Estonian Journal of Ecology, 2014, **63**, 4, 232–241 doi: 10.3176/eco.2014.4.03

Mean weight and total biomass of zooplankton as a core indicator of biodiversity of the Marine Strategy Framework Directive: an example of the Gulf of Riga

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Received 21 July 2014, revised 22 September 2014, accepted 1 October 2014

Abstract. Zooplankton has been acknowledged as an intermediate link between bottom-up and top-town regulators, thereby indirectly describing trophic interactions in various food webs. We used zooplankton as a core indicator of biodiversity in the species-poor ecosystem of the northeastern Gulf of Riga by evaluating its role as a dietary component of pelagic fishes. Furthermore, seasonal and interannual variation of total abundance and biomass of zooplankton with mean individual weight of a zooplankter was analysed based on field data collected between 1957 and 2013. The dominating species in mesozooplankton were rotifers and copepods. Abundance and biomass estimates of zooplankton indicated the highest values during summer months (June: peak abundance; August: highest biomass). The dominating species during the peak abundance were rotifers and copepods; the biomass maximum was indicated by copepods (in June) and cladocerans (in July and August). When averaged over summers, the total zooplankton abundance was 156.2 ± 2.4 thousand ind/m^3, biomass 62.9 ± 1.3 mgC/m^3, and zooplankter individual weight 0.433 ± 0.004 μgC/ind. Our study showed that mean zooplankter weight and total zooplankton biomass correlated with the age-specific herring weight data. To conclude, the structure and stock size of the zooplankton community adequately indicated strong effects of zooplankton on fish size and growth.

Key words: Baltic Sea, zooplankton, bioindication, predation, Marine Strategy Framework Directive.

INTRODUCTION

The value of zooplankton as an indicator of ecological processes arises from its position in various food webs. Zooplankton acts as a middle point between top-down (fishes) and bottom-up (phytoplankton) regulators (Jeppesen et al., 2011). Thereby, zooplankton indirectly indicates trophic interactions between phytoplankton/bacterioplankton and zooplankton as well as zooplankton and fishes, hence, eutrophication as well as fish predation on zooplankton (Haberman, 1996). Direct predation pressure from fish can significantly impact on zooplankton communities. For example, predation-induced mortality leads to a high percentage of overall mortality in copepods (Hirst and Kiørboe, 2002; Tang et al., 2006; Martinez et al., 2014). Larger individuals of zooplankton are normally consumed in case of high rates of fish predation, which leads into a situation where domination within zooplankton communities is given to smaller individuals (Haberman, 1996; Brucet et al., 2010; Jeppesen et al., 2011). In addition to the size of zooplankton, top-down predation pressure is also affected by the morphology of various life history stages of zooplankton (Brooks and Dodson, 1965; Otto et al., 2014). A common assumption is that marine zooplankton is bottom-up controlled. Thus, it could be used as an indicator of climate change effects in the open ocean where anthropogenic impact on top of the food chain is considered to be negligible (Adrian et al., 2006; Barton et al., 2013; Daewel et al., 2014). Nevertheless, recently species on lower trophic levels have shown cascading effects in various marine ecosystems due to the overfishing of top-down predators (Casini et al., 2008, 2014).

Various studies have focused on long-term dynamics of zooplankton in relation to hydro-climatic conditions in the adjacent sea (Viitasalo et al., 1995; Möllmann et al., 2000, 2008; Kotta et al., 2009). It is common in aquatic ecosystems that hierarchic response takes place along trophic levels, i.e. the intensity of response to eutrophication can vary among trophic levels (Hsieh et al., 2011; Lewandowska et al., 2014).

Surprisingly, mesozooplankton has not been included into the European Water Framework Directive (WFD) as a quality element. The importance of mesozooplankton in terms of ecological environmental assessment has been demonstrated in rivers and lakes, and the necessity of including mesozooplankton in the WFD has been outlined (Jeppesen et al., 2011). However, mesozooplankton is included into the EU Marine Strategy Framework Directive (MSFD). On the basis of work carried out by the MSFD HELCOM zooplankton working group, a core indicator of food web structure based on mesozooplankton, i.e. the average size or weight of a zooplankter, was proposed by Gorokhova et al. (2013a). The indicator is also supported by total values of zooplankton abundance and biomass. Thus, the measure captures both zooplankton community structure (by mean weight) and the stock size (by biomass or abundance).

In the current study we analysed the use of this indicator of good environmental status in the northeastern Gulf of Riga based on zooplankton data collected mainly from Pärnu Bay. The effect of zooplankton as a food source affecting fish growth was evaluated. Seasonal and interannual variation of total abundance and biomass of zooplankton together with mean weight of a zooplankter was analysed based on both seasonal and long-term data.

MATERIAL AND METHODS

Field data were collected from the northeastern Gulf of Riga, mainly from Pärnu Bay, between 1957 and 2013. In total 6746 quantitative samples of mesozooplankton were used (of these 3067 were collected from June to August). Zooplankton sampling and analysis followed the HELCOM recommendations (1988). Samples were collected with a Juday type plankton net (mouth opening 0.1 m^2; mesh size 90 μm) with vertical hauls from the seabed up to the surface. Samples were preserved upon collection in formalin and analysed in laboratory conditions.

Copepods were classified according to species, developmental stage (copepodites CI–V), and sex (adults); naupliar stages were not separated to species. Rotifers, cladocerans, and meroplankton (pelagic juveniles of demersal species) were identified to the lowest possible taxonomic level.

The biomass of zooplankton was calculated as carbon content by multiplying plankton abundance with individual carbon content. Data from Finnish researchers were acquired to identify individual carbon content of a zooplankter (Pellikka and Viljamaa, 1998). Furthermore, ring test results from 2007 were partially used in the analysis (HELCOM MONAS, 2013). To our understanding, the average individual weight of *Cercopagis pengoi* (150 µgC/ind) provided by Pellikka and Viljamaa (1998) is overestimated. For example, the mean weight of a comparable *Leptodora kindti* is between 12 and 150 µgC/ind. As the weight of *C. pengoi* varies to a large extent (approximately 25 times) (Ojaveer et al., 2001) and its dry weight value also varies extensively (1–9 times) (Grigorovich et al., 2000), the mean weight of *C. pengoi* at 15 µgC/ind was used in the current study. The age-specific herring (*Clupea harengus membrans*) weight (WAA) data averaged yearly between 1977 and 2012 from the Gulf of Riga were used (ICES, 2013).

RESULTS AND DISCUSSION

Rotifers, copepods, cladocerans, and meroplankton dominate in the northeastern Gulf of Riga (Kotta et al., 2009). Species richness within the zooplankton community is low. *Eurytemora affinis* and *Acartia* spp. compose the majority of the copepods, and *Eubosmina maritima* can be considered as the dominating cladoceran. During the past decades two invasive species, *Cercopagis pengoi* and *Evadne anonyx* from the Ponto-Caspian region, have successfully established within the local cladoceran community (Ojaveer and Lumberg, 1995; Põllupüü et al., 2008). The decline in local cladoceran species, especially the decline of *E. maritima*, correlates in time with the arrival of *C. pengoi*, which shows high abundance values during summer months in the northeastern Gulf of Riga and in Pärnu Bay (Ojaveer et al., 2004; Kotta et al., 2004, 2009).

Our data showed that the abundance and biomass of zooplankton were high from June to August (Table 1, Fig. 1). The dominating species in the mesozooplankton were rotifers (annual mean 44%) and copepods (39%). The relative importance of cladocerans and meroplankton remained below 10%. The dominating species in terms of biomass were copepods and cladocerans (47% and 31%, respectively), followed by meroplankton (15%) and rotifers (7%). The abundance of mesozooplankton during summer months from June to August commonly exceeded 120 thousand ind/m^3 and its biomass was above 50 mgC/m^3. The peak abundance occurred in June whereas the highest biomass was measured in August. The dominating species during the peak abundance were rotifers (>40%) and copepods (>30%). On the other hand, during the period of high zooplankton biomass copepods (50% in June) and cladocerans (>40% in July and August) dominated.

Table 1. Monthly abundance (mean ± SE; thousand ind/m^3) of mesozooplankton in the northeastern Gulf of Riga from 1957 to 2013

Month	Abundance
January	4.9 ± 0.6
February	5.1 ± 0.8
March	7.8 ± 1.2
April	47.2 ± 6.9
May	83.2 ± 3.8
June	172.1 ± 4.2
July	155.7 ± 3.7
August	126.7 ± 3.5
September	61.3 ± 1.6
October	35.2 ± 1.1
November	18.0 ± 1.2
December	6.3 ± 0.6

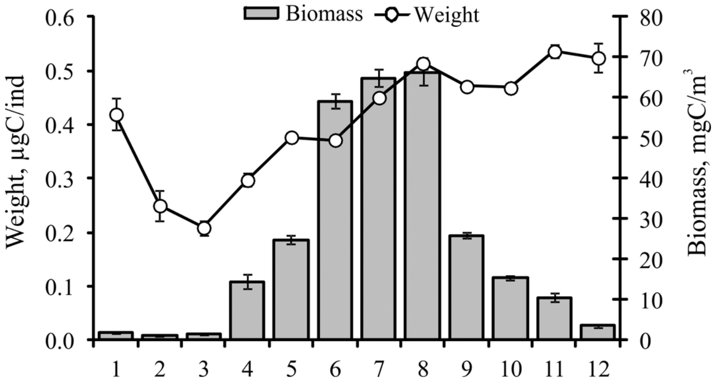

Fig. 1. Mean values of individual weight of a zooplankter (μgC/ind) and mesozooplankton biomass (mgC/m^3) throughout the annual cycle from 1957 to 2013.

Numerous studies carried out in the Baltic Sea have focused on the overall zooplankton abundance and relative composition, both of which have been linked to hydrology; the amount of biogenic nutrients, which influences the mass production of phytoplankton (Hansson and Rudstam, 1990; Vuorinen et al., 1998; Möllmann et al., 2008; Hansson et al., 2010; Díaz-Gil et al., 2014); or the global climate change (Alheit et al., 2005, Möllmann et al., 2008; Lewandowska et al., 2014). No clear correlation has been demonstrated between temperature and total zooplankton abundance in the Gulf of Riga, although the abundance of copepods increases with temperature. The summer biomass of the two dominating copepods, *Acartia* spp. and *Eurytemora affinis*, has decreased after 1990 even though the phytoplankton biomass has significantly increased over that time period (Jurgensone et al., 2011).

Individual mean weight of a zooplankter was at its minimum in February/March, followed by a period of increase up to August and then remained approximately the same until January (Fig. 1). Domination of early life stages of rotifers and copepods, especially those of copepod nauplii, within the plankton community resulted in the minimum individual weight values in early spring. The high individual mean weight in late autumn reflects the increased share of adults. Seasonal variation of mean zooplankter weight has been demonstrated also in freshwater environments (Haberman, 1996; Jeppesen et al., 2011).

Interannual comparisons were based on data from June to August because abundance and biomass estimates were the highest during summer months and summer months are represented in zooplankton samples every year. The estimates of summer abundance of zooplankton varied between 77.4 (1987) and 373.7 (1957) thousand ind/m^3 with a mean value of 156.2 ± 2.4 thousand ind/m^3. A relatively high abundance was noted in the late 1950s and during the 2000s, but no clear linear trend was observed (Table 2). Biomass estimates varied between 28.5 (1965) and 135.4 (1981) mgC/m^3 with a mean value of 62.9 ± 1.3 mgC/m^3. The highest biomass of zooplankton was observed in 1979, 1980, 1981, 1988, and 2003 (Fig. 2). Such interannual variability of zooplankton abundance and biomass values is plausibly due to changes in hydrology as several long-term studies around the Baltic Sea area have demonstrated that salinity and temperature affect the abundance or species composition of zooplankton (Viitasalo et al., 1995; Vuorinen et al., 1998; Dippner et al., 2000; Möllmann et al., 2000). The average annual weight of a zooplankter varied from 0.236 (1957) to 0.781 (1981) µgC/ind with a mean value of 0.433 ± 0.004 µgC/ind. In general the individual weight was high and exceeded 0.6 µgC/ind in 1979–1986 but also in 1989, 1991, and 2008. In other years values below 0.5 µgC/ind were measured (Fig. 2). A significant correlation was found between total biomass and abundance of zooplankton ($r = 0.555$; $p = 0.002$). Mean zooplankter weight correlated positively with biomass ($r = 0.582$; $p = 0.001$) and negatively with abundance ($r = -0.546$; $p = 0.003$). Large variation of mean zooplankter weight has been documented also in freshwater systems (Haberman, 1996; Jeppesen et al., 2011; Gauthier et al., 2014).

Abundant zooplankton with a large mean individual size should provide favourable feeding conditions for fish. The average weight at age (WAA) for herring in the Gulf of Riga was 0.025 kg between 1977 and 2012, and it showed a positive correlation with mean individual zooplankter weight ($r = 0.606$; $p < 0.001$) (Fig. 3). Furthermore, a positive correlation was present between WAA and zooplankton biomass ($r = 0.494$; $p = 0.002$). The Baltic Sea provides habitat for various planktonic fishes such as sprat and herring but also mysids, which all are considered as important controllers of zooplankton communities (Hansson and Rudstam, 1990; Rudstam et al., 1994; Möllmann et al., 2008; Otto et al., 2014). Several studies have demonstrated selective feeding of fishes in the Baltic Sea (Arrhenius, 1996; Flinkman et al., 1998; Casini et al., 2004). Herring generally prefer female copepods at their later life stages (Möllmann et al., 2004; Bernreuther et al., 2013) and

Table 2. Abundance of mesozooplankton (mean ± SE; thousand ind/m^3) from June to August in the northeastern Gulf of Riga between 1957 and 2013

Year	*n*	Abundance	Year	*n*	Abundance
1957	33	373.7 ± 64.5	1986	49	93.1 ± 13.8
1958	97	241.9 ± 25.3	1987	30	77.4 ± 11.0
1959	128	154.9 ± 10.0	1988	48	166.9 ± 20.6
1960	69	138.8 ± 10.1	1989	43	127.2 ± 20.2
1961	67	150.5 ± 24.2	1990	45	113.8 ± 14.5
1962	72	148.0 ± 14.5	1991	45	104.8 ± 8.0
1963	54	91.3 ± 9.8	1992	42	138.2 ± 15.2
1964	56	216.1 ± 28.8	1993	36	157.9 ± 30.0
1965	94	86.0 ± 4.9	1994	50	103.2 ± 9.5
1966	69	173.1 ± 14.5	1995	49	80.1 ± 7.7
1967	93	148.5 ± 9.4	1996	47	110.8 ± 13.4
1968	93	165.4 ± 14.2	1997	63	133.5 ± 16.7
1969	80	94.8 ± 7.8	1998	31	148.3 ± 18.8
1970	140	172.8 ± 10.9	1999	56	122.5 ± 12.4
1971	135	151.9 ± 9.9	2000	45	119.1 ± 11.9
1972	181	181.5 ± 12.4	2001	28	198.6 ± 21.3
1973	137	210.3 ± 12.5	2002	31	182.7 ± 21.9
1974	106	134.7 ± 7.4	2003	38	211.3 ± 45.6
1975	119	156.7 ± 12.1	2004	33	206.8 ± 23.1
1976	113	93.4 ± 5.9	2005	25	252.6 ± 45.3
1977	46	117.4 ± 9.2	2006	74	227.9 ± 15.6
1978	72	125.9 ± 12.9	2007	33	154.7 ± 16.3
1979	39	181.0 ± 11.7	2008	22	136.5 ± 23.0
1980	51	182.8 ± 13.8	2009	39	193.3 ± 25.4
1981	37	167.9 ± 20.6	2010	42	241.3 ± 21.0
1982	41	140.9 ± 12.9	2011	80	178.8 ± 16.8
1983	86	146.1 ± 9.3	2012	46	249.2 ± 37.1
1984	34	96.3 ± 7.7	2013	47	177.8 ± 17.9
1985	48	96.9 ± 12.9			

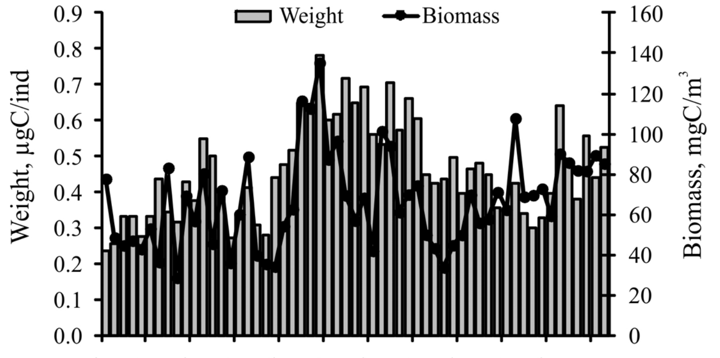

Fig. 2. Mean biomass (mgC/m^3) of mesozooplankton from June to August and mean zooplankter weight (µgC/ind) from June to August between 1957 and 2013.

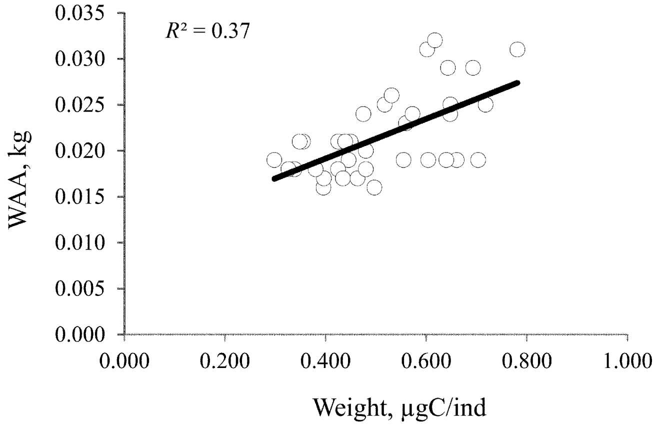

Fig. 3. Mean individual zooplankter weight (µgC/ind) against average weight at age (WAA) of 2–5 years-old herring between 1977 and 2012.

cladocerans with pigmented eggs and embryos (*Eubosmina*, *Podon*, *Pleopis*) (Flinkman et al., 1992; Gorokhova et al., 2013b). Therefore, important factors affecting the choice of prey for fish include the size of prey and water transparency.

The presence of abundant zooplankton with high individual mean weight means high grazing potential as well as favourable feeding conditions for fish. All other combinations of zooplankton abundance and size are suboptimal indicating limitations of energy transfer from primary producers to higher trophic levels together with poorer feeding conditions for fishes consuming planktonic material (Gorokhova et al., 2013a).

Throughout the study period of 57 years (1957−2013) the overall biomass of zooplankton was relatively low for 20 years when small individuals were dominating (Fig. 4). According to Gorokhova et al. (2013a), over the period of these 20 years, zooplankton was unable to support adequate fish growth showing low energy transfer efficiency to higher trophic levels. High biomass of zooplankton accompanied by large individuals was present during 17 years, exhibiting the availability of good quality food and efficient grazing on primary producers. Relatively large individuals dominated over 12 years while the overall biomass of zooplankton remained low. These years can be described as partially satisfying the feeding requirements of fish. A total of 8 years out of 57 displayed high biomass of zooplankton, meanwhile maintaining low average weight of individuals. In these years zooplankton partially fulfilled fish feeding requirements as well as exerted strong grazing on primary producers.

It can be concluded that the used biodiversity indicator desirably indicates grazing of zooplankton on phytoplankton as well as the effects of zooplankton on fish size and growth, thereby characterizing both bottom-up and top-down interactions within given pelagic food webs.

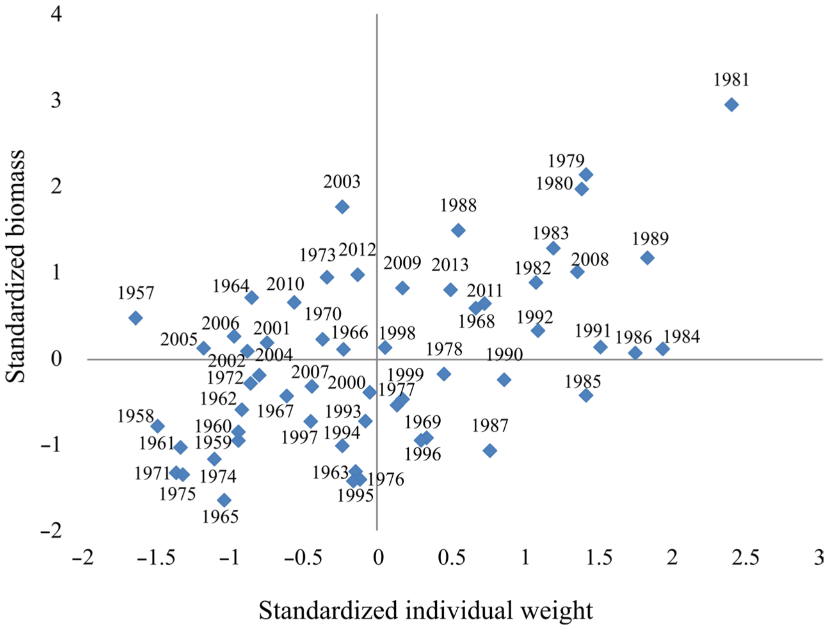

Fig. 4. Core indicator of zooplankton, which integrates mean size (µgC/ind) and total biomass (mgC/m^3) of zooplankton as z-scores, for data sets of the zooplankton in the NE Gulf of Riga between 1957 and 2013.

ACKNOWLEDGEMENT

Financial support for this research was provided by Institutional research funding IUTO2-20 of the Estonian Research Council.

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