Enhancing harvestable algal biomass production in wastewater treatment high rate algal ponds by recycling

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Abstract

High Rate Algal Ponds (HRAPs) are an efficient and cost-effective system for wastewater treatment and produce algal biomass which could be converted to biofuels. However, little research has been conducted to improve harvestable biomass production from these ponds. Laboratory and small-scale outdoor research reported in the literature indicates that selective biomass recycling is partially effective at controlling algal species in HRAP. This, therefore, offers the potential to select and maintain a rapidly settleable algal species. To date, algal species control of similarly sized, co-occurring algae has not been demonstrated in wastewater treatment HRAPs. Furthermore, the influence of algal recycling on biomass harvest efficiency, harvestable biomass productivity, net biomass energy yield and the growth of the dominant algal species in the HRAPs have never previously been investigated. The main hypothesis of this Ph.D. was: 'Recycling a portion of gravity harvested biomass ('recycling') back into the HRAP improves harvestable biomass production'. To test this, a series of experiments was conducted using pilot-scale wastewater treatment HRAPs, outdoor mesocosms and laboratory microcosms. Firstly, the influence of recycling on species dominance and biomass harvest efficiency was investigated using two identical pilot-scale HRAPs over two years. This pilot-scale study showed that recycling promoted the dominance of a rapidly settling colonial alga, *Pediastrum boryanum,* and maintained its dominance over the two year experimental period. Moreover, *P. boryanum* dominance was relatively fast to establish and was then stable and sustainable between seasons. The higher dominance of *P. boryanum* in the HRAP with recycling improved biomass harvest efficiency by gravity sedimentation from ~60% in the control HRAP without recycling to 85%. Unexpectedly, recycling also improved the 'in-pond' biomass productivity by 20%. The combination of the increased biomass productivity of the HRAP and the increased biomass harvestability with recycling improved the 'harvestable biomass productivity' by 58%. Overall, recycling increased the net biomass energy yield by 66% through the combined improvements in biomass productivity, harvest efficiency and a small increase in algal biomass energy content. To determine the reproducibility of these findings and investigate the mechanisms responsible, twelve outdoor mesocosms were studied. This mesocosm research repeatedly confirmed that recycling can establish *P. boryanum* dominance, and improve biomass productivity and settleability. Settleability was not only found to be improved by recycling the 'solid' fraction of the harvested

biomass but also by recycling of the 'liquid' fraction, potentially indicating the presence of extracellular polymeric substances. Several possible mechanisms to explain the increase in biomass productivity were identified. However, after review all but two were discounted: (*i*) the mean cell residence time (MCRT) was extended thereby increasing the algal concentration and thus allowing better utilization of incident sunlight; and (*ii*) the relative proportion of algal growth stages (which may have different net growth rates) was shifted, resulting in an increase in the net growth rate of the algal culture. To investigate these mechanisms further, the life-cycle of *P. boryanum* was studied in detail and showed, for the first time in the literature, that its net growth rate does indeed vary between the three life-cycle stages ('growth' > 'juvenile' > 'reproductive'). Given that the mesocosm studies in Chapter 4 showed that recycling increased the number of growth colonies by ~2-fold and juvenile colonies by ~4-fold then it is proposed that mechanism (*ii*) does appear to be viable. This Ph.D. work has demonstrated that recycling a portion of gravity harvested biomass could be a simple and practical method to enhance biomass productivity, harvest efficiency and energy content, which contribute to achieve higher 'harvestable biomass productivity' and 'energy yield' in wastewater treatment high rate algal ponds.

Acknowledgement

First to my supervisors Professor Andy Shilton at Massey University and Dr Rupert Craggs at NIWA (National Institute of Water and Atmospheric Research, Ltd) for their help, guidance and motivation throughout my research. Their support during my Ph.D. and all the valuable and critical comments on the research work particularly on a number of journal papers is greatly appreciated.

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Thanks must also go to the students from Europe for their valuable help during my outdoor experimental work conducted in the Ruakura HRAP research facility. In particular I wish to thank Mr Valerio Montemezzani from Italy, Mr Andy McDonald from U.S.A, Mr Tim Walles from Netherland, Mr TayFun Tastic and Mr Lukas Seibold both from Germany.

Lastly I would like to think my family for their patience, love and support throughout my years as a Ph.D. student.

Table of contents

Structure of the thesis

The chapters of this Ph.D. thesis are presented as a series of scientific journal papers. These papers have either been accepted for publication or submitted for review. Consequently there was some repetition in the paper introductions and methods sections. In order to reduce this repetition in the thesis, the introduction of the chapters has been shortened (particularly Chapters 3, 4 and 5). The chapters have also had some minor editing to improve clarity and consistency. A preface is included for each of these chapters to help link the chapters together and illustrate how each of these chapters contributes to investigate the objectives of this thesis. Some formatting changes have been made to ensure consistent style within the thesis. For example, the labels for Figures and Tables have been modified to include the chapter number (e.g. Figure 2 in the third paper was changed to Figure 3.2 in Chapter 3). Where the published papers refer to other papers within the thesis, these references have been changed to the relevant chapter within the thesis.

The structure of this thesis complies with Massey University guidelines given in the Doctoral Handbook, 2011.

List of papers and contribution

A list of the chapters and relevant publications is given below.

Chapter 1

Park, J.B.K., Craggs, R.J., Shilton, A.N. (2011). Wastewater treatment high rate algal ponds for biofuel production. Bioresource Technology 102 (1):35-42. (This publication have been cited 170 times according to Scopus by December 19th, 2013).

Chapter 2

Park, J.B.K., Craggs, R.J., Shilton, A.N. (2011). Recycling algae to improve species control and harvest efficiency from a high rate algal pond. Water Research 45 (20):6637-6649. (This publication have been cited 13 times according to Scopus by December 19th, 2013).

Chapter 3

Park, J.B.K., Craggs, R.J., Shilton, A.N. (2013). Enhancing biomass energy yield from pilot-scale high rate algal ponds with recycling. Water Research. 47 (13): 4422-4432.

Chapter 4

Park, J.B.K., Craggs, R.J., Shilton, A.N. (2013). Investigating why recycling gravity harvested algae increases harvestability and productivity in high rate algal ponds. Water Research. Water Research 47 (14): 4904-4917.

Chapter 5

Park, J.B.K., Craggs, R.J., Shilton, A.N. Growth, reproduction and life-cycle of the wastewater treatment High Rate Algal Pond alga, *Pediastrum boryanum*. Submitted to Water Research.

All the research that these papers are based on was conducted during my Ph.D. period. While the papers were completed with advice and editing from my supervisors, Professor Andy Shilton and Dr Rupert Craggs, I designed the experiments, conducted all experimental work, analysed the results and led all the papers as the first corresponding author. My contribution to jointly authored chapters was clearly documented the end of each thesis chapter (DRC 16) signed by both the principal supervisor (Professor Andy Shilton) and myself.