Rotifer trophic state indices as ecosystem indicators in brackish coastal waters*

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Abstract

Thanks to their short life cycles, rotifers react rapidly to changes in environmental conditions and so may be useful for biological monitoring. The objective of this paper was to investigate the applicability of rotifer trophic state indices as indicators of the trophic state of brackish waters, as exemplified by the Vistula Lagoon. Carried out in summer from 2007 to 2011, this study showed no significant correlation between the Lagoon's trophic state and the rotifer structure. This

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confirms the limited applicability of rotifer trophic state indices for evaluating water quality in brackish water bodies.

1. Introduction

The steadily deteriorating quality of surface waters is a common and widespread problem all over the world. It affects lakes and rivers as well as brackish coastal lagoons and estuaries. Brackish waters are specific environments. Constant contact between marine and continental forces causes significant variations and differences in salinity. Furthermore, their limited depth in relation to their large surface areas gives rise to a specific set of hydrodynamic conditions. This has an impact both on the physical and chemical parameters of the aquatic environment and on aquatic organisms (Kruk 2012, Paturej et al. 2012). Coastal brackish waters have always been exposed to the inflow of nutrients from drainage basins and oceans, a process that has intensified significantly as a consequence of human activities. In recent decades, eutrophication of brackish waters has been reported worldwide: from the Baltic Sea, the Adriatic Sea and the Black Sea to the estuaries of rivers and coastal waters in Japan, China, Australia and the USA (Bricker et al. 1999).

At present, there are numerous methods for evaluating the trophic state of water bodies, such as Carlson's trophic indices (Carlson 1977) or the method by Vollenweider adopted by the OECD (Vollenweider & Kerekes 1982). However, they are based on the assessment of physical and chemical parameters. Current legal regulations (Directive 2000/60/EC) require the quality of waters to be determined on the basis of biological aspects, with the other parameters complementing and supporting such an evaluation. The communities of organisms that may be used for this purpose include phytoplankton, macrophytes, phytobenthos, benthos and fish. The Water Framework Directive does not specify zooplankton as an indicator applicable to water quality evaluation, an omission that has attracted trenchant criticism (Moss 2007, Nõges et al. 2009, Jeppesen et al. 2011). Zooplankton organisms are key components of the food chain, mainly in shallow water bodies. Thanks to their short life cycles, such organisms, particularly rotifers, react quickly to changes in environmental conditions. Hence, the species composition of rotifers, or their abundance, may be used as biological indicators that reflect changes in water quality. The parameters of the rotifer community not only indicate the level of water pollution, but also serve to determine general tendencies in the changes in environmental conditions over time (Duggan et al. 2001, Tasevska et al. 2010, Ejsmont-Karabin 2012).

The objective of the paper was to investigate the applicability of rotifer trophic state indices as indicators of the trophic state in brackish waters based on the example of the Vistula Lagoon.

2. Material and methods

The study was carried out in the brackish Vistula Lagoon, which is situated in the southern Baltic Coastal Area (Kondracki 2002). The Lagoon is a broad, shallow water body (av. depth = 2.6 m, max. depth = 4.4 m, area of Polish part = 328 km^2), (Chubarenko & Margoński 2008). With regard to its salinity, the Lagoon was divided into two zones: the estuarine Western Basin with a low salinity (0.5–2 PSU; during storms it may increase to 4 PSU) and the Central Basin with a high salinity (2–4 PSU; during stronger inflows of brackish waters it may increase to 6 PSU) (Żmudziński & Szarejko 1955, Różańska 1963, Oleszkiewicz 1996, Kruk 2012). Samples were taken once a month during the summer (June–September) in 2007–2011 at 23 research stations (Figure 1).

The rotifers were sampled according to the standard methodology (Starmach 1955) with a Ruttner apparatus and a 10 L bucket at the shallow coastal stations. Next, 30 L of biological material was concentrated on an Apstein-type plankton net (30 μm mesh), which was then fixed with Lugol's solution and preserved with 4% formalin. Apart from collecting the plankton samples, the water transparency was measured with a Secchi disc and salinity with a WTW Multi 350i device. The concentrations of

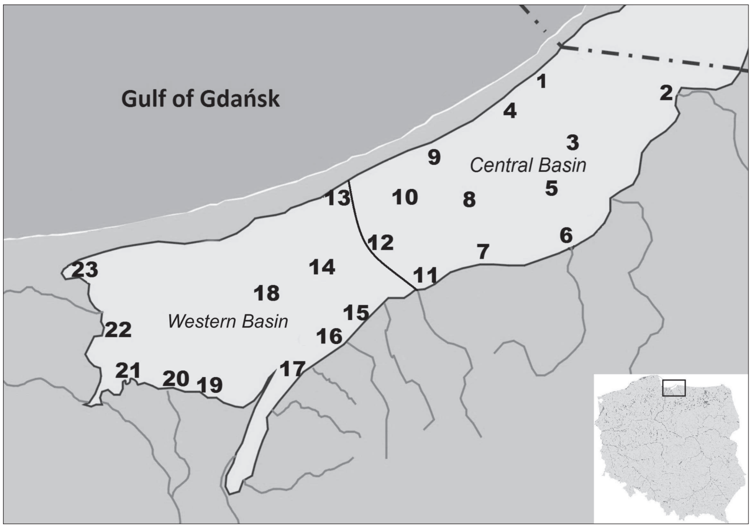

Figure 1. Location of research stations in the Vistula Lagoon

total phosphorus (Standard Methods 1999) and chlorophyll *a* (International Standard 1997) were also determined.

The sampled material was examined microscopically in order to perform a qualitative and quantitative analysis of the rotifers. The qualitative analysis was based on a classification of the organisms into species, whereas the quantitative analysis consisted in evaluating the abundance and biomass of the zooplankton in conformity with the guidelines by Starmach (1995), Hillbricht-Ilkowska & Patalas (1967), Bottrell et al. (1976) and Ejsmont-Karabin (1998). The structure of rotifers was estimated on the basis of the dominance coefficient proposed by Kasprzak & Niedbała (1981). The trophic state of the Vistula Lagoon was determined using Carlson's trophic indices calculated from: (i) the Secchi disc visibility (TSI_{SD}), (ii) chlorophyll *a* level (TSI_{chl}) and (iii) total phosphorus concentration (TSI_{TP}) (Carlson 1977), and from the rotifer trophic indices calculated on basis of: (i) the number (TSI_{ROT1}), (ii) biomass (TSI_{ROT2}), (iii) proportion of bacterivorous species in the rotifer population (TSI_{ROT3}), (iv) the number-to-biomass ratio (TSI_{ROT4}), (v) the proportion of the *tecta* form in the population of *Keratella cochlearis* (TSI_{ROT5}) and (vi) the proportion of high water trophic indicator species in the number of zooplankton (Ejsmont-Karabin 2012).

The salinity of the two basins was compared using Student's *t*-test. The number of zooplankton species, their abundance and biomass in the two Basins were compared using one-way ANOVA. In order to determine the applicability of rotifer indices for evaluating water quality in the Vistula Lagoon, multiple regression analysis was performed, taking into account the impact of salinity. All statistical analyses were carried out using STATISTICA 10.0 PL software.

3. Results

The Vistula Lagoon was characterized by zonal salinity (Table 1). In the Central Basin (stations 1–12) the salt concentration ($p = 0.0011$, $\alpha = 0.05$) was significantly higher than in the Western Basin (stations 13–23). The biological material sampled in 2007–2011 yielded a total of 44 rotifer species, most of which ($p = 0.0006$, $\alpha = 0.05$) were recorded in the freshwater Western Basin (Figure 2).

Eleven of the the identified species are regarded as indicators of high water trophicity (Table 2). In the qualitative structure, the predominant species at the majority of stations was *Keratella cochlearis cochlearis*, and its proportion in the total number of rotifers ranged from 20.2% to 94.8%. The following species made up a substantial proportion of the total rotifer number: *Filinia longiseta* (11.0–40.4%), *Keratella cochlearis tecta*

Table 1. Average values of salinity and physical and chemical parameters on the basis of which the trophic state of the Vistula Lagoon was determined in the years of the experiment

Habitat	Site	Salinity [PSU]	SDV [m]	chl *a* [μg L^{-1}]	TP [μg L^{-1}]
Central Basin	1	3.9 ± 0.6	0.4 ± 0.2	64.5 ± 27.9	200 ± 74.7
	2	0.1 ± 0.0	0.3 ± 0.1	29.0 ± 11.4	1366 ± 653.2
	3	3.9 ± 0.4	0.4 ± 0.1	52.8 ± 23.2	153 ± 28.5
	4	2.7 ± 0.5	0.3 ± 0.1	54.4 ± 33.4	1016 ± 256.6
	5	3.8 ± 0.5	0.4 ± 0.1	51.1 ± 25.9	189 ± 58.3
	6	2.9 ± 0.8	0.3 ± 0.1	69.6 ± 44.1	820 ± 565.7
	7	3.5 ± 0.6	0.3 ± 0.1	59.0 ± 35.2	193 ± 47.9
	8	3.8 ± 0.5	0.4 ± 0.1	63.6 ± 31.9	169 ± 41.1
	9	3.6 ± 0.8	0.4 ± 0.1	47.8 ± 31.0	173 ± 32.2
	10	3.7 ± 0.4	0.3 ± 0.1	67.2 ± 35.1	167 ± 40.5
	11	3.4 ± 0.9	0.3 ± 0.1	70.4 ± 40.7	215 ± 55.1
	12	3.8 ± 0.7	0.4 ± 0.1	69.3 ± 31.3	174 ± 63.6
Western Basin	13	2.7 ± 0.5	0.4 ± 0.1	77.5 ± 32.8	985 ± 516.5
	14	2.3 ± 0.3	0.3 ± 0.1	57.6 ± 29.7	188 ± 41.0
	15	2.2 ± 1.3	0.3 ± 0.1	56.0 ± 22.0	1756 ± 851.3
	16	1.2 ± 0.2	0.3 ± 0.1	29.5 ± 11.9	108 ± 47.6
	17	1.9 ± 0.4	0.3 ± 0.1	42.6 ± 19.7	150 ± 39.2
	18	2.3 ± 0.2	0.3 ± 0.1	59.8 ± 37.0	184 ± 48.4
	19	2.4 ± 0.5	0.3 ± 0.1	32.8 ± 14.9	195 ± 63.2
	20	1.9 ± 0.3	0.3 ± 0.1	26.2 ± 15.4	159 ± 51.7
	21	2.6 ± 0.8	0.2 ± 0.1	29.5 ± 9.6	171 ± 28.6
	22	1.3 ± 0.2	0.3 ± 0.1	32.8 ± 13.1	213 ± 74.5
	23	1.6 ± 0.7	0.8 ± 0.4	64.9 ± 47.4	1316 ± 577.9

(10.5–32.3%), *Brachionus angularis* at stations 4 (19.3) and 23 (32.6%), *Polyarthra longiremis* at stations 13 (26.4%) and 22 (20.7%), *Pompholyx sulcata* (15.5%) and *Synchaeta oblonga* (35.3%) at station 2.

During the experimental period, the average number of rotifers did not differ significantly between the two Basins: 1773 indiv. L^{-1} in the Central Basin and 1789 indiv. L^{-1} in the Western Basin ($p = 0.9718$, $\alpha = 0.05$, Figure 3). The maximum average abundance of rotifers was recorded at station 11, where *Keratella cochlearis cochlearis* was predominant (77.3% of the total rotifer number), whereas the lowest average density was recorded at station 19, where single rotifers were found.

As in the case of abundance, the average rotifer biomasses did not differ significantly between the two Basins: Central Basin – from 0.02 mg L^{-1} to 1.78 mg L^{-1}; Western Basin – from 0.01 mg L^{-1} to 1.22 mg L^{-1} ($p = 0.5380$, $\alpha = 0.05$, Figure 4). The high abundance of *Keratella cochlearis cochlearis*

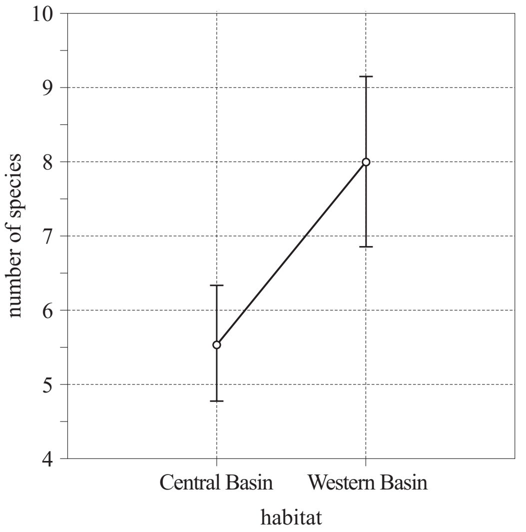

Figure 2. Average number of rotifer species in the Vistula Lagoon Basins during the experimental period

Table 2. Species composition of the rotifers collected from the Vistula Lagoon in 2007–2011

*Anuraeopsis fissa** (Gosse, 1851)	*Lecane luna* (Müller, 1776)
Ascomorpha saltans Batrsch, 1870	*Lepadella ovalis* (Müller, 1786)
Asplanchna priodonta Gosse, 1850	*Monommata longiseta* (Müller, 1786)
*Brachionus angularis** Gosse, 1851	*Mytilina mucronata* (Müller, 1773)
*Brachionus calyciflorus** Pallas, 1766	*Notholca squamula* (Müller, 1786)
*Brachionus diversicornis** Daday, 1883	*Polyarthra longiremis* Carlin, 1943
*Brachionus leydigii** Cohn, 1862	*Polyarthra vulgaris* Carlin, 1943
Brachionus quadridentatus Hermann, 1783	*Pompholyx sulcata** Hudson, 1885
*Brachionus urceolaris** Müller, 1773	*Proales* sp. Gosse, 1886
Cephalodella catellina Müller, 1786	*Rotaria neptunia* (Ehrenberg, 1830)
Cephalodella gibba Ehrenberg, 1832	*Rotaria rotatoria* (Pallas, 1766)
Colurella colurus Ehrenberg, 1830	*Synchaeta* sp. Ehrenberg, 1832
Colurella uncinata Müller, 1773	*Synchaeta baltica* Ehrenberg 1934
Euchlanis dilatata Ehrenberg, 1832	*Synchaeta kitina* Rousselet, 1902
Filinia brachiata Rousselet, 1901	*Synchaeta oblonga* Ehrenberg, 1831
*Filinia longiseta** Ehrenberg, 1834	*Synchaeta pectinata* Ehrenberg, 1832
Filinia terminalis (Plate, 1886)	*Synchaeta tremula* (Müller, 1786)
Keratella cochlearis cochlearis (Gosse,1851)	*Testudinella elliptica* (Ehrenberg, 1834)
*Keratella cochlearis tecta** (Gosse, 1886)	*Trichocerca pusilla** (Lauterborn, 1898)
*Keratella quadrata** (Müller, 1786)	*Trichocerca similis* (Wierzejski, 1893)
Lecane closterocerca (Schmarda, 1859)	*Trichotria pocillum* (Müller, 1776)
Lecane flexilis (Gosse, 1886)	*Trichotria tetractis* (Ehrenberg, 1830)

*species-indicators of high water trophic state (Karabin 1985).

at station 11 contributed to the large biomass there. The same applied to low biomasses, i.e. at station 19 where only single rotifers were found.

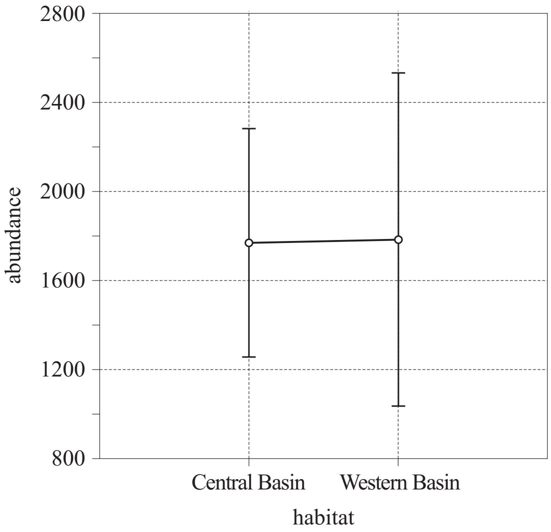

Figure 3. Average abundance of rotifer species in the Vistula Lagoon Basins during the experimental period

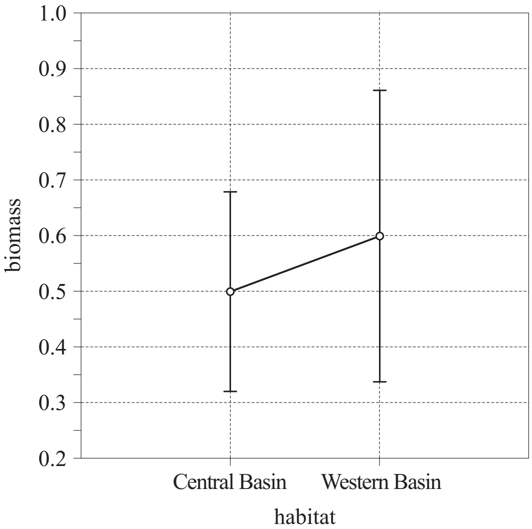

Figure 4. Average biomass of rotifer species in the Vistula Lagoon Basins during the experimental period

In the period under consideration (2007–2011), the trophic state of the Vistula Lagoon, as determined from its physical and chemical parameters (Table 1), explicitly indicated a polytrophic state. The average values of the Carlson coefficient were $TSI_{SD} = 64.0–83.2$, $TSI_{chl} = 78.4–99.1$ and $TSI_{TP} = 71.7–107.0$. The lowest average TSI values were recorded in the eastern part of the Lagoon, in the Central Basin (station 2), the highest values in the Western Basin (stations 19, 23). The biological material was also used to evaluate the trophic state of the Vistula Lagoon. The rotifer trophic state indices were calculated on the basis of this material: they were more varied than the Carlson indices. Given that the average values of $TSI_{ROT1} = 54.8$, $TSI_{ROT2} = 52.6$ and $TSI_{ROT6} = 53.9$, the trophic state of the Vistula Lagoon can be defined as mesoeutrophic. $TSI_{ROT4} = 63.1$ and $TSI_{ROT5} = 58.2$ classify this water body as eutrophic, whereas $TSI_{ROT3} = 64.3$ indicates a polytrophic state. The multiple regression equations obtained for indicators TSI_{ROT1} and TSI_{ROT2} were not statistically significant, which means that, given the values of the independent variables, it is impossible to predict the abundance and biomass of zooplankton. For the indicators TSI_{ROT3}, TSI_{ROT4}, TSI_{ROT5} and TSI_{ROT6} salinity was a statistically significant predictor.

4. Discussion

Together with progressive eutrophication, changes in the physical and chemical parameters of the environment may significantly modify the structure of zooplankton. Fertile water bodies harbour an abundance of small detritus-consuming and predatory forms, including rotifers (Kamaladasa & Jayatunga 2007). Their structure and abundance change with deteriorating oxygen conditions and decreasing water transparency, which accompany the process of eutrophication (Ferdous & Muktadir 2009).

According to many authors who have investigated freshwater water bodies, the numbers and biomass of rotifers have been increasing together with progressive eutrophication (Duggan et al. 2001, 2002, Xiong et al. 2003, Yoshida et al. 2003, May & O'Hare 2005, Tasevska et al. 2010). In addition, an increase in small, bacterivorous species, a decrease in average rotifer weight, an increase in the proportion of the *tecta* form in the population of *Keratella cochlearis* during the summer stagnation, and an increase in the proportion of high trophic indicator species in the total number of zooplankton have all been reported (Špoljar et al. 2011, Ejsmont-Karabin 2012). However, when analysing brackish water bodies, special environmental conditions should be taken into consideration, such as large variations in salinity and temperature that could significantly influence the composition of organisms (Armengol et al. 1998, Joyce et al. 2005, Marques et al. 2006), including that of rotifers (Bosque et al. 2001, Kaya et al. 2010). Salinity may be a significant variable affecting the distribution, abundance and composition of estuarine organisms (Orlando et al. 1994). The present study showed a clear division of the Vistula Lagoon into two zones of different salinity: the brackish Central Basin and the freshwater West Basin. The same observations were made earlier by Żmudziński & Szarejko (1955), Różańska (1963), Oleszkiewicz (1996) and Kruk (2012). Hence, some of the tendencies observed in freshwaters may not be found in brackish water bodies.

While investigating the zooplankton in the Vistula Lagoon, both earlier and in the present study, it was found that rotifers were the numerically predominant organisms (Różańska 1963, Adamkiewicz-Chojnacka 1983, Rychter et al. 2011, Paturej et al. 2012). This offers an excellent opportunity to use these organisms to evaluate the trophic index in this water body. Previous studies showed a pronounced increase in the number and biomass of rotifers together with progressive eutrophication (Heerkloss et al. 1991, Margoński & Horbowa 2003). The fact that the availability of nutrients affects the dominance of rotifers in the zooplankton structure of brackish water has also been reported by other authors. Janakiraman et al. (2010) found a positive correlation between the density of rotifers and the content of ammonium nitrogen. Similarly, Park & Marshall (2000) showed that in highly eutrophic waters the zooplankton biomass was dominated by rotifers, among other organisms, and that their percentage proportion in the biomass increased together with the increase in chlorophyll *a* concentration. Paturej (2006) also reported an increase in the number and biomass of rotifers with progressive eutrophication. However, the studies carried out in 2007–2011 do not corroborate these results. We did not find any significant correlation between the trophic state of the brackish water body and quantitative structure of rotifers.

Another observation reported in the literature was the occurrence of species typical of waters of high trophicity. Some rotifer species are regarded as indicators of eutrophication – they include most of the taxa from the genus *Brachionus*, *Anuraeopsis fissa*, *Keratella cochlearis tecta*, *Keratella quadrata*, *Filinia longiseta*, *Pompholyx sulcata, Proales* sp. and *Trichocerca pusilla* (Karabin 1985). The presence of these taxa in brackish waters has been reported by many authors (Wolska & Piasecki 2004, Paturej & Goździejewska 2005, Mageed 2007, Semenova & Aleksandrov 2009, Tasevska et al. 2010, Dmitrieva & Semenova 2011, Özçalkap & Temel 2011). Although we also recorded the presence of high trophic indicator species in our study, in contrast to Carlson's trophic indices, we found no statistically significant relationship for the bacterivorous rotifers, average rotifer weight or the proportion of the *tecta* form in the population of *Keratella cochlearis*. There was, however a significant correlation between the above-mentioned parameters and salinity. We therefore conclude that salinity is a more important factor in shaping the structure of the Rotifera community in brackish water bodies than trophicity.

In conclusion, rotifers make up a very important part of the zooplankton in brackish water bodies. Nevertheless, studies carried out with rotifer trophic state indices showed their limited applicability to the evaluation of trophic state in brackish waters. This is most probably due to the instability of the environmental conditions in coastal lagoons, mainly the considerable variability in salinity. Therefore, further research into biological methods for evaluating trophic state in brackish waters with zooplankton is warranted.

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