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Interactions between environmental factors and the mesozooplankton community from the Romanian Black Sea waters

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Abstract: The aim of the study was to trace the influence of several abiotic factors on the distribution of the mesozooplankton community from the Black Sea. Sampling was performed in cold and warm seasons of 2013–2020, from stations located on the three sectors of the Romanian Black Sea coast (northern-N, central-C, and southern-S). After determining the species composition, abundance, and biomass, the results were subjected to statistical analysis. A total of 25 taxa were identified, Copepoda representing the bulk of the community. The analysis of the main components explains, through the first two identified factors—temperature and salinity, the variation of environmental factors. The mesozooplanktonic community responded differently to the analysed environmental factors, recording positive and negative correlations, depending on the water column's depth; a positive correlation was observed between mesozooplankton and temperature while negative correlations were observed between nutrients (silicon) and mesozooplankton.

Key words: Analysis, temperature, salinity, taxa, Copepoda, abiotic

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1. Introduction
Zooplankton communities are highly subject to physical processes in the water column, constituting the accurate biological indicators of climate change (Beaugrand et al., 2002 a). Mesozooplankton is a size-based fraction of the zooplankton community, including taxa and stages with body length between 0.2 and 20 mm. The variations in the abundance and structure of zooplankton community are sensitive to environmental changes (Harris et al., 2000); the distribution and abundance of these organisms in water bodies provide useful information on the level of water pollution and marine ecosystem health (Gajbhiye et al., 1981). Besides their importance in the food chain and its sensitivity to climate change, zooplankton are used to assess the impact of global change (Drira, 2009); species composition, biomass, and wealth of zooplankton groups can be used to determine the strength of a biological system. The potential of zooplankton as a bioindicator species is high on the grounds that their development and conveyance are subject to some abiotic (e.g., temperature, salinity, stratification, and pollutants) and biotic parameters (e.g., limitation of food, predation, and competition) (Ramachandra et al., 2006). Any variation in zooplankton's structure has implications for fishing and ecosystem services (Caroppo et al., 2013). Eutrophication causes changes in the qualitative and quantitative structure of zooplankton, its use as an indicator of changes that may occur at the trophic level and ecological conditions caused by nutrient dynamics has a very important role (Jurczak et al., 2019).

Marine pelagic systems are strongly affected by the climate impact due to its influence on temperature, atmospheric circulation, wind direction, intensity of ocean currents, and changes in river flows but also by the upwelling (the replacement of surface waters with waters from the deep zone, richer in nutrients and deficient in oxygen). Climate also influences salinity, oxygen concentration (by changes in the thermal regime), nutrients (by controlling water column mixing, upwelling, fluvial input), and pH (by acidification). Thus, climate variability, whether natural or anthropogenic, can alter the ecological conditions of pelagic habitat, affecting species abundance and the composition of biological communities (Beaugrand and Kirby, 2018).

Because the distribution of the mesozooplankton community is closely related to the evolution of abiotic
environmental factors (Peterson et al., 1979), we analysed the variation of the main physicochemical parameters (temperature (T), salinity (S), and dissolved oxygen (O2) as well as nutrients (phosphates (PO4), silicates (SiO4), nitrates (NO3), nitrites (NO2), and ammonium (NH4)) to examine the structure and relationships between biological data and potential associated physicochemical data. We performed the analysis based on the three sectors of the Romanian coast (northern-N, central-C, and southern-S), where the environmental conditions are different.

The purpose of the paper was to compare mesozooplankton composition, abundance, and diversity between warm and cold seasons and to determine the grouping pattern of mesozooplankton and its relationship to environmental parameters.

2. Materials and methods
Samples were collected from stations within the marine monitoring network on the three sectors of the Romanian Black Sea coast (northern-N, central-C, and southern-S) (Figure 1), during 2013–2020, in the warm (May–October) and cold season (November–April). A number of 533 mesozooplankton samples and 387 samples of physicochemical parameters collected from 45 sampling stations were analysed. Zooplankton samples were collected according to the methodology detailed in the Black Sea monitoring manual (Alexandrov et al., 2014), by vertical tows, using a Juday net (0.1 m² mouth opening area, 150 μm mesh size) equipped with a flow meter for estimating the volume of water filtered. In the warm season, mesozooplankton samples were collected from standard depths (10–0 m, 25–10 m, 50–25 m, 100–50 m) while in the cold season, sampling was performed from the entire water column. The quantitative and qualitative processing of the mesozooplankton samples was performed in the Bogorov chamber, under Olympus SZX10. In the subsample(s) all plankters were counted until each of the three dominant taxonomic groups reached 100 individuals. For estimation of large animals’ numbers, the whole sample was examined in a Petri dish. The number of individuals and mean individual weights were used for estimating the density as ind m⁻³, respectively the biomass as mg m⁻³ wet weight (Alexandrov et al., 2014). Temperature and salinity were measured simultaneously with plankton sampling using the reversible thermometer and the CastAway CTD multiparameter. Several salinity samples and all nutrients’ samples were analysed in the NIMRD’s laboratory, according to the standard methods.
for seawater analysis (Hansen and Koroleff, 1999). For data analysis, we used XLSTAT and Primer for statistical analysis. XLSTAT is a statistical software program that can be employed to perform multivariate analysis of complex data sets (Vidal et al., 2020). PRIMER was used for shade plots, to assess species-specific contributions (SIMPER), and for principal component analysis (PCA) analysis. SIMPER examines the relationships between species and sample patterns, with variables that are likely to contribute to any differences between groups being identified. PCA is a multivariate statistical technique applied to reduce the number of variables into a few uncorrelated variables named principal components (or factors) based on patterns of correlation of the original variables (Vidal et al., 2020). Shade plots, which represent multivariate analysis that sometimes can fashion clear community structures, characterising responses of individual (or groups of) species across the sample, were also obtained by using the PRIMER software (Clarke et al., 2014). To develop the model, we used the significant \( p < 0.05 \) Pearson correlation coefficients between physicochemical parameters and mesozooplankton groups. The Pearson coefficient corresponds to the classical linear correlation coefficient, with values ranging from \(-1\) to \(1\), and measures the degree of linear correlation between two variables.

### 3. Results

#### 3.1. Mesozooplankton community structure

The analysis of the mesozooplankton community from the Romanian Black Sea area highlights variations both qualitatively and quantitatively. Regarding the number of identified mesozooplankton taxa, a decrease in the number of species is observed depending on the season, with a maximum of 25 taxa in the warm season and a minimum of 15 taxa in the cold season (Figure 2).

Quantitatively, the high densities and biomasses of *Noctiluca scintillans* (nonfodder mesozooplankton) in the warm season were observed (Figure 2). Copepods *Acartia clausi* and *Pseudocalanus elongatus* were best represented in both seasons. Moreover, high densities and biomasses were observed for the species *Centropages ponticus* in the warm season, this copepod appearing in plankton only at higher water temperatures (Figure 2). The group of cladocerans recorded higher densities and biomasses in the warm season, unlike in the cold season when they are less represented both qualitatively and quantitatively. The meroplanktonic component recorded higher biomasses and density values also in the warm season, this situation being also identified for the other groups category represented mainly by the tunicate *Oikopleura dioica* and the chaetognath *Parasigitta setosa* with high density and biomass values but also by the mysid *Mesopodopsis slabberi* with lower values from the quantitative point of view (Figure 2).

The SIMPER analysis for the warm and cold season highlights the large contribution that the nonfodder component represented by *Noctiluca scintillans* had in the warm season, in the cold season being less represented by density but dominating in terms of biomass (Table 1). The copepod *Acartia clausi* recorded high density values in both warm and cold seasons, dominating in the cold season (Table 1). The meroplanktonic elements Balanus and Bivalvia highly contributed in the warm season to the mesozooplanktonic community; in the cold season, only Bivalvia had higher density values.

#### 3.2. Environmental factors analysis

The seawater temperature varied between 5.20 °C and 27.12 °C (mean 18.58 °C, standard deviation 6.35 °C). Variability (expressed as standard deviation or coefficient of variation) was observed to be higher in the warm season (Table 2). The extremes were measured in the same year (2014), the minimum in the Danube Mouth area (Sulina, station SU20m), and the maximum in the central area (East Constanța, station EC30m). It should be noted that, in the long term (1953–2020) (Cazino Mamaia station, 0 m), the average annual temperature of the sea water shows an increasing trend \( r = 0.29 \) that culminates in the year 2020, in which it exceeded the multiannual average (1959–2019) with 2.8 °C (http://www-old.anpm.ro/upload/217086_RSM%202020.pdf).

Spatially, the lowest temperatures were measured in the northern sector, regardless of the season (t-test, \( p < 0.05 \)). Uncharacteristic temperatures (outliers and extremes) were observed only in the cold season and, in the majority, represented high values (Figure 3).

Salinity fluctuated in the range of 0.11‰–19.91‰ (mean: 14.66‰; standard deviation: 3.80 ‰) covering a wide range of the Venice (1959) classification, from freshwater (<0.5‰) to brackish mixo-polyhaline waters (18‰–30‰) (Figure 3).

All values less than 0.5‰ were measured in the warm season (May and June) on the Sulina profile (SU10m) in 2013 and 2015. In May 2014, when the Danube exceeded its flood levels in many regions, its influence on the marine ecosystem was much more extensive so that a value characteristic of fresh waters (0.11‰) was reached even on the 30 m isobath (SU30m). The maximum salinity was reached in July 2018, in the northern sector, at Portiţa (30 m), statistically being considered an uncharacteristic value for the area (Figure 3).

Having the lowest variability, the oxygen content of the Black Sea waters was within the range of 119.2–495.6 µM (3.81–15.86 mg/L) (Figure 3), both extremes belonging to the warm season (Table 1). The minimum was measured on the East Constanţa profile in June 2020 (EC30m) as a result of increased seawater temperatures, and the maximum in the northern sector (ML95m) in
May 2014 from photosynthetic production due to the seasonal phytoplankton bloom and high nutrient intake. The significant correlation with temperature is higher in the cold season ($r = -0.46$) when the variability is lower (Table 3), the influencing factors being predominantly abiotic (air and water temperature, the regime of winds, currents, and waves), the oxygen content being high (Figure 4).

Dissolved phosphates in seawater recorded levels from “not detected” to 3.04 µM. The maximum value exceeds about 10 times the permissible concentration for good ecological status and is found in the warm season (2018) on the Sulina profile (SU20m) (Figure 4).

As with phosphates, silicates generally originate from fluvial input (Table 1). However, the maximum concentration, 168.2 µM, was measured in the cold season (2018) on the Sulina profile (SU20m) (Figure 4).
The inorganic forms of nitrogen (nitrogens, nitrites, ammonium) are involved in the constant and balanced exchange between marine organisms and their environment. Despite the chemical stability of molecular nitrogen, nitrogen in the sea responds quickly to enzymatic activities and therefore can occur in any of 9 different oxidation states (N.O.), from –3 to +5. Reduced nitrogen (N.O. between –3 and –1) can appear as ammonia (N.O. = –3) and organic compounds in dissolved or particulate form. These substances are generally end products of assimilation by plants or marine bacteria and represent about 35% of the total combined nitrogen in the oceans. The most uncharacteristic and extreme values are also found in the warm season (Figure 4), all forms of nitrogen

(Figure 4) (March 2017) on the East Constanța profile (EC50m).

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Table 1. Simper analysis of mesozooplankton's taxa, by season.

<table>
<thead>
<tr>
<th>Warm season</th>
<th>Taxa</th>
<th>Average density (ind/m³)</th>
<th>Average sim</th>
<th>Sim/SD</th>
<th>Contrib%</th>
<th>Cum%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Noctiluca scintillans</td>
<td>68.12</td>
<td>12.39</td>
<td>1.49</td>
<td>19.92</td>
<td>19.92</td>
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<td></td>
<td>Acartia clausi</td>
<td>45.82</td>
<td>8.97</td>
<td>2.73</td>
<td>14.43</td>
<td>34.35</td>
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<td></td>
<td>Balanus</td>
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<td>7.57</td>
<td>2.16</td>
<td>12.18</td>
<td>46.52</td>
</tr>
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<td></td>
<td>Bivalvia</td>
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<td>7.34</td>
<td>2.69</td>
<td>11.8</td>
<td>58.33</td>
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<tr>
<td></td>
<td>Pleopis polyphemoides</td>
<td>24.7</td>
<td>5.31</td>
<td>3.24</td>
<td>8.54</td>
<td>66.87</td>
</tr>
<tr>
<td></td>
<td>Pseudocalanus elogatus</td>
<td>15.76</td>
<td>3.87</td>
<td>3.41</td>
<td>6.22</td>
<td>73.09</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cold season</th>
<th>Taxa</th>
<th>Average density (ind/m³)</th>
<th>Average sim</th>
<th>Sim/SD</th>
<th>Contrib%</th>
<th>Cum%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acartia clausi</td>
<td>39.41</td>
<td>15.66</td>
<td>3.72</td>
<td>26.78</td>
<td>26.78</td>
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<td>Pseudocalanus elogatus</td>
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<td>5.29</td>
<td>16.8</td>
<td>64.48</td>
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<tr>
<td></td>
<td>Bivalvia</td>
<td>14.56</td>
<td>4.84</td>
<td>6.82</td>
<td>8.28</td>
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Table 2. The Black Sea seasonal physicochemical parameters.

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<th>Variable</th>
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<th>Average</th>
<th>Median</th>
<th>Min.</th>
<th>Max.</th>
<th>25th percentile</th>
<th>75th percentile</th>
<th>Std.Dev.</th>
<th>Variation (%)</th>
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<tr>
<td></td>
<td>T [°C]</td>
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<td>8.76</td>
<td>8.50</td>
<td>5.20</td>
<td>13.27</td>
<td>7.54</td>
<td>9.71</td>
<td>1.96</td>
<td>22.37</td>
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<tr>
<td></td>
<td>S [‰]</td>
<td>98</td>
<td>15.98</td>
<td>16.01</td>
<td>0.55</td>
<td>19.75</td>
<td>15.20</td>
<td>17.84</td>
<td>2.77</td>
<td>17.33</td>
</tr>
<tr>
<td></td>
<td>O₂ [µM]</td>
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<td>330.8</td>
<td>332.3</td>
<td>242.5</td>
<td>416.7</td>
<td>302.8</td>
<td>357.3</td>
<td>31.9</td>
<td>9.64</td>
</tr>
<tr>
<td></td>
<td>PO₄ [µM]</td>
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<td>0.21</td>
<td>0.02</td>
<td>2.33</td>
<td>0.11</td>
<td>0.44</td>
<td>0.39</td>
<td>111.43</td>
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<tr>
<td></td>
<td>SiO₄ [µM]</td>
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<td>29.32</td>
<td>18.74</td>
<td>2.59</td>
<td>168.32</td>
<td>12.20</td>
<td>36.61</td>
<td>29.86</td>
<td>101.84</td>
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<td>0.69</td>
<td>21.20</td>
<td>1.87</td>
<td>3.92</td>
<td>3.95</td>
<td>99.25</td>
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<td></td>
<td>NH₄ [µM]</td>
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<td>6.82</td>
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<th>24.32</th>
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<td>S [‰]</td>
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<td>15.39</td>
<td>0.11</td>
<td>19.91</td>
<td>12.72</td>
<td>17.23</td>
<td>4.00</td>
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<td>305.5</td>
<td>119.2</td>
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<td>275.6</td>
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<td>PO₄ [µM]</td>
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<td>0.01</td>
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<td>0.38</td>
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<td>9.58</td>
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<td>1.89</td>
<td>12.41</td>
<td>8.02</td>
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</table>
having very high coefficients of variation (Tables 2 and 3).

3.3. Correlations between mesozooplankton's quantitative structure and environmental conditions in the warm season

In order to statistically analyse the data from 2013–2020, for each sector, we visualized the data based on general statistics (number of data, mean, median, minimum, and maximum values, 25th and 75th percentiles, as well as standard deviation). Next, we identified the range of natural salinity variability (considered undisturbed by the extremes due to the hydrological regime of the Danube and other coastal sources, precipitation or phenomena of evaporation and mixing of water masses), by excluding uncharacteristic values (outliers), thus also excluding the values extremes of the biotic component (Table 4).

The analysis of the main components (PCA, principal component analysis) explains, through the first two identified factors, 54.5% of the variation of environmental

Figure 3. Black Sea temperature, salinity, and oxygen box plot by sector and season, 2013–2020.
Figure 4. Black Sea nutrients box plot by sector and season, 2013–2020.
factors (PC1: 31.8%; PC2: 22.7%) (Figure 5). PC1 includes the effect of low salinity (–) and increased content (+) of phosphorus and silicon from river input [1] while PC2 takes into account the increase in temperature [2].

Knowing that temperature is a controlling factor of zooplankton dynamics in the sea by directly and indirectly modulating interactions between species (e.g., competition, prey-predator interaction, food web structures) (Beaugrand et al., 2002b), we continued the analysis of the environmental factors in the warm season, by analysing significant correlations (p < 0.05) between the densities of mesozooplankton groups and abiotic factors. Thus, we observed that in the warm season, the greatest affinity for the temperature gradient is found by other groups in the offshore area (100 m), whose abundance is negatively correlated (r = –0.76) (Figure 6), but also the cladocerans on the strip bounded by the 5 m and 50 m isobaths (with coefficients between 0.37 and 0.46) (Figure 6). The best correlation with salinity was observed in copepods (Figure 6), in the offshore area, on the 50 m isobath (r = 0.59). In contrast, the nonfodder mesozooplankton (Noctiluca scintillans) prefers areas with greater salinity variability, located between 5 m and 50 m (r = 0.41–0.54) (Figure 6). The maximum level of correlation was reached on the 30 m isobath where salinity varied in the range of 6.06‰–19.01‰ (median 14.81‰, standard deviation 2.98‰, coefficient of variation 20.69%). The development of meroplankton and other groups was correlated with salinity mainly in areas with shallow depths (Figure 6), (5–30 m) characterized by average salinity values between 13.75‰ and 14.63‰.

Phosphate concentrations represented an important factor of development especially in the offshore area, on the 60 m and 90 m isobaths for Cladocera's, respectively, other groups (Figure 6), in both situations r = 0.78. In these areas, phosphates had low values (mean 0.18 µM and 0.11 µM), assessed as normal for good environmental status. Thus, the correlation of the low levels of silicates (r = 0.46) with the abundance of copepods (Figure 6) in the offshore area (50 m isobath) was observed. Significant correlations were also obtained for meroplankton density, in the bathymetric strip between 40 m (r = 0.50) and 70 m (r = 0.57) (Figure 6). In general, negative correlations with silicate concentrations were obtained for the shallow zone (5–30 m), where levels are slightly higher. The only exception was found in the case of cladocerans (Figure 6) that developed in the offshore area (70 m), at low concentrations of silicates (r = –0.54). In the same context, Noctiluca scintillans was positively correlated (r = 0.49) with variations in silicate levels in the offshore zone (50 m) (Figure 6).

Variation in inorganic forms of nitrogen (nitrites, nitrates, ammonium) correlates differently with mesozooplankton groups. Thus, in the case of the abundance of cladocerans, no significant correlation was observed (Figure 6); in the case of copepods, the only one observed is in the offshore area (90 m), with ammonium

<table>
<thead>
<tr>
<th>Variable</th>
<th>T [°C]</th>
<th>S [%]</th>
<th>O₂ [µM]</th>
<th>PO₄ [µM]</th>
<th>SiO₄ [µM]</th>
<th>NO₂ [µM]</th>
<th>NO₃ [µM]</th>
<th>NH₄ [µM]</th>
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Table 3. Simple correlation coefficient (r) between physicochemical parameters, by season (red values = significant correlations).
concentrations \((r = 0.98)\), as well as *Noctiluca scintillans* \((r = 0.97)\) and meroplankton \((r = 0.95)\) (Figure 6). The variation of nitrate concentrations is directly proportional to the density of nonfodder mesozooplankton \((r = 0.68, 50 \text{ m})\), meroplankton \((r = 0.87, 10 \text{ m} \text{ and } r = 0.56, 40 \text{ m})\) and other groups \((r = 0.93, 10 \text{ m}, r = 0.74, 90 \text{ m})\) (Figure 6).

### 4. Discussion

#### 4.1. Mesozooplankton community structure

The seasonal changes show an impact on the physicochemical parameters which change the patterns of the composition of species, mostly depending upon the temperature value (Gokhale and Sharma, 2022). As in the present study, a
reduction in the number of mesozooplankton’s identified taxa was observed according to the differences recorded in sea water temperatures, from 25 taxa in warm season to 15 taxa in the cold season. Temperature alters the rates of various biological processes of copepods, such as their growth, productivity, and mortality, and influences the seasonal cycles of physical and chemical properties, such as stratification and nutrient availability in the upper water column, which influence phytoplankton and subsequently mesozooplankton, prey–predator interactions and region-specific trophic amplification (Chiba et al., 2015).

4.2. Environmental factors analysis
Physicochemical parameters play a major role in determining the assemblages, diversity and occurrence of zooplankton population in a water body. Certainly, the variability observed in the distribution of zooplankton is due to abiotic parameters, to biotic parameters (e.g., limitation of food, competition, predation) or to a combination of both (Christou, 1998). Even if zooplankton is present in a wide range of environmental conditions, many species are still limited by temperature, salinity, dissolved oxygen, and other physicochemical

Figure 5. Analysis of the main components (PCA) for the environmental factors from the Romanian Black Sea, by sector and season, 2013–2020.

Figure 6. Statistically significant correlation (p < 0.05) between the mesozooplankton groups and environmental factors grouped by isobaths, 2013–2020.
factors (Niyoyitungiyie et al., 2020). Physicochemical parameters are important for expertise in the sustainable development process and for management of healthy marine ecosystem (Kennish, 2000). The present study shows that there are variations in the abiotic factors from the Romanian Black Sea area. Both for temperature and salinity, an increased variability was observed in the warm season, due to the increased river flow in the northern sector and the influence of anthropogenic sources (Eforie wastewater treatment plant) in the southern sector. The lowest salinity (t-test, p < 0.05) was observed in the northern sector, under the influence of the Danube. As far as the oxygen is concerned, in the cold season the highest values are observed in the northern area; in the warm season, the decreasing gradient from N to S is significantly outlined (Figure 4). Zooplankton can tolerate lower oxygen concentrations than fish and may use oxygen gradients as refuges against predation (Horppila et al., 2000). Low dissolved oxygen concentration has little influence on zooplankton (Yang et al., 2012).

In general, the highest phosphate concentrations, as well as the high variability, are found in the northern sector, being influenced by the fluvial input, a phenomenon highlighted by the significant correlations with salinity (r = –0.66 in the cold season and r = –0.45 in the warm season).

The biological cycle of silicon in the marine environment is relatively simple, with diatoms taking up silicates which they incorporate into their frustules as biogenic silicon. As diatoms decompose, silicon dissolves into silicate form again or is deposited with phytoplankton debris (Kristiansen and Hoell, 2002). The concentrations of dissolved silicates in seawater were significantly correlated both positively and negatively, depending on the station depth and, most probably, also on the time taken with regard to diatom blooms, often followed by the increase in the production of mesozooplankton and then of fish—the traditional trophic chain where copepods are considered the main consumer (Kristiansen and Hoell, 2002).

The highest values for the inorganic forms of nitrogen were recorded in the warm season as a result of their use and regeneration in biological processes, a fact also confirmed by insignificant or very low correlations with salinity (Table 4). Human activities, atmospheric precipitation, continental drainage, and migration of marine animals that excrete nitrogen compounds are factors that play an important role in the supply and distribution of nitrogen (Riley and Skirrow, 1965) in the marine ecosystem.

4.3. Correlations between mesozooplankton's quantitative structure and environmental conditions in the warm season

The paper revealed the importance of salinity and temperature. These physical factors (temperature and salinity) controlling the mesozooplankton dynamics are the two most important environmental variables that influence the growth and egg production of marine copepods (Miller and Marcus, 1994; Holste and Peck, 2006). Temperature plays an even larger role in marine ecosystems: warming enhances the metabolism in marine ectotherms, which in turn increases oxidative stress via increased oxygen consumption (Lushchak, 2011). The reduction in salinity and simultaneous increase in temperature could, thus, lead to severe stress (Diekmann et al., 2012; Peck et al., 2015).

The correlations values between mesozooplankton's density and environmental factors showed variations, depending on the mesozooplankton group and water column depth. Copepods were best correlated with salinity, at depths of 50 m, where the variability of salinity is lower (median 16.03‰, standard deviation 1.26‰, coefficient of variation 7.78 %). Suboptimal salinity has a negative effect on egg production rate in marine copepods (Dutz and Christensen, 2018), acute change in salinity increasing the oxidative stress of marine organisms (Lushchak, 2011). Copepods correlated significantly with the silicate levels in the offshore area. This could be explained by the change of diatoms community toward more silicified species, or by the increase of diatom silification in the presence of grazers (Moriceau et al., 2018). Grazers' feeding activity may also increase the remineralization of the dead diatom frustules (Schultes et al., 2010).

Cladocera recorded a positive correlation with temperature values, especially in the shallow waters. Temperature regime is an important determinant of cladoceran community structure and abundance (Metzke and Pederson, 2012), having a large impact on seasonality and abundance of cladocerans by influencing time to maturity, brood size, and longevity (Wetzel, 2001).

The meroplanktonic component showed an increased development in shallow waters, being correlated with salinity. Salinity is a key ecological factor in the biology of meroplankton larvae, changes in salinity having a relatively weak influence during the development of meroplankton larvae but generating strong effects on the survival rate (Anger, 2003).

Other groups category positively correlated with phosphate in offshore waters and negative with temperature, the chaetognath Parasagitta setosa being affected by small changes in the environment such as salinity variations, pH, and temperature values. (Singarajah, 1966).

Noctiluca scintillans, the nonfodder mesozooplankton component recorded positive correlations with silicates, nitrates, and ammonium. Beyond its significance as a predator in determining carbon flow in marine food webs, Noctiluca scintillans is also an important agent of nutrient regeneration (Harrison et al., 2011), accumulating
From a qualitative point of view, the copepod group was dominant throughout the analysed period, with annual variations in the number of identified species. Another well-represented group was that of cladocerans, followed by the meroplanktonic component, the other groups category being less represented. The nonfodder component represented by the dinoflagellate Noctiluca scintillans was present in 2013–2020, throughout the analysed period with quantitative variations, reaching the development peak mainly in the warm season.

The PCA analysis highlighted that salinity and temperature were the main identified factors influencing the development of the mesozooplankton community.

The mesozooplanktonic groups responded differently to the analysed environmental factors. The category of other groups correlated negatively with temperature in the sea, as did the group of cladocerans, but at depths of 5 and 50 m. The group of copepods correlated positively with salinity in the offshore area and the dinoflagellate Noctiluca scintillans developed in areas with large salinity variations. The meroplanktonic elements also showed a correlation with salinity, but in shallower waters.

Acknowledgment

I would like to thank all my National Institute for Marine Research and Development “Grigore Antipa” colleagues, my PhD completion could not have been accomplished without their support.

References


Spatial and temporal zooplankton composition and abundance variations are result of many physical and chemical processes interacting with several biological processes. A complex set of related, possibly causal, factors have been implicated in the variations including physical and chemical variables.

Conclusion

During 2013–2020, the seasonal distribution of mesozooplankton species revealed a greater number of taxa identified in the warm season (25), the cold season being characterized by a maximum number of 15 taxa.

and regenerating large amounts of dissolved inorganic nutrients (i.e. NH\(_4^+\) and PO\(_4^{3-}\)) and more complex organic substances (Zhang et al., 2017). Nutrients have been emphasized by various ecologists as an important factor influencing the growth of Noctiluca scintillans (Pithakpol et al., 2000). Mesozooplankton function as both a consumer and a source for nutrients by simultaneously incorporating them into biomass and releasing dissolved nutrients (Walve and Larsson, 1999). Thus, particulate or dissolved nitrogen compounds coming from dead organisms and those excreted by plants and animals are quickly transformed into ammonia.

The main peculiarity of the Romanian Black Sea coast environmental factors is the natural variability, the marine waters being strongly affected by the fluvial input from the northwestern part of the Black Sea basin, by the wind regime and the succession of seasons. Added to this are the anthropogenic pressures resulting from human activities carried out especially in the central and southern areas: urbanization, industry, tourism, and ports.

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