The vertical distribution of maraena whitefish (*Coregonus maraena*) early juveniles in different times of day in a newly created oligotrophic lake.

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Abstract

Diel vertical distribution of strictly pelagic juvenile (23 - 47 mm total length) maraena whitefish *Coregonus maraena* (Bloch, 1779) was repeatedly investigated in spring primarily using hydroacoustics in the artificial post-mining Most Lake in the Czech Republic. At the same time, an ichthyoplankton trawl was used to identify acoustical targets. During the day, fish performed extensive shoaling behaviour in depths between 2 and approximately 40 meters and were not accessible for trawling. By evening, with decreasing light intensity, shoals started to disintegrate and at night fish were relatively homogeneously distributed in the water column from the surface down to a depth of 40 m. Juvenile maraena whitefish could be caught by trawl as the only fish species at night. Shoaling behaviour started again approximately 1.5 hour before sunrise. The data showed steep decreases in fish density between the two surveys in spring which indicates significant mortality of early juvenile coregonids as a result of poor availability of zooplankton in a highly oligotrophic post-mining lake.

Key words: Most Lake; ichthyoplankton trawling; hydroacoustics; shoaling behavior; vertical migrations

1 Introduction

Fish stocks in water bodies are based on the occurrence of species found in a specific region, and are formed by the particular characteristics of a given water body (Gassner et al., 2005; Irz et al., 2006). Reservoirs, created by damming the original river valley, comprise the majority of standing waters in the Czech Republic, because natural lakes are relatively scarce in Central Europe. Typical features of these mostly eutrophic water bodies are strong summer stratification with significant decrease of water temperature and oxygen concentration below approximately 5 meters (Prchalová et al.; 2009, Jůza et al., 2009).

Since the beginning of 21st century new large water bodies have been constructed in the northern part of the Czech Republic – post-mining lakes created by flooding the former surface coal mines (Kružíková, 2013; Šustera et al.; 2012). These artificial lakes usually have a similar area as reservoirs (few hundreds of hectares), and are also relatively deep (usually few tens of meters). Due to a relatively oligotrophic character, none or only metalimnetic oxygen depletions occur in deeper layers (Peterka, 2014). Dominant fish species in these lakes are cyprinids - usually roach and rudd *Scardinius erythrophthalmus* (Linnaeus, 1758) and also one percid species -perch *Perca fluviatilis* Linnaeus, 1758 (Peterka at al., 2013). In addition to these species, inhabiting especially warmer littoral habitats and to some extent pelagic habitats above thermocline, oxygen throughout the entire water column enables the presence of coldwater coregonids that usually are found in deep, well oxygenated lakes at similar latitudes. Coregonids are common in pelagic areas of deep stratified lakes across northern parts of Europe, Asia and North America (Rudstam and Magnuson, 1985, Marjomäki and Huolila, 1995; Busch and Mehner, 2009; Jurvelius et al., 2011) and natural lakes with similar characteristics as the post-mining lakes in Northern Bohemia, with coregonids being the important component of the fish stock, are situated also in neighbouring Germany and Poland (Mehner et al., 2003; Godlewska et al., 2014). As mentioned above deep natural lakes, representing suitable water bodies for coregonids are missing in the Czech Republic but the natural reproduction of maraena whitefish in newly created post-mining lakes was recognized shortly after stocking (Peterka, 2014) indicating the suitability of these artificial waterbodies for this species.

Significant and in comparison with other coregonid localities a unique characteristic of the post-mining lake investigated in this study is its age. Newly created lakes are usually extremely oligotrophic with high water transparency and low phosphorus concentration (below 10 μg l^{-1}). The availability of food may be a limiting factor for growth and survival of larval fish if low concentration of nutrients limits primary production (Hardy et al., 2008). Coregonids are predominantly zooplankton consumers and their mortality is significantly influenced by zooplankton density (Rellstab et al., 2004). A newly filled lake therefore provides the unique possibility to investigate density, mortality, growth, depth distribution and shoaling behavior in an extremely oligotrophic system with low primary production and high water transparency.

Diel vertical migrations (DVM) and shoaling behaviour were described as common strategies in coregonid populations (Hamrin, 1986; Ventling-Schwank and Meng, 1995; Gjelland et al., 2009) but the significance of this behaviour can differ during ontogeny. It is generally understood that the DVM is the result of a compromise between conflicting demands, since food availability, light, temperature and predation change with depth

(Ventling-Schwank and Meng, 1995) and their relative importance should be dependent on the size and environmental factors (Hamrin, 1986). Shoaling is recognized as an important antipredator behaviour and represents an alternative or supplementary defence strategy to DVM for pelagic fish (Gjelland et al., 2009). Distribution of larval, older juvenile and adult native coregonid populations in lakes has been studied many times (Lahnsteiner and Wanzenböck, 2004; Hamrin, 1986; Sandlund et al., 1992; Gjelland et al., 2009) but knowledge of the spatio-temporal distribution of coregonid juveniles in their earliest stages (May-June, *total length* (TL) <5 cm) is mostly lacking and this paper aims to elaborate on their early life history.

The main aim of this study is to investigate pelagic diurnal spatio-temporal distribution of maraena whitefish early juveniles and a newly created oligotrophic lake with a confirmed naturally reproducing coregonid population was used for this purpose. Repeated sampling during one season provides primary information about mortality and growth rates of coregonid juveniles in a lake with low productivity. This study attempts to address why these behavioural patterns are important during the early juvenile stage, and their differences and similarities with other ontogenetic stages of other coregonid species described in literature are discussed.

2 Material and methods

1.1 Study area

The study was carried out in the post-mining Most Lake situated near the town of Most (Northern Bohemia, 50.5379136N, 13.6456339E, Fig. 1a). The mining activity ended in the summer of 1999 and filling of the opencast mine started in autumn 2008 (Fultner and Valvoda, 2013). The lake was completely filled in 2012, and it has a surface area of 309.4 ha, a volume of 70.5×10^6 m^3, a maximum depth of 75 m, and a mean depth of 22 m. In spring, the mean depth of the thermocline is about 7 m, the secchi depth is around 5 m and the concentration of dissolved oxygen is about 10 mg l^{-1} throughout almost the whole water column (Fig. 2). The trophic status of the lake is characterized as oligotrophic with total phosphorus concentrations lower than 10 µg l^{-1} in the whole water column during the whole season. The springtime pH value is about 8. The dominant fish species are perch, roach, ruffe *Gymnocephalus cernua* (Linnaeus, 1758) and rudd (Peterka, 2014). Two predatory species, pike *Esox lucius* (Linnaeus, 1758) and wels, *Silurus glanis* (Linneaus, 1758) were stocked in the lake. Maraena whitefish have been regularly stocked in this lake since 2011 (46,000 inds. 70 - 155 mm standard length in 2011, 46,000 inds. 95 - 170 mm standard length in 2012, 46,000 inds. 83 - 163 mm standard length in 2013).

1.2 Data collection and analysis

1.2.1 Hydroacoustic survey

A vertically oriented echosounder, fixed on a trawling vessel was the main method used to monitor the spatio-temporal distribution and abundance of maraena whitefish early juveniles. Transects for mobile surveys and trawling were positioned in the central part of lake from depths of 25 to 75 m. Mobile surveys were carried out simultaneously with the trawling activities in the day and at night on May 20 and June 3, 2015.

Continuous stationary recording was conducted on June 10 and 11 between 6 pm and 7 am in the central part of the lake, deeper than 31 m, which allowed safe anchoring (Fig. 1a).

The Simrad EK 60 hydroacoustic system connected to an ES 120-7C composite transducer with a nominal angle of 7 degrees operating at a frequency of 120 kHz was employed for both mobile and stationary recordings. During the surveys, the transducer was mounted 0.5 m below the water surface. The system was properly calibrated following the manufacturer's recommendations using the calibration procedure as per Foote et al. (1987) before the surveys. The pulse repetition rate was set to 2.5 pings per second, using a pulse duration of 0.128 ms.

Recorded data were analyzed using Sonar5-Pro post-processing software, version 6.0.2 (Balk & Lindem, 2014). All recorded echograms were manually cleaned of noise (bubbles) and non-fish echoes. The bottom was automatically detected using the software's algorithm with a margin of 0.25 m, manually scrutinized and corrected when necessary to avoid the inclusion of bottom echoes in the analysis. The upper limit of the echogram area was set 2 m below the transducer face and the lower limit was set at the detected bottom line. Single echo detection (SED) criteria were set during the conversion of data files to Sonar5-Pro and were the same for the mobile and stationary surveys. The echo length was set from 0.6 to 1.8 relative to the length of the transmitted pulse, the maximum gain compensation was set to 3 (one way) and the maximum standard deviation of axis angles was set to 0.6. Automatic tracking was performed to produce fish tracks. All fish targets had to meet the following criteria to be recognized as a track: minimum track length (MTL), maximum ping gap (MPG) and vertical range gating.

MTL was set in depth dependent steps; for the upper part of the echogram (2 – 5 m) MTL was set to 1 echo, for the mid-ranges (5.1 – 7 m) MTL was set to 2 echoes, and for the lower part of the echogram (7.1 m to the bottom) MTL was set to 3 echoes. MPG was set to 1 and the vertical range gating was set to 0.15 m for the whole water column. The echo integration method was used for estimating fish density (CEN, 2014). Volume backscattering strength (S_v) was scaled by average target strength (TS) of in situ tracks as a source of density estimates. A regression for vendace (*Coregonus albula* Linnaeus, 1758) was used (Mehner, 2006b) to convert TS (dB) to fish total length (mm). The threshold for the SED echogram was set to -64 dB (1.8 cm) and threshold for the Amp echogram (40 logR) was set to -70 dB. Both thresholds were based on the minimum length of maraena whitefish juveniles caught in the trawl. For the mobile survey, transects were 10 minutes long and corresponded to the duration of trawling. Density estimation was conducted in 5 m depth layers down to 50 m depth, or the bottom, with the exception of the first layer, which was set from 2 m to 5 m. Each file of the stationary survey was approximately 23 minutes long. Density analysis for the stationary survey was done for whole water column from 2 m to 31 m (bottom). Maraena whitefish juveniles were clearly acoustically distinguishable from the other potential fish targets because they were unique in their size, and were also the only catch in the trawl (see results chapter).

1.2.2 Trawling

Fifteen trawl tows on May 20, 2015 (9 daytime tows, 6 night time tows), and 24 tows on June 3, 2015 (10 daytime tows, 14 night time tows) at different depth layers between 0 and 23 m were performed simultaneously with hydroacoustics. Only the pelagic area was taken into account in this study because fry beach seining around the lake confirmed the complete absence of coregonids in the littoral during both day and night (10 seine hauls in each term; the only catch were cyprinid larvae and a few perch juveniles). The main aim of trawling in this study was to identify acoustical targets, calibrate acoustical fish sizing, and sample the surface water layer (0-2 m; blind zone of echosounder). A pelagic, fixed frame ichthyoplankton trawl (mouth opening 2x2 m, mesh size 1 mm x 1.35 mm) with the collecting bucket at the end (Fig. 1b; Jůza et al., 2010) was used for fish sampling. The trawl had a funnel to prevent fish from escaping (Jůza and Kubečka, 2007). A floater attached to the upper part of the frame regulated the sampling depth of the trawl. The length of the rope between the frame and the floater kept the trawl at the required depth. The lower part of the trawl frame was equipped with two weights to keep the trawl vertically in required depth. The volume of water sampled was calculated for each haul. The research vessel Ota Oliva (64 HP diesel engine) towed the trawl approximately 100 m behind it at velocities of approximately 1 m/s.

Juvenile maraena whitefish captured by each trawl tow were immediately anesthetized and preserved in 4% formaldehyde solution. In the laboratory, each fish was measured for TL to the nearest mm. The catch was expressed in terms of density (number of fish per 100 m^3 of water sampled).

1.2.3 Zooplankton sampling and vertical profiling

In each session (May 20, June 3, June 10) zooplankton was collected during the day in the central part of the lake (Fig. 1a) concurrently as fish were monitored. A closing zooplankton net with a mouth diameter of 25 cm and mesh size of 200 µm was used for zooplankton sampling. In each sampling session the mixed contents of three vertical hauls in surface water layer (0-2 m) and also in depth around thermocline (6-8 m) was taken. The hypolimnetic layer (11-55 m) was sampled only during the third sampling campaign (June 10). The zooplankton material was immediately preserved in 4% formaldehyde solution. Zooplankton samples were counted in the laboratory under a microscope using a Sedgewick-Rafter chamber. Cladocerans were determined to species level, copepods were determined as cyclopoid or calanoid and their larval stage (nauplius) was distinguished. The density was calculated as number of individuals per 1 litre in each depth layer.

Water temperature and oxygen concentration were simultaneously measured during the day in 1 m steps in the central part of the lake using an ISY ProODO probe during each round of zooplankton sampling. Water transparency was also measured using a Secchi disk.

1.2.4 Statistical analysis

To compare the density and size of maraena whitefish juveniles between dates (May 20 and June 3) night data were used separately for hydroacoustics and trawling and a paired t-test was used (α=0.05). For comparison of trawling data only tows from layers sampled in both dates were analyzed (6 observations in each date). In order to stabilize the variance of the differences in the t-test, a logarithmic transformation was performed for density data.

Percentage differences in density between surveys performed on May 20 and June 3 represented a 14-day mortality value (± standard deviation).

Statistica software (Statsoft Inc., 2011) was used to perform the statistical analysis.

2 Results

2.1 Depth distribution of maraena whitefish juveniles

During both sampling sessions 187 juvenile maraena whitefish were captured at night by trawling and this species was the only one caught. This proved that the targets observed by hydroacoustics were maraena whitefish. Relatively similar patterns in depth distribution of juvenile maraena whitefish were observed hydroacoustically during day and night in both sessions. During the day the highest hydroacoustical density was observed in the depth layer between 5 and 10 meters (4 ind./100 m^3 in May and 1 ind./100 m^3 in June; Fig. 3a) and maraena whitefish juveniles were present from the surface down to 35 m in May and 40 m in June (Fig. 3a). Night hydroacoustical data revealed that the majority of maraena whitefish juveniles occupied the uppermost layer, which could be monitored by vertical hydroacoustics (2-5 m; Fig. 3b, 15 ind/100 m^3 in May and 3 ind./100 m^3 in June). Maraena whitefish juveniles were regularly captured in the surface water layer (0-2 m) at night. Night occurrence of maraena whitefish juveniles was found from the surface down to 45 m in May and 35 m in June using hydroacoustics (Fig. 3b).

2.2 Comparison of overall density and size of maraena whitefish juveniles between two sampling points

Both sampling methods found that the overall density of maraena whitefish juveniles decreased significantly between May 20 and June 3 (Fig. 4; trawl: $p<0.001$, $t = 6.1$, $Df = 10$; hydroacoustics: $p<0.001$, $t = 3.6$, $Df = 13$). Mortality during 14 days was 89 ± 24 % and 64 ± 14.3 % based on trawling and hydroacoustical data respectively.

In trawl catches, size increased only slightly between the sessions (mean TL in May 34.3 mm, mean TL in June 35.4 mm) and the difference was not statistically significant ($p=0.16$). Hydroacoustics revealed a slight decrease in TL (mean TL in May 29.7 mm, mean TL in June 28 mm), which was found significant ($p<0.001$).

2.3 Vertical distribution of maraena whitefish juveniles during day and night using stationary hydroacoustics.

In the daytime the echogram was practically empty during stationary monitoring (Fig. 5a) with the occasional occurrence of shoals (in fact shoals were much better detected during the mobile survey, when a larger volume was monitored). In the evening, with decreasing light intensity, the shoals started to disintegrate (Fig. 5b) and during the night fish were distributed homogeneously in water column (Fig. 5c,d). In early morning but still before sunrise the homogeneous distribution started to disappear and shoaling behavior was observed again (Fig. 5e). In the morning during sunrise the echogram was again usually empty during stationary recording with an occasional occurrence of shoals (Fig. 5f). Fish density started to increase shortly after sunset and peaked around midnight. At 03:30 a.m. (1.5 hour before sunrise), the water column was again almost empty and showed the daytime characteristics (Fig. 6).

2.4 Zooplankton density

The zooplankton community showed a similar vertical distribution pattern during the surveys. Higher density was observed in the metalimnion (6-8 m) rather than the surface layer or hypolimnetic layer (11-55 m, in the case of June 10), all and all the zooplankton density was very low in all sessions (Tab. 1). In the surface water layer, less than 1 ind./l was always observed in May and the zooplankton density was lower in later occasions. In the metalimnion zooplankton density was around 2 ind/l with the highest density in the first sampling session in May (2.54 ind./l, Tab.1). Also on June 10 in hypolimnetic layer, zooplankton density was approximately one tenth of that in metalimnion.

Nauplii of cyclopoid and calanoid copepods dominated the samples (Tab. 1). The "others" group consisting of minor components of samples was represented by *Bosmina longirostris* (Müller, 1776), *Chydorus sphaericus* (Müller, 1776), *Diaphanosoma brachyurum* (Liévin, 1848), *Alonella nana* (Baird, 1850), adult calanoid copepods and chironomids.

3 Discussion

This study presents the first attempt to describe basic ecological characteristics of early juveniles of an introduced population of coregonids in an extremely young post-mining oligotrophic lake with high water transparency. In the spring during the day juvenile maraena whitefish gathered in shoals practically throughout the whole water column up to 40 m whereas at night they were relatively homogeneously distributed up to the depth of 45 m with a peak between 2 and 5 m. Both hydroacoustics and trawling revealed a significant decrease of maraena whitefish density between sampling sessions, which points to high mortality in spring of the first year of life. Any significant increase of size between sessions with either method was used, which is a sign of very slow growth in a zooplankton poor lake with low productivity.

Mehner et al. (2011) stated the hydroacoustical density of juvenile coregonids in Lake Stechlin in June to be 6.1 ind./100 m^3 and 0.3 ind./100 m^3 in 2002 and 2010 respectively. Thus, the spring juvenile maraena whitefish density observed in Most Lake, is comparable with the density of coregonids in the natural lake in Germany. Our data however revealed extremely high mortality of maraena whitefish juveniles in spring. Urpanen et al. (2005) mentions the three weeks mortality of another coregonid, vendace *Coregonus albula* (Linnaeus, 1758), to be 64%-95% directly after hatching. During the larval stage mortality rates are usually the highest because of yolk sac reduction and the necessity to switch to exogenous feeding, and this stage in general represents the most sensitive stage in the development of the cohort (Lahnsteiner and Wanzenböck, 2004). The intensity of mortality in the juvenile stage is much lower - approximately 0.5-1.5% per day (Bradford and Cabana, 1997). In Most Lake, mortality of maraena whitefish early juveniles was several times higher (15 and 7 % per day in trawl and hydroacoustics respectively), rather comparable to mortality during the larval stage in vendace.

Because food concentration is the key factor to the survival and growth of young fish (Rellstab et al., 2004; Müller et al., 2007) and coregonids are predominantly zooplankton consumers (Eckmann, 1985; Hanazato et al., 1990), zooplankton density is probably the most important factor influencing mortality and growth. Rellstab et al. (2004) showed a clear relationship between food concentration and mortality of coregonid larvae. During the first 34 days of life, an elevated mortality of 40% or more resulted from a food concentration of 20 zooplankton organisms per liter or fewer (Rellstab et al., 2004). Also the growth rate of maraena whitefish juveniles was extremely low in Most Lake. Based on the trawling data the average growth rate was 0.08 mm per day and according to hydroacoustical recordings, the growth rate was even negative. Due to the large number of observations, a 1.7 mm difference between both occasions observed by hydroacoustics was statistically significant. It is evident that the approximately 1 mm difference revealed in trawl catches between sampling sessions is out of the resolving power of precise sizing by hydroacoustics means. Pelczarski (2004) noted that the mean growth rate of stocked whitefish juveniles in the southern Baltic area was 0.82 mm per day, approximately 10 times faster than in this study. The most probable reason for high mortality and slow growth was the extremely low zooplankton density in Most Lake (maximum of 2.5 ind./l), which is significantly below the threshold value of 20 ind./l noticed by Rellstab et al. (2004). Especially during the June survey, maraena whitefish juveniles were skinny and clearly not in good condition. Negatively density dependent growth is the same reason for slow growth in the coregonids populations when high fish densities cause slow growth (Marjomäki and Kirjasniemi, 1995; Viljanen et al., 2004; Urpanen et al., 2005). The density of juvenile maraena whitefish observed in Most Lake was comparable to the density of coregonids in the natural lake in Germany (see above in discussion) but extremely low zooplankton density per individual was probably the main reason for the slow growth and high mortality.

Another important aspect of high mortality can be predation. Maraena whitefish juveniles were predated only by larger perch in the lake. Seventeen percent of all piscivorous perch had maraena whitefish juveniles in their digestive tracts during the gillnet survey in 2015 and no maraena whitefish were found in the digestive tracts of catfish and pike (Peterka, pers. comm.). In such an oligotrophic lake, with limited densities of juvenile fish of other species, juvenile maraena whitefish obviously represent an important food source, especially for piscivorous perch. Our results show that the low productivity of the newly created lake leads to a limited amount of zooplankton, which became insufficient for the usual densities of maraena whitefish juveniles. This leads to slow growth during the first year of life and also enhanced mortality, because small maraena juveniles are longer under predation pressure of perch. Perch predation should be also taken into account when considering maraena whitefish mortality in a young oligotrophic lake.

Diel vertical distribution of coregonids has been investigated especially for the earliest (larval) stages (Urpanen et al., 2009; Ylönen et al., 2005; Ventling-Schwank and Meng, 2005), late summer juveniles (Hamrin, 1986; Sandlund et al.; 1992, Jůza et al., 2012,) and adults (Jensen et al., 2006; Gjelland et al., 2009; Mehner, 2006a). Diel distribution of early juveniles in spring is scarce in literature. Coregonid larvae prefer the warmer upper layer that enables them to grow faster during early spring (Eckmann, 1989). Urpanen at al. (2009) found that vendace and whitefish larvae were aggregated near the water surface mostly in the top 30 cm during the day in the first weeks after the ice melted, while Ventling-Schwank and Meng (1995) also found most of whitefish larvae 12-14 mm in size close to the water surface during both day and night. During this time period schooling was observed for the first time by these authors. It is evident that DVM of significant extent are not the case of coregonid larvae, however short vertical migrations caused by avoidance of UV radiation during the day were described (Ylönen et al., 2005). Clear DVM were described for juvenile vendace in July in lakes in southern Sweden (Hamrin, 1986). These migrations, depending on temperature, might include movement to the epilimnion at night, whereas during the day metalimnion around thermocline is utilized (Hamrin, 1986). In lakes with a strong temperature gradient and warm epilimnion, juvenile vendace also stayed below thermocline during the night (Jůza et al., 2012). The DVM are also common in adult coregonids and the trend is similar to that observed for juvenile coregonids in late summer. The only difference is that juvenile fish often utilize warmer water with higher light intensities during the day, whereas adults remain in deeper cold water (Hamrin, 1986). In coregonids diel vertical migrations can be also partial, when part of population does not migrate and exhibits a resident strategy (Mehner and Kasprzak, 2011). Spatio-temporal distribution of maraena whitefish in the early juvenile period with TL of about 35 mm was investigated in this study. According to Ventling-Schwank and Meng (1995) coregonids in the last larval stage (size 28-29 mm) congregated between 1.5 m depth and the water surface during the night and in the morning the fish swam in schools as far down as 4 m depth or stayed in loose shoals between this depth stratum and the surface. Our results indicate that the spatiotemporal distribution of early juveniles is unique, different from the distribution of larvae and late summer juveniles. We did not found significant DVM, because the whole epilimnion, metalimnion and a significant part of the hypolimnion were utilized during both day and night. During the night fish were homogenously distributed in water column and they were catchable for trawl, whereas during the day obvious shoaling behaviour was observed. Catching the shoal during the day by ichthyoplankton trawling is improbable because of their patchy distribution. Light intensities are also important, because in the absence of vision, fish are unable to react in the ordered manner to an approaching net (Glass and Wardle, 1989). During the day the catchability of the trawl is therefore reduced significantly.

Shoaling reduces the probability of being preyed on, and the rapid, coordinated movement by shoals serves to protect individual members (Pitcher and Parrish, 1993). Our data suggests that the aggregation to shoals during the day is a better strategy for early juveniles than extensive depth shifts, because the peak of fish density was only slightly shallower at night than during the day. Changes in activity patterns and vertical use of habitat typically occur during crepuscular periods (Pitcher and Parrish, 1993). Disintegration of shoals was obviously connected with decreasing light intensity. During the night fish were relatively homogeneously distributed in open water and the re-creation of shoals started again approximately 1.5 hour before sunrise, still in period with low light intensity. In comparison with shoal disintegration in the evening, shoaling behaviour was not directly driven by light. Pitcher et al. (1976) found for saithe *Pollachius virens* (Linnaeus, 1758) that vision is not required in order for the fish to school and that the lateral line organ could play an important role during schooling. Also our observation shows that the shoaling behaviour of early juveniles of maraena whitefish is not driven by light and shoals can be formed during low light intensities at night. The eye of coregonids is very sensitive to light. when at a light level of 0.05 lx they are able to prey on zooplankton (Ohlberger et al., 2008) or observe partners during a spawning

(Karjalainen and Marjomäki, 2018). Residual light in clear water of an oligotrophic lake close to the water surface, where the majority of coregonids spend the night, can be sufficient for starting of shoaling behaviour. More than one hour later, when the light intensity increases quickly, coregonids juveniles are safe in formed shoals.

This study is the first attempt to describe basic ecological parameters such as mortality, growth and spatiotemporal distribution of early juvenile maraena whitefish in a post-mining lake shortly after its filling. It shows that in a zooplankton-poor, oligotrophic lake the early juveniles are affected by extremely high mortality and slow growth. Vertico-temporal distribution was different from the distribution patterns of larvae and late summer juveniles that are well described in literature. A similar pattern with larvae was that the majority of early juveniles utilized the epipelagic area but also partly occurred in deeper layers below thermocline, which is typical for late summer juveniles. Homogeneous distribution of larvae at night changed to aggregated during the day (Ventling-Schwank and Meng, 1995). Extensive diurnal depth changes described for late summer juveniles of coregonids (Hamrin, 1986) were not the case in early juvenile stages, because the peak of occurrence shifted only slightly between day and night. However, vertical distribution of vendace was investigated in the study of Hemrin (1986) so the comparison with maraena whitefish is not straightforward.

While maraena whitefish are able to reproduce naturally in a post mining lake, scarcity of food limits their growth and as such their consequent survival into more stable second year of life is therefore also limited. Shoaling behaviour during the day, as an efficient antipredator behaviour, supports the survival of earliest stages but scarcity of food seems to be the main bottleneck. Future more detailed studies will be necessary to investigate the population dynamics of artificially stocked maraena whitefish in a newly created post-mining lake.

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Authors Contribution Statement:

TJ, VD, MČ, ZS, PB, MA, JP performed field work, VD analyzed acoustical data, TJ wrote the manuscript and processed trawl catches, PB performed statistical analysis, MA processed zooplankton samples, VD, MČ, ZS, MA, PB, JP did the final editing of the manuscript and JP provided financial support.

Conflicts of interest:

The authors have declared that no competing interest exist.

Ethics statement:

Fish sampling and treatment was conducted in compliance with guidelines from the Experimental Animal Welfare Commission under the Ministry of Agriculture of the Czech Republic.

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Figure captions

Fig. 1: (a) Map of the Most Lake and its location within the Czech Republic – lines in the lake map represent 10 m isobaths. Triangles sign the locations of stationary echosounding (black) and zooplankton sampling (white). (b) Diagram showing the sampling operation.

Fig. 2: Thermal and oxygen stratification in the Most Lake on May 20 (a), June 3 (b) and June 10 (c). Secchi depth (SecD) is also displayed. Only depth up to 25 m is shown. Below this depth temperature and oxygen concentration was constant.

Fig. 3: Depth distribution from hydroacoustic monitoring of juvenile maraena whitefish during day (a) and night (b) on May 20 (black column) and June 3 (white column) 2015. Error bars represent standard errors of mean.

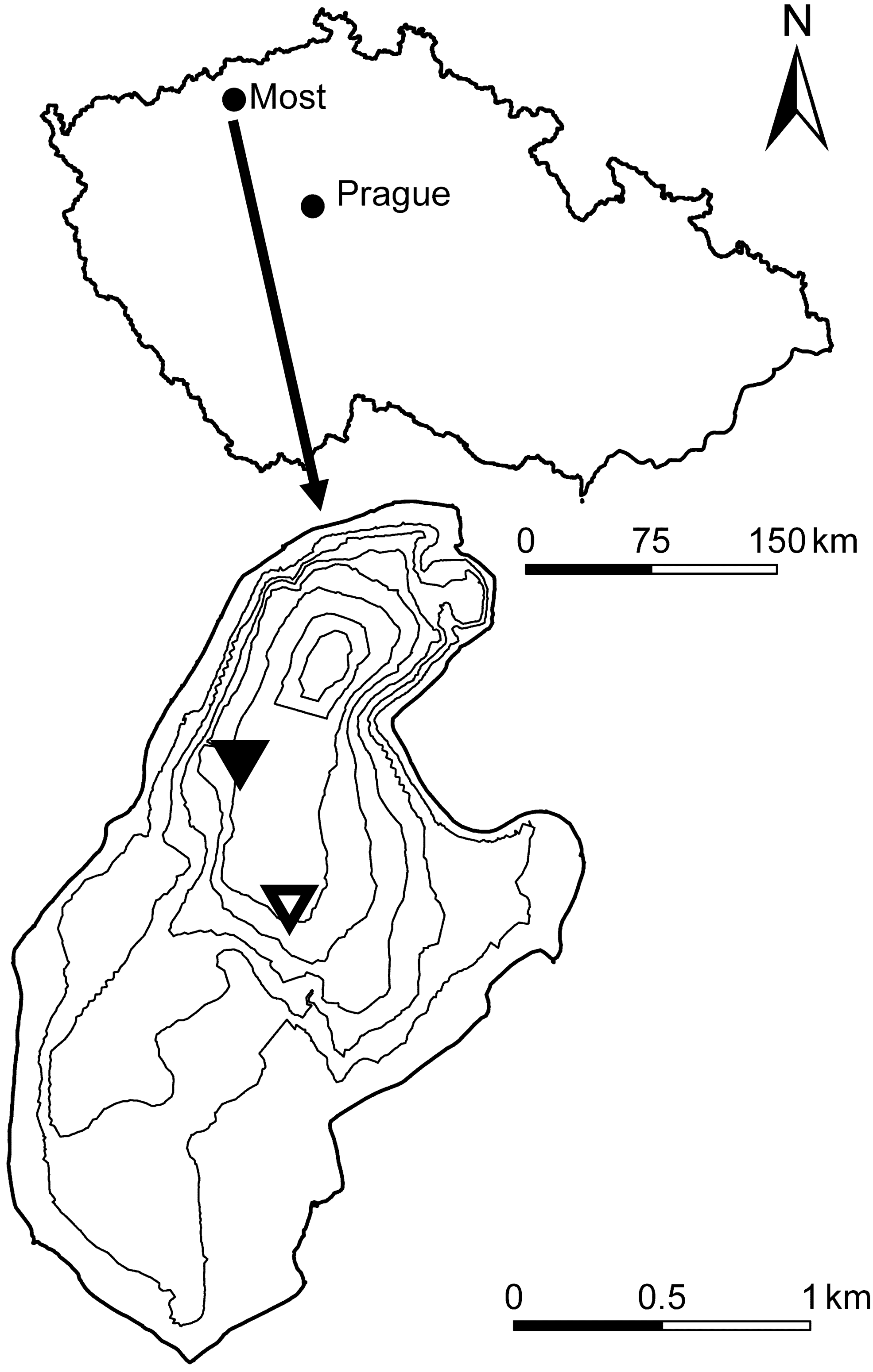
Fig. 4: Density of juvenile maraena whitefish in the Most Lake on May 20 (black column) and June 3 (white column) in trawl catches and hydroacoustical observations. Error bars represent standard errors of mean.

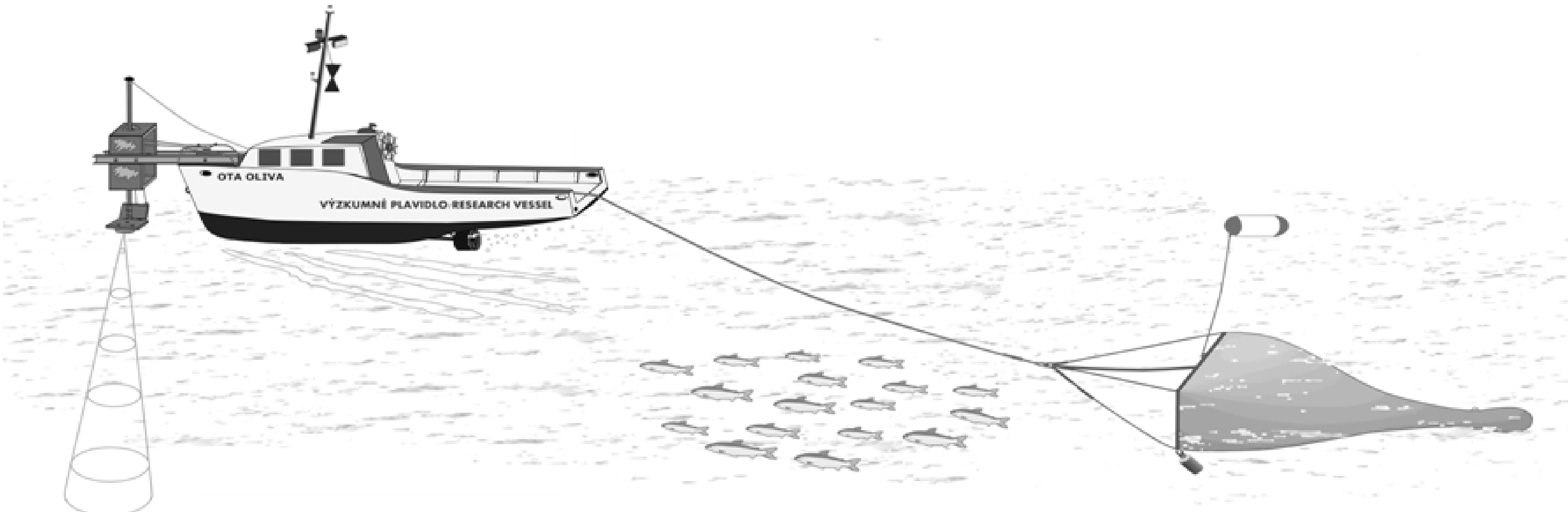
Fig. 5: Echograms showing typical distribution of juvenile maraena whitefish during day 18:30 (a), growing dark 19:40 (b), night 22:30; 1:00 (c,d), morning before sunrise 2:30 (e) and morning after sunrise 6:00 (f) on June 10-11. Twenty-three minutes of monitoring are shown in the echograms.

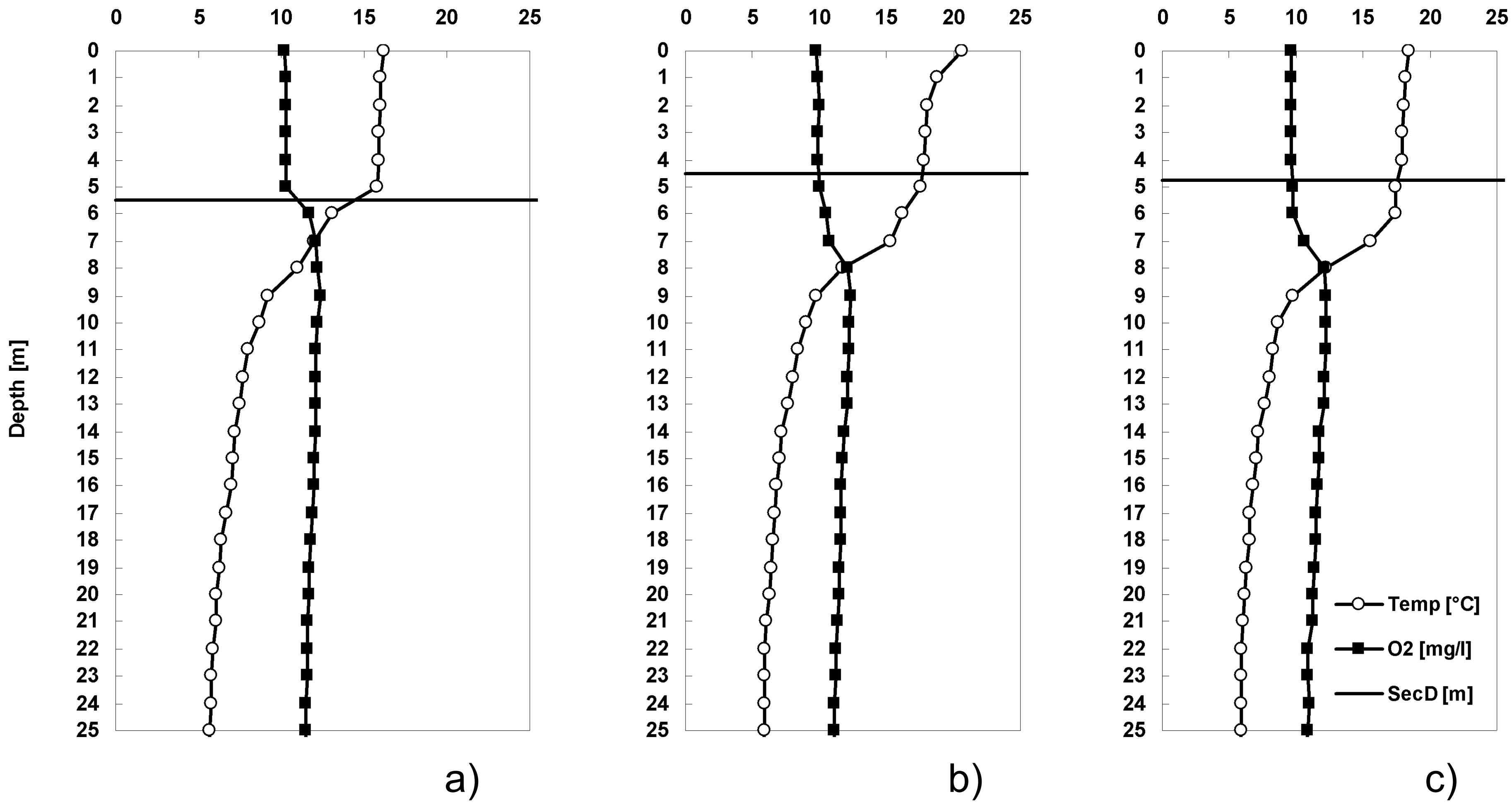
Fig. 6: Temporal changes in density of maraena whitefish juveniles during stationary hydroacoustic monitoring on June 10-11 above the depth of 31 m. Sunset and sunrise are displayed by arrows.

Table 1: Density and species composition of zooplankton during three sampling sessions in two (three 10 June) depth layers in the Most Lake in 2015. For groups included in category "Others" see Results section.

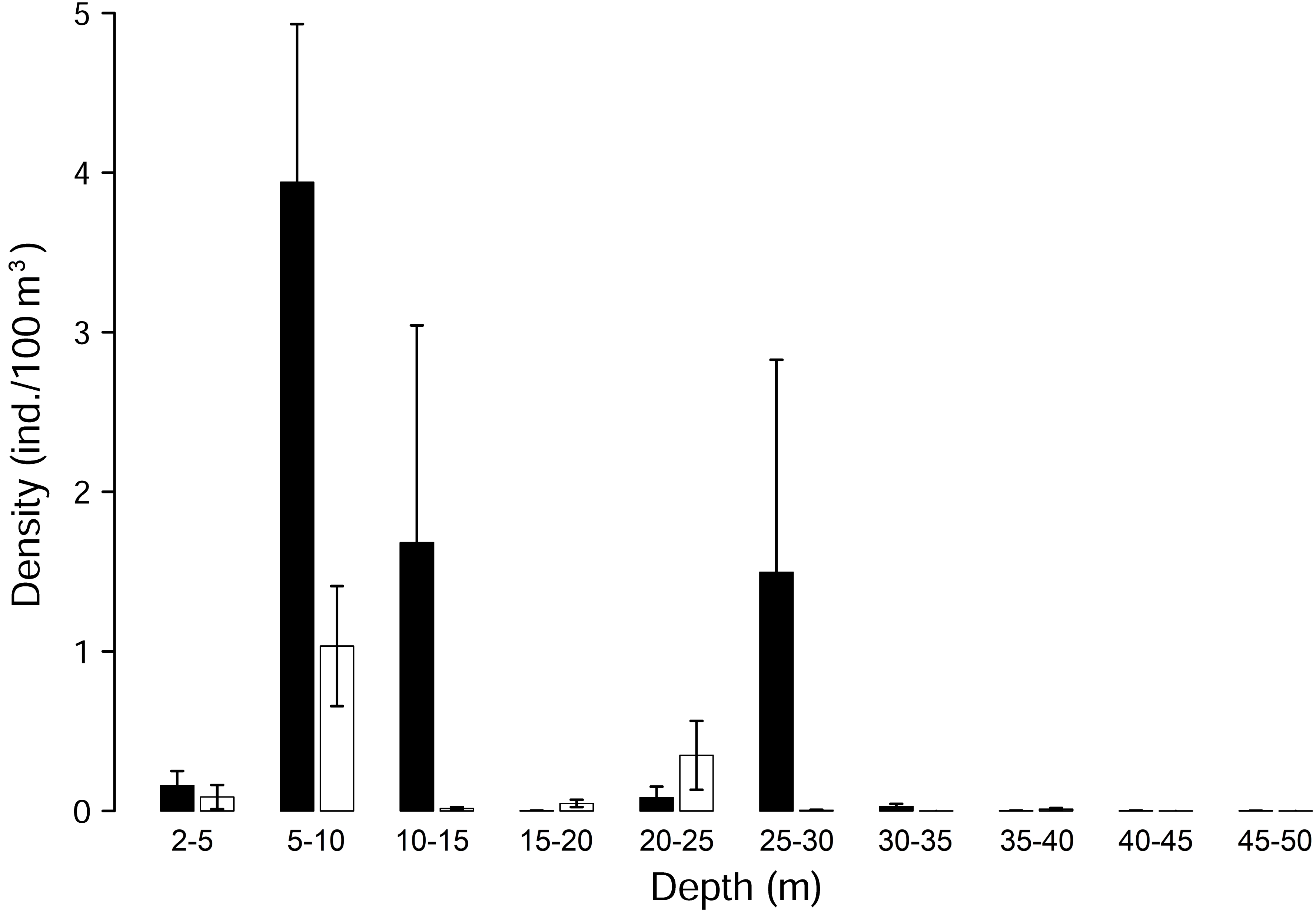
			Species composition %					
Date	Depth (m)	Zoopl.dens. (ind./l)	Cyclopoid nauplii	Cyclopoid copepodites	Calanoid nauplii	Calanoid copepodites	Daphnia longispina	Others
20.5.	0-2	0.84	39	29	24	4	1	3
	6-8	2.54	62	12	9	15		2
3.6.	0-2	0.09	11	22	29	4	15	19
	6-8	1.03	72	4	15	5	3	1
10.6.	0-2	0.02		29	43		14	14
	6-8	2	63	4	15	12	2	4
	11-55	0.22	1	5	63	18	9	4


N
Most
Prague
0
75
150 km
0
0.5
1 km

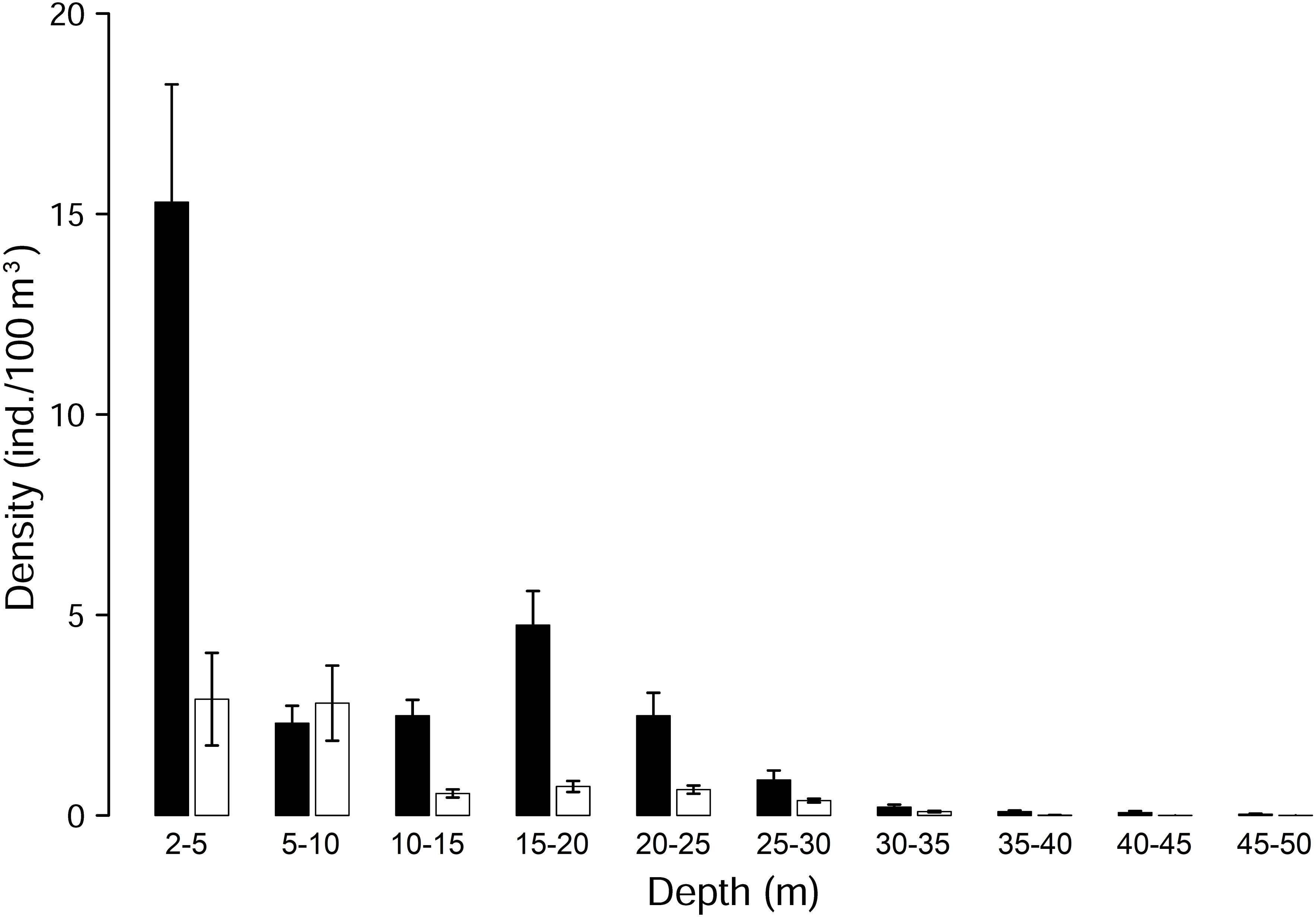

OTA OLIVA
VÝZKUMNÉ PLAVIDLO-RESEARCH VESSEL



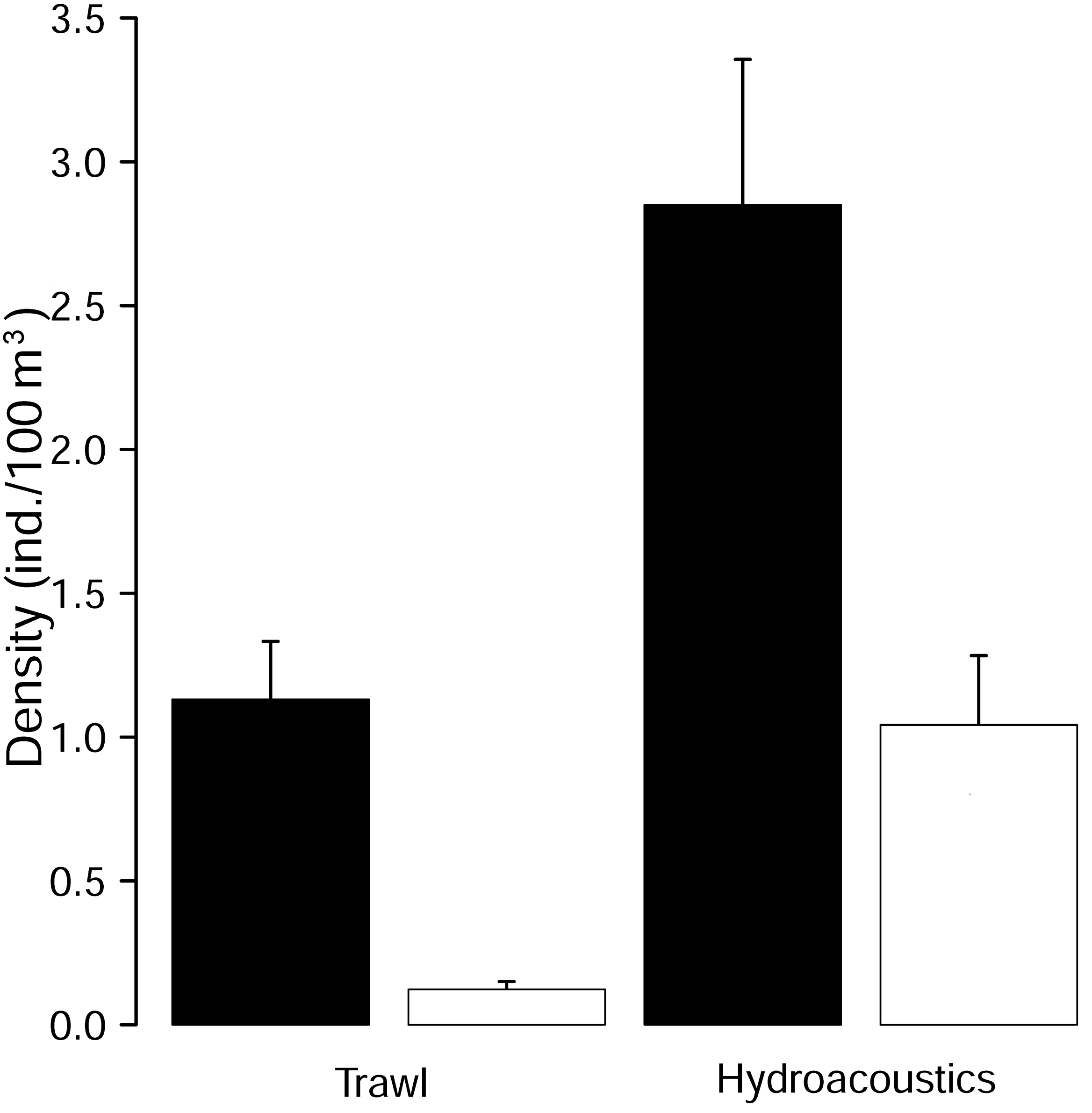
0 5 10 15 20 25
Depth [m]
a)
b)
c)
Temp [°C]
O2 [mg/l]
SecD [m]



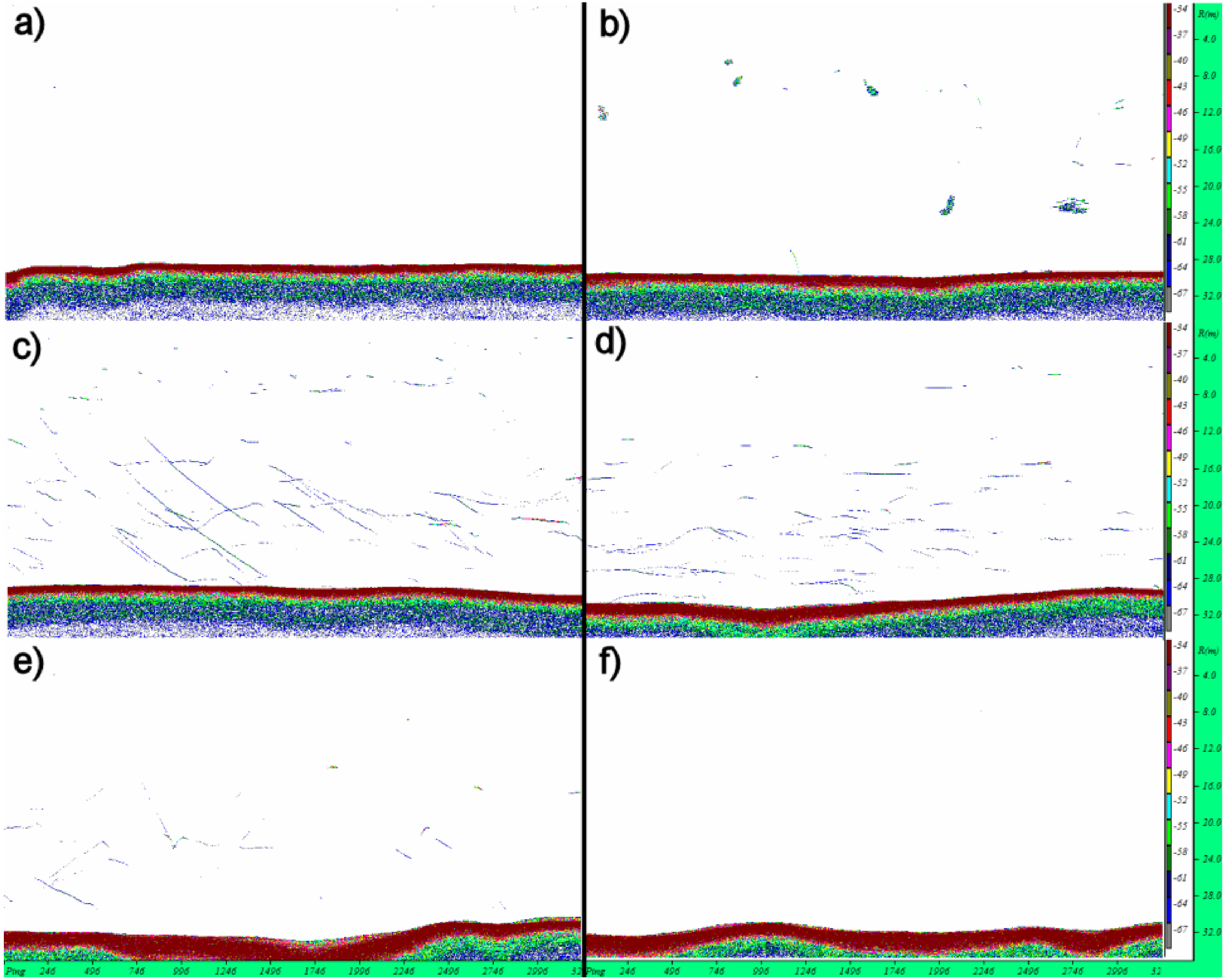
Density (ind./100 m3)
0
1
2
3
4
5
2-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
45-50
Depth (m)



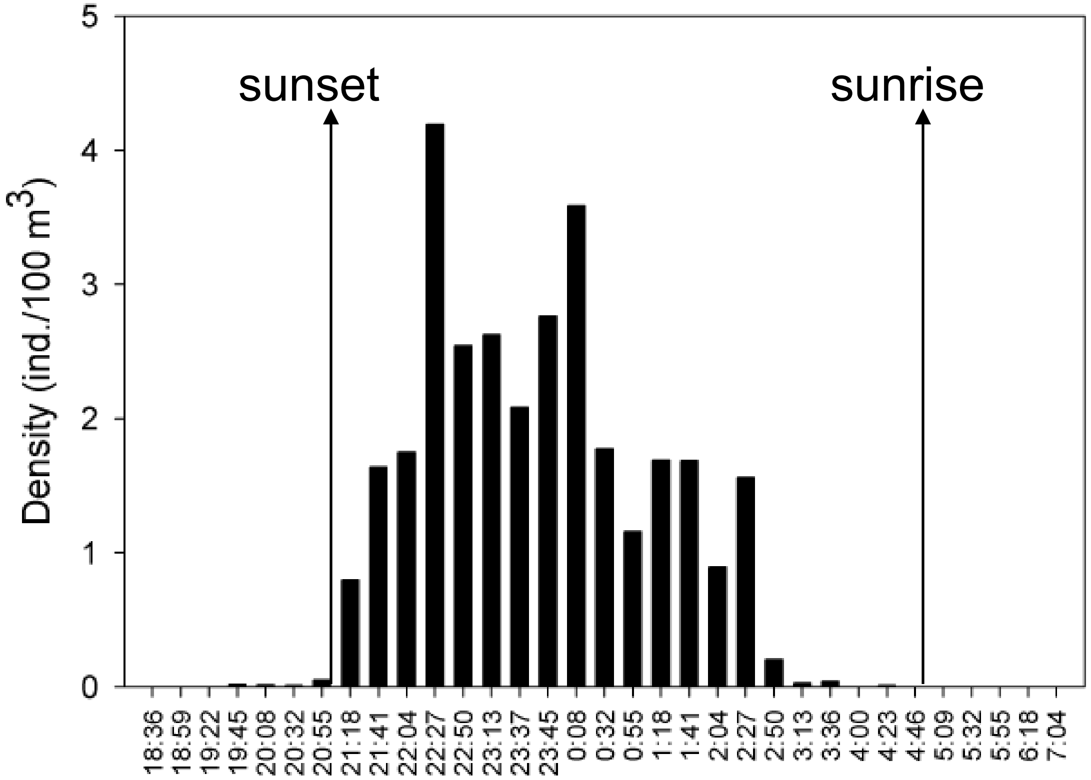
Density (ind./100 m3)
20
15
10
5
0
2-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
45-50
Depth (m)



Density (ind./100 m3)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Trawl
Hydroacoustics



a)
b)
c)
d)
e)
f)
R(m)
Ping



Density (ind./100 m3)
5
4
3
2
1
0
sunset
sunrise
18:36
18:59
19:22
19:45
20:08
20:32
20:55
21:18
21:41
22:04
22:27
22:50
23:13
23:37
23:45
0:08
0:32
0:55
1:18
1:41
2:04
2:27
2:50
3:13
3:36
4:00
4:23
4:46
5:09
5:32
5:55
6:18
7:04