Vendace (*Coregonus albula*) stock assessment in winter using a mobile echo-survey under ice

Juha Jurvelius[1], Timo J. Marjomäki[2], Esa Hirvonen[1], Juha Lilja[3] and Raimo Riikonen[3]

[1] *Finnish Game and Fisheries Research Institute, Saimaa Fisheries Research and Aquaculture, FI-58175 Enonkoski, Finland*

[2] *Department of Biological and Environmental Science, P.O. Box 35, FI-40014 University of Jyväskylä, Finland*

[3] *Finnish Game and Fisheries Research Institute, Joensuu Game and Fisheries Research, FI-80100 Joensuu, Finland*

As a consequence of a local disagreement between commercial fishermen and local fishing-right owners, we estimated the size of a vendace (*Coregonus albula*) stock in a southern boreal lake in Finland in March 2000. We applied a mobile under-ice echo-survey and catch sampling from winter seining. The sounder with a tape recorder was placed in a shuttle and towed under ice from hole to hole with a rope. The mean fish density was 4270 fish ha^{-1}. Vendace biomass was estimated to be ca. 36 tonnes. Commercial fishing started on a restricted scale after the completion of the assessment. The vendace yield was ca. 6 tonnes in the area during the remainder of the winter-seining season. The total winter seining catch amounted to ca. 40% of the initial vendace stock size in January 2000.

Introduction

Vendace (*Coregonus albula*) is the most important fish species in Finnish commercial inland fishery. The regional fluctuation of vendace stocks often encourages fishermen to look after fishable stocks outside their local lake district (Muje *et al*. 2004). Winter fishing is popular because the price of vendace in winter is usually high. However, the movement of fishermen between lakes sometimes creates concern among local people regarding for example the sustainability of fishing (Salmi and Auvinen 1998). Since the second half of the 1980s, Finnish winter seining has been motorized and it is thus an effective means of fishing (e.g. Turunen *et al*. 1997).

For the local fishing right owners, fishing by "outsiders" in the lake is sometimes an unwanted situation. However, in certain circumstances the law in Finland gives permission for "outsiders" to fish if the fish stock is in fishable condition. This condition is often one important reason for disagreement over winter seining rights. To solve the problem, it is not unusual for the local people to ask a biological research institute to assess the size of the stock and to set a quota for fishery. This is often a precondition to allow "outsiders" to fish.

In lake Puruvesi in central Finland, the vendace stock was scarce in winter 2000 (Auvinen *et al*. 2004). Thus fishermen from lake Puruvesi fished for vendace by winter seining in Ker-
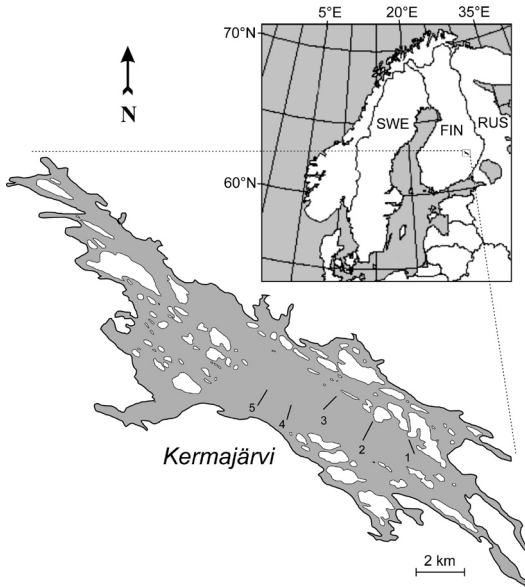
Fig. 1. Map of the study area. Echo-survey transects are marked with lines on the map. Transects 1, 2 and 3 are located in the commercial seine netting area.

majärvi nearby. Their yield was ca. 15 tonnes of vendace in January–March 2000. However, some local fishing right owners in Kermajärvi thought this was too much for the fishing to be sustainable, and they refused to allow this fishing to continue. After several meetings and negotiations, seining was again permitted in a restricted area after the size of the vendace stock had been assessed and quotas for fishing had been set on a "biological basis". In this assessment, a vendace stock was for the first time assessed with a mobile under-ice echo sounding.

Previous under-ice hydro-acoustic work focused on fish detection and behaviour (Pavlov *et al.* 1986, Presnyakov and Borisenko 1993, Jurvelius *et al.* 1999, Jurvelius and Marjomäki 2004). The vertical movements of pelagic fish in lakes usually set strict conditions for the timing of hydro-acoustic stock estimation especially in summer and to a lesser extent also in winter (e.g. Dembinski 1971, Jurvelius *et al.* 1984, 2000). For acoustic assessment of vendace stock, the time between sunset and midnight has been found to be the most suitable time.

In the present work, we (i) assessed by means of a mobile under ice echo-survey the size of the vendace stock in Kermajärvi, and (ii) set a quota for its commercial winter seining.

Material and methods

Study area

Kermajärvi (62°26´N, 43°00´E) is an 85 km² lake in eastern Finland. Its maximum depth is ca. 55 m and the mean is around 10 m. The study area consisted of the parts deeper than 15 m in the middle of the lake (Fig. 1). Its size was ca. 2100 ha. The depth in the commercial hauling area varied from 15 to 35 m. During the study period in winter from 22 to 23 March 2000, the ice was ca. 60 cm thick and there was about 35 cm of snow on it. At the study time, dawn was at 05:56 and sundown at 18:21.

Under ice, the water temperature was 1.2 °C at 1 m depth below the ice, and reached its maximum, 2.3 °C, near the bottom in the deepest areas. Oxygen concentration decreased from 16.7 mg l⁻¹ to 12.8 mg l⁻¹ between the surface and 40 m. Water colour in the surface layers of the study lake was ca. 20 Pt mg⁻¹ on 16 March 2000.

In lakes similar to Kermajärvi, the pelagic fish community is dominated by vendace and smelt (*Osmerus eperlanus*) (e.g. Jurvelius *et al.* 2000). Also whitefish (*Coregonus lavaretus*), small perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*) are common plankton feeders. Pike (*Esox lucius*), burbot (*Lota lota*), brown trout (*Salmo trutta*), pikeperch (*Sander lucioperca*) and large perch are usually the most abundant predators.

Echo-survey

Size assessment of under-ice fish stocks by hydro-acoustic methods has developed further some of the principles used in the commercial winter seining (e.g. Turunen *et al.* 1997, Jurvelius *et al.* 1999). In Kermajärvi, the survey consisted of five transects amounting in total to 3450 m (Table 1) in the central pelagic zone of the lake (Fig. 1). Three (1, 2 and 3) of them were the same as commercial hauling sites in the southernmost 5 km of the study area (Fig. 1). Transects 4 and 5 were located in the deepest area of the lake where no commercial fishing took place. Degree of coverage — the length of the echo-survey divided by the square root of the research area — was in this study 0.8.

The surveys were made with a down-beaming 70 kHz single-beam echo sounder (Simrad EY-M, 70-24-F transducer, 11° beam width, pulse duration 0.6 ms, pingrate 3 pulses s⁻¹). The sounder with a recorder and batteries was placed in a shuttle (Jurvelius *et al*. 1999). The shuttle floated against the ice in the water and it was towed from hole to hole with a rope. The towing speed was ca. 1 m s⁻¹. The echoes recorded were analysed by the Hydro Acoustic Data Acquisition System (Hadas: Lindem Data Acquisition, Oslo, Norway). The echoes with target strength (TS) ≥ –56 dB were interpreted as fish. Fish densities (fish ha⁻¹) were estimated mostly in 2 m thick layers from 2 m under the sounder to the bottom (Table 1). Mean fish density was estimated for each transect taking into account its depth profile. Transects were not divided horizontally into sub-samples. The echo-survey was conducted between sunset and midnight.

Because of different lengths of transects, the mean density ($\bar{y}$) of fish in the study area was calculated as the weighted mean in transects with transects' lengths as weights. The variance of mean density (Var($\bar{y}$)) was estimated with transects as sampling units and was according to Shotton and Bazigos (1984) calculated as

$$\mathrm{Var}(\bar{y}) = \frac{\sum_{i=1}^{n}\left[\left(y_i - \bar{y}\right)^2 l_i\right]}{\sum_{i=1}^{n} l_i \left(n-1\right)} \qquad (1)$$

where y_i is the fish density in the *i*th sampling unit, l_i is length of *i*th sampling unit, and *n* is number of sampling units. The 95% confidence intervals for mean fish densities were calculated assuming the density to be Poisson-distributed (Jolly and Hampton 1990, Malinen and Tuomaala 2005). Thus, the end points of the confidence limits were given by

$$\bar{y}\left[1 + \frac{\mathrm{Var}(\bar{y})}{\bar{y}^2}\right] \pm 2\sqrt{\mathrm{Var}(\bar{y})}. \qquad (2)$$

Exploratory fishing

Commercial fishermen did the exploratory seining in the study area for 3.5 h after the sunrise on 15 February and 23 March 2000. After the sunrise, fish school some 4 to 5 meters above the bottom (Jurvelius and Marjomäki 2004). Thus it is understandable that the seining operation was a 'bottom haul', the height of the gear being 10 m. The mesh-size in the cod-end of the seine was 10 mm from knot to knot. The total yield was sorted into species and the total weight of each species was measured. In February, the mean length of vendace and smelt as well as the mean weight of vendace were measured from a sub-sample of 100 specimens for both species. The age of vendace was read from scales. In March, the mean weight of both species was estimated by dividing the total weight of the species in the sub-sample by the number of its specimens in the sub-sample. In addition to this, the lengths and age structure of commercial vendace was studied in a catch sample on 3 August 2000.

Biomass of vendace in the study area = vendace density (fish ha⁻¹) × mean weight of a specimen (kg) × study area (ha). The proportion of vendace in the total fish density was estimated from the length distribution of the fish caught in winter seining and the TS distribution of the echo-counted fish in the surveys. It was assumed that the TS (dB)–length (*L*, cm) relationship

Table 1. Echo-survey transects in Kermajärvi on 22 and 23 March 2000. Every survey was performed between sunset and midnight.

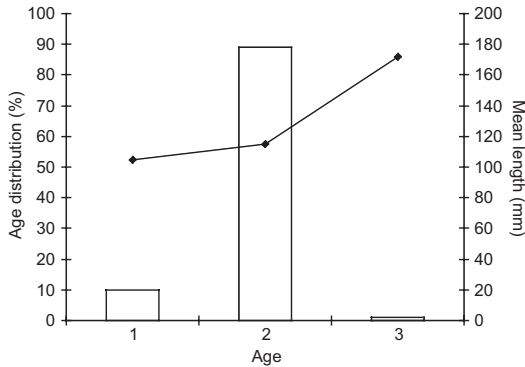| Transect	Date	Length (m)	Water depth (m)	Analysis depth (m)	Number of analysed layers
1	23 March	710	15–32	2–32	12
2	22 March	580	17–35	2–35	12
3	22 March	700	15–35	12–35	8
4	22 March	640	20–50	2–50	20
5	23 March	820	20–50	2–50	24

Fig. 2. Age distribution and mean length of different age groups of vendace specimens in a winter seining sample in Kermajärvi on 15 February 2000.

$L = 10^{(TS + 69)/20}$ holds roughly for vendace and smelt (Jurvelius *et al.* 1984, Jurvelius and Heikkinen 1988, Marjomäki & Huolila 1994). The acoustic targets with target strength ≥ 50 dB were divided into vendace and smelts according to their proportions in the length classes predicted by the equation above.

Results

Vendace and smelt were the only fish species caught in the commercial winter seining. About 95% of the fish caught were vendace. About 90% of the vendace catch in February were 2-year-old fish (Fig. 2). The mean length of both species was about 11.6 cm (Table 2). In August, younger vendace (age < 2+) had been recruited into the fishery and the specimens were considerably larger than in winter (Fig. 3).
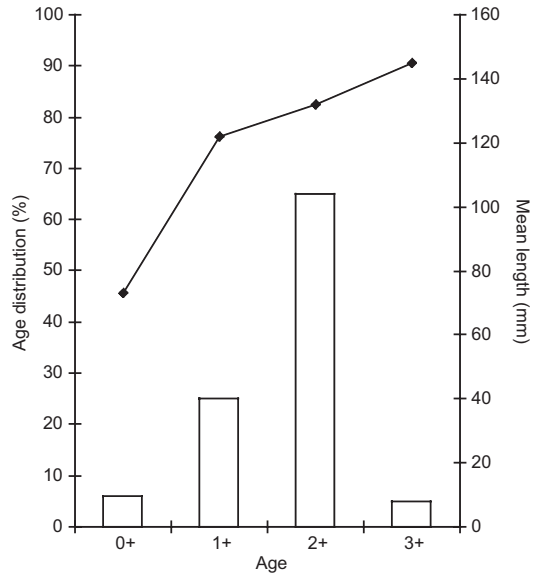

Fig. 3. Age distribution and mean length of different age groups of vendace specimens in a seining sample in Kermajärvi on 3 August 2000.

In the study area, the mean fish density in March was ca. 4270 fish ha^{-1} (95% confidence interval = 2820–5730) (Table 3). Almost 50% of the targets in the echo-survey had TS ≥ -50 dB (Fig. 4), and according to catch samples 95% of them were considered to be vendace. Thus the proportion of vendace in the total fish density was estimated to be 48%, and the mean vendace density was 2050 specimens per hectare in areas deeper than 15 m. This means that in the study area the vendace biomass was roughly 36 tonnes. The winter seining catch was 15 tonnes before the echo-survey. Thus the vendace biomass had

Table 2. Length and weight of the fish species in commercial winter seining catch samples in Kermajärvi in 2000. Smelt was sampled neither in February nor in August. In March, the mean weight was estimated by dividing the sample weight of the species with the number of its specimens.

Date	Vendace						Smelt					
	Length (cm)			Weight (g)			Length (cm)			Weigth (g)		
	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
15 February	11.5	1.0	100	8.4	2.6	100	–	–	–	–	–	–
23 March	11.6	0.9	100	7.9	–	882	11.7	1.8	46	8.6	–	46
3 August	12.6	1.8	93	13.0	0.5	93	–	–	–	–	–	–

been at least 51 tonnes (24 kg ha^{-1}) in the study area before seining in January. Winter seining catch was 6 tonnes after the echo-survey, and the vendace stock size in the study area after winter was 30 tonnes (14 kg ha^{-1}). The total winter seining catch amounted to less than 40% of the initial vendace stock size in January 2000.

Discussion

Immediately after completion of the vendace stock assessment commercial fishermen and local residents settled their arguments about winter seining in the lake. According to the agreement, 20 tonnes of vendace could be fished during March–April 2000 from a restricted (ca. 800 ha) area in the lake. This quota assured that the fishery was kept within the limits of sustainable use of the local vendace stock. The age structure of August vendace sample reinforced this conception. In addition, our hydro-acoustic studies, in August and October 2000, estimated that the vendace biomass in the study area was about 1.7 times larger than in April.

Commercial fishermen were satisfied with the agreement because the vendace stocks in neighbouring lakes were scarce and thus not suitable for winter seining. In March–April 2000, following the agreement, the commercial vendace catch was ca. 6 tonnes in Kermajärvi. During the following six years commercial fishing has continued in the lake without any further disagreements between interest groups. No more hydro-acoustic stock assessments have been requested; only catch statistics and samples were needed for monitoring of the local vendace stock.

The acoustic density estimate of fish under ice is much higher during the night than during the day (Jurvelius *et al*. 2000). The effect of sunrise and sunset on fish is marked; during the hours of darkness fish are in the mid-water clearly above the bottom (Jurvelius and Marjomäki 2004). Also the schooling of fish is less in darkness than in daylight. Thus the hours of darkness are the most suitable time for acoustic fish stock assessment. However, up-beaming acoustic studies have shown that a notable proportion of fish ascend on some nights very close to the ice and are thus within the blind zone
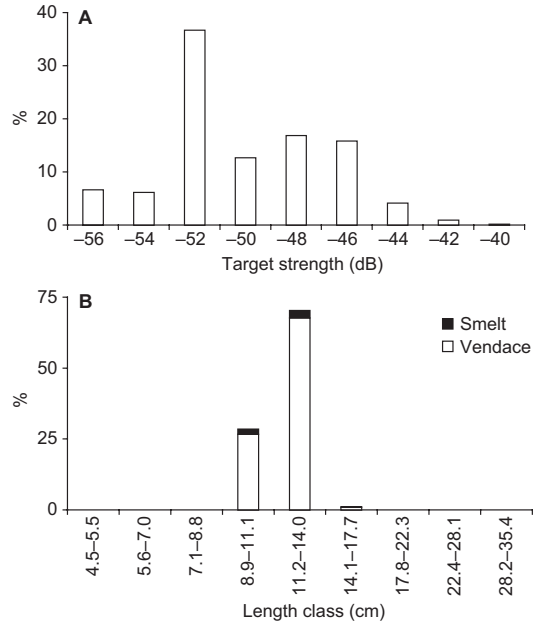

Fig. 4. Comparison of (**A**) acoustic TS-distribution and (**B**) length distribution of vendace and smelt in Kermajärvi in March 2000. The length classes and TS are related according to equation $L = 10^{(TS + 69)/20}$. In **A**, the numbers indicate the lower limits of each TS class.

of vertical down-beaming echo-surveys (J. Jurvelius and T. Marjomäki unpubl. data). This phenomenon may have caused some underestimation of fish density in this study. It is important to gain further understanding of the reason for this phenomenon and its predictability in order to eliminate this source of bias in assessment as much as possible.

Commercial fishermen wanted to avoid catching small fish, and thus they used a 10 mm cod-end in their seine. Sampling fish from this

Table 3. The weighted mean density (fish ha^{-1}) of fish and the descriptive statistics in the echo-survey transects in Kermajärvi in 2000.

Transect	fish/ha
1	3430
2	3860
3	2690
4	7050
5	4340
Weighted mean	4274
Weighted SD	1666
CV (%)	39

seine may strongly underestimate the proportion of small smelt in the lake (e.g. Jurvelius *et al*. 2005). In this work, this is seen in the comparison of TS and length distributions of the fish. However, small smelt usually stay in the first 10 m depth layer under the surface. In this lake, seining took place in deeper layers between 15 m and 30 m. To ensure more reliable fish samples for stock estimates, a 5 mm cod-end should be used also in winter fish sampling.

In this work, we have not emphasised the uncertainty in acoustic vendace stock biomass estimate. There are, however, many sources of uncertainty involved in this sort of estimation. Firstly, the acoustic mean density estimates contain considerable sampling error. Secondly, they may be biased due to fish behaviour and misinterpretation of non-fish targets as fish. Thirdly, the proportions of different fish species and their mean weight are typically estimated from catch samples. Further they are often far from random samples of the fish community. Finally, determining the area of distribution of certain fish species according to certain depth isopleths is only a rough estimation. In the future, these factors must be studied in detail in order to decrease the uncertainty and the risk of over-fishing.

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