



Phytoplankton and turbulence at selected scales

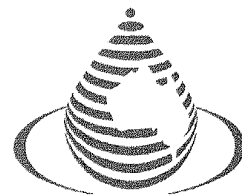
by

Rudi Herbert Regel

Limnology Group
School of Earth and Environmental Sciences
The University of Adelaide

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Summary

Water motion strongly influences phytoplankton access to sunlight and nutrients, which ultimately govern primary production. The motion predominantly takes the form of turbulence. Understanding primary production and the ecology of phytoplankton including harmful algal blooms (HAB) and their control requires an understanding of the relevant physical processes and the scales of their interaction. The interaction between phytoplankton and physical processes are diverse and occur at a range of spatial and temporal scales. The main objective of this thesis is to contribute to the understanding of how turbulence affects phytoplankton in freshwater systems. The major focus is the temporal and spatial scales in phytoplankton dynamics ranging from photochemistry in the surface mixed layer to small-scale shear and growth to intra-seasonal changes in community composition in a lake subject to high disturbances.

A major requirement in studying the relationship between environmental variability and physiological processes is the ability to sample and analyse biological components at appropriate temporal and spatial scales. The reliability of flow cytometry in combination with fluorescent stains (FDA, Sytox) and PAM fluorometry were tested to detect the response of phytoplankton to environmental variability. Staining protocols with FDA and Sytox were optimised for their ability to quantify cell metabolic activity and viability, respectively. 'Activity' and 'viability' states were established for 3 phytoplankton species subjected to heat treatment, nutrient limitation and replenishment and copper toxicity.

PAM fluorometry was used to investigate the influence of light intensity, duration of exposure and nutrient status on phytoplankton photo-physiology. Measurements of photochemical quenching, maximum change quantum yield of photosystem 2 (F_v/F_m) and effective absorption cross-section were made on both laboratory cultures and field populations. Each characteristic was found to be sensitive to light and nutrients for the different species examined. In particular, the magnitude of F_v/F_m was dependent upon light intensity and dose and provided a feature of phytoplankton that could be traced to assess the impacts of turbulent mixing and thermal stratification on cell entrainment and distribution. An experiment in the Myponga Reservoir (South Australia) demonstrated that F_v/F_m in combination with the other photo-physiology characteristics enables the calculation of photosynthesis with greater temporal and spatial resolution compared with traditional methods.

The interplay between wind mixing, thermal stratification and cell motility on phytoplankton distribution was investigated in the Torrens Lake (South Australia) with measurements carried out on the dinoflagellate, *Peridinium cinctum*. *In situ* profiles of chlorophyll fluorescence and cell counts, revealed the vertical migration of *P. cinctum*, ascending in the morning and descending in the afternoon. Swimming velocity reached $2.35 \times 10^{-4} \text{ m s}^{-1}$. Cell distribution was a function of wind speed and swimming velocity and reflected the entrainment model of Humphries and Imberger (1982). When $\psi < 1$, distribution was dominated by wind speed and when $\psi > 1$, distribution was dominated by swimming velocity. Measurements of F_v/F_m of *P. cinctum* cells through time and depth revealed minimal photo-inhibition although cells actively avoided high irradiance. A depression in F_v/F_m was observed in surface samples however, this recovered to initial values later in the day. A comparison between modeled daily photosynthetic rates of a migrating ($2,574.1 \text{ mg O}_2 \text{ m}^{-2}$) and a homogeneous population ($3,120 \text{ mg O}_2 \text{ m}^{-2}$) revealed that migration would not increase photosynthetic rates within the Torrens Lake. In addition to

phototaxis, it was postulated that dinoflagellates move deeper in the water column to avoid small-scale shear stress generated by turbulence in the surface mixed layer.

The maximum quantum yield (F_v/F_m) was also used to determine the light history of *Microcystis aeruginosa* colonies in the Torrens Lake. As insolation increased the lake stratified and colonies displayed a depression in F_v/F_m , which became less severe with depth. In the afternoon, wind speed increased entraining colonies and disrupting the discrete depth variable F_v/F_m response. The point where the photochemical response became homogenized allowed the determination of the shear velocity necessary to entrain colonies ($u^* = 0.003 \text{ m s}^{-1}$). This fits the entrainment model proposed by Humphries and Lyne (1988). Rates of F_v/F_m depression were light intensity dependent whereas recovery was dependent upon light dose. A model is presented which examined the influence of five mixing scenarios on the F_v/F_m of *M. aeruginosa*.

Field experiments examined the current flow around several artificial mixing devices including a surface mechanical mixer/draft tube system in the Myponga Reservoir (South Australia) and bubble plume aerators and aspirators within the Torrens Lake. An acoustic Doppler velocimeter was used to measure current velocity, which also enabled the calculation of turbulent intensity, shear velocity and the turbulent kinetic energy dissipation rate (determined using spectral analysis). Turbulent intensities, shear velocities, and turbulent kinetic energy dissipation rates were found to be high around the mixing devices relative to turbulence generated by wind. Turbulent kinetic energy dissipation rates ranged from $5 \times 10^{-7} \text{ m}^2 \text{ s}^{-3}$ to $3.4 \times 10^{-4} \text{ m}^2 \text{ s}^{-3}$, while shear velocity in the immediate vicinity of the devices was of a magnitude ($>5.9 \times 10^{-3} \text{ m s}^{-1}$) to entrain most phytoplankton. Measurements of metabolic activity and viability of phytoplankton above and below the Myponga Reservoir surface mixer/ draft tube revealed that transport and subsequent exposure to small-scale shear had no impact on the population. Current velocity measurements enable the zone of influence of artificial mixing devices to be determined which assists in the assessment of their performance.

A vertically oscillating grid-tank system was used to simulate observed turbulence levels around the artificial mixing devices. Turbulent intensity increased with an increase in oscillation frequency (1-5 Hz). Grid-generated turbulence affected *Microcystis aeruginosa* metabolic activity, viability and growth. At 4 Hz metabolic activity, viability and growth decreased which was most evident after 96 hours. Small-scale shear was postulated to be insignificant in *M. aeruginosa* ecology but may have a role in regulating colony size and may contribute to bloom decline under stressed conditions.

A field study examined the spatial and temporal heterogeneity in phytoplankton community composition within the lower Torrens Lake. Twenty-eight genera were identified during the 5-month sampling period representing phytoplankton with C-S-R (Grime, 1979) traits. Although, no single factor could be identified to affect species succession, summer rainfall events acted as a major disturbance by flushing and diluting the populations and reintroducing nutrients. Often C-S-R species coexisted in the lake verifying the intermediate disturbance hypothesis of Connell (1978). It is difficult to predict and manage phytoplankton community composition in small-shallow urban lakes such as the Torrens Lake due to the unpredictability of summer rainfall and the short time scale of events such as storm water runoff from the surrounding catchment.