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Under ice density and mobility of fish in winter-seining area of two Finnish lakes as revealed by echo-survey

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Abstract − The density and movements of fish under ice were studied with single-beam mobile surveys and fixed location split-beam surveys, as well as exploratory fishing in winter-seining areas of two shallow Finnish lakes during winter 1999. Fish schooled near the bottom during the day but the schools dispersed and fish ascended at night. Single and split-beam target strength distributions corresponded fairly closely with the length distribution of seine catch samples. Estimated fish densities were greater at night than in daylight. The swimming speed of smelt (*Osmerus eperlanus*) was 0.18 $m \cdot s^{-1}$ in daylight and 0.36 $m \cdot s^{-1}$ at night. The corresponding figures for vendace (*Coregonus albula*) were 0.11–0.17 and 0.05–0.08 $m \cdot s^{-1}$. Nights immediately before and after fishing were the best periods to estimate the effect of seining on fish density. The hydroacoustic fish density estimates at night corresponded closely with seine catches. We conclude that it is possible to estimate the effects of winter-seining by mobile under-ice echo-surveys and catch samples. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

echo-sounding / vendace / smelt / winter-seining / fish migrations

Résumé − Densité et mobilité des poissons sous la glace, sur une zone de pêche à la senne de deux lacs finlandais, par écho-intégration. La densité et les déplacements des poissons sous la glace ont été étudiés au moyen de sonar monofaisceau et de sonar à multifaisceau partagé fixe, ainsi qu'à partir de pêche dans deux lacs de Finlande, au cours de l'hiver 1999. Dans la journée, les poissons se regroupent près du fond, mais se dispersent et remontent à la surface durant la nuit. Les distributions des indices réflexion au sonar monofaisceau et en faisceau partagé correspondent à la répartition en taille des échantillons capturés à la senne. Les densités de poissons estimées sont plus grandes la nuit que le jour. La vitesse de nage de l'éperlan (*Osmerus eperlanus*) est de 0,18 $m \cdot s^{-1}$ le jour et de 0,36 $m \cdot s^{-1}$ la nuit. Les vitesses correspondantes pour le corégone (*Coregonus albula*) sont de 0,11–0,17 $m \cdot s^{-1}$ et 0,05–0,08 $m \cdot s^{-1}$. Les nuits immédiatement avant et après la pêche sont les meilleures périodes pour estimer les effets de la pêche à la senne sur la densité des poissons. L'estimation de la densité des poissons par hydro-acoustique la nuit correspond aux captures faites à la senne. On conclut qu'il est possible d'estimer les effets de la pêche à la senne l'hiver par échointégration mobile sous la glace et par échantillonnage des captures. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

échointégration / corégone / éperlan / pêche à la senne / déplacement des poissons

1. INTRODUCTION

Very low temperatures and the scarcity of sunlight, together with isolation from the atmosphere make under-ice conditions radically different from summer conditions, i.e. fish behaviour may differ significantly compared to the open water period. However, in comparison with the open water period, our knowledge on fish biology in ice-covered sub-Arctic lakes is rather limited. Still, in many areas the most profitable fish catches are made in winter. This can make the stocks concerned vulnerable to overfishing.

Winter fishing for vendace is of recreational, subsistence and commercial importance in Finnish lakes. The annual yield per fisherman varies by up to 50 t depending on stocks and fishing method. The price fishermen usually get for vendace is around 3 $US\$ \cdot kg^{-1}$. Although on a national level, vendace

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fishery is a relatively small-scale activity, on a local level it is of great cultural importance and of some economic importance, and, consequently, tends to be a subject of conflict. Catch-independent data of the vendace stock involved are often needed to reconcile the conflicting parties.

For fisheries management purposes, stock assessment methods independent of fishery are needed, especially if the fishery is fluctuating, e.g. for biological or economic reasons. Hydroacoustics provides an independent and fast method for showing, at least, the direction of change in fish density (Auvinen and Jurvelius, 1994). It would be advisable to expand the method also to the management of winter fishing.

Diel vertical fish migrations have been found to affect strongly the hydroacoustic assessment of pelagic fish stocks in shallow lakes in summer (Lindem, 1983; Jurvelius et al., 1988). The conditions under-ice provide some methodological advantages compared to summer time hydroacoustics: fish migration is usually most restricted at low temperatures, thereby enabling the production of a more realistic stock estimate. However, this migration pattern has not yet been demonstrated for cold-water species.

In the earliest studies on hydroacoustics in ice-covered water, Kudryavtsev (1971) described searching for fish through ice. Later, Pavlov et al. (1986) surveyed the behaviour of roach, and Steinhart and Wurtsbaugh (1999) the diel vertical migrations (DVM) of *Oncorhynchus nerka* through holes cut in the ice. Scanning sonar has been used to locate fish under ice (Presnyakov et al.,1993; Turunen et al., 1997), and we briefly described a method to study fish migrations under-ice with a mobile echo-survey (Jurvelius et al., 1999). The decrease in fish density calculated from echoes registered on echogram paper corresponded closely with the seining catch from the same area.

In this study, we addressed the following questions: 1) do fish show a diel migration pattern under ice, 2) are there differences between vendace and smelt in this pattern, 3) is echo-surveying accurate enough to monitor vendace stock exploitation, and 4) is fish mobility fast enough during winter to compensate for local depletion consecutive to hauling? We used a mobile single-beam echo-survey under-ice to estimate fish densities (fish·ha^{-1}), fixed position split-beam echo-sounding to estimate fish swimming speed (m·s^{-1}), and exploratory seining to take fish samples in the study area. The investigation was carried out in two shallow Finnish lakes in February–April 1999.

2. MATERIAL AND METHODS

2.1. Study area

Lake Karjalan Pyhäjärvi (61°47'N, 29°55'E) is a 248 km^2 oligotrophic and oligohumic lake in eastern Finland. Its water color is ca. 15 Pt mg·L^{-1}, and the mean depth is about 8 m (Niinioja and Ahtiainen, 1987). The depth in our study area was 28 m. We completed a hydroacoustic assessment of the vendace stock in this area in the mid 1980's (Jurvelius et al. 1988). The total vendace biomass was estimated to be ca. 15 t, i.e. 76 kg·ha^{-1}. Subsequently there was a period of scarcity of vendace stock lasting more than ten years in the area, and the pelagic fish community was dominated by smelt. There was no commercial fishing in this part of the lake during our study.

Lake Vuokalanjärvi (62°14'N, 29°09'E) is another oligotrophic and oligohumic lake in eastern Finland. Its water color is ca. 20 Pt mg·L^{-1} and its surface area is 18 km^2 (Lehtonen et al., 1998), the mean depth being about 10 m. The mean depth in our study area was 18 m. Commercial vendace seining went on in the study area between mid February and mid April in 1999. Its total catch was 1 700 kg, being 130 kg·haul^{-1}.

In the pelagic fish assemblage in both lakes vendace, whitefish (*Coregonus lavaretus*), perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*) are usually the most abundant planktivors (Auvinen, 1988; Lehtonen et al., 1998). Lake Karjalan Pyhäjärvi is known also for its strong smelt stock. Pike (*Esox lucius*), burbot *(Lota lota*), brown trout (*Salmo trutta*) and large perch are the most important predators in these lakes.

In both lakes, water temperature was ca. 0.5 °C 1 m below the ice, and reached its maximum (3.5–4 °C) 2 m above the bottom. At corresponding depths, oxygen concentration was ca. 10 mg·L^{-1} and 3.5 mg·L^{-1}, respectively. There was almost no variation in temperature and oxygen conditions during the study periods in 1999. The ice was ca. 80 cm thick and there was about 50 cm of snow on it.

2.2. Echosurveys

The study area was ca. 700 m long and 200 m wide in both lakes. In each lake, a 700 m long transect for mobile echo-surveys was set in the middle of the hauling area. A control transect was set in the same deep basin 300 m from the hauling area in Lake Pyhäjärvi. In Lake Vuokalanjärvi, the control transect was 1 km away in a nearby basin. Mobile echosurveys were carried out on February 2–3 and 23–24, March 29–31, and April 12–13 in 1999. The monitoring was stopped in April because the ice was melting. The sun rose at 9h26 and set at 17h07 at the beginning of the investigation. The corresponding figures were 5h47 and 21h05 at the end of the investigation. A fixed location echo-survey was done 100 m outside the hauling area in both lakes. Commercial fishermen did the exploratory seining in the study area during the first, third and fourth study period.

The mobile surveys were made with a 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 tape recorder and batteries was placed in a shuttle (Jurvelius et al., 1999). In this study the shuttle was towed from hole to hole with a rope. The towing speed was ca. 1 m·s^{-1}. Analysis of the echoes recorded was per-

Table I. Catches in exploratory winter-seining in 1999.

Species	Karjalan Pyhäjärvi		Vuokalanjärvi					
	February 3		February 24		March 30		April 13	
	Catch (kg)	Number	Catch (kg)	Number	Catch (kg)	Number	Catch (kg)	Number
Vendace	9	508	160	15 385	138.6	14 143	214	21 837
Whitefish	23	244	4	13	3	10	1.5	5
Smelt	79	14 630	0.2	33	1.4	233	0.2	33
Others	4	436	0	0	0	0	0	0
Total	115	15 845	164.2	15 431	143	14 386	215.7	21 875

formed by the Hydro Acoustic Data Acquisition System (Hadas; Lindem Data Acquisition, Oslo, Norway). Fish densities (fish·ha^{-1}) and target strength (TS)-distribution of echoes were estimated in layers of 2 m depth.

In the fixed location echo-surveys the monitoring was done through a hole in the ice. A vertically aimed 120 kHz split-beam echo-sounder (Simrad EY500, ES120-7F transducer, 7° beam width, 2 pulses·s^{-1}) was used.

The data was processed with an EP500-program (Simrad). In trace tracking, the minimum number of consecutive traces to accept a fish track was 4, the allowed depth window between consecutive traces was 50 cm, and the maximum number of consecutive missing pings in a series of traces was 1. The program was able to track a maximum of 30 fish·$ping^{-1}$. Each track could have a maximum of 10 traces. If a fish had more than 10 traces, the program considered only the first 10. The remainder was ignored, and not used to form a second track.

The EP500 program analysed the selected time period with tracking algorithm constituting the tracked fish, e.g. with ping number, depth, TS-values and swimming speed. From the fish traces selected by the program we checked the echoes on the echogram and then manually rejected the obscure ones. Then we compared fish swimming speeds calculated on an automatic and a manual basis. There was no difference between these methods. Thus we based our results of fish swimming speed on automatic tracking done by the EP500 program.

The program calculated the speed of an individual fish by measuring the distance between the fish position in the first and the last ping. We estimated the swimming speeds of fish in one depth layer between 8 and 24 m in Lake Karjalan Pyhäjärvi and between 8 and 14 m in Lake Vuokalanjärvi.

The best time for hydro-acoustic stock assessment is when the single fish echo density is at its maximum and the fish do not occupy the bottom and surface edges. This period was determined by studying natural migrations of fish by mobile echo-sounding in the study area before commercial seining.

To study natural diel variations in fish densities, the hauling area was surveyed several times with mobile echo-surveys one day before the seining began. The control area was surveyed also on fishing days. Surveys were completed in the morning, at noon and in the evening, usually 3 to 5 times daily. Fixed location echo-survey began one day before seining and it was stopped one day after the last seining.

The effect of winter-seining on fish density was estimated by echo-surveying the hauling area before and after fishing and comparing the catch per swept ha with these figures. The fixed location echo-sounder registered swimming speed before, during and after hauling.

2.3. Exploratory fishing

Commercial fishermen did the exploratory seining in both lakes during 3.5 h after sunrise. The area swept by the seine was 14 ha in Lake Pyhäjärvi and 12 ha in Lake Vuokalanjärvi. Every seining operation was a 'bottom haul', the height of the gear being 12 and 10 m, respectively. The mesh size of the cod-end of the seine was 8 mm from knot to knot. Altogether five seining operations were completed in this study. The yields were sorted into species, and the biomass and length distribution of all species were estimated from catch samples of ca. 5 kg each.

3. RESULTS

Exploratory seining implied that the fish species composition (*table I*) and fish length distribution differed highly between the two lakes (*figure 1*). In Lake Karjalan Pyhäjärvi smelt was the dominant species, while Lake Vuokalanjärvi was dominated by vendace. The mean length of vendace was 13.9 cm and that of smelt 9.5 cm in Lake Karjalan Pyhäjärvi. The corresponding figure for vendace in Lake Vuokalanjärvi was 11.9 cm.

The target strength distributions of the mobile and fixed position echosurveys were in close correspondence and they reflected well the length distribution of the catch samples (*figure 1*).

In both lakes and on every survey date, fish schools dispersed and fish ascended from close to the bottom at night and descended and schooled during the daylight hours (*figure 2*). The single fish resolution percentage indicated that the number of individual

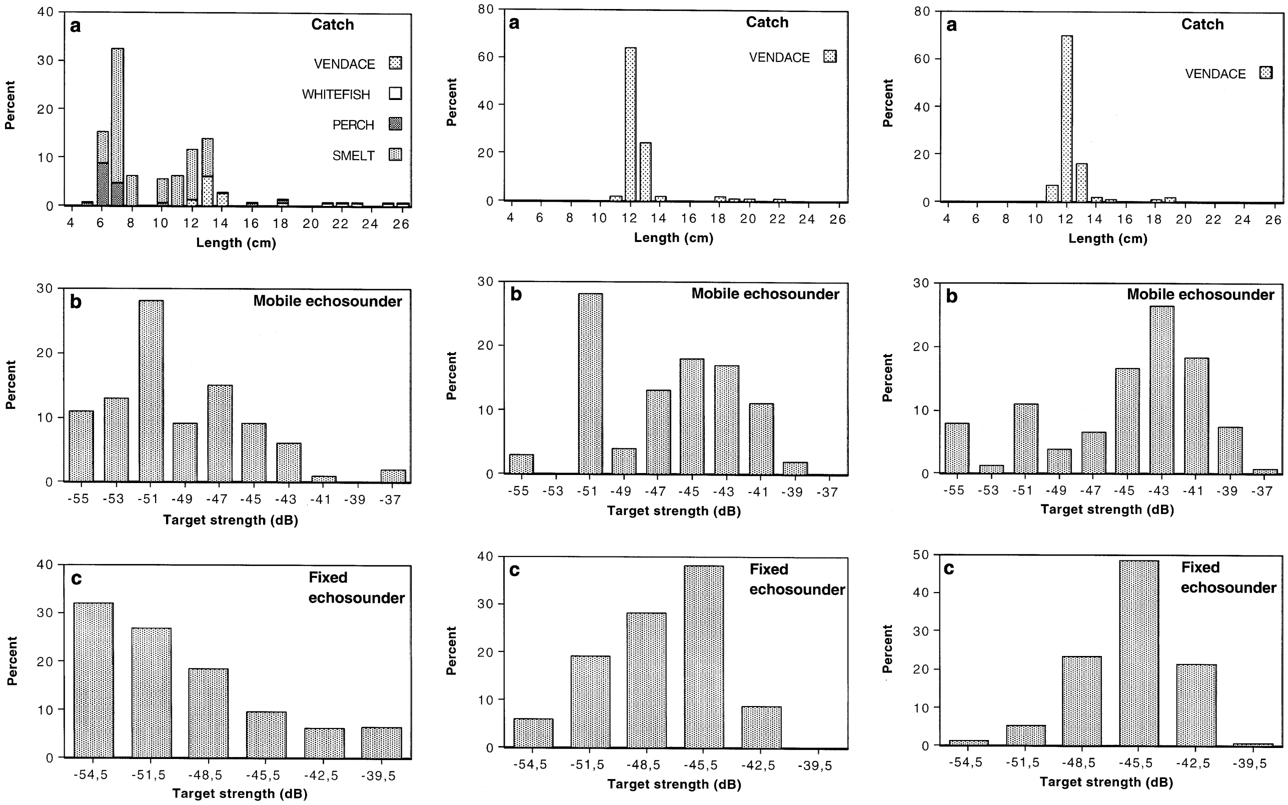

Figure 1. Length distribution of seine catch samples (a), and target strength distribution from night time mobile (b) and fixed position (c) echo-sounding in Lakes Pyhäjärvi February 2–3 (A), and Vuokalanjärvi February 23–24 (B) and March 29–31 (C) 1999. The TS of –47 dB corresponds to a 10 cm fish.

targets was typically highest during the dark hours in mobile surveys (*table II*). In every case, the density estimate was much higher during the night than during the day. Thus dark hours are the only suitable time for acoustic fish stock assessment under ice.

Fixed location surveying indicated that horizontal swimming velocity differed between day and night (*table III*). In Lake Pyhäjärvi, where smelt dominated, the targets moved faster during the night than during the day (Mann-Whitney U-test, $P < 0.001$), whereas in Lake Vuokalanjärvi, pelagic fish – mainly vendace – did the opposite. The direction of fish movement was random.

The fish density in the hauling area was lower in the night after hauling than before in every case (*table IV*) whereas the density even increased in the control area during the haul. The hydro-acoustic fish density at night before the haul corresponded closely with the seining catch from the area (*figure 3*). Estimating from night surveys, one haul took ca. 70% of the fish present in the study area. Yet fish density on the next night was only ca. 30% lower than the night before, which indicates that migrating fish filled up the hauling area in less than 24 h. No difference in the target strength distribution of fish echosurveyed before and after the seining was found.

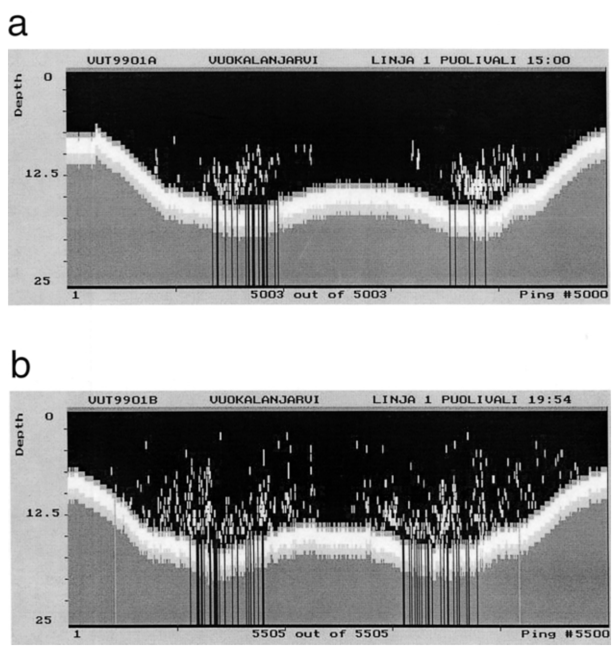

Figure 2. Echogram from Lake Vuokalanjärvi showing typical distribution of fish during day (a) and night (b).

Table II. Day-night variations in the fish density and single fish resolution in mobile surveys under-ice in 1999.

		Day		Night	
Place	Date	Density (fish·ha^{-1})	Resolution (%)	Density (fish·ha^{-1})	Resolution (%)
Pyhäjärvi	February 3	840	40	1 617	97
Vuokalanjärvi	Feruary 24	1 089	54	2 083	87
Vuokalanjärvi	March 30				
Survey area		58	90	1 094	80
Control area		68	48	1 652	96

4. DISCUSSION

Lakes, rivers and even parts of the sea areas in high latitudes are sometimes ice covered for months. Lack of suitable monitoring methods has, however, restricted our knowledge on the under-ice life and its role in the aquatic ecosystem. Under-ice echo-surveys may help us to gain this understanding. This study, as some previous hydro-acoustic work under-ice (Jurvelius et al., 1999), indicated that echo-sounding is sensitive enough to show fish density variations caused by winter-seining in the hauling area. It may even be possible in favorable conditions to estimate the catchability of the gear and the effects of fishing on the fish stock involved. In any case, mobile under-ice hydro-acoustics along with exploratory fishing will certainly improve winter seining management, which until now has relied only on the interpretation of catch and effort statistics. However, our results in the field of catchability must be considered as preliminary.

As we know, oxygen, temperature and wind conditions vary in summer, and thus affect fish migrations. These physico-chemical conditions were stable in the water layers under-ice; however, fish showed a diel migration pattern much like that in summer. Interestingly, in winter, under more than 1 m of snow and ice and 10 m of water, the diel vertical migration of fish seemed to be driven by the daily photoperiod. To study which of the three major hypotheses for the adaptive significance of DVM in fish – foraging (Narver, 1970), bioenergetics (Neverman and Wurtsbaug, 1994) or predator avoidance (Clark, 1988) – best fits the migration pattern found, studies on under-ice illumination, zooplantkton density and predator behaviour are needed. The increasing illumination during our research period in spring indicated that daylight might be of crucial importance in the timing and amplitude of fish migrations in general. To study problems related to fish migrations, it might be fruitful to work in winter and summer in the same area and with the same fish stock.

Smelt moved at night twice as fast as in daylight, while for vendace the reverse was true. Smelt moved at night approximately four times its body length per second, while for vendace the corresponding figure was less than half its body length. These speeds do not

Table III. Day-night variation in average swimming speed of fish under-ice estimated with fixed location split-beam surveys in 1999.

		Day		Night	
Place	Date	Speed (m·s^{-1})	Number of observations	Speed (m·s^{-1})	Number of observations
Pyhäjärvi	February 2–3	0.18	853	0.36	1 748
Vuokalanjärvi	February 23–24	0.17	148	0.05	87
Vuokalanjärvi	March 29–31	0.11	25	0.08	104

Table IV. The change in fish density in mobile surveys under-ice during the winter seine haul in hauling and control areas in 1999.

		Fish density (fish·ha^{-1})				
Place	Time	before haul	after haul	Change (%)	Catch (fish·ha^{-1})	Yield:density before (%)
Pyhäjärvi hauling	February 2–3 night	1 617	1 199	–25	1 130	69
	morning	1 337	707	–47	1 130	85
Pyhäjärvi control	February 2–3 night	3 031	6 135	+102	no fishing	
Vuokalanjärvi	February 23–24 night	2 083	729	–65	1 286	62
	afternoon	1 089	311	–71	1 286	118
Vuokalanjärvi	March 29–30 night	1 094	802	–27	1 199	101
Vuokalanjärvi	March 30–31 nigth	802	647	–19	410	51
Vuokalanjärvi	April 12–13 night	2 311	1 848	–20	1 823	78

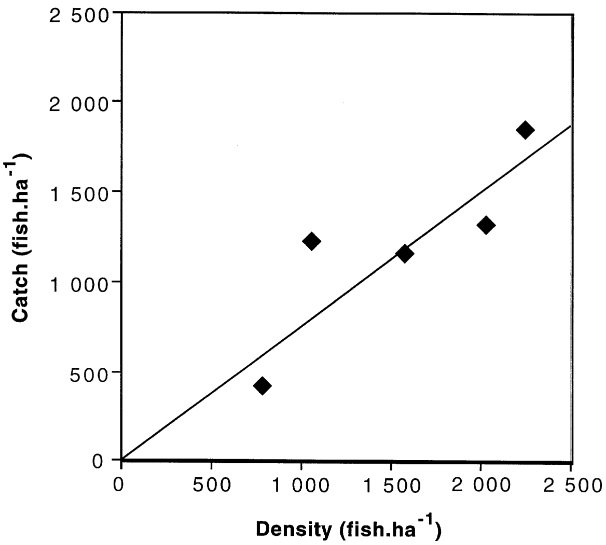

Figure 3. The relationship between hydro-acoustic fish density at night before seine haul and catch per swept area of seine. Line: Catch = 0.73 Density, $P < 0.001$.

differ much from the swimming speeds found in small brook trout (*Salvelinus fontinalis*), yellow perch (*Perca flavescens*) and alewives (*Alosa pseudoharengus*) (Arrhenius et al., 2000). Variations in predator assemblage and the length of daylight might play a role in our results. The severe storm and rapidly decreasing atmospheric temperature that occurred could also have some effect on smelt behaviour. The reasons behind these differences form an interesting and important ecological problem, and hydro-acoustics can have an essential role in its solving.

The mobile echo-surveys showed that fish performed under-ice diel vertical migrations. In both species, night surveys showed twice as much single fish echoes as day surveys. In fixed position surveys, the activity of smelt increased at night, while vendace was more active during the day than at night. Mobile single-beam hydro-acoustics was accurate enough to characterise the effect of seining on the fish density in the hauling area. Fixed position split-beam sounding revealed the direction of fish mobility to be mostly random. However, this was enough to compensate within about 24 h for the local depletion consecutive to hauling.

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