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CONTRIBUTION OF SPRING AND EARLY AUTUMN ZOOPLANKTON POPULATIONS TO THE ROMANIAN BLACK SEA WATERS PRODUCTIVITY, IN 2019

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Abstract

Based on 53 vertical samples collected in May, August and October 2019 in the waters of the Romanian Black Sea shelf, we assessed the seasonal dynamic of abundances and diversity of zooplankton within the surface and certain depths layers of the pelagic system. Along with the control exerted on the primary production as main grazers, zooplankton species constitute a significant part of most commercially exploited pelagic fish diet (e.g. anchovy, sprat, horse mackerel juveniles). As result of increased global and regional climatic variability, we detected a seasonal shift in the occurrence of key copepod species as well as significant fluctuations in abundances of total fodder zooplankton. In May 2019, the sudden warming of water column led to proliferation of Noctiluca scintillans and therefore, to reduction of fodder zooplankton stocks. With the changing of thermal regime, a rapid shift of zooplankton composition was detected in August comparative with October, mainly seen in explosive development of thermophilic copepod Centropages ponticus in summer and of eurythermic species Paracalanus parvus in early autumn.

Key words*: NW Black Sea, production, zooplankton.*

INTRODUCTION

Strong evidences on the Black Sea mesozooplankton spatial and temporal changes in the last decades have been brought by numerous authors, which detected the main natural and/or anthropogenic causes of its dynamic (Kideys et al., 2000; Shiganova and Bulgakova, 2000; Kovalev et al., 2001; Gubanova et al., 2001; Oguz and Gilbert, 2007; Stefanova et al., 2010; Shiganova et al., 2018; Vereshchaka et al., 2019, Opdal et al., 2019).

Major cornerstone events have occurred at the level of pelagic system pointing out to the outbreaks of invasive species *Mnemiopsis leidyi* and *Beroe ovata* at the late of 90s, following an intense eutrophication and pollution period and surged by a global temperature climatic variability and extreme cyclic phenomena such as the ENSO (Martı, 2014) and NAO (Llope et al., 2011).

All these concurred to a decrease of general zooplankton stock production and diversity (Oguz and Gilbert, 2007) and thus to alteration of food chain, with large implications in fish productivity (Daskalov et al., 2017; Mihneva, 2018; Hidalgo et al., 2018).

Long term monitoring studies of zooplankton production at the Romanian littoral were conducted mainly in the 70s – 80s (Porumb, 1972, 1974, 1979, 1982; Petran, 1985), when a method integrating data on abundance of each zooplankton species life stage, its lifespan, female fecundity and water temperature was proposed for assessing. In accordance, in the period 1970 - 1975, the total production of main copepod species was estimated at 502.72 $mg.m^{-3}$, with large seasonal variations between cold and warm months, and between species (Porumb, 1994-1995). In summer, the major species contributor turned out to be *Acartia clausi* with an average daily production of 1.55 $mg.m^3$ (about 60% of the whole copepods daily production), while *Pseudocalanus elongatus* and *Oithona nana* reached about 0.723 $mg.m^{-3}day^{-1}$ in winter-spring, and 0.54 $mg.m^{-3}day^{-1}$ in autumn, respectively. Later, during 1978 – 1980, the same author estimated a global production of zooplankton on the Romanian shelf at 191,308.86 tones, of which *Noctilluca scintillans* represented more than 80%. A recent review study evaluated a zooplankton production at the Black Sea level after 2000s up to the present at $230 \pm 87 * 10^{12}$ kJ $year^{-1}$ as comparing with the after and before 1976's production of 303±75*10^{12} kJ $year^{-1}$ and 193±72*10^{12} kJ $year^{-1}$, respectively (Opdal et al., 2019). More than 20% of daily zooplankton production is consumed by sprat and anchovy during spring - summer periods (Porumb, 1972, 1973; Bulgakova, 1996).

MATERIALS AND METHODS

The mesozooplankton was collected in three seasonal periods of 2019 (24 – 29 May, 15 – 20 August and 14 – 23 October) by vertical hauls using a "Juday" plankton net (equipped with a flowmeter), with a 36 cm diameter opening and mesh size of 150 µm, at discrete water column depths depending of thermocline, and of maximum chlorophyll and salinity gradient position. In laboratory, a total number of 53 samples were processed according to methodology for zooplankton studies in the Black Sea (Alexandrov et al., 2014). The samples locations were mainly confined to the north-western part of the shelf under direct influence of Danube (Figure 1).

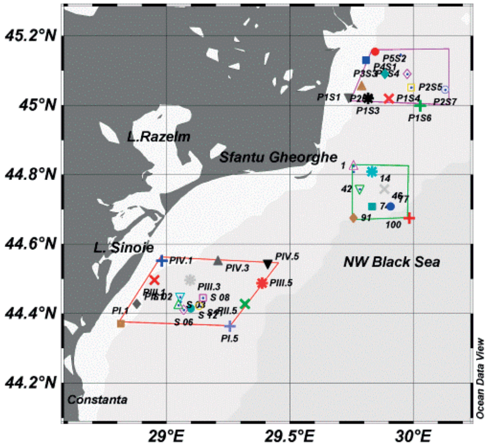

Figure 1. The stations map location within the perimeters and periods analysed in the present study (green polygon (L-35-120-D): 22 -28 May 2019 – 321.45 km^2; purple polygon: 15 – 20 August 2019 -701.18 km^2; red polygon: 14 -23 October 2019 ~ 800 km^2)

The wet weight mass (Petipa, 1957) of each species was converted to body carbon weight (mg C), according to several authors as given in Alexandrov et al. (2014). The body size of copepods was retrieved from Brun et al. (2017).

The specific daily growth rates of each species were calculated using the regression equations as showed in Uye and Shimazzu (1997). The seawater temperature value at each station (surface, thermocline and under thermocline) were taken into calculus, as this parameter was proved as determinant in relationship with weight–specific growth rate of zooplankton (Huntley and Lopez, 1992). The specific growth rates of benthic larvae (bivalves, gastropods and polychaetes) were estimated from regressions given by Hirst et al. (2003).The production rates of zooplankton species were calculated from the species- and stage-specific body masses (copepods) and their respective size-specific daily growth rates according to Hayashi and Uye (2008), Pi = Bi × Gi, where i, Bi and Gi are production rate (µg C $m^{-3}d^{-1}$), biomass (µg C m^{-3}) and specific growth rate (d^{-1}) of the species or taxonomic group i, respectively. The production rate of total net zooplankton community (P, mg C $m^{-3}d^{-1}$) was calculated as the sum of all individual taxon production rates.

Physical parameters

In May, the surface water temperature and salinity in the study area varied within 15.10°C to 20.68°C range, and 12.92 PSU and 16.14 PSU, respectively. Underneath (5 – 6 m depth), a thermocline was formed, a gradual decreasing of temperature, dissolved oxygen and increasing of salinity being recorded (7.74 – 9.90°C, 82 – 96%, 7.97 – 9.64 mg/l and 18.01 – 18.28 PSU up to 20 m depth followed by a slightly decreasing of temperature and a salinity increasing downward the bottom.

In August, the surface temperature varied within 24.66°C and 26.2°C range, with a sharp decrease at the level of thermocline to 13 -15°C (upper part generally set at depths between 8 and 20 m), and further on under it up to a constant temperature of 8.6-10.72°C. Salinity vertical profile was similar, slightly influenced by the Danube freshwater (average surface PSU: 17.45 and 18.40 PSU under thermocline).

In October, a mixed surface layer of 2 to 10 – 15 m thickness, with an average temperature and salinity of 18.27°C and 17 PSU, and beginning of a gentle thermo- and halocline formation characteristic to the early autumn season has been noticed. Under it, an average temperature of 11.6°C and a higher salinity (> 18 PSU) were recorded.

RESULTS AND DISCUSSIONS

Zooplankton population structure and abundance

In May, a relative low diversity formed of 6 copepod species (*Acartia clausi, Pseudocalanus elongatus, Calanus euxinus, Centropages ponticus, Paracalanus parvus, Oithona spp.*) and a small number of meroplankton representatives (bivalves, gastropods, polychaetes) were identified. The accentuated thermal leap at the end of May as compared with the previous couple of weeks (in average 7ºC), combined with a predominant northern cyclonic circulation and Danube freshwater input led to a rapid blooming of *N. scintillans*, and phytoplankton (surface Chl *a* 4.32 – 8.38 µg/l). In 70% of the stations, *Noctilluca* densities in the upper layer, dominated the overall zooplankton abundance, with values varying at the surface between 1352.73 ind.m^{-3} and 119.04 mg C.m^{-3} and 16,081.63 ind.m^{-3} and 1415.18 mg C.m^{-3}, respectively, with a high spatial heterogeneity (CV%=105.9). Its abundances decreased significantly under the thermocline (more than 20 times) (in average: 494.05±82.13 ind.m^{-3}) (Figure 2).

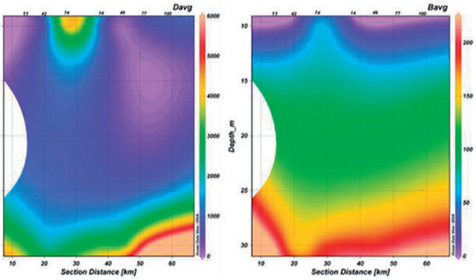

Figure 2. Spatial horizontal and vertical densities ($D_{avg.}$ - indv.m^{-3}) and biomasses (B_{avg} - mg.m^{-3}) of zooplankton in May (within the area L-35-120-D)

At that time, less than 15% of zooplankton abundance was constituted of typical thermophilic species *C. ponticus*, *Pleopis polyphemoides,* prefiguring an early development as result of sudden warming. Under the thermocline, the cryophilic copepods *P. elongatus* and *C. euxinus* with about 53% of population structure constituted of 3, 4 and 5 copepodite stages, dominated as abundance. The biomasses of ctenophore *Pleurobrachia pileus* and of chaetognat *Parasagitta setosa*, showed a proportional proliferation with those of copepodes development at a rate of 3 to 1. The meroplancton/holoplancton proportion was 22%.

In August, 21 taxa belonging to holoplankton and meroplankton and two jelly ones (*P. pileus* and *A. aurita*) were identified. The copepods with 10 species and cladocerans, with 4 species made the highest contribution to general diversity. Over 70% frequencies in the study area were given by *A. clausi*, *O. similis*, *O. davisae, C. ponticus, Evadne spinifera, P. setosa, Oikopleura (Vexillaria) dioica,* and bivalve larvae, while an incidental occurrence recorded *C. euxinus*, *P. polyphemoides*, and *Amphibalanus improvisus* larvae. *C. ponticus* attained its maximum abundances, with a maximal development of adult stages (copepodite stage 5 and females (females: male biomass ratio: 1.24) during this period. Up to 52% of total copepods abundances in some stations was formed of *C. ponticus*, while only 2 -5% by the species such as *Paracalanus parvus.* The abundances of zooplankton yielded general significant higher average abundances in the upper layer (F=18.71, df =18.15, $p<0.05$) (6730.9 ± 3390 ind.m^{-3}) than in thermocline (2902.4 ±1870.25 indv.m^{-3}), largely varying (CV% 50.37) between a maximum density in upper layer of 13678.25 indv.m^{-3} and a minimum of 639.7 ind.m^{-3}. In thermocline, it varied between 924.3 and 6797 indv.m^{-3} (CV% 64.4) (Figure 3).

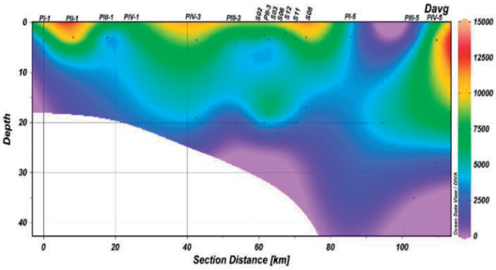

Figure 3. Spatial horizontal and vertical densities ($D_{avg.}$ - indv.m^{-3}) of zooplankton, in August 2019

The biomasses within the two layers exhibit a similar distribution, reaching an average of 126.46±73 mg.m^{-3} in the upper layer (16 - 311 mg.m^{-3}) and 55 ±44,9 mg.m^{-3} (9 – 145 mg.m^{-3}) within the thermocline (Figure 4).

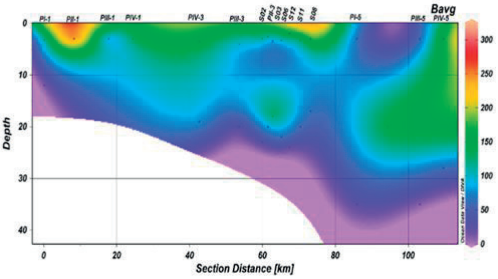

Figure 4. Spatial horizontal and vertical biomasses (B_{avg} - mg.m^{-3}) of zooplankton, in August 2019

In October, 13 holoplankton species (most abundant being: *Paracalanus parvus, Acartia clausi, Oithona davisae*) and 5 jelly ones (*N. scintilans, P. pileus, Beroe ovata, Obelia longissima, Clytia hemisphaerica*) were found in the study area.

The abundances and biomasses of the latter varied between 669 ind.m^{-3} and 58. 91 mg.m^{-3} to more than 10000 indv.m^{-3} and 940 mg.m^{-3}, respectively. The fodder zooplankton reached abundances comprised within 1, 401.70 indv.m^{-3}, and 84.40 mg.m^{-3} and 24,525.92 indv.m^{-3}, 1541.16 mg.m^{-3}, respectively (Figure 5).

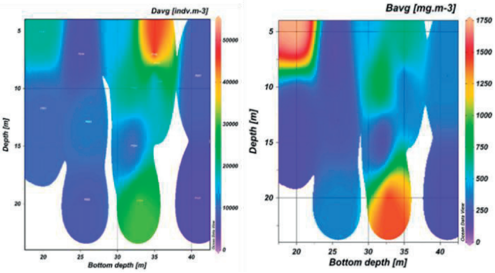

Figure 5. Spatial horizontal and vertical densities ($D_{avg.}$ -indv.m^{-3}) and biomasses (B_{avg} - mg.m^{-3}) of zooplankton, in October 2019

As result of presence of thick mixed surface water layer and lowering of thermocline at 15 m depth or more in most of the stations (except the shallower and those under direct influence of Danube stations), the zooplankton vertical distribution was relatively uniform, with marking differences both in the upper layer and thermocline in only three stations (Figure 4).

N. scintillans and jelly species contributed with 10 to 80% of total as biomass. On board observations noted an average abundance of *Beroe ovata*, *Mnemiopsis leidyi* and *Aurelia aurita,* within the neustonal layer of 5 – 32 ind.m^{-2} in average.

Species growth rates and production

The growth rates analysed as function of taxa body weight change at given temperature revealed significant (though, not statistically relevant) differences between species and seasons. Thus, considering a temperature range of 8.82°C – 26.2°C, specific growth rates of copepods species varied between 0.17 and 0.72 day^{-1}. *C. ponticus* among all reached the highest specific growth rate (0.65 – 0.71 day^{-1}) in August (the highest temperature), while in May this dropped at 0.44 day^{-1} and to 0.36 - 0.42 day^{-1} in October at similar temperature.

A. clausi, the first dominant species in all seasons, showed a variation of specific growth rates in the range of 0.12 - 0.29 d^{-1} in May, at 0.12 - 0.5 d^{-1} in August and within 0.15 – 0.28 d^{-1} in October. *P. parvus* showed comparable specific growth rates with *A. clausi,* but slightly lower. In May, the species recorded 0.17 – 0.34 d^{-1}, in August 0.51 d^{-1} (26°C) and 0.20 – 0.33 d^{-1} in October (11.6-18.73°C). In turn, *Oithona* spp. reached in May contrasting lower specific growth rates (0.06 – 0.16 d^{-1} within 8.82 - 19^{0}C range temperatures) as compared with the other copepods. However, in August, at higher surface temperature, it almost doubled the growth rate reaching a maximum of 0.4 d^{-1}.

In October, it maintained the rate in the limits of 0.09 – 0.19 d^{-1}. As for the cryophilic species *P. elongatus* and *C. euxinus* (assuming the same growth rate regression equation), it ranged between 0.17 – 0.26 d^{-1} in May and October, and between 0.47 – 0.69 d^{-1} in August. The filter feeding *O. dioica* out of all species had the highest growth rate in August, with an average of 2.05 d^{-1}, while the carnivorous *P. setosa*, 0.35 – 0.39 d^{-1} in May, 0.51 – 0.53 in August and 0.37 – 0.44 d^{-1} in October. The meroplankton taxa (bivalves, gastropods, polychaetes larvae, and barnacle) estimated growth rates varied between 0.44 – 0.55 d^{-1}, assuming a dependence of C body weights and not of temperature (Hirst et al., 2003).

The averaged total and surface layer zooplankton production was highest in August (87.22 and 78.10 mg Cm^{-3}d^{-1}, respectively). In

May and October, on the other hand, it yielded as much as 39 and 8 times lower surface production but comparable with the values from August was within the under thermocline layer (9.12 mg C m^{-3}d^{-1}) (Figure 6). To calculate the seasonal total production within the perimeters analysed, the duration of each season as shown in Porumb (1994 – 1995) (spring - 92 days, summer - 122 days and autumn - 61 days), and the water volumes within each perimeter (km^{3}), (calculated based on the area and average water column length within the perimeter) were considered. Thus, the average total production was as following: 13,538*103 tonnes for the May perimeter, 238,744*10^{6} tonnes for the August perimeter and 21,476*10^{3} for the October perimeter.

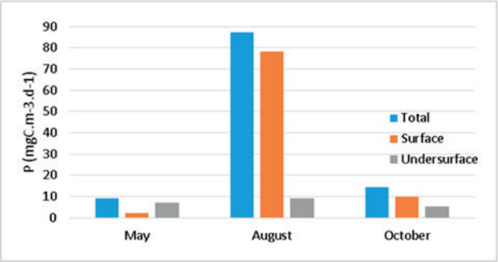

Figure 6. The zooplankton daily mean production (mgC.m^{-3}d^{-1}) of zooplankton in May, August and October 2019 on the Romanian shelf

This variability is mainly explained through the contribution of various species to zooplankton community within the periods analysed. The cladocerans (*Penilia avirostris*, *Evadne spinifera P. polyphemoides*, and *Pseudevadne tergestina*) contributed significantly to surface production (75%, 38.57 mg C m^{-3}d^{-1}).

The second important species, *O. dioica* 18.20%, 9.35 mg Cm^{-3}d^{-1}) followed by *C. ponticus* (2.42%, 1.24 mg Cm^{-3}d^{-1}) accounted for the difference to May and October surface production. During the latter, a shift in community production has been recorded, with the dominance of *P. parvus* (9.02%; 1.32 mg C m^{-3}d^{-1}) among copepods, followed by *A. clausi* (8.61%; 1.25 mg C m^{-3}d^{-1}). *O. dioica* still remained one of the most productive with 41.65%, respective 6.06 mg C m^{-3}d^{-1}. *C. euxinus*, in turn, formed in May the highest bulk of copepods production with about 9% and 1.03 mg C m^{-3}d^{-1}. However, the first ranked species was *P. pileus* with almost 60% (6.89 mg C m^{-3}d^{-1}) contribution, mostly confined within the under thermocline (Figure 7).

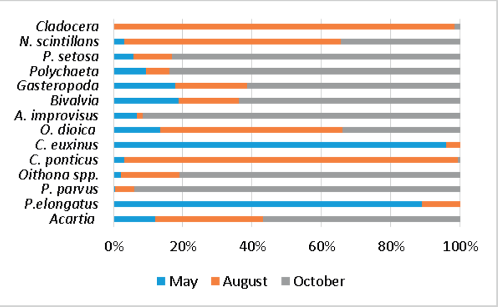

Figure 7. The contribution of zooplankton taxa to daily mean production (mgC.m^{-3}d^{-1})

The north-western shelf of the Black Sea is known as one of the most productive part of the Pontic basin and among other world marine ecosystems (Bologa et al., 1999; Demidov, 2008; Llope et al, 2011; Moncheva et al., 2014). This is mainly due to strong nutrients input from tributary rivers (Cociaşu et al., 2008; Bondar, 1989; Ragueneau et al., 2002) that trigger a high primary production almost all year round and seasonal secondary production peaks. Although several times less diverse than in other worldwide marine basins, the fodder zooplankton annually total production estimated in the early times of eutrophication (beginning of 70s) at the Romanian littoral managed to support sustainable stocks of commercially fishes. Thus, at the end of 70s, there was estimated a peak summer bulk production (without *Noctiluca*) of 2,067.90*10^{3} tonnes, of 322.64*10^{3} tonnes during spring, of 344.31*10^{3} tonnes in winter, and about nine times lower in autumn than in summer (Porumb, 1994-1995). Yet, at the same time, the dinoflagellate *N. scintillans* has become one of the dominant species, frequently overwhelming the fodder zooplankton production (Porumb, 1980, 1994 - 1995).

Similar to our study, in 80s, the species with high contribution to daily production were represented by *Acartia clausi* (1.5 mg.m^{-3}), *C. ponticus* (0.15 mg.m^{-3}), and *P. parvus* (0.18 mg.m^{-3}) in summer, and by *P. elongatus* (0.6 mg.m^{-3}) in spring (Pasternak, 1983).

After invasions of *M. leidyi* and later of *B. ovata* at the beginning of 90s, a new state has installed that led to changing of pelagic trophic web paradigm. Daskalov (2002) suggested that while the planktivorous fish reduced predominantly the stocks of bigger sized zooplankton (preferences consistent with the findings of Chouvelon et al., 2015) the new incomers took advantage of rapid development of small zooplankton. Indeed, Anninsky et al. (1998) suggested that the impact of *Mnemiopsis* is stronger on small zooplankton. Llope et al. (2011) inferred that this fact has led to a bottom –up effect, manifested through development of the new organizational trophic order at expense of the "classic" web trophic model (secondary carnivorous fish - planktivorous fish - big sized zooplankton, e.g., *C. ponticus*). The outcompeting preying capacity of jellyfish on zooplankton was also demonstrated by Opdal et al. (2019) who established a strong correlation between the food energy requirements of planktivorous fish and jellyfish before the 1976 (when jellyfish biomass started to increase), between 1977 and 2010 and after 2010. Their findings showed that in the first period, zooplankton accounted for ca. 12% of the combined fish-jellyfish energy consumption, for ca. 42% in the period after (1977–2010) and slightly declined in the recent time-period (2000–2010) to ca. 30%.

According to Vereshchaka et al. (2019), a new zooplankton evolution phase has been taking place since 2002, characterised by a strong 1-year signals (according to continuous wavelet transform analysis) of most taxa and of the total biomass and by a weak one for the *M. leidyi*. However, Stefanova et al. (2014, 2019) found a significant fluctuation of fodder zooplankton general stocks evolution in the period 2010 – 2016. Thus, by taking into consideration the proposed threshold values for the Good environmental status (280 - 550 mg.m^{-3} at coast; 300 – 130 mg.m^{-3} at shelf and 150 - 50 mg.m^{-3} at open sea) for the biomasses of trophic zooplankton, one of the quality indicators of zooplankton set for the Black Sea pelagic habitats (coastal, shelf and open waters), it was found that it failed to attain these amounts in coastal habitats in over 60% of the cases. According to the 2018 evaluation (ANPM, 2019; Muresan et al., 2019) and the present study, the fodder mesozooplankton biomass varied within 250 – 700 mg.m^{-3}, in over 80% of the coastal area sites.

Zooplankton and especially marine copepods biochemical composition was largely documented by several authors. For example, high levels of certain fatty acids like 16:0, EPA, and DHA (Sørensen et al., 2007), indispensable free amino acids, proteins (about 50% of dry weight), astaxanthin, thiamine, riboflavin, vitamin C, and vitamin E (Hapette and Poulet, 1990) in copepods are deemed essential for normal fish larval development, survival and growth, and stress tolerance (Olsen et al., 1991; Coutteau et al., 1997; Shields et al., 1999; Bell et al., 2003; Cahu et al., 2003; Hadas et al., 2003). *Oikopleura dioica* also, an abundant food resource for the planktivorous fish in the Black Sea (up to 25% of total zooplankton abundances), has the capacity to store fatty acids as high-energy droplets (Cima et al., 2002).

High stocks and good quality zooplankton prey are needed to support daily growth, survival and recruitment success of fish (Porumb, 1972; Shlyahov and Shlyahova, 2011; Plounevez and Champalbert, 1999; Nikolioudakis et al., 2012). At the Romanian littoral, there was estimated for example a monthly consume on zooplankton (including meroplankton) by *Sprattus sprattus* varying between 1,450 tonnes in April (when the species forms schools in coastal waters) to 8,000 tonnes in August. The main food items during this period are constituted of *A. clausi, P. elongatus, C. euxinus*, *P. parvus*, *P. settosa, O. dioica,* larvae of barnacles, polychaetes, and decapods (Porumb and Porumb, 1985; Glushtenko, 2011; Bișinicu et al., 2017; Mihneva, 2018). *Engraulis encrassicholus* population is able to consume up to 20% of the daily fodder plankton production of the Black Sea, while the larvae and juveniles of *Trachurus mediterraneus* may consume crustaceans up to 33% of the total wet weight of ingested food (e.g., *P. parvus, C. ponticus*), *O. dioica* (about 33% after its importance in diet) and *P. setosa* (3% also after importance), in the autumn season (Bulgakova, 1996). Other species such as *Clupeonella cultriventris*, *Atherina boyeri, Merlangius merlangus* or *Pomatomus saltatrix* feed also on zooplankton in different life stages.

CONCLUSIONS

The present data on zooplankton production and species richness distribution in spring, summer and autumn is in some respects in agreement with observations made in the 70s on the Romanian shelf. These characterized a period of ecological disruption caused by eutrophication and fish overexploitation but in the same time still productive, which is similar in many aspects with the current state. The seasonal daily growth rates of main zooplankton species along with the abundance data presented with this occasion showed a dynamic controlled by local and regional climatic variables as seen in May, August and October when the prolonged high seawater temperatures caused an enhanced primary production and blooms of *N. scintillans* and not ultimately a high secondary production of thermophilic species such as *C. ponticus, O. dioica* and cladocerans. The last decades' changes that affected the overall fodder zooplankton structure evinced its high resilient capacity so, soon after the disequilibrium occurred in the pelagic system of the Black Sea by arrival of *Mnemiopsis* and *Beroe,* has become a bottom-up regulator of trophic web. The recent literature and our own data show a slightly improvement of functional structure of trophic zooplankton, as result of decreasing or balancing of abundances of the two invasive species. As a main food source of commercially exploitable fishes in the Black Sea, the zooplankton itself should be regarded as a primary resource of the Black Sea and a good indicator of climatic changes. Keeping in mind its dietary value, the fishery productivity and management should have an integrative approach.

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