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Removing Constraints on the Biomass Production of Freshwater Macroalgae by Manipulating Water Exchange to Manage Nutrient Flux

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Abstract

Freshwater macroalgae represent a largely overlooked group of phototrophic organisms that could play an important role within an industrial ecology context in both utilising waste nutrients and water and supplying biomass for animal feeds and renewable chemicals and fuels. This study used water from the intensive aquaculture of freshwater fish (Barramundi) to examine how the biomass production rate and protein content of the freshwater macroalga *Oedogonium* responds to increasing the flux of nutrients and carbon, by either increasing water exchange rates or through the addition of supplementary nitrogen and CO_2. Biomass production rates were highest at low flow rates (0.1–1 vol.day^{-1}) using raw pond water. The addition of CO_2 to cultures increased biomass production rates by between 2 and 25% with this effect strongest at low water exchange rates. Paradoxically, the addition of nitrogen to cultures decreased productivity, especially at low water exchange rates. The optimal culture of *Oedogonium* occurred at flow rates of between 0.5–1 vol.day^{-1}, where uptake rates peaked at 1.09 g.m^{-2}.day^{-1} for nitrogen and 0.13 g.m^{-2}.day^{-1} for phosphorous. At these flow rates *Oedogonium* biomass had uptake efficiencies of 75.2% for nitrogen and 22.1% for phosphorous. In this study a nitrogen flux of 1.45 g.m^{-2}.day^{-1} and a phosphorous flux of 0.6 g.m^{-2}.day^{-1} was the minimum required to maintain the growth of *Oedogonium* at 16–17 g DW.m^{-2}.day^{-1} and a crude protein content of 25%. A simple model of minimum inputs shows that for every gram of dry weight biomass production (g DW.m^{-2}.day^{-1}), *Oedogonium* requires 0.09 g.m^{-2}.day^{-1} of nitrogen and 0.04 g.m^{-2}.day^{-1} of phosphorous to maintain growth without nutrient limitation whilst simultaneously maintaining a high-nutrient uptake rate and efficiency. As such the integrated culture of freshwater macroalgae with aquaculture for the purposes of nutrient recovery is a feasible solution for the bioremediation of wastewater and the supply of a protein resource.

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Introduction

The production of macroalgal biomass is a developing component of clean technologies for the remediation of wastewater and carbon dioxide within an integrated closed-loop cycle often referred to as industrial ecology [1,2]. The ultimate aim of industrial ecology is to replicate the efficiencies observed in biological systems, where all ecosystem resources are recycled and the waste of one species becomes the food of another [1]. Using this framework, industrial ecology is primarily concerned with shifting industrial processes from linear systems, in which resources move through a system to become waste, to a closed-loop system where wastes become valued as an input for the next production process. A major part of this process is the integration of production systems so that waste products can be easily accessed either as a raw material or as an energy carrier, with the emphasis on processes and practices that reduce greenhouse gas emissions and related environmental impacts of waste streams [3]. On a global scale one of the largest and most consistent sources of industrial waste is nutrients – nitrogen and phosphorous. A large proportion of this waste is created as a by-product of intensive animal agriculture [4]. Globally, nitrogen and phosphorous waste now exceed 138 Tg.y^{-1} and 11 Tg.y^{-1} respectively [5]. These waste nutrients are currently seen as a liability and are either lost to the atmosphere through denitrification or leached into the local environment where nitrogen enrichment and eutrophication problems can occur with global scale impacts [6–12]. However, these excess nutrients need not be relegated to waste but rather could be recycled and utilised as an input resource for the large-scale cultivation of phototrophic organisms, themselves to be recycled again as bioproducts [13–15]. Inorganic nitrogen in particular is the primary limiting nutrient for the production of algae and as such this waste nitrogen could be an ideal resource for the large-scale production of algal biomass [16]. The cultivation and subsequent on-site use of macroalgal biomass at sites with high-nutrient waste streams, such as intensive livestock production, can close the loop between waste production, waste capture and re-use. The on-site use of cultured biomass has the additional benefit of reducing the energy and transportation costs associated

with either bringing animal feeds to the farm or transporting algal biomass away.

Generally, the production of macroalgal biomass is highest when cultures are provided with a constant supply of nutrients-rich water [17–20]. In flow-through systems, nutrient supply (or nutrient flux as g nutrients m^{-2} day^{-1}) can be manipulated by

Marine and Aquaculture Research Facility at James Cook University. This research complied with all Australian laws.

This study was undertaken on private land owned by Good Fortune Bay Fisheries LTD. Permission to use this land was granted by the farm manager, Rod Pelling. No other permission was needed to use this land or perform our experiment.