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Density of 0+ peled (*Coregonus peled*) and whitefish (*C. lavaretus*) in late summer trawling as an indicator of their year-class strength in two boreal reservoirs

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Density of young-of-the-year (YOY) peled (*Coregonus peled*) in late summer trawling was used to estimate their forthcoming year-class strength (YCS) in two northern reservoirs, Lokka and Porttipahta. We applied virtual population analysis (VPA) in estimating year-class strength. A good correlation was found between YOY density and YCS of peled. In contrast, the density of YOY whitefish (*C. lavaretus*) did not reliably reflect their YCS. Annual number of trawling tows in 1991–2001 averaged 23 per reservoir. Precision (SE $\bar{x}^{-1}$) of the annual replicate samples averaged 0.33 and 0.31 for peled and whitefish, respectively. This level of precision was sufficient for detecting the large, often order-of-magnitude differences between annual mean YOY densities. As a practical application in fisheries management, YOY densities in survey trawling can be used in adjusting of stocking density and fishery of peled in the reservoirs studied.

Introduction

Larval fish densities have been used to predict YCS with varying success in seas, lakes and reservoirs (e.g. Rijnsdorp *et al.* 1985, Viljanen 1988, Sammons & Bettoli 1998). Year-class strength of whitefish (*Coregonus lavaretus*) was suggested to be determined during some weeks after hatching in Lake Constance, Germany (Eckmann & Pusch 1991). However, the long-standing paradigm in fisheries ecology, that recruitment levels are determined in the early larval stage, is not likely to be general (Bradford & Cabana 1997). For example, the amount of available food during the first 7 weeks of life affected the mortality and thereby YCS of lake whitefish in Lake Michigan (Freeberg *et al.* 1990). Critical period of peled (*C. peled*) and whitefish was assessed to be rather long in two reservoirs in northern Sweden (Lindström 1962). Density of vendace (*C. albula*) larvae predicted their YCS only in one of the seven lakes studied (Karjalainen *et al.* 2000). Intensive predation by perch (*Perca fluviatilis*) on vendace (about 3–6 cm TL) juveniles in the pelagic zone of lake Puruvesi was documented by Jaatinen *et al.* (1999). Predation by stocked brown trout (*Salmo trutta*) on YOY vendace has also been discovered to be intensive (Niva & Julkunen 1998). Because of the possibly late formation of coregonid YCS via predation during summer, we predicted that a late summer estimate of the density of about 10 cm TL coregonids should be more accurate in forecasting YCS than density estimate of larval or early juvenile fish. The number of YOY Lake Hallwil whitefish (*C. suidteri*) caught by trawling in autumn showed close correlation with year-class strength (Müller *et al*. 2002).

Estimates of the abundance of larval or juvenile fish populations are essential to the management of fish stocks. When a fish stock is supported by stocking it is important to get an estimate of the natural reproduction before the time of stocking. In Finland coregonid stocks are often managed by stocking in autumn with YOY fish reared in semi-natural ponds. In the reservoirs Lokka and Porttipahta, peled exhibited extreme variation in YCS in the 1980s and 1990s (Salonen & Mutenia 1992, Sutela *et al*. 2002). Stocking was ceased for four years in the early 1990s when massive year-classes from natural reproduction emerged in both reservoirs. New strategies in fisheries management were applied in harvesting the slow growing, overly dense peled population (Salonen & Mutenia 1992). The need for estimating annual success in natural reproduction of peled before the time of stocking was evident. We decided to fill this need by trawling with a specially designed light trawl for YOY coregonids. Instead of larval or early juvenile coregonids, we targeted juveniles of about 10 cm TL in late summer to reach an accurate density estimate after the period of most intensive mortality. We also evaluated the precision of the achieved density estimates, the possible need to elevate the number of tows to increase precision, and the ability of the YOY densities to forecast YCS of peled and whitefish in the two study reservoirs.

Table 1. Characteristics of the study reservoirs. Water quality data are from surface water annual averages 1982–1994 (Lepistö & Pietiläinen 1996).

	Lokka	Porttipahta
Inundation started (year)	1967	1970
Bog of the inundated area (%)	80	50
Permitted annual regulation amplitude (m)	5	11
Mean realised amplitude in 1976–1995 (m)	2.21	3.06
Surface area at highest water level (km^2)	417	214
Mean annual surface area (km^2)	355	175
Mean depth at the highest water level (m)	4.95	6.32
Mean depth at the lowest water level (m)	2.31	4.41
Maximum depth (m)	10.5	34.5
Retention time (years)	2.6	1.7
Mean duration of ice-cover (days)	230	220
pH	6.5	6.8
Total phosphorus ($\mu g\ l^{-1}$)	37	25
Colour (mg Pt l^{-1})	90	78

Study area

The two large reservoirs, Lokka and Porttipahta, were founded in Finnish Lapland (68°N) for hydroelectric purposes in the early 1970s (Mutenia 1985). Amplitude between annual lowest and highest water level has ranged between 1.86 and 3.45 m in Lokka, and between 1.93 and 3.65 m in Porttipahta in 1991–1998. Mean depth of Lokka is specially low, and the reservoir area varies considerably with water level changes. Ice covers the reservoirs from late October until early June, and late winter dissolved oxygen deficiency is typical to the reservoirs. The water has a brown colour due to the presence of humic substances, and the reservoirs can be characterised as meso- to eutrophic. Nutrient levels are about 3–5 fold as compared with those in natural lakes in the area (Table 1).

Peled of Siberian origin were introduced to the reservoirs by stocking larval fish beginning in 1972, and one summer old fish beginning in 1975 (Mutenia 1985). Stocking of larval peled ceased in the 1980s but was resumed in 2000. Stocking of one-summer-old peled continued through the 1980s and 1990s with the exception of 1990–1993 in Porttipahta, and 1991–1994 in Lokka, when stocking was interrupted because of strong year-classes from natural reproduction. Stocking density in the late 1990s averaged at 6.9 and 12.1 ind. ha^{-1} in Lokka and Porttipahta, respectively. Natural reproduction was ascertained by identification of peled larvae in the reservoirs. Prominent natural reproduction has occurred since 1986 (Salonen & Mutenia 1992).

A commercial fishery was established in the reservoirs in the 1970s (Mutenia 1985). Peled and whitefish have been the most important species in the fishery. In 1991–2000 peled yield averaged 74 700 kg (range 1500–190 000 kg) in Lokka and 57 400 kg (range 2600–155 800 kg) in Porttipahta. Whitefish yield averaged at 61 800 kg (range 33 500–101 000 kg) in Lokka and 7300 kg (range 4200–10 500 kg) in Porttipahta, respectively. Both peled and whitefish recruit to the fishery at the age of 2–4 years. Besides the coregonids, catches of pike (*Esox lucius*), burbot (*Lota lota*) and perch (*Perca fluviatilis*) have been considerable. Roach (*Rutilus rutilus*) and ide (*Leuciscus idus*) are also abundant in the reservoirs.

Material and methods

Young-of-the-year (YOY) coregonids were sampled in the pelagic areas of the reservoirs Lokka and Porttipahta in August–September 1991–2000 with a specially designed survey trawl (gap width 6 m, height 2 m, length 20 m, cod end mesh size 8 mm), towed with two boats powered by 30 hp outboard motors (Table 2). The duration of one tow was usually 20 min (range 10–30 min) and average towing speed 5.5 km h^{-1}. Since YOY coregonids tended to rise to near-surface layers in the evening, the tows were made at the surface during evening twilight or darkness from 2100 hours to 0200 hours. We aimed at making an equal number of tows within four reservoir sections of equal area, but in some years some sections were slightly over-represented. Annual towing time ranged from 5.7 h to 12.3 h in Lokka, and from 4.3 to 12.3 h in Porttipahta. Respective number of tows ranged from 15 to 35 in Lokka, and from 10 to 32 in Porttipahta. Trawling was always completed before the start of peled stocking in late autumn. Peled and whitefish were identified by their special morphological characteristics. Total length (TL) of peled and whitefish individuals were measured to the nearest millimetre in the field. Bycatch included roach, perch and older coregonid individuals. Towed area was calculated on the basis of length of the tow and trawl gap width (6 m). Although we assumed that all YOY coregonids had risen to between 0–2 m from the surface during the times of sampling, the density estimates (ind. ha^{-1}) are primarily to be taken as relative density estimates.

When starting the monitoring, we estimated that a moderate number of tows (20–30) would be sufficient for our need to detect order-of-magnitude differences in YOY densities. Precision of the juvenile coregonid density estimates was estimated as the coefficient of variation of the mean, $CV_x = SE\ \bar{x}^{-1}$ (Cyr *et al.* 1992). The coefficient of variation of the mean is a function of the average number of YOY fish found per

Table 2. Sampling effort in trawling in the reservoirs Lokka and Porttipahta.

Year	Lokka			Porttipahta		
	Dates	Number of tows	Towing time (h)	Dates	Number of tows	Towing time (h)
1991	31 Jul–27 Aug	15	5.7	25 Jul–10 Sep	10	4.3
1992	10–18 Aug	30	7.1	31 Jul–17 Sep	23	6.3
1993	16–19 Aug	25	7.5	9 Aug–14 Sep	32	10.5
1994	30 Aug–7 Sep	23	10.2	16–25 Aug	30	13.5
1995	4–14 Sep	27	12.3	21–31 Aug	28	12.8
1996	2–13 Sep	20	6.7	20–29 Aug	26	10.3
1997	4–15 Sep	24	8.0	25 Aug–1 Sep	19	6.0
1998	2–17 Sep	18	6.0	24 Aug–1 Sep	20	6.5
1999	16–23 Aug	19	6.3	24–30 Aug	15	5.0
2000	14–22 Aug	25	8.2	7–24 Aug	27	9.0
2001	8 Aug–12 Sep	35	11.2	15–21 Aug	23	7.7

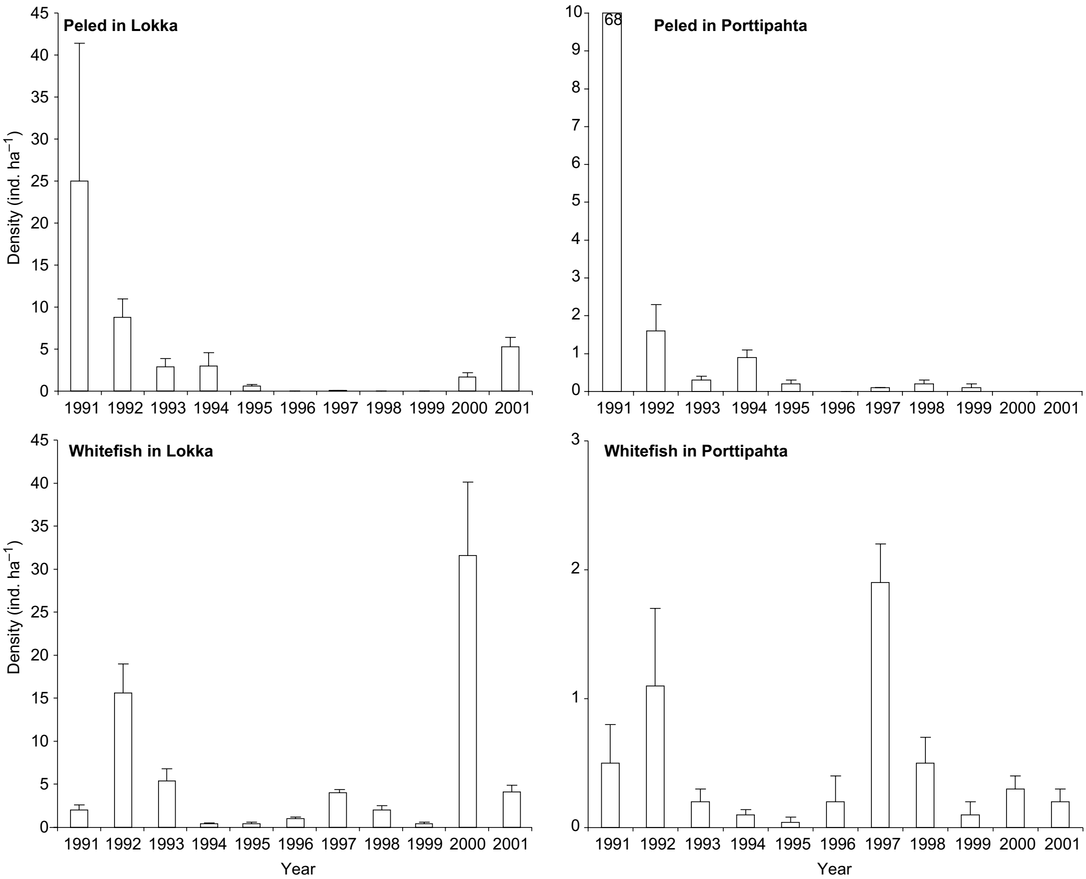

Fig. 1. Density (+ S.E.) of 0+ peled and whitefish based on the trawling in the reservoirs Lokka and Porttipahta.

sample ($\bar{x}$), inter-replicative variance (s^2), and the number of replicate samples collected (n):

$$CV_x = s\bar{x}^{-1}n^{-0.5} \quad (1)$$

Coefficient of variation (expressed as percentage) of YOY density of the replicate tows was calculated as:

$$CV\% = s\bar{x}^{-1}100\ (\%) \quad (2)$$

where s is standard deviation, and x is arithmetic mean of the sample.

Catch and fishing effort statistics were collected annually by surveys, which were sent to all fishing licence holders. All nonrespondents were sent a new questionnaire form after 2–3 weeks, resulting in a cumulative response rate averaging 79% (range 66%–89% in the study period). Additional data on the yield from the professional fyke net and trawl fishery was obtained from compulsory bookkeeping records.

To provide a basis for virtual population analysis (VPA), on an annual average, 622 (range 112–1596) and 526 (range 210–1021) peled samples from Lokka and Porttipahta reservoirs, respectively, were taken from the commercial fishery for analysis of length, weight, sex, maturity and age in 1991–2000. Age of the fish was determined from scales. An annual average of 402 (range 131–719) whitefish samples were taken from the Lokka fishery in 1991–2000. In these coregonid samples all main types of gears including gill net, fyke net and trawl (only in Porttipahta) were represented. Age distributions and mean weights of each species were determined for each gear type. Virtual population analysis was used to assess the size of peled and whitefish stocks by age groups and hence by different year-classes (Pope 1972). An instantaneous natural mortality estimate of 0.2 was applied for all age groups and years (Salojärvi 1991, 1992, Auvinen & Jurvelius 1994). The number of one-year-old fish given by VPA was used as an estimate of year class strength (YCS) for peled and whitefish. Sufficient data were available to obtain YCS estimates from the years 1991–1998 for peled from both reservoirs. A VPA could not be run for whitefish from Porttipahta due to the lack of systematic sampling for this species.

Spearman's correlation analysis (Sokal & Rohlf 1981) was applied in studying the relationship between the arithmetic mean YOY density in trawling and the corresponding estimated YCS.

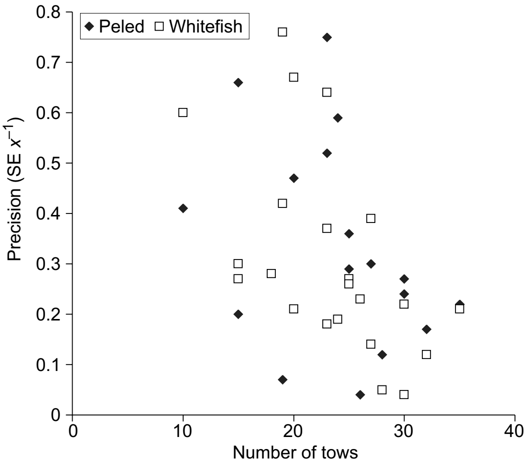

Fig. 2. Number of tows in trawling and the respective precision (SE $\bar{x}^{-1}$) of the YOY density estimates of peled and whitefish.

Results

Trawl catches and their precision

Variation between annual mean YOY densities was high especially with peled, but also with whitefish in both reservoirs (Fig. 1). Order-of-magnitude differences between consecutive years were frequent. The highest peled mean density (68 ind. ha^{-1}) was recorded in Porttipahta in 1991, while the next highest density was only 1.6 ind. ha^{-1}. Median YOY density of both peled and whitefish was 0.2 ind. ha^{-1} in Porttipahta. In Lokka, median density of peled was 1.7 ind. ha^{-1}, and of whitefish 2.0 ind. ha^{-1}. Annual mean length of the YOY peled in trawl catches averaged 114 mm (range 98–140 mm) in Lokka, and 97 mm (range 84–115 mm) in Porttipahta. Respective lengths for whitefish in these reservoirs were 100 mm (range 98–135 mm) and 101 mm (range 81–115 mm).

Coefficient of variation (CV%) of YOY density of the replicate tows averaged at 199% (range 100%–300% in the 10 years studied) for peled and 213% (range 48%–550%) for whitefish indicating clustered distribution of the YOY fish. Precision estimated as coefficient of variation of the annual replicate samples ranged from 0.07 to 0.75 with peled and from 0.05 to 0.76 with whitefish (Table 3). A high number of replicate tows (30–35) resulted in reasonably high precision averaging at about 0.2 (Fig. 2).

Correlation between YOY density and resulting YCS

Average YOY density of peled determined by trawling correlated positively with estimated YCS of the same year-class in Lokka (Spearman correlation coefficient $r_s = 0.96$, $p < 0.001$, $n = 8$) and Porttipahta ($r_s = 0.91$, $p = 0.002$, $n = 8$) (Fig. 3). In contrast, YOY density of whitefish did not correlate significantly with estimated YCS in Lokka ($r_s = 0.265$, $p = 0.526$,

Table 3. Precision (SE $\bar{x}^{-1}$) of annual YOY coregonid density estimates in the reservoirs Lokka and Porttipahta. Number of tows (n) is also indicated.

Year	Lokka			Porttipahta		
	n	Peled	Whitefish	*n*	Peled	Whitefish
1991	15	0.66	0.30	10	0.41	0.60
1992	30	0.24	0.22	23	0.75	0.64
1993	25	0.36	0.27	32	0.17	0.12
1994	23	0.52	0.37	30	0.27	0.04
1995	27	0.30	0.39	28	0.12	0.05
1996	20		0.21	26	0.04	0.23
1997	24	0.59	0.19	19	0.07	0.76
1998	18		0.28	20	0.47	0.67
1999	19		0.42	15	0.20	0.27
2000	25	0.29	0.26	27		0.14
2001	35	0.22	0.21	23		0.18
Mean	23.7	0.40	0.28	23.0	0.28	0.34

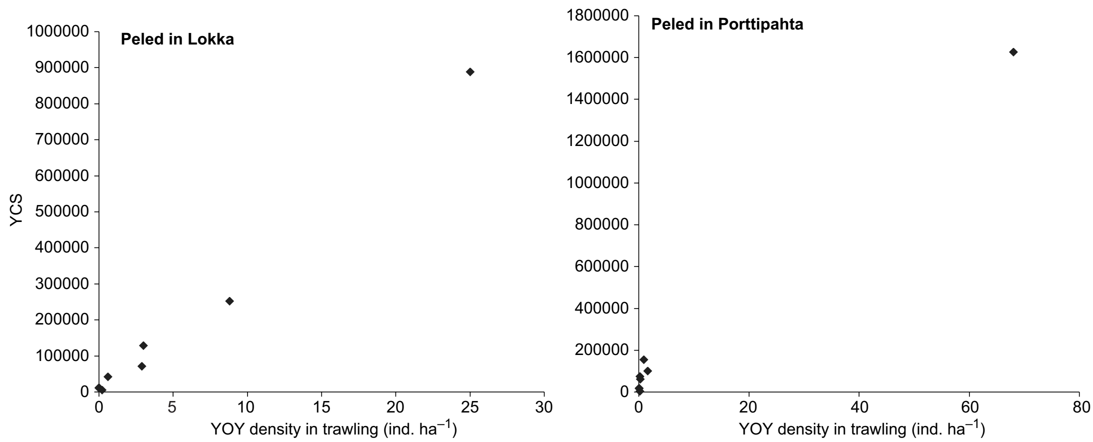

Fig. 3. Relationship between mean young-of-the-year (YOY) density and year-class strength (YCS) of peled in the reservoirs Lokka and Porttipahta.

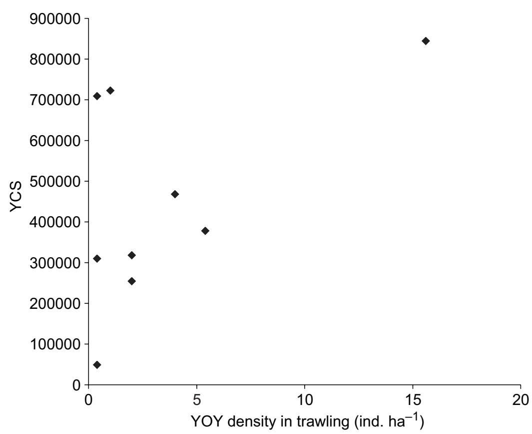

Fig. 4. Relationship between mean young-of-the-year (YOY) density and year-class strength (YCS) of whitefish in the reservoir Lokka.

n = 8) (Fig. 4). Only the years 1991–1998 were included in the above correlation analyses, because reliable YCS estimates by VPA could not be achieved from the later years.

Discussion

As a main result of the study we postulate that YOY peled density in late summer pelagic trawling can be used as a predictor of the forthcoming YCS in the reservoirs Lokka and Porttipahta. In contrast, the density of whitefish did not correlate with YCS in Lokka. Relatively large whitefish year-classes emerged in 1995 and 1996 in spite of low YOY densities in trawling. Precision of the density estimates in those years did not differ distinctively from the average. One possible explanation for the apparent low density of whitefish might be related to habitat choice by this species. Whitefish are less strictly pelagic and zooplanktivorous than peled. A higher proportion of benthic food in the diet of whitefish as compared with that of peled has been observed in Lokka (Niemitalo & Mutenia 1988). In years of abundant benthic or littoral food supply YOY whitefish may shift to littoral areas or depths under 2 m from surface beyond the reach of pelagic surface trawling. Food competition between a specialist planktivore (vendace) and whitefish induced food segregation including a shift in whitefish diet from zooplankton to zoobenthos and surface insects (Bohn & Amundsen 2001).

High correlation between trawling density of 0+ peled (from natural reproduction) and estimated YCS was probably facilitated by the fact that stocking of peled did not enhance YCS (Sutela *et al.* 2002). High peled YCS were recorded in years without stocking. Minimum water level in late winter was the key factor for the lake spawning peled in YCS formation in both reservoirs. Synchronism of the YCS in the two reservoirs also supports the view that environmental factors have an essential impact on YCS.

High interannual variation in the reproductive success of peled facilitated for its part the use of trawling YOY density as a YCS estimate. In our view, peled populations in the reservoirs are especially vulnerable to high interannual variation in YCS. Reservoirs tend to be less stable systems than natural lakes (Carline 1986). The water level regime in Lokka and Porttipahta reservoirs varies from year to year. In the years of low winter water level and accompanying oxygen deficiency, a large number of peled eggs are destroyed resulting in poor year-class strength (Sutela *et al*. 2002). Natural reproduction of the introduced peled in Lokka and Porttipahta was somewhat of a surprise for fishery managers (Salonen & Mutenia 1992), because in most cases introduced peled stocks have not formed reproducing stocks (Vostradovsky 1986, Gerdeaux *et al*. 1998). As compared with other coregonids, peled produces a large number of small eggs indicating r strategy (Vostradovsky 1986, Sutela *et al*. 2002), which is an adaptation to labile environmental conditions. To summarise, there are several sources of variation in interannual reproductive success of peled. Instability of the reservoirs may also have contributed to the year-class fluctuation of whitefish. In natural coregonid populations, fluctuation in recruitment is possibly less extreme (Gaboury & Patalas 1984, Linlokken 1994), and therefore a higher number of samples may be needed to obtain a suitable precision level to detect less than order-of-magnitude differences in YOY densities.

Estimates of larval or juvenile fish densities should be both accurate (unbiased) and precise (low variance). Biasing factors including, for example, the rapid increase in escape ability as the fish grow, have been identified especially during the larval stage and during metamorphosis (e.g. Gregory & Powles 1988). In our view, such biasing factors diminish after metamorphosis and the earliest juvenile stages because of retarded instantaneous growth rate and smaller relative changes in escape ability. Therefore, higher accuracy may be obtained by sampling large juvenile fish instead of larval or early juvenile fish. Intensive piscine predation on 0+ coregonids in summer (Jaatinen *et al*. 1999) also calls for estimation of their density later in autumn.

Heterogeneous spatial distribution of young fish and the resulting high variance among replicate samples may render useless the obtained population estimates (Cyr *et al*. 1992). There are two possible ways of increasing sample precision, either taking larger volumes of water or taking more replicate samples. We considered 20 min towing time in Lokka and Porttipahta cost-effective and recommendable for use in the future. High numbers (100–200) of replicate tows resulted in precision levels of about 0.02–0.03 when sampling vendace larvae in the littoral and pelagic zone of two lakes (Karjalainen *et al*. 1998). In our study reservoirs, however, a lower level of precision is acceptable because orders-of-magnitude variation across years in YOY densities outweigh the high variation among replicate tows. Still, in the future we suggest elevating the number of annual tows from the present average 23 to 30–35 in order to keep precision at a level of 0.2.

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