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ИнБЮМ – IBSS

Морской биологический журнал
Marine Biological Journal
2022, vol. 7, no. 1, pp. 78–92
https://doi.org/10.21072/mbj.2022.07.1.07

UDC [591.524.12:551.465](282.247.29.05)

# WIND EFFECT ON ZOOPLANKTON DISTRIBUTION IN THE ESTUARY OF THE PREGOLYA RIVER (THE BALTIC SEA BASIN) AFTER TECHNOGENIC TRANSFORMATION OF ITS RIVERBED

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Received by the Editor 04.02.2021; after reviewing 15.06.2021;
accepted for publication 24.12.2021; published online 22.03.2022.

In 2014–2018, large-scale hydrotechnical works were carried out in the estuary of the Pregolya River. The structural changes in the summer zooplankton in the river mouth in 2019 were revealed in comparison with the data obtained *prior* the riverbed transformation. In June 2019, zooplankton total abundance and biomass were of (136 ± 111) thousand ind.$\cdot$m$^{-3}$ and (860 ± 840) mg$\cdot$m$^{-3}$, respectively. It is comparable with mean annual data of 1996–2006: (71 ± 66) thousand ind.$\cdot$m$^{-3}$ and (664 ± 337) mg$\cdot$m$^{-3}$, respectively. In the summer of 2019, for the first time, the euryhaline species *Eurytemora affinis* inhabiting the Vistula Lagoon was recorded in the Novaya Pregolya branch. The presence of this species in the river branches, as well as the values of water salinity, may result from an increase in the frequency or intensity of water surges into the river from the Vistula Lagoon. In this regard, the wind conditions in 1998–2006 and 2011–2019 were analyzed. In 2011–2019, there was no increase in the frequency of winds acting along the effective surge direction (southwest and west ones) compared with those in 1996–2006. However, a rise in the frequency of storms was noted, *inter alia* in summer. Westerly storm winds cause upstream water inflow from the Vistula Lagoon and channel. Probably, the destruction of river macrophyte communities, concreting of embankments, and a change in the channel bottom configuration affected the intensity of water inflow from the lagoon into the river branches during surges and became the main factor affecting the distribution of euryhaline species from the lagoon in the river branches.

**Keywords:** zooplankton structure, surges, storm activity, wind direction, Pregolya River, Baltic Sea basin

The Pregolya River is a medium, slowly flowing river with a total length of 123 km (with tributaries, 292 km). It is the key freshwater object of the Kaliningrad region of the Russian Federation. The river estuary, the Vistula Lagoon (its part belonging to Russia is called the Kaliningrad Lagoon), and the Kaliningrad Sea Canal opening into the Baltic Sea form together a hydrodynamic system which is characterized by a mixture of freshwater and seawater and by vertical and horizontal salinity gradient (Chubarenko & Shkurenko, 2001 ; Krechik et al., 2020). At the spot where the Pregolya River flows into the Vistula Lagoon, mean salinity is about 3 ‰, and water with salinity of 1 ‰ inflows along the bottom. The near-bottom boundary of the wedge of brackish-water masses extends 11 km above the river estuary, and the near-surface boundary extends 7 km (Domnin et al., 2013).

In the estuary of the Pregolya River, along with a long-term trend of increase in mean water level (Abramov et al., 2013 ; Stont et al., 2020b ; Dailidienė et al., 2012), there is a periodic short-term increase in the level associated with the regime of surge winds and water inflow from the Baltic Sea to the Vistula Lagoon through the narrow and shallow Baltic Strait (Fig. 1). As a rule, water surges from the lagoon and the canal into the river occur in autumn and winter. This corresponds to the highest frequency of storm winds of the effective surge direction (for the Pregolya River, southwestern and western ones) when the trajectories of the centers of deep Atlantic cyclones pass over the Baltic Sea. Under storm winds, a backwater is formed in the Pregolya River. The water level rises, and the river flow could be directed to the source; in some cases, a surge wave propagates upstream, up to the city of Gvardeysk (Naumov, 2015 ; Sergeeva, 2013).

Kaliningrad – a city with a population of almost 500 thousand people – is located in the estuary of the Pregolya River. It is the area with large ports, an oil terminal, and other economic facilities; therefore, anthropogenic load on this river section is extremely high (Biologicheskie soobshchestva reki Pregolya, 2013). In 2014–2018, a large-scale technogenic transformation of the river section within the city occurred. A big stadium was built between the river branches – the Staraya Pregolya and Novaya Pregolya – on the Oktyabrsky Island. Existing bridges were reconstructed. New embankments and bridges were built. Filling and concreting of the banks of the river branches were carried out. During the construction of hydraulic structures, the profile of the channels in the river branches was significantly deepened and altered, and this affected the riverbed configuration. The area of the coastal zone declined, and the area of coastal aquatic vegetation decreased. Along with these changes in the estuary of the Pregolya River, variability of hydrometeorological characteristics of the Baltic Sea basin (with especially pronounced fluctuations in recent years) significantly affects the dynamics of its waters and, consequently, structural indicators of a zooplankton community (Stont et al., 2020a, b).

Information on composition, structure, distribution, and seasonal dynamics of zooplankton abundance, biomass, and production in the Pregolya River *prior* to the transformation of its estuary is given in a number of publications (Ezhova & Tsybaleva, 1995 ; Polunina, 2013, 2014 ; Polunina et al., 2018 ; Tsybaleva & Potrebich, 1995).

The aim of this study is to assess the current state of the zooplankton community in the estuary of the Pregolya River after the technogenic transformation of the riverbed taking into account the variability of wind conditions.

## MATERIAL AND METHODS

The lower reaches of the Pregolya River, the Vistula Lagoon, and the southeastern Baltic Sea (hereinafter SEB) were studied (Fig. 1A).

Mesozooplankton was sampled in the estuary of the Pregolya River. Total length of this area is about 17 km; it includes the branches Novaya Pregolya (hereinafter N. Pregolya) (stations 28, 29, and 30) and Staraya Pregolya (hereinafter S. Pregolya) (st. 28o, 29o, and 30o), a river section after the confluence of the branches (hereinafter SACB) (st. 24–27), and estuary (st. 22) (see Fig. 1B). Samples were taken from 10 sections, with one station located in the medial (midstream, central area of the riverbed) and the second located in the riparian zone (coastal area of the river). In 1996–2006, sampling was carried out monthly April to November; in 2011 and 2014, in the summer only (about 300 samples). In 2019, 20 samples were taken on 25–26 June. Sampling was carried out on small vessels.

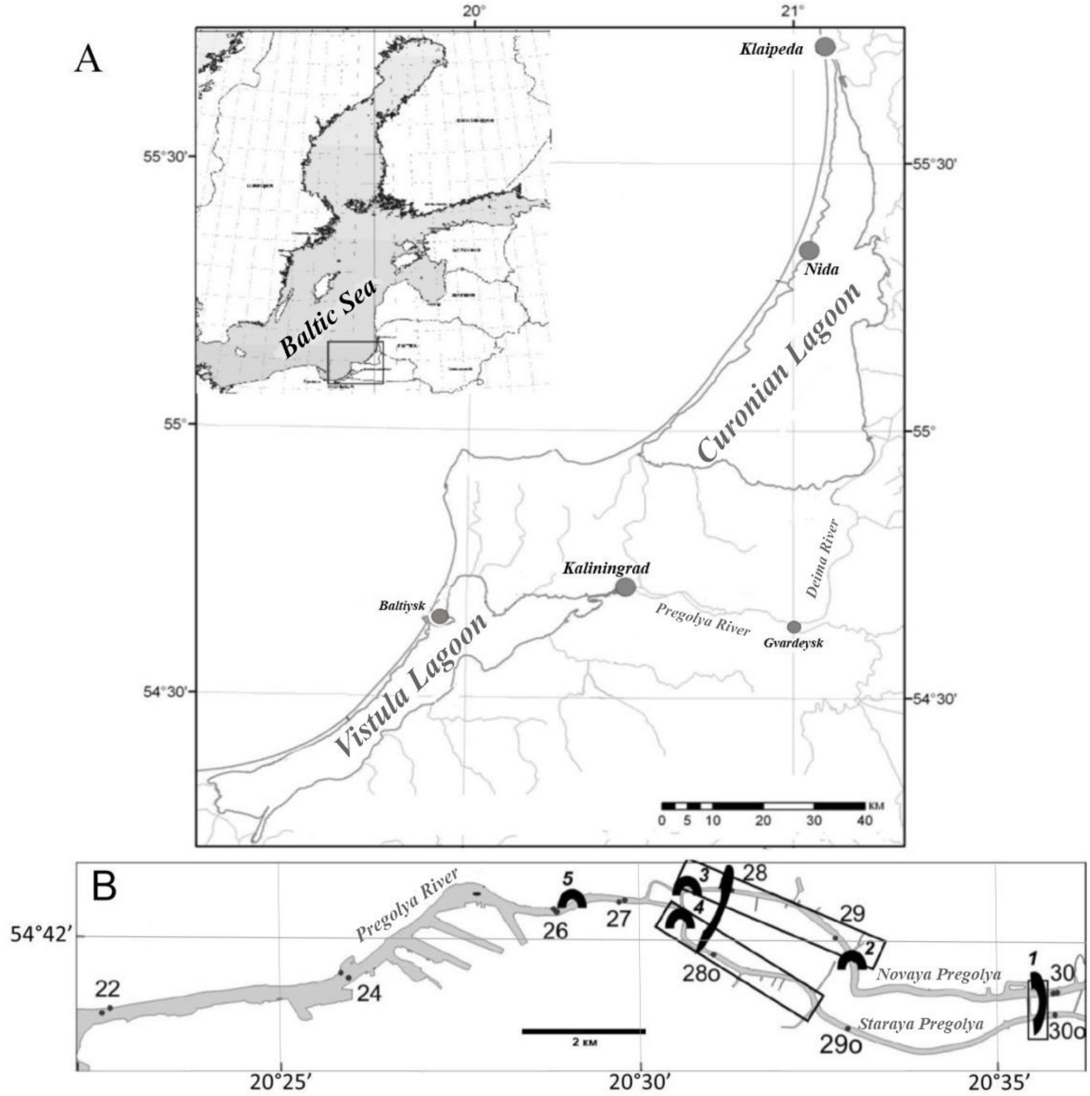

**Fig. 1.** Schematic map of the area studied (A) and zooplankton sampling sites in the estuary of the Pregolya River in 2019 (B) (22–30, sampling sites; 1–5, ∩, bridges; □, areas of the river subjected to large-scale hydraulic engineering works)

In the Pregolya River branches, the depth in the medial varies 2.0 to 4.0 m; sediments are silty, with high content of detritus. In the riparian zone, the sediments are predominantly sandy and sandy-pebbly; those contain detritus and sometimes anthropogenic waste. For the greater length of the river branches, there is a belt of vegetation in the riparian zone, except for st. 28 and 28o where the banks were concreted in 2014–2018. After the confluence of the branches and down to the estuary, the depth increases reaching 10 m due to artificial dredging of this river section (the ports of Kaliningrad are located there). The sediments are silty, and those often contain anthropogenic waste and various fractions of petroleum products; the banks are concreted for almost the entire section length.

In the medial, zooplankton was sampled with a small Juday net (diameter 14 cm; mesh 100 μm; net length about 1 m), totally from the bottom up to the surface: the end weight touched the sediments, then the net was raised. In the riparian zone, 50 L of water were sampled with a bucket, filtered through an Apstein net (mesh 100 μm), and fixed with 40 % formaldehyde solution down to a final concentration in the sample of 4 %. The samples were processed in accordance with a guideline (Metodicheskie rekomendatsii, 1984). The biomass was quantified according to equations of the dependence of body mass on body length (Balushkina & Vinberg, 1979). The data were processed statistically in Microsoft Excel. The values of Spearman's rank correlation coefficient, Fisher's exact test, and Shannon and Pielou indices were calculated.

Water temperature was measured with a water thermometer in a Spindler frame; transparency, with a Secchi disk. For determining salinity in the bottom layer, water was sampled with a Niskin bottle into 2-L plastic containers. Later, salinity was measured in a laboratory with an Ocean Seven 316 Plus probe (Idronaut, Italy). The values are given in practical salinity units (PSU).

To assess the variability of hydrometeorological conditions for 1998–2006, archival data were used of the Atlantic Branch of the Shirshov Institute of Oceanology of the Russian Academy of Sciences (Abramov & Stont, 2004). For 2011–2019, open data were used of observations at the weather station 26701 (UMKK, Baltiysk, 54°39′N, 19°55′E) (Pogoda v 243 stranakh mira, 2020). The conditions for the occurrence of storms and their trajectories in the SEB area were analyzed using synoptic maps of the Bracknell meteorological office (Weather and Climate Change, 2020).

## RESULTS

In the surface layer of the Pregolya River, the water temperature in June 2019 was +25.5…+26.0 °C; in the bottom layer, it varied within +20.1…+24.0 °C. In the river branches, higher values were registered. In the near-bottom layer in the estuary and SACB, the temperature was minimal (+20.1 °C) which is probably due to a flow of colder seawater along the bottom.

In the Pregolya River branches, water transparency varied 1.3 to 1.8 m; in the SACB, 1.2 to 1.5 m. In the estuary, the value was 1.0 m. There was a decrease in water transparency along the longitudinal profile of the river from the upper stations down to the estuary.

In the estuary and the SACB, the maximum values of near-bottom salinity (5.6 PSU) were noted; in the surface layer, salinity did not exceed 0.4 PSU. In the S. Pregolya branch, the value in the surface layer varied slightly and amounted to (0.252 ± 0.005) PSU, and the value in the near-bottom layer amounted to (0.256 ± 0.007) PSU. In the N. Pregolya, salinity in the surface layer was (0.250 ± 0.002) PSU, and in the bottom layer, it varied 0.250 to 1.459 PSU. The value of 1.46 PSU in the N. Pregolya branch indicates the water inflow from the lagoon and the canal into the river in summer.

During the sampling period, the wind was southeastern, weak (3–4 $m \cdot s^{-1}$).

Zooplankton was represented by 65 species and taxa of a higher rank: Rotifera, 25; Copepoda, 12; and Cladocera, 28. Bivalvia larvae were the most abundant in meroplankton. Several species of rotifers and cladocerans were recorded for the first time in this river section. Those were rotifers *Ascomorpha ecaudis* Perty, 1850, *Anuraeopsis fissa* Gosse, 1851, *Lepadella* sp., *Collotheca artrochoides* (Wierzejski, 1893), *Colurella* sp., and *Conochiloides* sp. Most of them are known as inhabitants of coastal water areas which are overgrown with macrophytes and characterized by high content of nutrients and suspended matter. Several typically freshwater cladoceran species were also registered by us in the river for the first time. Along the longitudinal profile of the river, *Pleuroxus trigonellus* (O. F. Müller, 1776) was found at almost all the stations; along the transverse profile, this species was the most abundant in the riparian zone. *Simocephalus serrulatus* (Koch, 1841) and *Pleuroxus (Picripleuroxus) striatus* Schoedler, 1863 were noted only in coastal thickets of the S. Pregolya riparian zone.

In the river estuary, representatives of marine plankton were recorded – the calanoid copepod *Temora longicornis* (O. F. Müller, 1785) and cladoceran *Evadne nordmanni* Lovén, 1836. Probably, those were brought to the estuary with a seawater surge from the canal. The abundance of these species was low – 140 and 9 ind.·m$^{-3}$, respectively.

The maximum number of zooplankton species was noted in the river branches (Table 1); most of Cladocera species inhabited that area. In the riparian zone of the river branches, with a definite belt of vegetation, the number of species is higher than in the medial due to Rotifera and Cladocera representatives.

In the SACB and down to the estuary, the diversity of zooplankton decreased. The minimum number of species was registered in the estuary where typical species of the Vistula Lagoon were found – the copepods *Acartia* spp., *T. longicornis*, and *Eurytemora affinis* and cladoceran *E. nordmanni*. Thus, in the river branches, zooplankton is more diverse.

**Table 1.** Number of zooplankton species of different groups in the Pregolya River, June 2019

| Zooplankton groups | River section | | | |
|---|---|---|---|---|
| | Estuary | SACB | N. Pregolya | S. Pregolya |
| Rotifera | 11 | 16 | 18 | 17 |
| Copepoda | 10 | 9 | 8 | 10 |
| Cladocera | 10 | 14 | 23 | 23 |
| Meroplankton | 2 | 2 | 1 | 1 |
| **In total** | **33** | **41** | **50** | **51** |

Copepoda representatives formed the basis of zooplankton. In the Pregolya River branches, freshwater cyclops *Mesocyclops leuckarti* (Claus, 1857) and *Acanthocyclops viridis* (Jurine, 1820) and their juvenile stages were common amounting to almost 65 % of total zooplankton abundance. After the confluence of the branches and in the estuary, the euryhaline calanoid copepod *E. affinis* and its juvenile stages developed in mass (about 33 % of total zooplankton abundance), but the ratio of *M. leuckarti* remained high (almost 26 %).

The contribution of Cladocera representatives to total zooplankton abundance in the studied period was small. In the river branches, their ratio was the most significant – about 15 % of total abundance. *Ceriodaphnia quadrangula* (O. F. Müller, 1785) amounted to about 6 % of total zooplankton abundance. Downstream, after the confluence of the branches, the ratio of Cladocera decreased down to 1 % of total abundance. For the entire river section studied, the abundance of cladocerans averaged less than 7 thousand ind.·m$^{-3}$.

Zooplankton distribution along the longitudinal profile of the river showed that higher values of its abundance were recorded after the confluence of the branches (Fig. 2). In the river branches, the maximum abundance values were 3–7 times lower than those registered for the SACB and the estuary.

The distribution of zooplankton biomass along the longitudinal profile of the river was similar to the distribution of abundance: the maximum values were noted after the confluence of the branches, primarily due to high abundance and biomass of the rather large species *E. affinis* (Table 2). The mean zooplankton biomass in the Pregolya River branches was about 200 mg·m$^{-3}$, and it was almost 10 times lower than the values in the river area after the confluence of the branches. Copepods formed the basis of the biomass. The biomass of cladocerans was higher in the riparian zone than in the medial.

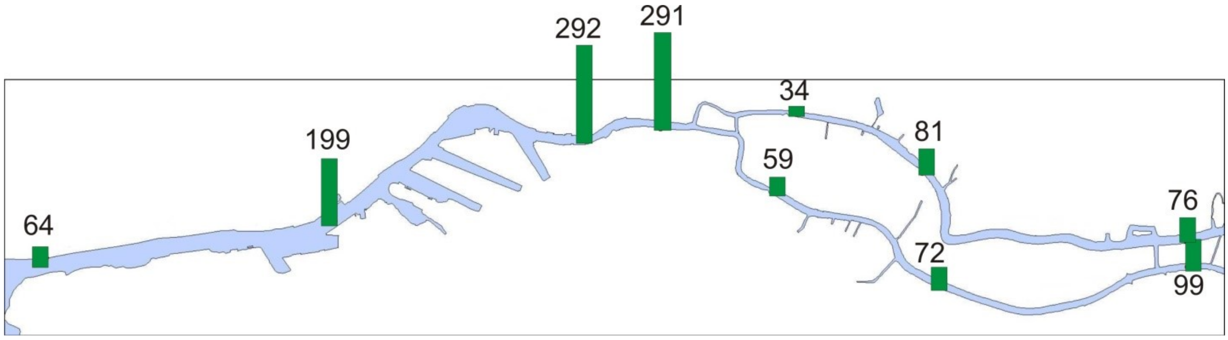

**Fig. 2.** Distribution of zooplankton (abundance, thousand ind.·m$^{-3}$) in the medial of the Pregolya River, June 2019

The values of the Shannon and Pielou indices for different river sections showed as follows: the most diverse and even community is that in the Pregolya River branches (Tables 1 and 2). For the entire estuary area, the Shannon index was 3.2, and the Pielou index was 0.77. This characterizes the zooplankton community as balanced, with high species diversity.

**Table 2.** Species number, abundance, biomass, and values of the Shannon and Pielou indices of zooplankton community at different areas of the Pregolya River, June 2019 (M denotes medial; R, riparian zone)

| Indicator | Estuary | | SACB | | N. Pregolya | | S. Pregolya | | Entire estuary area |
|---|---|---|---|---|---|---|---|---|---|
| | M | R | M | R | M | R | M | R | |
| Species number | 15 | 24 | 42 | 37 | 31 | 40 | 30 | 38 | 65 |
| Abundance, thousand ind.·m$^{-3}$ | 64–752 | | 30–291 | | 17–90 | | 39–101 | | 17–752 |
| Biomass, mg·m$^{-3}$ | 620–1,550 | | 182–5,600 | | 20–515 | | 161–534 | | 20–5,600 |
| Shannon index | 1.1 | | 1.9 | | 2.8 | | 2.8 | | 3.2 |
| Pielou index | 0.31 | | 0.51 | | 0.69 | | 0.71 | | 0.77 |

The highest abundance of the calanoid copepod *E. affinis* – an inhabitant of the Vistula Lagoon – was registered in the SACB and the estuary (Fig. 3); it is typical for this river section (Polunina, 2013 ; Polunina et al., 2018). In the summer of 2019, this species was noted in the N. Pregolya branch for the first time. During the sampling period, near-bottom salinity in the N. Pregolya was higher than in the S. Pregolya (Fig. 3). Earlier, an increase in near-bottom salinity was recorded in the S. Pregolya branch in autumn relative to the value for the N. Pregolya, and a conclusion was made about the predominant water flow into the S. Pregolya during surges (Polunina et al., 2018). In June 2019, a strong positive direct correlation was found between *E. affinis* abundance and bottom salinity: $R = 0.69$ at $p = 0.13$.

Wind frequency and strength significantly affect the water surge from the lagoon into the river. The analysis of wind conditions during the active technogenic transformation of the riverbed (2011–2019) and *prior* to it, according to the data of the Baltiysk weather station, confirmed the regional climatic peculiarity – the prevalence of winds of western rhumbs and orientation of the wind rose in the zonal direction (west–east) (Fig. 4) along which surges occur.

During the vegetation period (April to October), as compared to the annual course, the frequency of W–NW–N rhumbs increases, with a decrease in winds from the southern half of the horizon (Fig. 4). It is the westerly wind, especially the storm wind, that causes the brackish-water surge in the river estuary (Sergeeva, 2013).

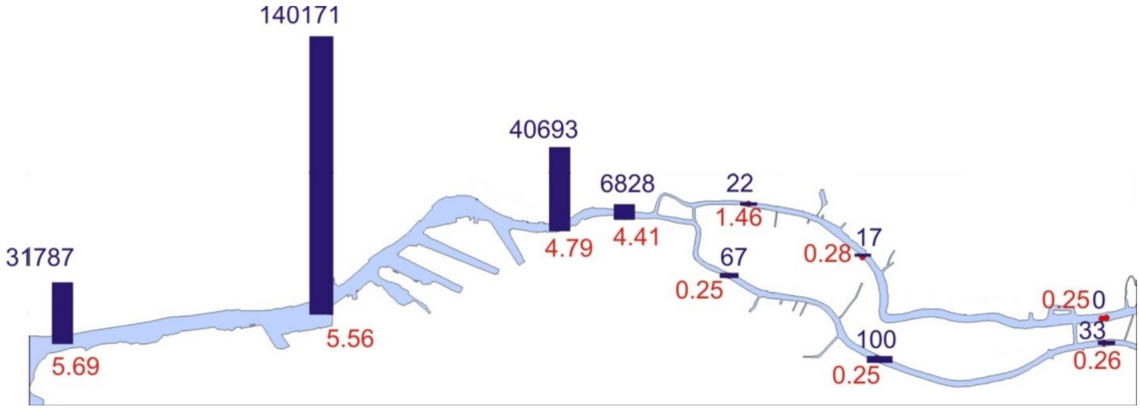

**Fig. 3.** Distribution of *Eurytemora affinis* (blue column, abundance, ind.·m$^{-3}$) and bottom salinity (red figures) in the estuary of the Pregolya River, June 2019

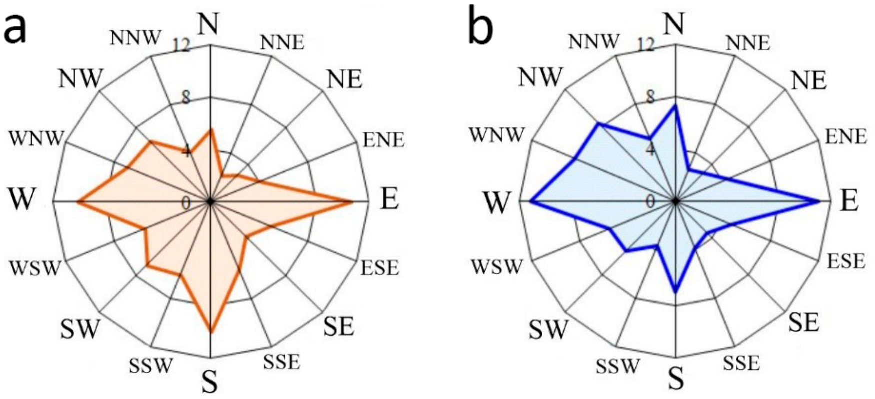

**Fig. 4.** Mean frequency (%) of wind directions (wind rose), Baltiysk, 2011–2019: a, mean annual; b, during vegetation period (April to October)

During the vegetation period (April to October) in 1996–2006 (*prior* to the large-scale technogenic transformation of the riverbed), the frequency of winds of the southwestern and western directions (SW–W) was 38 % of all the directions; the frequency of westerly winds was 25 %, and the frequency of southwesterly winds was 13 %. During the vegetation period in 2011–2019, winds of the southwestern–western direction maintained their prevalence: in total, their frequency amounted to 30 % of the frequency of winds of all the directions (western ones, 25 %; southwestern ones, 5 %). Statistical comparison of wind frequency for 1996–2006 and 2011–2019 revealed no significant differences ($F = 0.04$ at $p = 0.84$; $F$ critical = 4.60). No significant change was found in the frequency of winds of the effective surge direction (SW–W) in 2011–2019.

For the vegetation periods of 1996–2006, the relationship between the seasonal frequency and speed of westerly winds and the quantitative indicators of the euryhaline species *E. affinis* in the estuary of the Pregolya River was analyzed (Table 3).

A positive direct correlation was found between *E. affinis* abundance and the frequency of winds of western rhumbs: $R = 0.66$ at $p = 0.05$; the value of the Fisher's exact test $F$ was 4.56 at $p = 0.05$ ($F$ critical = 4.60). A strong direct positive correlation was recorded between the decapod abundance and speed of westerly winds: $R = 0.82$ at $p = 0.05$ ($F = 4.58$ at $p = 0.05$; $F$ critical = 4.60). This confirms the upriver penetration of euryhaline *E. affinis* with an increase in the frequency of westerly winds and, to a greater extent, in their speed.

**Table 3.** Seasonal dynamics of copepods *Eurytemora affinis* abundance and characteristics of the westerly winds in the estuary of the Pregolya River (mean for 1996–2006)

| Indicator | Ordinal month number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | IV | V | VI | VII | VIII | IX | X | XI |
| *Eurytemora affinis* abundance, ind.·m$^{-3}$ | 2,176 ± 1,139 | 5,066 ± 3,276 | 1,062 ± 1,003 | 995 ± 735 | 1,286 ± 1,172 | 9,269 ± 3,293 | 28,951 ± 20,154 | 36,856 ± 29,541 |
| Frequency of winds of western rhumbs, % | 29 | 31 | 39 | 29 | 35 | 34 | 41 | 39 |
| Mean speed ± $\sigma$ of winds of western rhumbs, m·s$^{-1}$ | 3.8 ± 2.49 | 3.7 ± 1.76 | 4.2 ± 2.39 | 4.0 ± 2.45 | 4.4 ± 2.69 | 4.1 ± 2.35 | 4.5 ± 3.46 | 5.7 ± 3.58 |

Let us consider storm situations when the wind speed exceeds 15 m·s$^{-1}$. In total, more than 70 storms were recorded April to October in 2011–2019 (Table 4). In autumn months (September and October), up to 7 storm situations were noted, with the wind speed reaching 22–23 m·s$^{-1}$. April to August, the frequency was 1–2 storms *per* month. In some years, there were no storms during these months. In 2011–2015, storms were mainly characterized by wind speeds of up to 18 m·s$^{-1}$. The exception was October 2012: there were 4 storms of the western rhumbs, with speeds of up to 21–23 m·s$^{-1}$. For the period 2016–2019, an increase in storm activity was observed in autumn. In 2017, Atlantic storms were characterized by westerly winds with a speed of up to 20–23 m·s$^{-1}$ (force 9–10 on the Beaufort scale) and duration of over 1.5 days. The number of storms in the selected subperiods remained practically the same: during the first one (2011–2015), 36 storms were recorded, while during the second one (2016–2019), 35 storms. The greatest contribution was made by autumn storms. In the second subperiod, with a decrease in the number of spring and summer storms, the number of autumn storms increased (up to 27).

The total duration of storms in the second subperiod (2016–2019) increased by almost 1.5 times – up to 641 hours (the value in 2011–2015 was 407 hours), especially in autumn. The intensity of storms increased: the mean maximum speed was (19 ± 3) m·s$^{-1}$, and the maximum duration was 41 hours (see Table 4).

**Table 4.** Key characteristics of storm winds (total and maximum number of storms *per* month; mean maximum and maximum measured speed; and total and maximum duration of storms) for the vegetation period and seasons of 2011–2019 according to meteorological monitoring data of the southeastern Baltic

| Characteristic | | 2011–2019 | | | | 2011–2015 | | | | 2016–2019 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IV–X | IV–V | VI–VIII | IX–X | IV–X | IV–V | VI–VIII | IX–X | IV–X | IV–V | VI–VIII | IX–X |
| Number of storms | Σ | 71 | 10 | 9 | 52 | 36 | 6 | 5 | 25 | 35 | 4 | 4 | 27 |
| | *max* | 7 | 2 | 2 | 7 | 5 | 2 | 2 | 5 | 7 | 2 | 2 | 7 |
| Measured speed, m·s$^{-1}$ | mean | 16 | 14 | 15 | 18 | 15 | 14 | 14 | 17 | 18 | 14 | 16 | 19 |
| | *max* | 23 | 14 | 18 | 23 | 23 | 14 | 18 | 23 | 22 | 14 | 17 | 22 |
| Duration, h | Σ | 1,343 | 150 | 162 | 1,076 | 407 | 35 | 46 | 319 | 641 | 52 | 42 | 447 |
| | *max* | 220 | 24 | 18 | 179 | 29 | 20 | 17 | 29 | 41 | 13 | 17 | 41 |

Statistical comparison of the data for two subperiods (2011–2015 and 2016–2019) did not reveal significant differences in either the number of storms ($F = 0.002$ at $p = 0.96$), or the measured speed ($F = 0.02$ at $p = 96$), or the duration of storms ($F = 0.28$ at $p = 0.61$) ($F$ critical = 5.99). The period 2011 to 2019 could be considered as uniform in terms of these indicators; the differences in the subperiods are insignificant.

## DISCUSSION

At the beginning of the vegetation period (April and May) in 2019, atypical hydrometeorological conditions were formed. In April, a synoptic situation contributed to the water surge in the coastal area of the SEB and to a sharp drop in sea level due to winds of the eastern rhumbs. According to the data from weather stations, April was the month with the least rainfall: Pionersky, 3.6 mm·month$^{-1}$; Baltiysk, 0.0 mm·month$^{-1}$; Nida, 0.0 mm·month$^{-1}$ (traces of precipitation); and Klaipėda, 3.3 mm·month$^{-1}$ (Pogoda v 243 stranakh mira, 2020). Due to a long precipitation deficit, the Pregolya River flow was minimal, and the SEB lagoons became shallow (Kileso & Stont, 2020). In early May, according to the data from the website Sea Level Anomalies (2019), a surge was observed in the eastern Kaliningrad Lagoon (the estuary of the Pregolya River) resulting from a storm cyclone with westerly winds. At the gauging station of the Museum of the World Ocean (the Pregolya River, 200 m downstream the confluence of the branches), an increase in the level by 50 cm was registered (from −10 up to +40 cm according to the Baltic normal height system), and a shift in the direction of the Pregolya flow was recorded (“reverse” flow with a speed of up to 0.3 m·s$^{-1}$). Salinity in the near-surface layer increased by about 5 times – 0.4 to 2.1 PSU.

In June 2019, when two Atlantic cyclones were passing, winds of the western rhumbs increased up to 14 m·s$^{-1}$, and this probably resulted in a surge of the lagoon water upstream of the Pregolya River. June was the warmest month of 2019, with average monthly temperature of +20.4 °C (Baltiysk) (Pogoda v 243 stranakh mira, 2020). Meanwhile, in the Kaliningrad region, the highest average monthly air temperatures are typical for July–August (Stont et al., 2020a). In June 2019, water temperature in the river was almost 5 °C higher than the mean annual values for 1997–2002 (Abramov & Stont, 2004). All these affected the low river flow. In the SEB water area, the level has increased significantly in recent decades (Stont et al., 2020b). The rise in water level was considered eustatic, and it was due to increased inflow through the Danish straits resulting from risen westerly form of atmospheric circulation. Because of bankside and dredging works, the cross-sectional area of the river expanded; this increases the river flow when the level rises (Sergeeva, 2005). The distribution of zooplankton populations is affected by river flow in estuary areas more significantly than by other parameters (temperature, salinity, feeding conditions, and predation) (Paturej, 2008 ; Peitsch et al., 2000).

An increase in storm intensity and duration results in a rise in the volume of water flow from the lagoon and the canal into the river during surges (Sergeeva, 2013). In the Pregolya River, the number of days of “reverse” flow reaches 90 *per* year; the highest speeds are observed in autumn and winter, but in July, speeds up to 0.4 m·s$^{-1}$ were recorded as well (Abramov & Stont, 2004). A general pattern of surges in rivers is penetration of planktonic organisms from a lagoon or sea upstream of the rivers (Paturej, 2008 ; Peitsch et al., 2000). In autumn, the main contributors to zooplankton total abundance, biomass, and productivity in the Pregolya River are euryhaline species *E. affinis* and *Acartia* spp. (Polunina et al., 2018).

In June 2019, the values of transparency of the studied river section exceeded the mean long-term values for 1994–2005 (Chubarenko, 2007); apparently, this is due to the cessation of work of several enterprises located on the river, *inter alia* a pulp and paper mill. The water transparency in the river estuary is lower since it is significantly affected by muddy waters of the Vistula Lagoon and the canal. The lagoon waters have higher levels of suspended matter (averaging about 30 mg·m$^{-1}$) than waters of the river and sea, and the maximum of suspended matter is characteristic of June–July (Chechko, 2006).

The maximum values of bottom salinity were recorded in June 2019 in the estuary and in the SACB – 5.6 PSU. In this river section, an increase in salinity up to 4 PSU was noted in previous years of research (1994–2005) as well, resulting from a seawater surge (Chubarenko, 2007). In July 2015, salinity in the SACB was 2.2 PSU; to the river estuary, it increased up to 4.4 PSU (Lukashin et al., 2018). Surges in the Pregolya River are especially significant in autumn, although those can occur in summer months as well; apparently, this was observed in June 2019 during the passage of two active cyclones with winds of western rhumbs.

In zooplankton of the studied river section, 65 species and taxa of a higher rank were registered in June 2019. There was no decrease in the number of zooplankton species compared to the data of 1996–2006 (Polunina, 2013) when the number of recorded species amounted to (62 ± 10). Both in 2019 and in the period *prior* to large-scale hydrotechnical works on the river, the basis of zooplankton was planktonic crustaceans. The peculiarities of distribution along the longitudinal profile of the river remained the same: in the river branches, freshwater cyclops prevailed, and in the section from the confluence of the branches down to the estuary, euryhaline species *E. affinis* prevailed. In the riparian zone, zooplankton total abundance and biomass ranged 17.6–762 thousand ind.·m$^{-3}$ and 278–1,870 mg·m$^{-3}$, respectively; in the medial, 34–292 thousand ind.·m$^{-3}$ and 254–5,647 mg·m$^{-3}$, respectively. In June 2019, mean zooplankton abundance and biomass [(136 ± 111) thousand ind.·m$^{-3}$ and (860 ± 840) mg·m$^{-3}$, respectively] were higher than mean values for June in 1996–2006, the period *prior* to the riverbed transformation [(71 ± 66) thousand ind.·m$^{-3}$ and (664 ± 337) mg·m$^{-3}$, respectively]. High abundance of *E. affinis* – an inhabitant of the Vistula Lagoon – was registered in the SACB and the estuary in June 2019, which is typical for these river areas and was recorded *prior* to the riverbed transformation as well (Polunina et al., 2018). A distinctive feature of the research of 2019 was the presence of this species in the N. Pregolya branch where it had not previously been found, according to the long-term data (1996–2006, 2011, and 2014). The presence of this species in the river branches, as well as water salinity values, may result from surges from the lagoon into the N. Pregolya.

The frequency and strength of westerly winds associated with storm cyclones significantly affect water surge from the lagoon into the Pregolya River. As known, in 1996–2010, there were a decrease in wind strength (speed) and its zonal component in winter and a slight increase in summer and autumn (Abramov et al., 2013). In the early XXI century, the activation of storm processes in the SEB was recorded, associated with the intensification of the western form of atmospheric circulation over the North Atlantic. This was noted in a number of publications (Drozdov & Smirnov, 2011 ; Medvedeva et al., 2015). In autumn and winter, storms are typical for the SEB water area; in summer, those are quite rare. With storm winds of the effective (SW–W) direction, the probability of surges increases. A rise in the total duration of storms in 2016–2019 was noted – almost two times compared to the values of 2011–2015. This led to an increase in the volume of water inflow from the lagoon into the Pregolya River (Sergeeva, 2005) and, accordingly, to penetration of zooplankton from the lagoon into the river.

In estuaries and lower reaches in other areas of the Baltic, a change in zooplankton composition and structure and increase in plankton quantitative indicators are registered resulting from penetration of brackish and marine species (Telesh, 2008 ; Paturej, 2008 ; Peitsch et al., 2000).

During the vegetation periods of 2011–2019, according to the data of the Baltiysk weather station, westerly wind prevailed. While purely westerly wind kept prevailing (25 %), the frequency of southwesterly wind decreased. Other researchers (Kustikova & Akhmedova, 2017) also registered a change in the structure of wind directions in the southern Vistula Lagoon for 2007–2016 (March to August).

The distribution of zooplankton species along the longitudinal profile of the Pregolya River is largely due to surges which depend on wind conditions. A decrease revealed in the cumulative effect of winds of the effective surge direction – from 38 % in 1998–2006 (the period *prior* to the riverbed transformation) down to 30 % in 2011–2019 – could not cause a significant increase in the frequency of surges into the river. Despite a slight decrease in the frequency of westerly winds, an increase in the strength and frequency of storm winds of the effective direction was observed during the vegetation period. A positive direct correlation was revealed between the abundance of euryhaline copepod *E. affinis* and the speed of westerly winds: $R = 0.82$ at $p = 0.05$. Destruction of coastal vegetation and concreting of embankments in the N. Pregolya area could contribute to the unimpeded inflow of the lagoon waters upstream of the river during surges.

**Conclusions:**

1. In 2019, after large-scale hydrotechnical works carried out in the lower Pregolya River, no decrease in the number of species of summer zooplankton was recorded. Several structural changes were noted. Some species were found which are known to live under conditions of high content of nutrients and suspended matter. Zooplankton quantitative indicators [abundance (136 ± 111) thousand ind.$\cdot$m$^{-3}$ and biomass (860 ± 840) mg$\cdot$m$^{-3}$] are commensurate with similar data *prior* to the riverbed transformation [(71 ± 66) thousand ind.$\cdot$m$^{-3}$ and (664 ± 337) mg$\cdot$m$^{-3}$, respectively]. In the river section from the confluence of the branches to the estuary, high abundance and biomass of *Eurytemora affinis* and *Acartia* spp. – inhabitants of the lagoon – were registered which is not typical for summer zooplankton. Earlier, high values of these indicators were characteristic of autumn alone. In the Novaya Pregolya branch, the euryhaline calanoid copepod *E. affinis* was recorded in summer for the first time.
2. No statistically significant change in the frequency of winds of the effective surge direction (SW–W) in 2011–2019 (30 %) relative to 1996–2006 (38 %) was revealed. High frequency of westerly winds and strength of storms in 2011–2019 were noted, and those affected the height of surges causing backwater, an increase in the level, and inflow of brackish water from the lagoon and the canal into the Pregolya River. This contributed to the distribution of the euryhaline species *E. affinis* from the Vistula Lagoon and the canal upstream of the river. A strong direct positive correlation was revealed between the abundance of crustaceans and wind speed. An increase in wind strength together with modification of the river transverse profile (concreting of the embankments and destruction of macrophyte thickets) affected the intensity of water inflow from the lagoon into the river branches during surges and became a key factor of distribution of euryhaline species in the river branches in summer.
3. Since the main urban water intake is located in the Staraya Pregolya branch, it is necessary to monitor the distribution of saline water from the lagoon along the longitudinal profile of the Pregolya River, *inter alia* using zooplankton indicator species – *E. affinis* and *Acartia* spp.

*Zooplankton sampling and processing in 2019 were carried out with the financial support of the Russian Foundation for Basic Research and Kaliningrad region under the project No. 19-45-390006; meteorological data collecting, under the project No. 19-45-390012. The analysis and interpretation of long-term data were carried out within the framework of the state research assignment No. FMWE-2021-0012.*

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# ВЛИЯНИЕ ВЕТРОВЫХ УСЛОВИЙ НА РАСПРЕДЕЛЕНИЕ ЗООПЛАНКТОНА УСТЬЕВОЙ ОБЛАСТИ РЕКИ ПРЕГОЛИ (БАССЕЙН БАЛТИЙСКОГО МОРЯ) ПОСЛЕ ТЕХНОГЕННОЙ ТРАНСФОРМАЦИИ ЕЁ РУСЛА

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В устьевой области р. Преголи в 2014–2018 гг. были проведены масштабные гидротехнические работы. На основе сравнения полученных в 2019 г. данных с материалами предыдущих исследований выявлены изменения в структуре сообществ летнего зоопланктона устьевой зоны. Общая численность и биомасса зоопланктона в июне 2019 г. составляли (136 ± 111) тыс. экз.$\cdot$м$^{-3}$ и (860 ± 840) мг$\cdot$м$^{-3}$ соответственно, что соизмеримо с усреднёнными величинами исследований 1996–2006 гг. — (71 ± 66) тыс. экз.$\cdot$м$^{-3}$ и (664 ± 337) мг$\cdot$м$^{-3}$ соответственно. Летом 2019 г. эвригалинный вид копепод *Eurytemora affinis*, массовый в Вислинском заливе, был впервые отмечен в рукаве Новая Преголя. Присутствие этого вида в рукавах реки, как и значения солёности воды, может быть следствием увеличения частоты́ или интенсивности нагонов вод Вислинского залива в реку. Проанализированы ветровые условия в периоды 1996–2006 и 2011–2019 гг. Увеличения частоты́ ветров, действующих вдоль эффективного сгонно-нагонного направления (юго-западные, западные), в 2011–2019 гг. в сравнении с 1996–2006 гг. не выявлено, однако отмечен рост частоты́ штормов, в том числе в летний период. Штормовые ветры западного направления способствуют поступлению воды из Вислинского залива и канала вверх по течению реки.

Вероятно, уничтожение сообществ речных макрофитов и бетонирование набережных, а также изменение конфигурации дна русла повлияли на интенсивность поступления вод из залива в рукава реки при нагонах и стали важным фактором, воздействующим на распространение эвригалинных видов из залива в рукавах реки.

**Ключевые слова:** структура зоопланктона, нагонные явления, штормовая активность, направление ветра, река Преголя, бассейн Балтийского моря