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LONG-TERM STUDY OF ZOOPLANKTON BIOMASS IN THE SOUTH-EASTERN PART OF THE GULF OF TRIESTE (ADRIATIC SEA)

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ABSTRACT

We present a dataset of zooplankton biomass spanning more than four decades (1974–2019). The dry mass of zooplankton ranged from below 10 to almost 100 mg m^{-3}, was highest in 1989–2002 and declined thereafter. The interannual variability of zooplankton dry mass in the period 1993–2018 was compared with the regional atmospheric index WeMOi, chlorophyll a and frequency of jellyfish blooms. Increased dry mass values were associated with a positive phase of the regional atmospheric index WeMOi, higher chlorophyll a and a lower frequency of jellyfish blooms.

Key words: net zooplankton, dry mass, time series, chlorophyll *a*, jellyfish blooms

STUDIO A LUNGO TERMINE DELLA BIOMASSA ZOOPLANCTONICA NELLA PARTE SUD-ORIENTALE DEL GOLFO DI TRIESTE (MARE ADRIATICO)

SINTESI

Gli autori presentano un set di dati sulla biomassa zooplanctonica che copre un arco temporale di oltre quattro decenni (1974–2019). Il peso secco dello zooplancton variava da meno di 10 a quasi 100 mg m^{-3}, raggiungendo i valori più elevati nel periodo 1989–2002 e diminuendo successivamente. La variabilità interannuale del peso secco dello zooplancton nel periodo 1993–2018 è stata confrontata con l'indice atmosferico regionale WeMOi, la concentrazione di clorofilla a e la frequenza delle fioriture di meduse. I valori più elevati del peso secco sono risultati associati a una fase positiva dell'indice atmosferico regionale WeMOi, a una maggiore concentrazione di clorofilla a e a una minore frequenza di fioriture di meduse.

Parole chiave: zooplancton, peso secco, serie storiche, clorofilla *a*, fioriture di meduse

INTRODUCTION

Zooplankton represents an important trophic step in the pelagic food web and connects the primary producers with the higher trophic levels. It acts as a recycler, converting particulate organic matter into dissolved pools, and plays an important role in the biological pump and carbon export (Steinbeck & Laundry, 2017). Monitoring zooplankton biomass over extended periods of time provides valuable insights into ecosystem health, productivity and resilience. By facilitating the assessment of anthropogenic impacts, such data can support the development of evidence-based management strategies, such as the European Marine Strategy Framework Directive (MSFD, 2008/56/EC) and the Integrated Monitoring and Assessment Programme (IMAP, UNEP/MAP, 2016) of the Barcelona Convention. Quantitative estimates of zooplankton biomass are therefore of paramount importance (Ratnarajah *et al.*, 2023), but in general, observational data are sparse.

The most commonly used metrics to determine net zooplankton biomass are settling and displacement volume (volumetric methods) and wet, dry and ash-free dry mass (gravimetric methods). The methodological bias is reduced if the displacement volume or wet mass is quantified instead of the settling volume, and even more so if the dry mass is measured and the fluids are eliminated (Postel *et al.*, 2000). While volumetric methods were already used in the 19th century to determine the quantity of net plankton, the measurement of dry mass became established as a widely used method in the 1960s (Hagen, 2000).

Alternatively, researchers can determine the abundance and taxonomic composition of the plankton community and then convert this data into dry mass using published conversion factors. This method is much more time-consuming, and the effort increases if the dry mass of a particular taxonomic group or species is determined directly, but the results provide additional important information.

The measurement of the bulk dry mass is straightforward and standardised in marine ecology studies despite some disadvantages. The main drawbacks include the destruction of organisms that cannot be used for further taxonomic analyses, the inability to capture variability due to differences in community structure, especially when the abundance of gelatinous organisms is considerable, and the lack of information on the specific biochemical composition, which is important for assessing the role of zooplankton in trophic dynamics. Nevertheless, the use of standard dry mass methods enables consistent results and can therefore be used for comparisons across different geographical locations and over time.

The main objective of the present study was to describe the long-term and interannual fluctuations of the zooplankton stock in the northernmost part of the Adriatic Sea and to identify possible changes. We report here the temporal patterns of net zooplankton dry mass in the Gulf of Trieste over more than four decades (1974–2019). We also investigated the relationships between zooplankton and phytoplankton biomass as well as the regional climate index as possible explanatory variables for the observed fluctuations. Finally, we use data on the occurrence of jellyfish blooms to interpret the observed changes in zooplankton biomass and identify a possible top-down control.

MATERIAL AND METHODS

Sample collection and processing

The zooplankton samples were collected in the south-eastern part of the Gulf of Trieste (northern Adriatic Sea) at the long-term ecological research site LTER Gulf of Trieste, Slovenia (LTER GoT SI, 22 m water depth, Fig. 1). The Gulf of Trieste is the northernmost extension of the Adriatic Sea and is characterised by a shallow water depth of less than 20 m on average. Due

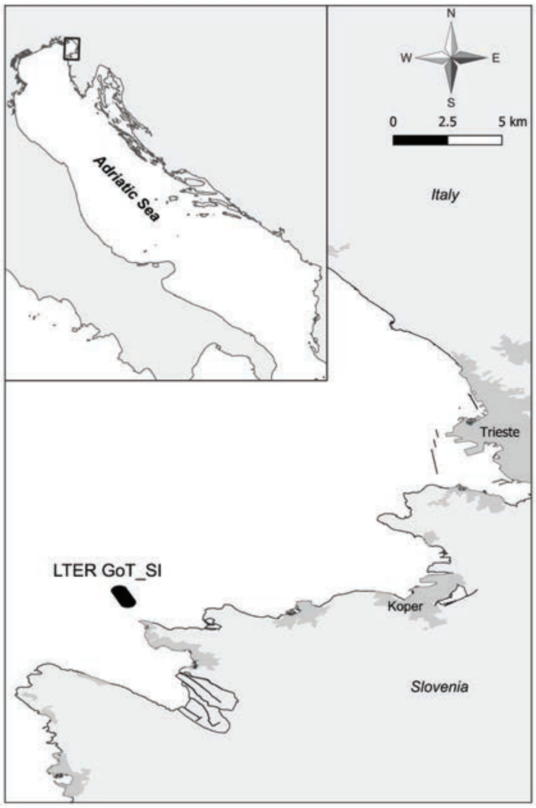

Fig. 1: The site of the long-term ecological research station LTER Gulf of Trieste, Slovenia.
Sl. 1: Lokacija dolgoročne ekološke raziskovalne postaje LTER, Tržaški zaliv, Slovenija.

to its location and shallow depth, the climatic conditions have a strong influence on the oceanographic and biological characteristics. The water column is thermally stratified in the warmer part of the year and well mixed in winter. The main freshwater source (the Soča River) flows into the Gulf from the north-west coast and plays an important role in the bottom-up control of phytoplankton (Vascotto *et al*., 2024). Our sampling station is located in the south-eastern part of the Gulf, which is more strongly influenced by the EAC (Eastern Adriatic Current) and the open waters of the northern Adriatic and is considered mesotrophic to oligotrophic (Brush *et al*., 2021).

The time series of zooplankton monitoring with different sampling frequencies was established in 1974. However, the monitoring was interrupted several times (1976–1978; 1981–1988; 2003) and was carried out regularly from 2004 until it was discontinued in 2019. The zooplankton samples were collected by vertical tows from the near bottom to the surface using three different nets: with a mouth opening of 0.25 m^2 and a mesh size of 212 µm (1974–1975), with an opening of 0.5 m^2 and a mesh size of 250 µm (1979–1980) and since 1989 with the WP2 net, mouth opening of 0.25 m^2 and a mesh size of 200 µm. The volume of water filtered was calculated from tow length and net opening. The samples were fixed on board with buffered formaldehyde (2%–4% final concentration).

The frequency of sampling varied from five to six times a year (1974–1975, 1979–1980, 1989–1992) to monthly from 1993 and bi-monthly from 2004. Since the beginning of 1993, the seawater samples for chlorophyll *a* determination have been collected using 5-litre Niskin bottles.

In the laboratory, the zooplankton samples were divided into two halves using a Folsom splitter and one half-split was used to determine the biomass (dry mass – DM). The DM samples were briefly rinsed with freshwater, placed in pre-weighed ceramic crucibles, dried at 60^0 C for 24 hours (Lovegrove 1966) and weighed to the nearest 0.1 mg. The results were expressed as dry mass in milligrams per cubic meter (mg DM m^{-3}). The concentrations of chlorophyll *a* (Chl *a*), corrected for phaeopigments, were determined fluorometrically in 90% acetone extracts (Holm-Hansen *et al*., 1965).

Time series analyses

Monthly time series of the entire DM dataset were generated and descriptive statistics (mean, geometric mean, standard error, median, standard deviation, and 10th and 90th percentiles) were calculated. We also calculated the coefficient of variation (CoV) as SD/mean. The normalised annual DM anomalies, calculated by dividing the anomalies by the long-term standard deviation, were estimated for the entire study period (1974–2019).

We investigated the relationships of DM with phytoplankton biomass (Chl *a*), the Western Mediterranean Oscillation climate index (WeMOi) and jellyfish blooms as potential explanatory variables for changes in zooplankton biomass. The basic working hypothesis was that zooplankton DM was influenced by Chl *a* as proxy of food availability and by WeMOi as proxy for environmental conditions. As we had several major interruptions in zooplankton sampling (1976–1978; 1981–1988) we analysed the fluctuations in zooplankton biomass in relation to Chl *a* and the WeMOi only for the last 25 full years of the study (1993–2018), using monthly series for all parameters. DM results were missing for some months (21 out of 301 results), which were scattered over the entire period. To fill in these missing values, the approx. function in R was used. The same was done for missing Chl *a* values (33 out of 301 results).

WeMOi measures the difference between the standardised atmospheric pressure in Padua, northern Italy, and San Fernando, Cádiz, Southwestern Spain (Martin-Vide & Lopez-Bustins, 2006) and reflects the regional weather conditions. The positive phase of WeMO correlates significantly with lower sea surface temperatures and higher river discharges and has been shown to be associated with increased productivity of plankton and small pelagic fish (Martin *et al*., 2012). Monthly WeMOi data were downloaded from crudata.uea.ac.uk/cru/data/moi/Web_WeMOi-2020.txt. Pearson's product moment correlations were used to assess the relationship between zooplankton DM and Chl *a*, and DM and WeMOi using time series of monthly data. Additional analyses considered a time lag of one month for zooplankton DM. The annual WeMOi is the average value of the corresponding monthly WeMOi (Martin *et al*., 2012).

Jellyfish blooms were defined according to the methodology described by Pestorić *et al*. (2021). During the study period, the following macrojellyfish species (Cnidaria, Scyphomedusae: *Aurelia solida*, *Chrysaora hysoscella*, *Cotylorhiza tuberculata*, *Pelagia noctiluca*, *Rhizostoma pulmo* and Ctenophora, Lobata: *Mnemiopsis leidyi*) were found to be blooming in the Gulf of Trieste (Kogovšek *et al*., 2010; Pestorić *et al*., 2021, own observations). The annual jellyfish bloom index (Jbi) was calculated as the cumulative number of months in a year in which macrojellyfish blooms occurred in the study area. The non-parametric Kruskal–Wallis test and Dunn's post-hoc multiple pairwise comparison test were used to determine whether there were significant differences in zooplankton DM results between years with different JBi. Hierarchical clustering and non-metric multidimensional scaling (NMDS) were used to visualise how the different years clustered based on the Bray-Curtis dissimilarities of the DM influenced by WeMOi and Jbi.

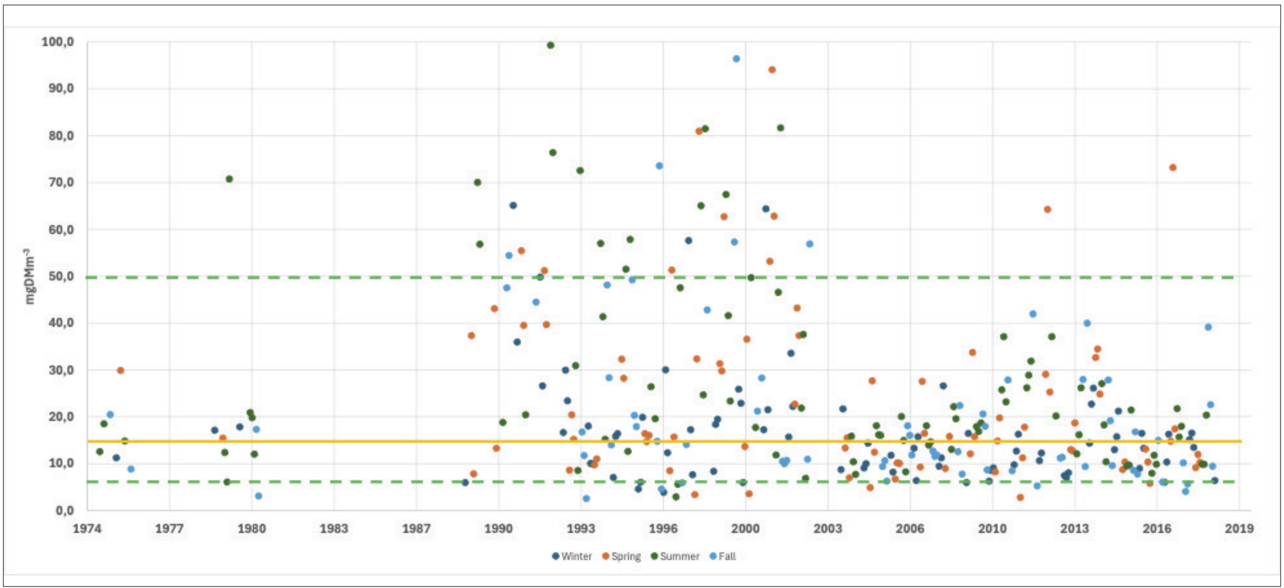

Fig. 2: Scatter plot of zooplankton dry mass (mg m^{-3}) over the study period (1974–2019), the median (full yellow line) and the 10th and 90th percentiles (dashed green lines). The different seasons are marked with different colours (winter – dark blue, spring – orange, summer – green, autumn – light blue).

Sl. 2: Diagram suhe mase zooplanktona (mg m^{-3}) v preiskovanem obdobju (1974–2019) z mediano (rumena linija) ter 10. in 90. percentilom (črtkani zeleni liniji). Sezone so označene z različnimi barvami (zima – temno modra, pomlad – oranžna, poletje – zelena, jesen – svetlo modra).

RESULTS

Fig. 2 shows all zooplankton DM (318 results) in the study period 1974–2019, while the descriptive statistics with mean, geometric mean, median, standard error and deviation are shown in Table 1.

Overall, zooplankton DM varied widely, from less than 10 mg m^{-3} (23% of results) to 99.3 mg m^{-3}, with 9% of results above the 90th percentile. CoV was slightly higher in the periods before 2004 (0.77 for 1974–1980, 0.74 for 1989–2002) and was lowest in the latter period (0.61). In the years 1989–2002, DM was frequently above the overall median (67% of results) and the mean (51% of results). In contrast, high results were less frequent in the years 1974-1980 and after 2004. In particular, the periods between 2004 and 2010 and after 2014 were characterised by low DM (66% of results were below the median and 86% below the overall mean).

Interannual and seasonal changes in zooplankton DM

The interannual variations in zooplankton DM were considerable (Figs. 2 and 3). Years with statistically significant ($p \leq 0.01$) lower DM values were observed before 1980 (except for 1979) and after 2004 (with the exception of 2012, 2014). The years with the highest annual CoV (> 0.8) were 1993–1997, 2012 and 2017, while the DM results fluctuated the least in 2004–2009 and 2014–2016 (CoV < 0.5). The annual fluctuations in zooplankton DM can be clearly visualised by calculating the normalised annual anomalies (Fig. 3): the positive anomalies are concentrated in the years 1989 to 2002, followed by the conspicuous negative anomalies from 2004 onwards.

Tab 1: Descriptive statistics for zooplankton dry mass results in the period 1974–2018.

Tab. 1: Opisna statistika za rezultate zooplanktonske suhe mase v obdobju 1974–2018.

Dry Mass (mg/m^3)	
Mean	22.4
Geometric Mean	17.1
Standard Error	1.0
Median	16.2
Standard Deviation	18.2
Sample Variance	332.8
10th Percentile	7.3
90th Percentile	49.8

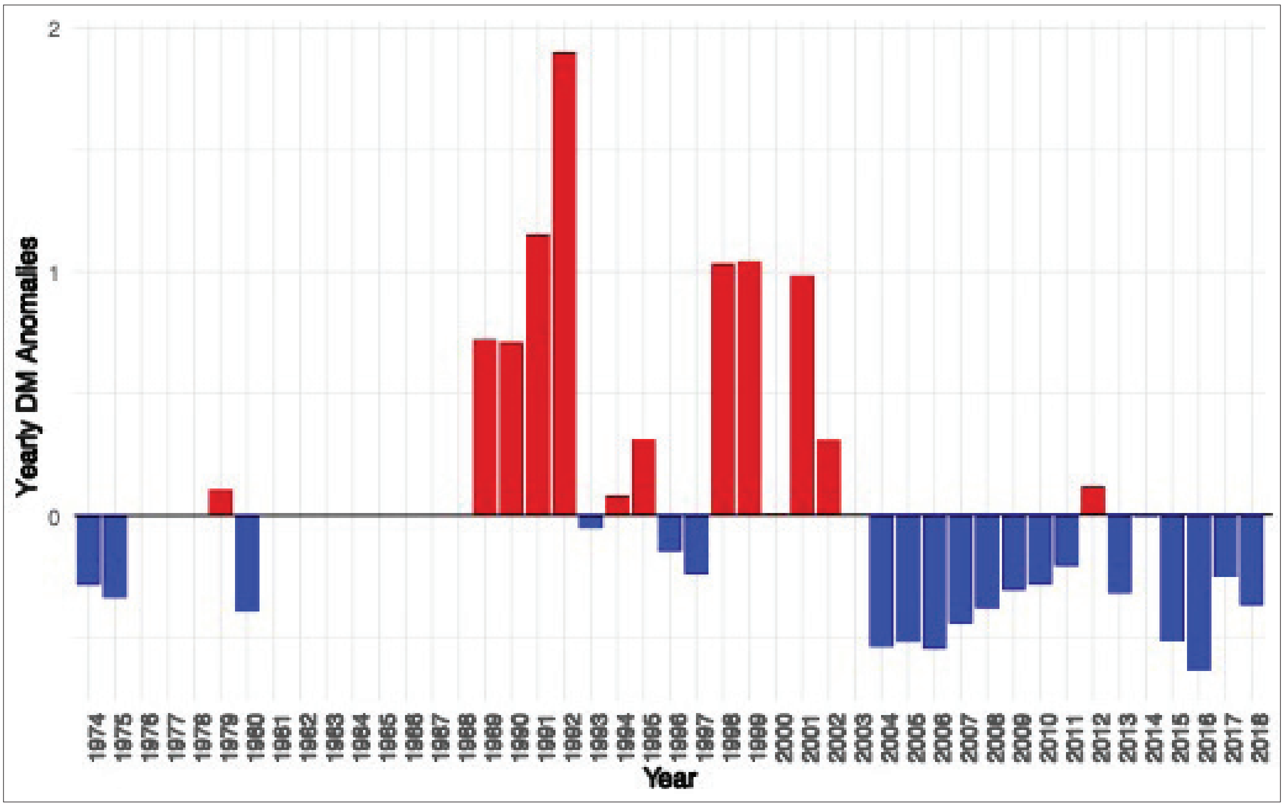

Fig. 3: Normalized annual anomalies of zooplankton dry mass during the study period (1974–2018).
Sl. 3: Normalizirane letne anomalije zooplanktonske suhe mase v obdobju 1974–2018.

The average annual cycle of zooplankton DM throughout the study period showed higher biomass but also greater variability in the warmer season (May–September) (Fig. 4), while values were lower in the colder months (December–April). The annual DM maxima were most frequently measured in May (44 % of all years), followed by September (16 %).

Comparison with Chl *a*, WeMOi and jellyfish blooms (Jbi)

Due to gaps in sampling and the lower frequency of sample collection, we decided to conduct further analyses and examine DM relationships to phytoplankton biomass and climate index only for results since 1993. Chl *a* fluctuated widely with maximum values above 10 mg m^{-3} (10.15 and 12.06 mg m^{-3} in November 1996 and February 1999, respectively), while the lowest value was measured in June 2018 (0.16 mg m^{-3}). In addition, the entire period after 2006 was characterised by lower Chl *a* with annual mean values below 1.0 mg m^{-3}, in contrast to the previous years with mean values of 1.07 to 2.11 mg m^{-3}.

The monthly WeMOi showed positive and negative values with the highest monthly value of 3.19 (April 1994) and the lowest –3.18 (June 2006). While a considerable part of the WeMOi was neutral (values between –1.00 and 1.00), the positive WeMO phase prevailed in the 1990s and early 2000s and the negative WeMO from 2002 onwards.

Correlations between zooplankton DM, Chl *a* and WeMOi were analysed using monthly data from 1993–2018. Although we found positive correlations between zooplankton DM and Chl *a* as well as DM and the positive phase of WeMOi, these were weak (0.131 and 0.151, respectively) and not significant. Reanalysis with a time lag did not improve the correlation.

Analysis of the annual WeMOi time series indicated that before 2002 the positive WeMO phase prevailed (Fig. 5). It is associated with higher rainfall and river flows as well as lower sea temperatures, conditions that are considered favourable for overall biological productivity (Martin *et al.*, 2012).

Throughout the study period, there were years without massive jellyfish blooms and/or with short-lived seasonal blooms of one or two species (Jbi ≤ 3) as well as years in which several species bloomed over a longer period and at different times of the year. Typically, the blooms of *A. solida* occurred in winter-spring, *C. tuberculata* in summer, *R. pulmo* in autumn-winter-spring and since 2016 *M. leidyi* in summer-autumn.

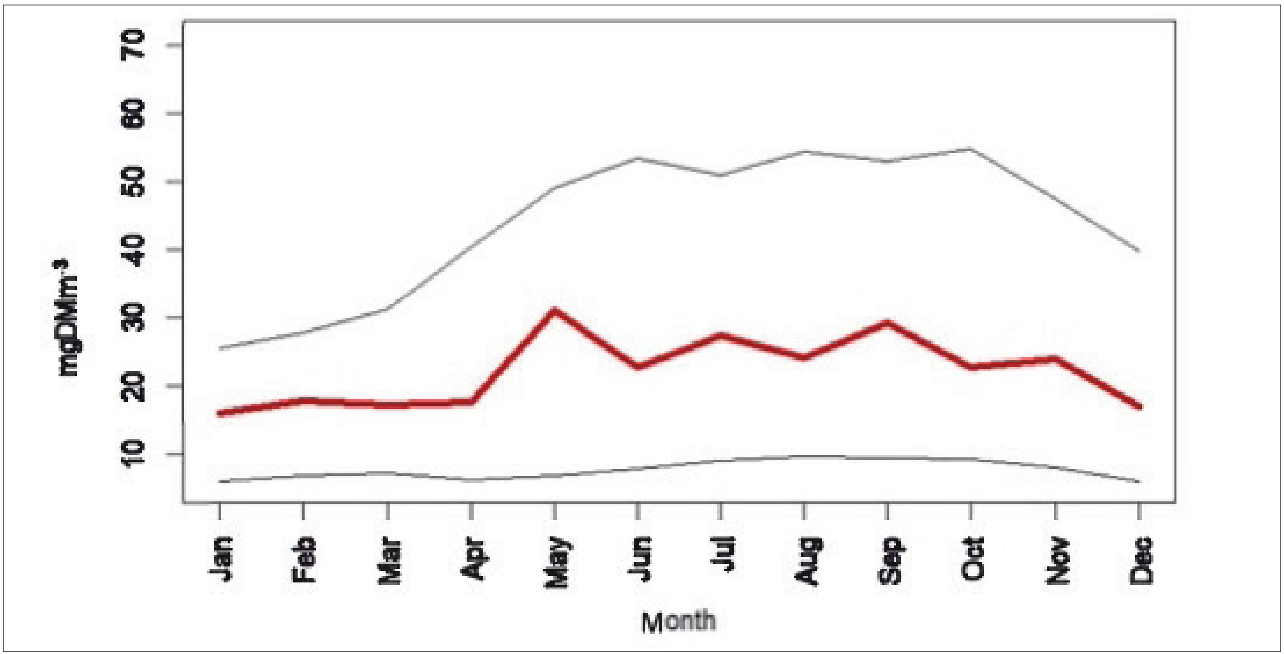

Fig. 4: Mean seasonal pattern (1974–2018) of zooplankton dry mass (mg m^{-3}) (red line) and the 10^{th} and 90^{th} percentiles (grey lines).
Sl. 4: Sezonskost povprečne (1974–2018) zooplanktonske suhe mase (mg m^{-3}) (rdeča linija) z 10. in 90. percentilom (sivi liniji).

The annual Jbi varied from 0 (no bloom in one year) to 10 (ten months with bloom in one year). Until 2004, there were nine years without blooms, moreover, the Jbi was lower in the years 2009–2014 (≤ 5) than in the years 2004–2008 and 2015–2019 (Jbi 6-10).

The Kruskal–Wallis test ($p = 0.0016$) and Dunn's post-hoc multiple pairwise comparison test ($p = 0.0016$) revealed significant differences in zooplankton DM between the years without blooms and the years with Jbi ≤ 3 and those with multi-species blooms over a longer period (Jbi ≥ 4). Hierarchical clustering and nMDS ordination of DM showed that WeMOi and Jbi affected DM in different ways and their influence varied across years. While a higher Jbi was associated with a lower DM (years from 2004 onwards), a higher DM was generally related to the positive WeMOi phase (1980s and 1990s).

DISCUSSION AND CONCLUSIONS

Many marine organisms that are critical to the functioning of the ecosystem and to humans, such as exploited fish, shellfish, squid, some marine mammals, seabirds and sea turtles, to name but a few, are affected by the quantity of zooplankton. Therefore, zooplankton biomass can be considered a key indicator of changes due to environmental and anthropogenic pressures, including responses to climate change. Zooplankton data are also important for the effective implementation of the MSFD (Gorokhova *et al.*, 2016), particularly for the development of methods to assess biodiversity in pelagic habitats (Descriptor 1) and food webs (Descriptor 4). Especially in the Mediterranean Sea, where zooplankton-based indicators are still in the development phase, long-term data are important to define the baseline situation and capture trends and shifts (Francé *et al.*, 2023).

Among the various methods used to determine zooplankton biomass, the dry mass procedure has been evaluated and standardised since the seminal work of Lovegrove (1966). Although there are many papers on various aspects of zooplankton in the northern Adriatic (Pearson *et al.*, 2021), few report on biomass, especially DM. In our article, we present the results of more than four decades of monitoring zooplankton biomass in the Gulf of Trieste using this standardised method. Furthermore, the very similar mesh size (200 – 250 μm) of the zooplankton nets used and the standardised determination of DM at 60^0 C ensure that our dataset provides comparable results over the period from 1974 to 2019.

The results of zooplankton biomass measurements of the Adriatic Sea during 1971–1981 were summarised in an article by Benović *et al.* (1984). These authors reported significant differences in zooplankton DM, with results from the northern Adriatic, including the Gulf of Trieste, being higher than in other coastal areas and open Adriatic waters. The range of DM values in

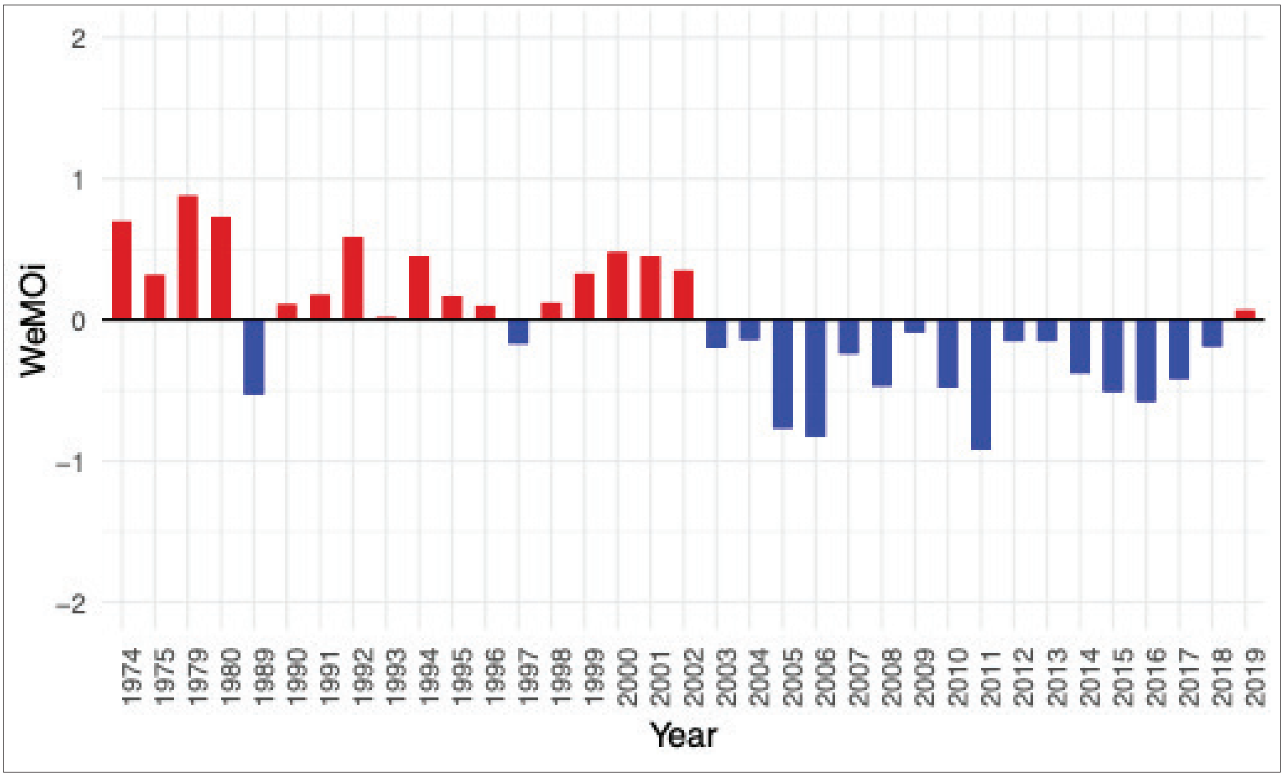

Fig. 5: Annual WeMOi (Western Mediterranean Oscillation index) from 1974 to 2019: red bars – positive WeMO phase, blue bars – negative WeMO phase.
Sl. 5: Letni indeks WeMO (Zahodna sredozemska oscilacija) v letih od 1974 do 2019: rdeči stolpci – pozitivna WeMO faza, modri stolpci – negativna WeMO faza.

the Gulf of Trieste was between less than 10 and over 100 mg m^{-3} (1.2 – 177.2 mg m^{-3}) and the mean value was 18.5 mg m^{-3}. The largest proportion of results (36.7 %) was between 10 – 20 mg m^{-3} with the highest values measured in spring and the lowest in winter. The observed seasonal dynamics was consistent with ours, but our mean DM value over the entire period 1974–2019 was thus higher (22.4 mg m^{-3}, Tab. 1). However, we found a significant difference between the period before and after 2003 (mean 29.5 vs. 16.0 mg m^{-3}, respectively). This decline in zooplankton DM in the Gulf of Trieste is consistent with the findings of Mozetič *et al.* (2012), who reported a regime shift in plankton between 2002 and 2003. This shift was related to lower nutrient concentrations due to reduced freshwater inputs from the Soča River in 2002–2007, particularly in 2003, a decline in seasonal diatom blooms and the dominance of smaller-sized phytoplankton.

A study (Kamburska & Fonda Umani, 2009) focussing on the temporal pattern of net zooplankton at a coastal station in the western part of the Gulf of Trieste covered two decades of monthly sampling (1986–2005) and was complemented by some earlier data. The DM values were in a similar range to ours (1 – 95 mg m^{-3}), and like us they found the highest monthly average in May and lower from November to February. In contrast to our observations of decreasing DM after 2003, they reported higher DM in the last two years of their study (2004, 2005 only until September), while their values in the 1990s were similar to ours. Nevertheless, the work of Benović *et al.* (1984), Kamburska & Fonda Umani (2009) and ours indicate a large seasonal and interannual variability of zooplankton DM, similar seasonal dynamics and a comparable range of DM values. However, in the last period of our study (after 2003), which was not covered by previous reports, we found a significantly lower zooplankton DM. Despite some interannual differences, this decline is consistent with general observations of oligotrophication in the northern Adriatic (Brush *et al.*, 2021).

Despite numerous studies on zooplankton communities, the estimated DM values of samples collected using nets with a comparable mesh size to ours (200–250 μm) have rarely been reported from other Mediterranean regions. A ten-year study (2007–2017) in the western Mediterranean (Fernández de Puelles *et al.*, 2023) showed considerable variability without clear temporal trends, with higher DM values (> 10 mg m^{-3}) in the western Alborán Sea and lower values (< 5 mg m^{-3}) in the eastern Balearic Sea. In an earlier study (1994–2003) in the Balearic Sea, Fernández de Puelles & Molinero (2008) also reported similarly low DM values with an average of 5.4 mg m^{-3}. Average annual DM values between 1.43 and 3.56 mg m^{-3} were found off Marseille, with the biomass being highest at the nearshore stations (Gaudy & Champalbert, 1998). Similar DM values (0.7 – 5.2 mg m^{-3}) were found in the coastal area of Cyprus, while higher DM values were measured in the Saronikos Gulf (up to 11.9 mg m^{-3} on average) and in the north-eastern Aegean Sea (Hannides *et al*., 2015). Lakkis (1990) reported values (2 – 20 mg m^{-3}) in the Lebanese coastal waters. These comparisons show that despite oligotrophication in recent decades, zooplankton DM in the Gulf of Trieste is still higher than in most Mediterranean regions.

In our analysis of monthly data, no clear relationship was found between the regional atmospheric index WeMOi and zooplankton DM, although a weak positive correlation was established, i.e. positive WeMOi were associated with higher DM. Despite the non-significant correlation, years with lower DM showed a higher frequency of negative WeMOi monthly values below - 2.00, which are assumed to have a stronger influence on dry conditions (Martín *et al*., 2012). Accordingly, Milošević *et al*. (2016), who studied seasonal and annual precipitation (1963–2012) in Slovenia, found that a positive WeMO phase led to more precipitation, especially in spring and autumn, which could have an impact on local river discharge.

In the northern Adriatic, a negative WeMO phase is associated with dry and stable weather with less precipitation and lower river discharge. In addition, higher surface temperatures during stronger and longer negative WeMO phase lead to stronger thermal stratification, which reduces the mixing of nutrients in the surface layers. While the analysis of the relationship between the monthly WeMOi data and zooplankton DM did not provide conclusive results, the annual WeMOi time series (1974 – 2019) showed a clear difference between the period before 2002, when the positive phase prevailed and zooplankton DM was higher, and the more recent period with negative WeMO phase and lower DM (Fig. 5).

Martín *et al*. (2012) found a clear link between climate fluctuations, i.e. positive WeMOi values, and higher sardine and anchovy production. They suggested that WeMOi impacted fish populations indirectly through effects on local environmental factors such as temperature and river discharge and referred to the positive phase of WeMO as a "cool waters, high river runoff phase". Their conclusion was that "a regional climatic index such as the WeMOi is more closely linked to local environmental conditions and explains a higher proportion of the variation in fisheries productivity than other climatic indices commonly used for the Atlantic Ocean, such as the NAOi".

Based on a 13-year study in the northwestern Mediterranean (Bay of Calvi), Fullgrabe *et al*. (2020) found a correlation between the winter NAO and the spring zooplankton peak and hypothesised an influence of large-scale processes on the regional zooplankton. In contrast, Feuilloley *et al*. (2022) found no significant correlation with NAOi and WeMOi in their long-term zooplankton study (1995–2019), which was also conducted in the northwestern Mediterranean (entrance to Villefranche Bay) and pointed to the importance of biotic interactions. Piontkovski *et al*. (2011) investigated the effects of atmospheric anomalies on zooplankton communities in the northern Adriatic and Black Sea using the NAO as an example and found that while some species showed a correlation with the NAO, changes in integrative characteristics such as DM were not pronounced. Berline *et al*. (2012) compared six mesozooplankton time series from 1957–2006, including the coastal location in the western Gulf of Trieste. They found no significant correlations between the climate indices and pointed out that local factors dominate at these coastal stations. However, they suggested that the link between local and large-scale climate should be further investigated if we want to understand the fluctuations in zooplankton.

Our analysis of 25 years (1993–2018) of paired phytoplankton and zooplankton samples showed a weak and statistically non-significant positive correlation between Chl *a* and zooplankton DM. This lack of strong coupling may be related to several reasons. Both biomass measurements are integrative and do not provide information on taxonomic composition and specific feeding relationships. Furthermore, there may be a different time lag between primary producers and consumers at different times of the year, in addition to possible predatory control of zooplankton.

Jellyfish can exert a strong top-down control on other zooplankton (Schneider & Behrends, 1998). The studies suggest that the effects are potentially large but show strong spatial and temporal variation depending on the occurrence of the blooms (Stoltenberg *et al*., 2021). Most studies on the control of zooplankton by jellyfish in European seas come from the enclosed marine systems such as the Baltic Sea and the Black Sea. However, Stoltenberg *et al*. (2021), who reviewed the trophic interactions of jellyfish in the Baltic Sea, conclude that the lack of spatially and temporally consistent data on both jellyfish and their prey communities does not currently allow for a more holistic and quantitative assessment of the impact of jellyfish on mesozooplankton.

We compared the frequency of jellyfish blooms and zooplankton DM in the northernmost gulf of the enclosed Adriatic Sea. Statistical tests showed that DM was significantly lower in years when jellyfish blooms of several species occurred over longer periods of time.

A similar conclusion was reached by Malej (1989), who studied zooplankton DM and community composition in three years, one of which was characterised by a prolonged *Pelagia noctiluca* bloom; the "*Pelagia* year" had the lowest DM. A more general conclusion can be drawn from the study by Wright *et al*. (2021). Despite the paucity of data on global jellyfish biomass, they used a global biogeochemical model to suggest that jellyfish play an important role in regulating global marine plankton ecosystems which has generally been neglected.

In summary, we report the results of zooplankton biomass over more than four decades in the Gulf of Trieste using a standardised method to determine dry mass. The use of nets with similar mesh sizes (200 – 250 μm) ensures that our dataset provides comparable results for the period 1974–2019. The range of DM values was large (< 10 to almost 100 mg m^{-3}), we found a significant difference between the period before and after 2002, and the decline in the last period was consistent with the regime shift in plankton observed between 2002 and 2003 by Mozetič *et al.* (2012). Although the correlations between monthly regional climatic index WeMOi, Chlorophyll *a* and zooplankton DM were not significant ($p > 0.05$), they were weakly positively correlated. Moreover, the period with lower zooplankton DM (after 2002) was characterised by the predominance of the negative WeMO phase. In addition, the statistical tests showed that DM values were significantly lower in years when several jellyfish species bloomed over longer periods.

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DOLGOROČNA ŠTUDIJA ZOOPLANKTONSKE BIOMASE V TRŽAŠKEM ZALIVU (JADRANSKO MORJE)

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POVZETEK

V prispevku poročamo o rezultatih zooplanktonske biomase v Tržaškem zalivu, ki smo jo merili z uporabo standardizirane metode za suho maso v več kot štirih desetletjih. V tem obdobju (1974–2019) smo za vzorčenje zooplanktona uporabljali mreže s primerljivo velikostjo okenc (200 – 250 µm) kar zagotavlja primerljivost meritev. Izmerjene vrednosti suhe mase so nihale v širokem razponu (< 10 do blizu 100 mg m^{-3}*), ugotovili smo statistično značilne razlike med obdobji pred in po letu 2003, upad biomase v zadnjem obdobju pa je bil skladen z ugotovitvami spremenjenega režima v planktonu med 2002 in 2003. Čeprav korelacija med regionalnim atmosferskim indeksom (WeMOi), klorofilno biomaso in zooplanktonsko suho maso ni bila statistično značilna, so bile višje vrednosti biomase povezane s pozitivno fazo WeMO in višjimi vrednostmi klorofila. Statistični testi pa so pokazali značilno nižjo biomaso zooplanktona v letih, ko smo beležili masovno pojavljanje več vrst želatinastega planktona, ki so trajali daljša obdobja.*

Ključne besede: mrežni zooplankton, suha masa, časovni niz, klorofil *a*, masovno pojavljanje meduz

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