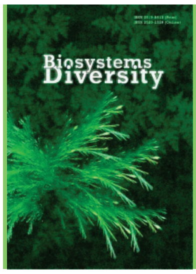

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Zooplankton in the zones of transformation of river runoff in the north-western Black Sea region and the Mediterranean Sea in 2017–2020

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Estuary zones play a key role in the regulation of the impact of continental processes on marine ecosystems. The zone "river–sea" is a unique area with specific conditions, geochemical and biological processes. They belong to the so called "ecological hot spots" and that is why their research is especially needed to understand possible changes in the ecosystems. In the present study we described the spatial distribution of zooplankton in the zones of transformation of river runoff in the Ukrainian part of the north-western Black Sea region and the Turkish coast of the Mediterranean Sea in 2017–2020. In the Black Sea, samples were collected from the coast of the Odesa Marine Region, Danube Region and coastal waters between Dnipro-Bug estuary and Yuzhne town. On the Turkish Mediterranean Sea coasts, samples were collected between Antalya city and Patara village (Mugla province). A total of 64 samples of the zooplankton were studied. We did not establish a direct dependence between zooplankton biomass and annual volume of river runoff (correlation between these metrics is from –0.25 to –0.80). 20 taxa of zooplankton in the Odesa Marine Region, 21 taxa in the Danube Region, 11 taxa in the Dnieper Region, 23 taxa in the Turkish coastal zone of the Mediterranean Sea were registered. Species of forage zooplankton were dominant over non-forage ones in all seasons and all investigated aquatoria. The percentage of *Noctiluca scintillans* (Macartney) Kofoid & Swezy, 1921 and jellyfish did not exceed 5% of the total biomass of zooplankton. In summer in the Black Sea, the majority of zooplankton by number and biomass was formed by organisms of meroplankton, species of Cyclopoida and Harpacticoida, in autumn – species of the genus *Acartia*, *Oithona davisae* Ferrari F. D. & Orsi, 1984, larvae of Cirripedia and *Penilia avirostris* Dana, 1849. The number and biomass of adults and Copepodid Stages of *Acartia* species increased from spring to autumn in all years. In populations of *Acartia* species Copepodid stages predominated over adults by number and biomass in all seasons. In the Mediterranian Sea, the majority of zooplankton by number and biomass was formed by larvae of benthic invertebrates and Copepoda. The abundance and biomass of zooplankton at a distance of 300 m from the river mouth were greater than directly at the mouth. The hydro-front was expressed near all investigated rivers, the maximum values of zooplankton number and biomass were observed here and they decreased in direction both towards the mouth of the river and towards the open sea.

Keywords: zone "river-sea"; genus *Acartia*; *Noctiluca scintillans*; Copepoda; Cladocera.

Introduction

Zones of contact of rivers and marine water play an important role in the marine ecosystems and belong to the so called "ecological hot spots" (Zaitsev, 1992; Zaitsev & Alexandrov, 1997; Onuchin et al., 2006; Ludwig et al., 2009; Irina et al., 2020). These zones are characterized by specific environmental conditions, unique geochemical and biological processes, which largely determine the influence of freshwater runoff on adjacent aquatoria, biological productivity, and form the most important properties of nearest pelagic and benthic communities (Gordeev et al., 1996; Flint et al., 2010; Osadchiev & Korshenko, 2017; Gordeev et al., 2022; Pasternak et al., 2022; Zhang et al., 2023; Sani et al., 2024). Anthropogenic impact of various types, which leads to eutrophication and pollution of water bodies, changes the basic characteristics of all components of the aquatic ecosystem. One of the most important components, structurally and functionally related to others, is the zooplankton (Alexandrov & Zaitsev, 1998; Bat et al., 2009; Alexandrov, 2017). Zooplankton, being the major consumer of the primary production, constitute the food source of organisms at higher trophic levels, including those of high economic value (Kovalev et al., 2001; Vinogradov et al., 2006; Alexandrova et al., 2007; Venkataramana et al., 2017). Ecological researches are a mandatory part of the study of the Ukrainian part of the Black Sea. Such studies are especially relevant for the marine coastal zones due to its geological structure, an extraordinary variety of natural processes and a strong anthropogenic impact (Zaitsev, 1992; Micheli et al., 2013). Environmental impact assessment is usually defined as a mandatory assessment procedure that analyzes and evaluates the impacts that human activities can have on the environment (Moncheva et al., 2002, 2012; O'Higgins et al., 2014). The goal of the other study was to describe structural and functional parameters of zooplankton communities in the different zones of transformation of river runoff of the Ukrainian of the Black Sea and Turkish waters of the Mediterranean Sea, their seasonal and interannual changes.

We suppose that there is no direct correlation beetwen zooplankton biomass and annual volume of river runoff. Maximal influence of river runoff on zooplankton development shoud be in the zone of hydrofront irrespective of the size of the river and its geographical position. Long-term tendencies of changes in the zooplankton community are the same in different zones of transformation of river runoff.

Materials and methods

Samples were collected and processed using standard methods (Alexandrov & Kharytonova, 2019). Zooplankton samples were taken from the aqutories of the Odessa beaches ("Luzanivka", "Langeron", "Dolphin" and "Hydrobiological station"), from Mys Adzhyyask, from the Danube Region, the Tiligul estuary (Fig. 1) and from the Mediterranean Sea near the village Adrasan and Demre town (Fig. 2). On the Mediterranean coast samples were taken from the mouth of each river and 200–300 m from it. In Adrasan and near Demre on December 2019 the sea hydro-front zone was clearly visible less than 500 m from the shore. Here samples were taken at the distance of 100 m from the river mouth, at the hydro-front and 100 m from it in the direction to the shore (Fig. 3). Information of zooplankton collected samples is shown in Table 1.

Fig. 1. Zooplankton sampling stations in the north-western part of the Black Sea: numbers of stations in Odesa Marine Region: *1* – Luzanivka, *2* – Langeron, *3* – Dolphin, *4* – Hydrobiological station

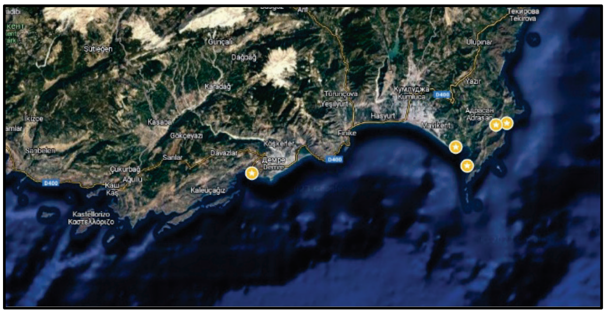

Fig. 2. Zooplankton sampling stations from the Mediterranean coast

Table 1
Zooplankton sampling

Sampling areas	Months of sampling	Number of samples collected
Luzanivka	02–07.20; 09–10.20	8
Langeron	02–07.20; 09–10.20	8
Dolphin	02–07.20; 09–10.20	8
Hydrobiological station	02–07.20; 09–10.20	8
Tiligul estuary and the adjacent part of the sea	06.2020	7
Danube Region	07.2020	4
Mys Adzhyyask	06.10.2020	8
Mediterranean coast	12.2019; 01.2020	18
Total samples	64	154

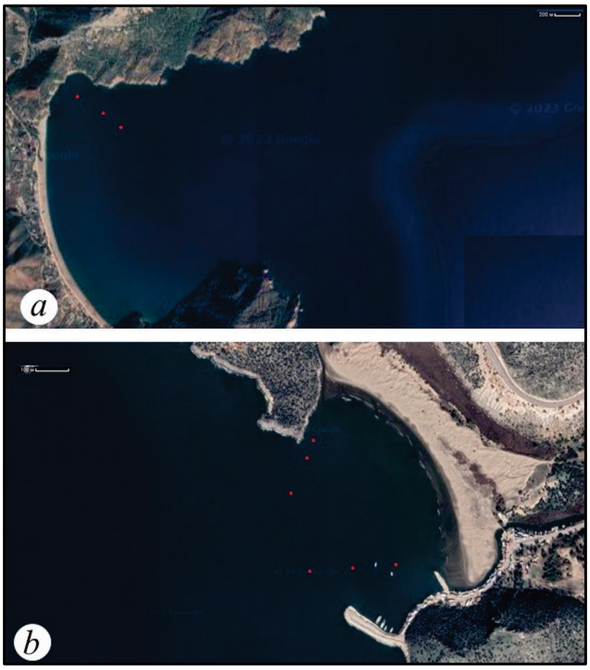

Fig. 3. Zooplankton sampling stations from the Mediterranean Sea near the village Adrasan (*a*) and Demre town (*b*)

The results were processed by standard methods with the calculation of mean value (x) and standard deviation (SD). Differences between variants were considered statistically significant at $P < 0.05$. The difference between the study variants was proved by using ANOVA.

Results

During 2017–2020, in the Odesa Marine Region twenty taxa of zooplankton: Protista – 1, Coelenterata – 2, Ctenophora – 2, Rotatoria – 1, Polychaeta – 1, Mollusca – 2, Cladocera – 2, Copepoda – 5, Cirripedia – 1, Isopoda – 1, Amphipoda – 1, Decapoda – 1 were registered. Seasonal changes of the number and biomass of zooplankton are shown in Figure 4.

The highest zooplankton number and biomass was observed in September–October, the minimum – in February–March. From February to April the main part of number and biomass was formed by the Rotifera *Synchaeta* sp., in May–June larvae of benthic invertebrates (Polychaeta, Bivalvia, Cirripedia), species of Cyclopoida and small Cladocera *Pleopis polyphaemoides* Leucart, 1859 dominated every year. In July the share of Copepoda was increased. In September–October Cladocera *Penilia avirostris* Dana, 1849 together with Copepoda formed the main part of zooplankton biomass. The organisms of forage zooplankton dominated over non-forage once in all seasons and near all investigated beaches. The share of *Noctiluca scintillans* (Macartney) Kofoid & Swezy, 1921 and jellyfish did not exceed a 5% of the total biomass of zooplankton.

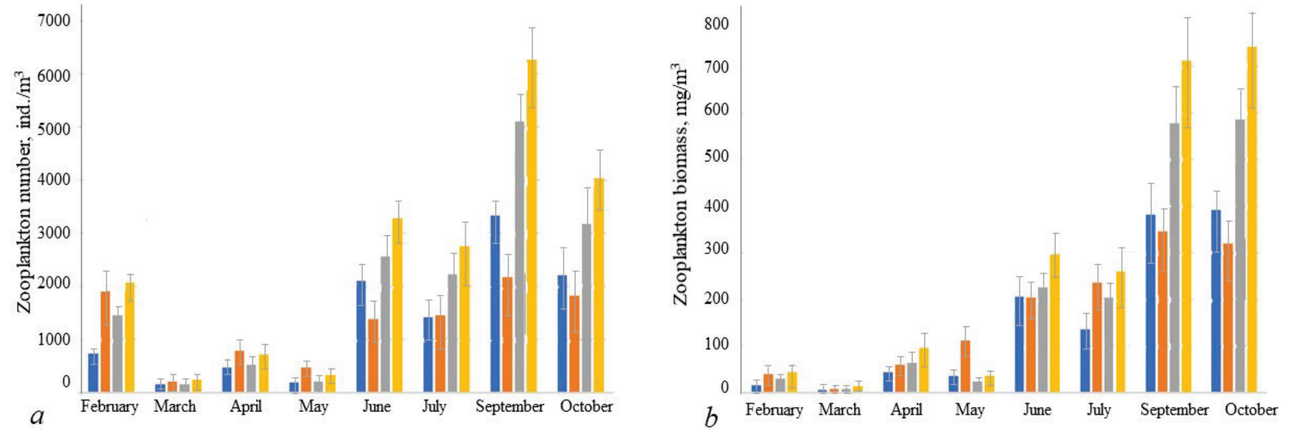

Fig. 4. Seasonal dynamics of zooplankton number and biomass of zooplankton in the coastal zone of the Odesa Marine Region in 2017–2020: *a* – average number (N, ind./m^3); axis X – month of investigation; axis Y – zooplankton number (ind./m^3); *b* – average biomass (B, mg/m^3); axis X – month of investigation; axis Y – zooplankton biomass (mg/m^3); difference significant at $P < 0.05$ ($x = SD$; $n = 3$); Odesa beaches: 🟦 – "Langeron", 🟧 – "Luzanivka", ⬜ – "Dolphin", 🟨 – "Hydrobiological station"

In 2017–2020 in the Danube Marine Region twenty five taxa of zooplankton: Protista – 1, Rotatoria – 4, Polychaeta – 1, Mollusca – 2, Crustacea – 14 (Cladocera – 6, Copepoda – 6, Decapoda – 2) Chordata – 1, Chaetognatha – 1 were registered. Most of the them belonged to the typical inhabitants of the marine waters of the north-western part of the Black Sea. Fresh water and oligohaline zooplankters were found as well. The lowest taxonomic diversity of zooplankton was observed in the area of dredging. The spatial distribution of zooplankton number and biomass is given in Table 2.

The highest number and biomass of zooplankton were observed at the station 17 (73,325.95 ind./m^3 and 1,379.71 mg/m^3). The main part of the zooplankton biomass was formed by *Parasagitta setosa* Müller, 1847, species of the genus *Acartia* and *Oithona davisae* Ferrari F. D. & Orsi, 1984. In August 2020 the biomass of forage zooplankton was high at all stations in the Danube Marine Region and reached the highest value from the last 5 years. The largest biomass of forage zooplankton (1362 mg/m^3) was observed at station 17. Thus, in the investigated areas in August 2020 a good state of the forage base of planktophagous fish was observed.

Table 2
The number (N, ind./m^3) and biomass (B, mg/m^3) of the common and forage zooplankton in the Danube Marine Region of the north-western part of the Black Sea in August 2020

Station	General zooplankton		Forage zooplankton		
	N	B	N	B	%
6	45,012.30	1,115.13	45,012.30	1,115.13	100
17	73,325.95	1,379.71	73,159.79	1,361.69	98.69
18	56,979.07	1,258.33	55,614.19	1,110.24	88.23
19	53,784.02	1,020.80	53,784.02	1,020.80	100
Average	57,275.34 ± 11,836.12	1,193.49 ± 157.95	56,892.58 ± 11,790.68	1,151.96 ± 146.38	96.73 ± 5.70

Seasonal dynamics of zooplankton abundance and biomass in the Danube Region in 2017–2020 is shown in Figure 5.

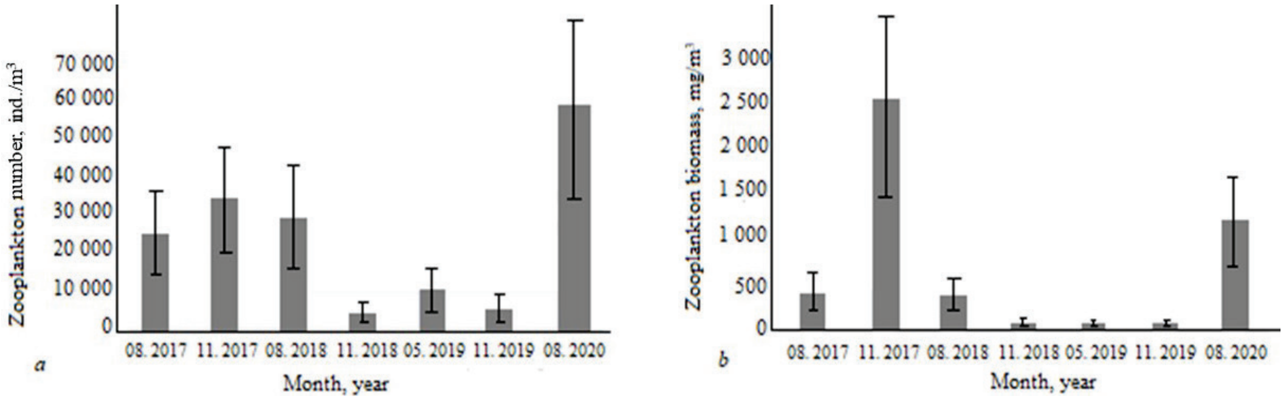

Fig. 5. Seasonal dynamics of zooplankton number and biomass in the Danube Region in 2017–2020: *a* – average number (N, ind./m^3); axis X – months and years of investigation; axis Y – zooplankton number (ind./m^3); *b* – average biomass (B, mg/m^3); axis X – months and years of investigation; axis Y – zooplankton biomass (mg/m^3); difference significant at $P < 0.05$ ($x = SD$; $n = 3$)

In 2017 the maximum number and biomass of zooplankton was registered in November. But in 2018, 2019 and 2020 maximum value was observed in August or May. *Oithona davisae* formed the main part of the zooplankton number in August 2017, together with *Acartia* species and species of meroplankton. In November *N. scintillans* dominated. In summer 2018 the main part of zooplankton number and biomass was formed by Copepoda, mainly by the alien species *O. davisae* and species of the genus *Acartia*. In autumn 2018 the same organisms dominated, as well as *P. setosa* and species of meroplankton. In 2019 the main zooplankton biomass was formed by species of meroplankton, in autumn by *N. scintillans* and *P. setosa*. In August 2020 by *P. setosa*, species of the genus *Acartia* and *O. davisae*.

In the aquatoria from Berezan island to Yuzhne town (the Dniper Region) in 2017–2020 11 taxa of zooplankton: Rotatoria – 1, Polychaeta – 1, Mollusca – 1, Crustacea – 7 taxa (Cladocera – 2, Copepoda – 4, Cirripedia – 1) were registered. The seasonal and interannual changes of number and biomass of zooplankton are given in Figures 6 and 7.

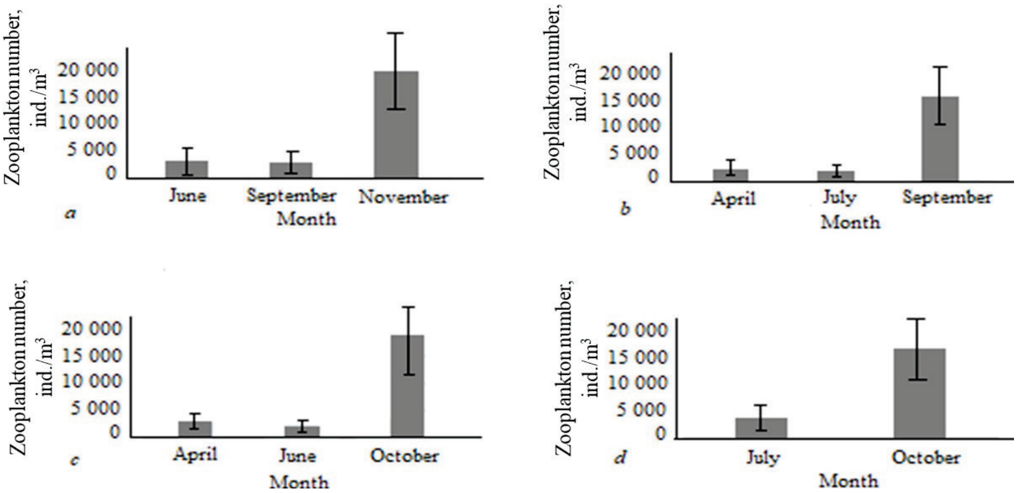

Fig. 6. Seasonal dynamics of the number of zooplankton in the Dniper Region in 2017–2020: *a* – in 2017, *b* – 2018, *c* – 2019, *d* – 2020; axis X – month of investigation; axis Y – zooplankton abundance (ind./m^3); difference significant at $P < 0.05$

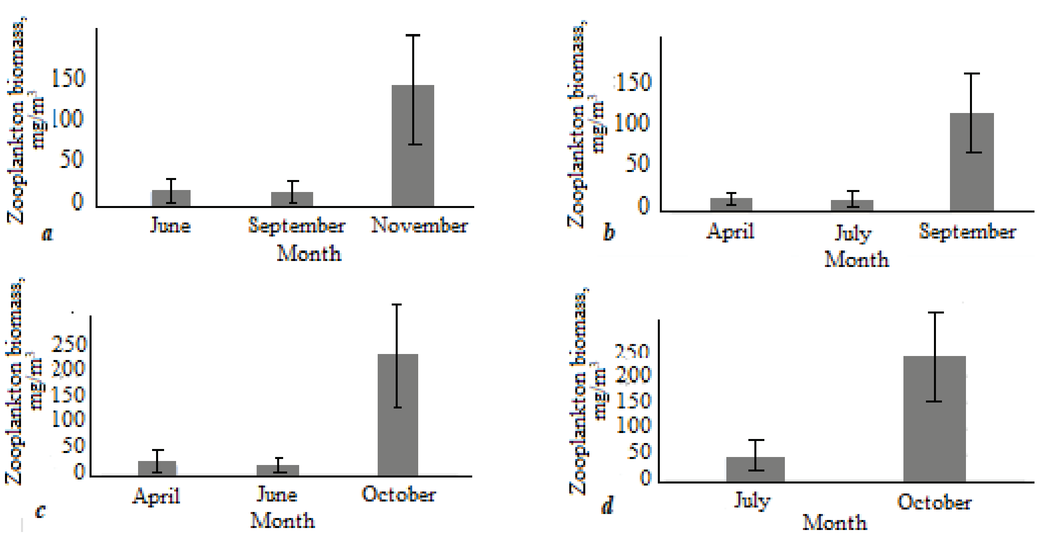

Fig. 7. Seasonal dynamics of the biomass of zooplankton in the Dniper Region in 2017–2020: *a* – in 2017, *b* – 2018, *c* – 2019, *d* – 2020; axis X – month of investigation; axis Y – zooplankton biomass (mg/m^3); difference significant at $P < 0.05$

In summer the main part of zooplankton number and biomass were formed by meroplankton, species of Cyclopoida and Harpacticoida. In autumn the abundance and biomass of zooplankton were higher than in summer and spring. At all stations in summer the main number and biomass of zooplankton were formed by meroplankton species, Cyclopoida and Harpacticoida. In autumn species of the genus *Acartia*, *O. davisae*, larvae of Cirripedia and *P. avirostris* dominated.

On the stations of the coastal zone of the Mediterranean Sea near the village Adrasan and Demre town (Turkey) in December 2019 and January 2020 23 taxa of zooplankton: Coelenterata – 2, Rotatoria – 1, Polychaeta – 1, Mollusca – 2, Echinodermata – 1, Cladocera – 2, Copepoda – 7, Cirripedia – 1, Decapoda – 2, Chordata – 3, Chaetognatha – 1 taxon were registered. Number and biomass of zooplankton are shown in Table 3. The number and biomass of zooplankton at a distance of 300 m from the river-mouth were greater than directly at the mouth. The hydrofront was clearly expressed near both rivers. The highest zooplankton number and biomass were observed at the hydro-front and decreased in direction towards the river mouth as well as towards the open sea. The main part of zooplankton number and biomass were formed by larvae of benthic invertebrates and Copepoda (Fig. 8). Phenological changes of the population structure of the genus Acartia in the Odesa Marine Region were observed (Fig. 9). Those species form the major part of the forage zooplankton. The adult stages of *Acartia* species were found mainly in autumn, the abundance of females was slightly higher than males however. Copepodid stages were observed in all seasons, in autumn their number and biomass were higher than in spring and summer. Seasonal changes of the population structure of *Acartia* species in the Danube Region are shown in Figure 10.

The number and biomass of adults and Copepodid stages of *Acartia* species increased from spring to autumn every year. Generally, the number and biomass of adult males was lower than of females, except for April 2018 and 2019. In populations of *Acartia* species, number and biomass of Copepodid stages were higher than those of adults, with an exception for August and October 2020. Seasonal changes in the population structure of species of the genus *Acartia* in the Dniper Region are shown in Figure 11.

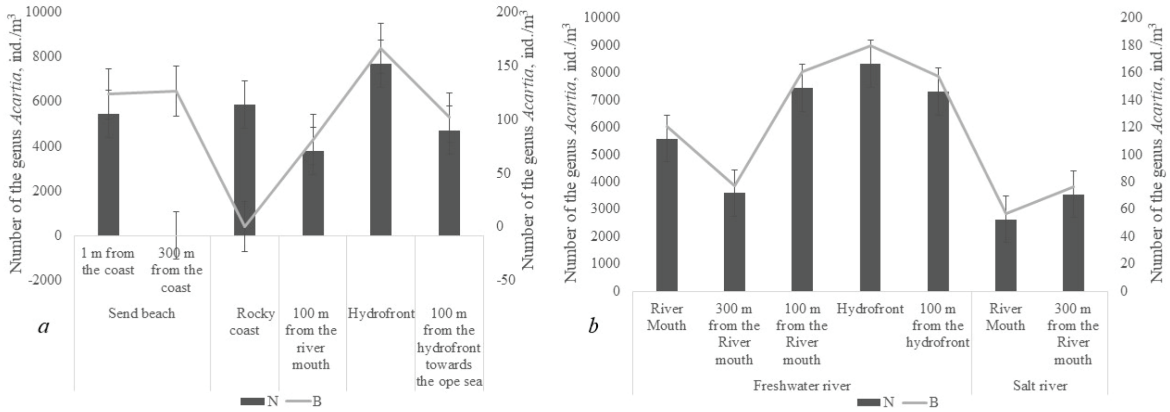

Fig. 8. The number (N, ind./m^3) and biomass (B, mg/m^3) of zooplankton of the Mediterranean Sea near the village Adrasan and Demre town in December 2019 and January 2020: *a* – Adrasan, *b* – Demre; axis Y – number (N, ind./m^3; x ± SD; n = 35) and biomass (B, mg/m^3; x ± SD; n = 22)

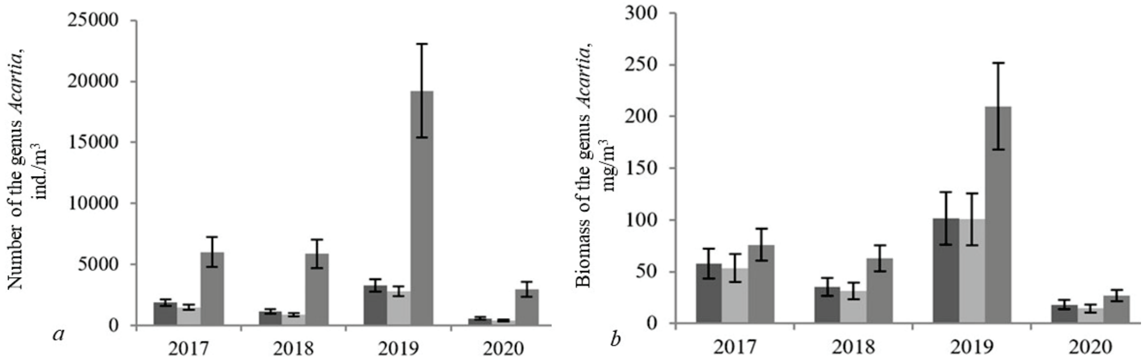

Fig. 9. Seasonal dynamic of number and biomass of the adults and Copepoditic stages of species of the genus *Acartia* in the Odesa Marine Region in 2017–2020: *a* – abundance (N, ind./m^3; x ± SD; n = 35), *b* – biomass (B, mg/m^3; x ± SD; n = 22); axis X – years, axis Y – metrics of Copepoda: ■ – *Acartia* spp. (*clause* + *tonsa*) ♀; ■ – *Acartia* spp. (*clause* + *tonsa*) ♂; ■ – *Acartia* spp. (*clause* + *tonsa*) cop. 1–5

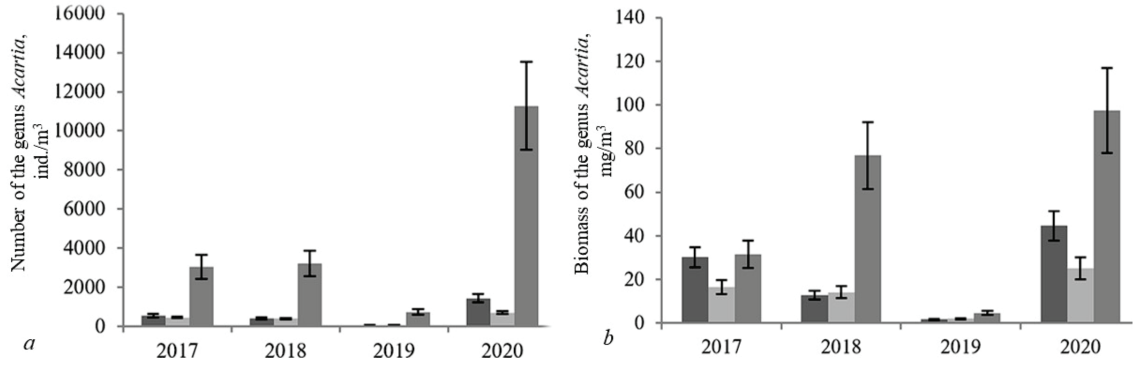

Fig. 10. Seasonal dynamic of number and biomass of the adults and Copepoditic stages of species of the genus *Acartia* in the Danube Region in 2017–2020: *a* – abundance (N, ind./m^3; x ± SD; n = 35), *b* – biomass (B, mg/m^3; x ± SD; n = 22); axis X – years, axis Y – metrics of Copepoda: ■ – *Acartia* spp. (*clause* + *tonsa*) ♀; ■ – *Acartia* spp. (*clause* + *tonsa*) ♂; ■ – *Acartia* spp. (*clausi* + *tonsa*) cop. 1–5

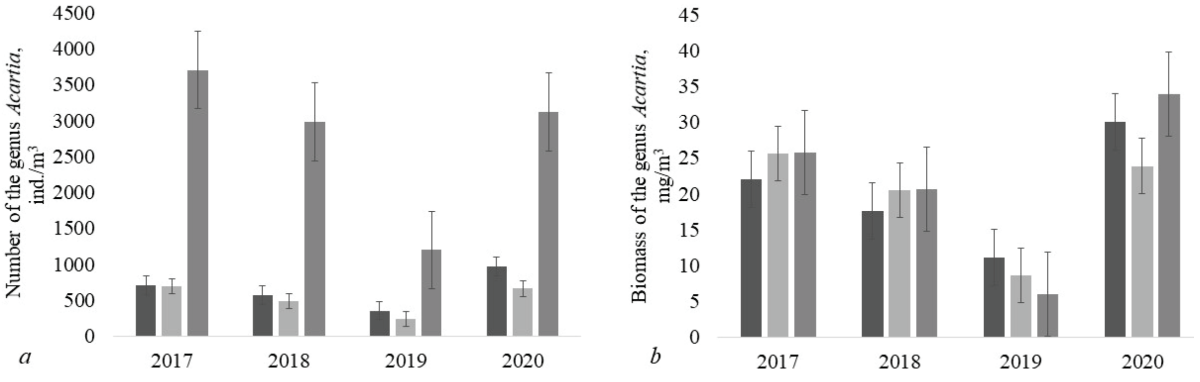

Fig. 11. Seasonal dynamic of number and biomass of the adults and Copepoditic stages of species of the genus *Acartia* in the Dniper Region in 2017–2020: *a* – abundance (N, ind./m^3; x ± SD; n = 35), *b* – biomass (B, mg/m^3; x ± SD; n = 22); axis X – years, axis Y – metrics of Copepoda; ■ – *Acartia* spp. (*clausi* + *tonsa*) ♀; ■ – *Acartia* spp. (*clausi* + *tonsa*) ♂; ■ – *Acartia* spp. (*clausi* + *tonsa*) cop. 1–5

It was found that in the Danube Region the number of females were greater than that of males, except for May 2019. In summer, the number and biomass of adults and Copepodid Stages were higher than in autumn. As well as in the Odessa and Dniper Regions, the share of Copepodid stages in the biomass of the *Acartia* species was greater than those of the adult stages.

Discussion

River runoff does not significantly affect the taxonomic structure of zooplankton of the Odesa Marine Region, most of the registered taxa belong to marine ones. In the Danube Region the impact of river runoff is much more significant especially in the dredging area, freshwater and olygohaline species were regularly registered here. In the Dniper Region occurrence of freshwater zooplankters decreases from the station Beresan to station Yuzne town. From the Adzhyyask to Odessa city, freshwater organisms are very rare and their occurrence correlates with maximum value of Dnieper runoff mostly in spring.

It was shown that total zooplankton biomass and percentage of *N. scintillans* are clearly decreasing in Ukrainian waters and the percentage of Copepoda is increasing. These trends show positive changes in the forage base of commercial planktophagous fishes and ecological status of the investigated aquatoria (Kharytonova & Nabokin, 2020; Kharytonova et al., 2020, 2021).

So, the main trends in changes of the mesozooplankton community in the Black Sea are decrease in percentage of *N. scintillans* in total zooplankton biomass and increasing percentage of Copepoda. These trends indicate decrease in the pressure of the negative eutrophication factor and show positive changes in the forage base of commercial planktophagous fishes and ecological status of the Black Sea waters. These tendencies are in good agreement with the conclusion of Polishchuk (Polischuk & Nastenko, 2006) that the Black Sea ecosystem is in a state of de-eutrophication and the establishment of a new "ecological norm". Results described above well agree with those trends: total zooplankton biomass is lower than in the period of anthropogenic eutrophication, percentage of Copepoda is higher than prior to 2010 and percentage of *N. scintillans* is lower than prior to 2010 and almost never is higher than 30%. At the same time modern state of the zooplankton community of all investigated aquatoria does not completely accord with those during the period of "ecological norm" (before 1970). Average biomass is lower and its interannual changes are more unstable.

We did not establish direct dependence between zooplankton biomass and annual volume of river runoff (correlation between these parameters is from –0.25 to –0.80. Unfortunatly we cannot analyse possible correlation berween monthly volumes of runoff of the zooplankton biomass due to lack of hydrological data.

It was established that number and biomass of adult and Copepodid stages of *Acartia* species increased from spring to autumn. This tendency well agreed with data provide by other researchers. They concluded that adult specimens were registered year-round with maximum value in autumn. These peaks shifted slightly in time depending on temperature. As a rule, number and biomass of adult males were lower than females. In all seasons number and biomass of Copepodid stages were higher than adults.

According to the historical data in NWBS, the share of Copepoda in the zooplankton biomass was 73% in the 1960s. *Oithona nana* Giesbrecht, 1893 (47%), *Pseudocalanus elongatus* Boeck, 1865 (28%) and *Acartia* (*Acartiura*) *clausi* Giesbrecht, 1889 (17%) dominated. The share of *A. clausi* was 26% in 1965–1975. It increased up to 73% in the 1970s and the number of large neuston Copepoda (Pontellidae) decreased at the same time (Zaitsev & Alexandrov, 1997; Kovalev et al., 1999). They completely disappeared in the 1990s–2000s. During the last few years (2017–2018, 2020) single specimens of Pontellidae were registered in the Danube Region. In the 1980s the share of Copepoda in total biomass of zooplankton was around 67%, i. e. almost the same as in the 1970s. At the time, *A. clausi* formed 30% of Copepoda biomass. At the beginning of the 1990s *A. clausi* formed up to 100% of Copepoda biomass (Gubanova, 2000). After the invasion of *Acartia tonsa* Dana, 1849 it underwent an explosion in number in 2005 in Odesa bay. The ratio between *A. clausi* and *A. tonsa* was 1:137 at that time (Vorobyova et al., 2017). In 2016, the share of *A. clausi* and *A. tonsa* in total zooplankton biomass was 81% in the Danube Region. It decreased to 58% in 2017, to 48.5% in 2018 and to 49.4% in 2019. After 2011, *O. davisae* started to form a significant part of the Copepoda biomass in NWBS (Altukhov et al., 2014). In 2016 its share was 29.2%, in 2017 – 20.5%, in 2018 – 21.4% and in 2019–23.5% (Kharytonova & Dyadichko, 2021). The percentage of Copepoda in total zooplankton biomass is lower than in the period of ecological norm and higher than during the eutrophication period.

The contact area river–sea is an ecotone where there is a special development of life with certain quantitative indicators and species diversity. Such areas are especially sensitive to anthropogenic impact.

It is known (Abbas & Talib, 2018) that in any type of aquatic ecosystems under anthropogenic eutrophication a leading role in the formation of biomass is played by short life-cycled organisms (Protista, Rotatoria). But the share of long-cycled zooplankton (Copepoda) has decreased in total biomass of the zooplankton.

Conclusions

20 taxa of zooplankton: Protista – 1, Coelenterata – 2, Ctenophora – 2, Rotatoria – 1, Polychaeta – 1, Mollusca – 2, Cladocera – 2, Copepoda – 5, Cirripedia – 1, Isopoda – 1, Amphipoda – 1, Decapoda – 1 were registered in the Odesa Marine Region. The highest level of the average number and biomass of zooplankton was observed near station "Hydrobiological station", the minimal – near beaches "Lanzheron" and "Luzanivka". Species of forage zooplankton dominated over non-forage in all seasons and all investigated aquatories. The percentage of *N. scintillans* and jellyfish did not exceed 5% of the total biomass of zooplankton.

25 taxa of zooplankton: Protista – 1, Rotatoria – 4, Polychaeta – 1, Mollusca – 2, Crustacea – 14 (Cladocera – 6, Copepoda – Decripoda – 1), Chordata – 1, Chaetognatha – 1 were registered in the Danube Region. The main part of zooplankton biomass was formed by *P. setosa* and the alien species *O. davisae*. In August 2020 biomass of forage zooplankton reached the highest level over the last 5 years (1.0–1.3 g/m^3).

11 taxa of zooplankton: Rotatoria – 1, Polychaeta – 1, Mollusca – 1, Crustacea – 7 taxa (Cladocera – 2, Copepoda – 4, Cirripedia – 1 were registered in the Dnieper Region. In autumn the number and biomass of zooplankton were higher than in summer and spring. The maximum biomass of zooplankton (60.5 mg/m^3) was observed in July 2019 near Mys Adzhyyask, the minimum (35.4 mg/m^3) – near the Berezan island. In 2020 the maximum biomass of zooplankton was observed in October near Yuzhne town (275.7 mg/m^3), the minimum – near Kobleve village (158.1 mg/m^3). In summer at all stations, the main number and biomass of zooplankton were formed by organisms of meroplankton, species of Cyclopoida and Harpacticoida, in autumn – species of the genus *Acartia*, *O. davisae*, larvae of Cirripedia and *P. avirostris*.

The maximum value of the number and biomass of zooplankton were registed in summer and autumn in all investigated aqutories. The minimum value was registed in February–March. From February to April *Synchaeta* sp. dominated by abundance and biomass in all years and in all aquatoria. In May–June larvae of benthic invertebrates (Polychaeta, Bivalvia, Cirripedia), species of Cyclopoida and *P. polyphaemoides* dominated. In July the share of Copepoda increased, and in August–November they played a leading role together with *P. setosa* and *P. avirostris*.

We did not establish a direct dependence between zooplankton biomass and annual volume of river runoff (correlation between these parameters is from –0.25 to –0.80). Unfortunatly we cannot analyse possible correlation berween monthly volumes of runoff of the zooplankton biomass due to lack of hydrological data.

The number and biomass of adults and copepodid stages of *Acartia* species increased from spring to autumn in all years and investigated aquatoria. In populations of *Acartia* species copepodite stages predominated over adults by number and biomass in all seasons.

23 taxa of zooplankton: Coelenterata – 2, Rotatoria – 1, Polychaeta – 1, Mollusca – 2, Echinodermata – 1, Cladocera – 2, Copepoda – 7, Cirripedia – 1, Decapoda – 2, Chordata – 3, Chaetognatha – 1 were registered in the Turkish coastal zone of the Mediterranean Sea in December 2019 and January 2020. The number and biomass of zooplankton at a distance

of 300 m from the river mouth were greater than directly at the mouth. The hydro-front was expressed near all investigated rivers, the maximum value of zooplankton number and biomass was observed here and decreased in direction both towards the mouth of the river and towards the open sea.

References

Abbas, M. I., & Talib, A. H. (2018). Community structure of zooplankton and water quality assessment of tigris river within Baghdad/Iraq. Applied Ecology and Environmental Sciences, 6(2), 63–69.

Alexandrov, B. G. (2017). Modern views about contour structure of aqutic environment and new approaches for the Black Sea and Azov Sea monitoring. Bulletin NAS of Ukraine, 12, 42–49.

Alexandrov, B. G., & Kharytonova, Y. V. (2019). Kerivnytstvo z monitorynhu zooplanktonu mors'kykh vod Ukrayiny ta vyznachennya yikh ekolohichnoho stanu za standartamy Dyrektyvy YeS pro Mors'ku stratehiyu [Guidelines for monitoring zooplankton of marine waters of Ukraine and determining their ecological status according to the standards of the EU Marine Strategy Directive]. The project of the regulatory document submitted for consideration to the Ministry of Ecology of Ukraine on July 29, 2019. Odesa. P. 33 (in Ukranian).

Alexandrov, B. G., & Zaitsev, Y. P. (1998). Black sea biodiversity in eutrophication conditions. In: Kotlyakov, V., Uppenbrink, M., & Metreveli, V. (Eds.). Conservation of the biological diversity as a prerequisite for sustainable development in the Black Sea region. Nato Science Partnership Subseries, 46, 221–234.

Alexandrova, V., Moncheva, S., Slabakova, N., Stefanova, K., & Doncheva, V. (2007). Application of biotic indices and body size descriptors of phyto- and zooplankton communities in Varna Lagoon for ecological status assessment. Transitional Waters Bulletin, 3, 17–21.

Altukhov, D. A., Gubanova, A. D., & Mukhanov, V. S. (2014). New invasive copepod *Oithona davisae* Ferrari and Orsi, 1984: Seasonal dynamics in Sevastopol Bay and expansion along the Black Sea coasts. Marine Ecology, 35(1), 28–34.

Bat, L., Gökkurt, O., Sezgin, M., Üstün, F., & Sahin, F. (2009). Evaluation of the Black Sea land based sources of pollution the coastal region of Turkey. The Open Marine Biology Journal, 3, 112–124.

Catianis, I., Vasiliu, D., Constantinescu, A. M., Pojar, I., & Grosu, D. (2020). Water quality assessment in a river-sea transition zone. Recent results from district aquatic enviroments of the Danube Delta biosphere reserve area, România. Geo-Eco-Marina, 25, 71–89.

Flint, M., Semenova, T., Arashkevich, E., Sukhanova, I., Gagarin, V., Kremenetskiy, V., Pivovarov, M., & Solovyev, K. (2010). Structure of the zooplankton communities in the region of the Ob River's estuarine frontal zone. Oceanology, 50, 766–779.

Gordeev, V. V., Shevchenko, V. P., & Novigatsky, A. N. (2022). The river-sea transition zone (marginal filter) of the Northern Dvina River as an effective trap of riverine sedimentary matter on its way to the open area of the White Sea. Oceanology, 62, 221–230.

Gordeev, V., Martin, J., Sidorov, I., & Sidorova, M. (1996). A reassessment of the Eurasian river input of water, sediment, major elements, and nutrients to the Arctic Ocean. American Journal of Science, 296, 664–691.

Gubanova, A. (2000). Occurrence of *Acartia tonsa* Dana in the Black Sea. Was it introduced from the Mediterranean? Mediterranean Marine Science, 1(1), 105–109.

Kharytonova, Y. V., & Dyadichko, V. G. (2021). Long-term changes of Copepoda (Crustacea) abundance and biomass in the Danube and Odessa Regions of the Black Sea as indicator of water quality. In: Chorna, V. et al. (Eds). European vector of development of the modern scientific researches. Baltija Publishing, Riga. Pp. 22–41.

Kharytonova, Y. V., & Nabokin, M. V. (2020). Zooplankton of the north-western part of the Black Sea in 2016–2019 and assessment of the quality of the environment by its indicators. In: Kempinsk, U., Henryk, S., Vozhehova, R. (Eds.). Scientific Developments of Ukraine and EU in the Area of Natural Sciences. Baltija Publishing, Riga. 685–700.

Kharytonova, Y. V., Nabokin, M. V., & Dyadychko, V. G. (2020). Zooplankton vidkrytoyi chastyny Chornoho moria v 2016–2019 rr. ta otsinka yakosti vodnoho seredovyshcha za yoho pokaznykamy [Zooplankton of the open part of the Black Sea in 2016–2019 and assessment of the quality of the aquatic environment-according to its indicators]. Ecological Sciences, 29, 87–94 (in Ukrainian).

Kharytonova, Y. V., Nabokin, M. V., Mgeladze, M. M., Vadachkoria, P. A., & Dyadichko, V. G. (2021). Current state and long-term changes in the mesozooplankton community of the Ukrainian and Georgian parts of the Black Sea as indicators of its ecological status. Biosystems Diversity, 29(1), 47–58.

Kovalev, A. V., Skryabin, V. A., Zagorodnyaya, Y. A., Bingel, F., Kideys, A. E., Niermann, U., & Uysal, Z. (1999). The Black Sea zooplankton: Composition spatial/temporal distribution and history of investigations. Turkish Journal of Zoology, 23(2), 195–209.

Kovalev, A., Mazzocchi, M., Siokou, I., & Kidets, A. (2001). Zooplankton of the Black Sea and the Eastern Mediterranean: Similarities and dissimilarities. Mediterranean Marine Science, 2(1), 69–78.

Ludwig, W, Dumont, E., Meybeck, M., & Heussner, S., (2009). River discharges of water and nutrients to the Mediterranean and Black Sea: Major drivers for ecosystem changes during past and future decades? Progress in Oceanography, 80(3), 199–217.

Micheli, F., Halpern, S., Walbridge, S., Ciriaco, S., Ferretti, F., & Fraschetti, S. (2013). Cumulative human impacts on Mediterranean and Black Sea marine ecosystems: Assessing current pressures and opportunities. PLoS One, 8(12), 79889.

Moncheva, S., Dontcheva, V., Shtereva, G., Kamburska, L., Malej, A., & Gorinstein, S. (2002). Application of eutrophication indices for assessment of the Bulgarian Black Sea coastal ecosystem ecological quality. Water Science Technology, 46(8), 19–28.

Moncheva, S., Racheva, E., Kamburska, L., & D'Hernoncourt, J. (2012). Environmental and management constraints on tourism in Varna Bay, Bulgarian Black Sea coast. Ecology and Society, 17(3), 35.

O'Higgins, T., Farmer, A., Daskalov, G., Knudsen, S., & Mee, L. (2014). Achieving good environmental status in the Black Sea: Scale mismatches in environmental management. Ecology and Society, 19(3), 54.

Onuchin, A., Balzter, H., Borisova, H., & Blyth, E. (2006). Climatic and geographic patterns of river runoff formation in Northern Eurasia. Advances in Water Resources, 29(9), 1314–1327.

Osadchiev, A., & Korshenko, E. (2017). Small river plumes off the northeastern coast of the Black Sea under average climatic and flooding discharge conditions. Ocean Science, 13, 465–482.

Pasternak, A., Drits, A., Arashkevich, E., & Flint, M. (2022). Differential impact of the Khatanga and Lena (Laptev Sea) runoff on the distribution and grazing of zooplankton. Frontiers in Marine Science, 9, 881383.

Polischuk, L. N., & Nastenko, E. V. (2006). Mezo- i makrozooplankton [Meso andi macrozooplankton]. In: Zaitsev, Y. P., Aleksandrov, B. G., & Minicheva, G. G. (Eds.). North-western part of the Black Sea: Biology and ecology. Naukova Dumka, Kiev. Pp. 229–237 (in Russian).

Sani, T., Marini, M., Campanelli, A., Toffolo, M., Goffredo, S., & Grilli, F. (2024). Evolution of freshwater runoff in the Western Adriatic Sea over the last century. Environments, 11(1), 22.

Venkataramana, V., Sarma, S., & Reddy, M. (2017). Impact of river discharge on distribution of zooplankton biomass, community structure and food web dynamics in the Western Coastal Bay of Bengal Regional. Studies in Marine Science, 16, 267–278.

Vinogradov, M. E., Lebedeva, L. P., & Lukasheva, T. A. (2006). Condition of coastal mesoplankton communities in the northeastern area of the Black Sea in 2005. Oceanology, 46, 817–826.

Zaitsev, Y. P. (1992). Recent changes in the trophic structure of the Black Sea. Fisheries Oceanography, 1, 180–189.

Zaitsev, Y. P., & Alexandrov, B. G. (1997). Recent man-made changes in the Black Sea. In: Ozsoy, E., & Mikaelyan, A. (Eds.). Ecosystem sensitivity to change: Black Sea, Baltic Sea and North Sea. Nato Science Partnership Subseries, 27, 25–31.

Zhang, L., Hu, B., Zhang, Z., & Liang, G. (2023). Research on the spatiotemporal evolution and mechanism of ecosystem service value in the mountain-river-sea transition zone based on “production-living-ecological space” – Taking the Karst-Beibu Gulf in Southwest Guangxi, China as an example. Ecological Indicators, 148, 109889.