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Dynamics of smelt (*Osmerus eperlanus*) numbers in Lake Peipsi over a decade

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Abstract. Between 1996 and 2006, fyke-netted spawning *Osmerus eperlanus* of L. Peipsi were examined for length, weight, sex, proportions of year classes, and the duration of the spawning period. In Septembers over the same period, the stocks of smelt and age-0+ pikeperch were estimated by bottom-trawling the off-shore areas of the lake. In July 2005, both smelt and age-0+ pikeperch *Sander lucioperca* were examined for length, age-0+ pikeperch also for food items. The numbers of age-0+ smelt were determined most significantly by the weather conditions immediately after spawning and depressed by large numbers of age-0+ pikeperch, whereas the yield, duration of spawning, and strong/weak year classes among spawners turned out to be irrelevant.

Key words: smelt, pikeperch, abundance, year classes, spawning period, shallow lake.

INTRODUCTION

In the Baltic Sea area, European smelt (*Osmerus eperlanus* (L.)) inhabit both brackish and fresh waters, they are found in rivers and lakes (de Groot, 2002; Shpilev et al., 2005). Like many European shallow eutrophic lakes, L. Peipsi is inhabited by a freshwater form of smelt. It has traditionally been an important fishing item. Being usually highly abundant although of short life span, smelt is significant for the topmost part of the food web, converting the energy of zooplankton into piscivorous fish (Laugaste et al., 2007). Smelt prefer cool waters with the temperature of 14–15 °C and oxygen content above 5 mg L^{-1} (Vinni et al., 2004). The growth rate and life span of smelt are determined mostly by the availability and size of food items – cladocerans *Bosmina* spp. and *Daphnia* spp. (Belyanina, 1971). During the 20th century, two periods with low numbers of smelt (1959 and 1972–1975) were caused by summer anoxia (Pihu, 1966; Pihu & Kangur, 2001). The 21st century commenced with unfavourable climatic conditions for smelt, and both its number and proportion in catch have declined (Vaino et al., 2005). Excellent climatic conditions in 2005 evoked simultaneously abundant, strong cohorts of age-0+ smelt, perch, and pikeperch. This study attempts, on the basis of biological indicators, to specify factor(s) that have shaped the numbers of smelt in L. Peipsi.

STUDY AREA

Nowadays smelt mainly inhabit the northernmost part of L. Peipsi–Pihkva (area of 2611 km^2, average depth 8.3 m, maximum depth 12.9 m, 33 fish species registered), of which 55% belongs to Estonia (Sokolova, 1983; Haberman et al., 2000). A large area and an extremely low depth characterize this eutrophic lake and determine the succession of thermal processes. Wind and waves mix water layers evenly and water temperatures differ between the surface and bottom layers only by 1–1.5 °C in summer (Kostyuchenko et al., 1974). On average, the lake is ice-free after 10 April (Sokolova, 1983). In April, the water temperature normally rises week by week, first from 0.5 to 1.6 °C, then to 4.4 °C, and by the first week of May it reaches an average of 9.0 °C.

Smelt is the main forager on zooplankton in L. Peipsi as its erstwhile competitor, the vendace *Coregonus albula*, is rare nowadays. Smelt spawn after ice-break at water temperatures above 4 °C (Hutchinson & Mills, 1987), when shoals of spawners move along with the melting ice-cover towards the littoral spawning grounds. In general, spawning commences first in the southernmost part of L. Peipsi and two to three days later in the northernmost part, and lasts for about a week at 4–9 °C. Almost the entire annual catch of smelt is fished within these few days. For decades, the number of fyke nets allowed for fishing the spawning smelt has been about 300. Bottom trawling, also used for fishing smelt, is allowed only for research.

The absolute fecundity of smelt in L. Peipsi is 13 000 (Pihu, 2003), the relative fecundity up to 1050 (Belyanina, 1971). The life span is two years, although in favourable conditions smelt matures in autumn, spawns at age 1 in spring, and then dies. Less than 1% of the population becomes piscivorous and spawns repeatedly. Smelt usually prefers to spawn on stones and gravel, avoiding silt bottoms (de Groot, 2002), but fyke nets constitute a suitable substrate for fertilized eggs in L. Peipsi.

MATERIAL AND METHODS

During 1996–2006 smelt was sampled annually in two distinct periods. Vernal data were collected daily at up to six sampling points along the western coast from fyke nets (mesh size 5 mm, up to 2 km off the shore, at a depth of 2–4 m). Random samples that ranged annually from 506 to 2487 smelt (total 16 052) comprised both male and female individuals with gonads of the fourth stage of maturity. Each autumn, 118–749 (total 3999) smelt along with age-0+ pikeperch were randomly sampled at the end of September by bottom trawling in the southern (at depths of 4–6 m), central and northern (at depths of 6–10 m) parts of the lake. Autumn samplings were carried out over five days, up to 5 hauls a day, totalling 16–25 hauls per autumn from different locations in the off-shore area at sufficient depths on the Estonian side of L. Peipsi. On 24 July 2005 (the year of unusually high numbers of juvenile fish), age-0+ pikeperch were collected along with smelt by bottom trawling near the Estonian–Russian border.

All samples were analysed according to Bagenal & Tesch (1978). Total length (TL, to the nearest 1 mm), total weight (TW, to the nearest 0.1 g), and sex were determined for each individual. The spawning period of smelt was specified visually according to the stage of gonad maturity and considered to have ended when 90% of the females had spawned. Age was determined from the length-frequency distributions of samples and from scales (50 individuals per sample). To determine the length of pikeperch at transition to piscivory, 369 age-0+ specimens were dissected and the stomach contents were examined.

Bottom trawling was characterized as follows: a haul was carried out for 30 min at a speed of 5 km per hour over a sampling area of 2.5 ha. The catch was sorted by species and year classes (King, 1996). The abundance of smelt and age-0+ pikeperch was calculated as an average of the number of fish caught per trawled hour.

RESULTS

The greatest yield of smelt (2214 t) over the past decade on the Estonian side of L. Peipsi was caught in 2002. Between 1998 and 2002, the average yield was as high as 1269±241 t. Since 2003, the yield of smelt was low, less than 10% of that in 2002 (Table 1). In the decade studied, smelt spawned ordinarily as they did in 1997–2001, i.e. between 25 April and 6 May (Fig. 1). Cold winters with thick and lasting ice (1996 and 2003) that melted only in early May delayed the spawning period, whereas an abrupt increase in temperature in the middle of April 2002 advanced it. On average, smelt spawned for 7.1 days. When spawning was shifted to May, the duration decreased to 3–4 days.

Table 1. Official catch of smelt (*Osmerus eperlanus*) by fyke nets and the mean abundance of smelt and 0+ pikeperch (*Sander lucioperca*) in the Estonian side of L. Peipsi in 1996–2006

Year	Official catch of smelt, t	Number per trawled hour in autumn (16–25 hauls)		
		Smelt		Pikeperch
		Age 0+	Age 1+	Age 0+
1996	478	3 508	46 428	2
1997	401	26 529	15 200	793
1998	1 421	6 343	31 712	322
1999	947	12 114	1 877	281
2000	1 140	3 128	18 266	263
2001	623	804	24 796	851
2002	2 214	1 193	8 269	124
2003	187	108	1 282	<1
2004	30	2 128	26 600	128
2005	169	12 750	10 200	2 108
2006	83	<1	<1	<1
Mean	669.4	6 236.9	16 784.6	443.1
SD	677	8 088	14 584	626

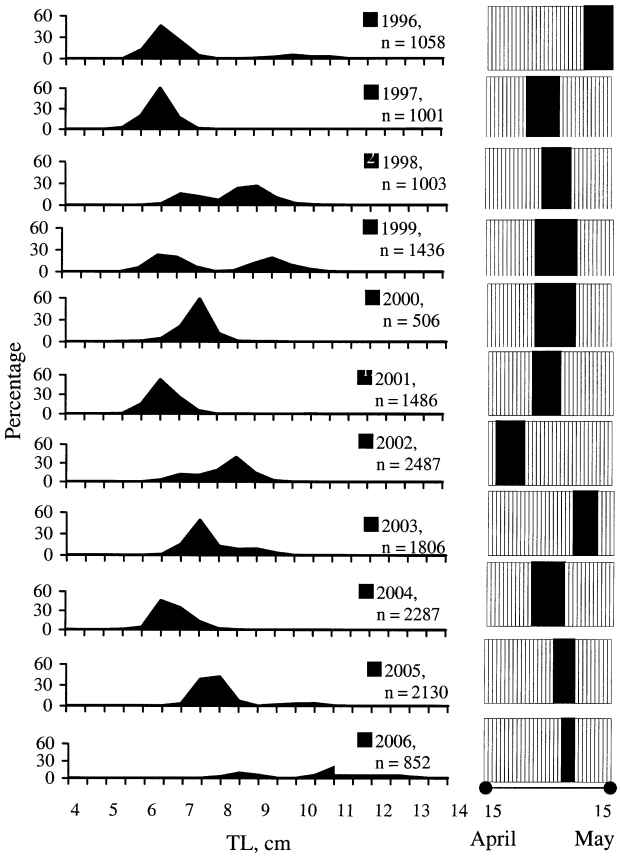

Fig. 1. Length–frequency distribution of spawning smelt *Osmerus eperlanus* in L. Peipsi in 1996–2006; adjoining filled bars indicate the spawning period in days.

Two year classes predominated in the spawning shoals of smelt: age 1 and age 2; older individuals were either absent or constituted only up to 0.1% of the total. Throughout the decade, the shares of both year classes fluctuated, although age 1 mostly outnumbered others except in 1998 (when two thirds of the spawners were at age 2), 2002, and 2006. In 1997 and 2004, the spawning stock comprised only age-1 smelt; in 1999, two thirds of the spawners were at age 1; and in 2001 only 0.5% of the spawners were older than one year.

Over the decade studied, the average TL values at age 1 varied by up to 2 cm. The average TL of age-1 smelt was less than 70 mm in five years, between 70 and 80 mm in four years, and in 2006, when the abundance was low, as high as 85.6 mm. In 2006, the average TL of the age-2 cohort attracted attention by its unusually high value of more than 100 mm specimens. Averaged over the decade, the TL of age-1 spawners was 71.8 ± 3.401 mm and of age-2 spawners, 96.1 ± 4.375 mm.

Vernal explorations showed that during 1997–2004 an age-1 spawner weighed 1.15–1.77 g with low variability between years (Fig. 2). At age 2, spawners weighed 2.6–3.8 g on average with the exception of 5.3 g in 2001. High average

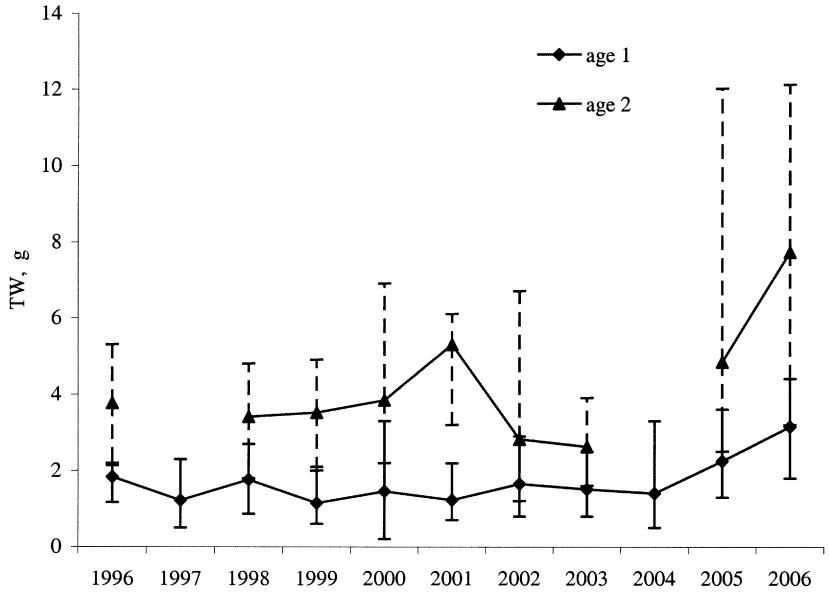

Fig. 2. Average weight (TW) of spawning smelt *Osmerus eperlanus* in L. Peipsi in 1996–2006; bars indicate minimum and maximum values.

TW values were measured for age-1 smelt in 2005 and 2006 (2.25 g and 3.65 g, respectively) and for age-2 smelt an exceptionally high value of 7.7 g in 2006. The average TW of smelt year classes declined by 0.5 g from late September until spawning time. In 1998, when age-2 smelt predominated, the relationship $TW = 0.0048\ TL^{3.07}$ ($r^2 = 0.92$; $n = 746$) described the spawners.

Males usually outnumbered females 3 to 2. A few exceptions were registered at Lohusuu (1 to 1 ratio), the northern part of L. Peipsi.

The trawl catches in September ranged widely (0.003–108.7 kg per trawled hour), differing both between areas and years. In two thirds of the trawled area the yield reached 30 kg per hour, while the highest yield of 60 kg per hour was confined to less than 15% of the total area. At the end of the 1990s, the catch averaged 59.3 (45.6–107.9) kg per trawled hour (the largest catch was in 1997). Since 2002 the average yield declined to 2–6 kg per trawled hour (the largest was 30 kg in 2004) with the minimum in 2006 when only a few individuals were captured. The number of smelt did not depend directly on either the catch or numbers of age-0+ pikeperch, except in 2005 (distinguished by an outstandingly high number of age-0+ piscivores).

Of the 369 age-0+ pikeperch examined for food items in July 2005, 115 had consumed age-0+ smelt (1–7 smelt ingested, average 3.1 per stomach). Pikeperch of the same length as age-0+ smelt, i.e. less than 7 cm, had with a few exceptions either empty stomachs or had fed on zooplankton, while piscivorous age-0+ pikeperch had already outgrown the age-1+ smelt (Fig. 3).

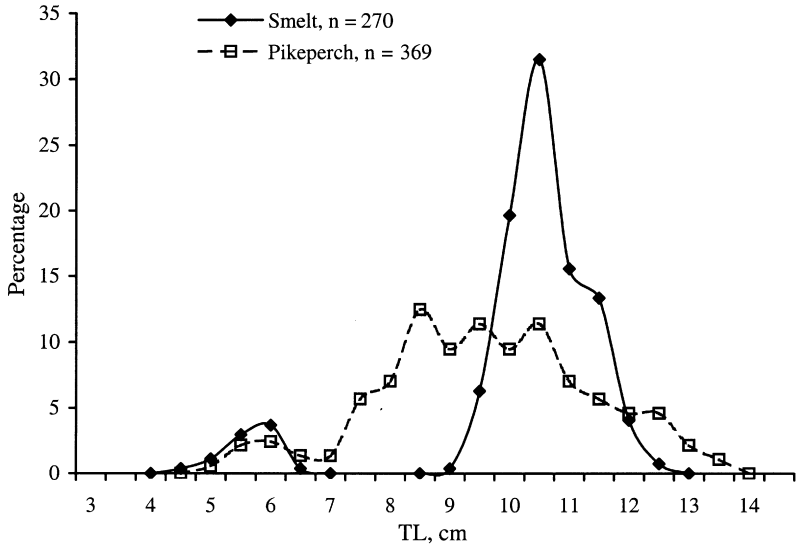

Fig. 3. Length–frequency distribution of smelt *Osmerus eperlanus* and age-0+ pikeperch *Sander lucioperca* in L. Peipsi on 24 July 2005.

DISCUSSION

At the end of the 1990s the fish composition of L. Peipsi was characterized by very high numbers of pikeperch and a concurrent decline of stenothermal fish species (vendace *Coregonus albula*, whitefish *Coregonus lavaretus*). The number of smelt fluctuated between years, with a marked decline since 2002, which has no obvious cause.

The movements of smelt shoals were difficult to follow. Horppila et al. (2000) argue that vertical movements during foraging on food items, dependent on the oxygen content, make the yields of smelt uneven. The numbers assessed on the basis of bottom trawling may underestimate the cohort because of the specific methodological and technical features of the gear (Mous et al., 2004). The numbers of smelt are depressed by high water temperature and eutrophic conditions in addition to high numbers of pikeperch (Lammens, 1990). In shallow eutrophic lakes with high turbidity, smelt is frequently foraged by age-0+ and older pikeperch (Hansson et al., 1997; Kangur & Kangur, 1998). According to Shirkova (1966), pikeperch in L. Peipsi is piscivorous at 7 to 12 cm (TL). We found that all pikeperch were piscivorous at a length of 7 cm (TL) and a few already at 5.5 cm. Age-0+ pikeperch consumed only age-0+ smelt; age-1 smelt was obviously foraged by older piscivores.

In several large lakes the yield of smelt has been found to depend on ambient temperature (Nyberg et al., 2001). In L. Peipsi the numbers of smelt are reduced by high water temperatures in summer (Kangur & Kangur, 1998; Kangur et al., 2002), and were greatly depressed during the mid-1970s (1973–1975). In this study the highest densities fluctuating year by year, were found in the deeper

central area of the lake with cooler temperatures. Comparison of the numbers of smelt and age-0+ pikeperch shows that low numbers of pikeperch did not increase the numbers of smelt; instead, other piscivorous species (such as perch *Perca fluviatilis*) seemed to consume age-0+ smelt. However, in 2005, a very numerous cohort of age-0+ pikeperch diminished the numbers of smelt to a minimum. The decline in the numbers of smelt and age-0+ pikeperch continued in 2006 as age-0+ smelt and pikeperch were not present in the autumnal yields and the cohort of age-1+ pikeperch predominated.

The large fluctuations in the numbers of smelt in L. Peipsi over the decade studied did not obviously depend on commercial fisheries, spawning conditions, or the proportions of year classes in the spawning grounds. Instead, the strength of each year class was mostly determined by climatic conditions immediately after spawning, i.e. in the first half of May, and by the numbers of age-0+ pikeperch in autumn. Extremely high numbers of age-0+ pikeperch depressed the numbers of smelt notably.

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REFERENCES

Bagenal, T. B. & Tesch, F. W. 1978. Age and growth. In *Methods for Assessment of Fish Populations in Fresh Waters. IBP Handbook*. Vol. 3 (Bagenal, T. B., ed.), pp. 101–136. Blackwell Scientific Publications, Oxford.

Belyanina, T. N. 1971. Comparative data on the biology of smelt. In *Regularities in the Growth and Maturation of Fish* (Nikol′skij, G. V. & Reshetnikov, Yu. S., eds), pp. 153–168. Nauka, Moscow (in Russian).

de Groot, S. J. 2002. A review of the past and present status of anadromous fish species in the Netherlands: is restocking the Rhine feasible? *Hydrobiologia*, **478**, 205–218.

Haberman, J., Jaani, A., Kangur, A., Kangur, K., Laugaste, R., Milius, A., Mäemets, H. & Pihu, E. 2000. Lake Peipsi and its ecosystem. *Proc. Estonian Acad. Sci. Biol. Ecol.*, **49**, 3–18.

Hansson, S., Arrhenius, F. & Nellbring, S. 1997. Diet and growth of pikeperch (*Stizostedion lucioperca* L.) in a Baltic area. *Fish. Res.*, **31**, 163–167.

Horppila, J., Malinen, T., Nurminen, L., Tallberg, P. & Vinni, M. 2000. A metalimnetic oxygen minimum indirectly contributing to the low biomass of cladocerans in Lake Hiidenvesi – a diurnal study on the refuge effect. *Hydrobiologia*, **436**, 81–90.

Hutchinson, P. & Mills, D. H. 1987. Characteristics of spawning-run smelt *Osmerus eperlanus* (L.), from a Scottish river with recommendations for their conservation and management. *Aquacult. Fish. Manage.*, **18**, 249–258.

Kangur, A. & Kangur, P. 1998. Diet composition and size-related changes in the feeding of pikeperch, *Stizostedion lucioperca* (Percidae) and pike, *Esox lucius* (Esocidae) in the Lake Peipsi (Estonia*). Italian J. Zool.*, **65**, 255–259.

Kangur, A., Kangur, P. & Pihu, E. 2002. Long-term trends in the fish communities of lakes Peipsi and Võrtsjärv (Estonia). *Aquat. Ecosystem Health Manage.*, **5**, 379–389.

King, M. 1996. *Fisheries Biology, Assessment and Management*. Blackwell Science Ltd., Cornwall.

Kostyuchenko, V. P., Semenova, A. A. & Khlobastina, G. A. 1974. Hydrological–hydrochemical characteristics of Lake Pskovsko-Chudskoe. *Izv. GosNIORKh*, **83**, 5–15 (in Russian).

Lammens, E. H. R. R. 1990. The relation of biotic and abiotic interactions to eutrophication in Tjeukemeer, The Netherlands. *Hydrobiologia*, **191**, 29–37.

Laugaste, R., Haberman, J., Krause, T. & Salujõe, J. 2007. Significant changes in phyto- and zooplankton in L. Peipsi in recent years: what is the underlying reason? *Proc. Estonian Acad. Sci. Biol. Ecol.*, **56**, 106–123.

Mous, P. J., van Densen, W. L. T. & Machiels, M. A. M. 2004. Vertical distribution patterns of zooplanktivorous fish in a shallow, eutrophic lake, mediated by water transparency. *Ecol. Freshwater Fish*, **13**, 61–69.

Nyberg, P., Bergstrand, E., Degerman, E. & Enderlein, O. 2001. Recruitment of pelagic fish in an unstable climate: studies in Sweden's four largest lakes. *AMBIO*, **30**, 559–564.

Pihu, E. 1966. On dwarf smelt biology and catches in Lake Peipsi-Pskov. In *Hydrobiological Researches IV* (Pihu, E. & Mäting, A., eds), pp. 175–183. Valgus, Tallinn (in Russian).

Pihu, E. 2003. Lake dwarf smelt. In *Fishes of Estonia* (Ojaveer, E., Pihu, E. & Saat, T., eds), pp. 148–151. Estonian Academy Publishers, Tallinn.

Pihu, E. & Kangur, A. 2001. Fishes and fisheries management. In *Lake Peipsi. Flora and Fauna* (Pihu, E. & Haberman, J., eds), pp. 100–112. Sulemees Publishers, Tartu.

Shirkova, A. P. 1966. Pikeperch in Lake Peipsi-Pskov. In *Hydrobiological Researches IV* (Pihu, E. & Mäting, A., eds), pp. 213–220. Valgus, Tallinn (in Russian).

Shpilev, H., Ojaveer, E. &. Lankov, A. 2005. Smelt (*Osmerus eperlanus* L.) in the Baltic Sea. *Proc. Estonian Acad. Sci. Biol. Ecol.*, **54**, 230–241.

Sokolova, A. A. 1983. *Hydrometeorological Regime in Lakes and Reservoirs of USSR. Lake Peipsi-Pskov*. Izdanije Finansy i statistika, Leningrad (in Russian).

Vaino, V., Krause, T., Raspel, E., Peedimaa, V. & Saat, T. 2005. Fishery on Lake Peipsi. In *Estonian Fishery* (Saat, T. & Aps, R., eds), pp. 55–67. Tartu University (in Estonian).

Vinni, M., Lappalainen, J., Malinen, T. & Peltonen, H. 2004. Seasonal bottlenecks in diet shifts and growth of smelt in a large eutrophic lake. *J. Fish Biol.*, **64**, 567–579.

Viimase aastakümne jooksul peipsi tindi arvukuses toimunud muutused

Teet Krause ja Anu Palm

Peipsi järve põhilise planktonitarbija, tindi *Osmerus eperlanus* arvukust uuriti aastatel 1996–2006 kudemisperioodil tindimõrdade ja sügisperioodil põhjatraali saakide alusel. Määratleti tindiparvede asukohad, püütud isendid mõõdeti, kaaluti, määrati sugu ja vanus; saagis määrati vanusegruppide osakaal, kevadel ka kudemisperiood. Lisaks analüüsiti 2005. aasta juuli põhjatraalipüükide saagis leidunud tindid ja samasuvised kohad; kohade seedetrakti uuriti röövtoidulisuse osas. Töö tulemusena selgus, et tindi arvukust mõjutab eelkõige kudemisperioodile vahetult järgneva dekaadi ilmastik, suvel mõjutab tindi arvukust samasuvise koha üleminek röövtoidulisele eluviisile. 2005. aasta tugev kohapõlvkond vähendas planktonis sisalduvat energiat röövkaladesse üleviiva tindi Peipsi järve asurkonna madalseisu.