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SPATIO-TEMPORAL DISTRIBUTION OF FISH IN THE NORTHERN PART OF LAKE SVENTE

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ABSTRACT

Spatial distribution and abundance of pelagic fish were studied in the northern part of Lake Svente. Features of temporal and spatial distribution of fish were studied using hydroacoustic methods. Hydroacoustic technique has the obvious advantage of being non-lethal. Acoustic data were collected by a BioSonics DT-X digital echosounder operating at the frequency of 200 kHz. Physicochemical parameters of the water column were measured same as vertical samples of zooplankton were collected at the deepest location of the transect. Study results confirmed significant time and depth effects on estimates of fish abundance in the pelagic zone. Differences in the spatial distribution of larger and smaller fish were observed depending on the time of the day. The interaction between fish and zooplankton was found to be ambiguous and complex. Study results confirmed spatio-temporal heterogeneity of fish distribution along vertical and horizontal gradients in deep lakes.

Key words: fish density, spatial distribution of fish, Lake Svente, hydroacoustic method

INTRODUCTION

Lakes are important freshwater habitats providing significant attraction for the public. Moreover, according to the Water Framework Directive (2000/60/EC of the European Parliament and of the Council (23.10.2000) *establishing a framework for Community action in the field of water policy*), member states of European Union need to achieve good ecological status of surface waters based on different groups of biota (European Commission, 2000/60/EC). Therefore, understanding of freshwater ecosystem functions is an important condition for effective management of coregonid lakes. Spatial distribution of fish in water ecosystems is complex. There are external and internal factors that determine the spatial distribution of fish populations. These factors influence migration, feeding, predator avoidance, reproduction and habitat selection of fish. Traditionally, environmental background is mentioned as the major factor that correlates the spatial heterogeneity of fish (Planque et al., 2011; Laevastu & Hayes, 1981). Abiotic factors especially strongly shape vertical gradients in deep lakes (Eiler & Eiler, 2004). It is assumed also that the pattern of space use is a complex result of individual species making decisions based on the trade-off between foraging behaviour and predation risk (Rojas & Ojeda, 2010). Light regime is one of the important factors that contribute to vertical and horizontal migrations of fish. Thus, it is assumed that the spatial distribution of fish populations in the lake is unstable through the time (Drastik et al., 2009). This study is one of the first attempts to evaluate fish spatial distribution in Latvian lake using hydroacoustics. This kind of survey technique has the obvious advantage of being non-lethal and allows acquiring high-resolution spatio-temporal data with relatively reduced sampling effort (Simmonds & MacLennan, 2005). The main objective of this study was to evaluate spatial distribution and abundance of fish in the northern part of Lake Svente, taking into account vertical gradients of physicochemical parameters, acoustic fish size, distribution of zooplankton and diel cycle.

MATERIALS AND METHODS

Study area

Lake Svente is a relatively deep, slightly eutrophic lake of 7.35 km^2. It is situated in the south-east of Latvia (55°51'N, 26°21'E). The lake is included in the region of protected landscapes of Augshzeme and its surroundings make a complex protected area of landscapes (Poikane et al., 2001; Brakovska & Škute, 2007). The mean depth of the lake is about 7.7 m, maximum depth - 38 m. The northern part of the lake is 20 - 35 m deep and has a strongly marked depression (35 m). Lake Svente takes the ninth position among the ten deepest lakes of Latvia (Brakovska & Skute, 2007). Almost 70% of the fish fauna of Lake Svente consisted of roach (*Rutilus rutilus*) and tench (*Tinca tinca*), whereas predators were represented by perch (*Perca fluviatilis*) (9%) and pike (*Esox lucius*) (13%). Also present, although in low abundances, were bream (*Abramis brama*) and carp (*Carassius carassius*) (Fisheries rules of Lake Svente, 2001). Lake Svente is popular tourists' site and is favoured by fishermen. Making the researches in the Lake Svente three groups of zooplankton were found out: Cladocera, Rotifera and Copepoda (Brakovska & Škute, 2007).

Data sampling

Acoustic backscattering data were collected by a BioSonics DT-X digital echosounder operating at the frequency of 200 kHz, split-beam 6.8° transducer and a pulse duration of 0.4 ms. The device was calibrated by the standard sphere method (Foote et al., 1987). Fish were sampled on the same line transect both during the day (1:00 PM) and night (1:00 AM) in August, 2010, 2011 and 2012. Line transect was situated in the deepest part of the lake. The total length of transect was approximately 1000 m. The transducer of the echosounder was placed 50 cm below the surface at the back of the boat and tilted slightly downward. The boat speed was maintained at 2 m sec^{-1}. The hydroacoustic acquisition threshold was set at – 130 dB and the ping rate of 5 per second. Hydroacoustic and positional data were visualized and continuously stored on a portable computer running the BioSonics Acquisition® program (version 6.0). Physico-chemical parameters (water temperature °C, conductivity µS cm^{-1}, dissolved oxygen mg l^{-1}, chlorophyll-α µg l^{-1} and oxidation-reduction potential (ORP) mV, pH) of the water column were measured consequently at the deepest location of the transect by a calibrated HACH® DS5 multi-parameter sonde, which allowed for the data capture every 1 m from the lake bottom to the surface. Zooplankton samples were collected both during the day (1:00 PM) and night (1:00 AM). The vertical sampling of zooplankton was obtained in the deepest site of the transect (35 m). Samples were collected with Hydro-Bios plankton net (64 µ). The vertical hauling of the samples was realized in the 5 m interval from the bottom to the surface. The zooplankton samples were preserved in 4% formalin immediately for further analysis and enumeration.

Data analysis

Raw acoustic data were imported to and visualized in, Echoview® (version 4.9). Hydroacoustic data were calibrated and echograms were scrutinized to exclude unwanted reverberation and echo traces in the water column that were not fish. Sound speed and absorption coefficients were calculated in Visual Acquisition® and entered in Echoview® to find out the effects of temperature and salinity on the obtained acoustic data (Hagginbottom et al., 2009). Hydroacoustic data of transect were divided vertically into 5 m depth zones and horizontally into 50 m bins. Fish density was obtained using the echo integration method. The target strength (TS) and volume back scattering strength (Sv) thresholds used in the analysis were –64 dB and –70 dB, accordingly (Parker-Stetter et al., 2009). Values of the target strength were generated in Echoview® for single targets within each analysis cell identified by the split-beam single target detection algorithm (Hagginbottom et al., 2009). The TS frequency distributions were compared between epilimnion and hypolimnion. These two zones of the water column were defined with respect to the thermocline. Data of the physico-chemical parameters were exported from the HACH® DS5 multi-parameter sonde to the Microsoft Excel® software for visualization and further analysis. Zooplankton abundance was expressed as individual in m^{-3} (ind. m^{-3}). Zooplankton biomass was calculated according to literature (Ruttner-Kolisko, 1977; Bottrell et al., 1976; Kisilev, 1959).The following formula was used to calculate the zooplankton abundance in a sample:

N = (a x b x 1000) / (c x d), where

a - a calculated number of organisms (average);
b - a volume of concentrated sample;
c - a sample volume;
d - a volume of filtered water;
N - a number of organisms per m^{-3}.

Fish length was estimated from target strength based on standard multi-species equation TS= 19.2•log10(L)+0.9•log10(λ)-62.3 (Love, 1971; Brandt et al., 1991). The obtained data of fish densities were first checked for normality and homogeneity of variances, using Kolmogorov's and Bartlett's tests. Analysis of Variance (ANOVA) tested the time effect on fish density estimates and mean target strength. The differences in fish densities between 5 m depth zones were analysed by Analysis of Variance (ANOVA). Prior to ANOVA testing variables were log-transformed to meet the assumption of normality (McDonald, 2009). The relationship between mean depth of horizontal bin and fish density same as mean target strength in corresponding bin, was tested using the Pearson correlation coefficient. All statistical tests were considered significant at the 0.05 significance level. Data analyses were performed, using SPSS® (version 11.5.0).

RESULTS

Water Quality

The water quality parameters characterize abiotic environmental background of the fish habitats in the lake. Therefore, physicochemical parameters potentially could influence spatial distribution of fish in Lake Svente. The values of water temperature varied from 5.2°C at the bottom to 22°C at the surface, dramatically decreasing at the depth of 6 – 10 m. The thermocline was observed at this depth in Lake Svente (Figure 1).

Nevertheless, temperature profile was relatively uniform below 20 m. Concentration of dissolved oxygen varied from 3.6 mg l^{-1} near the bottom to 9.5 mg l^{-1} at the depth of 5 – 10 m (Figure 1). Marked depletion of dissolved oxygen concentration was observed at the 10 – 25 m depth zone. The pH profiles were similar to the temperature profiles. The values of pH varied from 6.8 – 7 at the bottom to 8.2 at the surface (Figure 1). The value pH was slightly higher at 5 – 10 m and 20 – 35 m depth zones during the night. The values of chlorophyll-α concentration varied from 0.6 μg l^{-1} at the surface and bottom to 3 μg l^{-1} at the 8 – 10 m depth (Figure 1). Metalimnetic peak of chlorophyll-α concentration and maximal concentration of dissolved oxygen could be probably explained by the marked presence of phytoplankton at this depth. It should be noted that chlorophyll-α concentration was lower above the thermocline and slightly

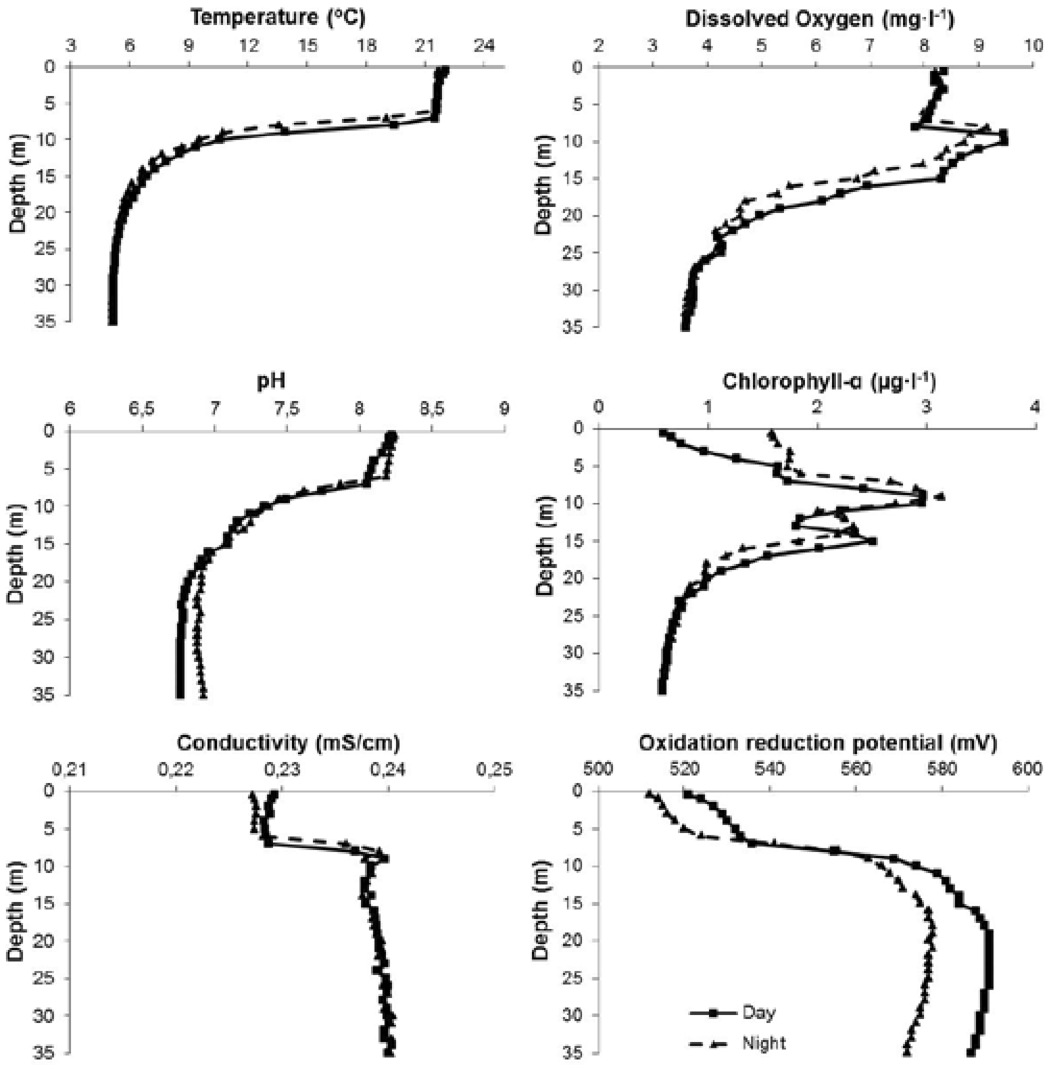

Figure 1. Profiles of the water temperature, dissolved oxygen concentration, pH, chlorophyll-α concentration, conductivity and oxidation reduction potential in Lake Svente for each of the two sampling periods in August, 2011.

higher at the 15 - 20 m depth during daylight. The conductivity profiles in Lake Svente were inversely related to the temperature profiles, indicating that unmeasured dissolved minerals were present in greater concentrations with depth (Figure 1). ORP values varied from 512 - 520 mV at the surface to 572 - 590 mV near bottom (Figure 1). ORP was higher above the thermocline and below it during the day. Sampling results of the water physico-chemical parameters showed that Lake Svente was strongly stratified in August.

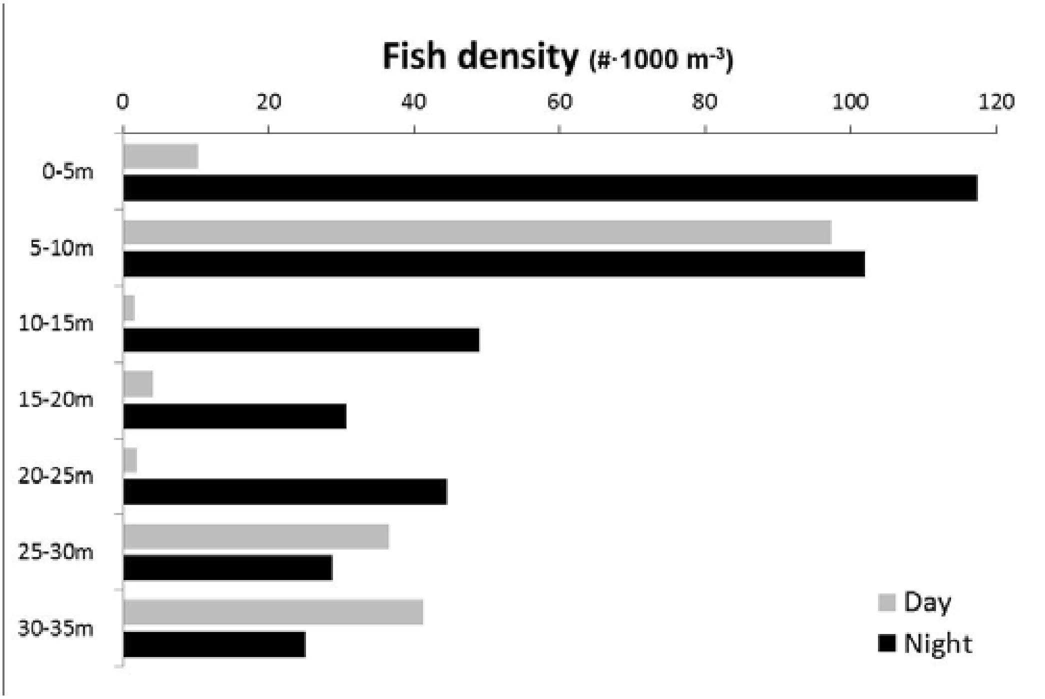

Figure 2. Volumetric fish density (fish• 1000m^{-3}) in Lake Svente for each of the two sampling periods.

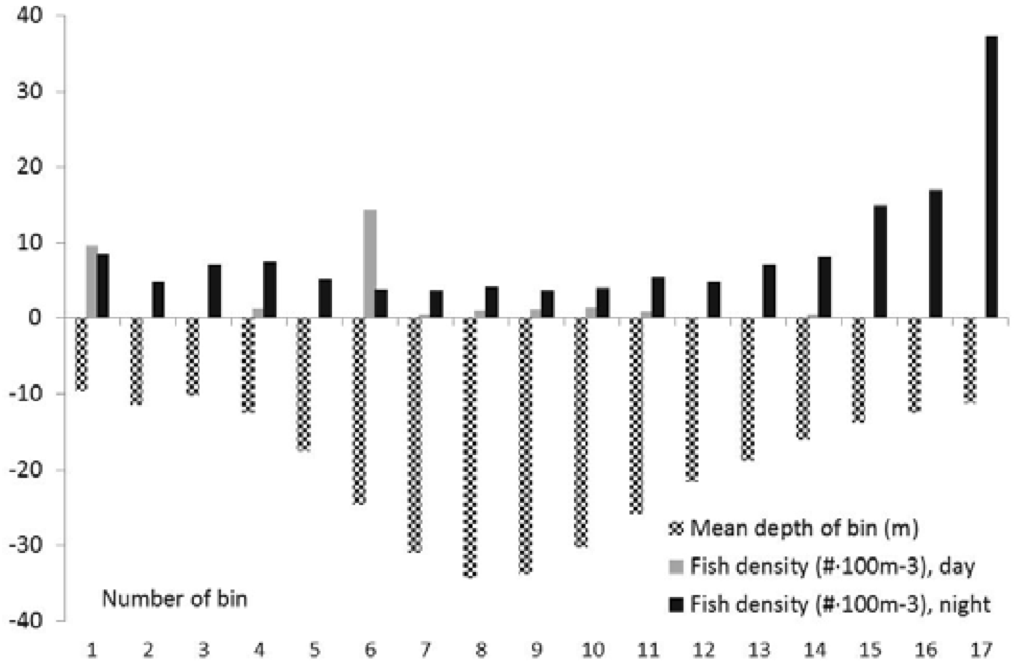

Figure 3. Horizontal distributions of fish along the transect. Volumetric fish density (fish•100m^{-3}) in each horizontal bin of transect for each of the two sampling periods.

Fish Distribution

The statistical analysis indicated that the estimated fish density differed between day and night surveys (ANOVA, P=0.003). Study results showed that the values of fish density were higher during the night surveys than during the day surveys. The differences in fish abundance were especially obvious at the 10 – 25 m depth zone (Figure 2). Fish density estimates were variable also across 5 m depth zones (ANOVA, P=0.04) during the day, whereas fish density did not vary significantly along vertical gradient during the night (ANOVA, P=0.36). Results didn't show significant difference in fish density estimates between the years (ANOVA, P=0.78). The 5 – 10 m depth zone and depth zones below 25 m were abundant in spite of time of the day, whereas middle part of the water column and the 0 – 5 m depth zone were markedly populated during the night only (Figure 2). Fish density varied along the horizontal gradient of the transect. Uneven distribution of fish was obvious during the day (Figure 3). The highest fish density was recorded in the first and sixth bin, where fish schools were observed. Fish were situated also in the middle part of transect during daylight. This part of transect corresponded to bottom depression. The mean depth of bins at this part of transect was greater than 25 m. However, at night fish were distributed more evenly than during the day. Nevertheless, significant negative correlation (Pearson: r = -0.67; P=0.02) was revealed between the mean depth of horizontal bin and fish density in corresponding bin (Figure 4). Thus, values of fish density had shown tendency to decrease along the onshore-offshore gradient during the night.

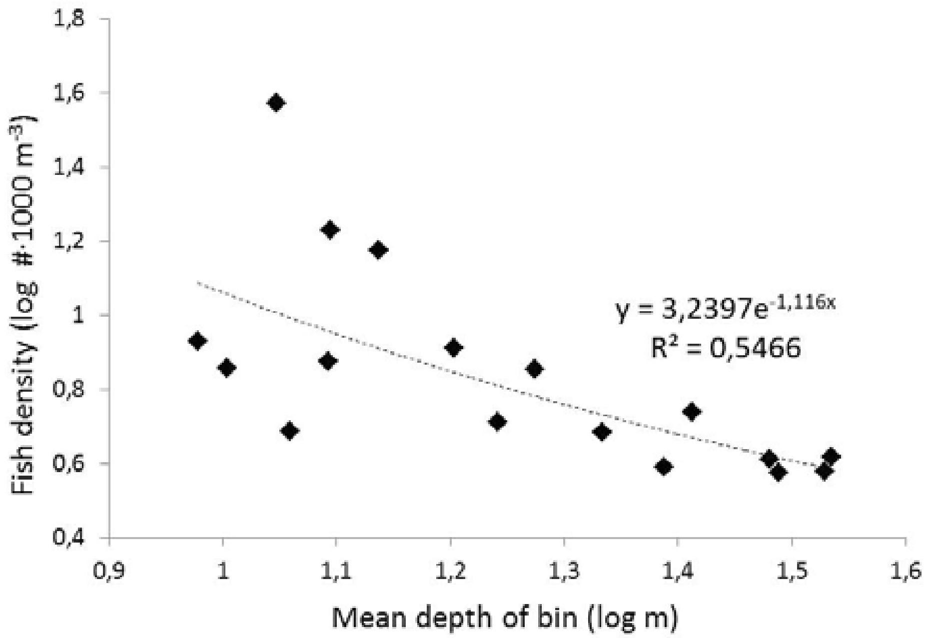

Figure 4. Correlation between mean depth of horizontal bin and fish density in corresponding bin. Numbers are log-transformed.

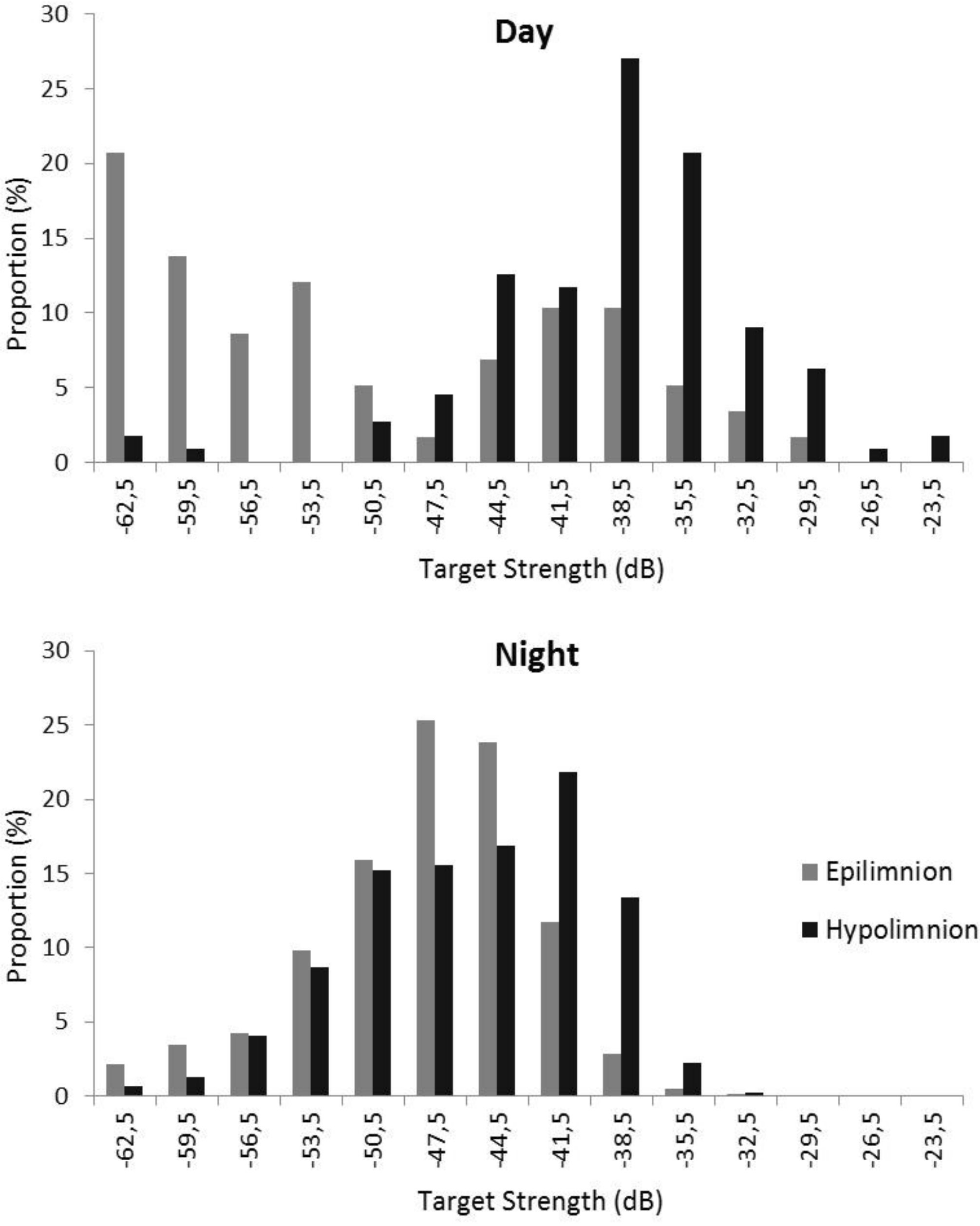

Figure 5. TS distributions in Lake Svente, examples of the day and night survey conducted in August, 2012 for the epilimnion and hypolimnion.

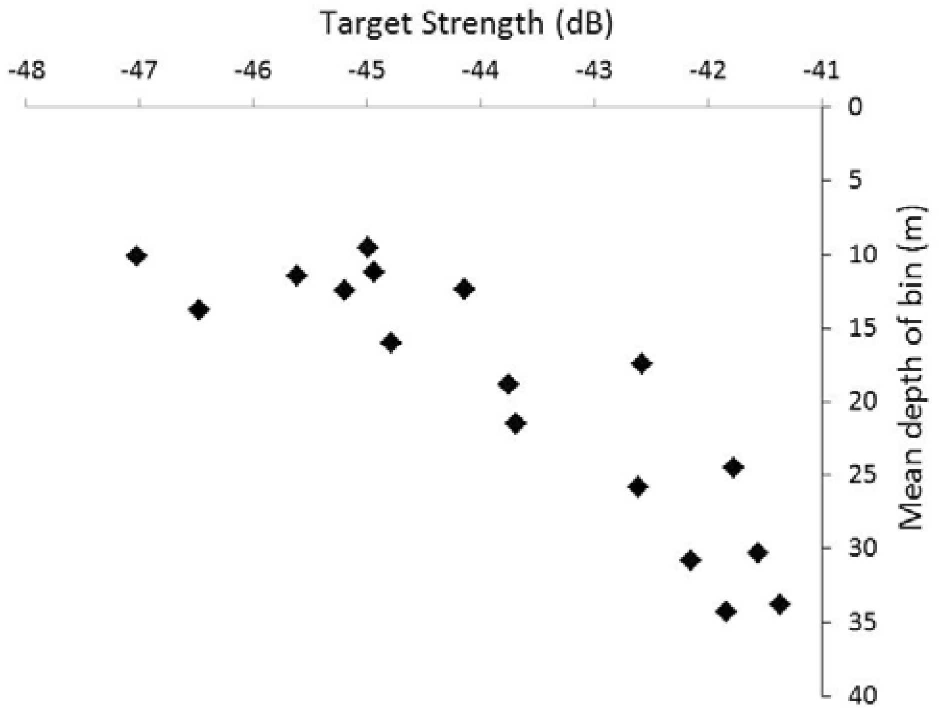

Figure 6. Correlation between mean depth of horizontal bin and mean target strength in corresponding bin.

Target Strength Distributions

The TS strength data implicitly provide information on the fish size. The results indicated that TS distribution differed between epilimnion and hypolimnion during the day, whereas at night it was almost similar (Figure 5). The larger fish were mostly represented in the hypolimnion during the day. However, some of them were observed also in the epilimnion. The TS of majority of targets varied from -50.5 dB (5 cm) to -29.5 dB (63 cm) in hypolimnion. Two size-specific fish groups predominated in the epilimnion during the day. The TS of smaller fish group varied from -62.5 dB (2 cm) to -50.5 dB (5 cm), whereas TS of larger fish group varied from -44.5 dB (10 cm) to -35.5 dB (30 cm). The results didn't show sharp spatial segregation between larger and smaller fish along the vertical gradient at night. Statistical analysis yielded significant difference (ANOVA, P=0,047) in the mean TS of fish targets between the day and night surveys in August 2011. The mean values of TS in 5 m depth intervals were lower at night. This fact probably suggested that smaller fish were the most numerous in the pelagic part of the lake at night than during the day. Nevertheless, significant positive correlation (Pearson: r = 0.88; P=0.001) was found between the mean depth of horizontal bin and mean target strength in corresponding bin along the horizontal gradient (Figure 6). This relationship showed that size of detected fish had shown tendency to increase along the onshore-offshore gradient.

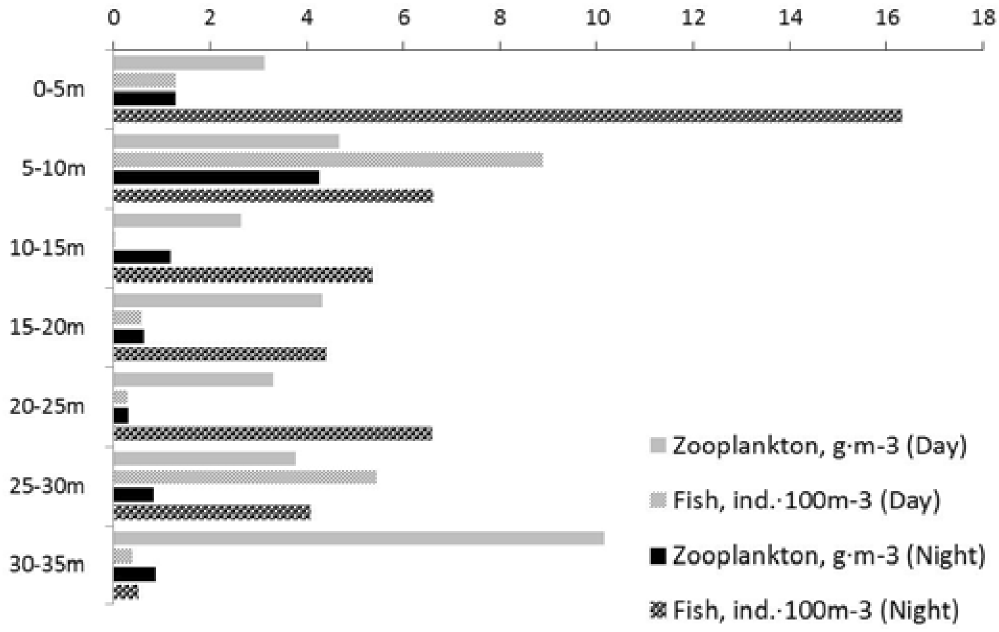

Figure 7. Vertical distribution of fish and zooplankton in Lake Svente for each of the two sampling periods.

Zooplankton

The results of zooplankton sampling showed that biomass of zooplankton was higher during the day than at night in the pelagic part of the lake (Figure 7). Biomass of zooplankton varied from 2.65 g m^{-3} to 10.16 g m^{-3} during daylight, whereas at night the biomass did not exceed 4.26 g m^{-3}. It should be noted that the maximal biomass of zooplankton was observed at the 30 – 35 m depth during the day. The abundance of zooplankton varied according to time of the day along vertical gradient, excepting 5 – 10 m depth zone, where biomass was approximately constant.

DISCUSSION

Consistent with our expectations abiotic factors showed spatial variations that were strongly influenced by the water stratification. The summer stratification of water was observed in Lake Svente during previous surveys and during several surveys in a similarly deep lake of this region (Brakovska & Škute, 2007; Jurevics, 2008). Profiles of physico-chemical parameters were found to be relatively uniform in the temporal dimension, but obviously varied in the spatial dimension (Figure 1). Therefore, diurnal variations of fish spatial distribution along the vertical gradient could not be explained completely by physico-chemical parameters. The significant impact of water temperature and dissolved oxygen concentration on spatial location of fish was emphasized (Eiler & Eiler, 2004). The abrupt decrease of dissolved oxygen concentration probably could partially explain relatively low fish densities at the 10 – 25 m depth zone during the day. Nevertheless, the 25 – 35 m depth zone, where low concentration of oxygen was observed, was populated by fish. Tendencies of fish and zooplankton spatial distributions along the vertical gradient were similar during the day, except for the deepest part of hypolimnion. However, at night similar patterns of vertical distributions were only observed at the 5 – 20 depth zone. Thus, it seems that the zooplankton vertical distribution could partially determine vertical distribution of fish in the upper part of the water column during the day. Nevertheless, predator-prey interactions also intend avoidance behaviour of prey. Therefore, the relatively high biomass of zooplankton at the deepest part of hypolimnion during the day could be explained by the avoidance behaviour. The scarce light and the probable absence of planktivorous fish in the 25 – 35 m depth zone made it a deep refuge for the zooplankton during the daytime. A relatively high fish density at night could have been caused by a horizontal migration of fish (DHM) to the certain portion of the lake or it may have just reflected a movement of fish from the littoral zone into the pelagic zone at night. However, results of this study could not sufficiently confirm or deny these assumptions because we had no data about the patterns of fish distribution across the whole lake. The analogical situation of the increase in fish density in the open water at night was described by Eiler (2004) and Masson et al. (2001). This pattern of fish spatio-temporal distribution confirmed a significant time effect on the estimates of fish density. We assumed that the patterns of spatial segregation of larger and smaller fish in Lake Svente during the daylight (Figure 5) could be explained by the foraging behaviour and predator-prey interactions among different size-specific fish groups, taking into account the light regime (Rojas & Ojeda, 2010; Sih, 2005). A relatively low zooplankton abundance in the pelagic part of the lake at night probably could be explained by predation loses and horizontal migration of the zooplankton to the littoral zone as response to the increased fish pressure in the pelagic part of the lake. Nevertheless, fish density had shown tendency to increase, whereas fish size to decrease in horizontal bins along offshore-onshore gradient. These facts probably mean that the part of smaller fish follow their prey (zooplankton), avoid from larger fish or night dispersion of fish had not completed yet. It should be noted that minimal depth of analysed transect was 10 m. Thus, we couldn't judge validly about ecosystem functioning in the shallow littoral zone. A relatively high fish density at the depth of 5-10 m during the day and night could be explained by constantly high zooplankton abundance at this depth during both periods of diurnal cycle. Thus, marked presence of phytoplankton in metalimnion probably is significant factor that determine presence of fish and zooplankton at this depth in spite of time of the day. The results showed that spatial distribution of fish both along the horizontal and vertical gradients was markedly heterogeneous during the day and less heterogeneous at night. Thus, the significant impact of light regime on spatial behaviour of fish populations had been confirmed. The light regime probably determined particularities of space use as a complex result of the individual species making decisions based on the trade-off between foraging behaviour and predation risk (Rojas & Ojeda, 2010). However, the light regime couldn't be the most important factor that correlated spatial distribution of fish at night. Therefore, fish were distributed more evenly along the vertical and horizontal gradients at night. The high fish density in the warm epilimnion zone (0 – 5 m depth) during the night probably pointed to the significance of water temperature when light conditions were approximately similar along the vertical gradient.

CONCLUSIONS

The results of this study confirmed the spatio-temporal heterogeneity of fish distribution in deep stratified lakes. The light regime (time of the day) obviously is one of the most important factors that determine fish spatial distribution and abundance in the pelagic part of Lake Svente. The significance of light cues for understanding mutual changes in spatial location of zooplankton and fish during the day-night cycle was emphasized (Mookerji et al., 1998). Thus, measuring light intensity in the water column and zooplankton sampling along the horizontal gradient need to be performed in further studies. Although hydroacoustic technique is a suitable method for studying spatial distribution of fish in deep lakes, gill netting should be included in the survey design to realize better spatio-temporal interactions among different fish species and size-specific fish groups in multispecies lakes especially in the littoral zone.

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