UNIVERSIDADE TÉCNICA DO ATLÂNTICO
INSTITUTO DE ENGENHARIA E CIÊNCIAS DO MAR
WEST AFRICAN SCIENCE SERVICE CENTRE ON CLIMATE CHANGE AND ADAPTED LAND USE

Master Thesis

VERTICAL MIGRATION AND DISTRIBUTION OF ZOOPLANKTON ALONG A LATITUDINAL TRANSECT IN THE EASTERN NORTH ATLANTIC

SIENFOUNGO TRAORE

Master Research Program on Climate Change and Marine Sciences

São Vicente
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Vertical migration and distribution of zooplankton along a latitudinal transect in the eastern north Atlantic

Sienfoungo Traore

Master's thesis presented to obtain the master's degree in Climate Change and Marine Sciences, by the Institute of Engineering and Marine Sciences, Atlantic Technical University in the framework of the West African Science Service Centre on Climate Change and Adapted Land Use

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Dedication

I dedicate this modest work to my late father, Mr. TRAORE Tchingo, and my mother, TRAORE Passogui. I thank them for their patience, love and trust in me.

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Resumo

O zooplâncton é um grupo diverso de animais que se encontra nos oceanos, desde microscópicos a invertebrados de maiores dimensões, e é crucial para os ecossistemas marinhos. Algumas espécies de zooplâncton migram verticalmente para as profundidades anóxicas durante o dia, o que pode afetar o consumo de oxigênio e a libertação de compostos dissolvidos, como o amônio, nas águas profundas. Este estudo fornece uma visão geral da distribuição do zooplâncton no Oceano Atlântico Norte oriental. Amostras de zooplâncton foram recolhidas em diferentes profundidades de 125 m, 800 m, 1000 m e 2000 m ao longo de um transecto de Cabo Verde ao Canal da Mancha, utilizando uma rede múltipla com malha de 150 µm. Uma análise da composição taxonómica identificou 11 taxa. Copepoda e Sagittoida foram os organismos mais abundantes. As estações localizadas em zonas de ressurgência apresentaram biomassas elevadas. As estações amostradas durante a noite foram mais abundantes do que as amostradas durante o dia. Os dados hidroacústicos do EK80 confirmaram que os organismos migraram verticalmente entre o dia e a noite. Uma biomassa significativa foi observada na zona de oxigénio mínimo (OMZ).

Palavras-chave: Zooplâncton, migração vertical diurna, abundância, biomassa

Abstract

Zooplankton are diverse animals found in the ocean, ranging from microscopic to larger invertebrates, and they are crucial to marine ecosystems. Some zooplankton species migrate vertically towards the oxygen-poor waters during the day, which could affect oxygen consumption and release of dissolved compounds, such as ammonium, into deep water. This study provides an overview of zooplankton distribution in the eastern North Atlantic Ocean. Zooplankton was sampled depth stratified along a transect from Cabo Verde to the English Channel using a 150 µm multinet. An analysis of taxon composition identified 11 taxa. Copepoda and Sagittoidea were the most abundant organisms. Stations located in upwelling areas had high biomasses. Stations sampled at night had higher abundances than those sampled during the day. Hydroacoustic data from the EK80 indicated that organisms migrated vertically between day and night. Biomass in the oxygen minimum zone (OMZ) was high.

Keywords: Zooplankton, diurnal vertical migration, abundance, biomass

Abbreviations and acronyms

AC	Azores Current
BP	Biological Pump
CaC	Canary Current
CO2	Carbon dioxide
CTD	Conductivity, Temperature, and Depth Profiler
CVFZ	Cape Verde Frontal Zone
CVOO	Cape Verde Ocean Observatory
DVM	Diel vertical migration
EASIW	Eastern Atlantic Subarctic Intermediate Water
ENACW	Eastern North Atlantic Central Water
ENACWP	Eastern North Atlantic Central Water of subpolar
ENACWT	Eastern North Atlantic Central Water of subtropical
ESTOC	European Station for Time-Series in the Ocean of the Canary Islands
ETNA	Eastern Tropical North Atlantic
ETNA	eastern tropical North ATLANTIC
MW	Mediterranean Water
NAC	North Atlantic Current
NADC	North Atlantic Drift Current
NAO	North Atlantic Oscillation
NEC	North Equatorial Current
NECC	North Equatorial Counter Current
ODV	Ocean Data View
OMZ	oxygen minimum zone
PoC	Portugal Current

POC	Particulate Organic Carbon
SACW	South Atlantic central water
TS	Target Strength

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1. Introduction

Zooplankton are macro- and microscopic animals that include representatives of almost all major taxa, especially invertebrates. They are drifting organisms that rely on water currents, while nekton are swimming organisms that can move independently (Pearre, 2003). Both zooplankton and nekton play important roles in aquatic ecosystems, contributing to the overall biodiversity and functioning of these watery habitats. However, this study will focus on zooplankton. Zooplankton are a central component of marine ecosystems and play an essential role in marine food webs and biogeochemical pathways as they consume a wide range of particulate matter. Their faecal pellets contribute significantly to the passive flux to the seafloor (Julie, 2012). They form the link between the primary and tertiary trophic levels (Kiko et al., 2020; Kiko & Hauss, 2019) and play a fundamental role in the cycling and transporting of biogenic elements in the ocean (Dam & Baumann, 2017).

Some zooplankton species migrate vertically between the surface layer (where they feed during the night) and intermediate depths (where they hide from predators during the day). These migrations actively export organic and inorganic matter from the surface layer as these organisms excrete, defecate, breathe, and die while also becoming prey to predators (Kiko et al., 2020). Vertical migrations into the mesopelagic environment (zone between 200 and 1000 m below sea level) also provide adaptive value, just like in other habitats. However, there still needs to be an agreement on the factors that immediately trigger these migrations. It is believed that light plays a significant role in controlling the timing of daily vertical migrations, as they usually happen in relation to sunrise and sunset (Frank & Widder, 2002). The vertical distribution of zooplankton can also be influenced by water masses or their ability to swim. Goldthwait & Steinberg (2008) discovered increased zooplankton abundances in the surface layer of mesoscale eddies in the Sargasso Sea compared to the surrounding open ocean.

Zooplankton plays an essential role in the biological carbon pump by creating particles that quickly sink in the form of faecal pellets (Wilson et al., 2013) and dead bodies (Frangoulis et al., 2011). Furthermore, several species help transport of carbon to depth with their daily vertical migrations by respiring, defecating and dying at daytime depths. The carbon in transported matter is an energy source for pelagic and benthic organisms. According to studies on global biogeochemical models, the active flux facilitated by diel vertical migration (DVM) zooplankton can locally contribute between 10 to 50% of the downward flux towards the mesopelagic zone (Aumont et al., 2018; Bianchi et al., 2013). This process ultimately contributes to the carbon supply of the mesopelagic zone (Omand et al., 2020; Stukel et al., 2018) and plays a crucial role in the ecosystem.

Recent climate change and eutrophication have led to increased oxygen depletion and temperature increases in marine ecosystems. However, the impact of oxygen stress and global warming on the distribution of zooplankton, which is the main trophic link between primary producers and fish, remains somewhat unknown in the deep sea (Karpowicz et al., 2020). Along the RV Polarstern 135/2 2023, from Cabo Verde to the English Channel, a Multi Plankton Sampler (MultiNet "Midi", MN) was deployed at ten stations for plankton samples in different water layers. The main objective is to understand the variations and migrations of zooplankton. To achieve this goal, this study aims to answer the following research questions:

- Does the composition of significant zooplankton taxa change with latitude?
- Is there a category of zooplankton more abundant than others along the transect?
- Does the environment influence this distribution? These questions will be compared to the previous studies.

The stability of ecosystems is essential for human well-being, as they provide us with a range of services, including food production, climate regulation and biodiversity protection (Holmlund & Hammer, 1999). Marine ecosystems provide these services, with zooplankton playing a central role in nutrient cycling and the biological pump (Bianchi et al., 2013). For example, the DVM of zooplankton in the biological pump (BP) is critical as it plays a significant role in the ocean's ability to sequester carbon from the atmosphere, which is essential for regulating global climate (Boyd et al. 2019). With increasing greenhouse gas emissions affecting the climate by acting on hydrographic parameters such as temperature, studying these hydrographic parameters to understand the effects of zooplankton vertical distribution is essential.

1.1.Objectives

This study aims to investigate the distribution of zooplankton across a latitudinal transect along in the Easter North Atlantic, as well as their vertical migration patterns during day and night . Specifically, it aims:

1. To examine the structure of the water masses along a latitudinal gradient using environmental data collected by CTD to see how this affects the density and biomass of zooplankton.

2. To analyze the zooplankton community (biomass and abundance) at different depths by means of broader taxonomic groups along a latitudinal gradient from Cabo Verde to the English Channel.
3. To analyze the variation in depth distribution between day-night at four selected paired stations to quantify vertical migration and compare with hydroacoustic data.

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2. Literature review

Zooplankton organisms feed on all kinds of small particles (phytoplankton, detritus, other zooplankton) and the faecal pellets they egest make a significant contribution to the passive flux of the surface layer (Kiko & Hauss, 2019). They are in turn important food for higher trophic-level animals, such as fishes. The main characteristic of zooplankton is drifting , they variability in space and time in any aquatic ecosystem (S.C. Goswami (Retd.), 2004).

Zooplankton have been classified into different types based on taxonomy, size, feeding strategy and spawning mechanism (Mitra et al., 2014). They comprise a diverse group of metazoan and protistan secondary and tertiary consumers occupying several trophic levels in the pelagic food web (Steinberg & Landry, 2017) and perform a variety of ecosystem functions such as energy transfer and nutrient cycling. Zooplankton are direct consumers of primary production, serve as food for fish, and are important drivers of nutrient and carbon cycling (Julie, 2012).The nitrogen regenerated by zooplankton excretion is critical to support the production of phytoplankton and bacteria. Their faecal pellets and carcasses are an important organic carbon source for detrital organisms (Richardson, 2008).

Zooplankton DVM results in the active export of organic and inorganic matter from the surface layer as zooplanktonic organisms excrete, defecate, respire and are attacked at depth (Bandara et al., 2021; Lampert, 1989; A. R. Longhurst et al., 1990). According to Kiko & Hauss, (2019) diurnal depth is highly dependent on water clarity and is deepest in the oligotrophic blue ocean. The core of the mid-water OMZ coincides with the diurnal depth of many DVM species, according to large-scale analyses of acoustic backscatter data (Bianchi et al., 2013, 2014). According to Kalvelage et al. (2015), microbial degradation of downwelling organic matter in upwelling regions and subsequent metazoan respiration associated with low ventilation lead to the formation of such OMZ (Czeschel et al., 2011), the core of which is often virtually anoxic (Revsbech et al., 2009).

Brassard et al.(2023) identified three patterns of diurnal vertical migration (DVM) of zooplankton. The first pattern, known as direct DVM or normal DVM, involves a single descent to maximum depth during the day and a single ascent to minimum depth during the night. The second pattern is reverse migration, where zooplankton migrate to deeper water at night and return to shallower water near the surface during the day. The third pattern is reverse DVM, where zooplankton migrate to shallower water at night and return to deeper water during the day or remain at a constant depth throughout the day (Vos et al., 2002). Richardson, (2008) described the adaptive importance of diurnal vertical migration of zooplankton, highlighting certain disadvantages and advantages for these organisms. He pointed out that there are several costs associated with migration, for example, reduced food availability can lead to growth problems and low fecundity. Swimming up and down the water column reduces the fitness of organisms as they require more energy than those that remain at the surface. In addition, the development time of the eggs carried by the females is prolonged when they migrate to depths where temperatures are lower. According to Ramos-Jiliberto et al., (2004), the final effect of DVM on a population depends on the balance between the benefits of increased survival and the costs. This concept is explained in Figure 1.

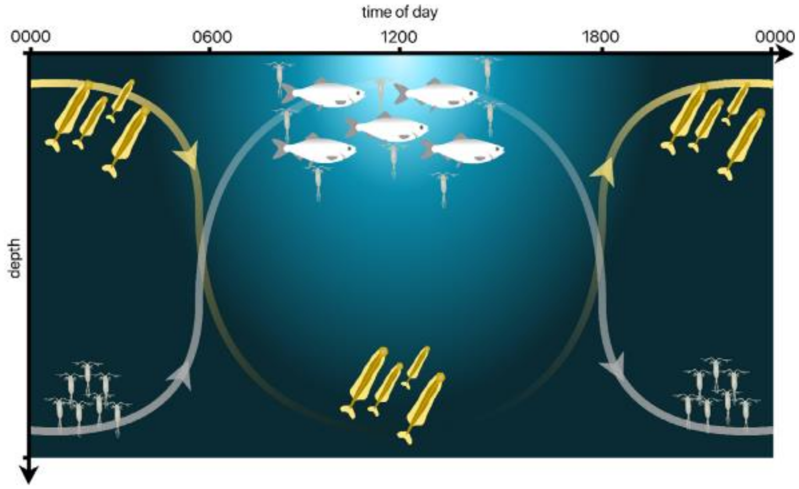

Figure 1: A model suggesting that plankton that feed visually, such as fish, tend to consume larger prey, resulting in a classic DVM pattern among large zooplankton (Sagittoidea) shown in yellow. On the other hand, smaller zooplankton (copepods) are less appreciated by the visual predator and are predated by Sagittoidea, giving rise to an inverse DVM pattern represented in grey. source: (Bandara et al., 2021).

Another essential factor that may explain DVM patterns is the presence of low-oxygen conditions at intermediate depths. Hauss et al., (2016) described the distribution and migration of zooplankton in low-oxygen eddies in the eastern tropical North Atlantic (ETNA). This study was the first to observe the effects of these eddies on pelagic metazoans in the region. They were able to identify the effects of individual mesoscale eddies on the distribution and vertical migration of zooplankton near Cape Verde. Their study revealed four strategies adopted by migrating zooplankton: the first was to remain at the surface to avoid the oxygen minimum zone (OMZ), the second was to migrate towards the shallower core of the OMZ during the day and return to the surface at night, the third was to remain within the OMZ during the day and night, and finally the last was to migrate from the surface through the OMZ to more oxygenated depths and vice versa. The first three approaches could result in reduced active transport of particulate and dissolved matter compared to normal DVM patterns in the region. Still, the fourth approach could result in deeper and, more efficient export of the Particulate Organic Carbon (POC).

Based on the same logic, several other studies have been carried out on the involvement of DVM in particulate matter fluxes around the globe. Kiko & Hauss (2019) are among these authors, who estimated the active fluxes mediated by zooplankton in the oxygen minimum zone regions of the Peruvian upwelling system by observing the impact of the highly intensive OMZ found off Peru on the metabolic activity of DVM organisms. It was concluded that oxygen is a key abiotic factor that can structure species distribution and modulate metabolic activity.

The respiration and excretion of zooplankton significantly impact the distribution of oxygen and nutrients. The excretion of mesozooplankton provides more than 50% of the estimated nitrogen and phosphorus requirements of phytoplankton in the tropical and subtropical oligotrophic Atlantic (Isla & Anadón, 2004).Different species of zooplankton have developed tolerance thresholds for low oxygen availability, which is why oxygen minimum zones (OMZs) play a vital role in determining the distribution of zooplankton in the pelagic ecosystem of the subtropical and tropical oceans (Auel & Verheye, 2007; Saltzman & Wishner, 1997; Wishner et al., 1998).

Kiko et al. (2020) studied zooplankton-mediated fluxes in the eastern tropical North Atlantic (ETNA). The study revealed that many migrants have a diurnal distribution depth of 300-600 m, which coincides with an expanding and intensifying oxygen minimum zone (OMZ). Zooplankton's DVM is responsible for 31% to 41% of nitrogen loss in the upper 200 m of the water column. Resident and migratory zooplankton are responsible for 7-27% of total oxygen demand at depths of 300-600 m. Decreases in oxygen levels at mid-depth could modify the elemental cycle of oxygen and carbon in the ETNA and have an impact on the elimination of nitrogen from the surface layer.

Studies conducted in different regions have shown that low to moderate oxygen level in OMZs have minimal impact on zooplankton biomass. However, such levels can cause species distribution changes (Longhurst, 1967; Weikert, 1982).

In the ocean, OMZs have been associated mainly with regions where mid-water oxygen levels fall below 60 µmol O2 kg^{-1}, including hypoxic (5-60 µmol O2 kg^{-1}), suboxic (<5 µmol O2 kg^{-}

^{1}), and even anoxic (0 µmol O2 kg^{-1}) waters (Engel et al., 2022). Hypoxic and suboxic thresholds are operational and, to some extent, arbitrary. Still the physiological and behavioral performance of many zooplankton and nekton organisms are affected below the hypoxic threshold, while specifically adapted species may use hypoxic areas as a refuge (Ekau et al., 2010; Hoving et al., 2020; Seibel, 2011).

Physiological responses to temperature change may differ between primary, secondary and tertiary consumers, influencing trophic coupling via changes in productivity or phonological shifts and mating dynamics (Moyano et al., 2017). The temperature change can alter plankton behavior with unexpected consequences such as increased swimming speed, altered phenology of annual migrations to feeding and/or spawning areas and population abundance. Reduced oxygen can increase the metabolic rate and decrease the organisms tolerance range, making it more vulnerable to climate change. Likewise, benthic marine species with a planktonic larval phase that must develop to a benthic stage to join the adult population are also affected by water column.

3. Materials and Methods

The purpose of this section was to outline all the materials employed in the study, provide a concise explanation of the research procedures, and clarify the process of data collection and analysis.

3.1. Study area

The study was carried out in the central-eastern Atlantic, from Cabo Verde 17ºN to the European continental shelf at coast 47ºN (Figure 2) via the Cabo Verde Frontal Zone (CVFZ) and the Bay of Biscay. The CVFZ is a term used to describe the southeastern zone of the subtropical gyre circulation found in the North Atlantic Ocean. It acts as a boundary between the North Atlantic Central Water (NACW) and the South Atlantic Central Water (SACW) (Dove et al., 2021). The Bay of Biscay is part of the Atlantic Ocean and is bounded by the northern and western coasts of Spain and France, respectively. Its oceanic circulation is weak and generally variable, with the frequent presence of cyclonic and anticyclonic eddies resulting in instabilities of the continental margin currents which interact, with the bottom topography and are called SWODDIES or Slope Water Oceanic Eddies (Ferrer et al., 2007). Oceanic regions can be distinguished through characteristic water masses based on oxygen, temperature, chlorophyll-a, salinity, light, abundance, and biomass of plankton and nekton (Sutton et al., 2017). The primary water masses in the transect include the Eastern North Atlantic Central Water of subpolar (ENACWP) and subtropical (ENACWT) central waters of the North-East Atlantic.

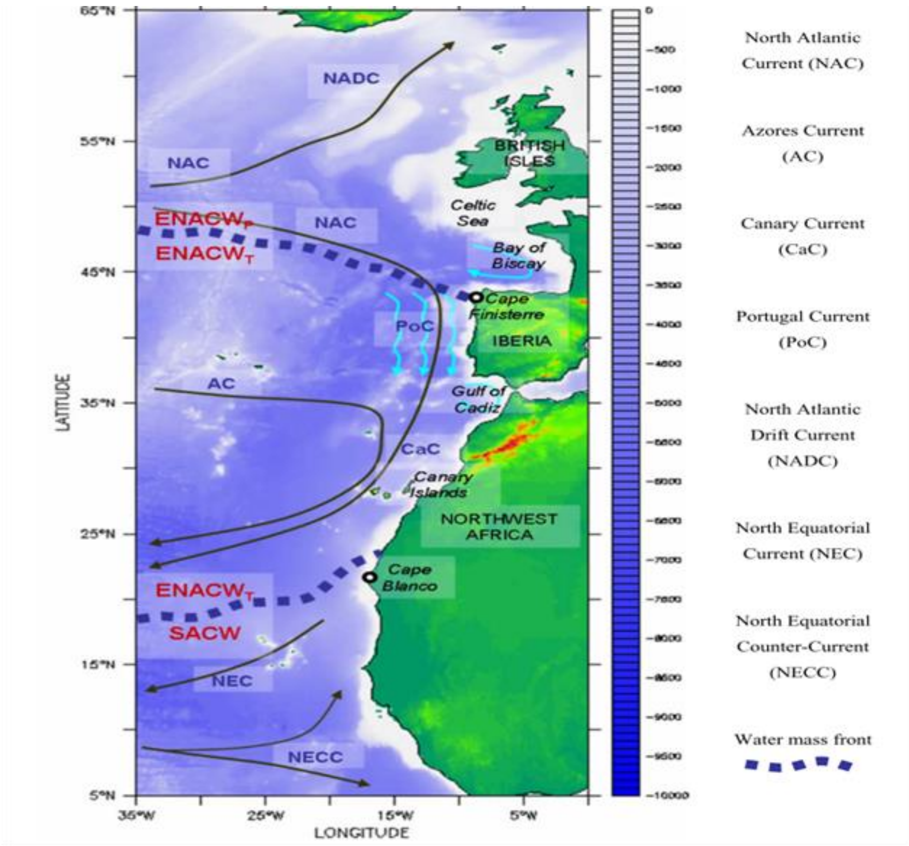

Figure 2: Water masses patterns in the eastern North Atlantic region. Source (Mason et al., 2006)

3.2.Sampling of environmental parameters

The survey was carried out on board the German research icebreaker RV "Polarstern" of the Alfred Wegener Institute for Polar and Marine Research during the cruise 135/2 from 28 March 2023 to 11 April 2023. Vertical profiles of temperature, conductivity, pressure, dissolved oxygen, and fluorescence were recorded at every station using a Seabird 911Plus conductivity, temperature, and depth profiler (CTD), equipped with a dissolved oxygen sensor, as well as a Seapoint chlorophyll fluorometer sensor (Figure 3). To determine chlorophyll levels, fluorescence readings obtained from samples at various depths (0-200 m) was used for calibration (Hernández-León et al., 2019).

Figure 3: CTD used during the cruise.

3.3.Zooplankton data sampling onboard

Twelve vertical multinet deployments were made for plankton sampling with a maximum deployment depth between 2000 m and 125 m, collecting a total of 60 samples from a total of 10 stations (Figure 4). The multinet was equipped with multiple opening-closing devices with five nets (150 µm mesh size) attached to a steel frame with a mouth opening of 0.25 m^2 (Figure 5), which were opened and closed at different depths. The water sampling column was split into five sampling intervals (Table 1).

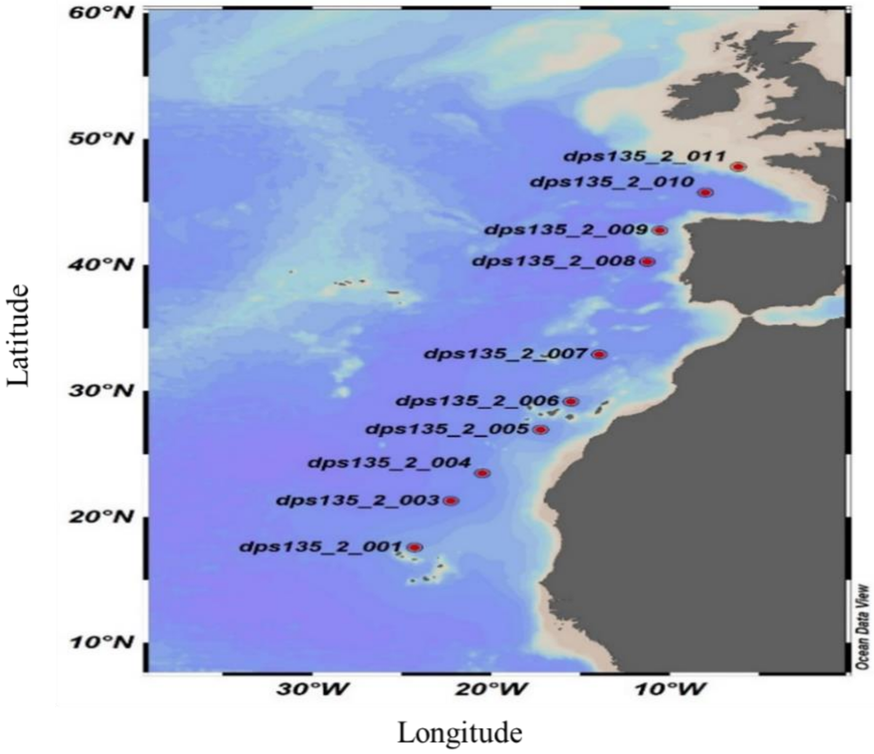

Figure 4*:* Location of the sampling stations represented in red points.

Figure 5: Multinet Type MIDI. a showed the Multinet going in the water, b showed the assembly of the 5 Nets

Table 1: Sampling stations name, number of depth layers sampled, vertical range sampled (meters).

Sampling Stations	UTC time	Catching period	Vertical range (m)
1	04:18	N	0-1000
3	12:04	D	0-800
4	5:00	N	0-800
5	11:22	D	0-800
6a	04:46	N	0-1000
6b	09:17	D	0-1000
7	11:29	D	0-800
8	12:36	D	0-800
9a	04:07	N	0-800
9b	07:41	D	0-2000
10	12:03	D	0-800
11	06:43	D	0-125

Sampling stations were distributed in 2 groups: During daytime (D) and nightly (N). Coordinated Universal Time (UTC) is the time at which the data was collected. The sampling intervals for sampling stations (3, 4, 5, 7, 8 and 9a and 5) were: 800 – 400, 400 – 200, 200– 100, 100 – 50, 50 – 0. For sampling stations 1 and 6 the intervals were: 1000 – 600, 600 – 300, 300 – 200, 200 – 100, 100 – 0. The 9b sampling station intervals were: 2000 -1500, 1500 – 1200, 1200 – 600, 600 – 100, and 100 – 0. And for 11 station sampling intervals were 125 – 100, 100 – 75, 75 – 50, 50 – 25, 25 – 0.

In order to assess the biomass, abundance and population dynamics of ecosystem resources, especially small pelagic and mesopelagic fishes, hydroacoustic methods are a standard tool. A high-precision scientific echosounder (EK80 Kongsberg Maritime AS) was used to monitor and analyze the plankton and micronekton community throughout the transect at 38, 70, 120 and 200 kHz, of which the 38 kHz data were used for analysis. Transducer information and ping settings of the EK80 used are shown in Table 2 below. No calibration was performed during the cruise due to lack of time. Continuous hydroacoustic data collection took place during all cruise activities: along transits and during station work. Surface data down to 1200 m was considered usable with the EK80 software and transferred to the AWI data centre for publication on PANGAEA.

Table 2: Transducer information

Transducer model	Serial number	Nominal frequency (kHz)	Ping mode	Pulse duration (s)	Transmit power (W)
ES38-7	438	38	cw	0.004096	2000
ES70-7C	696	70	cw	0.001024	750
ES120-7C	2218	120	cw	0.000512	250
ES200-7C	879	200	cw	0.000512	45

3.4. Laboratory Analysis of Multinet Catches

Once the samples had been collected from the seawater, they were preserved with 4% borax-buffered formaldehyde solution and transported to the Thünen Institute laboratory for morphological identification. To identify the taxonomic composition of each sample, the samples were placed in Petri dishes and used a dissecting microscope Leica M125 for identification. Figure 6 shows three organisms were able to photograph through the stereomicroscope. Large and medium-sized taxa were counted, while sub-samples ranging from 100 to 300 zooplankton elements were taken from the smallest zooplankton, exclusively Copepoda, using a Motoda separator. These sub-samples (corresponding to 1% of the sample) were analyzed together with those counted to estimate the number (n) of organisms. However, to calculate zooplankton abundance (individuals/m^3) and biomass these sub-samples were not taken into account.

The elements of each taxonomic group were separated and placed in small 20 x 30 cm glass plates, which were then dried in an electric oven at a constant temperature of 60 ºC oven for 24 hours. Once dried, a balance was used to determine the weight (g) of each taxonomic group per station, taking into account the weight of the empty plates. This information was needed to calculate zooplankton biomass.

Figure 6: Some examples of zooplankton identified under the microscope. In a and b, the largest specimens are Euphausiacea of different species, whereas the smaller organisms are Copepoda; c is a *Cyclothone* sp. larvae.

3.5. Data Analysis

3.4.1. Abundance calculation

The calculation of abundance (individuals/m^3) took into account the number (n), the proportion of the sample counted (k), i.e. the proportion of the total volume in relation to the volume of the sub-sample(s), and the volume of water filtered by the sampling net (m^3). Plankton densities (normalized as numbers per m^3) were calculated as follows:

$$D_{i,k} = \sum_j \left(v_{j,k}^{-1} * n_{i,j,k} \right) \qquad \text{(Eq: 1)}$$

Where:

- $D_{i,k}$: is the number of individuals per taxon i per m^3 of seawater at station *k*;
- $v_{j,}$: is the volume estimated based the flowmeter and the area of net mouth j at station k and
- $n_{i,j,k}$: is the number of individuals of taxon *i* in net j at station *k* (Dove et al., 2021).

To calculate abundance per m² at the station 6 and 9, the abundance per m³ was multiplied per water layer depth because of the difference of the sampling interval

3.4.2. Biomass

After drying, the biomass of the samples was calculated in grams per m^3 using the equation:

$$Dry\ mass\ of\ zooplankton\ \left(\frac{g}{m^3}\right) = \frac{Total\ dry\ mass\ of\ zooplankton\ (g)}{Volume\ of\ water\ filtered\ (m^3)} \qquad \text{(Eq: 2)}$$

3.4.3. Acoustic Echosounder (EK80)

Each organism produces an individual backscatter, called target strength (TS; dB re 1 m^2).Integrated backscatter within an area or volume can be used to identify the horizontal and vertical distribution of targets over the transect. For example, to study the vertical migration of zooplankton, the integrated amplitude of the EK80 echo caused by the backscatters was converted to a volumetric backscatter Sv (dB) to correct for the depth dependence of the data (Kiko et al., 2020). Volume backscattering (Sv in dB re m^{-1} or sv in $m^2.m^{-3}$) is the summation of the contribution from all targets within the sampling volume scaled to 1 m^3. Sv is a proxy for the density of organisms and the primary measurement for acoustically estimating fish densities and abundance (Kloser et al., 2016)

When individual targets are very small and there are many of them in the sampled volume, their echoes combine to form a received signal that is continuous with a variable sampling amplitude. The echo intensity is therefore a measure of the biomass in the water column. The basic acoustic measure is the volume backscatter coefficient (s_v), obtained from the echo integration. s_v is defined as follows

$$\frac{s_v = \sum \sigma_{bs}}{V_0} \qquad \text{(Eq: 3)}$$

Where:

- V_0: is the sampled volume,
- σ_{bs}: is the backscattering cross-section.

The volume backscatter coefficient was transformed into the mean volume backscatter strength by:

$$S_v = 10\log(s_v) \qquad [\text{dB re m}^{-1}] \qquad \text{(Eq: 4)}$$

3.4.4 Analyzing relationships between abundance, and hydroacoustic data

The relationship between organism abundance and acoustic measure was analyzed using Pearson correlation analysis (equation 5) and linear modeling. Correlations were performed with Day-Night abundances at the stations 6 and 9 and the Sv from acoustic data.

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \qquad \text{(Eq: 5)}$$

Where:

- r = correlation coefficient
- x_i=value of the x- variable in a sample

- $\bar{x}$ = mean of the value of the x-variable
- y_i=values of the value of the y- variable in a sample
- $\bar{y}$ =value of the y- variable in a sample

The correlation showed the strength and direction of the relationship. The correlation coefficient ranges between -1 and +1. Equation 3 shows that by definition a positive relationship between Sv and abundance in terms of numbers of backscattering cross sections exists. Values compromising this positive relationship or with a significant deviation from the linear regression model were treated as outliers.

Linear regression models describe a continuous response variable as a function of one or more predictor variables.

$$y = a + bx \qquad \text{(Eq: 6)}$$

Where:

- x: is the explanatory variable
- Y: is the dependent variable
- b: is the slope of the line, and
- a: is the intercept (the value of y when x = 0).

A hypothesis testing was performed to determine the statistical significance of the correlations. The null hypothesis for these tests (H0) is that there is no correlation between abundance and Sv. The alternative hypothesis (H1) is that there is a correlation between abundance and Sv. The p-value was set at 0.05 (95% confidence level), so if $p<0.05$, the null hypothesis would be rejected and the alternative hypothesis accepted. For correlation analyses and linear modeling, this was an F-test, for the difference between day and night abundance this was a t-test. The t-test is a statistical test that is used to compare the means of two groups while the F-test used to compare the variances of two groups.

3.5. Data Analysis Tools

Data analysis and visualization in this study was carried out using a combination of Excel, ODV and the R programming language. Ocean Data View (ODV) is a software package for interactive exploration, analysis and visualization of oceanographic and other geo-referenced profile time series, trajectory or sequence data (Schlitzer, 2022). R is a statistical computing and graphics system. It provides, among other things language, high-level graphics, interfaces to other languages, and debugging facilities (Isaacson, 1974).

4. Results

4.1. Oceanography

Temperature and salinity showed strong vertical stratification (Figure 7a; b) from station 1 (17°N) at the Cabo Verde Ocean Observatory (CVOO) to station 8 (40°N). From station 8 onward the vertical gradients became less pronounced. Oxygen showed a sharp decline (Figure 7c) at the first three stations, which was the apparent location of the CVFZ, and from stations 5 to 10, oxygen concentration increased near the surface and below 1500 m. The highest salinities (peaking at 37.5) were found between 150 m and 200 m, between stations 1 (29°N) and 8 (47°N), and the lowest (peaking at 34) were found between 700 m and 1000 m, from station 1 (17°N) to station 3 (21°N).

The lowest temperatures (Figure 7a) coincided with the lowest salinities (Figure 7b).In contrast, the highest temperatures were found near the surface from CVFZ to station 6 (29°N), the European Station for Time-Series in the Ocean of the Canary Islands (ESTOC). The Mediterranean Water (MW) appeared as a zone of relatively high salinity and temperature of 600 m between stations 7 (32°N) and 8 (40°N).

Between stations 1 and 7, the maximum chlorophyll-a values were observed at 25 m and 100 m, depths, with the weakest chlorophyll-a maximum at station 1 (CVOO). Between stations 9 and 10, the chlorophyll-a maximum was shallow (0 m -75 m; Figure 8d). The minimum of shallow chlorophyll-a was observed between station 7 and station 8 in the ENACW water between the sea surface to 50 m depth. The zone of maximum deep chlorophyll-a coincided with the OMZ at the station 1, 3, 4, and 5.

The vertical oxygen section showed the OMZ between stations 1 (17°N) and 3 (21°N), with the lowest oxygen values between the sea surface and 1000 m depth. Near-surface values increased in a northward gradient along the transect, with the highest values at the northernmost station 10 and the lowest values at station 1.

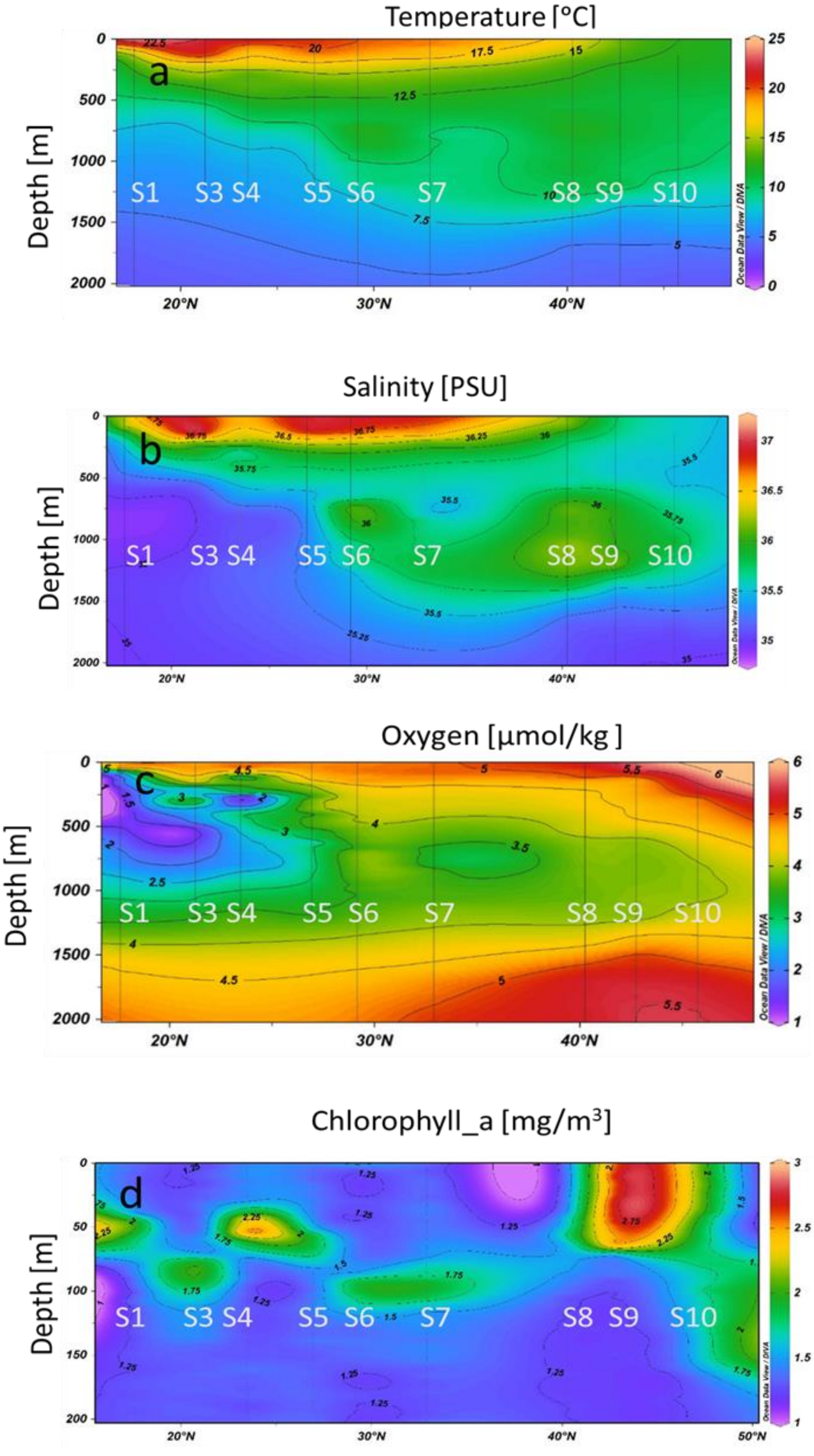

Figure 7: Surface to 2000 m display of oceanography sections across the transect. Temperature in ºC (a); salinity in PSU (b); dissolved oxygen in µmol/kg (c); Chlorophyll-a in mg/m^3 (d). The thin vertical lines within the figure represent the collection stations (S1, S3, S4, S5, S6, S7, S8, S9, and S10). Station 11 was not include because it was in shallow water

To determine the similarity of hydrographic parameters and stations, temperature, salinity, oxygen and chlorophyll were normalized (mean 0, unit variance) and then grouped after cluster analysis. Three groups of stations were distinguished for descriptive purposes (Figure 8). The first group consisted of 3 and 4, which represent the tropical group with a relatively high surface temperature and low oxygen levels between 200 m and 700 m depth. Stations 3 and 4 were closely linked to the CVFZ. The second group, comprising stations 5, 6 and 7, was characterized by a lower sea surface temperature and an increasing presence of MW in the center at depths of 1000 m. The third group, comprising stations 8, 9 and 10, was characterized by lower surface salinity, lower sea surface temperature and higher oxygen levels.

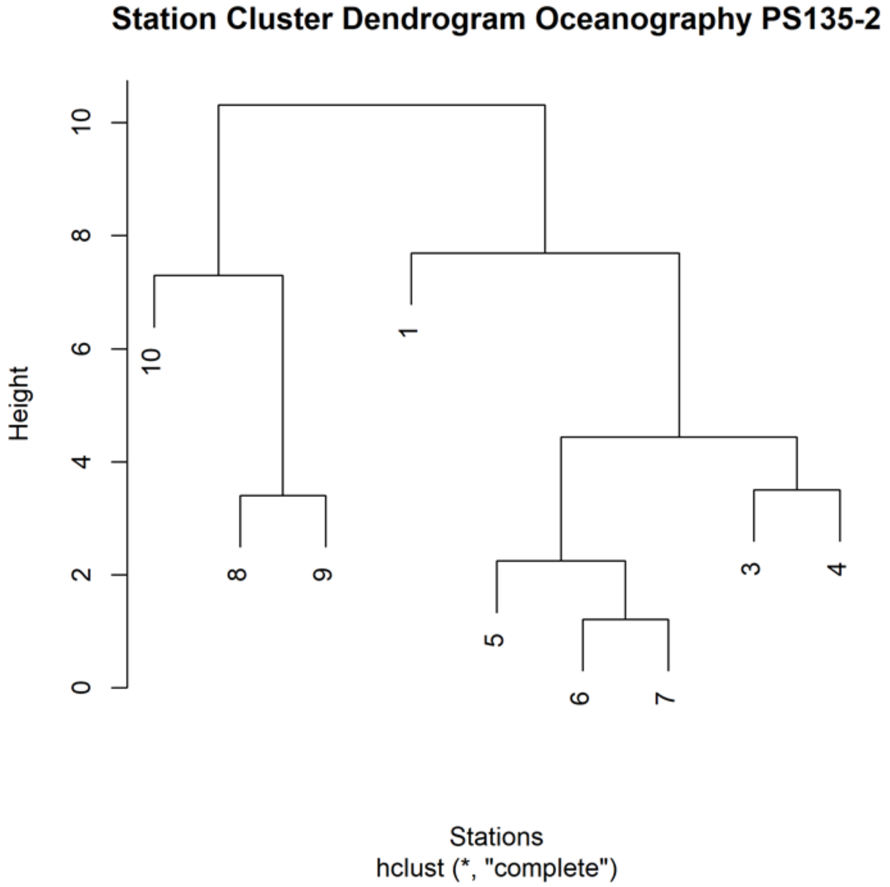

Figure 8: Hierarchical Cluster Analysis results to determine groups of stations based on oceanographic parameters. For convenience, the stations were divided into three groups: The tropical southern part (1, 3, and 4); the subtropical part (5, 6, and 7) and the temperate part (8, 9, and 10).

Analysis of water masses based on temperature and salinity characteristics (Emery & Meincke, 1986), quoted by Dove et al. (2021), showed that from station 4 (23◦N) to the northernmost part of the transect, the ENACW dominated the upper part of the water column. At stations 1 (17◦N) and 3 (21°N), temperature and salinity values corresponded to a mixture of SACW and ENACW, indicating the location of the CVFZ. Eastern Atlantic Subarctic Intermediate Water

(EASIW) was found from about 900 m at both CVFZ stations (1 and 3) and stations 4 and 5 north of the CVFZ. The 6 northernmost stations (6, 7, 8, 9, and 10) showed an intrusion of MW from 600 m to the bottom of the CTD cast (1000 m) (Figure 9).

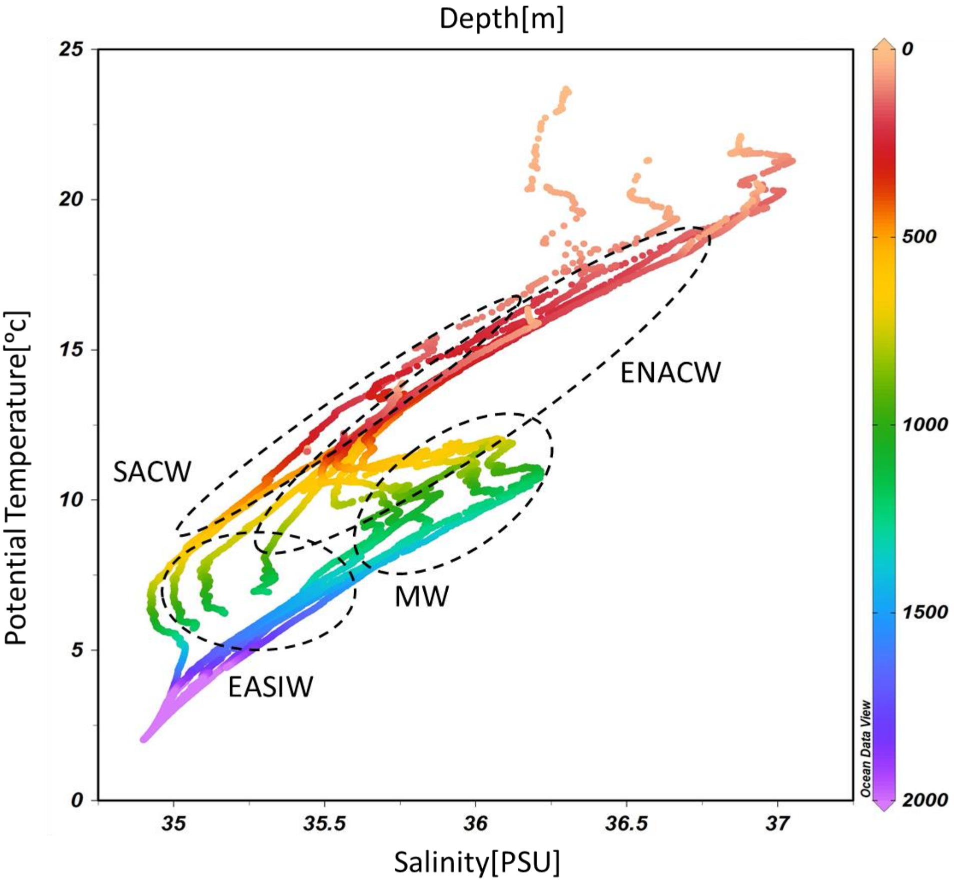

Figure 9: Temperature-Salinity (TS) diagram of 12 stations along the transect. South Atlantic Central Water (SACW), Eastern North Atlantic Central Water (ENACW), Mediterranean Water (MW), Eastern Atlantic Subarctic Intermediate Water (EASIW). Station 11 was not included because it was in shallow water.

4.2. Abundance and Biomass

4.2.1. Taxa

In this study, two different orders within the crustaceans were identified: Copepoda and Euphausiacea; two orders within Mollusca: Gastropoda and Pteropoda; and seven other categories: *Doliolum* sp. (n=177), Foraminifera, Gonostomatidae (bristlemouths or lightfishes, or anglemouths), hydromedusae, Polychaeta, *Pyrosoma atlanticum* (n=48) and Sagittoidea. Gonostomatidae were found in deep waters between 800 m and 400 m during the day. However, during night sampling they were found near the surface between 200 m and 100 m. Copepoda were the most abundant at each station, and the total count was 10226 for all stations, followed by Sagittoidea (n=919) and Euphausiacea (n=797). The lowest counts per category were obtained from Gastropoda, with a total count of 4 (Table 3). The presence of taxa was almost the same for all stations. However, the taxa (n=946) found at the station 9a were high compare to the taxa of the other stations. At station 9a the number of specimens per taxa was followed as: Copepoda (n=420), *Doliolum* sp (n=114), Euphausiacea (n=129), Foraminifera (n=22), Gonostomatidae (n=1), Polychaeta (n=17), Pteropoda (n=233), Sagittoidea (n=2). Followed by stations 10, 6a and 1. Station 8 had a medium number of taxa with a total of 337 specimens. Figure 10 shows the number of organisms sampled by category. Highest number of Copepoda were found at station 10, with a total of 1571 Copepoda (Figure 10).

Table 3: Taxa total counted across the transect

Taxon	**Total counted**
Doliolum sp.	177
Euphausiacea	797
Foraminifera	22
Gastropoda	4
Gonostomatidae	41
Hydromedusae	62
Polychaeta	105
Pteropoda	325
Pyrosoma atlanticum	48
Sagittoidea	919
Copepoda	10226

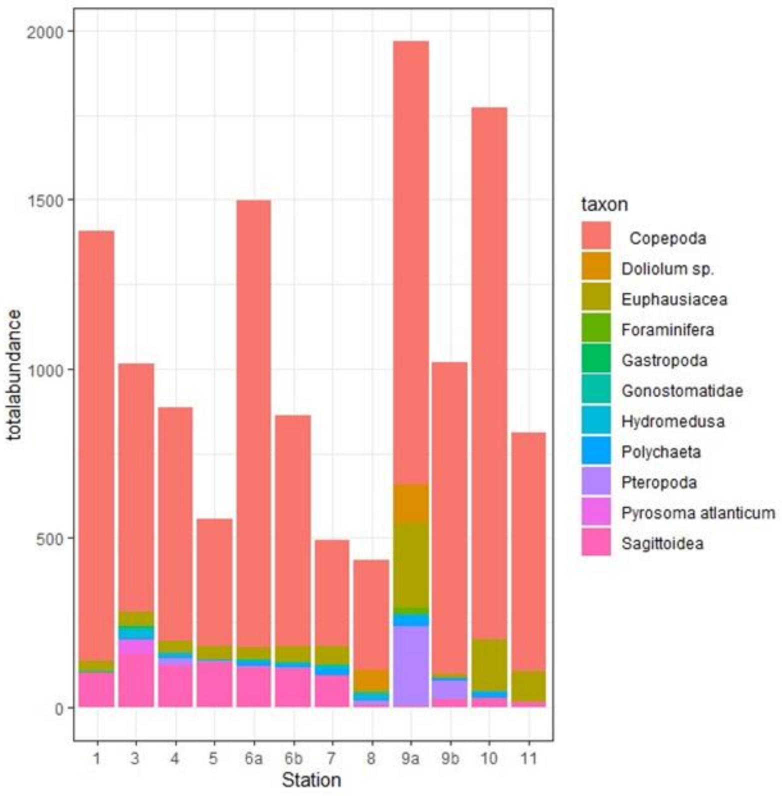

Figure 10: Vertical total count of taxon along the sampling stations. 6a: station night sampling, 6b: day sampling; 9a: station 9 night sampling, 9b: day sampling

Copepoda is among the most efficient organisms in the marine environment due to their ability to exploit different conditions in the water column and favorable conditions for accessing food, thanks to their torpedo shape that gives them high mobility (Kiørboe, 2011). They also account for a significant proportion of the biomass and productivity of marine environments. Copepoda are recognized as undifferentiated or selective suspension feeders or carnivores (Rocha-Díaz et al., 2021). The order Euphausiacea contains about 85 species, many of which are widespread in the world's oceans.

Sagittoidea are mesoplanktonic predators found in most marine habitats. They have two sets of retractable chitinous tentacles flanking a ventral mouth. Depending on their size and stage of development, they feed mainly on Copepoda, Diplostraca, Amphipoda, Euphausiacea and fish larvae. These arrow-like creatures are of great ecological value, particularly as an important food source for commercial fish such as sardines and mackerel (Choo et al., 2022).

Pyrosoma atlanticum, *Doliolum* sp, and hydromedusae belong to a group of gelatinous zooplankton found in marine environments. These organisms have a high water content in their tissues, around 95%, and are transported by currents as part of their planktonic existence. They have delicate bodies that are easily damaged by collecting nets (Stenvers et al., 2021)

4.2.2. Abundance

- **Abundance by station**

At station 1, Copepoda was the most common taxa, followed by Sagittoidea and Euphausiacea. Station 3 had a similar balance between Copepoda and Sagittoidea, but Copepoda was found to be more abundant. Euphausiacea, *Pyrosoma atlanticum*, and hydromedusae had a low abundance. Station 4 had both Copepoda and Sagittoidea as the most abundant taxa, while Euphausiacea, Pteropoda, hydromedusae, and Polychaeta were the least abundant. At station 5, Sagittoidea became the most abundant taxa, surpassing Copepoda, while Euphausiacea ranked third in abundance. Gonostomatidae, hydromedusae, and Pteropoda had a low abundance. At station 6a, Copepoda was the dominant taxa, followed by Sagittoidea. However, Euphausiacea, Polychaeta, Gonostomatidae, and *Pyrosoma atlanticum* were almost non-existent. At station 6b, Copepoda was more abundant than Sagittoidea and Euphausiacea, while Gonostomatidae, Pteropoda, and *Pyrosoma atlanticum* had a slight abundance. Station 7 saw a competition in abundance between Sagittoidea and Copepoda, which were the most abundant, while the abundance of Euphausiacea, Polychaeta, Gonostomatidae, hydromedusae, and Pteropoda was comparatively lower. Station 8 showed that Copepoda was more abundant than *Doliolum* sp and Euphausiacea. On the other hand, hydromedusae, Pteropoda, Gonostomatidae, Polychaeta, and Sagittoidea were less abundant than *Doliolum* sp. The results from station 9a indicated that the dominant organism was Copepoda, followed by Pteropoda and Euphausiacea, which were almost equally abundant. *Doliolum* sp, Foraminifera, Gonostomatidae, Polychaeta, and Sagittoidea were the least abundant organisms. At station 9b, Copepoda dominated abundance, and there was a slight abundance of Pteropoda. However, Euphausiacea, hydromedusae, Polychaeta, and Sagittoidea were very low in abundance. At station 10, the abundance of Copepoda was remarkable in contrast to that of Euphausiacea, hydromedusae, Polychaeta, and Sagittoidea. And finally, at station 11, abundance was dominated by Copepoda. While Euphausiacea, hydromedusae, and Sagittoidea were low in abundance.

To summarize, Copepoda were found to be the most abundant organism group at each station along the transect. Following Copepoda, Sagittoidea were the second most common group at stations 1 to 7, with Euphausiacea trailing behind. Other organisms like *Doliolum* sp, Foraminifera, Gastropoda, hydromedusae, Gonostomatidae, *Pyrosoma atlanticum*, Polychaeta, and Pteropoda were not as abundant. Euphausiacea was most abundant at the station 9a with an abundance of 15.4 individuals/m^3, station 10 (9.73 individuals/m^3), and station 11(12.57 individuals/m^3) along the transect. These stations were also the most abundant along the transect. The greatest abundance of Pteropoda (17.97 individuals/m^3) and *Doliolum* sp (7.99 individuals/m^3) were found at station 9a. From the station 8 to station 11 less abundance of Sagittoidea (0.26 individuals/m^3 at station 8, 0.16 individuals/m^3 at station 9a, 0.21 individuals/m^3 at station 9b, 1.27 individuals/m^3 at the station 10, and 2.73 individuals/m^3 at the station 11) was observed. Station 3 got the highest abundance of Sagittoidea with a total of 7.98 individuals/m^3 (Figure 11).

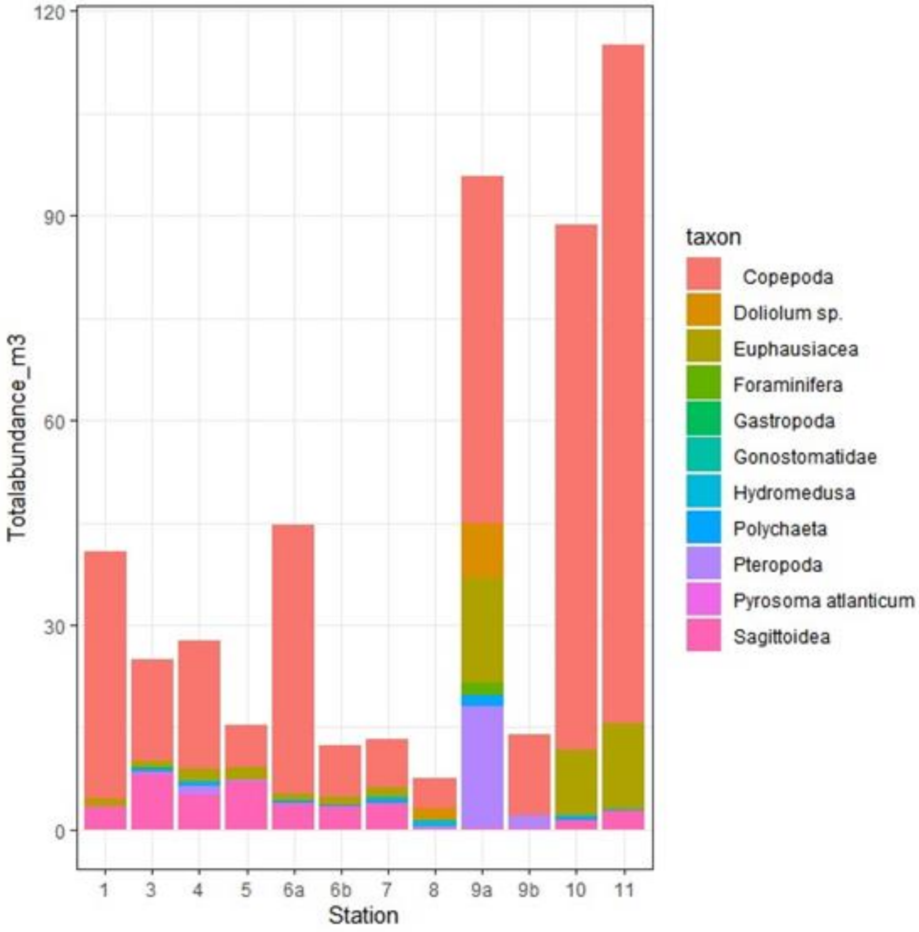

Figure 11: Vertical distribution of zooplankton abundance (ind/m^3) along the transect

- **Layer, and sampling time.**

Knowing that the DVM existed samples were split into two groups along the transect: those collected during the day and those collected at night. One goal was to study the general migration of organisms over two distinct periods in order to compare matched stations (day-night samples collected from the same stations with the same water mass) for future studies. However, it is important to note that the samples collected during day and night were not necessarily matched. Hence to derive a general description of day and night patterns, the eight samples taken during the day at stations 3, 5, 6b, 7, 8, 9b, 10, and 11 were analyzed, followed by four samples taken at night at stations 1, 4, 6a, and 9a. Highest abundance in each tow were encountered at the surface. Only one station (9b) was collected at a depth of more than 1000 .and a few organisms such as Copepoda, Euphausiacea, and Sagittoidea were present in this interval (Figure 12).

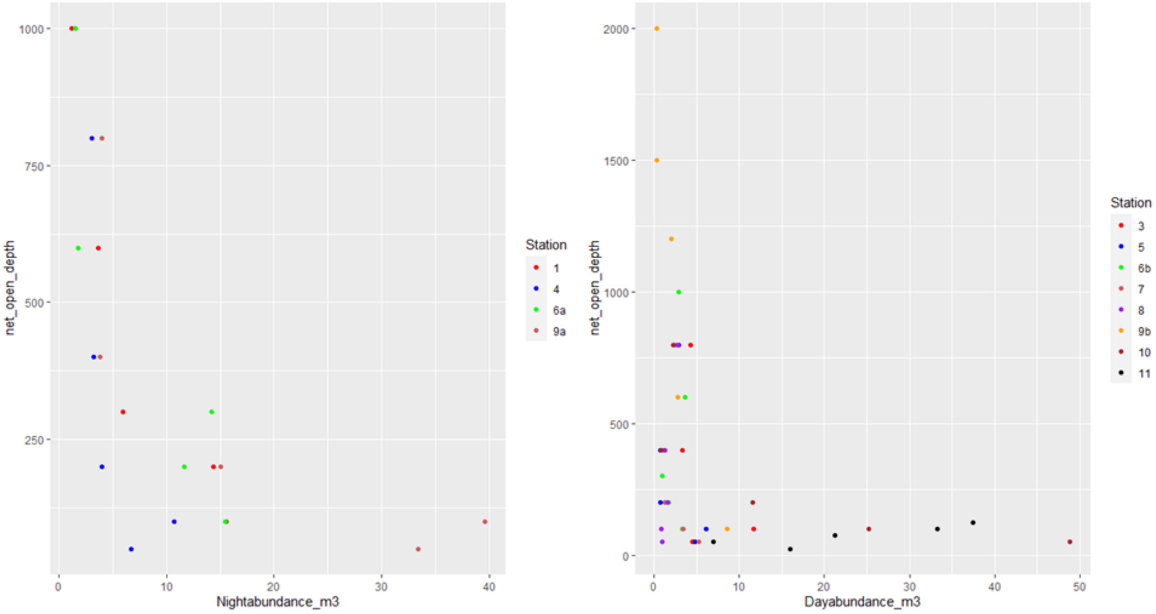

Figure 12: Total abundance at different depth (epipelagic zone, mesopelagic zone and bathypelagic zone) of the total sampling. Split into two groups The 8 day sample at left and the 4 night sample at right. Station 11 daytime was in the shallow water.

4.2.3. Biomass

- **Biomass by station**

The study found that there were differences in abundance and biomass at each station. Although copepod biomass was highest overall, this was not the case at every station. For example, at station 1 Euphausiacea had a higher biomass than Copepoda, but Copepoda had a higher abundance. Additionally, at stations 9a and 9b, the biomass of Pteropoda and *Doliolum sp*. was greater than that of Copepoda. Station 10 had the highest biomass, with Copepoda dominating followed by Sagittoidea. The biomass of station 1 was similar to that of station 10, but station 9a had the next highest biomass. Station 7 had the lowest biomass. However, the biomass of individuals at station 9a was more balanced compared to stations 10 and 1. Finally, Foraminifera, Gastropoda, and Gonostomatidae had the lowest biomasses (Figure 13).

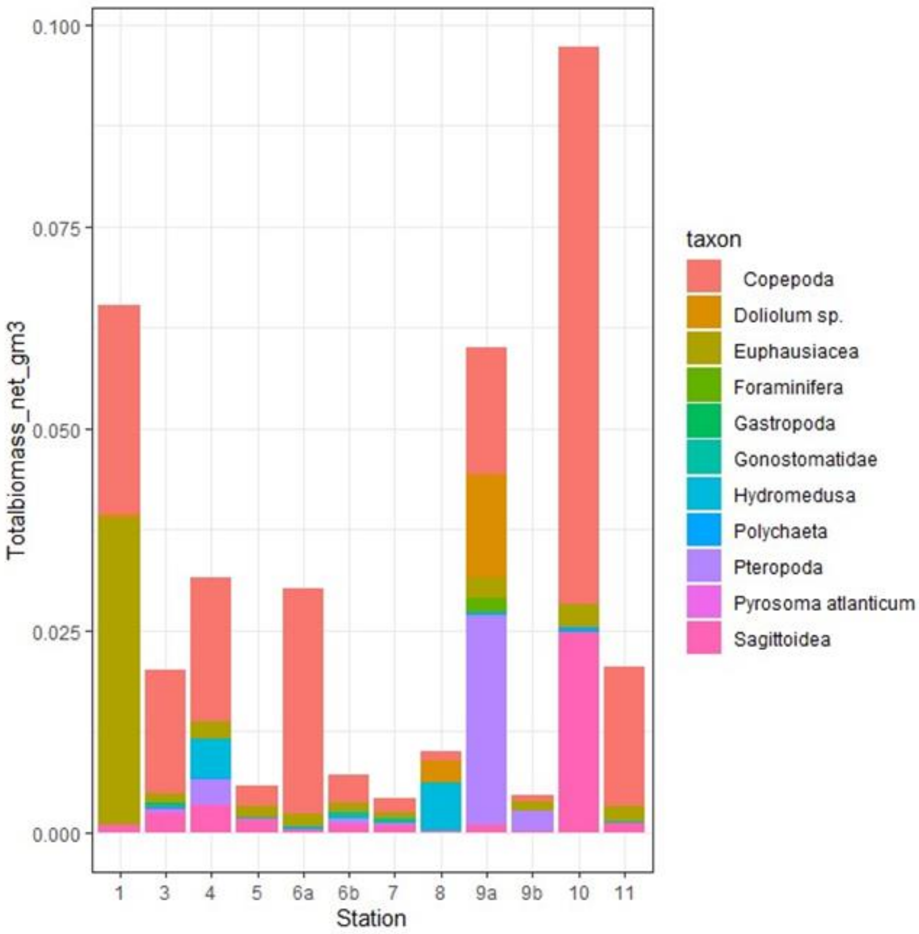

Figure 13: Taxon mean biomass per station along the transect

- **Biomass by layer, and sampling time.**

The highest biomass of organisms was found in depths closer to the surface. Additionally, the results had indicated that the biomass was decreasing as the depth was increasing (Figure 14).

In Figure 13, a difference was observed in the abundance of organisms between day and night, as well as in Figure 14 at biomass level. Despite the fact that the night samples were only half as many as the samples taken during the day, and that oceanographic conditions varied between stations, it was possible to compare matched stations (6a, 6b, and 9a, 9b).

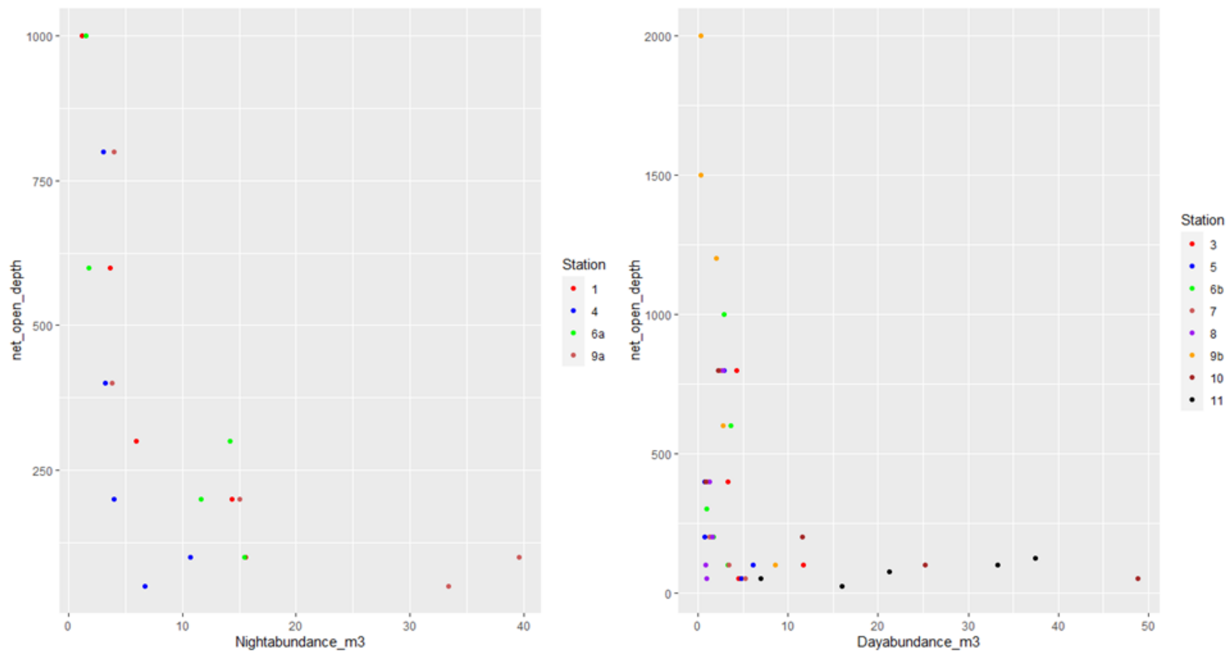

Figure 14: Total biomass at different depth (epipelagic zone, mesopelagic zone and bathypelagic zone) of the total sampling. Split into two groups: The 8 day sample (right) and the 4 night sample (left). Station 11 daytime was in shallow water.

4.3.Relationship abundance, biomass, and oceanographic parameters

4.3.1. Abundance

In the southern tropical region, the highest daytime abundance (40.69 individuals/m^3) was at station 1, and the highest nighttime abundance (27.7 individuals/m^3) was at station 4. In the subtropical region, station 5 got the highest abundance (15.27 individuals/m^3) during the day and station 6a got the highest abundance (44.64 individuals/m^3) during the night. In the temperate region, station 9a got the highest nighttime abundance (95.76 individuals/m^3), and station 11 got the highest daytime abundance (115.05 individuals/m^3). Overall, high abundance was found the temperate region. The shallow station (station 11) got the highest abundance of all stations.

4.3.2. Biomass

In the southern tropical region, station 1 had the highest biomass (0.062 g/m^3) during the day, and station 4 had the highest biomass (0.029 g/m^3). In the subtropical region, station 6a had the highest biomass (0.031 g/m^3) during the night, and 6b had highest biomass (0.004 g/m^3) during the day. In the temperate region, station 9a had the highest biomass (0.055 g/ m^3) nighttime, and station10, had highest biomass (0.114 g/ m^3) daytime.

The abundance and biomass were high in areas of upwelling along the transect. This distribution was due to the high concentration of nutrients.

4.4.Day-Night sampling comparison and Acoustic EK80

4.4.1 Day-Night sampling comparison (2 Day and 2 Night samples)

A comparison of day and night sampling was conducted using station 6 and station 9, both of which were sampled during day and night. This ensured that the samples were likely taken from the same body of water.

Initially, the abundance of organisms at station 6 during the night (6a) and the abundance of organisms at station 9 during the night (9a) were compared.

Given that the sampling depths were different, a standardization to 800 m water column depth was carried out for the samples to balance the sampling depths. It turned out that the abundance of samples taken at night was greater than during the day. Station 9b also had the highest abundance (Table 4). However, the difference was not significant (t-test p-value p=0.068) because of the low sample size (n=2).

Table 4: Day night comparisons for station 6 and 9, abundance standardized 800 m water column depth

Station	catching period	abundance_m2
6a	N	9512.1
6b	D	3684.1
9a	N	13344.7
9b	D	2918.0

4.3.2 Day-Night sampling comparison and Sv

The acoustic results in Figure 15 showed typical sound scattering layers at different depths. A remarkable and persistent deep scattering layer was recorded and observed at a depth of about 500 m. Throughout the monitoring, a diurnal vertical migration of organisms from the deep layers to the surface layers during the night and back to the deep layers at dawn was observed. In addition, the concentrations of backscattered organisms in the surface layer, particularly in the upper 100 m, increased alternately due to the difference in migration between day and night.

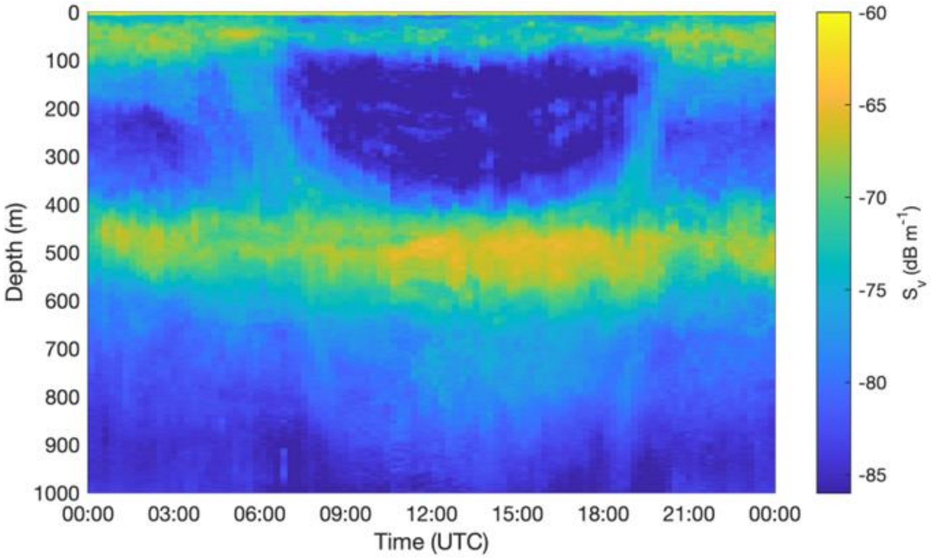

Figure 15: Echogram showing the 38 kHz data from the EK80 of station 6

The correlation of day-night abundances with acoustic data showed one outlier for the day correlation and three outliers for the night correlation. All those outliers were discarded because they affected the correlation (Table 4). These outliers could be because by the larger organisms such as *Cyclothone* sp or hydromedusae, which were present in this net and had a large backscatter radius or Copepoda, which were the most abundant along the transect.

Table 5: correlation between Day-night abundance and Sv

	Before the outliers removing	After removing outlier
Day r-value	0.22	0.93
Night r-value	-0.18	0.94
Day p-value	0.60	0.002
Night p-value	0.61	0.002

After eliminating the outliers at depths of 600 m at station 6a, 100 m and 50 m at station 9a, and 100 m at station 9b, the Sv mean and the abundance of organisms during the day and night were re-analyzed.

The slope of the abundance and Sv of day was 25.8 while the slope of night was 2.1 (Table 6). The difference in the slope indicated the organism migrated during the day were different from those migrated during the night

Table 6: Linear model of abundance and Sv at stations 6b and 9b (daytime) and stations 6a and 9a (nighttime)

Model parameters	Estimate	Standard error
Daytime intercept	-99.040	2.823
Daytime abundance	25.812	4.554
Nighttime intercept	-83.5572	0.9479
Nighttime abundance	2.1265	0.3394

The results showed a positive correlation between Sv and abundance during the day and the night (Figure 16). The slope was very different between day and night (Figure 16 and 17).

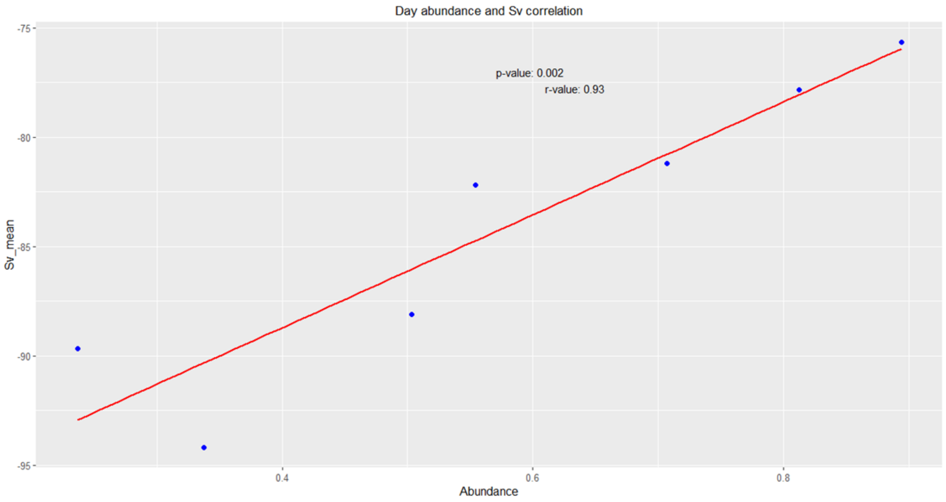

Figure 16: Correlation between mean Sv and day abundance (6b and 9b).X-axis scaling was different in Figures 16 and 17.

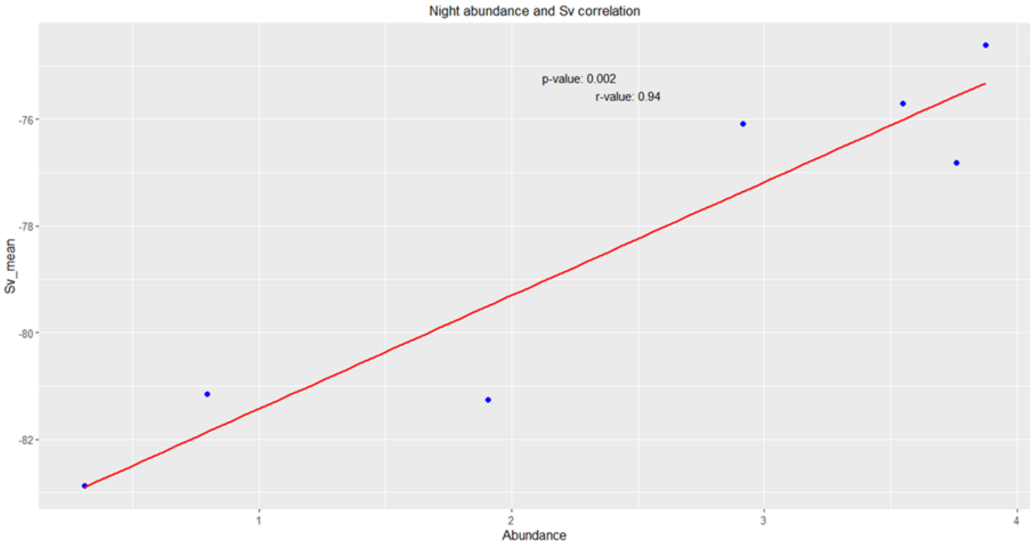

Figure 17: Correlation between mean Sv and night abundance (stations 6a and 9a). X-axis scaling was different in Figures 16 and 17.

5. Discussion

This study was conducted in the northeast Atlantic Ocean, from Cabo Verde to the English Channel. The main objectives were to examine the structure of the water masses along the transect using environmental data collected by CTD to see if the environment influences the distribution of zooplankton, to analyze the zooplankton community at different depths using broader taxonomic groups to understand the composition of the main zooplankton taxa and which taxon is dominant, and to analyze the variation in depth distribution between day and night at four selected paired stations to quantify vertical migration and compare with hydroacoustic data.

5.1. Abundance, biomass and relationships to oceanography.

Abundance was high at stations 9a, 10 and 11, while biomass was high at stations 1, 9a, and 10. The biomass was high at station 1 the OMZ due to the large size of some of the Euphausiacea sampled. Perhaps it could be said that temperature and oxygen affect the vertical migration of zooplankton. Kiko et al.(2020) found low oxygen areas had high biomass. Station 9 has the highest Chlorophyll a with a value between 2.5 mg/m^3 to 3 mg/m^3 (Figure 7). The OMZ region is characterized by a high productivity of nutrient and reduced circulation of the water. The high biomass distribution in OMZ could be explained by several reasons, of which the first reason is that the elevation of the pycnocline and nitracline in the OMZ region creates favorable conditions for primary productivity, which is probably the main reason for the increase in biomass in this region. The other reason for the observed differences could be that biomass is increased in parts of the zooplankton size spectrum that was not observed (Kiko et al., 2020). Some authors also agreed that oxygen and temperature affect zooplankton abundance and biomass (Świerzowski et al., 2000). Global warming is predicted to decrease ocean dissolved oxygen concentration, expanding OMZ and harming ecosystems and economies (Stramma et al., 2008).

The increased biomass in OMZ is due to a typical behavior of the organisms: they are metabolically adapted to remain in low oxygen conditions (Childress, 1975), unlike some of their predators, and therefore use it as a survival strategy. OMZ zones have been shown to influence the composition, biomass and abundance of the micronekton community (Papiol & Hendrickx, 2016). In the Joint Global Ocean Flux Study (2002) in the Indian Ocean, micronekton biomass increased under the OMZ (Karuppasamy et al., 2010). At the stations 9 and 10, biomass was more evenly distributed throughout the water column. Foxton, (1971) collected samples of the family Acanthephyridae at different latitudes in the North Atlantic, where he observed that migrants from the tropical zone made deeper and more distinct migrations and that samples from northern regions were more segregated throughout the water column, regardless of the phase of the day, due to temperature. Despite the characteristics of the water column, each species has a different migration pattern and range, which could be the subject of future work.

Some authors have suggested that the climate affects zooplankton (Dam & Baumann, 2017). Climate variability in and around the Polar Regions (e.g. associated with the North Atlantic Oscillation or NAO) leads to changes in the large-scale circulation patterns and hydrological regime of the northern North Atlantic (Stempniewicz et al., 2007). They identified the increase in warm water flux from the ocean as a key oceanographic consequence of the NAO (Dickson et al., 2000). The NAO in turn affects the distribution, abundance, composition and size structure of zooplankton communities (Beaugrand et al., 2002). Finally, changes in the size and energy content of key zooplankton prey affect energy transfer in the pelagic food web.

5.2. Vertical abundance and biomass distribution patterns

The results also showed that organisms were more abundant in shallow water than deep water. It is possible that resource limitation in the deep sea is the reason behind this phenomenon. In an ecosystem, individuals may compete for limited resources such as food or space. As the population grows, every individual may have access to a smaller portion of these resources. This can result in reduced growth and an overall decrease in size or mass. Moreover, other factors like predation pressure or environmental stressors can also lead to a lower biomass when the abundance is high. Migration is due to the segregation of organisms in the water column as a function of many factors.

The vertical distribution of zooplankton across the Atlantic Ocean was in agreement with other authors. Vereshchaka et al.(2017) showed that the abundance of zooplankton taxa depended on surface productivity, which is strongly linked to depth. Cushing, (1950) found that migration depends on light intensity, temperature, surface phytoplankton concentration and ontogenetic phase (Vereshchaka et al., 2019).

The results of this study cannot confirm a diel vertical migration within the zooplankton community in the eastern North Atlantic because the statistical test between day-night at the station 6 and 9 was not significant. This result could be due to the fact that we only had two day stations and two night stations for the day/night comparison. However, significant linear relationships between Sv and abundance were observed. The correlation between Sv and abundance at the station 6 and 9 suggested that it had a DVM. Kiko et al.(2020) found that decapods and mysids moved from day depths of 542-651 m to 250-316 m at night, and that Euphausiacea moved from day depths of 371-499 m to 138-300 m at night. Longhurst (1967) and Kiko & Hauss (2019) found the same result. This migration to the surface could be due to several reasons. One could be feeding, as nocturnal migration allows organisms to move closer to the surface where there is more food, as many organisms feed on organic particles drifting close to the surface, such as phytoplankton. Another reason could be to avoid predators such as fish (Aumont et al., 2018). Alternatively, migration could even be an innate behavior of these migratory organisms (Bandara et al., 2021). The dominant organism group of our study was Copepoda. This result was also similar with those of Vereshchaka et al. (2017) . They identified 300 plankton taxa of which 243 were copepods.

Bianchi et al. (2013) suggested that marine conditions control DVM. These conditions include abiotic factors such as light, oxygen, temperature and salinity, and biotic factors such as sex, age, feeding conditions and changes in behavior and physiology. They can occur either by changing the structure of the migrating population or by regulating its diurnal depth. Water turbidity can affect the depth of migration. Solar radiation reaches further in clean water than in turbid water. It was observed shallow migrations at the station 6 and 9 maybe because these regions are characterized by well-structured upwelling systems that bring cold, nutrient-rich water to the surface, increasing primary productivity and resulting in less transparent waters. Station 6 was affected by Canary Current upwelling and station 6 by Iberian Peninsula upwelling as moving away from the coast, the water becomes clearer and sunlight penetrates deeper, forcing animals to migrate to greater depths.

5.3. Acoustics and abundance

The positive correlation between Sv and abundance showed that zooplankton migrate vertically during the day and night. However, the organisms that migrate during the day could be different from those that migrate during the night, as the slopes of the two periods were different (Table 6). This difference could be explained by the fact that the plankton net was not able to catch larger organisms. Kristense & Dalen, (1986) found a similar result with the Euphausiacea abundance correlating with the Sv. They found strong correlations between the distributions estimated by acoustics and those obtained from net catches with a correlation coefficient higher than 0.98. However, Demer & Hewitt, (1995) found a negative correlation between Euphausiacea biomass and quantitative acoustics during the day and at night.

6. Conclusions

The study aimed to comprehend the vertical migration and distribution of zooplankton along a latitudinal transect in the North-East Atlantic. The composition of zooplankton remained consistent in the eastern Atlantic based on the chosen taxonomic resolution. The zooplankton composition remained consistent in the eastern Atlantic, but their distribution differed depending on latitude. The abundance and biomass of zooplankton were influenced by productivity, which was measured by chlorophyll-a concentration, as well as oxygen and temperature levels.

The zooplankton was classified into 12 categories of organisms (Copepoda, *Doliolum* sp, Euphausiacea, Foraminifera, Gastropoda, *Cyclothone* sp, Hydromedusa, Polychaeta, Pteropoda, *Pyrosoma atlanticum* and Sagittoidea). Of these 12 taxa, Copepoda were the most abundant along the transect, followed by Sagittoidea and the least abundant were gastropods.

In terms of vertical distribution, the diurnal vertical migration pattern was identified, where organisms are separated along the water column according to size. However, other factors have a major influence on these organisms. An OMZ was identified at the stations 1, 3, and 4. In turn, biomass was high also in the temperate region at the station 9a, and 10, the latter in the Bay of Biscay.

Zooplankton is an important part of the diet, its consumption depends on availability, location and time. Zooplankton contains high levels of protein (over 50% of dry matter in some groups) and unsaturated fatty acids (around 10% of dry matter) (Anton-Pardo & Adámek, 2015).

7. Recommendations

Diurnal vertical migration is a survival strategy for many taxa. Physical and biological processes link surface production to the deep ocean. During diurnal vertical migration, organisms feed at the surface and at great depths, they excrete, respire, defecate and die. In this way, they remove carbon from the surface and transport it to the depths of the ocean. This process is called the biological pump. In order to better understand the behavior and distribution of the copepods involved in this study, I suggest future research:

- Addressing the same problem but using a different net size.
- Sample more day-night paired samples to increase statistical power.
- Sampled at the same depths for all samples to avoid the need to recalculate indices.
- Combined with a more extensive analysis of hydroacosustics.

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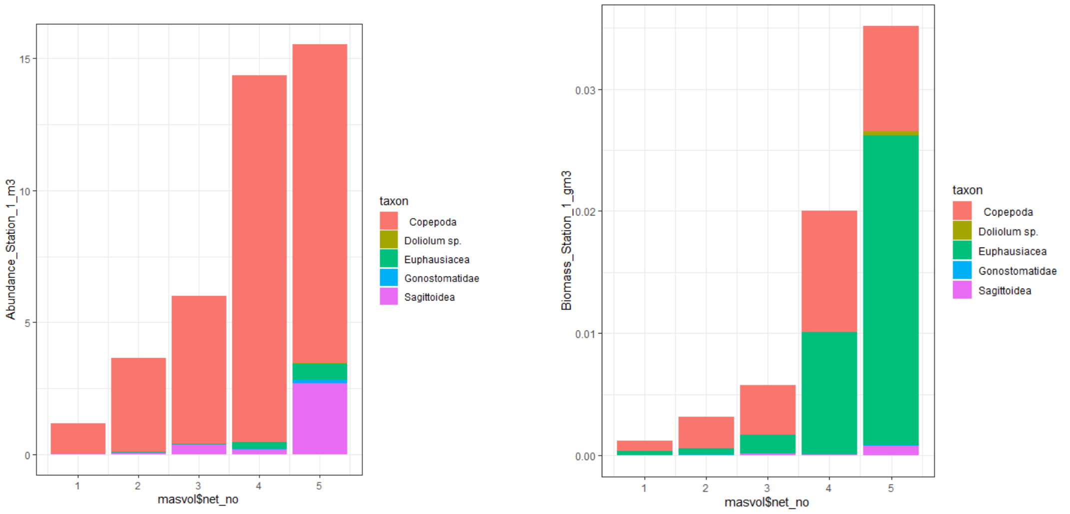
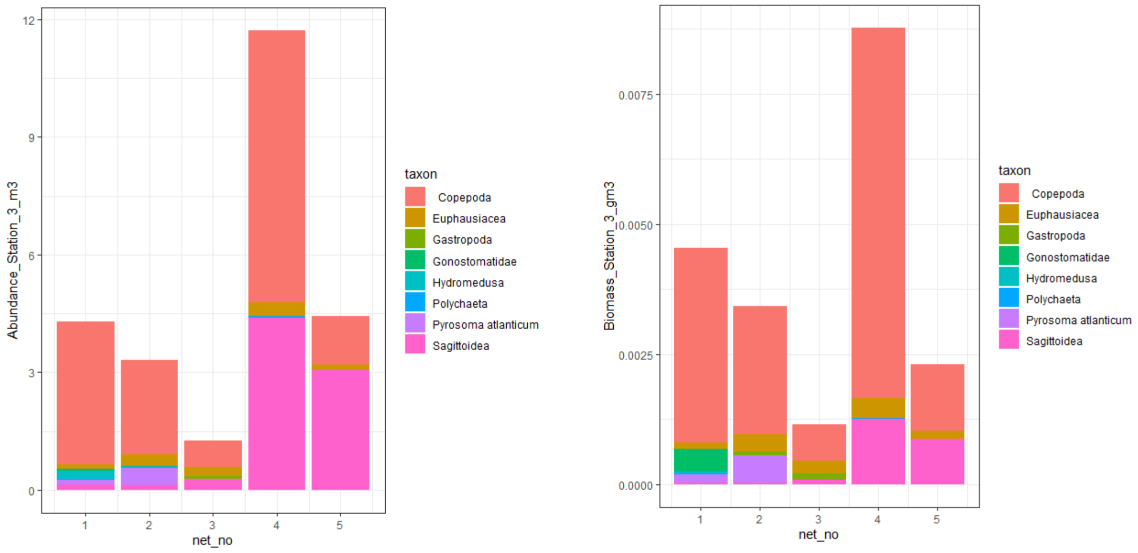
Appendix

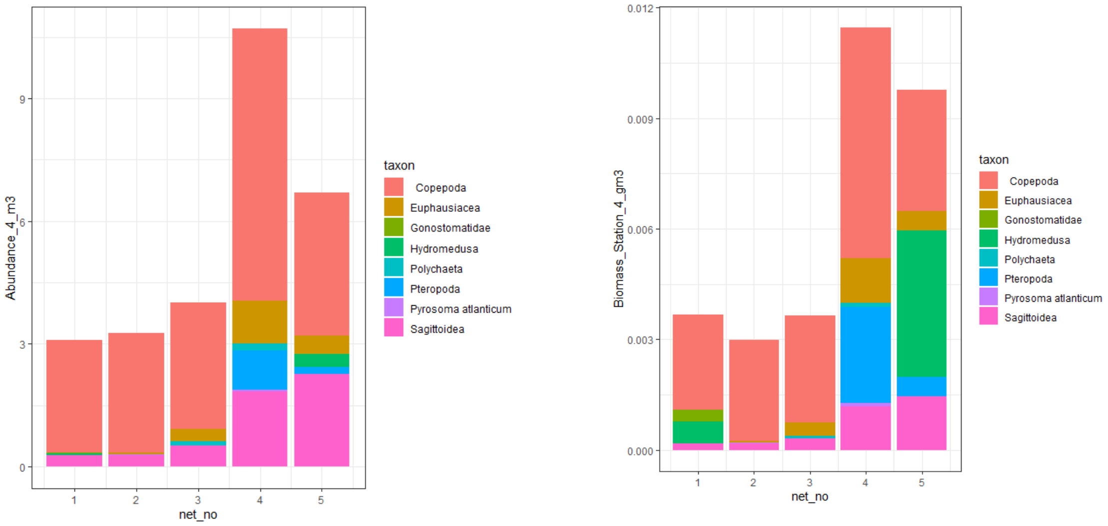
The following figures or tables show the partial or complete data used to carry out the above analysis



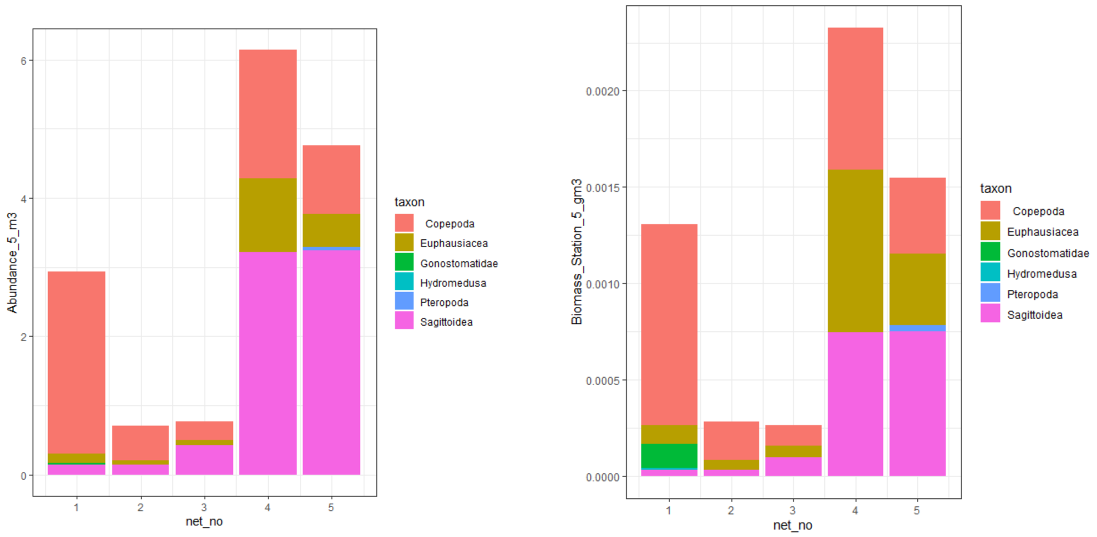
Appendix 1: Zooplankton distribution at station 1.per net number. Abundance (at left) and Biomass (at right)



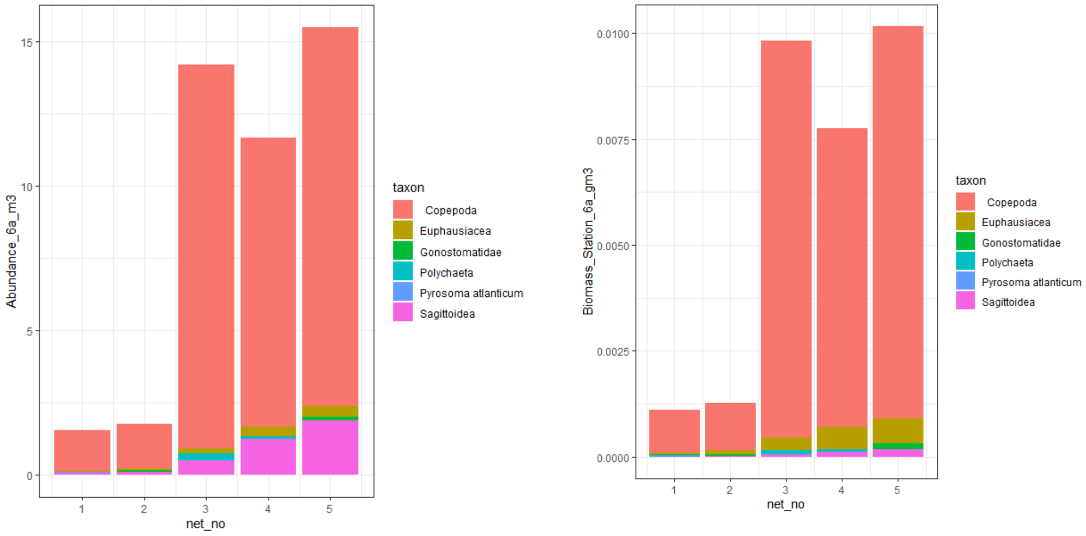
Appendix 2: Zooplankton distribution at station 3.per net number. Abundance (at left) and Biomass (at right)



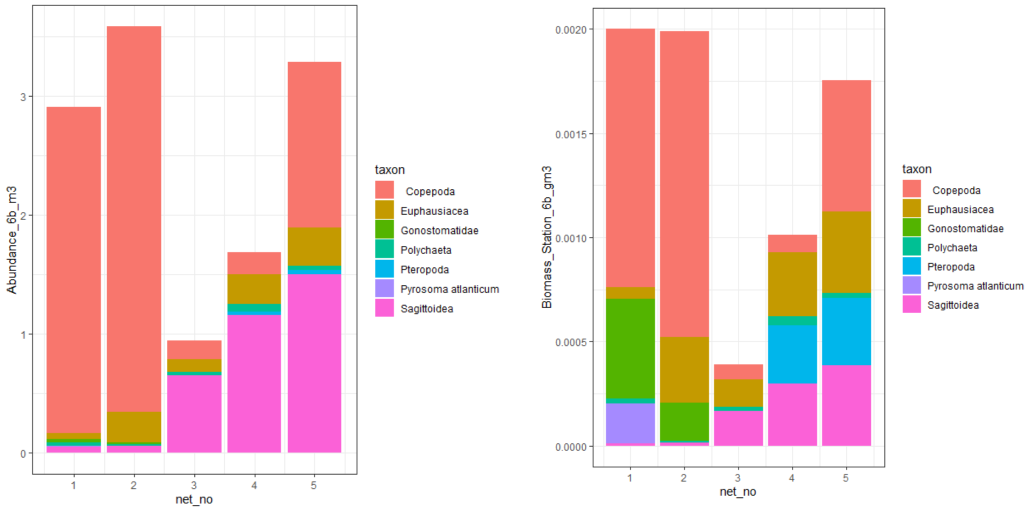
Appendix 3: Zooplankton distribution at station 4.per net number. Abundance (at left) and Biomass (at right)



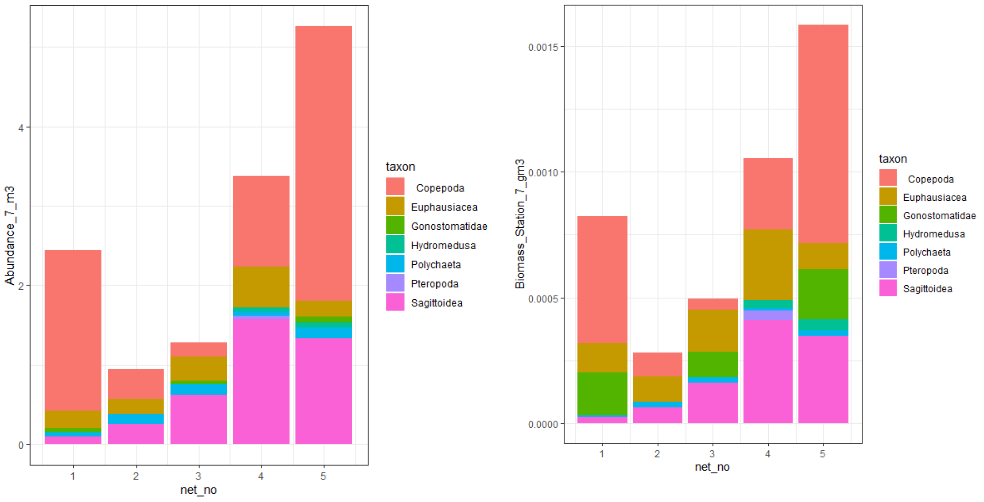
Appendix 4: Zooplankton distribution at station 5.per net number. Abundance (at left) and Biomass (at right)



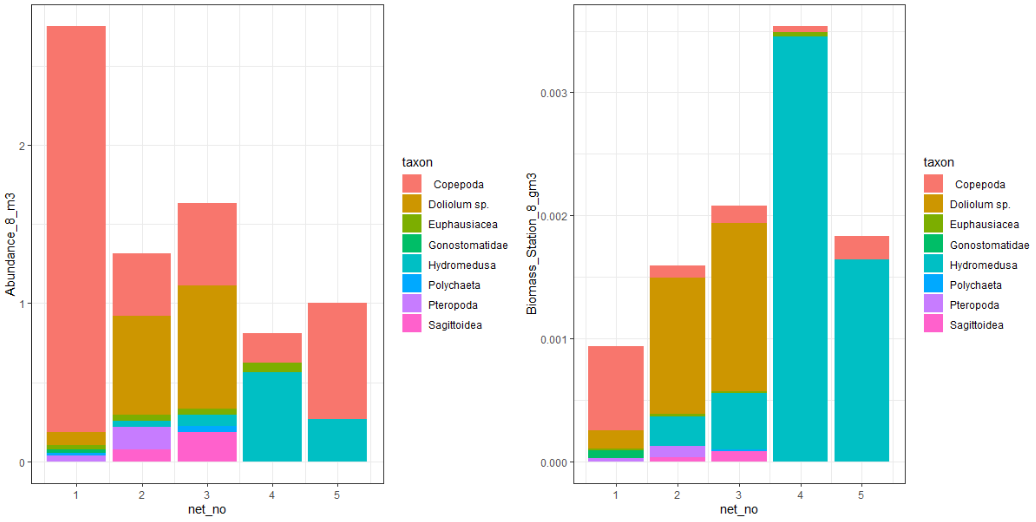
Appendix 5: Zooplankton distribution at station 6a.per net number. Abundance (at left) and Biomass (at right)



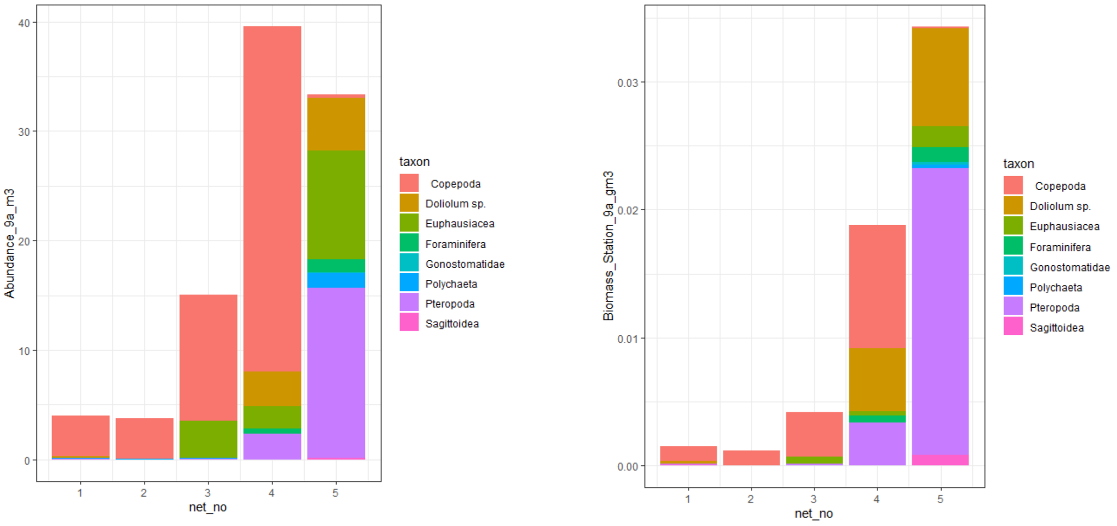
Appendix 6: Zooplankton distribution at station 6b.per net number. Abundance (at left) and Biomass (at right)



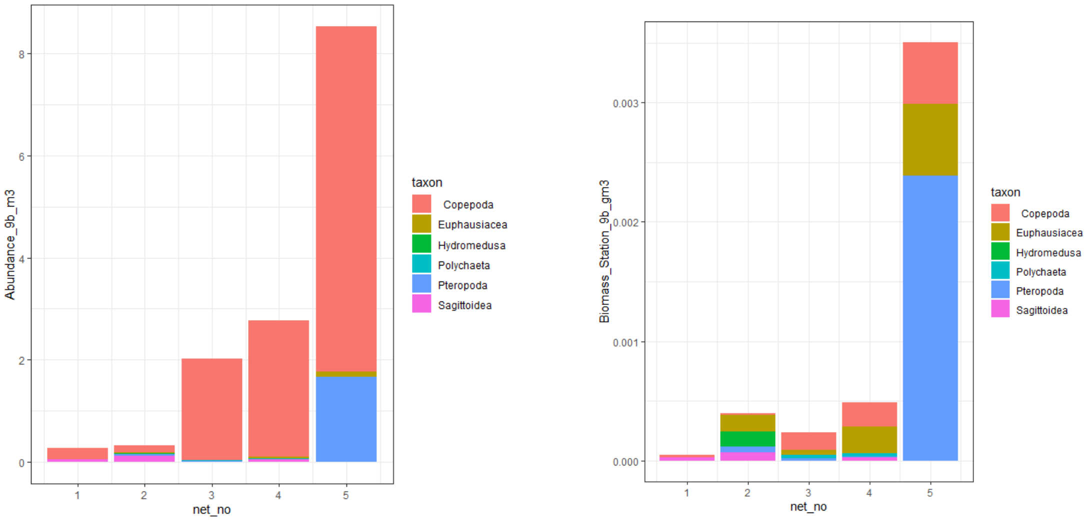
Appendix 7: Zooplankton distribution at station 7.per net number. Abundance (at left) and Biomass (at right)



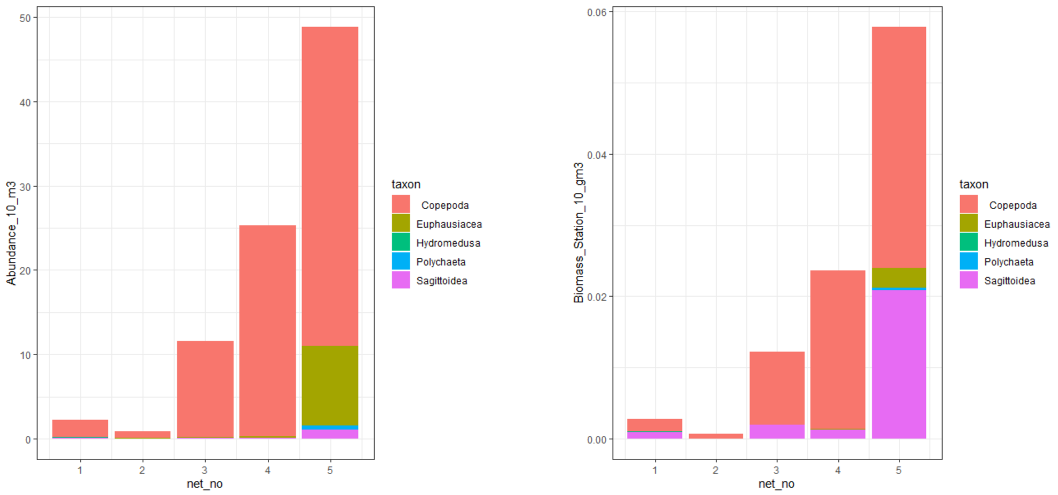
Appendix 8: Zooplankton distribution at station 8.per net number. Abundance (at left) and Biomass (at right)



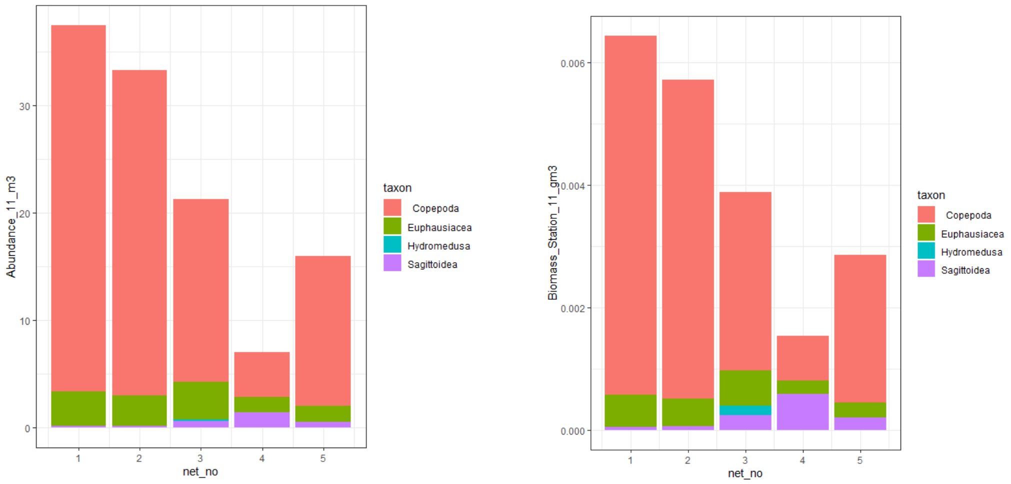
Appendix 9: Zooplankton distribution at station 9a.per net number. Abundance (at left) and Biomass (at right)



Appendix 10: Zooplankton distribution at station 9b.per net number. Abundance (at left) and Biomass (at right)



Appendix 11: Zooplankton distribution at station 10.per net number. Abundance (at left) and Biomass (at right)



Appendix 12: Zooplankton distribution at station 10.per net number. Abundance (at left) and Biomass (at right)

Appendix 13: total abundance (ind/m3) per taxonomic group of the 10 sampling stations

Taxon	total abundance (ind/m3)
Doliolum sp.	9.518690297
Euphausiacea	47.13423482
Foraminifera	1.730769231
Gastropoda	0.105326877
Gonostomatidae	0.726666025
Hydromedusa	1.847744736
Polychaeta	3.644941911
Pteropoda	21.16982502
Pyrosoma atlanticum	0.68970037
Sagittoidea	39.24189301
Copepoda	374.4239863

Data availability

The data were collected in the North-East Atlantic Ocean by myself, Sienfoungo Traore, with the help of Svenja Christiansen. You can get the data from the following people:

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