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THE EFFECT OF ABOVE-WATER ARTIFICIAL LIGHT ON THE ZOOPLANKTON ABUNDANCE IN CAGES FOR FISH REARING

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K e y w o r d s: concentrating of zooplankton, illuminated cage, phototaxis, lake.

A b s t r a c t

The fish larvae rearing method in illuminated cages was originally dedicated to the coregonid spp. Its technical variants are currently applied in rearing other fish species. This method is based on the attraction of zooplankton by a light source placed inside a fish cage. Zooplankton is the sole or main food source for the fish inside such a cage, therefore an effective means of attracting the plankton is critical to effective fish rearing. The aim of this paper is to assess the influence of above-water illumination in the zooplankton abundance in lake-based fish rearing cages. The experiment was conducted in eutrophic Lake Maróz (Northeastern Poland). Observations were conducted starting at dusk in lit (24V, 60W electric bulb located just above the water surface) and unlit cages. The above-water illumination significantly increases the abundance of the Cladocera and adult Copepoda forms inside the cage. At the same time, a significantly reduced attraction to visible light was noted for the juvenile Copepoda and Rotifera forms. Overall, the above-water illumination is an effective method. The level of zooplankton density and its overall abundance might be dependent on the zooplankton's qualitative structure.

WPŁYW NADWODNEGO ŚWIATŁA NA LICZEBNOŚĆ ZOOPLANKTONU W SADZACH DO PODCHOWU RYB

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S ł o w a k l u c z o w e: sadz oświetlony, fototaksja, koncentracja zooplanktonu, jezioro.

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Abstrakt

Sadze oświetlone pierwszy raz zastosowano przy podchowie larw koregonidów. W różnych wariantach technologicznych jest obecnie wykorzystywana przy podchowie innych gatunków ryb. Metoda ta jest oparta na wabieniu zooplanktonu przez światło umieszczone we wnętrzu sadza. Dla ryb w sadzach zooplankton jest głównym źródłem pokarmu. Dlatego skuteczność jego wabienia jest kluczowa dla efektywności podchowu. Celem niniejszej pracy jest ocena wpływu nadwodnego oświetlenia na liczebność zooplanktonu w środowisku jeziorowych sadzów do podchowu ryb. Eksperyment przeprowadzono w jeziorze Maróz (północno-wschodnia Polska). Obserwacje prowadzono w sadzach oświetlonych od zmierzchu żarówką elektryczną umieszczoną tuż nad powierzchnią wody (24V, 60W) oraz w sadzach nieoświetlonych. Oświetlenie nadwodne w porze nocnej istotnie zwiększa liczebność Cladocera oraz dorosłych form Copepoda w sadzach. Jednocześnie wykazano istotnie mniejsze wabiące oddziaływanie światła widzialnego na młodociane formy Copepoda oraz Rotifera. Nadwodne źródło światła jest rozwiązaniem efektywnym. Zagęszczenie zooplanktonu pod wpływem światła i ogólna liczebność organizmów pokarmowych dla ryb mogą być znacząco uzależnione od struktury jakościowej zooplanktonu.

Introduction

The influence of variable light source intensity on the dial vertical migration (DVM) of the zooplankton continues to be the subject of numerous studies (RINGELBERG and FLIK 1994, MARTYNOVA and GORDEEVA 2010). The method of fish rearing in illuminated cages was developed in Poland during the 1970s and was dedicated to the coregonid spp. (MAMCARZ 1995a). This method is based on the attraction of zooplankton by a light source placed inside a fish cage (MAMCARZ 1995b). The technical variants of this method included submerged and surface cages illuminated by an a submerged light source (MAMCARZ and NOWAK 1987, MAMCARZ 1995a). The effectiveness of zooplankton concentration using an a submerged light source was also assessed in several papers and range from twofold (ZILIUKENE 2005), 5–15 fold (CECCUZZI et al. 2010) to about 40-fold (SICHROVSKY et al. 2013). They indicate the multitude of factors influencing the zooplankton concentration in cages (MAMCARZ 1995b, FERMIN and SERONAY 1997).

Submerged incandescent 60W bulbs (ZILIUKENE 2005), submerged 12V halogen bulbs (SICHROVSKY et al. 2013), also 60W LED bulbs (CECCUZZI et al. 2010) were used for attraction of zooplankton. Above-water light sources were also utilized in experimental fish rearing cages (SKRZYPCZAK et al. 1998b, FURGALA-SELEZNIOW et al. 2014). Using above-water light sources, alternative systems of zooplankton accumulation and transport (pump) to the rearing cages were developed (SKRZYPCZAK et al. 1998a). The effectiveness of concentrating zooplankton is dependent on the intensity and range of the light source. It has been hypothesized that relative changes in light intensity trigger a migratory response in zooplankton (RINGELBERG and FLIK 1994, NESBITT et al. 1996, DODSON et al. 1997). It must be assumed that placing a light source above the water surface restricts the illuminated zone because when light passes from air into water, the light is refracted (or bent) towards the normal (GOODMAN 1993).

Presently several zooplankton sampling methods are used. One of them is engine driven pump, which didn't revealed significant advantage over 10L Schindler-Patalas trap (SICHROVSKY et al. 2013). Another known and used trap is Ruttner's bottle. Traditional conical shape net for taking samples is still used (CECCUZZI et al. 2010, MARTYNOVA and GORDEEVA 2010). None of the zooplankton sample collection methods is universally-applicable. On the contrary, each of them is usually dedicated to specific environmental conditions (PAGGI et al. 2001). The effectiveness of sample collection and the reliability of the obtained results continues to be largely dependent on the accurate selection of methods and the researcher's manual abilities (LIVINGS et al. 2010).

The aim of this paper is to assess the influence of above-water illumination on the zooplankton abundance in lake-based fish rearing cages.

Materials and Methods

The experiment was conducted in May 2013 in Lake Maróz, Poland (eutrophic, max. depth 41.0 m, 53° 32'N, 20°25'E, 3.32 km). The experimental environment were cuboid shape net cages (side length 1.0 m; volume 2.0 m^3) for fish rearing, made of nylon with mesh size 1.2 mm. The zooplankton samples were collected every three days in empty cages (no fish were present): one illuminated (CI) and the other unlit (CU). The distance between the two cages was 8 meters. In the CI cage, the light source was an electric bulb (24V, 60W), located just above water's surface and switched on 2 hours before sample collection. The samples were collected simultaneously in both cages (usually between 23:00–23:30) using a plankton net (mesh size 30 μm, round intake with diameter 2.2 dm, 3.8 dm^2, filtration surface 24 dm^2, volume 9.0 dm^3) hauled vertically from the bottom of the cages to the water surface (2.0 m). Each haul penetrated 76 dm^3 of water column volume. The average haul velocity was about 0.05m s^{-1} (total haul time of about 40s). The samples were condensed to the volume of 0.1 dm^3, preserved in Lugol solution and conserved in a 4% formaldehyde solution. The zooplankton identification was performed until the lowest possible taxonomic unit was identified in accordance with the following methodologies: FLÖSSNER (1972), KIEFER and FRYER (1978), KOSTE (1978). The quantitative analysis was performed using the Sedgewick-Rafter counting chamber and reported in the volume unit (ind. dm^{-3}). The zooplankton was observed at the level of three taxonomic groups: Cladocera, Copepoda (adult and juvenile forms) and Rotifera. The level of light-induced plankton density was expressed using the concentration ratio of organisms (ind. dm^{-3}) in the lit and unlit cages (CI/CU ratio). To assess the general differences in the CI/CU ratios of the analyzed zooplankton groups, non-parametric analysis of variance was applied (Statistica 10.0 for Windows, Statsoft; Tulsa, UK). The results were processed by ANOVA with the non-parametric Kruskal-Wallis test to determine the statistically significant differences ($p \leq 0.05$).

Results

Large variability of the zooplankton abundance was noted in the fish rearing cages. The largest concentration of the Rotifera was noted on May 31st: 1065 ind. dm^{-3} in the illuminated cage (CI) and 816 ind. dm^{-3} in the unlit cage (CU) (Figure 1). The qualitative analysis of that day's samples revealed 8 species, with *Pompholyx sp.* being the most common. On the day of Rotifera's least abundance (May 16th, CI 142 ind. dm^{-3} and CU 119 ind. dm^{-3}), the species structure was dominated by the *Keratella sp*. Whereas on May 19th the Rotifera abundance in the CU was slightly greater than in the CI, 365 and 332 ind. dm^{-3}, respectively. On the same day, the greatest abundance of the Cladocera was noted (CI 554 ind. dm^{-3} and CU 140 ind. dm^{-3}) (Figure 2). Among the five Cladocera species, *Daphnia sp.* was the most abundant in both cages. Whereas the Cladocera were the least abundant on May 28th (CI 35 and 9 ind. dm^{-3}). The Copepoda were also the least abundant on that day: CI 66 ind. dm^{-3} and CU 44 ind. dm^{-3}) (Figure 3). Whereas the greatest Copepoda abundance was noted on May 4th: CI 908 ind. dm^{-3} and CU 761 ind. dm^{-3}. In both cases the juvenile forms (nauplius and copepodit) had the greatest influence on the total abundance of the Copepoda. Furthermore, it is the Copepoda forms that was noted to have the most instances of lack of accumulation in the illuminated cage. The values of CI/CU≤1.0 were noted on a total of five sample collection days (Figure 4). In four other cases, the CI/CU ration oscillated between 1.2 and 1.3. Only on May 25th its value reached 2.8 and it was noted in the conditions of decreased total plankton abundance (348 ind. dm^{-3} and 209 ind. dm^{-3}, respectively). The mean CI/CU ratio for the juvenile Copepoda (CP-J) was 1.26 (±0.57) and was not statistically different from the mean CI/CU ratio for the Copepoda (CP-T) and Rotifera (Table 1). This last taxonomic group was noted to have the smallest mean CI/CU ratio: 1.16 (±0.15). However, the values CI/CU≤1.0 were noted only twice for the Rotifera: May 13th and May 19th (Figure 4). The greatest density indicators were noted for the Cladocera and the adult Copepoda (CP-A): 5.5 on May 22nd and 4.6 May 4th. For both forms, the noted CI/CU ratio did not fall below 2.1. The CI/CU ratios for the Cladocera and

Copepoda adults were statistically larger than the CI/CU ratios for the rest of the zooplankton forms (*P*<0.01). The mean CI/CU ratio for the Cladocera was 3.96 (±0.99), and for the Copepoda 3.38 (±0.91). However, no statistically significant differences were noted between them (ANOVA, Kruskal-Wallis test, *P<0.01*).

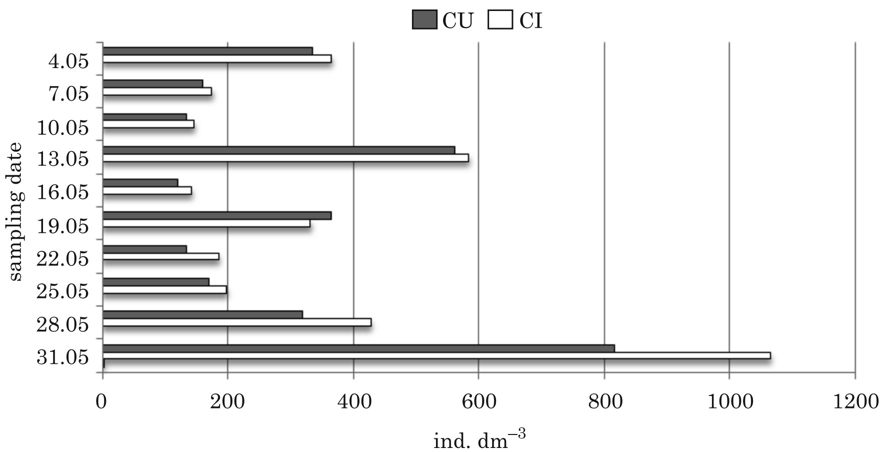

Fig. 1. The Rotifera density in fish rearing cages (CI- cage illuminated; CU- cage unlit)

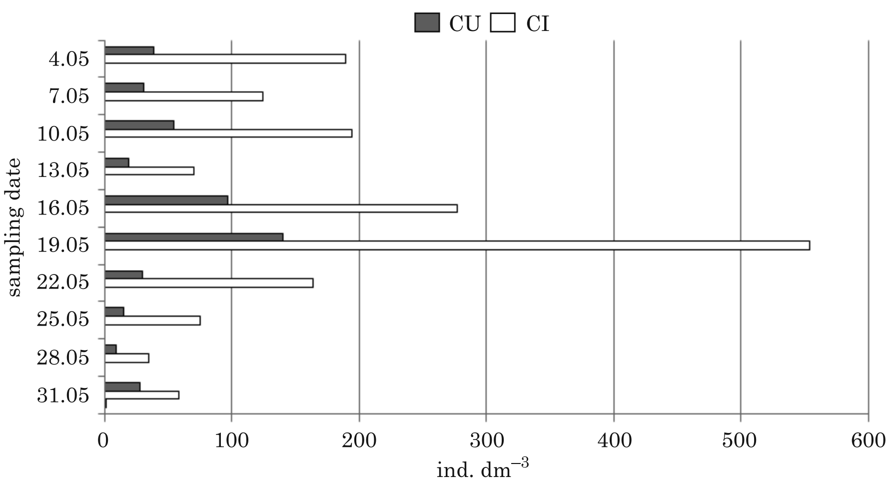

Fig. 2. The Cladocera density in fish rearing cages (CI- cage illuminated; CU- cage unlit)

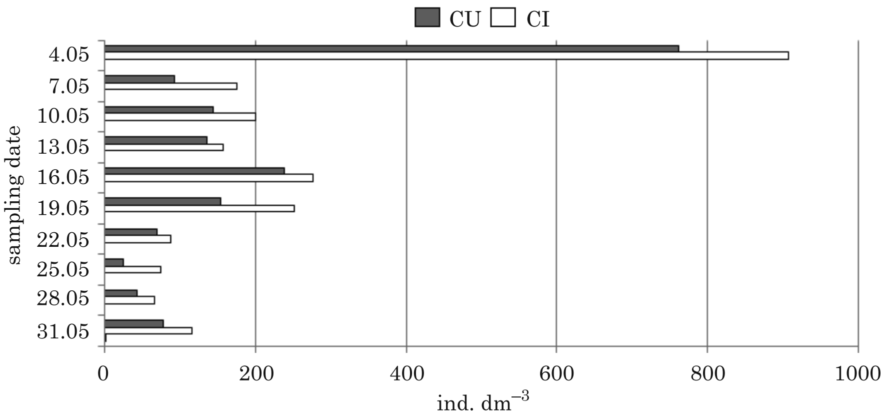

Fig. 3. The Copepoda density in fish rearing cages (CI- cage illuminated; CU- cage unlit)

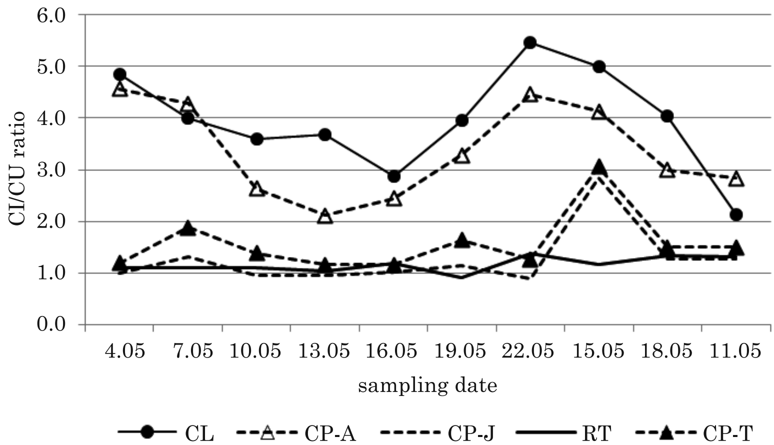

Fig. 4. The zooplankton density ratio (CI/CU) during the experiment (CI- cage illuminated; CU- cage unlit; CL- Cladocera; CP-A – Copepoda adult forms; CP-J – Copepoda juvenile forms; CP-T – Copepoda total; RT – Rotifera)

Table 1. Mean density of zooplankton (CL – Cladocera; CP-T – Copepoda total; CP-A – Copepoda adults forms; CP-J – Copepoda juvenile forms; RT – Rotifera) in fish rearing cages (CI – illuminated; CU – unlit). The means of ranks CI/CU ratio with the different letter index are statistically different (Kruskal-Wallis test H=36.19; df4; N=50; P<0.01)

Parameter	Unit of measure	CL	CP-T	CP-A	CP-J	RT
Mean CI abundance	ind. dm^{-3} (±SD)	174 (±153)	231 (±248)	70 (±54)	162 (±200)	362 (±286)
Mean CU abundance	ind. dm^{-3} (±SD)	46 (±41)	174 (±215)	21 (±14)	153 (±205)	311 (±227)
Mean CI/CU ratio	$\bar{x}$ (±SD)	3.96 (±0.99)	1.57 (±0.57)	3.38 (±0.91)	1.26 (±0.57)	1.16 (±0.15)
Mean of ranks CI/CU ratio	$\bar{x}$	41.7^{A}	22.5^{B}	3.2^{A}	11.9^{B}	13.2^{B}

Discussion

During conducted experiment were ascertained dynamic qualitative and quantitative changes in the lake zooplankton. The seasonal changes in the zooplankton abundance are caused by numerous biotic and abiotic factors which were extensively studied (WANG et al. 2007, SUTHERS and RISSIK 2009). We demonstrated an influence of the above-water light source on the zooplankton density that is partially consistent with the observations by MAMCARZ (1995b). In that study, the highest indicators of zooplankton density were noted in a shallow pond (2.0 m), the lowest were noted in a stratified lake and the greatest increase in abundance was noted in the Cladocera but also was observed in the Copepoda and Rotifera (MAMCARZ 1995b). Therefore, a pronounced reaction to light must be expected in plankton organisms which are sensitive to light, such as many of Cladocera and Copepoda which undergo vertical migration. Light is one of the key factors guiding their migration behavior during the 24-hour cycle (LAMPERT and SOMMER 2001, KUCZYŃSKA-KIPPEN 2008). Some of the representatives of the *Daphnia spp.* demonstrate negative phototaxis in response to UV-emitting light sources and positive phototaxis in response to visible light (MOORE 1912, STORZ and PAUL 1998). Whereas some of the Copepoda spp. do not demonstrate sensitivity to UV light and the basis of their migration behaviors remains unexplained (WILLIAMSON et al. 2011). The *Eudiaptomus sp.* and *Cyclops sp.* demonstrate diverse migration behaviors but their concentration in the surface layers during night time is undisputed (PASTERNAK et al. 2006). At the same time, no migration activity has been noted in the Copepoda nauplius forms, which may result from their reduced sensitivity to light stimuli (LAMPERT 1992, LOOSE 1993). Phototaxis among the Rotifera is also equivocal and controversial (KIM et al. 2014). Various species of zooplankton evolve different ways to avoid predation pressure (descent into depth or diapauses in life cycle), vertical or horizontal migrations, compensation of elevated mortality with increasing feeding and reproduction output, changes in habitat use (PASTERNAK et al. 2006). This may partly explain why we observed a significantly reduced level of Rotifera and juvenile Copepoda accumulation in the illuminated cage. PASTERNAK et al. (2006) suggest that movement potential of nauplii and copepodite stages I and II of *Eudiaptomus graciloides* and *E.gracilis* is much less than that of the older individuals.

Conclusions

The above-water illumination significantly increases the abundance of the Cladocera and adult Copepoda forms inside the cage. At the same time, a significantly reduced attraction to visible light was noted for the juvenile Copepoda and Rotifera forms. Our results indicate that above-water illumination might be effective in concentrating the zooplankton in surface cages. The level of zooplankton density and its overall abundance might be dependent on the zooplankton's qualitative structure. Reduced zooplankton density in illuminated cages should be expected in case of dominance of taxa less sensitive to light stimuli. The analysis of this phenomenon requires further study.

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