# HYDROACOUSTIC ASSESSMENT OF SPATIOTEMPORAL DYNAMICS OF TOXIC CYANOBACTERIUM *MICROCYSTIS*: THE ROLE OF PHYSICAL FACTORS IN BLOOM FORMATION

Ilia Ostrovsky [a], Assaf Sukenik [a], Yosef Z. Yacobi [a], Boris Katsnelson [b], Ernst Uzhanskii [b] Wesley J. Moses [c],

[a] Israel Oceanographic and Limnological Research, Kinneret Limnological Laboratory, Migdal, Israel
[b] Leon H. Charney School of Marine Sciences, University of Haifa, Israel
[c] Naval Research Laboratory, Washington, District of Columbia, USA

Contact author: Ilia Ostrovsky, Israel Oceanographic and Limnological Research, Kinneret Limnological Laboratory, P.O.Box. 447, Migdal 1495001, Israel
Tel: +972-46618916, fax: +972-46724627, email: ostrovsky@ocean.org.il

***Abstract:*** *Toxic cyanobacterial blooms disrupt the functioning of aquatic ecosystems and water use. The main difficulty in monitoring stems from the heterogenic spatial distribution of cyanobacteria. We detected that gas-containing Microcystis colonies are strong acoustic backscatterers at ultrasound frequencies and can be quantified with an echo sounder and an Acoustic Doppler Current Profiler (ADCP). Volume backscattering strength ($S_v$) was measured in Lake Kinneret with Simrad EY60 echo sounder at 120-kHz, and two Teledyne ADCPs - Sentinel V20 (1000 kHz) and Sentinel V50 (500 kHz). The Sv measured with EY60 was calibrated against chlorophyll-a concentration, a proxy for biomass, and then used to quantify the spatial distribution of Microcystis biomass. During hot windless days, a thin surface stratified layer develops, where buoyant cyanobacteria concentrate, absorb solar radiation, and are thus exposed to high temperature and light. This generates optimal conditions for Microcystis growth. Different hydrodynamic processes at various spatial scales play an important role in the formation of surface cyanobacteria patches as seen on satellite images. We demonstrate that acoustic data can be used to detect surface patches of Microcystis that contribute to high cyanobacterial biomass production.*

***Keywords:*** *Echo sounder, ADCP, acoustic remote sensing, cyanobacteria, Microcystis, spatial heterogeneity, surface scum formation, Lake Kinneret.*

## INTRODUCTION

Toxic cyanobacterial blooms have become a common occurrence all around the world [1]. Cyanobacteria, a diverse group of photosynthetic oxygenic microorganisms, possess cellular mechanisms and acclimation capacity to develop dense populations in lakes, water reservoirs and streams, frequently referred to as ‘‘blooms’’. Such blooms may produce toxins, disrupt the functioning of aquatic ecosystems and affect water use.

The heterogenic spatial distribution of cyanobacteria presents a major obstacle in quantifying and studying the dynamics of such blooms. On the vertical scale, these organisms can occupy different strata, whereas horizontally, floating cells and colonies may accumulate at certain locations because of wind and water movements [2]. One of the most common and ubiquitous cyanobacterial genera that frequently bloom in freshwater bodies is *Microcystis* spp. [3]. Gas vesicles (a hollow cellular structure made of proteins) bring the density of a colony to a nearly neutrally buoyant state [3]. Through the production of heavy carbohydrates during photosynthesis and their decomposition in the dark (due to respiration), the density of *Microcystis* cell changes, such that cells migrate down or up depending on light availability [4]. Frequently, a thin layer of cyanobacteria, a scum, is created and may persist for several days. Low turbulence allows buoyant cells to migrate up, while high turbulence causes uniform distribution of cells in the water column [5]. Colonies play an important role in the concentration of *Microcystis* near the water surface since larger colonies have a higher rise velocity and largely contribute to scum formation [6].

Due to the rapidly changing spatial dynamics of buoyant colonies, *Microcystis* population in surface scums cannot be accurately quantified using traditional sampling devices (water samplers, nets) that disrupt the floating scums through physical contact. This problem can be resolved using remote measurement techniques. The presence of echo-contrasting gas bubbles in *small planktonic organisms* allow the use of acoustic signals to study their spatial distribution and vertical migration [7, 8].

In this study, we investigated the possibility of quantifying gas-containing colonies of cyanobacterium *Microcystis* in a subtropical deep lake using different acoustic ultrasonic devices. Then, we calibrated the acoustic volume backscattering strength of cyanobacterium against fluorometrically-measured chlorophyll-*a* (chl-*a*) concentration, a proxy of its biomass. Finally, we studied the spatiotemporal heterogeneity of cyanobacterium and explored the role of physical factors in the formation of its winter-spring bloom in Lake Kinneret (the Sea of Galilee, Israel).

## MATERIALS AND METHODS

The portable scientific Simrad EY60 echo sounder 120 kHz (7° opening angle) and two five-beam Teledyne RD Acoustic Doppler Current Profilers (ADCPs) - Sentinel V50 (500 kHz) and Sentinel V20 (1000 kHz) - were used to study the acoustic backscatter from gas-containing cyanobacterium *Microcystis* in Lake Kinneret in February-March of 2012-2013 and 2017. Special attention was paid to the distribution of *Microcystis* in the upper stratum, where the wind stress and surface waves cause turbulent mixing and thus affect the distribution of buoyant organisms. The ADCPs were moored in peripheral lake areas at depths of 20 m and 10 m. The depth bin length was 0.6 m and 0.3 m for V50 and V20, respectively; 256 individual pings were recorded at 30-minute intervals. The ADCP data

were used for calculating the volume backscattering strength, $S_v$ (dB), from the echo intensity and transducer parameters by using the sonar equation [9, 10].

The EY60 was operated in two modes: (a) the upward oriented transducer was suspended in the water at a depth of 5-8 m and (b) the downwards oriented transducer was floated on the water surface. The pulse width was set at 0.128 ms, and the sampling interval at 0.2 s. The lower threshold for data collection was -100 dB. The data collected with EY60 were processed using a hydroacoustic post-processing software, Sonar 5-Pro [11].

Echo sounder sampling was accompanied by CTD (Conductivity, Temperature, Depth) water column profiling. ADCP measurements were carried out concurrently with continuous measurements of water temperature with two moored thermistor chains. The meteorological data were acquired from Lake Kinneret database (courtesy of Y. Lechinsky and A. Rimmer).

Chl-*a* concentrations were measured fluorometrically [12] in the laboratory within an hour after the samples were collected.

## RESULTS AND DISSCUSSION

We found that gas-containing *Microcystis* colonies are strong acoustic backscatterers at ultrasound frequencies. During the period of intense *Microcystis* bloom, the mean volume backscattering strength, $S_v$ (dB), measured with upward and downward oriented 120 kHz transducer, is closely related to the chl-*a* concentration, which is a good proxy of the phytoplankton concentration (Fig. 1). High correlation ($r > 0.9$) between *Sv* and the logarithm of chl-*a* concentration suggests that the biomass of cyanobacterium can be quantified *in situ* with an echo sounder.

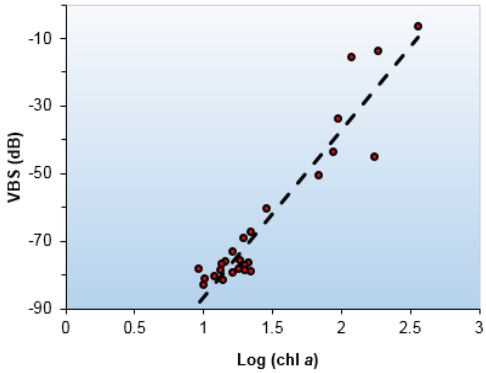


*Fig.1. Relationship between the mean volume backscattering strength (VBS, dB) measured with EY60 and the logarithm of chl-a concentration during the period of Microcystis aeruginosa bloom in Lake Kinneret in February-March of 2012 and 2013.*

Fig. 2 displays the typical depth distribution of $S_v$ of the sound scattering layer (SSL) along a cross section during a windless sunny day within the period of winter *Microcystis* bloom. Microscopic analysis confirmed that *Microcystis* colonies were the predominant objects in the upper part of the water column.

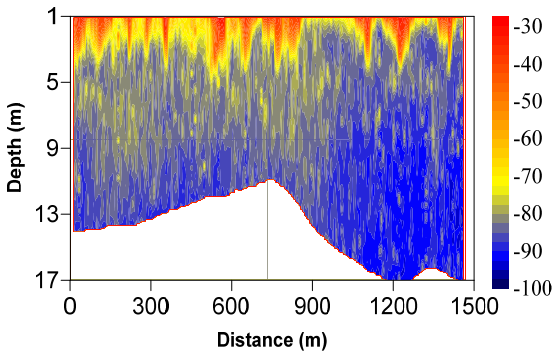


*Fig.2: Echogram of the surface sound scattering layer during Microcystis bloom on a windless sunny day (21/02/2013) in Lake Kinneret. The record was performed with a downward-beaming echo sounder EY60. The colour bar shows the $S_v$ (dB) scale.*

Vertical distribution of cyanobacterium biomass is closely linked with thermal stratification. In winter months, the development of the thin warm surface water layer during sunny low-wind days detaches the deeper colder stratum from the air-water interface. This results in suppression of wind-driven turbulence in lower water mass and promotes buoyant *Microcystis* colonies to rise rapidly to the surface where light and temperature conditions are beneficial for fast growth of cyanobacterium biomass. In early spring, when stratification became permanent, close similarity in the dynamics of the upper sound-scattering cyanobacterium layer and thermal stratification became evident (Fig. 3). Such coherent dynamics between two variables portray strong positive correlation of cyanobacterium biomass with temperature. The variability of thickness of the upper warm stratum is caused by wind-driven internal waves and/or vertical mixing dynamics.

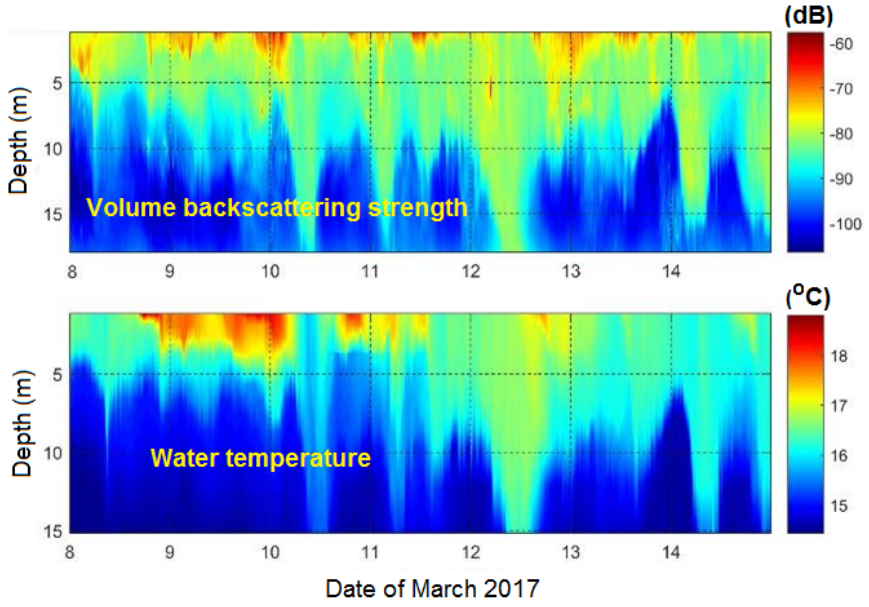


*Fig. 3: Temporal and spatial variability of the upper sound-scattering layer (upper panel) and water temperature (lower panel) in March 2017 during a period of Microcystis bloom. The volume backscattering strength was computed from ADCP installed at 20-m depth. Temperature evolution at station was derived from thermistor-chain profiles.*

Water movement at various spatial scales may largely contribute to the formation of *Microcystis* patches (e.g. Fig. 4). For instance, patches can be produced as a result of internal wave dynamics since waters above an internal wave converge and sink in its trough and upwell and diverge over its crest. The convergence zones accumulate positively buoyant phytoplankton [13]. The presence of internal waves in Lake Kinneret in winter-spring time has been documented based on fluctuations of the near-surface sound scattering layer along cross-sections (Figs. 2) and from the analysis of thermistor chain time-series data (Fig. 3).

The satellite image taken on 11-Mar-2013 (Fig. 4) shows areas of high and low *Microcystis* biomass. The observed large spatial heterogeneity demonstrates the complexity of total biomass estimation in the case of *Microcystis* bloom. Analysis of the spatial distribution of chl-*a* concentration shows that the relatively small areas with high chl-*a* concentrations contribute largely to the total biomass. Surface patches play an important role in the overall cyanobacterium bloom development since the dense *Microcystis* patches effectively absorb solar radiation and thus contribute to further heating of the topmost cyanobacterium layer that creates optimal conditions for high rates of *Microcystis* photosynthesis and biomass growth.

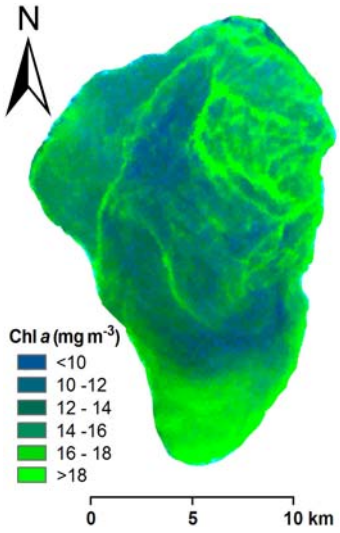


*Fig.4. HICO (Hyperspectral Imager for the Coastal Ocean) image portraying the distribution of chl-a concentrations in Lake Kinneret on March, 11 2013 during the Microcystis aeruginosa bloom.*

*Microcystis* community tends to increase when the stability of stratified water layers increases. The increasing lake stratification due to global warming could be favourable for development of buoyant toxic cyanobacteria blooms. Other factors (e.g. changes in nutrient availability and wind-induced mixing) should be taken into account for accurate forecasting of the effect of global climate change on harmful algal bloom (HAB) development.

## CONSCLUSIONS

The gas-containing *Microcystis* can be detected, mapped, and quantified using a scientific echo sounder and ADCP at ultrasonic frequencies. The suggested acoustic

remote sensing approach allows investigating spatial heterogeneity, colony migration and diurnal and seasonal changes of cyanobacterial abundance and surface scum formation.

During hot calm days in winter and spring, a thin surface layer develops, where buoyant cyanobacteria largely concentrate, absorb solar radiation, and further increase the surface temperature. The formation of surface patches and scums is essential for the production of high *Microcystis* biomass in lakes and reservoirs.

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