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Do fish and blue-green algae blooms coexist in space and time?

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ABSTRACT

Measurements of fish and blue-green algae distributions were performed simultaneously in the shallow Sulejów reservoir (Poland) to check for their coexistence in space and time. An EK 60 Simrad echosounder with a horizontally beaming 200 kHz transducer was used to record the fish population, while a phycocyanin fluorescence on-line detection method was used to estimate the cyanobacterial biomass. Maps of the fish population and cyanobacteria cell distributions sampled every 20 s were produced using kriging techniques. The subsequent analysis of the distribution maps showed that concentrations of fish and algae sometimes do overlap in space and time, thus increasing the risk of fish contamination and human morbidity. More studies are required to further explore the relationship between fish and cyanobacteria.

1. Introduction

Lakes and reservoirs provide many important ecosystem services, including drinking water supply, commercial and recreational fishing, transportation, and general recreation. In the past decades, increasing eutrophication has led to frequent outbreaks of cyanobacterial blooms in many lakes and reservoirs all over the world (Dokulil and Teubner 2000; Tarczyńska et al., 2001; Anderson et al., 2002; Briand et al., 2003; Chorus 2005; Mankiewicz-Boczek et al., 2006a; Xie et al., 2007; Izydorczyk et al., 2008a, 2008b; Gągała et al., 2010). The probability of cyanobacterial toxic blooms will likely increase in the next several decades due to the consequences of climate change on freshwater ecosystems, which will pose potential risks to fish ecology and ecosystem sustainability (Paerl and Huisman 2008; Jöhnk et al., 2008; Wagner and Adrian 2009; Huber et al., 2012; Kosten et al., 2012).

Cyanobacteria (e.g., *Microcystis, Anabaena*) cause serious environmental problems because they are able to produce a series of natural toxins (cyanotoxins). Of the produced toxins, microcystins (MCs) are the most common (Chorus and Bartram 1999). Toxins produced by cyanobacteria threaten not only aquatic animals, by accumulating in fish and other species, but also people, who may be exposed to cyanotoxins directly, by drinking contaminated water, or indirectly, by consuming contaminated fish (Xie et al., 2005; Chen et al., 2009; Sierosławska et al., 2012).

Numerous laboratory studies have demonstrated the negative effects of cyanobacteria on fish, especially those related to cyanotoxicity and the accumulation of toxins in the body tissues of the fish (Carbis et al., 1996; Palikova et al., 2004; Cazenave et al., 2005; Deblois et al., 2008; Sierosławska et al., 2012; Perga et al., 2013). However, such investigations in natural ecosystems have been scarce (Cazenave et al., 2005; Xie et al., 2005; Deblois et al., 2008; Sotton et al., 2011). It should be noted that in the Sulejów reservoir, approximately 90% of the cyanobacterial blooms were found to be toxic (Jurczak et al., 2004). Thus, it is essential to better understand the spatial interactions between cyanobacterial blooms and fish assemblages. This may be crucial for estimating the potential health risks of consuming fish harvested during bloom events. The present work aims to predict the high-resolution spatial relationship between fish and cyanobacterial blooms to help understand how cyanobacterial blooms impact the spatial distribution of fish in the Sulejów Reservoir. To our knowledge, this work is the

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first study to perform simultaneous and continuous spatial measurements of both the fish population and the *Microcystis* biomass distribution. This allowed us to observe both study objects with similar resolution over space and time.

2. Methods

2.1. Study area

Measurements were performed in July 2013 in the Sulejów Reservoir (51°26′00″N, 19°55′25′″E) (Fig. 1), located in the Pilica River valley of central Poland. This water supply used to be the main source of drinking water for cities located in the region. Due to the deterioration in the water quality, this function is now limited (Tarczyńska et al., 2001). Presently, the reservoir mainly serves as an important recreational area, especially for anglers. It is a typical lowland shallow reservoir, with an area of approximately 2700 ha, an average depth of 3.3 m and a max depth of 11 m. The reservoir is eutrophic, and the chlorophyll *a* concentration during growth seasons reaches a mean value of 30 $\mu g\,dm^{-3}$ and can exceed 150 $\mu g\,dm^{-3}$ during phytoplankton blooms. The dominant species of cyanobacteria in the area is *Microcystis aeruginosa* (Wagner and Zalewski 2000; Izydorczyk et al., 2008b). The analysis of cyanobacterial bloom samples confirmed their highly hepatotoxic character (Tarczyńska et al., 2001; Jurczak et al., 2004; Mankiewicz-Boczek et al., 2006a,b; Izydorczyk et al., 2008a; Gągała et al., 2013). The dominant fish species of the reservoir include roach (*Rutilus rutilus*), bream (*Abramis brama*), ruffe (*Gymnocephalus cernua*), silver bream (*Blicca bjoerkna*), perch (*Perca fluviatilis*), pikeperch (*Stizostedion lucioperca*) and pike (*Esox lucius*) (Frankiewicz and Świerzowski 2004).

2.2. Hydroacoustic measurements

Hydroacoustic measurements were conducted from a boat sailing at a constant speed of approximately 1.5 $m\,s^{-1}$ along 10 predetermined parallel transects (Tr 1-Tr 10) and one transect along the main axis of the reservoir (Tr 11) – Fig. 1. The transects were separated by approximately 500 m, and only segments perpendicular to the main axis of the reservoir were used for the analysis of the fish distribution. Transect 11 was analysed separately for the investigation of the relationship between the fish and cyanobacteria distributions at a resolution of 20 s. Data were collected in July 2013 during bloom occurrence, starting one hour after sunset, when the fish tend to disperse in the open water (Drastík et al., 2009). A SIMRAD EK60 split-beam echo-sounder operating at a frequency 200 kHz was used, with one transducer of 7 degrees beam angle at −3 dB, beaming horizontally. Only during the first run 2 transducers were used, one horizontal and one vertical (operating simultaneously by multiplexer). Since using two transducers was noticeably slowing the data record, and the vertical transducer did not provide much data possible for the analysis (too shallow) we assumed that horizontal beam provides the representative information on fish population and did not use the vertical transducer in further measurements. The recorded range was 50 m, which corresponds to an approximately 6 m depth in the acoustic sampling (Kubecka 1996). The pulse duration was 0.128 ms, and the repetition rate was 5 times per second. The echo-sounder was calibrated 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 in a computer and later processed by the Sonar 5 Pro software (Balk and Lindem 2008). The areal sound backscattering coefficient Sa ($m^2\,ha^{-1}$) (MacLennan et al., 2002) was considered as a proxy of fish biomass (Simmonds and MacLennan 2005; Boswell et al., 2010). The volume numerical fish density estimates were carried out using the echo integration method (Sv/TS scaling) (Balk and Lindem 2008). Single echo detections (SED) after deconvolution (Kubecka 1996) were used as the source of the target strength TS distributions, in dB (MacLennan et al., 2002). Due to the high noise level, thresholds were fixed at −45 dB for the individual targets (40 log R) and −51 dB for the echointegration (20 log R) in accordance with the recommendations of the European and American standards (Parker-Stetter et al., 2009). This corresponds to fish lengths of approximately 6 cm, as determined by the side aspect equation (Love 1969; Frouzova et al., 2005), or 10 cm, as determined from the all aspect equation (Love 1977). The integration interval was set to 20 s for the cyanobacteria–fish relationship studies (resolution of cyanobacteria measurements), 100 m for producing the distribution maps and the total length of each transect for fish numerical density assessment. With horizontal beaming, only volume density estimation is possible. The areal fish density was determined from the multiplication of the volume density by the average lake depth, i.e., 3 m. Because the transects had different lengths, the mean numerical fish density for the whole lake was calculated as an arithmetic mean, weighted by the transect lengths (Simmonds and MacLennan, 2005). The kriging interpolation method included in Surfer software version 8 was used for mapping the fish and cyanobacteria distributions.

2.3. Measurements of phycocyanin fluorescence

The measurements of phycocyanin fluorescence were synchronized in time with the hydroacoustic measurements. They were in situ recorded using a Turner Fluorometer Model 10-AU-005 using the Phycocyanin Optical Kit (P/N: 10-305) including the Cool White Mercury Vapor Lamp, a 630 nm excitation filter and a 660 nm emission filter. The fluorometer was operated in the continuous flow mode, pumping the surface water, which was flowing through a 25 mm cell. During the flow, measurements were taken in the selected intervals (2 min intervals on the first day and 20 s intervals afterwards) and recorded by a data logger. The minimum level of detection was approximately 1000 cells cm^{-3}. To calibrate the measurements for the phycocyanin fluorescence and cyanobacteria biomass, as well as the phytoplankton community structure, 12 subsamples of surface water were collected from the pump during the continuous fluorescence measurements. They were preserved in Lugol's solution and sedimented in the laboratory. Phytoplankton were counted using a Fusch-Rosenthal counting cell. The cyanobacterial biomass (fresh weight) was determined based on the volumetric analysis of cells using geometric approximation. The biomass computed in volume units was transposed to fresh mass (FM), assuming the specific mass of phytoplankton as a unit (=1) (Komarkova et al., 1995). The calibration curve was determined as following:

$$\text{cyanobacterial biomass}\,[\text{mg}\,\text{dm}^{-3}] = 0,6614 \times \text{phycocyanin fluorescence}\,[\text{RAW – relative units}]$$

Due to the shallowness of the reservoir and high level of water mixing, it was assumed that the concentration of cyanobacteria at the surface is representative of the total water column, or at least of the surface layer occupied by fish at night.

2.4. Environmental parameters

Basic physicochemical parameters, such as the temperature, oxygen concentration, pH and conductivity, were measured in situ at the same time as the hydroacoustic survey using the YSI ProODO Digital Professional Series meter with an optical oxygen sensor and WTW Multi 340i meter. These measurements were taken at sta-