
Pelagic diatoms	'Diatom' AND 'Pelagic'	PhytoplanktonType=Diatom **AND** DiatomDepth=Pelagic
Tychopelagic diatoms	'Diatom' AND 'Tychopelagic'	PhytoplanktonType=Diatom **AND** DiatomDepth=Tychopelagic
Nuisance and toxin-producing diatoms	'Diatom' AND either 'Toxic' OR 'Nuisance'	PhytoplanktonType=Diatom **AND** (HAB = Toxic)
Nuisance and toxin-producing dinoflagellates	'Dinoflagellate' AND either 'Toxic' OR 'Nuisance'	PhytoplanktonType=Dinoflagellate **AND** (HAB = Toxic)
Holoplankton	'Holoplankton' only	Habitat=Holoplankton
Meroplankton	'Meroplankton' only	Habitat=Meroplankton
Large copepods	'Copepod' AND 'Lg'	Copepod=Y **AND** ZooSize=Lg
Small copepods	'Copepod' AND 'Sm'	Copepod=Y **AND** ZooSize=Sm
Ciliates	Ciliate'	PhytoplanktonType=Ciliate
Microflagellates	'Phytoplankton' AND 'Sm'	PhytoplanktonType=Dinoflagellate **AND** PhytoplanktonSize=Sm

Table 2: Each lifeform is constructed of organisms with particular traits. A query is then used to assign lifeforms to individual species.

	Easy to ID/speciate	Difficult to ID/speciate
Known traits	High	Low
Unknown traits	Low	Low

Table 3: A simple method of confidence valuation was used to determine the confidence in each lifeform.

A simple method of confidence assessment was used to determine the confidence in each lifeform (**Table 3**). Using expert opinion, each lifeform was evaluated on two characteristics: the ability to identify and speciate organisms in that lifeform using light microscopy and the understanding of the accuracy of determining traits assigned to the lifeform. For example, low confidence is assigned to the lifeform pair ‘diatoms vs auto- and mixo-trophic dinoflagellates’ as the mixotrophic and autotrophic mode of feeding of many dinoflagellates species is currently uncertain. Thus the accuracy of assigning the life form category is low in this case. Likewise, the lifeform pair ‘carnivorous zooplankton v. non-carnivorous zooplankton’ has a low confidence designation since the feeding habits of many abundant and common zooplankton species remain unknown. Only pairs with two high-confidence lifeforms (8 out of 12 lifeform pairs) were used in the OSPAR reporting (**Table 1**).

In summary

- ***Species are assigned functional traits and combinations of traits are used to construct lifeforms***
- ***Lifeform pairs consist of ecologically-relevant lifeforms, with each pair having an ecological rationale for selection***
- ***A simple confidence assessment method was used to evaluate the confidence in each lifeform. Only pairs containing two high-confidence lifeforms have been used for reporting***

3.2 Database and management

Data were requested following an OSPAR commissioned data call in May 2016. The data reporting format is within the annex; ANNEX>DATA>data_call> OSPAR_PH1_PH2_PH3_Reporting_Format.xls along with a guidance document. Details of the data provided are outlined in **Table 4.**

Key
Data not provided but potentially accessible if contacted directly
Data provided but not formatted
Data OSPAR formatted
Data formatted and species lists added, ready for analysis

OSPAR region	*Ecohydrodynamic area*	*Institute - Region*	*Contacts*	*Lat*	*Lon*	*Sampling frequency*	*Parameters*	*Period*	*doi/usage/notes*
ALL	ALL?	SAHFOS-CPR UK/European Seas	David Johns djoh@sahfos.ac.uk			Monthly	P + Z	2004-2014	Access and re-use may be restricted, contact Data Owner. doi:10.7487/2016.263.1.1008
Region II: Greater North Sea	Indeterminate	MSS - Stonehaven	Elieen Bresnan Kathryn Cook E.Bresnan@MARLAB.AC.UK	56.96	-2.13	Weekly	P + Z	1997-2014	Access and re-use may be restricted, contact Data Owner
	Region of freshwater influence	SEPA – Firth of Forth	Malcom Baptie (Elieen Bresnan) E.Bresnan@MARLAB.AC.UK	56.02	-3.17	Monthly	P		
		Cefas - Warp, Dowsing, W Gabbard, Gabbard, Liv Bay 1, Liv Ba, Celtic Deep, Oyster Goup	Elisa Capuzzo, Veronique Creach, Michelle Devlin michelle.devlin@cefas.co.uk			3 monthly	P		Access and re-use may be restricted, contact Data Owner
	Seasonally stratified	PML – L4	Angus Atkinson Claire Widdicombe aat@pml.ac.uk	50.25	-4.22	Weekly	P + Z	1992-2014 (P) 1988-2015 (Z)	Access and re-use may be restricted, contact Data Owner
	Seasonally stratified?	MSS – Scalloway (Shetlands)	E.Bresnan@MARLAB.AC.UK	60.18	-1.23	weekly	P	2002-present	
	Mixed inshore; tidal mixing	MSS – Scapa (Orkney Islands)	E.Bresnan@MARLAB.AC.UK	58.74	-3.04	weekly	P	2002-present	
	Permanently mixed	NLWKN - island "Norderney" and sampled at high tide. Landesamt für Landwirtschaft, Umwelt und ländliche Räume des Landes Schleswig-Holstein (LLUR)	Annika Grage annika.grage@nlwkn-ol.niedersachsen.de	53.697033	7.165052	Weekly	P + Chla TEMP SUSP DOXY PH PSAL	1999-2014	Access and re-use may be restricted, contact Data Owner
	Indeterminate	SMHI - Swedish national monitoring data - Swedish West coast	marie.johansen@smhi.se	56.6666	-12.1167	Monthly	P + Z	1986-2015 (P) 2007-2015 (Z)	Access and re-use may be restricted, contact Data Owner
	Seasonally stratified	AFBI – western Irish Sea	Cordula Scherer, Matt Service Matt.Service@afbini.gov.uk	53.78	-5.64	Monthly	P	2008-2010	Access and re-use may be restricted, contact Data Owner
	Permanently mixed	AFBI LBy06 – proposed new site	Matt.Service@afbini.gov.uk			3 monthly			
	Predominantly haline stratification	SEPA- Inner Firth of Clyde		55.94	-4.89	Monthly	P		
Region III: Celtic Seas	Complex seasonality	MSS – Loch Ewe	Elieen Bresnan Kathryn Cook E.Bresnan@MARLAB.AC.UK	57.84	-5.61	Weekly	P + Z	2002-2014	Access and re-use may be restricted, contact Data Owner
	Predominantly haline stratification	SAMS – LY1 (Firth of Lorne/Loch Linnhe)	Paul Tett Paul.Tett@sams.ac.uk	56.48	-5.5	Monthly	P	2000-present	
	Region of Freshwater Influence	EA – ECMAS - Inner Bristol Channel Minehead	Mike Best mike.best@environment-agency.gov.uk			Monthly	P	2010-2014	Access and re-use may be restricted, contact Data Owner
Region IV: Bay of Biscay and Iberian Coast?	Indeterminate	INSTITUTO ESPAÑOL DE OCEANOGRAFÍA - Radiales	enrique.nogueira@GI.IEO.ES			Monthly	P + Z		Access and re-use may be restricted, contact Data Owner
Region V: Wider Atlantic									
		Department of Bioscience Aarhus University - Danish	Hans Jakobsen & Eva Friis Møller efm@bios.au.dk hhja@bios.au.dk						Access and re-use may be restricted, contact Data Owner. Not recognized data format - ICES format?
		Water Framework Directive (WFD) - Phyto over 430 sites	Mike Best mike.best@environment-agency.gov.uk	430 sites	430 sites	Not always consistent	P	2007-2015	Access and re-use may be restricted, contact Data Owner

Table 4. Details of the plankton data provided. ANNEX>DATA>EcApRHA_data_providers.xlsx.

Due to data access restrictions, the datasets that were provided and the structured database will be managed using the restricted data access portion of the OSPAR Data and Information Management System, odims.ospar.org. Should the data need to be accessed, permission is required from the data/contacts/institute listed in **Table 4**.

Of the datasets acquired, Swedish Meteorological and Hydrological Institute (SMHI - Sweden), Plymouth Marine Laboratory (PML – United Kingdom) and Continuous Plankton Recorder (CPR-SAHFOS) data were used for analysis. The remaining datasets will be incorporated into the analysis when further resources become available.

The spreadsheets of data for each institute/provider used for the analysis were incorporated into a database (MongoDB) for efficient query. MongoDB is a free and open-source cross-platform document-oriented database engine, available for download here:

https://www.mongodb.com

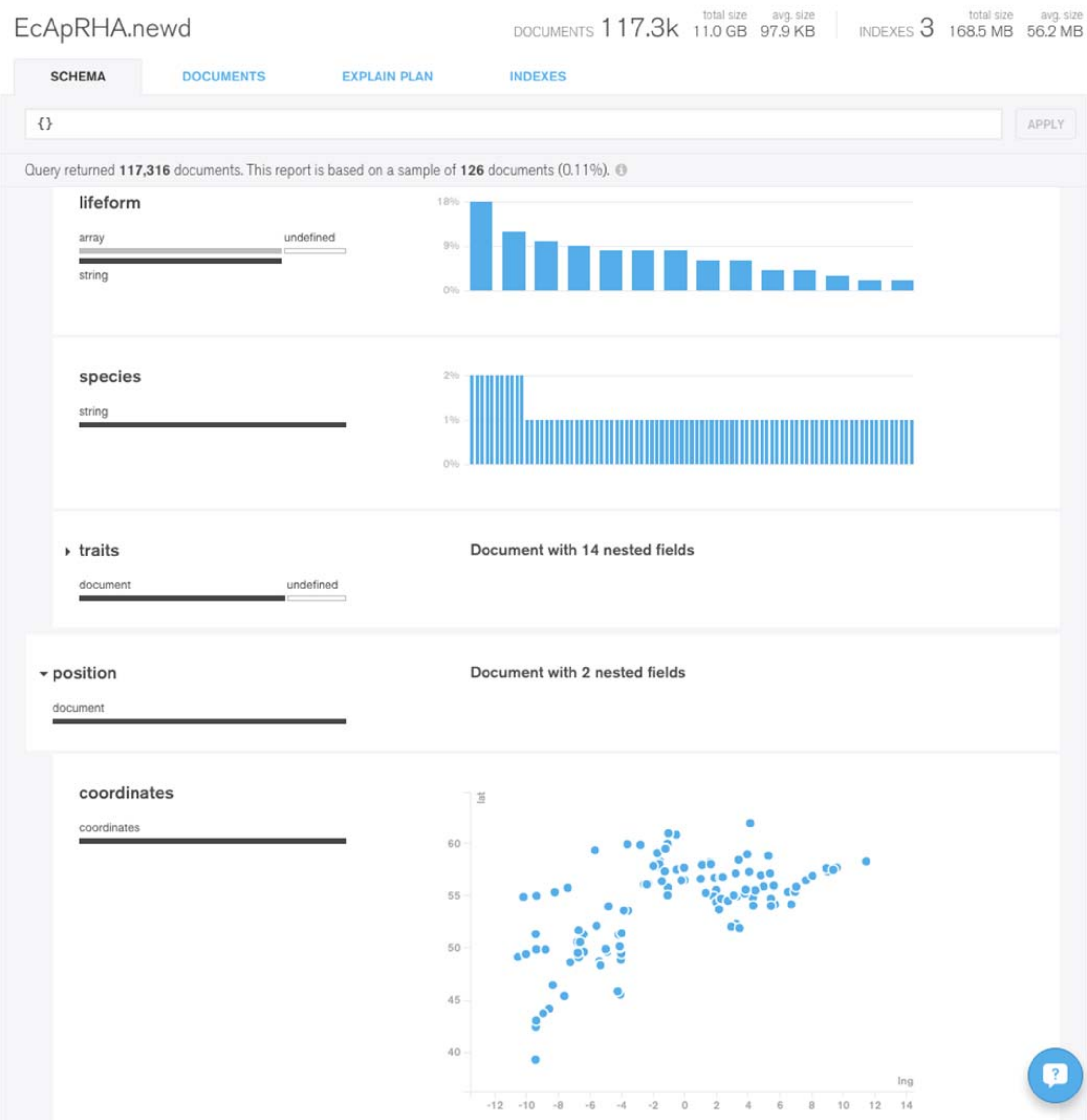

Figure 2: Visual example showing a sub-sample of the database within MongoDB database viewer Compass (a free GUI (Graphical User Interface) for MongoDB).

Custom Python scripts have been implemented to ingest the datasets, assign traits (**Table 2**) and lifeforms (**Table 1**) to species and then query the datasets into monthly lifeforms based on the traits, an example is given in **Figure 3**, shown in MongoDB Compass.

The database has been named 'EcApRHA', which consists of three collections:

1. The collection named ‘master’ is used as the master species list. This collection contains all of the species names, their Aphia ID and the traits and lifeforms associated with those taxa. It has the following structure:

master:

{_id:<unique ID>

Taxon:<taxon>

SecondaryID:<unique id>

AphiaID:<WoRMS ID>

traits:{<document of trait:value pairs>}

lifeform:[<array of traits >]}

2. The collection named ‘newd’ holds the new data that is added to the database from the different data providers, this collection contains the geo-spatial and abundance values for the different taxa. It has the following structure:

newd:

{_id:<unique ID>

Position:{Coordinates:[<array of lat and lon>],type:’point’}

date_time:<ISOdatetime>

depth_min:<minimum depth>

depth_max:<maximum depth>

survey:<survey ID>

plankton:[{

abundance: <measure of abundance>

species: <species>

aphiaid:<WoRMS ID>

traits:[<array of traits>]

lifeform:[<array of lifeforms>]}]}

3. The collection named ‘aphiaid’ is used to look up the new species that have been added to the database via their Aphia ID in order to assign traits from the masterlist. It has the following structure:

aphiaid:

{_id: <unique ID>

species: <species name>

aphiaid: <WoRMS ID>

survey: <survey ID>}

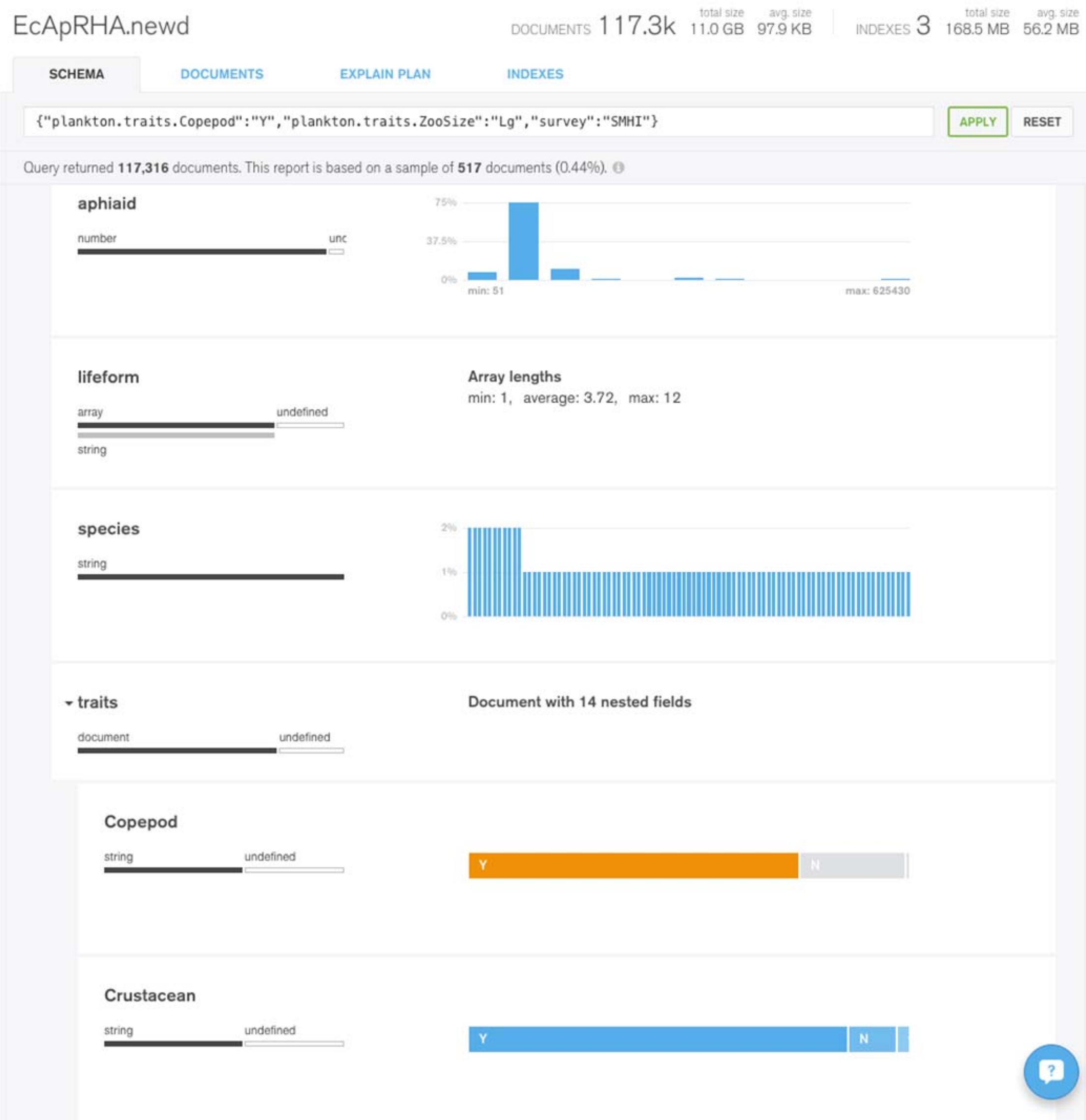

Figure 3: Visual example of a MongoDB query based on traits to investigate large copepods at Swedish Meteorological and Hydrological Institute (SMHI). The example query submitted to the database is written in the top text box of the figure.

3.3 Ecohydrodynamic areas

As in Gowen et al., 2011 and Scherer et al., 2014, ecohydrodynamic areas (EHD) (Van Leeuwen et al., 2015) were used to sub-divide OSPAR regions II, III and IV (http://www.ospar.org/convention/the-north-east-atlantic) into bio-physically defined regions for analysis (see **Figure 4**). EHDs were determined through analysis of a 50-year hind cast using the General Estuarine Transport Model (GETM) physical model of North Sea hydrodynamics (the model is at lower resolution in the Celtic Seas and is not developed for the Bay of Biscay). EHDs are constructed using density stratification, the most important large-scale physical feature in shallow shelf seas (Van Leeuwen et al., 2015). Density stratification occurs when the buoyancy of surface waters (influenced by fresh-water input or solar heating) is stronger than turbulence and vertical mixing, which limits vertical exchange across the pycnocline (van Leeuwen et al., 2015). The predominant EHD area types, based on water-column structure, are:

- Permanently mixed watersthroughout the year
- Permanently stratified waters throughout the year

- Regions of freshwater influence (ROFIs)
- Seasonally thermally stratified waters (for approximately half the year, including summer)
- Intermittently stratified waters
- Indeterminate regions (inconsistently alternate between the above)

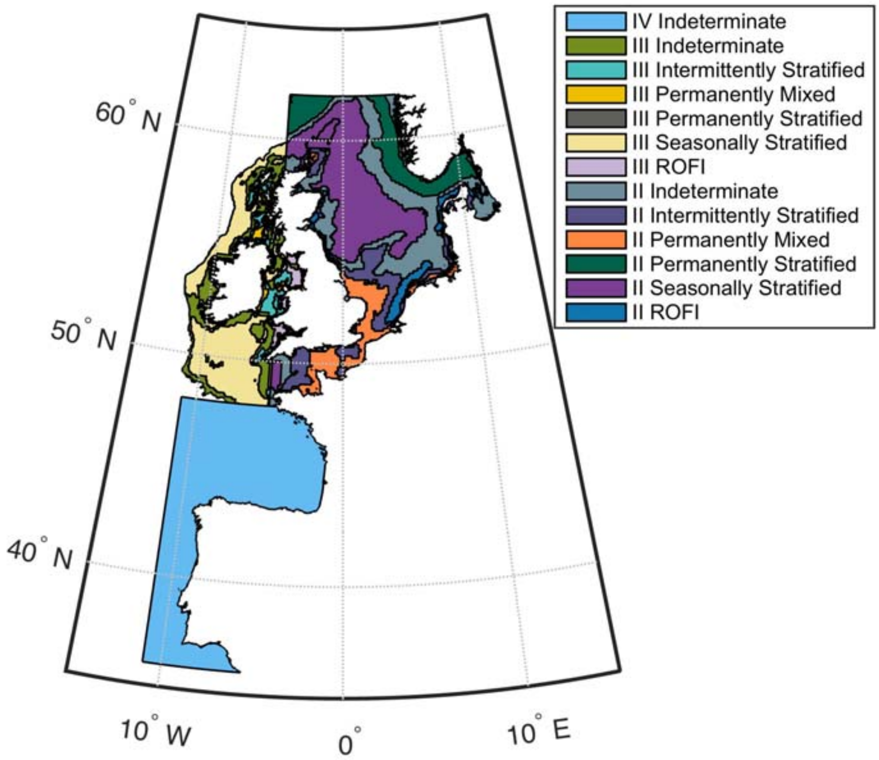

Figure 4. Map of eco-hydrodynamic areas (EHDs) in the Greater North Sea (II), Celtic Seas (III) and the Bay of Biscay and Iberian coast (IV), coloured by EHD type and region number. EHDs are constructed based on key water column features, which are important to plankton community structure and dynamics.

At the time of this analysis (2016), the EHD model is more reliable and detailed for the Greater North Sea than for the Celtic Seas. The model has not been developed for the Bay of Biscay and Iberian Coast so that area is considered as a single region of indeterminate status.

In summary

- ***Ecohydrodynamic areas (EHDs) are a geographical representation of the conditions which suits plankton distribution, dynamics and community composition***
- ***EHD's are constructed based on water column density stratification***

3.4 Plankton data

To date, the analysis has been carried out using phytoplankton and zooplankton data from three different sources. The data submitted by the Swedish Meteorological and Hydrological Institute (SMHI - Sweden) and Plymouth Marine Laboratory (PML – United Kingdom) are fixed point time-series. Four near-shore stations from SMHI were used in the analysis. These fall into the EHD region that describes the indeterminate regions of the Greater North Sea. Both zooplankton and phytoplankton are sampled 1-2 times per month throughout the year. The PML station (L4) is 13 km offshore from Plymouth and is sampled for zooplankton and phytoplankton and a suite of other variables on a weekly basis. Unlike the fixed point stations, data from the Continuous Plankton Recorder (CPR) survey is collected at a much broader spatial scale through the use of ships of opportunity. CPR data are collected offshore and in the open ocean and are best analysed at a monthly time scale. The CPR survey is coordinated by the Sir Alister Hardy Foundation for Ocean Science (SAFHOS) in the UK. Data from the different providers were not combined for analysis due to differences in sampling, plankton analysis and enumeration methods. Instead, the datasets were analysed separately. Each dataset has internal QA/QC procedures to ensure consistency and accuracy of the data.

As the SMHI stations are located in the Indeterminate EHD of the Greater North Sea their data were averaged for analysis. All CPR samples were averaged for each EHD type in each OSPAR sub region (see **Figure 5**). When further resources become available, more datasets from other OSPAR contracting parties will be incorporated into the analysis.

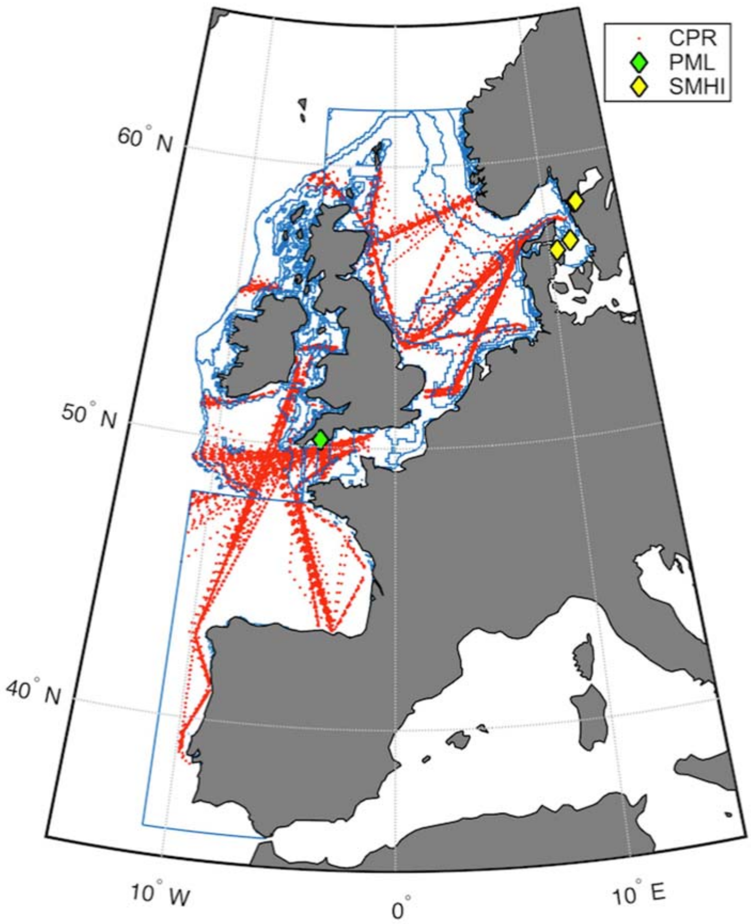

Figure 5: Map of sample locations. The data used for this analysis were obtained from the UK (CPR and PML L4) and Sweden (SMHI). Future work will expand the plankton database to include data from additional countries.

3.5 Plankton Index

As mentioned above, the Plankton Index was originally conceived by Tett et al. (2008) and developed into an indicator for UK waters during a Defra-funded project (Gowen et al. 2011; Scherer et al 2014). The work here furthers development to support OSPAR's implementation of the Marine Strategy Framework Directive.

The Plankton Index tool was used to track changes in the plankton community (following the state-space theory, see next section for details). This tool can be freely downloaded from the 'Resources' tab on Paul Tett's webpage:

http://www.sams.ac.uk/paul-tett

Under the ‘Software’ section:

Plankton Index : (2015) Matlab script package and guide to theory and software

Both files are provided in the annex provided; ANNEX> Plankton Index Code and Manual. This requires the software package Matlab to run the tool.

3.6 State-space theory (adapted from Scherer et al., 2014)

The following text is adapted from Scherer et al., 2014, but is included here as it is critical to the PH1 methodology.

As detailed in Gowen et al., 2011 and Scherer et al., 2014, Tett et al. (2008) proposed to track changes in the state of the phytoplankton community by means of plots in a state-space and calculating a Plankton Community Index (referred to here as a Plankton Index, PI). The conceptual framework is that ecosystems can be viewed as systems with an instantaneous state defined by values of a set of system state variables which are attributes of the system that change with time in response to each other and external conditions. Building on this approach and plotting plankton lifeform abundances in a multi-dimensional state space provides a means of monitoring changes in the organization of plankton communities. A state can be defined as a single point in state space, with co-ordinates provided by the values of the set of state variables, in our case two lifeform abundances, which together are used as a pair (Scherer et al., 2014).

In the example illustrated in **Figure 6**, the axes of the 2 dimensional (2D) space are the abundances of two lifeforms. Each point represents the state of the ecosystem in terms of the two lifeforms at the time the water sample was collected. Subsequent samples yield additional pairs of abundance values that can be mapped onto the lifeform state space.

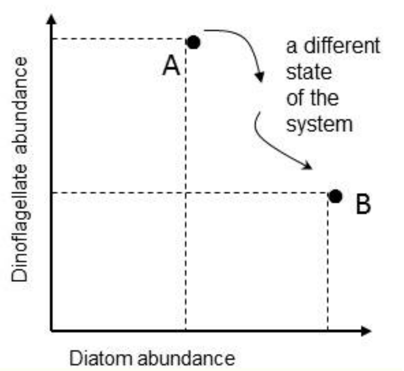

Figure 6. Mapping the abundance of two lifeforms in state space. Point A is the ecosystem state at the instant a water sample was taken and is characterised by the abundance of two lifeforms. Another sample, taken in the same location, yields abundance that map to a different point in the diatom-dinoflagellate state-space (point B). Adapted from Scherer et al., 2014.

As detailed in Scherer et al., 2014, the path between the two states is called a trajectory, and the condition of the plankton is defined by the trajectory drawn in the state space by a set of points. Such trajectories reflect: (i) cyclic and medium-term variability (the higher order consistencies in the plankton that result from seasonal cycles, species succession and inter-annual variability); (ii) long term variability that might result from environmental pressure. The seasonal nature of plankton production and the succession of species in seasonally stratifying seas, results in this trajectory tending in a certain direction (as plankton growth increases in the spring and declines during autumn), such that the trajectory tends towards its starting point. Given roughly constant external pressures, the data collected from a particular location over a period of years forms a cloud of points in state space that can be referred to as a regime. Long-term variability may show a persistent trend of movement away from a starting point in state space (Scherer et al., 2014).

To define a regime, an envelope can be drawn about this group of points, using a convex hull method. Because of theoretical arguments that the envelope should be doughnut-shaped with a central hole, bounding curves can be fitted outside and inside the cloud of points (**Figure 7**).

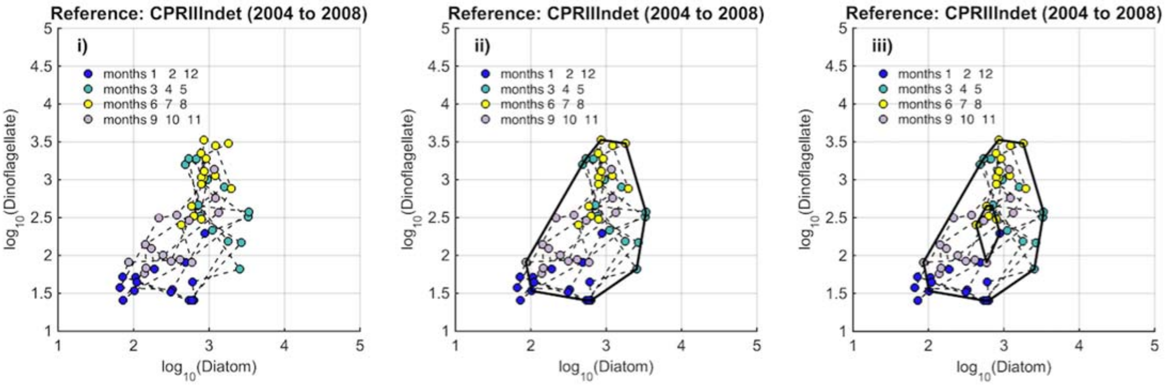

Figure 7. Creating the envelope in three steps, from left (i) to right (iii): An example of a regime defined by the envelope drawn by the convex hull method. The plot is displayed on a logarithmic scale because this is a common method of showing the full extent of seasonal variability. The data are from indeterminate area within the Greater North Sea (EHD II Indet, see **Figure 4**). The colour of each point corresponds to the season it was sampled within; winter months=blue, spring months =aqua, summer months =yellow, autumn months =purple. Modified from Scherer et al., 2014.

As stated in Scherer et al., (2014), the size and shape of the envelope are sensitive to sampling frequency and the total numbers of samples. Envelopes are made larger by including extreme outer or inner points, and the larger the envelope, the less sensitive it will be to change in the distribution of points in state space and therefore to detect a change in condition. Conversely, if too many points are excluded the envelope will be small and even minor changes will result in a statistically significant difference. It is therefore desirable to exclude a proportion of points(p), to eliminate these extremes, and so the 90th percentile was used. Envelopes are therefore drawn around the cloud of points to include a proportion (p = 0.9) of the points: with 5 % of points that were most distant from the cloud's centre, and 5 % of points that were closest to the centre excluded.

In order for a Plankton Index (PI) to be calculated, it is necessary to establish starting conditions as the basis for making comparisons. In the example here, data collected from the indeterminate area within the Greater North Sea (see **Figure 4**) between 2004 and 2008, are used to create an envelope. The envelope, thus drawn (**Figure 8i)**) defines a domain in state space that contains a set of trajectories of the diatom-dinoflagellate component on the marine pelagic ecosystem and thus represents the prevailing regime during the starting period.

Again, as detailed in Scherer et al., (2014), the next step is to map a new set of data into the starting condition state space and compare these new data (at least a dozen points (**Figure 8ii)**. The value of the PI is the proportion of new points that fall inside the envelope (or to be precise, between the inner and outer envelopes). In the example shown in **Figure 8**, 24 % or 17 of the 71 new points lie outside, and the PI is 0.76. A value of 1.0 would indicate no change, and a value of 0.0 would show complete change, with all new points plotting outside the starting condition envelope. The envelope was made by excluding 10 % of points, so some new points are expected to fall outside: 7.1 (10 % of 71), in the case of the example. Is 17 significantly more than 7.1? The exact probability of getting 17 by chance alone when only 7.1 are expected, can be calculated using a binomial series expansion, or by a chi-square calculation (with 1 df and a 1-tail test). The conclusion is that the value of 0.76, is significantly less than the expected value of 0.9, and so the condition of the phytoplankton in this region, as determined by diatoms and dinoflagellates, was statistically significantly (p< 0.01) different between the two periods.

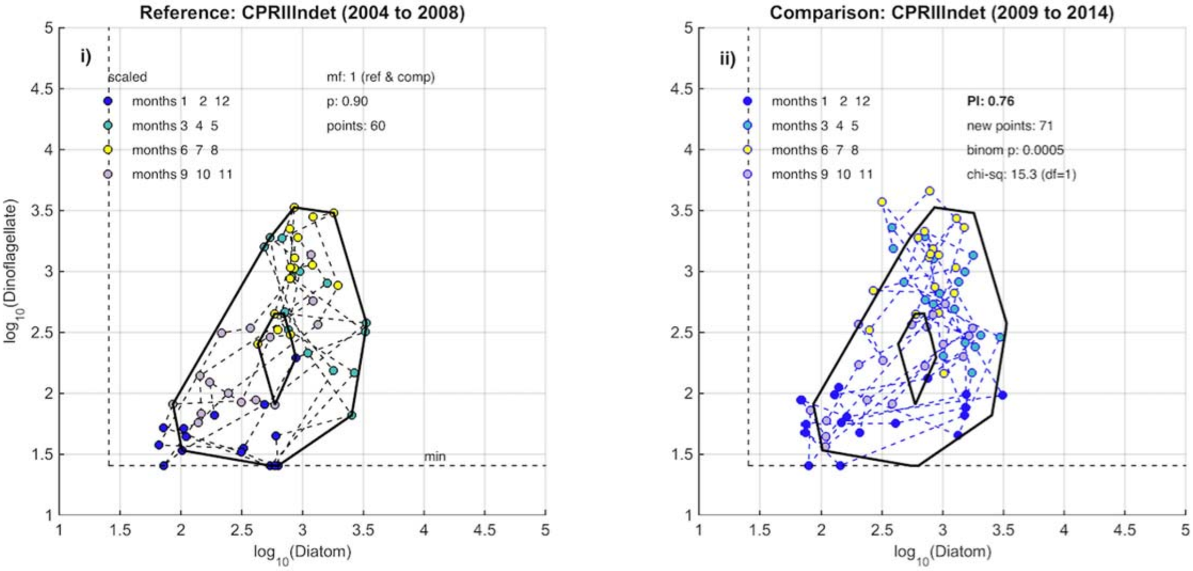

Figure 8. An example for the comparison between two periods within the indeterminate area of region II (see **Figure 4**), i) is the reference period of 2004 to 2008, ii) is the comparison period of 2009 to 2014. The PI value of 0.76 shows a significant change between the two communities with a binomial p-value of 0.0005 (where significance is reached for p-value < 0.01). Adapted from Scherer et al., (2014).

A time-series of the index is produced by comparing the starting condition envelope with data collected from each subsequent year; this is shown in **Figure 9.** Although in **Figure 8** the example showed a significant change between the two periods, upon investigation of the annual PI time-series in **Figure 9**, there are no significant changes on an annual basis. The year that showed the most change from the reference condition was 2012 (lowest PI value in **Figure 9ii)**). This is because there was a larger bloom of dinoflagellates than previous years.

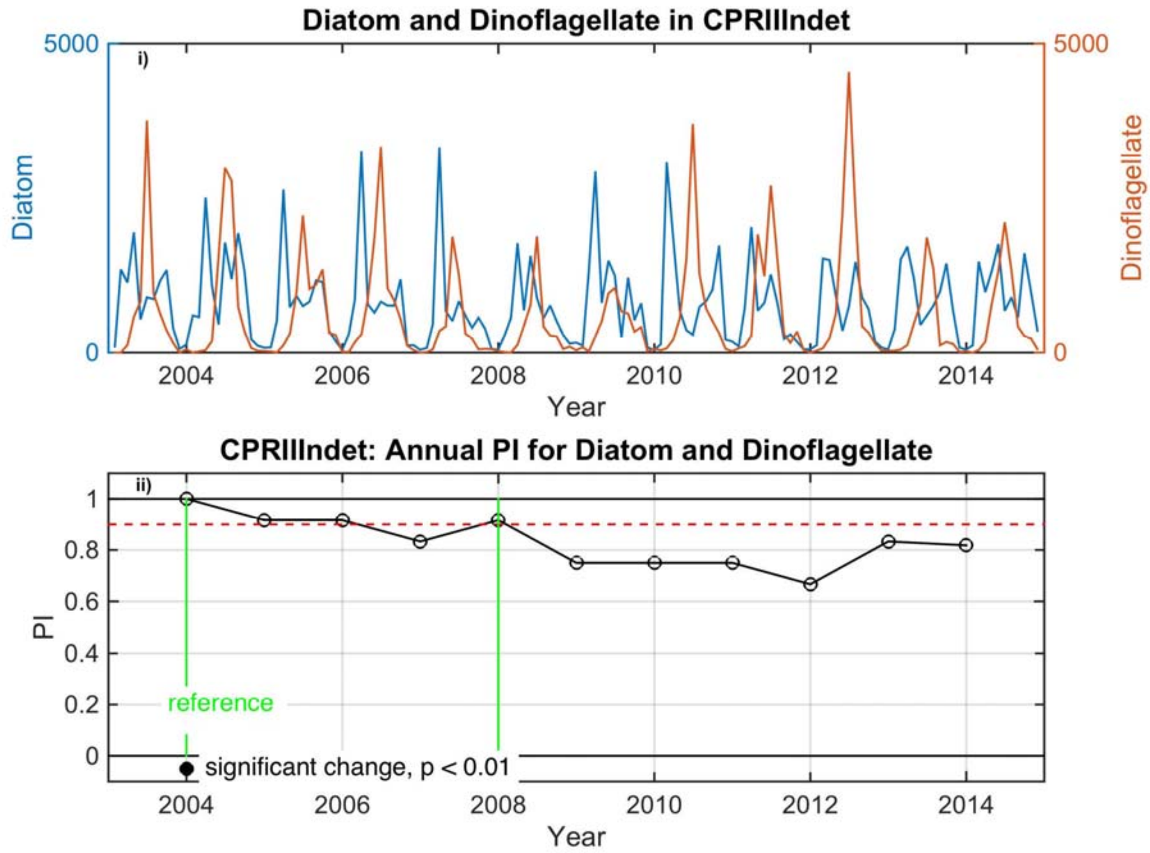

Figure 9. An example of the annual PI time-series plotted with the monthly plankton data. i) Monthly time-series of diatom (blue) and dinoflagellate (orange) abundance using CPR data in the EHD area II Indeterminate (see **Figure 4**). ii) Annual time-series of PI values that are calculated by comparison to the reference envelope that was created in Figures 7 and 8 (green lines, between 2004 and 2008). Annual PI not significantly different from the starting condition (p>0.01) = open circle. Annual PI significantly different from the starting condition (p<0.01) = closed circle (black).

Two lifeforms will not be sufficient to describe all of the important characteristics of the plankton. In principle, there is no constraint to adding more lifeforms to the state space plots (see Tett et al., 2013 and Scherer et al., 2014.). The rule is that each additional lifeform has to be different from those already used and the axis for each new lifeform has to be drawn at right-angles to all existing axes. The state space map therefore has to be drawn in as many dimensions as there are state variables (lifeforms) but this becomes complicated when considering the number of lifeforms that we might want to use to fully represent the community structure of the plankton (Scherer et al., 2014)..

3.7 Starting conditions and analysis

The period of 2004-2008 was selected for the starting conditions as each dataset used (CPR, SMHI, L4) has adequate data during that period to construct a reliable starting condition envelope. Additional European datasets will be added in the future as resources become available. This envelope represents starting conditions and not reference conditions. The starting condition envelope was compared with data from the subsequent six-year period (2009-2014). The 2009-2014 period was chosen as it corresponds to the most recent period with data and it is the same temporal length as the MSFD assessment period. Gowen et al. (2011) and Tett et al. (2008) provide further technical information on the method.

The individual outputs of the plankton lifeform indicator analysis for L4, SMHI and CPR data are provided in the annex; ANNEX> PH1 Results extended; as figures and data snapshots.

In summary

- ***Two dimensional state space plots of specific pairs of plankton lifeforms can be used to investigate the pelagic habitats and can be combined to provide a holistic plankton indicator to track changes in the condition of the planktonic component of the pelagic ecosystem.***
- ***Time-series of the index will be used to track persistent changes in the condition of the plankton over time and to relate any such trend to trends in anthropogenic and climate pressures.***
- ***<u>At this stage of analysis, starting conditions do not represent reference conditions.</u>***

4 Knowledge Gaps/Recommendations

The integration of regional and local scale data has been initiated by creating a database linking species to lifeforms. This provides a more complete dataset for analysis, and should be maintained and updated for future assessments. There are a number of actions that should be carried out in order to develop the method and implementation further, listed below:

- Determination of time period representing starting conditions and identification of assessment thresholds should be tested.
- Refinement of spatial scale into ecohydrodynamic areas in the Bay of Biscay.
- Investigation into appropriate HAB lifeform pair.
- Investigation and incorporation of additional and/or refined lifeforms and the interpretation of their relative dynamics.
- Incorporation of additional plankton datasets into the database.
- Examination of drivers of change in plankton lifeforms in each area.
- Additional scientific research is required to determine traits for many plankton species – for some species even information about basic biological characteristics, such as diet, is not yet known.
- Investigation into the role of pico and nanoplankton in the ecosystem. These small size categories are difficult to measure routinely and thus mainly ignored. Their ecosystem role needs further investigation so that they can be included in an appropriate new or existing lifeform.
- Addition of other datasets to build and develop the database further. It is desirable to have a centralised database, this will need to be maintained and developed as new information becomes available.

5 Glossary

Term	Description	Source
Accumulative impacts	The effect or consequence of a single pressure type on an ecosystem component over a period of time. The impact will be determined by both the exposure and the sensitivity (the ability of a habitat to tolerate pressure and the time the habitat needs to recover following removal of the pressure) of an ecosystem component to a pressure type.	Judd et al. 2015; ICES 2016
Aggregate	The combination of comparable information from an indicator or criterion across temporal and spatial scales.	Borja et al. 2014
Anthropogenic pressure	A human activity causing an effect on any part of the ecosystem and that may change the environmental state or condition of that part of the ecosystem over a given period of time. A pressure can be of physical, chemical or biological nature. A list of defined pressures has been formally agreed by the OSPAR Intercessional Correspondence Group on Cumulative Effects (ICG-C).	Foden et al. 2011, Goodsir et al. 2015, Oesterwind et al. 2016, OSPAR Intercessional Correspondence Group on Cumulative Effects (ICG-C)
Baseline condition	The qualitative or quantitative description of the state a EUNIS level habitat type against which subsequent values of state are compared. A baseline condition can be set at different levels (e.g. pristine, least damaged, or to be maintained in its current state) according to the management objective for that particular habitat.	OSPAR 2012
Benthic Habitat	The place where species, characterised by the physico- chemical (e.g. sediment, depth, salinity, temperature, etc.) and biological conditions (fauna, flora, algae) in the area. Benthic habitats may comprise of one or several biological communities depending on the European Nature Information System (EUNIS) habitat classification level. EUNIS is a system to classify benthic habitats on different nested scales. The higher the level, the more detail and sub-types of habitats are included.	Davies et al. 2004; Elliott et al. 2016
Biota	The living parts of the environment, including the association of a lot of interrelated populations that belong to different species inhabiting a common environment.	
Biological community	Assemblage or association of populations of two or more different species occupying the same geographical area and in a particular time.	Verhoef & Morin 2010

Coastal waters	Coastal waters are those waters surrounding the coastline of a country out to 1nm.	
Criteria	A particular aspect of biodiversity that requires their status to be assessed e.g. population size.	OSPAR 2012
Cumulative pressure	The size and location of multiple pressures, which overlap in an area or on a habitat.	Foden et al. 2011; Judd et al. 2015
Descriptor	Qualitative features which are used to assess GES. 11 are described within the MSFD, three of which (biological diversity, seafloor integrity and food webs) relate to the EcApRHA project.	EU. 2008
Ecological Quality Ratios	Refers to an index (between 0 and 1) used to assess MSFD biological indicators against reference conditions for a specific area.	Borja et al. 2004, 2007, Borja & Rodríguez 2010, Tett et al. 2013
Ecosystem	An ecosystem consists of biotic (community of organisms) and abiotic (physical, chemical and biogeochemical) features, processes and interactions in a defined space at a given time.	(Dauvin et al. 2008, Curtin & Prellezo 2010)
Ecosystem approach	The comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity.	OSPAR, 2016d
Ecosystem components	The term ecosystem component (mentioned in Annex VI of the Directive 2008/56/EC: 'measures that influence the degree of perturbation of an ecosystem component' and 'tools which guide human activities to restore damaged components of marine ecosystems') includes both biota and habitats as parts of the ecosystem. With regard to the NEAT tool, different ecosystem components have been defined such as birds, fish, benthic vegetation or pelagic organisms.	Patricio et al. 2014 ; www.devotes-project.eu/neat-manual-v1-2; combined with my complementary information
Ecosystem perspective:	The EcApRHA project draws from the OSPAR definition of the ecosystem approach. However, within the frame of the project, an ecosystem perspective refers to the exploration of potential cross-overs between the different indicators of descriptors 1, 4 and 6 developed by each of the EcApRHA work packages. By identifying cross-overs between the different indicators and descriptors of the three work packages it is hoped to be able to integrate where possible, the assessment of the different indicators. In identifying links between the	

	indicators and the state of the marine environment it is hoped that management options can be proposed based on pressures exerted on the marine environment.	
Environmental Status	Refers to the overall state of the environment in marine waters, taking into account the structure, function and processes of the constituent marine ecosystems together with natural physiographic, geographic, biological, geological and climatic factors, as well as physical, acoustic and chemical conditions, including those resulting from human activities inside or outside the area concerned	EU. 2008
Good Environmental Status	Refers to the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations.	EU. 2008
Ground-truth	*In situ* sampling to verify a marine habitat type and its condition.	EMODnet 2016
Habitat	The term ‘habitat’ has several meanings in common usage linked to the biotic and abiotic environment. The use of the term 'habitat' in the EcApRHA project, taking into account food webs, pelagic and benthic habitat work package indicators developed, refers to the environment a species or community of species inhabit/occupy at a particular stage in its life cycle.. In the NEAT tool, the habitat (e.g. pelagic, reef) is hierarchically defined under a spatial assessment unit (SAU). These habitats are nested and hierarchically structured so an indicator can be assigned to one or more SAU.	OSPAR 2016; Patricio et al. 2014; www.devotes-project.eu/neat-manual-v1-2
Indicator	Are distinct features that help quantify descriptors outlined within the MSFD.	EU. 2008
Integrated approach	The combining of information from different (scientific) indicators into one higher-level indicator or to criterion-level, or the combining of information from two or more criteria to descriptor level or to an alternative grouping of criteria (e.g. for an ecosystem component, or for a grouping of criteria below descriptor level).	Borja et al. 2014
Least damaged habitats or condition	The state of a habitat that may have been subject to some anthropogenic impacts or disturbance, but whose structure and functions are not adversely modified. The latter will need a certain level of	Elliott et al. 2016

	expert judgment. However, through exploring pressure-state relationships, it will be possible to determine whether the least damaged habitat's structure and function are not adversely modified.	
Metadata	The data helping to define or to understand other data. For example, date of sampling and geographical location of a station which is associated with biological data such as species abundance.	FGDC Content Standard for Digital Geospatial Metadata Workbook, Ver 2.0, May 1, 2000 within BH2_IA2016.doc
Monitoring	The different observatory methods to survey species, habitats, ecosystems, etc. in time.	Schmitt et al. 1996
Multi-metric indices	A quantitative monitoring and assessment tool to undertake an integrative assessment of the marine environment or part of. The tool combines measures of the status of the marine environment into a single unit.	(Schoolmaster et al. 2012)
Pelagic habitat	Environmental (i.e. physico-chemical and biological) conditions that support biological communities in the water column of shallow or deep sea, or enclosed coastal waters. Because of the strong temporal nature of the pelagic environment, the water column at a given location will be classified differently at different times of the year (EUNIS habitat type code A7).	EEA 2016
Predominant species and habitat	Habitat category referred to in Table 1 of Annex III to the Directive. Widely occurring and broadly defined habitat types (e.g. shelf sublittoral sand or mud) that are typically not covered by other legislation (see 'special habitat types').	OSPAR 2012
Region	The MSFD derestriction is split into four regions (Baltic sea, the North East Atlantic Ocean, the Mediterranean Sea and the Black Sea) to facilitate implementation of the Directive, taking into account hydrological, oceanographic and biogeographic features.	EU. 2008
Ecohydrodynamic region (EHD)	Bio-physically defined areas, constructed using density stratification, the most important large-scale physical feature in shallow shelf seas. Density stratification occurs when the buoyancy of surface waters (influenced by fresh-water input or solar heating) is stronger than turbulence and vertical mixing, which limits vertical exchange across the pycnocline.	van Leeuwen et al. 2015

Special habitat	Habitat that are protected under the habitats and water framework directive and OSPAR.	EU. 2008
Sub-region	An area within EU regional seas which has similar range of benthic habitats and oceanic conditions. Within OSPAR's mandate, the North East Atlantic Ocean, this includes the Celtic seas, Greater North Sea, Bay of Biscay and the Iberian Coast, Macaronesian biogeographic region.	EU. 2008

6 Glossary Reference

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