Long-term plankton and environmental monitoring dataset from the ~~Marine Protected Area~~ marine protected area of the Iroise Marine Natural Park (2010–2023) in the Iroise Sea, North Atlantic

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Abstract. CE2 CE3 CE4 This data paper presents a long-term monitoring dataset of phytoplankton (2010–2022) and zooplankton (2010–2023) communities, as well as associated environmental parameters (2010–2023), from the Iroise Marine Natural Park, Iroise Sea, North Atlantic, France's first ~~Marine Protected Area~~ marine protected area (Drago et al., 2025). The dataset combines traditional microscopy-based phytoplankton counts with zooplankton data (abundances) obtained from digitized images using the ZooScan imaging system, along with surface and bottom temperature and salinity measurements. Sampling was conducted seasonally along two main transects and three coastal stations, capturing both spatial and temporal dynamics of plankton communities. Phytoplankton was identified at the species level by the same taxonomist during all the ~~time-series~~ time series (573 taxa in total). From their individual images, zooplankton ~~was~~ were automatically sorted into 103 taxonomic and morphological groups, validated by an expert, and compiled into a data table, allowing both community and individual approaches using abundances and biovolumes at both individual and community levels. Individual zooplankton images have also been made available for further morphometric analyses. This ~~14 year long~~14-year-long, spatially and temporally resolved zooplankton imaging dataset is part of an ongoing effort to enhance the availability of zooplankton imaging data, locally and globally. This, as a whole dataset, can be used to study the influence of ~~coastal-offshore~~ coastal–offshore environmental gradients on marine plankton biodiversity patterns, especially in protected waters at the intersection of the English Channel and the Atlantic Ocean, in a region characterized by the presence of the Ushant front.TS1

1 Introduction

Planktonic organisms play a pivotal role in marine and freshwater ecosystems (Grigoratou et al., 2025). They are key contributors to the biological carbon pump, with phytoplankton fixing atmospheric CO_2 (Iversen, 2023; Siegel et al., 2023) and zooplankton exporting this carbon passively through the sinking of molts and carcases and fecal pellets, ~~and~~ as well as actively through diel vertical migration (Steinberg and Landry, 2017). At the base of the aquatic food

webs (Ikeda, 1985), these organisms sustain diverse marine life, from marine mammals ~~, birds and~~ and birds to fish (Chavez et al., 2008; Frederiksen et al., 2006), with substantial ~~socio-economic~~ socioeconomic implications as water quality indicators (Suthers et al., 2019) and as a food source for fisheries (Lehodey et al., 2006; van der Lingen et al., 2006), but ~~also~~ they also have potential negative impacts on aquaculture, human health, and activities during harmful bloom events (Griffith and Gobler, 2020).

Long-term monitoring of planktonic communities through ~~time-series~~ time series datasets has proven invaluable for understanding marine ecosystem dynamics. The number of sustained observation programs has grown significantly in past decades, spanning diverse environments from coastal monitoring stations to ~~open ocean~~ open-ocean sites (Batchelder et al., 2012; Berline et al., 2012; Grandremy et al., 2024). These datasets have revealed crucial insights into planktonic dynamics across multiple temporal and spatial scales, though continued expansion of such monitoring efforts remains important for comprehensive ecosystem understanding (Jonkers et al., 2022; Pitois and Yebra, 2022).

Imaging technologies have emerged as powerful tools for studying planktonic communities, enabling high-throughput analysis of both taxonomic and trait-based characteristics (Irisson et al., 2022; Orenstein et al., 2022). Datasets originating from these technologies are providing unprecedented views into the diversity and distribution of zooplankton (Panaïotis et al., 2023; Perhirin et al., 2023; Vilgrain et al., 2021) and phytoplankton (Bolaños et al., 2020; Kenitz et al., 2020; Sonnet et al., 2022). These diversity and distribution patterns reveal how plankton communities respond to environmental changes and drive ecosystem processes. They provide critical insights into food web dynamics, carbon cycling efficiency, and ecosystem health (Grigoratou et al., 2025; Miloslavich et al., 2018). These imaging approaches allow for faster processing of more samples while capturing detailed morphological information. Indeed, although studies have traditionally focused on the taxonomic diversity of plankton, there is a growing recognition of the relevance of trait-based approaches, which can offer deeper insights into ecosystem functioning and community responses to environmental changes (Kiørboe et al., 2018; Litchman et al., 2013; Martini et al., 2021). Traits such as body size and shape, feeding mode, and motility can provide a more mechanistic understanding of plankton ecology and their role in biogeochemical processes (Buitenhuis et al., 2013; Litchman et al., 2015).

Despite these technological advances, significant challenges remain in making plankton datasets widely accessible and useful for the broader scientific community, particularly given the substantial costs and human resources involved in marine sampling campaigns, including varying detection capabilities across instruments and lack of standardized data formats across platforms, ~~and~~ as well as insufficient metadata documentation. The need for standardized, well-documented, and openly accessible datasets is increasingly critical, particularly for supporting long-term ecological monitoring and modeling efforts. Following FAIR principles (~~Findable, Accessible, Interoperable, and Reusable~~findable, accessible, interoperable, and reusable) defined by Wilkinson et al. (2016), modern plankton datasets must include comprehensive metadata and standardized protocols to ensure their utility across different research applications (Titocci et al., 2025). Recently, several plankton datasets have been published following the FAIR principle (Acri et al., 2020; Devreker et al., 2024; Dugenne et al., 2024; Grandremy et al., 2024). Following this trend, we present here a long-term dataset (2010–2024) from the Iroise Marine Natural Park, France's first ~~Marine Protected Area~~ marine protected area (MPA). The dataset includes a phytoplankton ~~time-series~~ time series based on microscopy counts (conducted by two taxonomists throughout the study period) and a zooplankton dataset that comprises digitized images obtained by the ZooScan imaging system and associated abundances. Both datasets are accompanied by contextual environmental variables (temperature, salinity). These datasets will contribute to a better understanding of plankton dynamics in protected Atlantic waters, while serving as examples of how traditional and modern approaches could be effectively combined and shared to support observational studies, monitoring surveys, and modeling efforts (Holland et al., 2025).

2 Study site

The Iroise Marine Natural Park ("Parc Naturel Marin d'Iroise" in French; https://parc-marin-iroise.fr/TS2), established in 2007 as the first French ~~Marine Protected~~ marine protected Area (MPA), spans 3550 km^2 off the western coast of Brittany. Managed by the French Biodiversity Agency (Office Français de la Biodiversité, OFB), this MPA encompasses the Iroise Sea, a unique ecosystem located at the intersection of the English Channel and the Atlantic Ocean. The MPA's monitoring activities align with two major European directives: the Water Framework Directive (WFD/DCE, 2000/60/CE, https://eur-lex.europa.eu/eli/dir/2000/60/ojTS3) for coastal waters and the Marine Strategy Framework Directive (MSFD/DCSMM, 2008/56/CE, https://eur-lex.europa.eu/eli/dir/2008/56/ojTS4), which aims to achieve Good Environmental Status of marine waters. In the context of the Iroise Marine Natural Park (IMPN), this translates into a regulatory framework requiring high levels of protection with regulated activities. Implementation includes governance actions such as the management council providing guidance on agricultural activities that may impact eutrophication and initiatives to enhance the purifying role of coastal wetlands. As ~~Essential Ocean Variables~~ essential ocean variables (EOVs), plankton communities are key indicators within the MSFD framework, providing crucial information about ecosystem health and food web dynamics (Batten et al., 2019). Monitor-

ing planktonic communities is particularly relevant for MPAs like the Iroise Marine Natural Park, as their rapid responses to environmental changes provide early warning signals of ecosystem shifts, such as harmful algal blooms, that are crucial for adaptive management strategies. It is also particularly relevant for fisheries (Benedetti et al., 2019; Berthou et al., 2010; Duhamel et al., 2011), as small pelagic ~~fishes~~ fish like sardines (*Sardina pilchardus*) feed on plankton (Garrido et al., 2008). As a result, the Iroise Sea also holds significant economic and cultural importance for France's sardine fishery. A substantial portion of France's sardine catches come from this region and adjacent waters, with the port of Douarnenez serving as a historic sardine fishing hub and exemplifying a traditional sardine fishing community (Le Floc'h et al., 2020). Beyond its ecological and conservation value, this economic and cultural heritage contributed to the creation of the Iroise Marine Natural Park as the first ~~Marine Protected Area~~ marine protected area in France. This makes the long-term monitoring of plankton communities crucial not only for biodiversity conservation but also for preserving the economic and cultural heritage that led to its designation as France's first ~~Marine Protected Area~~marine protected area.

The Iroise area also serves as a natural laboratory for studying planktonic community responses to climate change and understanding connections between lower trophic levels and fisheries. This is due to its complex oceanography, particularly the seasonal Ushant thermal front (Le Boyer et al., 2009; Pingree et al., 1975), which can act as a barrier for the dispersal of planktonic organisms between the Lusitanian biogeographical province in the ~~South and the Boreal~~ south and the boreal biogeographical province in the ~~North~~ north (Ayata et al., 2010). This front, along with an inner front and distinct ~~surface-bottom~~ surface–bottom dynamics, creates diverse habitats that support rich plankton communities and overall marine biodiversity (Cadier et al., 2017; Ramond et al., 2021; Schultes et al., 2013).

3 Material and methods

3.1 Sampling

Plankton community sampling in the Iroise Marine Natural Park was conducted through regular monitoring cruises operated by the OFB-PNMI on board the vessel N/O *Albert Lucas* for the years 2011 and 2012 ~~,~~ and on board the *ValBelle* PM 509 vessel in the ~~North~~ north and the *Augustine* PM 510 vessel in the ~~South~~ south between 2013 and 2024. Sampling design (Fig. 1; Table 1) included two parallel transects following a ~~coastal-offshore~~ coastal–offshore gradient, as well as three coastal stations (Molène, Sein, and Douarnenez). Transects were strategically chosen and positioned within water masses that are influenced by front dynamics when the front is established. Along each transect, sampling stations were positioned at regular intervals to ensure capture of multiple water masses, given that the front position varies (Cadier et al., 2017; Chevallier et al., 2014). The northern transect B (offshore of Brest) included seven stations (B1 to B7 from the coast to offshore) and extended slightly further than the southern transect D (offshore of Douarnenez), which comprised six stations (D1 to D6, with D1 being more eastward than B1). Field sampling was conducted by two teams of four people each: one team covering the northern transect and one covering the southern transect. All stations were sampled within a single day by the two teams, requiring approximately 10 h from sample collection to fixation. Transect cruises were scheduled to capture seasonal variations, with sampling conducted in late spring, mid-summer, and mid-autumn, covering three of the four seasons until 2017 (~~See~~ see the transect sampling plan for zooplankton in Table S1 in the ~~Suppplement~~Supplement TS6 and for phytoplankton is Table S2 in the ~~Suppplement~~Supplement). From 2017 until 2023, the sampling frequency ~~has~~ increased from three to ~~4~~four times per year (see Tables S1 and S2 for details). For the three coastal stations (Molène, Sein, and Douarnenez), phytoplankton were sampled every ~~two~~ 2 weeks and zooplankton every month across the indicated time periods in Table S3 in the ~~Suppplement~~Supplement. The highly variable weather of the region occasionally prevented comprehensive sampling of hydrobiological variables and plankton at all stations, as occurred in fall 2012 and spring 2016 for the transect sampling sites, while coastal stations were less affected. Additionally, late winter 2020 sampling was interrupted due to COVID-19 restrictions. Sampling was reduced in 2014, then resumed in 2015 after reassuring the funders of the utility of collecting phytoplankton, zooplankton, and physical parameter data. The Douarnenez station being the same as ~~the~~ station D1, data from both are treated as originating from the same station (D1) in this paper.

3.1.1 Hydrological data acquisition

Water samples were collected ~~bi-monthly~~ bimonthly by the Iroise Marine Natural Park technical personnel using a 5 L Niskin bottle following the Service d'Observation en Milieu LITtoral (SOMLIT) (Cocquempot et al., 2019) and Institut Universitaire Européen de la Mer (IUEM) protocols. Temperature and salinity were measured at sea at each station with a CE5 WTW probe (Cond 1970i) equipped with a standard conductivity measuring cell (TetraCon 325/C) ~~,~~ at the subsurface (approximately 1 m depth) and 1 m above the bottom. From 2017, temperature and salinity were also measured at sea using a ~~CTD~~ CE6 conductivity–temperature–depth (CTD) sensor (NKE MP7 sensor).

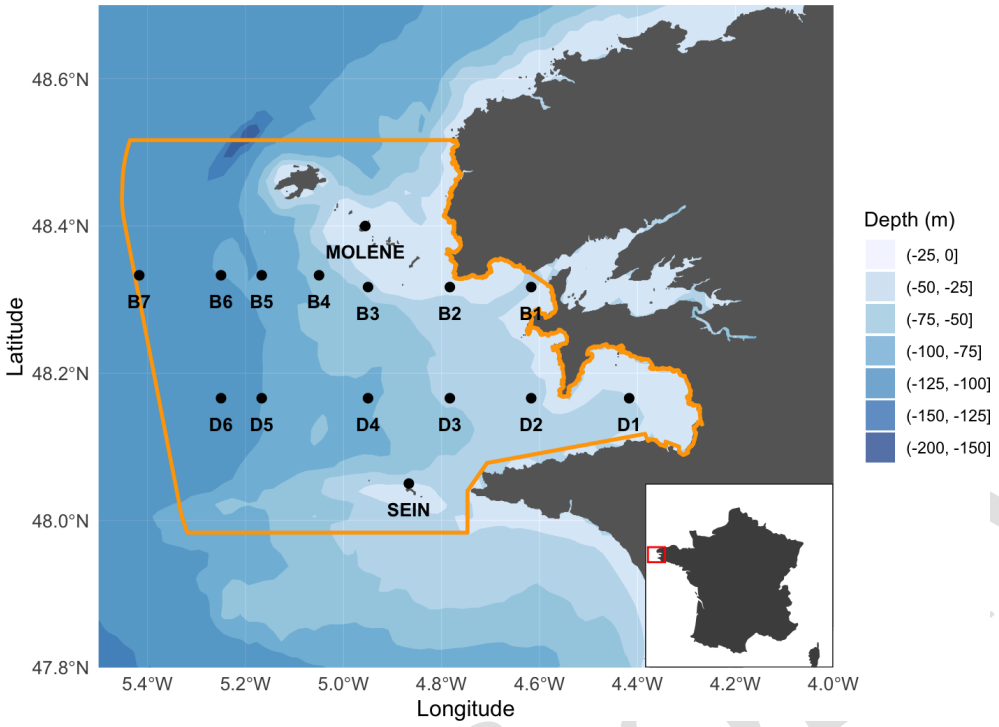

Figure 1. Sampling zone in the Iroise Marine Natural Park with northern transect B (stations B1 to B7 from coast to open ocean), southern transect D (stations D1 to D6 from coast to open ocean), and coastal stations Molène, Sein, and Douarnenez (D1). PNMI limits are traced in yellow and bathymetry is shown in the background. Bathymetry data were obtained ~~through~~ using the getNOAA.bathy() function from the R package marmap (Pante et al., 2023).

Table 1. Coordinates and sampling depth of the stations on the two transects and the coastal stations. For the transect stations, the sampling was done both at the subsurface and at depth. For the coastal stations (Molène, Sein, Douarnenez), the sampling was only done at the subsurface (approximately 1 m depth).

Station	Lat. (° N)	Long. (° W)	Bathymetry (m)	Bottom sampling depth (m)
B1	48° 19,02	04° 37,02	25	20
B2	48° 19,02	04° 46,98	24	20
B3	48° 19,02	04° 57,00	18	15
B4	48° 19,98	05° 3,00	50	45
B5	48° 19,98	05° 10,02	100	80
B6	48° 19,98	05° 15,00	111	90
B7	48° 19,98	05° 25,02	118	90
D1/Douarnenez	48° 9,96	04° 25,02	26	20
D2	48° 9,96	04° 37,02	38	30
D3	48° 9,96	04° 46,98	51	45
D4	48° 9,96	04° 57,00	87	75
D5	48° 9,96	05° 10,02	100	90
D6	48° 9,96	05° 15,00	113	90
Molène	48° 23,600′	04° 57,20′	15	No bottom sampling
Sein	48° 02,600′	04° 52,00′	41	No bottom sampling

3.1.2 Phytoplankton sampling

For phytoplankton sampling, 250 mL of water ~~were~~ was collected from the 5 L Niskin bottle~~and~~, preserved in 250 mL glass flasks with 1 mL of Lugol's solution, and stored at ambient temperature in darkness. Coastal stations were sampled ~~bi-monthly at sub-surface~~ bimonthly at the subsurface only. For the transect stations (D1 through D6 and B1 through B7), phytoplankton was initially sampled at ~~sub-surface~~ subsurface and bottom depths before 2017 (see Table 2). Fol-

Table 2. Evolution of environmental and phytoplankton sampling protocol in the Iroise Marine Natural Park (2010–2023).

Sampling	Before 2017	2017–2019	After 2019
Environment (~~Temperature~~temperature, salinity)	With WTW probe	With CTD	
Phytoplankton (transect stations)	Subsurface and bottom sampling		Subsurface and 15 m depth sampling (chlorophyll *a* peak)
Phytoplankton (coastal stations)	Subsurface sampling		

Figure 2. Temporal distribution of phytoplankton and zooplankton sampling effort from 2010 to 2023. The stacked bars represent the number of samples collected per season (~~Fall~~fall, ~~Spring~~spring, ~~Summer~~summer, ~~Winter~~winter) for each year. ~~Upper~~ The upper panel shows phytoplankton sampling frequency (total number of phytoplankton samples = 785), while the lower panel shows zooplankton sampling frequency (total number of zooplankton samples = 650). Note that phytoplankton sampling was reduced in 2014, while no zooplankton samples were collected that year.

lowing the introduction of CTD profiling in 2017, vertical profiles from 2017–2018 revealed that at offshore stations (B5–B7 and D5–D6), the chlorophyll *a* maximum, when present, consistently occurred between 15–18 m depth. At coastal stations (up to 40 m deep), strong vertical mixing typically maintained a homogeneous water column with no deep chlorophyll maximum, though when present, it also occurred at approximately 15 m depth. Based on these observations, bottom sampling was discontinued in 2019 and replaced with sampling at 15 m depth to better capture phytoplankton biomass.

The present dataset comprises 785 phytoplankton samples in total (Fig. 2). The annual number of phytoplankton samples varied annually (from 12 in 2010 and 2014 to 97 in 2017), with reduced winter sampling due to weather conditions. The sampling effort increased notably from 2010, reaching a peak of 97 samples in 2017, then gradually decreased to approximately 50 samples in 2022.

3.1.3 Zooplankton sampling

Zooplankton samples were obtained using a 200 µm mesh size WP2 plankton net with a 57 cm mouth diameter equipped with a flowmeter. At the sampling site, the WP2 net was deployed as vertically as possible to a maximum depth of 5 m above the sediment. However, the dynamic sea conditions in this area usually resulted in the cable forming a small angle. The net was then retrieved at a speed of 1 m s^{-1} TS7. In the case of flowmeter malfunction (e.g., due to clogging by algae), the filtered volume was estimated by multiplying the net's mouth area by the length of cable deployed and it was flagged in the sample_comment column of the corresponding EcoTaxa table. This calculation assumed consistent and adequate filtering efficiency across all sampling events. After initial rinsing, the cod-end tap was opened and the sample was collected in a 25 cm diameter sieve with 200 µm mesh. The tap was then closed, the net was rinsed again, and the tap reopened to collect any remaining organisms in the sieve. This rinsing and collection procedure was repeated ~~2–3~~two to three times depending on sample density to ensure complete organism recovery. The collected zooplanktonic organisms were transferred into a 250 mL double-sealed polypropylene flask and preserved by adding buffered formaldehyde in a 2 : 1 formaldehyde-to-sample ratio to achieve a final concentration of 4 %. The annual number of zooplankton samples ranged from 16 samples in 2010 (the first year of sampling) to 68 samples in 2013, reflecting variations in sampling frequency due to weather conditions (Fig. 2). In total, 650 zooplankton samples were collected.

3.2 Plankton identification and processing

3.2.1 Phytoplankton identification

Phytoplankton identification was performed on 50 mL subsamples following concentration using Utermöhl settling chambers (Hasle, 1978). Enumeration was conducted using phase contrast microscopy (Wild M40 inverted microscope) along diametrical transects at 300× or 600× magnification. Following Lund et al. (1958), the entire chamber surface was analyzed when warranted by specimen size or abundance. Taxonomic identification was performed to the lowest feasible level, with diatoms, dinoflagellates, and nanophytoplankton generally identified to genus or species. The employed methodology precluded identification and measurement of picophytoplankton (organisms < 2 µm in size). Indeed, due to their size, the cyanobacteria identified in this study were large colonial and filamentous forms (> 100 µm) from the Chroococcaceae~~and Oscillatoriaceae,~~ , Oscillatoriaceae, and Microcoleaceae (genus Trichodesmium) families, ~~and~~ hence belonging to the microphytoplankton size class. The dataset provided on SEANOE (see ~~Data availability~~ the "Data availability" section) contains the lowest identification level. For readability and visualization purposes, we decided to present phytoplankton data regrouped at the phylum level and zooplankton at a coarser level compared to the Ecotaxa definition.

3.2.2 Zooplankton digitization

Zooplankton samples were digitized using the ZooScan imaging system (Gorsky et al., 2010), a waterproof flatbed scanner that generates high-resolution (2400 dpi, pixel size: 10.56 µm) 16-bit grayscale images. All steps from digitization to identification were carried out at the EMBRC Quantitative Imaging Platform (PIQv) of the Institut de la Mer de Villefranche (https://sites.google.com/view/piqv/TS8). Prior to scanning, samples underwent a size-based separation process to prevent the underrepresentation of larger, less abundant organisms that might otherwise be lost in the fractionning process. This involved sieving the samples through a 1000 µm mesh, creating two distinct size classes: one for organisms exceeding 1 mm (large fraction) and another for those below this threshold (small fraction). A 100 µm mesh sieve, smaller than the net mesh size, was also used to prevent sample loss. Each size fraction was then fractionated using a Motoda plankton splitter (Motoda, 1959) to reduce the number of organisms per scan and limit object overlap as much as possible~~objects overlap~~, following recommendations by Vandromme et al. (2012) and Jalabert et al. (2024).

3.2.3 Zooplankton image processing and identification

ZooScan images were processed using the ZooProcess software (Gorsky et al., 2010). The ZooScan captures 16-bit grayscale images of both the background and plankton samples, which are then converted to 8-bit. This conversion maps pixel values from 0 (black) to 255 (white) while preserving the meaningful ~~grey~~ gray range of the original image.

This normalization ensures comparability across different ZooScans without compromising identification ~~identification~~ accuracy, as the 8-bit resolution still exceeds the opacity variations found in preserved plankton. Next, a background image was subtracted from each sample image to create a nearly white background. To minimize measurement bias from overlapping objects, each subsample underwent manual separation of touching organisms and detritus particles on the scanning tray prior to imaging. These "multiple" images, which can affect abundance and biovolume estimates, were manually separated as recommended in ~~(~~Vandromme et al. ~~,~~(2012) following the protocol detailed in Jalabert et al. (2024).

Finally, particle processing was performed, where objects were segmented and extracted based on two thresholds: a gray-level intensity of 243 and a minimum ~~Equivalent Spherical Diameter~~ equivalent spherical diameter (ESD) of 300 µm. The final output includes a table with 42 measurements (such as area, major and minor axes, ~~grey~~ gray level, and transparency~~…~~) (https://zenodo.org/records/

Table 3. Number of unique taxa and occurrences across taxonomic ranks in marine phytoplankton samples from 2010 to 2022.

Taxonomic rank	Number	Occurrence
Phylum	2	2476
Forma	7	8666
Class	12	14 856
Subclass	2	2476
Order	10	12 380
Family	4	4952
Genus	168	207 984
Species	359	444 442
Variety	5	6190

14704251TS9) along with individual ~~Regions of Interest~~ regions of interest (ROIs) for each detected object.

The digitized objects were then imported into the EcoTaxa web platform (Picheral et al., 2017, https://ecotaxa.obs-vlfr.fr/TS11), where supervised learning algorithms performed initial taxonomic classification, followed by a manual validation by human experts from the PIQv (Irisson et al., 2022). Organisms were categorized into 103 biological categories, excluding detritus, bubbles, and other scanning artifacts (Fig. 3). On average, per scan, there were 1152 ± 1030 (mean $\pm$ ~~sd~~SD) elements (living and not living combined) for the large fraction (organisms exceeding 1 mm) and 2160 ± 1581 elements for the small one (organisms smaller than 1 mm), which corresponded to an average per scan of 545 ± 513 living objects for the large fraction and 1337 ± 1107 living objects for the small fraction.

3.3 Data processing

3.3.1 Environmental data processing

For both temperature and salinity, after removing abnormal data (e.g., negative salinity), the data ~~was~~ were binned on a 1 m depth bin interpolated on a 1 m vertical resolution. Additional quality control included outlier detection and removal based on a 0.001 quantile threshold.

3.3.2 Phytoplankton data processing

The 785 phytoplankton samples contained 573 unique taxa distributed across ~~9~~nine taxonomic ranks from ~~Phylum to Variety~~ phylum to variety level, with the majority represented at the genus (164 taxa) and species (359 taxa) levels (Table 3).

The Douarnenez station, being sampled at the same location as the D1 station from the southern transect, was redesignated as D1 while retaining a "Douarnenez" tag in the dataset for subsequent analyses. Based on the sampling month, data were grouped by season: winter (December, January, February), spring (March, April, May), summer (June, July, August), and fall (September, October, November). Proportions of each taxon were computed at various taxonomic levels to examine taxa distribution on both seasonal and annual scales.

3.3.3 Zooplankton data processing

Zooplankton imaging data ~~was~~ were downloaded from Ecotaxa projects (see Table S4 in the ~~Suppplement~~ Supplement for the detailed references of Ecotaxa projects), resulting in a dataset containing a total of 655 930 individual images of zooplankton organisms after removing artifacts and non-target objects (e.g., parts of organisms, seaweed).

Abundances (in individuals m^{-3}) were computed using the subsampling ratios (column acq_sub_part of the Ecotaxa table) for both the large (acq1) and small (acq2) size fractions (see methods in Sect. 3.2.2). They were then normalized by total sampled seawater volumes (column sample_tot_vol of the Ecotaxa table) following Eq. (1):

$$\text{Abundance}_{\text{taxon}} = \frac{\left(n_{\text{taxon}_{\text{acq1}}} \times \text{acq}_{\text{sub}_{\text{part}_{\text{acq1}}}}\right) + \left(n_{\text{taxon}_{\text{acq2}}} \times \text{acq}_{\text{sub}_{\text{part}_{\text{acq2}}}}\right)}{\text{sample total volume}}, \quad (1)$$

where n is the number of individuals for the corresponding taxon.

The area (in pixels) obtained through ZooProcess image analysis was converted to mm^2 using the converting column from the Ecotaxa table called process_particle_pixel_size_mm. This allowed ~~to compute~~ computing the equivalent spherical diameter (ESD, in mm) following Eq. (2):

$$\text{ESD} = 2 \times \sqrt{\frac{\text{Area}}{\pi}}. \quad (2)$$

To compute the biovolume (in mm^3) of each organism, we used the spheroid method based on area measurements following Eq. (3):

$$\text{Spheroid} = \frac{4}{3} \times \pi \times \left(\frac{\text{ESD}}{2}\right)^3. \quad (3)$$

This approach was chosen to avoid errors that can occur with ellipse fitting, especially for organisms with irregular shapes or protruding appendages. Area measurements, obtained through ZooProcess image analysis, provide a more consistent basis for estimating biovolume across diverse plankton morphologies (Drago et al., 2022).

The image data were thereafter grouped into 17 broader taxonomic groups (see Table 4).

4 Data quality control

Multiple quality control procedures were implemented throughout data collection, processing, and analysis to ensure data reliability and consistency. These procedures covered environmental parameters, phytoplankton identification, and zooplankton classification.

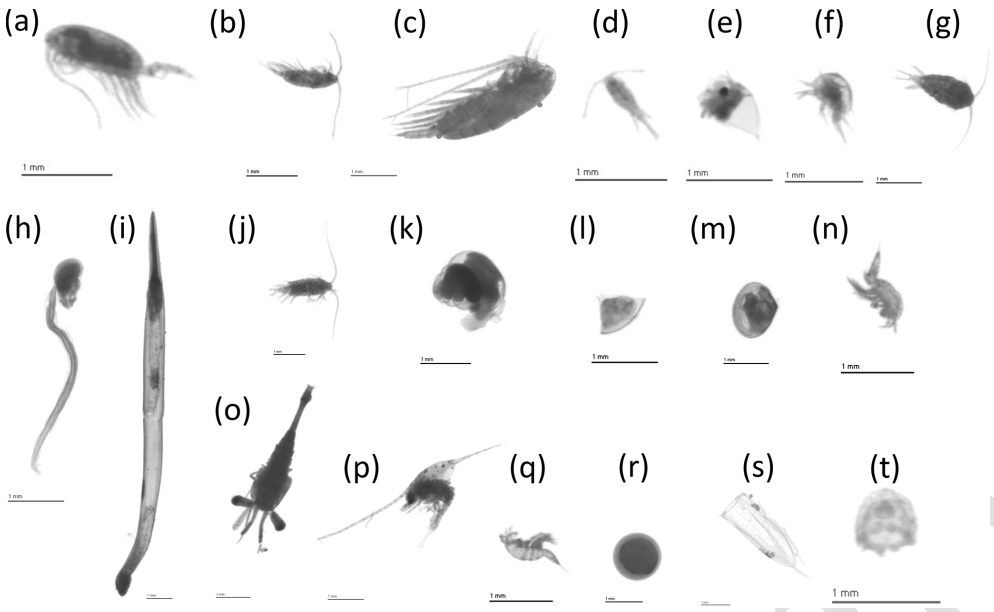

Figure 3. Examples of planktonic organisms imaged by the ~~Zooscan~~ ZooScan for the 20 most abundant taxa. (a) Calanoida, (b) Acartiidae, (c) Calanidae, (d) Oithonidae, (e) Podonidae, (f) nauplii < Cirripedia, (g) Temoridae, (h) Oikopleuridae, (i) Chaetognatha, (j) Centropagidae, (k) Limacinidae, (l) cyphonaute, (m) Bivalvia < Mollusca, (n) Oncaeidae, (o) Eumalacostraca, (p) larvae < Porcellanidae, (q) Harpacticoida, (r) egg < other, (s) nectophore < Diphyidae, (t) Hydrozoa. Note that a scale bar of 1 mm is represented in each image for comparison. TS10

For environmental parameters, systematic quality checks were performed on temperature and salinity measurements. Abnormal values, such as negative salinity readings, were removed from the dataset. The remaining data underwent binning on 1 m depth intervals with interpolation at 1 m vertical resolution.

Phytoplankton identification quality was maintained through taxonomic consistency. For transect samples, all microscopic analyses were performed by a single specialized taxonomist (~~Beatriz~~ Béatriz Beker from the French network RESOMAR) throughout the entire study period (2010–2022). She participates in quality assurance programs including the Phytoplankton Proficiency Test organized by the Marine Institute-IOC-BEQUALM-NMBAQC to ensure taxonomic accuracy. For coastal station samples, another taxonomist (Sylvain Coulon) conducted identifications for samples from Douarnenez (2013–2018), Sein (2013–2020), and Molene (2013–2017), representing 241 of 336 coastal samples, using the same taxonomic reference list as Béatriz Beker, while Béatriz Beker identified the remaining coastal samples. This approach ensures consistency in counting methodology and taxa identification across the time series. Sylvain Coulon collaborates with Ifremer specialists for taxonomic validation and regularly participates in REPHY (~~REPHY-French Observation And Monitoring Program For Phytoplankton And~~ REPHY – French Observation and Monitoring Program for Phytoplankton and Hydrology In Coastal Waters, 2023) and PHYTOBS (https://www.phytobs.fr/TS12) networks (workshops, intercalibration exercises) to ensure consistent phytoplankton identification standards.

For zooplankton data, initial classification was performed using supervised learning algorithms, followed by expert validation as described in Irisson et al. (2022). Particularly for samples collected between 2018 and 2023, experts from the PIQv (Quantitative Imaging Platform of Villefranche) reviewed and validated all the already classified objects, making corrections where necessary, serving as a strong quality assurance indicator. This validation process ensured taxonomic homogenization across projects during these years. This dual approach – combining efficient computational methods with expert biological knowledge – optimizes the balance between processing speed and taxonomic precision. It allows for the reliable analysis of large-scale plankton datasets while maintaining high standards of scientific rigor. While all identifications have been reviewed by at least one human operator, we cannot fully guarantee the correctness of each of the > 655k identifications. Some taxonomic uncertainty may persist at finer classification levels, particularly for samples processed before 2018 when taxonomic expertise was fully standardized across operators. However, standardized protocols and systematic validation procedures established during the study period provide confidence in data consistency at the taxonomic group level.

Table 4. Names of the taxonomic groups of the zooplankton dataset according to the Ecotaxa annotation (column "~~annotation~~Annotation_category"), the regroupment proposed in this paper (column "~~groups~~Groups")~~as well as~~, and the associated number of images and their relative frequencies across the complete dataset. The groups are listed in decreasing numbers of images.

~~annotation~~Annotation_category	~~groups~~ Groups	~~count~~ Count	%	~~annotation~~Annotation_category	~~groups~~ Groups	~~count~~ Count	%
Calanoida	Copepoda	186 346	28.41	Clione	Mollusca	432	0.07
Acartiidae	Copepoda	87 405	13.33	Copepoda < Maxillopoda	Copepoda	385	0.06
Calanidae	Copepoda	43 307	6.60	protozoea < Mysida	Malacostraca	329	0.05
Oithonidae	Copepoda	37 620	5.74	nectophore < Physonectae	Cnidaria	325	0.05
Podonidae	Branchiopoda	33 082	5.04	Tomopteridae	Annelida	292	0.04
nauplii < Cirripedia	Mollusca	24 308	3.71	Echinoidea	Echinodermata	249	0.04
Temoridae	Copepoda	22 220	3.39	Ophiurida	Echinodermata	194	0.03
Oikopleuridae	Appendicularia	21 523	3.28	veliger		189	0.03
Chaetognatha	Chaetognatha	21 023	3.21	Amphipoda	Malacostraca	184	0.03
Centropagidae	Copepoda	19 436	2.96	Foraminifera	Harosa	170	0.03
Limacinidae	Mollusca	15 142	2.31	Metridia	Copepoda	130	0.02
cyphonaute	Bryozoa	14 634	2.23	Leptothecata	Cnidaria	121	0.02
Bivalvia < Mollusca	Mollusca	12 727	1.94	Liriope < Geryoniidae	Cnidaria	117	0.02
Oncaeidae	Copepoda	10 936	1.67	Aglaura	Cnidaria	101	0.02
Eumalacostraca	Malacostraca	9865	1.50	juvenile < Salpida		100	0.02
larvae < Porcellanidae	Decapoda	9011	1.37	Atlanta	Mollusca	92	0.01
Harpacticoida	Copepoda	6780	1.03	Mollusca	Mollusca	91	0.01
egg < other		6314	0.96	Pontellidae	Copepoda	75	0.01
nectophore < Diphyidae	Cnidaria	5636	0.86	Monstrilloida	Copepoda	68	0.01
Hydrozoa	Cnidaria	5305	0.81	Harosa	Harosa	61	0.01
nauplii < Crustacea		4864	0.74	body < megalopa	Decapoda	60	0.01
Ophiuroidea	Echinodermata	3512	0.54	Ctenophora < Metazoa	Ctenophora	58	0.01
calyptopsis < Euphausiacea	Euphausiacea	3398	0.52	Insecta		49	0.01
Corycaeidae	Copepoda	3232	0.49	Phoronida		49	0.01
zoea < Brachyura	Decapoda	3052	0.47	invisible membrane < egg	Fish	48	0.01
cypris	Mollusca	2989	0.46	Ophiothrix	Echinodermata	37	0.01
Metridinidae	Copepoda	2821	0.43	Branchiostoma		35	0.01
egg < Sardina pilchardus	Fish	2617	0.40	larvae < Crustacea		33	0.01
Penilia	Branchiopoda	2598	0.40	larvae < Squillidae	Malacostraca	30	< 0.01
gonophore < Diphyidae	Cnidaria	2491	0.38	Sapphirinidae	Copepoda	22	< 0.01
Doliolida	Thaliacea	2450	0.37	Gymnosomata	Mollusca	18	< 0.01
Obelia	Cnidaria	2382	0.36	Siphonophorae	Cnidaria	15	< 0.01
cirrus	Mollusca	2293	0.35	Ostracoda		14	< 0.01
Gammaridea	Malacostraca	2283	0.35	phyllosoma	Decapoda	14	< 0.01
Euchaetidae	Copepoda	1999	0.30	Scyphozoa	Cnidaria	13	< 0.01
egg < Actinopterygii	Fish	1966	0.30	Creseidae	Mollusca	12	< 0.01
Fritillariidae	Appendicularia	1743	0.27	Isopoda	Malacostraca	10	< 0.01
Candaciidae	Copepoda	1569	0.24	chain < Salpida		9	< 0.01
pluteus < Ophiuroidea	Echinodermata	1500	0.23	Cephalopoda	Mollusca	6	< 0.01
Hyperiidea	Malacostraca	1233	0.19	ephyra < Scyphozoa	Cnidaria	6	< 0.01
eudoxie < Diphyidae	Cnidaria	1122	0.17	Cavolinia inflexa	Mollusca	5	< 0.01
zoea < Galatheidae	Decapoda	1040	0.16	Crustacea		5	< 0.01
Annelida	Annelida	832	0.13	Nemertea		5	< 0.01
pluteus < Echinoidea	Echinodermata	722	0.11	Caprellidae	Malacostraca	3	< 0.01
Salpida	Thaliacea	718	0.11	Cumacea	Cumacea	3	< 0.01
Sertulariidae	Cnidaria	710	0.11	Pycnogonida		2	< 0.01
Actinopterygii	Fish	663	0.10	Abylidae	Cnidaria	1	< 0.01
Echinodermata	Echinodermata	651	0.10	Acantharea	Harosa	1	< 0.01
larvae < Annelida	Annelida	637	0.10	Aequorea	Cnidaria	1	< 0.01
megalopa < Brachyura		507	0.08	Cirripedia		1	< 0.01
bract < Diphyidae	Cnidaria	444	0.07	Cyclopoida	Copepoda	1	< 0.01
				Physonectae	Cnidaria	1	< 0.01

5 Database structure and analysis

Both monitoring programs show increased complexity over time, evolving from sporadic sampling in 2010–2011 to more systematic seasonal coverage in recent years (Fig. 2). This temporal heterogeneity may affect the detection of seasonal patterns and short-term variability, particularly in the earlier years (2010–2016) ~~where~~ when fewer seasons were sampled compared to the more frequent sampling in later years (2017–2022), potentially influencing the interpretation of long-term trends and seasonal dynamics.

5.1 Database structure

The dataset contains three distinct tables all containing both text and numerical data.

The first dataset contains phytoplankton data and follows a similar organizational structure:

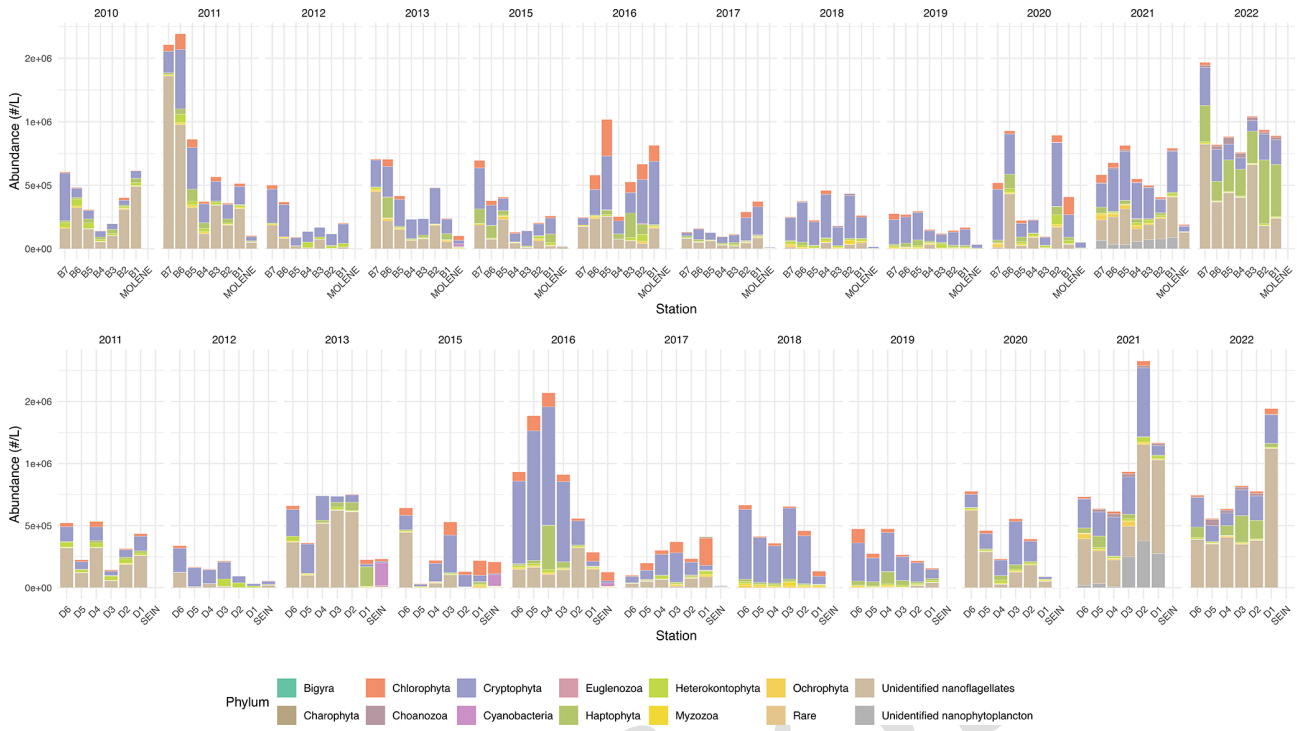

Figure 4. Mean absolute abundance (cells L^{-1}) of phytoplankton phyla at surface sampling stations across two transects (B on top and D on the bottom) as well as at Molene and Sein coastal stations from 2010 to 2022. Each stacked bar represents the total community count at a sampling station, with the size of each ~~coloured~~ colored bar indicating the absolute abundance of each phylum. The upper panel displays the B transect (B1–B7) and the Molène coastal station, while the lower panel shows the D transect (D1–D6) and the Sein coastal station. Each phylum is represented by a distinct ~~colour~~ color as shown in the legend.

- Metadata information (columns 1–8):
  - Station name (column 1)
  - Transect name (column 2)
  - Coordinates: longitude and latitude (columns 3–4, in DD.dddd)
  - Sampling time: date, year, month, and ~~julian~~ Julian day (columns 5–8)
- Environmental measurements:
  - Surface, 15 m, and bottom temperature (columns 9–11, in °C)
  - Surface, 15 m, and bottom salinity (columns 12–14, in PSU)
- Phytoplankton taxa concentrations:
  - Surface abundance in cells L^{-1} (columns 15–582, prefix "surface_" + taxa name)
  - Bottom abundance in cells L^{-1} (columns 583–1150, prefix "bottom_" + taxa name)

The complete taxonomic hierarchy for each phytoplanktonic taxon, from kingdom to its identification level, was retrieved using the *worrms* ~~R-package~~ R package (Chamberlain and Vanhoorne, 2023). Each ~~taxa~~ taxon is provided in the third dataset with the corresponding unique identifier called aphiaID from the World Register of Marine Species (WoRMS Editorial Board, 2025), which enables unambiguous species identification across databases.

The second dataset integrates zooplankton measurements with their corresponding environmental parameters and is organized as follows:

- Metadata information (columns 1–8):
  - Station name (column 1)
  - Transect name (column 2)
  - Coordinates: longitude and latitude (columns 3–4, in DD.dddd)
  - Sampling time: date, year, month, and ~~julian~~ Julian day (columns 5–8)
- Environmental measurements:
  - Surface and bottom temperature (columns 9–10, in °C)
  - Surface and bottom salinity (columns 11–12, in PSU)

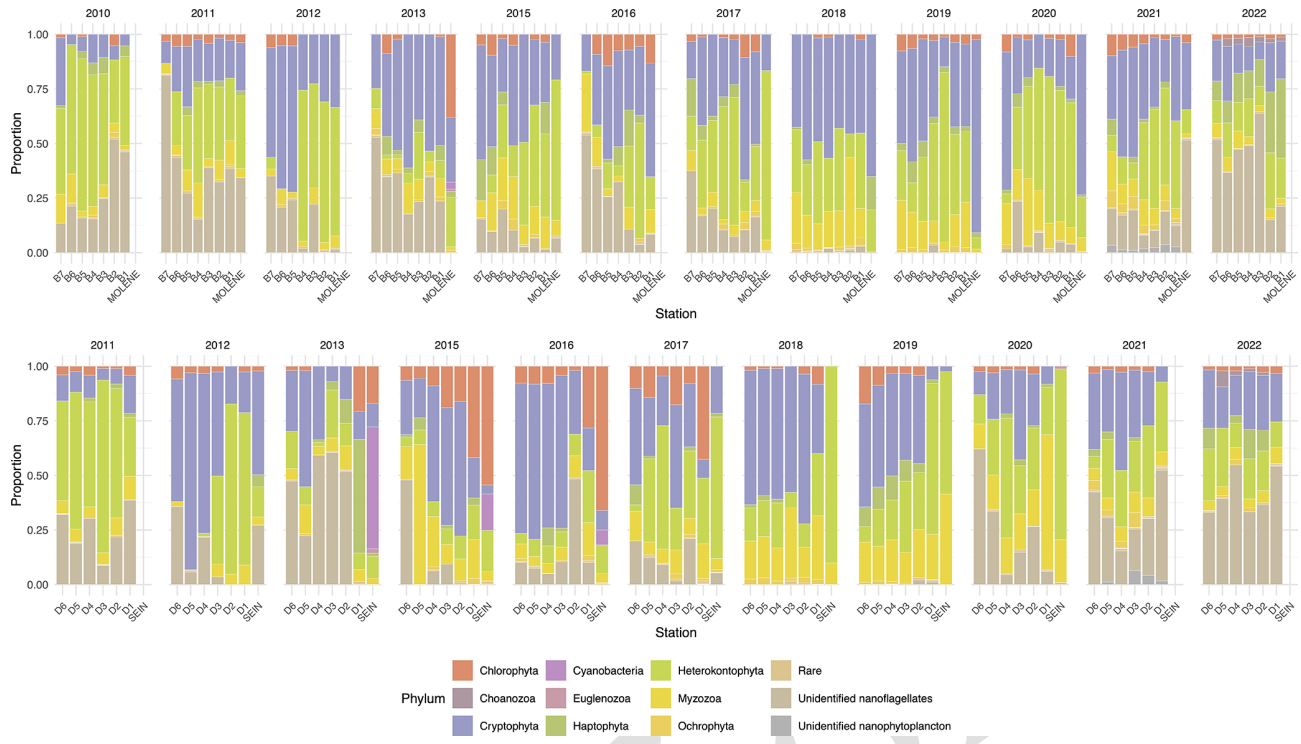

Figure 5. Relative abundance (% of total individuals) of phytoplankton phyla at surface sampling stations across two transects (B on top and D on the bottom) as well as at Molene and Sein coastal stations from 2010 to 2022. Each stacked bar represents the community composition at a sampling station, with the proportion of each phylum calculated as the percentage of the total abundance of individuals counted at that station. The upper panel displays the B transect (B1–B7) and the Molène coastal station, while the lower panel shows the D transect (D1–D6) and the Sein coastal station~~from~~. Each phylum is represented by a distinct colour as shown in the legend.

- Biological data for each taxonomic group:
  - Sample abundance in individuals m^{-3} (columns 13–116, prefix "conc_" + taxa name)
  - Total biovolume in $mm^3\ m^{-3}$ (columns 117–220, prefix "tot_biov_" + taxa name)
  - Mean individual biovolume in mm^3 (columns 221–324, prefix "mean_biov_" + taxa name)

5.2 Phytoplankton distribution

Figure 4 shows the mean annual phytoplankton abundances across the sampling area, highlighting the remarkable temporal and spatial variability throughout the study period. The absolute abundance shows substantial temporal and spatial variability throughout the study period. Notable peaks in total phytoplankton abundance occurred in 2011 and 2022 in transect B, with mean abundances exceeding 2×10^6 cells L^{-1} at some stations. In transect D, remarkable abundance peaks were observed in 2016 and 2021–2022, where mean abundances also exceeded 2×10^6 cells L^{-1}.

There does not appear to be a consistent coastal-to-offshore gradient in phytoplankton abundance throughout the years in either northern and southern stations. This absence of a clear gradient could likely result from temporal averaging across seasons, which obscures the spatial effects of the seasonal Ushant thermal front that would be evident in season-specific analyses.

To have a better look at the composition, we can observe phytoplankton relative abundance as presented in Fig. 5. In surface waters, the phytoplankton composition showed interannual and spatial variations along both transects. Several groups dominate the community structure across stations and years, including Cryptophyta (in orange), Heterokontophyta (in dark green), Myzozoa (in light green)~~and Nanoflagellates~~ , and nanoflagellates (in light brown). Nanoflagellates are one of the predominant groups in all the years except for 2018 and 2019 ~~where~~ when they are present in very low proportion. Some groups, such as Cyanobacteria, nanophytoplankton, and Euglenozoa, appear sporadically and in lower proportions.

Some years present a ~~coast-offshore~~ coast–offshore gradient in community composition, but most years ~~don't~~ do not present a clear pattern of distribution (Fig. 5). The two coastal stations of Molène and Sein sometimes display a very different distribution. This is especially visible for the station Sein that presents a high to low presence of ~~cyanobacteria~~ Cyanobacteria from 2013 to 2016.

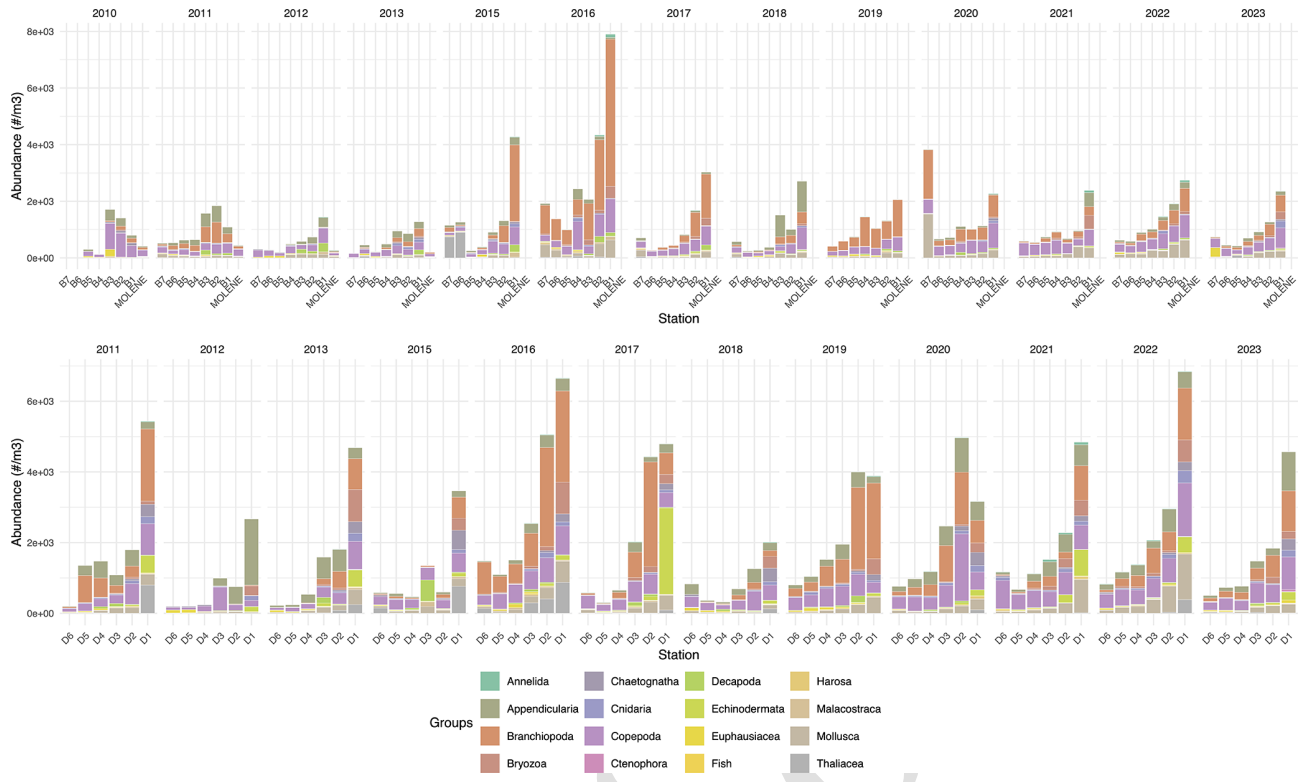

Figure 6. Mean absolute abundance (individuals m^{-3}) of zooplankton phyla at surface sampling stations across two transects (B on top and D on the bottom) and at Molene coastal station from 2010 to 2023. Each stacked bar represents the mean absolute abundance at a specific station, with different ~~colours~~ colors indicating distinct taxonomic groups as shown in the legend. The upper panel shows data from the B transect (stations B1–B7) and Molene station, while the lower panel displays data from the D transect (stations D1–D6). Note that the Cumacea group was excluded as it contains only ~~3~~three images.

5.3 Zooplankton distribution

Zooplankton data collected from 2010 to 2023 revealed a pronounced ~~coastal-offshore~~ coastal–offshore gradient in mean absolute abundance throughout the years (Fig. 6), with decreasing zooplankton concentrations as distance from the coastline increased. Coastal stations (especially B1 and D1) consistently exhibited the highest values, with maximum values reaching up to 7.9×10^3 individuals m^{-3} during peak periods in ~~the~~ transect B. Notably, the D transect stations exhibited abundance values exceeding 2×10^3 individuals m^{-3} more frequently than stations along transect B.

The zooplankton community shows clear spatial gradients in dominant groups (Fig. 7). Copepoda and Branchiopoda exhibit a pronounced ~~coastal-oceanic~~ coastal–oceanic gradient, with higher proportions in coastal stations decreasing towards ~~open ocean~~ open-ocean stations. Conversely, Mollusca shows an inverse gradient with higher proportions at offshore stations compared to coastal areas. The southern transect (D) is characterized by notably higher proportions of Appendicularia compared to the northern transect. Overall, the community structure remains relatively consistent over the ~~13-year~~ 13-year study period across both transects, suggesting a relatively stable ecosystem structure in the region.

Code availability. Following the FAIR principle (Wilkinson et al., 2016), all code used for data processing and analysis is publicly accessible through our GitHub repository (https://github.com/neccton-algo/PNMI_data_paperTS13).

Data availability. The table containing abundances of phytoplankton and zooplankton as well as zooplankton biovolume are available in the SEANOE data portal: https://doi.org/10.17882/105465 (Drago et al., 2025). Individual zooplankton images are available to be viewed and explored on the Ecotaxa web application (Picheral et al., 2017, https://ecotaxa.obs-vlfr.fr/TS14; no registration needed). The references for the projects are available in Table S4.

6 Concluding remarks

Recent studies have shown significant changes in small pelagic fish communities across French waters, particularly regarding decreases in mean body size and condition (Menu

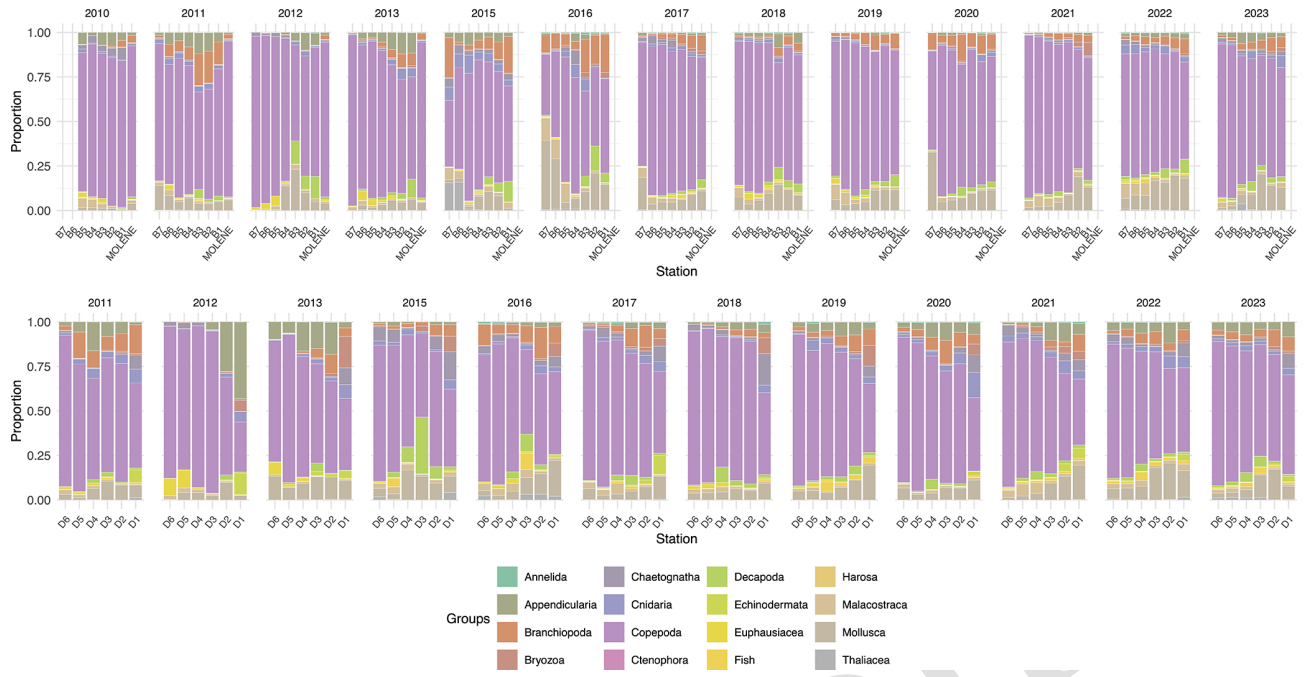

Figure 7. Relative abundance (% of total individuals) of the 16 zooplankton taxonomic groups across two transects (B on top and D on the bottom) and at Molene coastal station from 2010 to 2023. Each stacked bar represents the community composition at a sampling station, with the proportion of each group calculated as the percentage of the total number of individuals counted at that station. Note that the Cumacea group was excluded as it contains only ~~3~~three images. The upper panel displays the B transect (B1–B7) and the Molène coastal station, while the lower panel shows the D transect (D1–D6). Each faunistical group is represented by a distinct ~~colour~~ color as shown in the legend.

et al., 2023; Queiros et al., 2019), highlighting the critical importance of long-term monitoring of plankton communities (Holland et al., 2025) which constitute their primary food resource (Brosset et al., 2016; Sommer et al., 2018).

The combined physical and biological data ~~enables~~ enable tracking ecosystem responses to environmental changes while providing baseline data for assessing ecosystem health in the Iroise Marine Natural Park. Beyond its ecological significance, this MPA and the Iroise Marine Natural Park hold particular importance for France's sardine fishery. The region, with Douarnenez as a historic sardine fishing hub, supports a significant portion of France's pelagic fisheries, particularly for purse seiners. This makes the long-term monitoring of plankton communities crucial not only for biodiversity conservation but also for preserving the economic and cultural heritage that led to its designation as France's first ~~Marine Protected Area~~marine protected area.

While no comparable ~~pluriannual~~ pluri-annual multistation planktonic datasets exist within the Iroise Marine Natural Park, other ~~french~~ French coastal monitoring programs (e.g., SOMLIT for chlorophyll *a*, Goberville et al., 2010; Savoye et al., 2024; REPHY for toxic phytoplankton, Chenouf et al., 2022) provide only limited single-point data lacking spatial coverage for meaningful comparison. Yet, several regional surveys offer potential for broader comparative analyses: the PELGAS survey (Bay of Biscay, 2006–2015), primarily focused on small pelagic fish, also provides phytoplankton data, vertically integrated chlorophyll *a* biomass (Doray et al., 2018), and microphytoplankton taxonomic composition (Houliez et al., 2021). For zooplankton, the same sampling and scanning methodology was used, providing vertically integrated mesozooplankton biomass (Doray et al., 2018), as well as the complete dataset (Grandremy et al., 2024). EVOHE surveys (Bay of Biscay, since 1987) provide autumn data on ~~phyto-~~ phytoplankton and microzooplankton taxonomy and abundance, as well as mesozooplankton taxonomy and ~~size-class~~ size class biomass (see https://sextant.ifremer.fr/record/709a4b9f-557e-46cb-9af2-d1453b491f98/TS15). The PELTIC program (English Channel, Celtic Sea, and Bristol Channel, 2012–2023) could also provide comparative phytoplankton abundance data but is similarly limited seasonally (Cefas, 2024)~~s~~.

These comparisons underscore the importance and uniqueness of the comprehensive PNMI dataset presented here.

The consistent phytoplankton identification methodology throughout the ~~13 year~~ 13-year time series (2010–2022) by two experienced taxonomists using the same taxonomic reference list ~~,~~ ensures taxonomic continuity and reliability, providing a robust foundation for studying long-term changes in phytoplankton community structure. The high taxonomic

resolution of this dataset (573 distinct phytoplankton taxa across multiple taxonomic levels) enables detailed analyses of phytoplankton community dynamics, biodiversity patterns, and responses to environmental gradients. Additionally, the use of a standardized protocol using the ZooScan imaging system for zooplankton imaging data enables detailed morphometric measurements and creates a standardized visual record, complementing other recently published planktonic datasets that employ various techniques such as microscopy (Acri et al., 2020; Devreker et al., 2024) and imaging instruments (Dugenne et al., 2024; Grandremy et al., 2024). Making such an imaging dataset openly available offers further opportunities for future ~~functional-trait-based~~ functional-trait-based analyses of plankton dynamics (Litchman et al., 2015; Perhirin et al., 2023; Vilgrain et al., 2021). The plankton communities' descriptors that can be accessed and derived from this dataset (abundances and biovolumes for zooplankton) are proposed at multiple taxonomic levels and accessible through the EcoTaxa web platform (Picheral et al., 2017). These datasets contribute to global plankton monitoring efforts by combining traditional and modern approaches in a standardized format, supporting diverse ecological studies and modeling applications where zooplankton representation has traditionally been simplified usually through size discrimination (Everett et al., 2017). Publishing comprehensive long-term datasets combining phytoplankton, zooplankton, and environmental data in ~~open access~~ open-access formats demonstrates their scientific value to funding agencies and supports the continuation of costly but essential ecological monitoring programs. The integration of long-term monitoring and technological innovations strengthens our ability to understand and protect marine ecosystems while providing valuable insights for both immediate research needs and future applications.

Supplement. The supplement related to this article is available online at [the link will be implemented upon publication].

Author contributions. Conceptualization and ~~Methodology~~methodology: LD, CC, PP, SDA. Data curation and ~~Validation~~validation: LD, CC, BB, LJ. Formal analysis, ~~Investigation~~investigation, ~~Visualization~~visualization: LD. Funding acquisition: PP, SDA. Project administration and ~~Resources~~resources: CC, PP, SDA. Supervision: SDA. Writing – original draft: LD, SDA. Writing – review and editing: LD, CC, PP, BB, LJ, JBR, SDA.

Competing interests. The contact author has declared that none of the authors has any competing interests.

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