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Feeding of 0+ smelt *Osmerus eperlanus* in Lake Peipsi

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Abstract. The feeding of 0+ smelt (*Osmerus eperlanus*) was studied in Lake Peipsi (Estonia/Russia). Smelt fed mainly on zooplankton, especially on cladocerans and copepods, and not on rotifers. The dominant taxa in smelt food were *Daphnia* sp., *Bosmina longirostris*, *Bosmina coregoni*, *Chydorus sphaericus*, *Eudiaptomus* sp., *Mesocyclops* spp., and cyclopoid copepods. Copepods constituted a greater percentage of the food of smelt at the beginning of July; from August cladocerans dominated. Size-selectivity was variable: in July and August smelt selected larger-bodied species, while from September onwards both large- and small-bodied species were eaten.

Key words: predation, 0+ smelt, zooplankton, large shallow lake, Lake Peipsi.

INTRODUCTION

Smelt *Osmerus eperlanus* (L.) is the main zooplanktivorous fish species in Lake Peipsi and is so an important predator on zooplankton and large invertebrates in this lake. Smelt is zooplanktivorous at younger ages, gradually shifting to larger invertebrates during growth, and the oldest and largest smelts are piscivorous (Karjalainen et al., 1997; Vinni et al., 2004). When smelt start feeding, the number of suitable food organisms available is critical for fish survival. Rotifers and crustacean zooplankton (cladocerans and copepods) are important food items during the first summer because the mouth width seems to be the critical determinant of the ability of smelt to handle large food items (Strelnikova & Ivanova, 1983; Næsje et al., 1987). Phytoplankton can also be important as an initial food item for newly-hatched smelt larvae, as found in Norwegian Lake Mjösa by Næsje et al. (1987). Later, from mid-summer to autumn, age-0 smelt in Lake Mjösa feed mainly on copepods and cladocerans, with no strong preference for either of these groups (Næsje et al., 1987). In the Kuronian Lagoon (coastal waters of the Baltic Sea), young smelt prefer cladocerans from June to September, copepods in September, and cladocerans after that (Vashkevichiute, 1959). In Finnish lakes, age-0 smelt feed mainly on copepods, sometimes on cladocerans, most often in proportion to their availability in the plankton (Sterligova et al., 1992; Karjalainen et al., 1997).

Earlier research on smelt feeding in Lake Peipsi and in Lake Pihkva (Tikhomirova, 1974) showed that smelt larvae feed mainly on cladocerans (*Bosmina*, *Chydorus*, *Daphnia cucullata*, and *Diaphanosoma brachyurum*, occasionally *Leptodora* and *Sida*) and copepods (*Diaptomus*, *Cyclops*, *Mesocyclops*) during the spring–summer period. In June and July, chironomid larvae and adult insects become more important, and smelt of 6.9 cm and longer feed mainly on fish larvae. The results of Vashkevichiute (1959) from the Kuronian Lagoon also showed that chironomids are the main smelt food in mid-summer. Chironomids are often consumed by older smelt, from the second summer onwards.

Data on the feeding behaviour of the fish in Lake Peipsi are scarce, and far from sufficient for understanding the functioning of the food web in this lake. The aim of the present study was to analyse the diet of smelt in Lake Peipsi. The food eaten was also compared with the food available in the lake.

STUDY SITE, MATERIAL, AND METHODS

Lake Peipsi (3558 km^2) is located in eastern Estonia, on the border of Estonia and Russia. It consists of three parts: lakes Peipsi *s.s.*, Lämmijärv, and Pihkva. The present paper deals with Lake Peipsi *s.s.* It is a moderately eutrophic polymictic lake with a mean depth of 8.3 m, average concentrations of total phosphorus 40 mg P m^{-3} and total nitrogen 700 mg N m^{-3} (Nõges et al., 2008). Descriptions of the phyto- and zooplankton of Lake Peipsi are given by Laugaste et al. (2001) and Haberman (2001), respectively.

Lake Peipsi provides a great variety of biotopes with a diverse trophic state. As a result of this the flora and fauna of this lake are quite rich both in the number of species and in their abundance. Lake Peipsi can be considered a large water body of quite high productivity. The biomass of phytoplankton has fluctuated from 1 to 125 g m^{-3} and the mean biomass of zooplankton (in summer) is 3.1 g m^{-3}. The fish catches have usually been 8000–11 000 t or 22–31 kg ha^{-1} yr^{-1} since the 1930s. The main commercial fishes in the lake are smelt, pikeperch, perch, bream, pike, ruffe, roach, and until the early 1990s also vendace.

Smelt samples were collected in summer and autumn 2003 with a bottom trawl (height 3 m, width 18 m, 10 mm knot-to-knot mesh size at cod-end) once a month from July to November. The samples were collected at 58°42.227N, 27°17.653E after previous monitor trawling. Considering the mesh size, smaller smelts could have escaped from the mesh and therefore the average length of 0+ smelt may have been influenced. The total length (TL, to the nearest 1 mm) and total weight (TW, to the nearest 0.1 g) of each individual were measured by the method of Bagenal & Tesch (1978). Smelt age was estimated from the length-frequency distribution of the 0+ and 1+ age groups. If the groups overlapped, age was determined on the basis of scales.

Fish alimentary tracts were removed and examined on Petri dishes under a microscope at ×32 magnification. A numerical method (Hyslop, 1980) was used for alimentary tract analysis. Zooplankton specimens were identified at least to genus level. The zooplankton biomass consumed was calculated using the wet weight of zooplankton specimens from in-lake samples. The total number of fish analysed was 71 (7 samples were taken between 1 July and 5 November; sample sizes ranged from 5 to 15 fish) and there were two fish with empty alimentary tracts. The lengths of 1163 fish were measured; the range of fish lengths was 2.4–7.3 cm.

For the determination of in-lake zooplankton composition and biomass, zooplankton samples were collected from the pelagic zone of the lake. In September and October, these samples were collected at the same time and station as the fish samples. In July, August, and November, the monthly data from the state monitoring programme of Lake Peipsi were used. It is therefore necessary to interpret the zooplankton data with some caution. The protocol agreed in EC project ECOFRAME (Gyllström et al., 2005) was partly applied during zooplankton sampling. It prescribes a 10-litre sample taken from depth-integrated water. Water was taken at each 0.5 m by a 2-litre Ruttner sampler and poured into a 30-litre vessel to produce depth-integrated water. Zooplankton samples were collected by pouring 10 litres of depth-integrated lake water through a 48 μm mesh. The samples were preserved with acidified Lugol's solution (0.5% final concentration). Each sample (15 mL) was analysed in a Bogorov chamber under a microscope at ×32–56 magnification. The wet weight of each specimen was calculated on the basis of its length using the Ruttner-Kolisko (1977) formula for rotifers and the Studenikina & Cherepakhina (1969) and Balushkina & Winberg (1979) formulae for cladocerans and copepods. Total zooplankton biomass was obtained by multiplying the abundance of each species with the appropriate average individual weights. For total zooplankton biomass, the biomasses of all species were summed.

The program Statistica for Windows version 6.0 was used for statistical analysis. The ANOVA module was used to compare means.

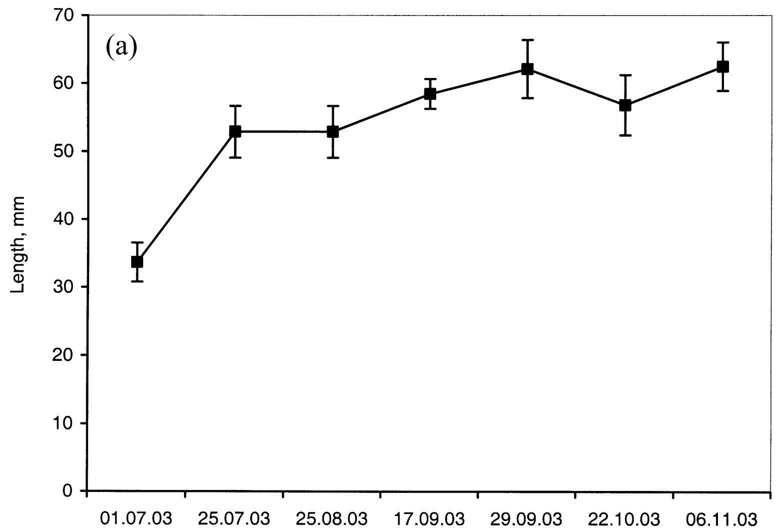
Ivlev's electivity index was defined as:

$$E = (r_i - p_i)/(r_i + p_i),$$

where E is the index of electivity, r is the relative abundance of prey category i in the gut, and p_i is the relative abundance of prey category i in the environment (Wootton, 1998).

RESULTS

The average lengths of smelt on different sampling dates were 33–63 mm. Total length increased continuously from July to September and stabilized somewhat thereafter (Fig. 1). Zooplankton attained maximum abundance in September and minimum in October. The maximum total biomass of zooplankton was observed



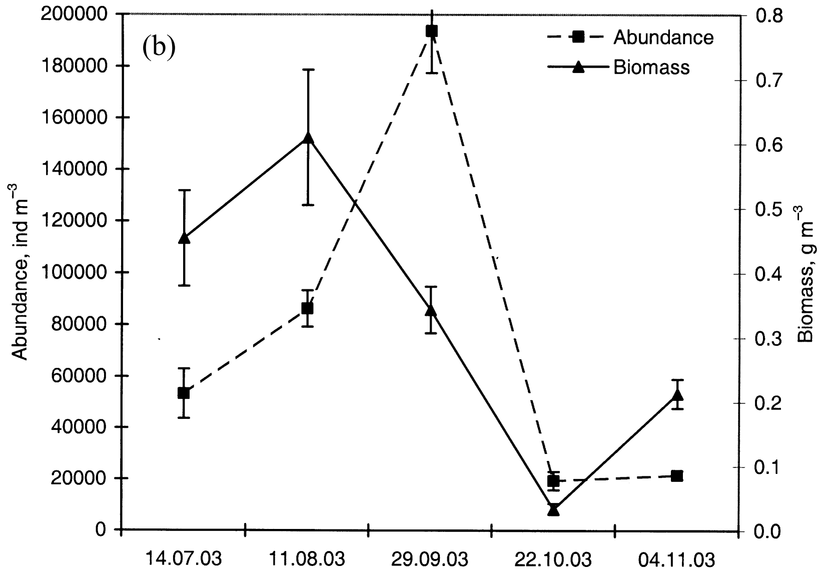


Fig. 1. Average length of age 0+ smelt in test catches (a) and the abundance and biomass of zooplankton (b) in Lake Peipsi.

in August and the minimum in October (Fig. 1). The dominant zooplankton groups were in July and November copepods; in August, September, and October rotifers (Fig. 2). By abundance the dominant zooplankton species were nauplii and cyclopoids (45% and 36%, respectively) in July; *Polyarthra major*, *P. luminosa*, and cyclopoids (23%, 21%, and 21%, respectively) in August; *P. luminosa* and *Keratella cochlearis* (26% and 23%, respectively) in September; *K. cochlearis* and *Chydorus sphaericus* (54% and 15%, respectively) in October; and cyclopoids and nauplii (29% and 18%, respectively) in November.

Age 0+ smelt mainly consumed zooplankton (99%); chironomids, ostracods, and diatoms were taken in negligible amounts (Fig. 3). The abundance of cladocerans consumed increased from July to November; the abundance of copepods fluctuated more but was lower than that of cladocerans. Cladoceran biomass in the gut of smelt increased until the end of September, then decreased; copepods followed almost the same pattern. The biomass of cladocerans consumed was greater than that of copepods (Fig. 3). Copepods predominated in the fish food earlier in summer, and cladoceran species became dominant later (Fig. 4). Due to the selectivity of the gear used, the abundance, biomass and main species of the consumed zooplankton may have been influenced by the larger than real size of 0+ smelt. In the in-lake zooplankton cyclopoids and *Daphnia* sp. dominated in summer; *C. sphaericus* and cyclopoids dominated later (Fig. 5). Insects, water mites, and chironomids were also consumed but because of their scarcity they were gathered into the group Others.

The smelt diet included very few rotifers: only *Lecane* sp. was consumed in August (1.4% of the average abundance). The main zooplankton groups eaten were cladocerans and copepods. Cladocerans generally dominated over copepods,

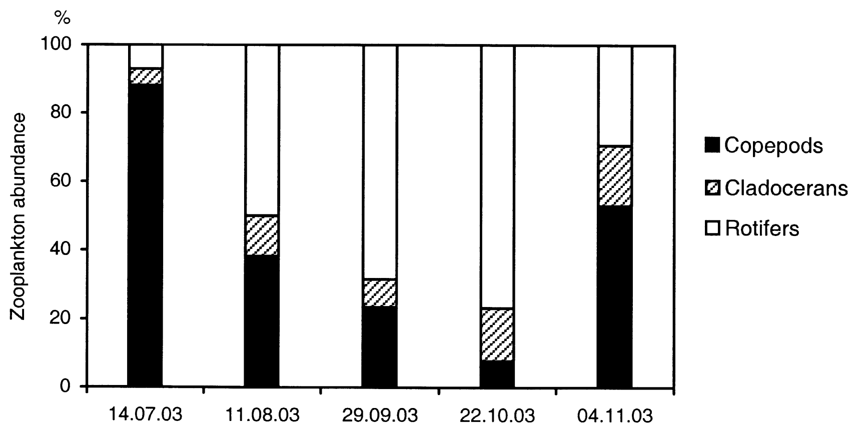


Fig. 2. Proportions of zooplankton group abundances in Lake Peipsi on different dates.

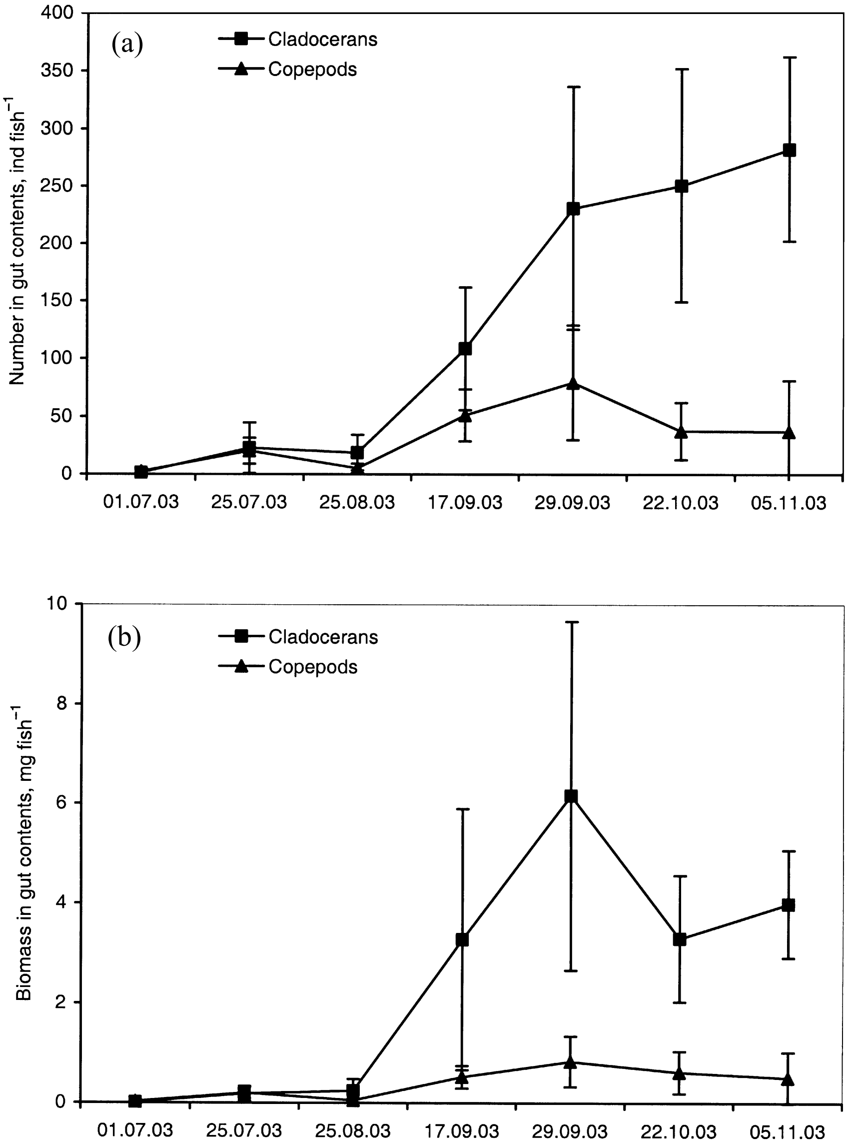


Fig. 3. Abundance (a) and biomass (b) of zooplankton groups in the gut contents of 0+ smelt in Lake Peipsi.

though at the beginning of July more copepods than cladocerans were taken ($p < 0.05$ for the differences). Among the copepods consumed, *Eudiaptomus* sp. dominated at the beginning of July; cyclopoids prevailed from the end of July onwards. No copepod nauplii were found in the guts of smelt. Chironomids were eaten at the end of September and ostracods in November (0.03% and 0.04% of the average consumed zooplankton abundance, respectively).

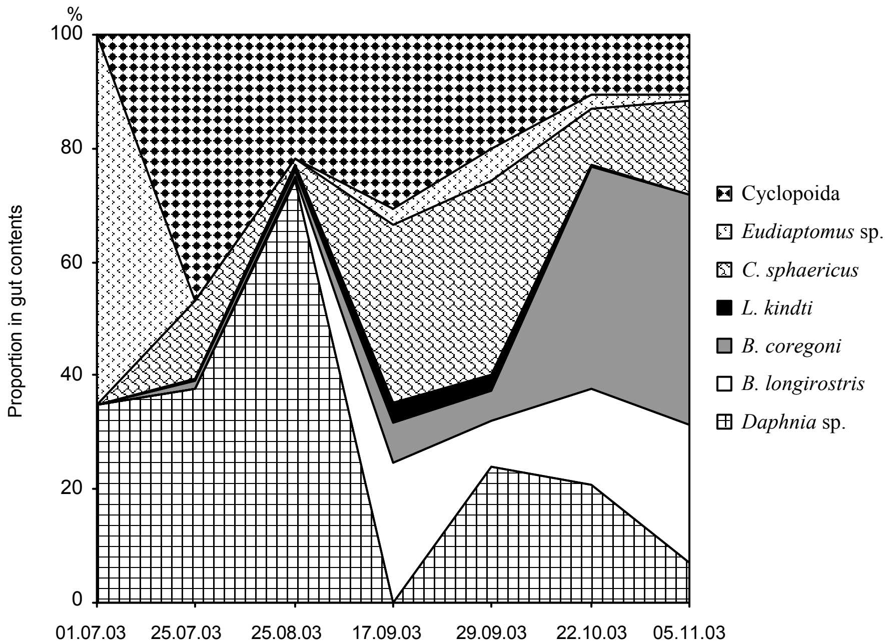


Fig. 4. Properties of main zooplankton species consumed by smelt in Lake Peipsi on different dates.

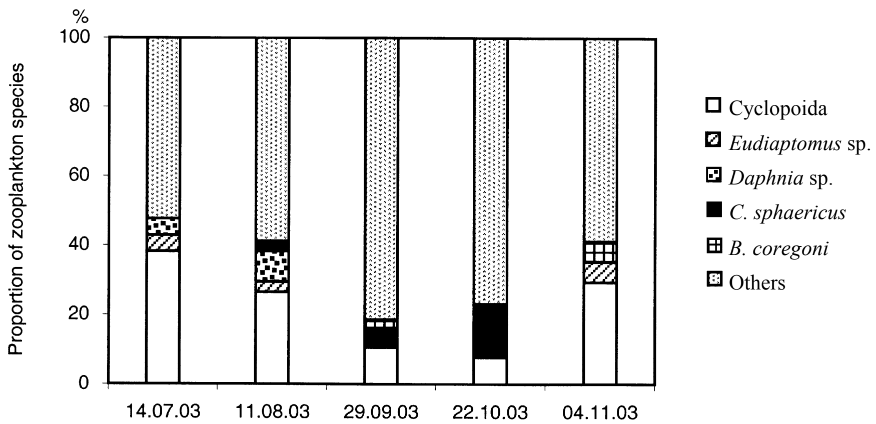


Fig. 5. Proportions of the abundances of main zooplankton taxa consumed by smelt in Lake Peipsi.

Table 1. Ivlev's selectivity indices of 0+ smelt in Lake Peipsi

	1.7.03	25.7.03	25.8.03	17.9.03	29.9.03	22.10.03	5.11.03
Daphnia sp.	0.31	0.66	0.68		1.00	1.00	0.89
Bosmina longirostris			0.08	1.00	1.00	1.00	1.00
Bosmina coregoni		0.33	0.25	0.61	0.08	1.00	0.75
Leptodora kindti		0.07	0.17	0.40	1.00	0.40	0.33
Chydorus sphaericus		0.47		0.66	0.48	–0.26	1.00
Mesocyclops spp.		0.90	0.44	0.69	0.52	–0.77	0.33
Eudiaptomus sp.	0.66			0.40	1.00	1.00	–0.59
Copepoda sp.						0.05	–0.80

According to Ivlev's electivity index (Wootton, 1998), age 0+ smelt preferred cladocerans to copepods (Table 1). At the beginning of July, smelt selected mainly large-bodied species and randomly ate smaller species; from July onwards, large- and small-bodied species were both taken.

Statistical analysis (ANOVA; $p < 0.05$) showed that the selectivity for *Daphnia* was lower at the beginning of July than from the end of September onwards. The selectivity for *B. coregoni* was higher in October and November than in earlier months. The selectivity for *B. longirostris* was lower in July and August than from September onwards. The selectivity for *L. kindti* was lower in July, August, and November than at the end of September. No differences in selectivity towards *L. kindti* were found in the middle of September or in October. Selectivity towards *C. sphaericus* was negative in October, zero in August, and highly positive in other months. Selectivity towards *Mesocyclops* was negative in October and highly positive in summer and in September. Selectivity for *Eudiaptomus* was high in July, at the end of September, and in October, moderate in the middle of September and negative in November.

DISCUSSION

According to our data, age 0+ smelt in L. Peipsi consumed mainly zooplankton and only small numbers of chironomids and ostracods; cladocerans were more important than copepods. Tikhomirova (1974) previously found that similar-sized smelt consume mainly insect larvae in July with a few cladocerans and copepods, and in September take mainly cladocerans and a few copepods. According to Vashkevichiute (1959), the percentage of chironomids in the food ration of smelt in the Kuronian Lagoon is high in July (49% of the biomass consumed) and ostracods are of little importance. Age 0+ smelt also consume mainly zooplankton (98%) in Finnish lakes (Karjalainen et al., 1997; Vinni et al., 2004). Presumably, smelt can continue feeding on zooplankton for quite a long time if there are enough large-bodied zooplankters in the lake and therefore there is no need to shift to other food resources. Also, individual peculiarities may influence food selection. A similar shift may likewise be caused by food competition among several fish species. Our results suggest that such food competition is quite unlikely in Lake Peipsi.

It has been shown that age 0+ smelt can feed also on phytoplankton in particular situations and to continue feeding on zooplankton thereafter. After a diatom bloom in Lake Mjösa in Norway, diatoms dominated in the diet of smelt in June, when external feeding began, and rotifers and juvenile copepods were consumed only randomly (Næsje et al., 1987). According to our study, the differences between the zooplankton available in the water and the zooplankton consumed by smelt showed that smelt prefer larger food particles, especially cladocerans, which may be captured and handled more easily than copepods. Gal′tsova (1975) found that cladocerans make up 59% in the food of smelt in July and 92% in September. Kühl (1970) and Strelnikova & Ivanova (1983) obtained different results, showing that at the beginning of external feeding smelt feed only on rotifers and juvenile copepods. In Lake Mjösa, smelt consume both cladocerans and copepods in the same proportions from July onwards as these groups occur in the plankton (Næsje et al., 1987). Balcher (1983) found that young rainbow smelt (*Osmerus mordax*) prefer copepods to cladocerans, locating cladocerans from a similar distance to copepods but avoiding attacks on the spiny cladoceran forms. In Lake Peipsi, cladocerans were presumably more easily preyed than the fast-moving copepods. Copepods were eaten randomly, except for large *Eudiaptomus* and *Mesocyclops*, which were positively selected. The same was shown in Lake Mjösa where smelt also selected spiny cladocerans such as *Bythotrephes longimanus* and *Polyphemus pediculus* (Næsje et al., 1987).

Smelt in Lake Peipsi preferred large-bodied zooplankters in July and August, but from September onwards both large- and small-bodied zooplankters were selected. Ivanova (1982) also noticed that 0+ smelt in the Rybinsk Reservoir select large food items in early summer and later feed on both small and large crustaceans. This may be due to predation pressure on zooplankton: in early summer there are not so many 0+ fish and large-bodied zooplankters are quite abundant. When the pressure increases the large-bodied zooplankters become less numerous and it is energetically preferable to consume both small- and large-bodied zooplankters. According to Gliwicz et al. (2004), the selectivity of smelt is similar for small- and large-bodied prey categories, but is lower for elongated-bodied species (*Daphnia*) than for compact-bodied species (*Bosmina*, *Chydorus*). Our study gave opposite results: selectivity for elongated-bodied species was higher than for compact-bodied species (selectivity for *B. longirostris* and *B. coregoni* was lower than for *Daphnia* species). The lower selectivity of smelt in Lake Peipsi for *Bosmina* than for *Daphnia* seems to stem from differences in body size, since the bigger *Daphnia* are more readily visible to smelt than the smaller *Bosmina*. For this reason, *Daphnia* can be also detected from a greater distance than *Bosmina*.

Smelt in Lake Peipsi had higher selectivity for *B. longirostris* than for *B. coregoni*, although *B. coregoni* was more represented in the in-lake zooplankton and its body size was larger. Presumably smelt avoided the long rostrums of *B. coregoni*.

In our study, smelt fed mainly on *Daphnia* sp., *B. longirostris*, *B. coregoni*, *C. sphaericus*, *Eudiaptomus* sp., *Mesocyclops* spp., and cyclopoid copepods. This confirms the results of earlier investigations (Tikhomirova, 1974) in which most of these species were also the main food sources for smelt in Lake Peipsi. According to Ibneeva (1983), smelt prefer in LakePeipsi large-sized *D. galeata*, *Limnosida frontosa*, *B. berolinensis*, *L. kindti*, and the copepod *E. gracilis*. The percentage of these species in the total zooplankton abundance was quite low, except in the case of Cyclopoida, which were quite abundant in August and November. The low abundance of the preferred zooplankton species in lake water may in fact be the consequence of the predation pressure from fish and invertebrates. The stability of smelt diet throughout the 30-year period indicates that the ecosystem of Lake Peipsi has a relatively constant status, enabling the dominant complex of plankton species to remain unchanged for years. There have been some fluctuations in smelt numbers, caused by disease and predation by pikeperch, but they have not influenced the zooplankton composition, because other planktivorous fish (whitefish) and 0+ fish have continued to consume zooplankton in the absence of smelt (Pihu & Kangur, 2001). The dominant zooplankton species have indeed not changed, only the degree of dominance (%) has changed for some species (Haberman, 2001). The food selection of smelt in Lake Mälaren, Sweden (Northcote & Hammar, 2006) and in Lake Hiidenvesi, Finland (Vinni et al., 2004) is also quite similar to that in Lake Peipsi. However, *C. sphaericus* dominated the food consumed in Lake Peipsi during September, but *C. sphaericus* was never a main food object in Mälaren and in Hiidenvesi.

CONCLUSIONS

Age 0+ smelt in Lake Peipsi mainly consumed zooplankton, especially cladocerans and copepods, and not rotifers. The dominant taxa were *Daphnia* sp., *Bosmina longirostris*, *Bosmina coregoni*, *Chydorus sphaericus*, *Eudiaptomus* sp., *Mesocyclops* spp., and cyclopoid copepods. Smelt preferred cladocerans to copepods. Smelt food selection in Lake Peipsi depended on the in-lake zooplankton composition.

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0+ peipsi tindi *Osmerus eperlanus* toitumine Peipsi järves

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On uuritud 0+ peipsi tindi (*Osmerus eperlanus*) toitumist Peipsi järves. Peipsi tint toitub peamiselt zooplanktonist, eriti aerjalgsetest ja vesikirbulistest, kuid mitte keriloomadest, mistõttu on tal suurim mõju vähilaadsele zooplanktonile. Domineerivad taksonid peipsi tindi toidus on *Daphnia* sp., *Bosmina longirostris*, *Bosmina coregoni*, *Chydorus sphaericus*, *Eudiaptomus* sp., *Mesocyclops* spp. ja sõudikuliste kopepodiidid. Aerjalgsed moodustavad suurima osa tindi toidust juuli algul, pärast juuli lõppu domineerivad vesikirbulised. Zooplanktoni suurusselektiivsus on muutuv: juulis ja augustis valib tint suuremõõtmelisi liike, septembrist alates nii suure- kui väikesemõõtmelisi liike.