Phytoplankton and turbulence at selected scales

by

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Contents

Contents.......... iii
List of figures.......... ix
List of tables.......... xiii
Summary.......... xiv
Declaration.......... xvi
Acknowledgements.......... xvii

Chapter 1. Introduction.......... 1

1.1 A question of scale.......... 1
1.2 Limnological progress.......... 3
1.3 Biological techniques.......... 4
1.3.1 Flow cytometry and fluorescent probes.......... 4
1.3.2 Fluorometry, photosynthesis and chlorophyll fluorescence.......... 6
1.4 Turbulence.......... 8
1.4.1 Turbulence theory and energy spectrum.......... 9
1.4.2 Turbulence generation.......... 11
1.4.3 Turbulence length scales.......... 11
1.5 Phytoplankton- turbulence relations.......... 14
1.5.1 Large-scale turbulence, phytoplankton entrainment- photosynthesis.......... 14
1.5.2 Small-scale turbulence and phytoplankton.......... 17
1.6 Cyanobacteria, water quality and artificial mixing.......... 20
1.7 Lake management and project study sites.......... 22

Chapter 2. Testing the procedural protocols.......... 34

2.1 Introduction.......... 34
2.1.1 Fluorescent probes and flow cytometry.......... 35
2.1.2 Fluorometry and variable fluorescence.......... 37
2.1.3 Objectives.......... 37
2.2 Experimental designs and methods.......... 38
2.2.1 Phytoplankton cultures.......... 38
2.2.2 Probe assay development.......... 39
2.2.2.1 Flow cytometry.......... 39
2.2.2.2 Fluorescein diacetate staining and esterase activity.......... 39
2.2.2.3 Sytox staining and cell viability.......... 40
2.2.3 Microscopy.......... 41
2.2.4 Testing probe assays.......... 41
2.2.4.1 Estimation of the number of viable & nonviable cells in a population.......... 41
2.2.4.2 Detection of nutrient limitation and repletion.......... 42
2.2.4.3 Detection of copper toxicity.......... 42
2.2.5 PAM fluorometry and phytoplankton photo-physiology.......... 43
2.2.5.1 Photochemical quenching.......... 43
2.2.5.2 Maximum quantum yield of photosystem 2.......... 45
2.2.5.3 Effective absorption cross-section.......... 46

2.2.5.4 Photosynthetic rate.. 46
2.2.6 Influence of light intensity and nutrients on photo-physiology................ 47
2.2.7 F_v/F_m depression and recovery kinetics.. 47
2.2.8 Measurement and modeling of photosynthesis in a natural population....... 48
2.2.9 Statistical analysis.. 50
2.3 Results.. 51
2.3.1 Optimisation of FDA staining... 51
2.3.2 Optimisation of Sytox staining... 52
2.3.3 Estimation of the number of viable & nonviable cells in a population........ 53
2.3.4 Detection of nutrient limitation and repletion.................................. 53
2.3.5 Detection of copper toxicity... 55
2.3.6 Influence of light intensity and nutrients on photo-physiology................ 56
2.3.7 F_v/F_m depression and recovery kinetics.. 57
2.3.8 Measurement and modeling of photosynthesis in a natural population....... 58
2.4 Discussion.. 59
2.4.1 Fluorescent probes and flow cytometry.. 59
2.4.2 Fluorometry... 62
2.4.3 Conclusions... 66

Chapter 3. Vertical migration, entrainment and photosynthesis of the freshwater dinoflagellates, *Peridinium cinctum* in a shallow urban lake............................ 87

3.1 Introduction.. 87
3.2 Methods.. 89
3.2.1 Site description.. 89
3.2.2 Field experiment... 89
3.2.2.1 Shear velocity, *P. cinctum* swimming velocity and entrainment........... 90
3.2.2.2 F_v/F_m photo-physiology measurements.. 91
3.2.2.3 Integral photosynthesis.. 92
3.2.3 Laboratory experiments.. 92
3.2.4 Photo-physiology measurements... 93
3.3 Results.. 94
3.3.1 Field experiment... 94
3.3.1.1 Meteorology and thermal stratification...................................... 94
3.3.1.2 Entrainment versus disentrainment.. 95
3.3.1.2.1 Chlorophyll fluorescence.. 95
3.3.1.2.2 *Peridinium cinctum* cell number... 96
3.3.1.2.3 Maximum quantum yield, F_v/F_m... 96
3.3.1.2.3.1 Bottle F_v/F_m.. 97
3.3.1.2.3.2 Lake F_v/F_m.. 97
3.3.1.2.3.3 Ratios of bottle to lake F_v/F_m.. 98
3.3.1.3 Entrainment criterion.. 98
3.3.1.4 Depth-time integral of photosynthesis... 99
3.3.2 Laboratory experiments.. 99
3.4 Discussion.. 100

Chapter 4. Changes in the photochemistry of *M. aeruginosa* in response to light and mixing........ 116

4.1 Introduction........ 116
4.2 Methods........ 119
4.2.1 Field measurements........ 119
4.2.1.1 Field site description........ 119
4.2.1.2 Evidence if photoinhibition in natural a populations........ 119
4.2.1.3 Measurement of maximum quantum yield, F_v/F_m........ 120
4.2.1.4 Meteorological station instrumentation........ 120
4.2.1.5 Calculating the rate of inhibition and recovery........ 121
4.2.2 Modeling........ 121
4.2.2.1 Model validation........ 121
4.2.2.2 Modeling photoinhibition........ 122
4.2.2.2.1 Scenario 1 A stratified water body with no motion and no vertical migration........ 122
4.2.2.2.2 Scenario 2 A cell circulating within the surface mixed layer........ 122
4.2.2.2.3 Scenario 3 A nocturnally mixed water column, which stratifies at dawn........ 123
4.2.2.2.4 Scenario 4 Langmuir circulation........ 123
4.2.2.2.5 Scenario 5 A simulation of turbulent water motion........ 124
4.3 Results........ 125
4.3.1 Field experiments........ 125
4.3.1.1 Evidence of depressed F_v/F_m in natural populations........ 125
4.3.1.2 Entrainment of *M. aeruginosa* colonies........ 125
4.3.1.3 The rate of depression and recovery of F_v/F_m in *M. aeruginosa*........ 126
4.3.2 Modeling........ 128
4.3.2.1 Model validation........ 128
4.3.2.2 Modeling photoinhibition........ 129
4.3.2.2.1 Scenario 1 A stratified water body with no motion........ 129
4.3.2.2.2 Scenario 2 A cell circulating within the surface mixed layer........ 129
4.3.2.2.3 Scenario 3 A nocturnally mixed water column........ 130
4.3.2.2.4 Scenario 4 Langmuir circulation........ 130
4.3.2.2.5 Scenario 5 A simulation of turbulent water motion........ 132
4.4 Discussion........ 133
4.4.1 Evidence of depressed F_v/F_m in natural populations........ 133
4.4.2 Simulation of photoinhibition in natural populations........ 133
4.4.3 Entrainment of *M. aeruginosa* colonies........ 134
4.4.4 Size distribution of colonies and its impact on photoinhibition........ 135
4.4.5 The scale of light penetration, turbulent transport and photoinhibition........ 136

Chapter 5. The measurement of flow and small-scale turbulence around artificial mixing systems in a deep reservoir and shallow lake........ 152

5.1 Introduction........ 152
5.2 Materials and methods........ 156
5.2.1 Field sites and artificial mixing systems........ 156
5.2.2 Myponga Reservoir experiments........ 156
5.2.2.1 Surface mixer flow characteristics........ 156

5.2.2.2 Phytoplankton transport through draft tube.................................... 157
5.2.2.3 Phytoplankton adjacent to and 70 m from surface mixer.................... 157
5.2.2.4 Phytoplankton and flow cytometry analysis.................................... 158
5.2.2.4.1 Metabolic activity and FDA staining technique.................... 158
5.2.2.4.2 Cell viability and Sytox staining technique.......................... 159
5.2.2.4.3 Flow cytometry.. 159
5.2.2.4.4 Statistical analysis of phytoplankton measurements................ 159
5.2.3 Torrens Lake experiments.. 160
5.2.3.1 Bubble plume aerator... 160
5.2.3.2 Submerged aspirator and high volume surface aerator..................... 160
5.2.3.3 Wind versus mixer generated circulation...................................... 161
5.2.4 Flow velocity and turbulence measurements and analysis..................... 161
5.2.5 Wind generated turbulent kinetic energy dissipation rates..................... 163
5.3 Results.. 164
5.3.1 Turbulence analysis.. 164
5.3.2 Myponga Reservoir experiments... 165
5.3.2.1 Surface mixer flow characteristics... 165
5.3.2.1.1 Meteorological conditions.. 165
5.3.2.1.2 Flow velocities below the mixer... 165
5.3.2.1.3 Turbulent intensity, shear velocity and turbulent kinetic energy dissipation.. 165
5.3.2.2 Phytoplankton transport through mixer and draft tube...................... 166
5.3.2.3 Phytoplankton adjacent to and 70 m from surface mixer.................... 166
5.3.3 Torrens Lake experiments.. 168
5.3.3.1 Bubble plume aerator... 168
5.3.3.1.1 Meteorological conditions.. 168
5.3.3.1.2 Temperature and flow velocities.. 168
5.3.3.1.3 Turbulent intensity, shear velocity and turbulent kinetic energy dissipation.. 169
5.3.3.2 Submerged aspirator.. 170
5.3.3.2.1 Meteorological conditions.. 170
5.3.3.2.2 Temperature and velocity profiles.. 170
5.3.3.2.3 Turbulent intensity, shear velocity and turbulent kinetic energy dissipation.. 172
5.3.3.3 High volume surface aerator.. 173
5.3.3.3.1 Meteorological conditions.. 173
5.3.3.3.2 Temperature and velocities... 174
5.3.3.3.3 Turbulent intensity, shear velocity and turbulent kinetic energy dissipation.. 175
5.3.4 Wind-generated turbulence... 176
5.4 Discussion.. 176
5.4.1 Measurement of turbulence... 177
5.4.2 Myponga mixer flow and turbulence analysis.................................. 178
5.4.3 Torrens Lake bubble plume aerator flow and turbulence analysis........... 180
5.4.4 Torrens Lake aspirator and aerator flow and turbulence analysis............ 181
5.4.5 Comparisons between artificial and naturally generated turbulence.......... 182
5.4.6 Conclusions.. 185

Chapter 6. The influence of small-scale turbulence on *Microcystis aeruginosa*....... 216

6.1 Introduction.. 216
6.2 Methods.. 218
6.2.1 Test organism and experimental design.. 218
6.2.2 Vertically oscillating grid system... 219
6.2.3 Flow and turbulence measurement... 220
6.2.4 Statistical analysis.. 221
6.3 Results... 221
6.3.1 Turbulent intensity.... 221
6.3.2 Responses of *M. aeruginosa*.. 221
6.3.2.1 Cell esterase activity... 222
6.3.2.2 Cell viability.. 222
6.3.2.3 Cell division... 223
6.3.2.4 Cell chlorophyll fluorescence.. 223
6.3.2.5 Cell size and granularity... 223
6.4 Discussion.. 224

Chapter 7. Spatial and temporal heterogeneity of phytoplankton in a shallow urban lake.. 239

7.1 Introduction.. 239
7.2 Materials and methods... 242
7.2.1 The Torrens Lake and study sites.. 242
7.2.2 The monitoring program... 244
7.2.3 Statistical analysis.. 245
7.3 Results.. 246
7.3.1 Torrens Lake limnological characteristics.. 246
7.3.1.1 Hydrological and meteorological conditions..................................... 246
7.3.1.2 Water column stability... 247
7.3.1.3 Nutrients... 248
7.3.1.4 Dissolved oxygen.. 249
7.3.1.5 Water clarity... 249
7.3.1.6 Ratio of euphotic to mixed depth.. 249
7.3.2 General description of phytoplankton... 250
7.3.2.1 Chlorophyll *a* concentration.. 250
7.3.2.2 Cell volume... 250
7.3.2.3 Phytoplankton species composition... 250
7.3.3 Phytoplankton richness and diversity.. 255
7.3.4 Phytoplankton community change... 256
7.3.5 Sample date groupings- identification of major change in phytoplankton.... 257
7.3.6 Relationship between phytoplankton composition and major environmental changes.. 260
7.4 Discussion... 261
7.4.1 Allogenic factors.. 261
7.4.2 Phytoplankton composition and diversity.. 263
7.4.3 Effects of disturbances on phytoplankton... 265
7.4.4 Implications for phytoplankton control and monitoring....................... 266
7.4.5 Conclusions.. 267

Chapter 8. General summary and discussion.. 300

8.1 Phytoplankton and turbulence... 300
8.2 Biological techniques and field studies.. 300
8.3 Phytoplankton entrainment and implications... 305
8.4 Turbulent intensity and phytoplankton.. 306
8.5 Lake management.. 307

Bibliography.. 309

Appendix 1.. 327

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 x 10^{-4} 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 mg O_2 m^{-2}) and a homogeneous population (3,120 mg O_2 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 ($u^* = 0.003$ 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 5×10^{-7} m^2 s^{-3} to 3.4×10^{-4} m^2 s^{-3}, while shear velocity in the immediate vicinity of the devices was of a magnitude ($>5.9 \times 10^{-3}$ 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.