

## **Qualitative and quantitative methods for sampling zooplankton in shallow coastal estuaries**

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### **Abstract**

There are many techniques for collecting zooplankton, hence the data obtained using different methods can differ from each other. The effectiveness of quantitative and qualitative zooplankton sampling with the use of the Ruttner sampler and the Apstein plankton net was compared during a study conducted in the Vistula Lagoon.

The analyzed zooplankton community comprised Crustacea and Rotifera species. No significant differences ( $p = 0.5294$ ,  $\alpha = 0.05$ ) in the qualitative composition of zooplankton samples collected with the Ruttner sampler and the Apstein plankton net were noted in the saltwater intrusion section. Significant differences ( $p = 0.0277$ ,  $\alpha = 0.05$ ) were observed in the freshwater inflow, indicating that the Ruttner sampler delivers more reliable results in zooplankton communities marked by greater qualitative variation. Significant differences ( $\alpha = 0.05$ ;  $p = 0.0008$  for saline section and  $p = 0.0000$  in freshwater section) in the effectiveness of quantitative sampling from both lagoon sections suggest that fewer individuals are collected with the plankton net than with the Ruttner sampler.

**Key words:** catching devices/sampling gears, Ruttner sampler, plankton net, Vistula Lagoon, gear efficiency.

### **1. Introduction**

Many different devices are used for sampling zooplankton. Every sampler has its advantages and limitations in terms of sampling ease and efficiency, which is why hydrobiologists search for devices that could increase sampling efficiency and decrease human effort (Nunez *et al.* 2008).

There is no single, standardized method for collecting zooplankton samples. Various sampling tools are used, including simple plankton nets, scoops, vessels, pumps as well as devices that rely on the

latest technological advancements, such as Video Plankton Recorders (VPR), Optical Plankton Counters (OPR) or Remotely Operated Vehicles (ROV). The results of studies examining material collected with the use of various tools are difficult to compare since the efficiency of the deployed devices varies subject to the parameters of the studied communities and the local environment (Adamkiewicz-Chojnacka, Róžańska 1985; Kršinić 1990). Analyses of lake trophy, ecological structure and pollution levels require reliable information about zooplankton's

qualitative and quantitative composition (Karjalainen *et al.* 1996). The deployed sampling tools should guarantee reliable measurements. Despite the availability of sophisticated devices that both collect and process zooplankton samples (Masson *et al.* 2004), plankton nets and scoops continue to be the most popular collection tools.

A plankton net is the oldest plankton sampling device. Zooplankton is caught by throwing it and dragging through the upper layers of the reservoir. This method, although simple and inexpensive, has certain drawbacks. Construction of the net, their mesh sizes, porosity, speed of sampling, avoidance by target organisms, escape of sampled organisms, and clogging may influence size and taxa as well as abundance of collected animals. Samples collected with a plankton net in shallow waters of the littoral zone and in areas with dense phytoplankton fail to deliver reliable results. When towed, the net creates powerful hydrodynamic whirlpools that could further lower catching efficiency (Starmach 1955; Kršinić 1990).

Popular plankton collection devices are also gears, such as Ruttner sampler. It is used to collect plankton from the surface as well as from deeper strata. Its main disadvantage is a flat bottom which can create whirlpools when immersed, thus falsifying the results (Starmach 1955).

The efficiency of the above tools varies due to differences in their structure and sampling accuracy. The data supplied by the two devices cannot be compared, which undermines the reliability of research results. The selection of appropriate sampling equipments poses another difficulty since estuarine waters are usually shallow which excludes the use of certain devices.

The objective of this study was to analyze the differences in the structure and density of zooplankton communities collected with the Ruttner sampler and the plankton net, and to compare the efficiency of both devices in studies of zooplankton composition and abundance in shallow coastal bodies of water.

## 2. Materials and methods

The study was carried out in the Polish section of the Vistula Lagoon with an area of 328 km<sup>2</sup>, which accounts for 43.8% of its total area, located according to Kondracki (2001) in the macroregion of the Gdańsk Coastland. This brackish lagoon stretches along a 90 km section of the southern Baltic coast. The lagoon is partially cut off from the Baltic Sea by the Vistula Spit, and the only point of connection is the Strait of Pilawa (Strait of Baltiysk).

The catchment basin of the Vistula Lagoon covers a total area of 23 871 km<sup>2</sup>, of which 61% belongs to Poland (Chubarenko, Margoński 2008).

Freshwater is supplied by rivers that feed into the lagoon. Pregola, the largest river on the Russian side of the lagoon, supplies 42% of freshwater (Chubarenko, Tchepikova 2001). The key contributors on the Polish side of the Vistula Lagoon are the rivers Pasłęka, Elbląg and Nogat. The intrusion of saline waters from the Baltic Sea takes place via the Strait of Baltiysk (Bielecka, Kazmierski 2003).

The Vistula Lagoon is a very shallow body of water with an average depth of only 2.7 m and a maximum depth of 5.2 m (Chubarenko, Margoński 2008). The lagoon's small depth and inland location prevent thermal and salinity stratification. Water temperature is homogenous through most parts of the year, and partial stratification may be observed only in winter under ice cover. Salinity levels, determined in the range of 1 PSU at the mouth of the Nogat River to around 7 PSU near the Strait of Baltiysk, fluctuate on a seasonal basis. The lowest salinity is reported in the winter when ice cover prevents the mixing of waters and inhibits inflows from the Baltic Sea. The highest salinity levels are observed in the fall when strong winds force the flow of sea waters into the lagoon (Róžańska 1963).

With respect to its biological and hydrographic conditions, the Polish part of the Vistula Lagoon is divided into two regions: the section close to the river mouth and a central region. The area near the river mouth, characterized by freshwaters due to river inflows, is enclosed by the Vistula River delta to the line connecting Kały, the Gdańsk Lighthouse and the wharf. The central part of the lagoon is characterized by varied salinity, significant wave motion and a sandy bottom (Żmudziński, Szarejko 1955).

The effectiveness of selected zooplankton sampling devices – the Ruttner sampler with the capacity of 5 dm<sup>3</sup> and the Apstein plankton net with 30 µm mesh – was determined by performing qualitative and quantitative analyses of zooplankton collected in the saline and freshwater sections of the Vistula Lagoon. In this case, in August 2006, biological material was sampled, simultaneously with both tested tools, at 11 sites in the saline part (sites 1-11) and 10 sites in the freshwater section of the Vistula Lagoon (sites 12-21) (Fig. 1). A total of 42 samples were collected for biological analyses. For both of the tools the same volume of samples were taken (25 liters of water), based on the Ruttner sampler capacity, and on the area of the plankton net's inlet opening. With the Ruttner sampler material was collected from the surface to the depth of 1 m, then it was concentrated in a plankton net, and fixed with Lugol's solution and 4% formalin solution. With the plankton net samples were gathered by a single 1 m long haul from the depth of 1 m, and then fixed in the same way as in the case of Ruttner samples.

A qualitative analysis of material involved the classification of planktonic organisms into three

taxonomic groups: Rotifera, Cladocera and Copepoda. A quantitative analysis was performed according to the methods proposed by Starmach (1955), Hillbricht-Ilkowska, Patalas (1967) and Bottrel *et al.* (1976).

The effectiveness of material collections performed with the use of the Ruttner sampler and the Apstein plankton net was compared statistically in the *STATISTICA PL 8.0* application. The quantitative effectiveness of zooplankton sampling was compared by the dependent t-test for paired samples ( $\alpha = 0.05$ ) to verify the null hypothesis ( $H_0$ ), stating that there are no significant differences in zooplankton abundance between two tested devices. The comparison of qualitative efficiency of zooplankton collection was performed using a Wilcoxon signed-rank test. There was estimated the probability of the null hypothesis ( $H_0$ ) that the share of individual taxa in the compared methods are the same.

### 3. Results

A qualitative analysis of zooplankton revealed the presence of 12 species in the freshwater part of the Vistula Lagoon (8 Rotifera, 3 Cladocera and 1 Copepoda) and 17 species in the saline region (8 Rotifera, 3 Cladocera and 6 Copepoda) (Table I).

A detailed qualitative analysis of the material harvested in the lagoon's freshwater part revealed greater species diversity of zooplankton collected with the Ruttner sampler. The zooplankton species composition from the plankton net was less diverse, and it did not account for the following taxa: *Bosmina longirostris*, *Asplanchna priodonta*, *Trichocerca pusilla* and *Filinia longiseta* – all of which were identified in the samples collected with the other tested device. The presence of *Chydorus sphaericus* and *Cyclops vicinus* was noted in samples gathered from all sites. The collections made with both devices yielded a similar number of species which ranged from 5 to 9 in the material from the Ruttner sample, and from 5 to 8 in samples from the plankton net. In the saline region, the species composition of plankton fauna collected with a net did not differ significantly from that gathered with the Ruttner sampler. *Acartia tonsa* and two forms of *Keratella cochlearis* were noted in the samples from both tested devices at all sites. The presence of *Chydorus sphaericus*, *Diaphanosoma brachyurum* and *Acartia longiremis* was reported in the majority of sites. *Leptodora kindtii* and *Keratella quadrata* were observed sporadically. The only species not identified in the material from a plankton net was *Asplanchna priodonta*. The reason for this phenomenon could be very low abundance of this taxa. In

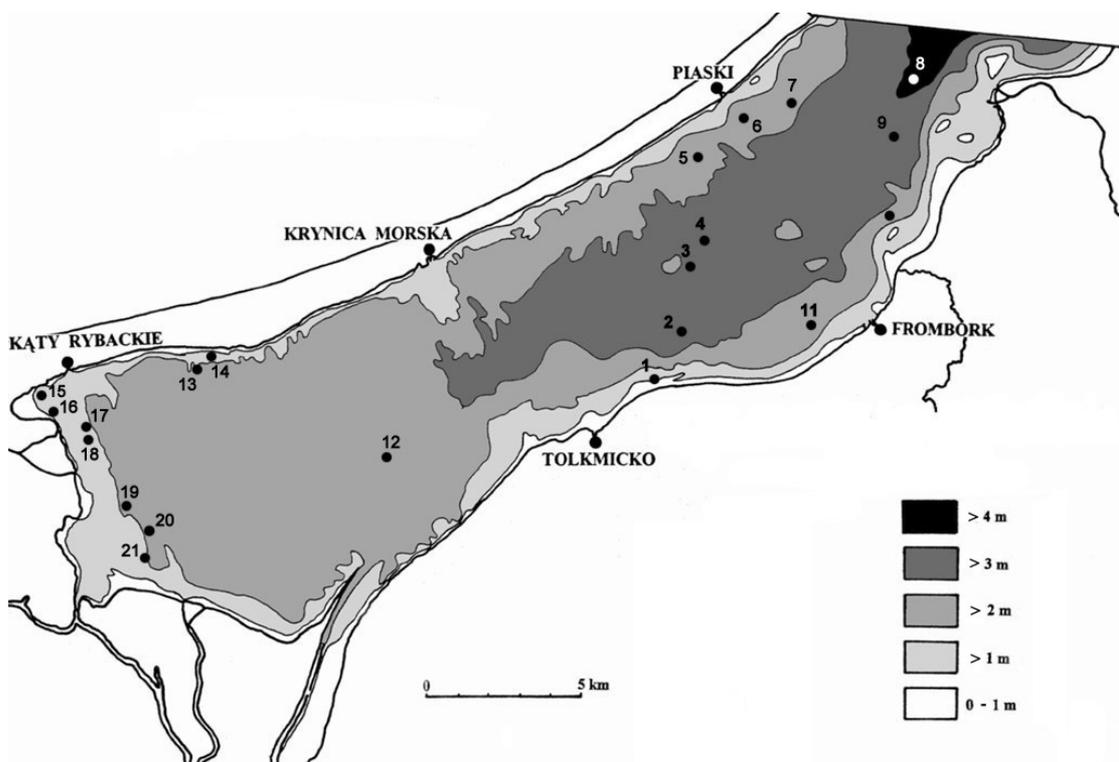


Fig. 1. Sampling sites in the Vistula Lagoon.

**Table 1.** Species composition of zooplankton in the saline and freshwater sections of the Vistula Lagoon and the number of species in samples collected with the Ruttner sampler (LR) and the plankton net (Ls).

Site	freshwater section																																					
	Saline section																																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21																	
LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls	LR Ls																	
<i>Asplanchna priodonta</i> (Gosse 1850)																																						
<i>Brachionus angularis</i> (Gosse 1851)	+	+	+	+																																		
<i>Filinia longiseta</i> (Ehrenberg 1934)				+																																		
<i>Keratella cochlearis tecta</i> (Gosse 1886)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+																	
<i>Keratella cochlearis cochlearis</i> (Gosse 1851)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+																	
<i>Keratella quadrata</i> (O.F. Müller 1786)	+																																					
<i>Polyarthra euryptera</i> (Ehrenberg 1838)																																						
<i>Pompholyx sulcata</i> (Hudson 1885)																																						
<i>Trichocerca pusilla</i> (Lauterborn 1898)	+	+																																				
<i>Bosmina longirostris</i> (O.F. Müller 1785)																																						
<i>Chydorus sphaericus</i> (O.F. Müller 1785)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+																	
<i>Diaphanosoma brachyurum</i> (Liévin 1848)	+	+	+																																			
<i>Leptodora kindtii</i> (Focke 1844)	+																																					
<i>Acartia longiremis</i> (Dana 1846)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+																	
<i>Acartia tonsa</i> (Dana 1846)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+																	
<i>Acartia bifilosa</i> (Ciesbrecht 1881)																																						
<i>Centropages hamatus</i> (Lilljeborg 1853)	+	+																																				
<i>Cyclops vicinus</i> (Uljanin 1875)																																						
<i>Eurytemora affinis</i> (Poppe 1880)	+	+																																				
<i>Mesocyclops leuckartii</i> (Claus 1857)	+	+	+	+																																		
Number of zooplankton species	10	8	6	11	7	7	8	9	6	6	7	7	6	6	8	8	9	8	7	10	7	5	5	4	7	7	5	4	5	5	8	6	6	5	6	4	6	6

samples from a second tool there were observed only a single individuals. In samples collected with the Ruttner device, the number of species ranged from 4 to 8 at each site. A similar number of taxa (5-9) was reported in net collections (Table I).

Three taxonomic groups were identified in the zooplankton of the Vistula Lagoon: Cladocera, Copepoda and Rotifera. In the freshwater section, water fleas were the most populous represented group of planktonic organisms (52.6% of total zooplankton density). They were followed by copepods (33.8%), while rotifers were the least abundant group and constituted only 13.6% share of total zooplankton density. In the saline region, copepods were the predominant species (45%), although their abundance approximated that of the rotifers (40.3%). The least abundant group of plankton organisms in the saline section of the lagoon were Cladocera (14.6%) (Fig. 2).

The zooplankton of the freshwater part of the Vistula Lagoon was characterized by a diverse distribution pattern. Rotifera were most populous represented by *Brachionus angularis* at nearly all analyzed sites. Its abundance ranged from 6 ind. L<sup>-3</sup> in samples collected with a net to 142 ind. L<sup>-3</sup> in material from the Ruttner sampler. Relatively large populations of *Keratella cochlearis cochlearis* (1-79 ind. L<sup>-3</sup>) and *Keratella cochlearis tecta* (1-111 ind. L<sup>-3</sup>) were also observed. The density of the remaining taxa was below 10 ind. L<sup>-3</sup>. Species such as *Asplanchna priodonta*, *Filinia longiseta* and *Trichocerca pusilla* were noted only in material gathered with the Ruttner device. *Pompholyx sulcata* formed equally small populations, but it

was determined in both types of samples. The only Rotifera species found in all saline water samples were *Keratella cochlearis tecta* and *Keratella cochlearis cochlearis*. The remaining taxa were noted at individual sites. *Polyarthra euryptera* was reported from only three sites with maximum abundance of 100 ind. L<sup>-3</sup>. *Brachionus angularis* was observed at four sites, but its abundance was generally low.

Only 3 Cladocera species were identified, nonetheless those taxa formed relatively large populations. Species occurring at all stations was *Chydorus sphaericus*. Its abundance ranged from 14 ind. L<sup>-3</sup> in net samples to 890 ind. L<sup>-3</sup> in the material collected with the Ruttner sampler. In general, the above species was more highly represented in samples gathered with the Ruttner device. The remaining taxa, *Bosmina longirostris* and *Diaphanosoma brachyurum*, were noted sporadically, and the former was reported only in collections from the Ruttner sampler. As regards Cladocera populations in the saline part of the lagoon, *Diaphanosoma brachyurum* was determined at the majority of sites in material from both tested devices. The above taxon formed relatively wide populations of 5 to 52 ind. L<sup>-3</sup>. *Chydorus sphaericus* did not colonize all sites, and its density ranged from trace quantities to 33 individuals per sample. The presence of *Leptodora kindtii* was observed only at the first site, at the density of 5 and 7 ind. L<sup>-3</sup>, respectively.

*Cyclops vicinus* was the only copepod species reported in the freshwater part. The taxon was abundant in material from the plankton net and the Ruttner sampler in all analyzed sites. The examined samples also revealed the presence of juvenile

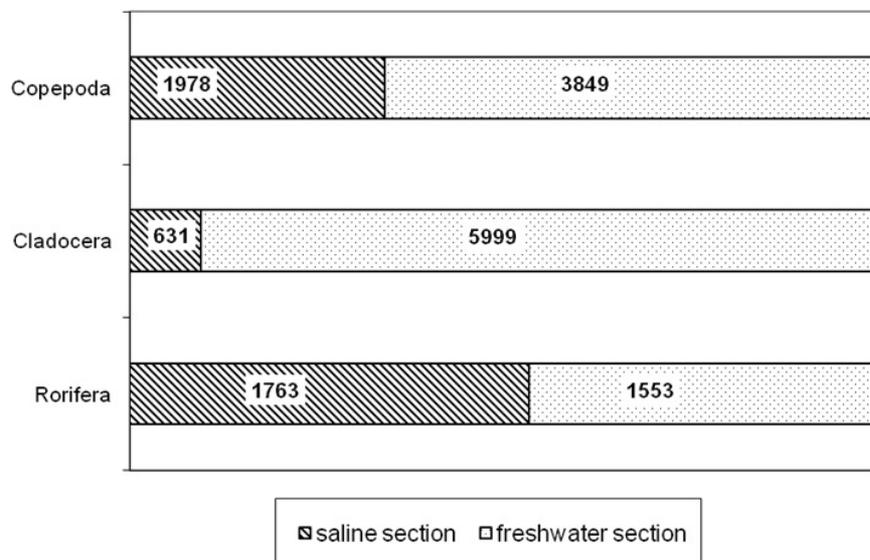


Fig. 2. Total zooplankton abundance (ind. L<sup>-3</sup>) in the saline and freshwater sections of the Vistula Lagoon in August 2006.

stages of copepods which were marked by similar abundance in both types of collected material. Copepodite stages of the Copepoda were rarely noted, but they were more abundant in samples gathered with the Ruttner device. A higher number of Copepoda species was determined in the saline section of the Vistula Lagoon. *Acartia tonsa* and *Acartia longiremis* were noted at all sites with the density of 2-42 ind. L<sup>-3</sup> and 2-71 ind. L<sup>-3</sup>, respectively, in samples collected with the Ruttner device, and 1-29 indiv. dm<sup>-3</sup> and 1-56 indiv. dm<sup>-3</sup>, respectively, in material sampled with the plankton net. Taxa such as *Acartia bifilosa*, *Eurytemora affinis*, *Centropages hamatus* and *Mesocyclops leuckarti* were observed only at selected sites where they formed very small populations, in particular *Eurytemora affinis* and *Centropages hamatus* (from 1 to 6 ind. L<sup>-3</sup>). Copepodites and nauplii were the predominant forms of this subclass, and they were observed in abundance at all sites (623 ind. L<sup>-3</sup> in material from the Ruttner sampler and 511 ind. L<sup>-3</sup> in samples collected with the plankton net).

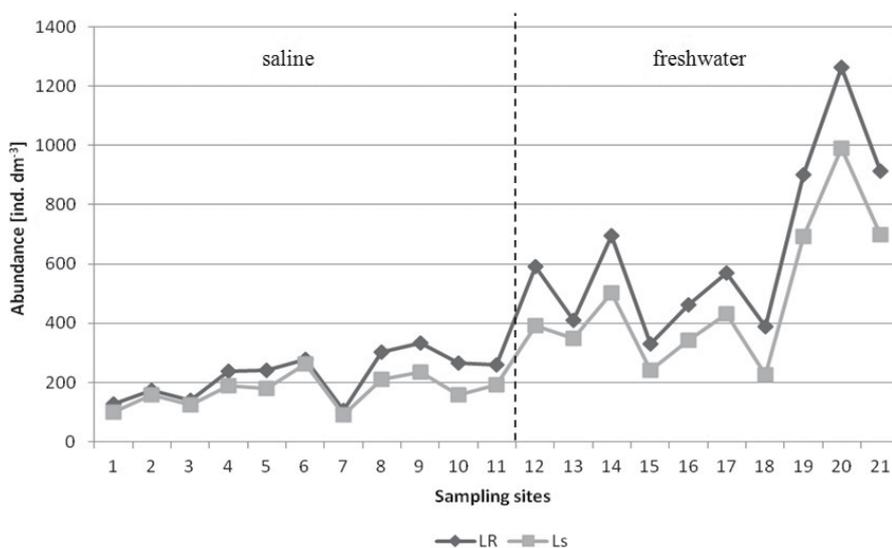
In general, the total abundance of zooplankton species at the studied sites was determined in the range of 91-991 ind. L<sup>-3</sup> (plankton net) to 106-1264 ind. L<sup>-3</sup> (Ruttner sampler). Higher abundance was noted in freshwater material collected both with the Ruttner sampler (6533 ± 296 ind. L<sup>-3</sup>) and the plankton net (4868 ± 241 ind. L<sup>-3</sup>). In the saline region of the lagoon, plankton density reached 2465 ± 76 ind. L<sup>-3</sup> in the material from the Ruttner device and 1907 ± 55 ind. L<sup>-3</sup> in net samples. The material collected with the Ruttner sampler was characterized by higher abundance than the specimens

gathered with the plankton net at all sites (Fig. 3). The total abundance of samples from the Ruttner sampler was higher by 558 ind. L<sup>-3</sup> in the saline part and by 1665 ind. L<sup>-3</sup> in the freshwater section.

The Wilcoxon test shows no statistical difference (0.5294,  $\alpha = 0.05$ ) between Ruttner sampler and plankton net in terms of their qualitative efficiency in the saline part of the lagoon. While in the freshwater section, significant differences in qualitative collection were reported between the Ruttner sampler and the plankton net ( $p = 0.0277$ ,  $\alpha = 0.05$ ). The above indicates that material collected with the Ruttner device has a qualitative composition closer to the actual than net samples. In turn comparing the quantitative effectiveness of sampling with tested gears showed statistically significant differences in the zooplankton densities collected with the Ruttner sampler and plankton net, both in the saline ( $p = 0.0008$ ,  $\alpha = 0.05$ ) and freshwater ( $p = 0.0000$ ,  $\alpha = 0.05$ ) parts of the Vistula Lagoon. It can, therefore, be concluded that the plankton net caught fewer zooplankton individuals than the Ruttner device.

#### 4. Discussion

The horizontal and vertical distribution of zooplankton populations is determined by various factors, and may vary widely (John *et al.* 2001). Environmental factors, such as temperature, dissolved oxygen levels and light access, as well as biotic factors, including the predation pressure of planktivorous fish, significantly affect the taxonomic composition and abundance of zooplankton



**Fig. 3.** Zooplankton abundance (ind. L<sup>-3</sup>) in samples collected in the Vistula Lagoon in August 2006 with the use of the Ruttner sampler (LR) and the plankton net (Ls).

communities (Lampert, Sommer 1996, Wang *et al.* 2007). Dissolved salt content is one of the key factors modifying the zooplankton structure of the Vistula Lagoon. The mixing of saline water from the Baltic Sea with freshwater inflows from rivers that feed into the lagoon creates a supportive environment for specific plankton habitats. For this reason, the Vistula Lagoon has been divided into a freshwater region (close to the river mouth in the south-western part of the water body) and the seawater intrusion section (central part of the lagoon) (Róžańska 1964). The lagoon's zooplankton is represented mainly by Rotifera, Cladocera and Copepoda. Low and varied salinity levels do not support the growth of numerous plankton species (Róžańska 1964). The Vistula Lagoon is inhabited by freshwater species characteristic of river-mouth areas, marine taxa as well as species characteristic of brackish waters found in the area affected by saline water intrusion (Siudziński 1977). An analysis of the species composition and abundance of the studied zooplankton groups indicates that the qualitative and quantitative structure of Rotifera is similar in both freshwater and saline sections of the lagoon. As regards crustaceans, a higher number of Copepoda species was observed in the saline region. Cladocera and Copepoda formed visibly more abundant populations in the freshwater section of the analyzed water body. The zooplankton composition of the Vistula Lagoon has remained fairly constant over the years, as demonstrated by Róžańska (1962, 1963, 1964), Adamkiewicz-Chojnacka (1978) and Adamkiewicz-Chojnacka, Majerski (1980).

The differences in the distribution of planktonic organisms can significantly influence sampling effectiveness. For this reason, any changes in sampling procedures and tools could produce notable differences in zooplankton density. A comparison of samples collected with the involvement of various methods could, therefore, lead to discrepancies in the interpretation of results and false conclusions. This risk is particularly high in water bodies characterized by highly diverse zooplankton structure and trophic levels (Masson *et al.* 2004).

None of the existing plankton sampling devices are suitable for use in all types of aquatic environments. The majority of traditional tools, such as tow-nets and plankton traps, have been designed for the open waters of large and deep lakes (Paggi *et al.* 2001).

Very few studies have compared the effectiveness of zooplankton sampling tools, and most research efforts focus on the density rather than the species diversity of the observed populations. The majority of studies compare plankton nets with various types of bathymeters, traps and plankton pumps which are generally found to be superior to

the former. The Ruttner sampler proved to be a more effective catching device than the plankton net in our study. Significant differences were noted in the density of zooplankton collected with the Ruttner device and the plankton net. Our results suggest that fewer individuals are collected with the plankton net than the Ruttner sampler. The above correlation was observed already in the 1970s during a study of the Vistula Lagoon conducted by Adamkiewicz-Chojnacka, Róžańska (1985). The above authors fitted a regression curve to experimental data for the purpose of comparing the material collected with a plankton net and the Ruttner sampler. In most samples, the Ruttner device yielded more abundant populations, but both tools were characterized by similar variations in abundance. The cited researchers concluded that both tools can be successfully deployed in studies of the Vistula Lagoon's zooplankton to examine general changes in faunal abundance, whereas the abundance of specific populations is more reliably estimated with the use of the Ruttner sampler.

In a study of the coastal waters of the Baltic Sea, Wiktor (1982) observed the highest species diversity of samples collected with the Apstein plankton net in comparison with other tested devices, i.e. Patalas plankton trap and Nansen plankton net. The material from the Apstein net was characterized by the highest general abundance (individuals per m<sup>3</sup>), which points to the higher efficiency of this device. The above results were reported solely in respect of crustaceans, one of the key zooplankton components in the studied area. As regards Rotifera and Cladocera organisms, the Apstein net proved to be a less efficient catching device than the Patalas sampler. The cited author concluded that the Patalas sampler was a superior device for analyzing the distribution, abundance and dynamics of the above zooplankton groups, whereas the Apstein net was suitable for collecting general information about the development of zooplankton. In comparison with the above devices, the Nansen net produced underestimated results in all zooplankton groups, therefore, it was regarded as unsuitable for studies investigating the coastal belt of the Baltic Sea.

The limited effectiveness of zooplankton sampling with plankton nets has been demonstrated by numerous authors. Plankton nets are not suitable for quantitative sampling, as they do not perform equally for all species. Their efficiency is determined by the size of animals, hauling speed and mesh clogging (Knoechel, Campbell 1992).

Karjalainen *et al.* (1996) found that plankton nets were less efficient than tube samplers. Significant differences (Wilcoxon test,  $p < 0.05$ ) in population density were noted only with regard to rotifers and naupilii, while they were not reported

for other zooplankton groups. The above authors concluded that the tube sampler yielded more reliable results in reference to small-sized animals, whereas the plankton net was found to be a more efficient device for collecting large, rare or mobile organisms. Devries *et al.* (1991) compared the density of zooplankton material collected with a plankton net, a tube sampler and the Schindler-Patalas trap. In their study, the density of samples from the tube sampler was generally equal to or higher than the density of material gathered with the plankton net and the Schindler-Patalas trap. A comparison of the plankton net and the plankton pump produced similar results. Samples collected with the pump more accurately reflected the density of zooplankton populations, whereas the net was more effective in catching swimming organisms. The sampling process involving the plankton net was faster, easier and less expensive (Masson *et al.* 2004). Recent comparative studies point to the lower efficiency of plankton nets. A comparison of quantitative data obtained with the use of Wisconsin nets and column samplers suggests that the latter are characterized by greater precision with respect to zooplankton sampling in shallow homogenous water bodies (Livings *et al.* 2010). In another study, a new sampling device, the Nunez sampler, was compared with three long-employed catching devices, an integrated tube sampler, a plankton tow, and a Van Dorn bottle. The plankton tow proved least effective. The efficiency of the Nunez sampler, the integrated tube sampler and the Van Dorn bottle was comparable. The Nunez sampler is also characterized by ease of use and a fast mode of operation (Nunez *et al.* 2008).

A comparison of the effectiveness of the Bongo plankton net and the Longhurst-Hardy Plankton Recorder (LHPR) showed that the LHPR is a more effective tool for evaluating zooplankton abundance and biomass. Total zooplankton biomass determined with the use of LHPR was significantly higher than that estimated with the Bongo net (Stehle *et al.* 2007). In 1978–2006, Kane (2009) compared data from Bongo net and Continuous Plankton Recorder (CPR) samples. Long-term (interannual) trends and seasonal variability in total zooplankton counts determined with the use of both samplers were similar. Absolute zooplankton abundance levels were higher in Bongo net samples, while the abundance of several taxa was underestimated in CPR samples. The CPR supported more accurate identification of regional trends in zooplankton abundance. The results of comparing the CPR and vertical net hauls were quite different. Zooplankton abundance was substantially higher in the CPR samples (144–103 indiv. m<sup>-3</sup> on average) than in the net samples (82–47 indiv. m<sup>-3</sup> on average) (Hunt, Hosie 2003).

Remsen *et al.* (2004) used a High Resolution Sampler, a towed-platform that can concurrently sample zooplankton with plankton nets, an Optical Plankton Counter (OPC) and the Shadowed Image Particle Profiling and Evaluation Recorder (SIPPER), a zooplankton imaging system, to directly compare zooplankton abundance, biomass, taxonomic composition and size distribution between simultaneously collected net samples, OPC data and digital imagery. Plankton nets were again found to be less efficient than optical and digital devices. The net data were taxonomically similar to the results of previous studies in the region, but nets significantly underestimated zooplankton abundance and biomass. According to the cited authors, *in situ* imaging sensors should be included in comparative zooplankton studies. The application of OPC is limited by the presence of suspended solids, since the device is not able to distinguish between detritus particles and zooplankton (Li *et al.* 2010).

The quantitative efficiency of samples collected with a plankton net is relatively low, nevertheless the net is a useful supporting tool in the process of biological sampling. Cook, Hays (2001) compared the effectiveness of a plankton net (WP2) and an automated plankton sampler (U-Tow). Their results indicate that U-Tow accurately determines the species composition of the studied populations, but zooplankton density values were substantially overestimated. In this case, the plankton net can be additionally applied to calibrate the results. As demonstrated by Broughton and Lough (2006), the use of a plankton net and another sampler increases the accuracy and efficiency of sampling. The authors compared data from a Video Plankton Recorder (VPR) and a Multiple Opening and Closing Environmental Sensing System (MOCNESS). The proportional contribution of taxa to the total zooplankton abundance was not affected by differing gear, but the VPR produced two-fold higher abundances than the MOCNESS. In this case, VPR data could be verified using net sampled zooplankton data.

Plankton nets are not always less efficient than other zooplankton samplers. Nayar *et al.* (2002) evaluated the performance of a newly-designed, portable, pump-based zooplankton sampler (ZOOPHY), as compared with the conventional towed plankton net. The authors found no statistically significant differences in the species composition and total abundance of zooplankton sampled with the two gears, and concluded that ZOOPHY was as efficient in collecting zooplankton as conventional plankton nets. The pump-based sampler allows to avoid such problems as improper metering and mesh clogging, frequently encountered while using towed plankton gears.

The efficiency of plankton nets has also been studied. Gjørseter *et al.* (2000) compared the perfor-

mance of WP2 and MOCNESS nets. WP2 biomass values were higher for the smallest size zooplankton fraction, whereas the MOCNESS tended to give higher biomass values for the largest size fraction. However, the total zooplankton biomass obtained by these two methods was not significantly different, suggesting that data from both types of gear should be used to estimate total zooplankton biomass over larger areas. A study comparing the sampling efficiency of CalCOFI ring nets and bongo nets yielded similar results. The only consistent difference detected between these two nets was a significant increase in the abundance of salps in the bongo net (Ohman, Lavaniegos 2002). Gorbatenko, Dolganova (2007) compared the qualitative and quantitative characteristics of zooplankton caught using five different types of plankton nets. According to the cited authors, in complex hydrobiological studies involving both qualitative analyses and quantitative estimates of zooplankton, the material should be collected with different instruments. Big Juday nets and bongo nets were found to be most suitable for that purpose.

Few authors have compared sampling gears without accounting for the plankton net. In a study comparing the tube sampler with the Schindler-Patalas plankton trap, Knoechel, Campbell (1992) observed that the quantitative efficiency of the tube sampler was comparable to that of the trap, while the sampling effort was visibly reduced.

Some devices can be used to describe the vertical distribution of zooplankton. Halliday *et al.* (2001) carried out sampling with the use of a double Longhurst-Hardy Plankton Recorder (LHPR) system, and they compared the obtained results with concurrent Optical Plankton Counter (OPC) data. Zooplankton abundance recorded by the OPC was higher throughout the water column, compared with the LHPR, therefore OPC data should be interpreted cautiously. Similar conclusions were formulated by Grant *et al.* (2000) who also compared the above two devices. Differences in absolute zooplankton abundance determined using LHPR and a Continuous Plankton Recorder (CPR) were noted in another study. The efficiency of CPR was lower, in comparison with LHPR (abundance underestimation), most probably due to the active avoidance of the former by some zooplankton species (Richardson *et al.* 2004). Batten *et al.* (2003) reported that catches with the use of CPR are almost always lower, compared with other devices, but CPR data well reflect the seasonal cycles of zooplankton.

Zooplankton collection in shallow vegetated bodies of water poses serious difficulty. Samples are usually collected with gear originally designed for lakes (Frisch, Wohltmann 2005), unsuitable for sampling shallow habitats. Therefore, efforts are

made to design new devices for sampling zooplankton in shallow ponds, and their efficiency is tested by comparing against the existing performance standards. Paggi *et al.* (2001) compared the efficiency of a self-designed trap tube sampler (TTS), the Ruttner bottle (RB) and the Schindler-Patalas plankton trap (SPPT) in shallow waters. TTS was found to be equally or more effective than SPPT and RB. TTS created small whirlpools, and when pulled out of the water, the device did not contribute to the resuspension of bottom deposits. A bag-sampler, another simple device for collecting zooplankton in shallow vegetated ponds, was characterized by higher efficiency than a plastic beaker. The bag sampler supported the collection of a larger number of species and higher densities of copepods. The samples collected with the bag sampler revealed differences in the distribution pattern of copepod development stages in the investigated water body. Other advantages of the bag-sampler include its small size and weight, and the possibility of fast exchange of sample bags between sample locations (Frisch, Wohltmann 2005).

The efficiency of the tested devices cannot be determined with equal certainty in qualitative analyses. In a study comparing the effectiveness of the plankton net and the plankton pump, Masson *et al.* (2004) did not observe differences in the species composition of zooplankton samples. In this study, the species composition of zooplankton in the Vistula Lagoon differed between samples collected with a bathymeter and a net only in the freshwater section. Our results suggest that in addition to the method of collection, sampling efficiency is also affected by environmental factors that contribute to the qualitative variation of the analyzed populations. The samples collected with the Ruttner sampler yielded more reliable results. The Ruttner device is particularly effective in sampling small planktonic organisms (De Bernardi 1984). This observation was validated by Kakareko *et al.* (2008) who reported the presence of large cladoceran species, such as *Leptodora kindtii* and *Bythotrephes longimanus*, in the gastric digesta of fish, but not in lake water samples collected with the plankton net and the Ruttner sampler. The above suggests that large predatory crustaceans are capable of escaping from both devices.

### Conclusions

The Vistula Lagoon is a brackish water body that is exposed to both continental and marine impacts. The lagoon's zooplankton was studied to compare the qualitative and quantitative effectiveness of two sampling tools (Ruttner sampler and Apstein plankton net). The zooplankton structure at the examined sites was determined.

The zooplankton of the Vistula Lagoon comprises three groups of organisms: Rotifera, Cladocera and Copepoda. The number of planktonic species is spatially diversified. The greatest species diversity is observed in respect of Rotifera taxa collected both with the Ruttner sampler and the plankton net. The noted fluctuations in the quality and quantity of zooplankton can be attributed to variations in local abiotic conditions. Cladocera are the predominant group in the freshwater section of the Vistula Lagoon, followed by Copepoda and Rotifera. In the saline region, copepods were observed in greatest abundance, rotifers were only slightly less abundant, while cladocerans were characterized by the lowest population density.

The effectiveness of the Ruttner sampler and the Apstein plankton net was compared by the t-test (quantitative sampling effectiveness) and the Wilcoxon signed-rank test (qualitative sampling effectiveness). The observed differences in the species composition of material collected in the saline section imply that the Ruttner sampler yields more reliable results in habitats characterized by greater qualitative diversity of zooplankton communities, resulting most probably from the impacts of environmental factors. The plankton net produced less accurate data on quantitative catches in both saline and freshwater sections, and zooplankton abundance was more reliably estimated with the use of the Ruttner sampler.

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