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Night fish avoidance of *Microcystis* bloom revealed by simultaneous hydroacoustic measurements of both organisms

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ABSTRACT

Simultaneous observations of fish and cyanobacteria were conducted in the shallow Sulejów Reservoir (Poland) during the occurrence of *Microcystis* bloom. A Simrad EY60 split beam echosounder with a 200 kHz transducer beaming horizontally was applied to assess fish and cyanobacteria spatial distribution. Additionally, fish size distribution and species composition were evaluated with gillnets, and cyanobacterial biomass was determined by using an online phycocyanin fluorescence probe. Physico-chemical parameters and water samples for biological analyses were collected at 14 fixed stations situated along the acoustic transects. We found cyanobacteria represented by the genus *Microcystis*, with their toxigenic genotypes in all analyzed samples. The hydroacoustic results provided direct evidence for fish night avoidance of the bloom. The biomass of fish and cyanobacteria demonstrated opposing trends and their peak values spatially mismatched. The number of fish caught in gillnets within the bloom area was about half that caught outside the bloom area. In spite of the presence of intracellular microcystins (hepatotoxin) at all stations, no extracellular microcystins were identified in water samples and in fish tissues.

1. Introduction

Deterioration of water quality is a world-wide problem. In the past decades, increasing eutrophication has led to frequent outbreaks of cyanobacterial blooms in many lakes around the world (Anderson et al., 2002; Briand et al., 2003; Chorus, 2005; Gkelis et al., 2006; Kobus et al., 2013; Meriluoto et al., 2017; Tarczyńska et al., 2001). In addition, recent climate change observations and scenarios suggest that the probability of the occurrence of cyanobacterial blooms will be even higher in the near future (Jöhnk et al., 2008; Paerl and Huisman, 2008; Wagner and Adrian, 2009). Cyanobacterial dominance in water systems can have serious economic and societal consequences, as it limits the range and value of important ecosystem services of inland waters, including recreational use, aquaculture and drinking water usage (Carmichael, 1992; Huisman et al., 2005; Ibelings et al., 2014; Paerl and Huisman, 2009; Paerl et al., 2001). *Microcystis*, one of the major components of cyanobacterial blooms, produces metabolites such as microcystins (MCs). These can be toxic to many aquatic organisms, including zooplankton and fish (Babica et al., 2007; Hansson et al., 2007; Sotton et al., 2014, 2012a,b; Sun et al., 2012, 2011; Tellenbach et al., 2016; Trinchet et al., 2013). MCs are mainly retained within producer-cells during cyanobacterial bloom development and might be released into water after lysis of cyanobacterial cells during bloom collapse. The released toxins can then affect a wide range of aquatic organisms and have deleterious effects on them, including accumulation in animal tissues (Papadimitriou et al., 2009; Sierosławska et al., 2012; Sotton et al., 2012a,b; Xie et al., 2007b, 2005).

Cyanobacteria have gas vesicles responsible for the adjustment of cell position in the water column to get optimal position for photosynthesis and growth. Usually the shape of the gas vesicles is spherical, but *Microcystis aeruginosa* have a form of a hollow cylindrical tube with a diameter of 60–70 nm and maximum length of ca. 600 nm (Dunton and Walsby, 2005). Additionally, *M. aeruginosa* forms large colonies ranging from 100 μm to even 2 cm in size (Kaczkowski et al., 2017). These properties make cyanobacteria effective sound scatterers. Usually, signals from cyanobacteria recorded by an echosounder are

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treated as unwanted noise and removed during analysis of hydroacoustic survey data. We did, however, measure fish and cyanobacteria spatial distribution simultaneously, which enabled us to observe them with the same resolution in space and time.

In spite of the extensive literature concerning the negative effects of cyanobacteria on fish, there are only a few studies related to natural ecosystems, which deal with the spatial distribution of fish during toxic cyanobacterial bloom events (Ernst, 2008; Godlewska et al., 2016; Kaczkowski et al., 2017; Potter et al., 1983; Sotton et al., 2011; Wojtalik et al., 2006). In all published studies so far, fish spatial distribution has been measured continuously with an echosounder, while cyanobacteria have been measured at fixed locations along the transects. The distributions of both fish and bloom are highly variable and change continuously in time and space (Izydorczyk et al., 2005), hence, non-point rapid measurement methods are required to enable a deeper understanding of the complex relationships between them. However, to our knowledge, no research presenting simultaneous and continuous spatial measurement of cyanobacteria and fish occurrence with an echosounder has yet been published.

The study is a part of the project "Do fish adapt to cyanobacterial blooms" financed by the Polish National Science Centre (http://www.erce.unesco.lodz.pl/story/national-projects), and this fraction aims at an assessment of fish spatial distribution in the Sulejów Reservoir in relation to cyanobacterial bloom and its toxicity. We hypothesize that fish avoid those areas covered by cyanobacterial blooms, and in this way decrease their exposure to toxic MCs, and avoid or substantially limit their negative impact.

2. Materials and methods

2.1. Study area

Measurements were performed in the Sulejów Reservoir (51°22′-51° 28′ N, 19°51′-20°01′ E), central Poland, on two consecutive nights (September 2 and 3, 2015) during the occurrence of a cyanobacterial bloom. The Sulejów Reservoir is a typical lowland shallow reservoir, with an area of approximately 2700 ha and an average depth of 3.3 m, in which cyanobacterial blooms are observed regularly at the end of the vegetation season (Izydorczyk et al., 2008a,b; Tarczyńska et al., 2001). The dominant species of bloom-forming cyanobacteria is usually *M. aeruginosa*, which produces the microcystins MC-LR, MC-YR and MC-RR (Gągała et al., 2013; Jurczak et al., 2004; Kaczkowski et al., 2017; Mankiewicz-Boczek et al., 2006). The dominant fish species of the reservoir assemblage include roach (*Rutilus rutilus*), bream (*Abramis brama*), ruffe (*Gymnocephalus cernua*), white bream (*Blicca bjoerkna*), perch (*Perca fluviatilis*), pikeperch (*Sander lucioperca*) and pike (*Esox lucius*). The average sizes of the most common cyprinids are 20–30 cm total length, but larger specimens of bream and piscivorous fish, up to more than 50 cm, are quite common (Frankiewicz and Świerzowski, 2004; Kaczkowski et al., 2017).

2.2. Hydroacoustic measurements

Hydroacoustic measurements were performed from a boat sailing at a constant speed of approximately 1.5 m s^{-1} along 10 pre-determined parallel transects (Tr1–Tr10, Fig. 1). The transects were separated by a distance of approximately 500 m. Data were collected on September 2 and 3, 2015, starting one hour after sunset, when fish are dispersed in the open water, and were completed at least one hour before sunrise. A Simrad EY60, 200 kHz split beam echosounder, equipped with an ES200-7 × 7 (opening at -3 dB) composite transducer beaming horizontally was used to record the data. The transducer was mounted to the side of the boat at a depth of 0.5 m, tilted down by 3.5° and panning 90° to the boat's along-ship axis. The pulse duration was 0.128 ms, and the repetition rate was 10 pings per second. The echosounder was calibrated beaming vertically in the deepest part of the lake at the beginning of the study, following the standard calibration procedure (Foote et al., 1987). Data were stored on a computer and later processed by the Sonar5-Pro (S5) software (Balk and Lindem, 2014).

Fish and cyanobacteria were separated using the Cross-Filter Detector (CFD) module in S5, set up for target-noise separation. The CFD method and module were originally developed to overcome tracking problems in noisy environments, where missing single echo detections from fish and false detections from noise tend to fool ordinary trackers. The CFD uses filters to obtain an adaptive threshold of the echogram. The regions found by the adaptive thresholder are tested with respect to features such as echo-length and track-length to ensure that only single fish tracks are detected. A classical single echo detector is applied to the detected tracks to obtain correct target strength, range and beam position.

When fish targets have been detected, these detections can either be removed from the echogram as noise or kept while removing everything else. We could have set up the CFD to directly do the fish tracking and cyanobacteria estimation on the original echograms, but in order to verify the detection process we let the CFD produce a set of echogram-files with fish-tracks and another set of echogram-files with cyanobacteria and with the detected fish-tracks removed. Studying these two different echogram-sets before carrying out the final processing provided us with a good way of verifying that the CFD had separated fish and cyanobacteria well.

The same CFD detector parameters were applied to produce the two echogram-file sets, except for a growing operation applied for the production of the cyanobacteria echograms. The growing operator has a similar function as the margin has for the bottom detection. It reduces the risk the cyanobacteria data being infested by higher intensity fish echoes. For detecting the fish echogram set, the CFD's adaptive thresholder was set up with foreground filter [1, 3], background filter [55, 1], and offset = 7 dB. The notation [x, y] indicates the number of samples in the range domain followed by the number of samples in the ping domain. The CFD's evaluator was set up to remove targets smaller than 5 samples and longer than 125 samples in the ping domain. No other features appeared to be needed for correct detection. TS for individual echoes in detected fish tracks were found using the CFD's built in classical single echo detector setup with Echo length = [0.7.. 1.3], Multiple peak suppression = medium, Max gain comp = 3 (one way), and Max Phase dev = 0.8. Threshold for the SED was set to −45 dB in order to match the applied −51 dB echogram threshold with respect to the split beams off-axis compensation (6 dB for 2-ways).

For detecting the cyanobacteria echogram-file set, the CFD was set up in the same way except for an additional growing operator applied after the track length evaluator. The operator was set to add 5 samples before and after the track detections in the ping domain and to add 3 samples above and below in the range domain. The regions covered by these grown detections of fish were then removed from the echograms resulting in cyanobacteria echograms without fish tracks.

The final analysis was then performed on the two echogram sets using the same positioned analysis cells and the same threshold (−51 dB). The applied threshold models where 40LogR for the fish-echograms and 20logR for the cyanobacteria echograms.

The areal sound backscattering coefficient Sa ($m^2\,ha^{-1}$) (MacLennan et al., 2002) was considered as a proxy for fish and cyanobacterial biomass (Simmonds and MacLennan, 2005).

Maps of fish and cyanobacteria spatial distributions were based on an Elementary Sampling Distance Unit (ESDU) of 100 m and were produced using the kriging interpolation method in Surfer 8 software. The *t*-test for unequal sample sizes was used for comparison of the acoustic measurements, with cyanobacterial biomass as the discriminating factor.

2.3. Fish gillnet catches

Fish sampling was performed with multi-mesh gillnets during the