DOI: 10.55268/CM.2024.54.70

EFFECTS OF PHYSICOCHEMICAL STRESSORS ON MARINE COPEPOD POPULATIONS: A REVIEW

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ABSTRACT

Copepods are the key organisms in aquatic ecosystems; they are exposed to a variety of stressors that can significantly influence their behavior, distribution, and life cycle. Understanding how stressors influence such communities becomes a priority in marine ecology. This paper reviews the most important effects of stressors such as temperature, salinity, light, oxygen, and nutrients, and their effects on marine copepods that have been analyzed in laboratory experiments highlighting the impact of stressors on organisms. Most stressors influence the distribution and behavior of the organisms. Temperature also influences the metabolic activity, development, and reproduction of copepods; variations in salinity can affect osmotic regulation and physiological functioning, while oxygen influences the processes of respiration and metabolism. Light and nutrients also significantly impact the growth and reproduction of copepods and are essential for sustaining their populations in aquatic ecosystems. Complex interactions between multiple stressors and their effects on marine copepods are less studied. By studying the bibliography related to the experiments carried out on marine copepods and how they are influenced by the environmental factors mentioned above, I can provide a better understanding of the fact that copepods are vulnerable to environmental changes, and this information can contribute to the development of strategies effective for the conservation and management of marine ecosystems.

Keywords: marine copepods, marine ecosystem, physicochemical factors, stressors, behaviors.

INTRODUCTION

The planetary ocean is populated by the kingdoms Monera, Protista, Fungi, Plantae, and Animalia, some of which are specific to the marine environment (Pérès, 1961). Depending on their position on the globe, oceans and seas have different characteristics and very different environmental conditions (e.g. topographical, geographical, bathymetric).

Almost all of Earth's ecosystems are affected by a variety of stressors, and managing impacts on biodiversity and degradation of ecosystem services requires approaches that consider the interaction of these multiple stressors (King *et al.*, 2022).

Pelagic life is found throughout the water column, although the number of individuals and species decreases with increasing depth. Regional and vertical distributions of pelagic life are influenced by nutrient abundance and dissolved oxygen, presence or absence of sunlight, water temperature, salinity, and pressure (Fiksen, 1995). Copepods are the most abundant metazoans on Earth and have impressive short-term adaptations to environmental stressors, although they face very varied conditions in the natural environment.

The magnitude of fluctuations in physicochemical factors can affect the ability of copepods to adapt to climate change (Almén *et al.*, 2014). Given the major role of copepods in marine food webs and the functioning of ecosystems, it is good to know the limits of abiotic factors and the responses of copepod populations to the action of multiple stressors, natural or of anthropogenic origin (Almén *et al.*, 2014; Chhaba and Dabhade, 2018).

This review highlights the main stressors such as temperature, salinity, light, oxygen, and nutrients that influence marine copepod populations by affecting their distribution, behavior, and physiological functions. All these environmental factors impact copepod's metabolism and therefore are essential for their growth and reproduction in aquatic ecosystems. Most zooplankton organisms in the Black Sea are eurytherms, but in the cold period, cold-water stenothermic organisms and eurytherms are evenly spread due to the mixing of water in the oxic layer and the lack of thermocline. In the warm season (summer-autumn) the vertical distribution of zooplankton organisms is highlighted, these being influenced by thermal factors. During this warm period, the Black Sea water separates into two distinct water masses: the upper layer, with a water temperature between 19° - 30° C, and the deep layer, with a water temperature that gradually descends to 7° - 8° C. This separation of water masses with different temperatures is called thermocline (Porumb, 1995; Zenkevich, 1963).

For zooplanktonic organisms, thermocline is a delimitation of the vertical distribution of species according to thermal preferences. Eurythermic organisms inhabit the entire water column. Stenothermic organisms that prefer high water temperatures (*Centropages ponticus, Penilia avirostris, Evadne spinifera,* and *Pseudevadne tergistina*) stay in the upper layer, while stenothermic organisms that prefer low water temperatures (*Pseudocalanus elongatus, Oithona similis, Pleurobrachia pileus,* and *Parasagitta setosa*) stay in the deep layer (Porumb, 1995; Zenkevich, 1963). These species have a specific seasonal distribution, and the thermal factor is directly responsible for the vertical distribution of organisms in the water mass.

Salinity plays an important role in species distribution, especially in the vertical distribution of plankton as one of the main abiotic factors that condition aquatic life, given that its fluctuations influence the entire ecosystem. The total content of dissolved mineral salts determines the marine environment's osmotic value, which requires the osmoregulation of marine and brackish species (Ionescu and Peterfi, 1976; Lazăr, 2017). The limits of salinity values at which zooplankton species thrive are little known. The Black Sea zooplankton has species adaptable to salinity variations in its composition, allowing them to withstand brackish waters, being euryhaline species (Petipa *et al.*, 1960).

Sunlight is an essential factor in the distribution of zooplankton species, especially in deep water. Due to their phototropic character, organisms can carry out daily vertical migrations. For example, adults of the species *Calanus sp.* and copepodites in the IV-V stages of development, with the help of large fat reserves in the body, make much larger daily migrations than the young, stage II ones (Petran and Onciu, 1977, 1981).

Nutrients are chemical elements or species involved in phytoplankton production of organic matter. Some of them are regenerated several times in the water column, while other parts are sediments. In general, vertical nutrient transport is less efficient than gravitational force, so concentrations increase with depth (Lazăr, 2017).

Copepod species have different distribution strategies in response to the current variability of water in vertical profiles. Species that have changed their vertical distributions and abundance are associated with the area's depth and intensity of maximum oxygenation. Copepods have adjusted their vertical migration by preferring the upper horizon of water at night, changing the depth where they can enter the diapause phase, or extending/narrowing their depth range in the mixed water layer (Wishner *et al.*, 2020).

Nutrient variability may be altered by natural and anthropogenic pressures on the marine environment. Thus, through changes in wind, wave, and current regimes together with those of the hydrological regime of the Danube, high concentrations, even extreme, of nutrients reaching the surface layers through upwelling or increased freshwater intake can occur (Băcescu *et al.*, 1965; Lazar *et al.*, 2018). Zooplankton, as a community of heterotrophic organisms, is indirectly influenced by nutrient intake through changes in phytoplankton. However, zooplankton is an essential element in the regeneration of nutrients in the water column by removing ammonium as the main product of excreted nitrogen (Valdés *et al.*, 2018). Thus, zooplankton through excretions produces nitrogen compounds available to nitrifying communities in the surface layer, which in turn contribute with oxidized inorganic nitrogen to the primary productivity of the system (Zehr and Ward, 2002), moreover, the effects of copepod excretions are not limited to the upper layers (Escribano *et al.*, 2009).

Therefore, influencing the impact of multiple stressors is an important aspect of ecology with significant investigations revolving around potential interactions between them. The uncertainty is whether and how these stressors might influence each other. When two stressors work simultaneously, they can increase their individual effects, resulting in a synergistic interaction. In such cases, their combined effects exceed what would be anticipated from their impacts (Burgess *et al.*, 2022; Lafferty and Holt, 2003).

This review aims to explore the responses of copepods to various environmental factors, particularly when these factors shift and become stressors for marine copepod populations. Specifically, it focuses on laboratory experiments that investigate how changes in physicochemical conditions affect copepods. The review synthesizes the findings from these experiments, highlighting the responses of marine copepods to these environmental changes. Additionally, it identifies gaps in the current literature, particularly in studies related to copepods from the Black Sea, where research on these stressors is limited. Based on this analysis, the review suggests the need for further experimental work to better understand how these environmental factors can become stressors under suboptimal conditions, potentially impacting copepod survival and population dynamics.

RESULTS AND DISCUSSION

The role of copepods in the marine ecosystem

The pelagic trophic network (Fig. 1) plays a central role in regulating the exchange of CO_2 between the atmosphere and surface waters, as well as in the transfer of deep-sea organic carbon. Within the food web, zooplankton serve both as trophic links between primary producers and higher trophic levels and as recyclers that convert carbon particles and nutrients into solutes (Steinberg and Landry, 2017).

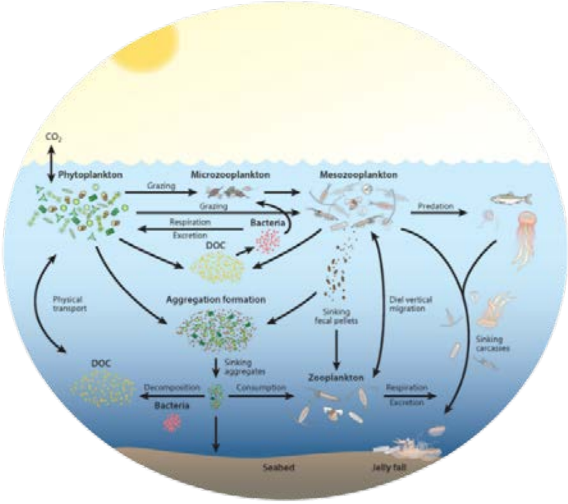

Fig. 1. Diagram of the food web, at the level of marine plankton (Steinberg & Landry, 2017)

The food that small copepods eat (ex. Centropages spp., Temora spp., Acartia spp., Pseudo/Microcalanus spp., < 1 mm length) is less well known than that of larger copepod species, such as members of the genus Calanus. In addition, most of the information on how to feed small copepods is from coastal areas such as Acartia sp., versus offshore taxa. Although it is generally assumed that small copepods, including nauplii, feed primarily on small phytoplankton, most of this information comes from laboratory studies of growth or feeding (Turner, 2004). These size categories are functionally diverse assemblies, comprising several trophic levels with complex feeding relationships (Sanders and Wickham, 1993; Steinberg and Landry, 2017).

In the euphotic zone, phytoplankton takes up CO2 through photosynthesis, being consumed by herbivorous micro and mesozooplankton. In the food chain, microzooplankton are the major prey of mesozooplankton. Organic carbon in the form of phytoplankton particles is inhaled by zooplankton in the form of CO2 and excreted as dissolved organic carbon, which is used by phytoplankton or bacteria to feed the microbial loop. Organic carbon in the form of particles from mesozooplankton is transferred further into the food web by higher-level predators. Mesozooplankton and its predators ingest faeces that sink into the water. Vertical migrators feed in surface waters at night and metabolize compounds they have invested in the mesopelagic zone during the day and seasonal vertical migrations. In this way, zooplankton and bacteria in the mesopelagic zone ingest and metabolize sinking organic carbon particles, which leads to attenuation of particle accumulation in the substrate (Fig. 1).

Dissolved organic particles can also come from exuvium or dead copepods, as well as macrozooplankton blooms, which produce large amounts of particulate organic matter on the substrate (Fig. 1). The dissolved organic carbon produced by phytoplankton and zooplankton in surface waters is exported to the mixed layer by advection (Fig. 1). Advection, particle sinking, and vertical migrations perform the "biological carbon pump," biological processes that mediate the transfer of carbon and nutrients from the ocean surface to depth through vertical migrations of zooplankton (Lebrato and Jones, 2011; Steinberg and Landry, 2017).

The influence of climate change on copepods

Recent studies have reported changes in copepod communities in response to climate and anthropogenic change, changing species diversity and abundance, geographical distribution, and occurrence by season (Keister *et al.*, 2012).

Zooplankton species are bioindicators sensitive to disturbances in the natural environment. The Marine Strategy Framework Directive states that zooplankton can be used to highlight environmental changes and anthropogenic influences, such as chemical pollution in the marine environment (Lomartire *et al.*, 2021).

Copepods have the potential to act as a biological malaria control mechanism by eating mosquito larvae. However, copepods serve as an intermediate host to many parasites that are transmitted further down the food chain (Walter & Boxshall, 2022). A potential factor in the abundance of fish stocks is the abundance of zooplankton (the main food source of fish), especially the abundance of copepods (Lomartire *et al.*, 2021).

Considering the size of the planetary ocean and its capacity to assimilate heat, a huge amount of thermal energy is needed to increase the average annual temperature on Earth's surface. An increase in global average temperature (Fig. 2) has been taking place since pre-industrial times (1880-1900), and the heat assimilated by the terrestrial and aquatic environment is felt over time. Since 1980, there has been a steady increase in the global annual average temperature (Lindsey *et al.*, 2020).

In the context of anthropogenic change, plasticity is important because opportunities for dispersal and adaptation are often limited. The anthropogenic impact is so rapid that evolutionary processes are constantly changing globally. Animals can respond to environmental change in three key ways: dispersal, phenotypic adjustment, or adaptation to changes in environmental conditions (Beaugrand *et al*., 2010; Chen *et al*., 2012; Wong & Candolin, 2015).

Phenotypic changes induced by anthropogenic activities are generally greater than those related to natural environmental variation, therefore the adaptation of organisms is largely due to phenotypic plasticity and not genetic evolution (Beaugrand *et al*., 2010; Chen *et al*., 2012; Wong & Candolin, 2015).

Any event that causes changes in organisms can be classified as a stressor. These stressors could include lack of food, increased density pressure, predator pressure, climatic events, or anthropogenic causes. Although most physiological systems are affected by stress, the systems that regulate reproductive physiology and behavior are the most sensitive (Steinberg & Landry, 2017; Williams *et al.*, 1994; Wong & Candolin, 2015).

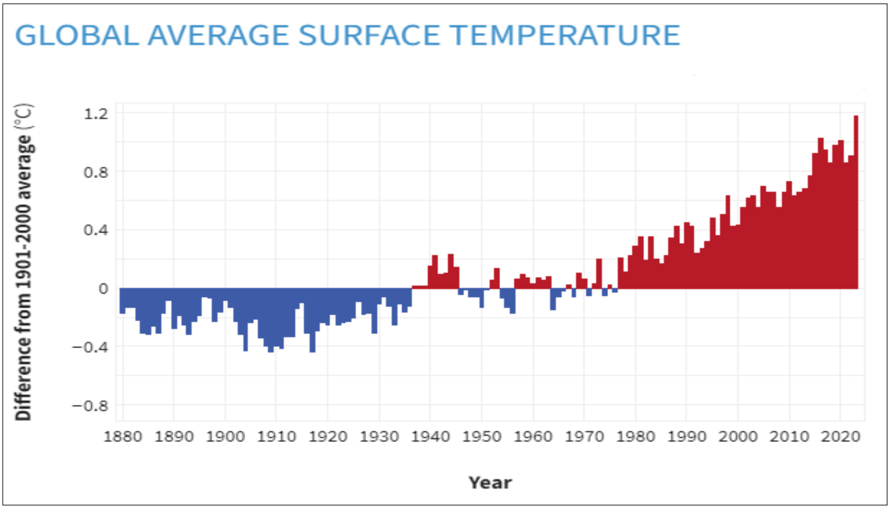

Fig. 2. Annual temperature of the earth's surface compared to the average of the twentieth century in 1880–2020 (blue - cooler than average years, red - warmer than average years), (Lindsey *et al.,* 2020)

Long-term changes in epipelagic zooplankton abundance, distribution, and community structure in many regions are attributed to global warming, with associated changes in the carbon cycle. In the North Sea, rising sea surface temperatures have led to a long-term decline in the subarctic herbivorous copepod *Calanus finmarchicus* accompanied by a long-term increase in phytoplankton (Beaugrand *et al.*, 2010; Steinberg and Landry, 2017).

Thus, a warming ocean has a multitude of potential effects, either directly, acting on feeding rates, metabolism, growth, and reproduction, or indirectly through changes in surface water stratification and vertical mixing that affect zooplankton migrations and prey (Kjellerup *et al.*, 2012) and phytoplankton consumption resulting from other autotrophic and heterotrophic processes at certain temperatures (Brown *et al.*, 2004; Chen *et al.*, 2012; Rose and Caron, 2007; Steinberg and Landry, 2017).

Stressors acting on copepods

1. *Temperature*

The effects of temperature on embryonic development time, egg hatchability rate, and productivity, have been demonstrated in many copepod species (Beyrend-Dur *et al.*, 2011). Temperature acts directly, influencing the structure of copepod populations through changes in metabolism and energy balance, which in turn affects the growth and reproduction of organisms (Kjellerup *et al.*, 2012).

Temperature can also affect metabolic processes related to oxygen consumption (Abdullahi, 1990; Ban, 1994; Roddie *et al.*, 1984), which in turn affects the ability of organisms to resist environmental changes, leading to excessive use of proteins decreasing survival rate (Klein Breteler *et al.*, 1995).

Thus, a change in the composition of mesozooplankton, if the water temperature rises earlier (in the spring season) than usual, affects secondary producers (Kjellerup *et al.*, 2012).

Studies on fat-rich species such as *C. finmarchicus* and *Calanus glacialis*, tested at temperatures between 0 to 10 °C, have shown that an increase in temperature and the availability of food can produce changes in mesozooplankton composition, such as changes in the density and biomass of copepod populations in this case, which may become dominant due to increases in temperature values in their habitat (Karnovsky *et al.*, 2010; Kjellerup *et al.*, 2012).

Other studies conducted over various temperature ranges (from 10 to 35 °C) demonstrated that prolificacy and reproduction rate increased as the temperature increased, but these values decreased when the temperature exceeded 30 °C. Therefore, the optimum breeding temperature and average hatchability rate varied between 25 and 30 °C (Li *et al.*, 2009; Milione and Zeng, 2008). As the temperature rises, the development time required for each larval stage's evolution decreases, the development pace increases, and the survival rate increases with increasing temperature. (Li *et al.*, 2009).

Water temperature acts on copepod metabolism by inhibiting productivity, modifying the reproductive period, feeding), influencing the life cycle of species, generating differences in zooplankton densities and biomass (Porumb, 1995).

Analysis of quantitative zooplankton data, correlated with temperature, revealed that changes in biological components accompany temperature variation. There have been periods when temperature variations (water heating) have occurred in winter in different years. Thus, between 1973 and 1986, temperature values higher than multiannual averages were recorded, thus influencing the metabolism of zooplankton organisms, and favoring their multiplication. This phenomenon is explained by the fact that with increasing temperature, the number of days, and degrees necessary for reproduction accumulates faster, and the process of reproduction of species begins earlier, and their abundance increases in early spring, reaching a maximum of development higher than summer or autumn values (in 1974), even 6-7 times more (Porumb, 1995).

Research on marine copepods has demonstrated a 43.9% reduction in body size across the context of global warming. This finding implies that smaller copepod species may become increasingly predominant (Bișinicu *et al*., 2023; Campbell *et al*., 2021).

In conclusion, the temperature factor is the decision-making factor in the life of copepods, because temperature values influence the hatchability rate, reproduction rate, development time, survival rate, and feeding rate producing changes in metabolism, and under adverse conditions diapause sets in.

2. Salinity

According to the Venice classification ("The Venice System for the Classification of Marine Waters According to Salinity", 1958), The waters of the Black Sea are characterized by a brackish, mesohaline, variable salinity water, lower in the northern area under the direct influence of the Danube. With an average salinity of 17–18 g/L, the salinity of the Black Sea is influenced by low-salinity surface waters, freshwater intake from rivers, precipitation, evaporation, and upwelling, which overlay deep, high-salinity waters of Mediterranean origin, and persistent pycnocline (Lazar *et al.*, 2024). The winds from the N and NE are dominant, bringing freshwater masses, and those from the S and SW increase the salinity of the water through the upwelling phenomenon (Băcescu *et al.*, 1965). Stratification of water masses, a phenomenon specific to the Black Sea, determines the salinity increase in the water column reaching up to 22 - 23‰.

Salinity plays an important role in species distribution, especially in the vertical distribution of plankton, as one of the main abiotic factors that condition aquatic life, given that its fluctuations influence the entire ecosystem. The total content of dissolved mineral salts determines the osmotic value of the marine environment which requires osmoregulation of marine and brackish species (Ionescu and Peterfi, 1976; Lazăr, 2017).

In the Black Sea, salinity variations result from the Danube's freshwater intake. The Black Sea receives an average annual volume of 400 km^3 of water, of which the Danube alone accounts for about half the quantity (Chirila, 1965). The winds create currents that mix marine and fluvial water masses by driving them in different directions, alter temperature and salinity and directly influence the life of organisms through physicochemical changes in water producing qualitative and quantitative changes in plankton composition (Chirila, 1965).

The limits of salinity values at which zooplankton species thrive are little known, because the Black Sea zooplankton has in its composition species adaptable to salinity variations, allowing them to withstand brackish waters, being euryhaline species (Petipa *et al.*, 1960).

Unlike the general response to temperature variation, changes in salinity can exert a relatively weak influence on the duration of larval development with strong effects on survival rate, and developmental delay is usually detected only under conditions of extreme salinity (Anger, 2003). An ecologically important example, salinity in combination with other stressors such as various pollutants reduce organisms' tolerance to salinity (Anger, 2003).

Migratory copepods adapt to frequent changes in the environment, including pH, temperature, salinity, oxygen, and light. In coastal ecosystems, rapid salinity variability is a major challenge for marine life. Especially in the coastal area of the Romanian coast, where the Danube meets the Black Sea, marine organisms can experience sudden fluctuations in salinity due to various processes, such as increased flow of the Danube, mixing water following storms, or the action of sea currents. These phenomena may be most pronounced during spring when the Danube brings a significant amount of freshwater, enriched with nutrients. However, the lethal effects of these changes on copepods have been insufficiently studied. Variations in pH can cause significant physiological constraints, especially when the environment becomes acidified, approaching the survival limits of these organisms (Almén *et al.*, 2014; Steinberg and Landry, 2017).

Research on copepod species, such as *Acartia clausi, Oithona nana,* and *C. ponticus*, indicates a higher tolerance to salinity variations, being found both in the Danube Delta and in the south of the Romanian seaside (Porumb, 1975).

In contrast, species such as *P. elongatus* and *O. similis* show less tolerance to salinity variations and are more common in waters from the southern part of the Romanian coast (Porumb, 1975) are present in large numbers below the thermocline, where also meet populations of *Calanus euxinus,* where the temperature is lower and salinity is higher, and the values are constant (Porumb, 1975).

The *Acartia tonsa* copepod, a ubiquitous and dominant species in aquatic environments, stands out for its ability to rapidly convert ingested food into organic compounds, being essential for the organic matter cycle in marine ecosystems (Turner *et al.*, 1999). This species stores only small amounts of lipids and quickly ceases growth without food. Studies by Calliari *et al.* (2008) revealed that *A. tonsa* and *A. clausi* are subject to sudden changes in salinity, with varying results. These experiments were designed to simulate the extreme conditions to which copepods can be subjected in natural environments, such as sudden variations in salinity in estuaries or areas affected by freshwater intrusion. Thus, following a shock of 32 to 4 PSU, *A. tonsa* recorded a mortality of 31%, while *A. clausi* suffered a mortality of 22% a decrease from 32 to 14 PSU. The results indicate that *A. tonsa* is more susceptible to extreme conditions than *A. clausi* (Calliari *et al*., 2008; Cervetto *et al*., 1995). Sudden decreases in salinity appear to be less lethal for copepods compared to sudden increases. Furthermore, changes in salinity can inhibit feeding rates, with implications for energy accumulation and organic matter transfer in marine ecosystems. The adaptation of copepods to variations in salinity involves complex mechanisms such as osmoregulation and anisosmotic regulation of cellular fluids (Calliari *et al*., 2008; Pequeux, 1995).

They are species that can survive in a wide range of salinities, such as *A. tonsa,* with the ability to withstand short-term extreme values, both low and high, between 1 and 72 PSU (Cervetto *et al.,* 1999; Hansen *et al*., 2012). This species usually lays its eggs in the upper layers of water, where pycnoclines are formed, which are areas characterized by significant differences in density between surface and deep waters (Anger, 2003; Cervetto *et al*., 1999; Hansen B. *et al.,* 2012; Hansen J. *et al*., 2010). The effect of salinity on *A. tonsa* eggs was studied in a range from 0 to 76 PSU. The volume of eggs underwent immediate changes, increasing from 2.8 x 105 µm3 at 35 PSU to 3.8 x 105 µm3 at 0 PSU, returning to its original size when salinity was returned to 35 PSU. These results suggest that eggs are unable to regulate their volume or osmoregulation when subjected to salinity changes (Anger, 2003; Hansen *et al*., 2012).

Gradual changes in salinity did not affect embryo hatchability, but exposure to extreme hypersalinity, e.g. 72 PSUs, for one hour resulted in eggs exploding and embryo death (Fig. 3). Contrary to these results, some previous studies have shown that *A. tonsa* eggs in certain areas were able to withstand hypersalinity levels (50 and 75 PSU) even for periods of up to 20 minutes (Anger, 2003; Hansen B. *et al.,* 2012).

Hatchability of eggs exposed to extreme salinities, such as 50, 60, and 70 PSUs, has been observed in a few cases, but nauplii died soon after hatching. This phenomenon is like that of adults of *A. tonsa*, who die when exposed to changes in salinity by more than 10 PSU units (Anger, 2003; Hansen B. *et al*., 2012).

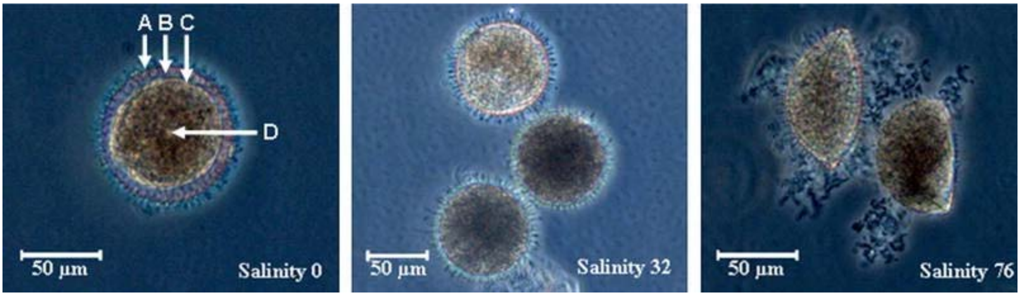

Fig. 3. Eggs of the copepod A. tonsa are exposed to sudden and substantial changes in salinity A - yolk-shell and chorion shell, B - perivitelin space, C - plasma membrane of the egg and D – embryo (Hansen B. *et al*., 2012)

Hatching can occur at lethal salinity levels when embryogenesis is complete, but subsequent nauplii death at extreme salinities suggests that the embryo cannot detect salinity changes in the natural environment or that the embryo does not exhibit osmoregulation within the plasma membrane (Højgaard *et al*., 2008).

The experiment conducted by Chen *et al*. (2006) for 10 days at four different salinity levels (5, 10, 15, 20 PSU) revealed that *Pseudodiaptomus annandalei* exhibits the highest hatchability and survival rate of nauplii (98%) at a salinity of 15 PSU. However, the hatchability of eggs of this species is strongly affected by salinity changes, being normal between 15 and 20 PSU, but much more difficult at 35 PSU. Even under these conditions, only one nauplius survived for 10 days at 35 PSUs, and a few dead nauplii could occasionally be observed on the bottom of the vessel, indicating that embryos can develop but cannot survive in seawater with 35 PSU (Chen Q. *et al*., 2006).

Studies of *Eurytemora affinis* in the Seine Estuary have shown that this species is most common in areas with low salinity (2-15 PSU). The reproductive parameters of adult females and males were adversely affected by high salinity and low temperatures (Chen Q. *et al*., 2006). Postembryonic mortality was particularly high at temperatures of 10°C and salinity of 25 PSU. Reproduction was more efficient in the salinity range of 5-15 PSU, with small variations in mortality. The high reproductive potential of the species at temperatures of 15 °C and low salinity explains its high density during spring and early summer (Devreker *et al*., 2012; Mouny and Dauvin, 2002).

The optimal salinity for breeding these species is 15 PSU, with a maximum daily reproduction and hatchability rate. Further analysis demonstrated that females had a higher tolerance to salinity variations than males. Climate change and anthropogenic impacts can influence salinity and nutrient concentrations, intensifying the effects of eutrophication. When copepods are exposed to sudden variations in salinity, their metabolism slows down, hatching is inhibited, and mortality increases.

In conclusion, salinity influences the osmoregulation of copepods, influences feeding that affects energy accumulation at the individual level, vertical species distribution in the water column, hatchability, and survival rate. Various pollutants reduce the tolerance of organisms to the saline environment and combined with temperature changes increase the mortality rate. Therefore, sudden increases in salinity are much more lethal than decreases. For example, the hypersaline water caused the eggs of the species *A. tonsa* to explode, while in the case of hyposalinity, the eggs swelled and did not hatch.

3. Light

The sunlight plays a crucial role in the adaptation and behavior of aquatic organisms, especially copepods, by influencing vertical migrations, phototropic behavior, circadian rhythm, and even physiological processes. Sunlight is a highly variable environmental factor with significant short-term (24-hour) change (Porumb, 1995). This variation influences the distribution of organisms according to the phototropic character of the species (Porumb, 1995). It is mentioned that some copepod species, such as *Calanus sp.,* perform larger daily vertical migrations due to body fat reserves compared to smaller species (Petran and Onciu, 1977, 1981).

Vertical migrations are influenced by biotic factors such as food availability and the stage of development of organisms, on the other hand, light stimuli influence the behavior of copepods on a small scale (Waggett and Buskey, 2006). Some organisms use light to maintain their upright position, others exhibit positive phototactic behavior by orienting themselves towards light, while others exhibit a negative response to light. Furthermore, it is highlighted that constant light can inhibit the growth, and reproduction of aquatic organisms, having negative effects on their activity (Cohen and Forward, 2002), for example, *Centropages typicus, Calanopa americana,* and *A. tonsa* have nictemeral migration, and *Anomalocera ornata* have diurnal migration. The species *Labidocera aestiva* does not respond to light and tends to remain on the same horizon (Cohen and Forward, 2002).

Changes in light regime affect endocrine activity, influence aspects such as the life cycle of these organisms: the reproduction, development, egg production, hatching, moulting, and death of copepods. A specific study by Farhadian *et al*., (2014) showed that intensity and light regimes can influence the hatchability and development processes of copepods (Farhadian *et al*., 2014; Miliou, 1992). It was observed that lower light intensity led to a higher hatchability rate and shorter development time, and certain light regimes had beneficial effects on growth and production (Farhadian *et al*., 2014) these organisms (*Apocyclops dengizicus)*. The light factor is an essential aspect in the ecology and adaptation of copepod species, impacting both behaviorally and physiologically and regulating their life cycle.

In conclusion, sunlight has a significant impact on zooplankton species, influencing their distribution in water mass, daily behavior, and vital processes.

Adaptations to changes in light are essential for copepods to survive in their aquatic environment.

4. Oxygen

Oxygen is considered the most crucial and representative of all gases dissolved in water, playing a significant role in assessing the functionality of these ecosystems (Horne, 1969; Lazăr, 2017; Peres, 1961, 1963; Riley and Chester, 1971).

Dissolved oxygen concentrations and fluctuations are essential in assessing the impact of eutrophication and other forms of pollution on marine ecosystems. The variability of the oxygen regime, expressed over different periods (annual, seasonal, daily), depends on several factors acting simultaneously. Factors contributing to dissolved oxygen enrichment include the regime of currents and winds, photosynthetic processes of marine vegetation, and contact with the atmosphere. On the other hand, some factors reduce dissolved oxygen concentrations, such as contact of supersaturated water masses with the atmosphere, biological and chemical processes involving oxidation reactions, and stratification of water masses (Horne, 1969; Lazăr, 2017; Peres, 1961, 1963; Riley and Chester, 1971).

The decrease in oxygenation levels of ocean waters, including the expansion of areas with minimal amounts of oxygen, is attributed to global warming. Forecasts indicate that in the future, deep ocean areas with low oxygen will have even lower concentrations than at present (Breitburg *et al*., 2018; Levin, 2018; Wishner *et al*., 2020).

The mesopelagic mixed layer zooplankton community plays a crucial role in ocean ecosystems by being sensitive to oxygen concentrations in the environment. Mesopelagic species adapt to oxygen variability by altering their distribution patterns. The expansion of low-oxygen areas could affect the distribution and abundance of these species, with potential consequences for ocean ecosystems (Robinson *et al.,* 2010; Steinberg and Landry, 2017).

Copepod species adjust their distribution strategies according to the variability of vertical oxygen profiles. These adjustments include changes in vertical distributions and migration depths depending on the intensity of water oxygenation (Robinson *et al*., 2010; Steinberg & Landry, 2017).

In conclusion, zooplankton are essential for the balance of marine ecosystems, being sensitive to oxygen levels in water and playing a key role in adapting them to oxygen variations. Changes in the distribution and behavior of zooplankton species, such as copepods, in response to changes in oxygen concentration.

5. Nutrients

Essential nutrients such as phosphorus, nitrogen, and silicon are efficiently extracted from seawater and incorporated into the cells of marine organisms. Vertical nutrient transport can be influenced by natural and anthropogenic pressures, such as changes in wind, wave, and current regimes, or by increased freshwater intake. Human activities, such as the use of agricultural fertilizers or wastewater discharges, can lead to excessive nutrient introduction into the marine environment, leading to eutrophication, with negative consequences for the marine ecosystem (Băcescu *et al*., 1965; Lazar *et al*., 2018).

Phytoplankton, through its photosynthetic activity, converts nutrients into organic compounds essential for the development of marine organisms. Thus, phytoplankton are a vital component of the marine ecosystem, ensuring primary productivity and sustaining marine food webs (Gomoiu, 1992).

Zooplankton are indirectly influenced by nutrients through phytoplankton changes but also regenerate nutrients in the water column by removing ammonium. These excretions contribute to the availability of nitrogen to other marine communities, influencing the primary productivity of the ecosystem. Some species of copepods can migrate to low-oxygen areas, thus providing a source of ammonium for these environments. The diet of zooplankton influences the type of compounds released through excretion, and the absence of an adequate nutrient source can affect the development and reproduction of populations (Bianchi *et al*., 2014; Escribano *et al*., 2009; Valdés *et al.*, 2018; Zehr & Ward, 2002).

Anthropogenic pressures, such as the introduction of nutrients from agricultural, industrial, and urban activities, have a significant impact on the marine environment. Excessive intake of nutrients can lead to eutrophication of water, generating negative consequences such as reduced water transparency, decomposition of dead organisms, and oxygen consumption. These changes can directly affect both phytoplankton and zooplankton, altering the species composition and ecological balance of the marine ecosystem (Commission on the Protection of the Black Sea Against Pollution, 2007; Lazăr, 2017; Programme Coordination Unit UNDP/GEF Assistance, 1999).

In conclusion, phytoplankton and zooplankton are two essential components of the marine environment, and understanding their interactions and how they are affected by environmental pressures is crucial for the conservation and management of marine ecosystems.

6. Oxidative stress on copepods

Zooplankton, especially copepods, can adapt to variability in coastal environmental conditions and are relatively resistant to extreme variations in temperature, oxygen, and pH. This adaptability is due, in part, to an efficient glutathione recycling system, which functions as an antioxidant defense system against oxidative stress. However, high levels of oxidative stress can negatively affect copepod tissues, influencing their survival and reproduction rate (Glippa *et al.*, 2018).

Zooplankton can be indirectly affected by environmental factors such as salinity fluctuations, hypoxia, and ultraviolet radiation. These factors can cause oxidative stress in marine organisms, generating the production and accumulation of intermediates containing oxygen in reduced form, damaging lipids, proteins, and DNA (Lesser, 2006).

High anthropogenic impacts may intensify these negative effects, leading to decreased egg production rates and increased oxidative stress in copepod populations (Martínez *et al.*, 2017). For example, in areas with high anthropogenic impact, higher levels of oxidative damage occur among copepod species (Glippa *et al.*, 2018).

In conclusion, nutrients and environmental factors significantly influence zooplankton populations, and understanding these interactions is essential for the conservation and proper management of marine ecosystems.

This analysis of review draws upon bibliographic sources detailing laboratory experiments that investigate the effects of altered survival conditions in experiments on marine copepods. The review emphasizes both the key findings, and the knowledge gaps identified in the existing literature. To address these gaps, environmental factors and copepod life history traits were examined in conjunction with how these factors can, under certain conditions, act as stressors. Given the limited availability of studies on laboratory experiments on Black Sea marine copepods in the existing literature, I propose to carry out additional experiments in the future to examine how specific environmental factors can become stressors when conditions deviate from optimal for these populations.

CONCLUSIONS

Temperature emerges as a pivotal factor shaping the life cycles of copepods, impacting various vital parameters such as hatchability, reproduction, development, and survival rates. Salinity, on the other hand, plays a crucial role in osmoregulation, feeding behavior, and tolerance to pollutants, with hypersalinity proving particularly detrimental to certain species. Sunlight influences zooplankton distribution and behavior, highlighting the necessity of adaptations for survival.

Zooplankton, especially copepods, are crucial for marine ecosystem balance, particularly in oxygen distribution. Understanding the intricate interplay between phytoplankton, zooplankton, and their environment is paramount for effective conservation and management strategies. Nutrients and environmental factors exert significant influence on zooplankton populations, underlining the importance of comprehending these dynamics for marine ecosystem conservation.

Acknowledgement. I would like to thank Professor Dr. Geta Rîșnoveanu, from University of Bucharest, Romania, who is my PhD coordinator and who guided me in structuring the chapters of this review.

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