Aquaculture Benefits of Macroalgae for Green energy Production and Climate change Mitigation

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Abstract— It is an established fact that climate change caused by human-induced concentrations of greenhouse gases (GHG), especially CO_2 emissions, are increasing in the earth's atmosphere and is one of the greatest challenges the world is currently facing. Algae play significant roles in normal functioning of the atmospheric environment and are important candidates for climate change mitigation. Macroalgae (over 20 commercial seaweed species) are the second most cultured species of aquatic organisms after finfish. More than 92 % of the world's macroalgae production comes from mariculture. Macroalgae have a higher photosynthetic efficacy (6 – 8 %) than that of terrestrial plants (1.8 – 2.2 %). An investigation into seaweed as a food source for the South African abalone (*Haliotis midae* L.) has led to an increased knowledge of its fisheries and aquaculture conditions. *Ulva* spp are grown on a large scale in paddle wheel ponds and is currently South Africa's largest aquaculture product. Its growth rate, ease of harvesting, resistance to contamination by other algal species and minimal production loss make it preferable to microalgae and to other macroalgae for large scale renewable energy production and CO_2 capturing systems. Of all macroalgae, *Ulva* spp are exciting prospects in terms of energy efficiency. Findings have further revealed that biotransformation of *Ulva* to Liquefied Petroleum Gas (LPG) is viable. Large scale aquaculture production of *Ulva* spp is occurring in South Africa and biotransformation to LPG is possible and economically feasible with additional benefits from farming activities including bioremediation, ocean de-acidification, mineral-rich plant stimulants, and the capturing of atmospheric and dissolved CO_2 during growth to assist in climate change mitigation.

Index Terms— Aquaculture, biogas, climate change, CO_2, green energy, macroalgae, South Africa, *Ulva*

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INTRODUCTION

The Earth's radiative energy balance is undergoing change due to the increase in greenhouse gases, primarily CO_2 from fossil fuel combustion, and from anthropogenic aerosols [1]. The long term trend of increasing atmospheric CO_2 has become a focal point in current research across atmospheric, terrestrial, and marine science disciplines. An evolved understanding of how our current global climate is being and will be influenced by continuing increases in CO_2 emissions and subsequent global warming, is required to predict how climate change will impact our livelihood and the future health of ecosystem integrity. In response, several developed and developing nations like the EU, USA, Canada, Brazil, Argentina, Colombia, China, New Zealand and Japan have incorporated biofuel targets into their renewable energy policies in recent years [2]. Meanwhile in Africa, South Africa was one of the very first countries to provide the necessary political will and desire to explore opportunities for a green economy, through the National Green Economy summit in 2010 [3]. South Africa emits approximately 400 million tons of CO_2 annually, ranks among the 20 highest contributors to CO_2 emissions overall, and produces approximately 2 % of global greenhouse gas (GHG) emissions, yet it has only 0.7 % of the world's population, and produces 0.9 % of the world GDP [4] [5]. According to the Intergovernmental Panel on Climate Change (IPCC) atmospheric carbon may increase to 20 billion tons/year by 2100, up from 7.4 billion tons/year in 1997; concentrations of CO_2 in the earth's atmosphere may double by the middle of the 21st century with deleterious environmental effects [6].

Biomass energy is the conversion of biomass into useful forms of energy such as electricity, heat, and liquid fuels [7]. Macroalgae or seaweeds, undergo CO_2 fixation to attain a high biomass production, and may assist in sequestering atmospheric sources of CO_2. Of all macroalgae in South Africa, the algae *Ulva* spp are one of the most promising prospects from an energy point of view. *Ulva* spp are grown on a large scale, and are currently South Africa's largest aquaculture product [8] [9] [10] [11].

Macroalgae are able to grow in varying conditions, both in fresh or salt-water bodies, and are tolerant of a diverse range of pH conditions [12]. There are about 36000 species of algae, and most species are exploited from the wild as the technology for their propagation is yet to be fully developed [13] [14] [15], although significant strides have been made more recently. Macroalgae are capable of producing more biomass per square meter than any fast growing terrestrial plant and are the second most cultured species of aquatic organisms after finfish [16] [17]. In the last 50 years, about 100 macroalgae species have been commercially cultivated from the genera *Gracilaria*, *Euchema*, *Laminaria*, *Undaria*, *Ulva*, *Chondrus*, *Porphyra*, *Palmaria* and *Monostroma* [18] [19] [20] [10] [21] [22] [23] [24] . Currently over 92 % of the world's macroalgae production comes from aquaculture species [25] [26] [24]. Macroalgae aquaculture in South Africa started as an off shoot of the abalone (*Haliotis midae* L) farming industry [27]. Since its inception in the 1990s, abalone aquaculture in South Africa has developed rapidly and the country is currently the second largest producer outside Asia [28] [27]. This rapid development was partly achieved due to demand being driven by the decline of South African abalone fisheries due to poaching. By 2006 several South African seaweed concession areas had harvested up to 99 % of their MSY [27]. This lead the industry to explore alternative abalone feed. One of the alternatives proposed were seaweeds cultivated in aquaculture effluent [29]. Since then over 2000 tons of *Ulva* spp. were cultivated as feed. Researchers performed a SWOT analysis of the seaweed cultivation industry and stated that *Ulva* product diversification is needed to increase its potential in South Africa [9]. The objective of this work was to investigate the potential for large scale anaerobic digestion of *Ulva* spp to produce methane gas from a readily available aquaculture product. If the large scale production of biomethane proved environmentally and economically feasible and sustainable, it could serve as an alternative to the dwindling oil supply and help mitigate global CO_2 emissions.

MATERIALS AND METHODS

Biomass Production

Macroalgae production experiments were carried out during winter at Benguela Abalone Group on the West Coast of South Africa in four 32 m X 8 m (180 m^3) concrete paddle ponds, filled to approximately 0.55 m depth with unfiltered seawater on a flow through system. Ponds received 2 volume exchanges per day. The set up were characterized as follows:

- 0: base pond with standard seawater (control)
- 1 X nutrients added to improve growth (single fertilizer ratio)
- 2 X nutrients added to improve growth (double fertilizer ratio)
- 3 X nutrients added to improve growth (triple fertilizer ratio)
- 4 X nutrients added to improve growth (quadruple fertilizer ratio)
- 6 X nutrients added to improve growth (sextuple fertilizer ratio)
- 8 X nutrients added to improve growth (octuple fertilizer ratio)

Initial biomass of 500 kg/*Ulva* spp were stocked in each pond and growth rates were measured every 21 days (~3 weeks) for a period of 3 months. The stocked *Ulva* spp in ponds 2, 3 and 4 were fertilized (every 7 days in order to allow assimilation) with a mixture of (10:16:0) Maxipos® and Ammonium sulphite at 100g/kg providing both nitrogen and phosphorous respectively. Fertilization was carried out in the evenings with the incoming water turned off and the paddle wheel remaining in motion. Four physico-chemical parameters were measured per hour for 24 hours and included temperature (Temp °C), pH, dissolved oxygen (DO, mgl^{-1}) and light ($\mu E\ m^{-2}\ s^{-1}$). The Waterproof CyberScan Series 300 Dissolved Oxygen meter specially designed to measure oxygen and temperature simultaneously was used to detect DO and temperature values. pH was determined with the aid of a portable pH meter model 8414 that also measures temperature at 0.1 °C. Irradiance levels were measured using a Biospherical Instruments probe (QSP200).

Wet to Dry Weight Ratios

Samples were taken, washed in distilled water to remove any impurities, weighed, and then oven dried for 3 days at 50 ˚C or until weight stopped decreasing. Wet to dry weight ratios were calculated by the following equation:

$(Dwt/Wwt\ X\ 100)$

Wwt = wet weight,

Dwt = dry weight

Biogas Production

Harvested samples of *Ulva* spp were prepared for biomethane analysis by rinsing in clean water and stored frozen at 0 °C until analysis. Samples were anaerobically digested in batch cultures for 25 days using [30] methods of methane fermentation of seaweed biomass.

Statistical Analyses

All data were analyzed statistically on graphpad prison V statistical software using one way analysis of variance (ANOVA) followed by Dunnet's multiple comparison test; all tests were performed at $p.< 0.05$ % significance level.

RESULTS AND DISCUSSIONS

Growth differed substantially among treatments from one pond to another as illustrated in table 1. The lowest value was recorded in the control, which contained no fertilizer and also produced the least biomass with a 113 % increase at harvest. A progressive increase in weight gain was seen with reference to fertilizer increase from one pond to another, with the highest weight being recorded in the quadruple fertilizer experiment of 691 % increase. Growth rates differed substantially among treatments from one pond as a result of the previous week's fertilization. This result is consistent with other published works [29]. Marine algae accumulate nutrients by means of a two stage process consisting firstly of a rapid and reversible physico-chemical process of adsorption on the surface of the algae, and then secondly of a slower metabolically arranged intracellular uptake [31] [32]. Thus the effects of a fertilization regime are often felt in the second growth period. As this trial was performed in winter, periods of sunlight influenced growth, with higher growth rates being experienced towards spring (i.e. the end of the trial). Findings showed that *Ulva* growth rates are seasonal and so we can assume that production would increase in summer [33]. These increases are slightly lower than those obtained using smaller tanks [33] , however, the CAPEX and OPEX costs of the paddle ponds provide the greatest production per unit areas and is more efficient than any other type of farming [34] [20].

Table 1: Biomass and biogas values of the farmed *Ulva* spp at the end of the experimental period: Initial stocking density/pond= 500kg, 3 weeks/harvest.

	Wet weight (kg) (mean ± SD)	Biomass available for anaerobic digestion (kg) (mean ± SD)	% Increase
No fertilizer	1045 ± 32.5	543 ± 32.5	108
Single fertilizer	1150 ± 171.1	650 ± 171.1	130
Double fertilizer	1370.5 ± 382.5	870.5 ± 382.5	174
Triple fertilizer	1235 ± 162.6	735 ± 162.6	147
Quadruple fertilizer	2406.5± 1546.4	1906.5 ± 1546.4	381
Sextuple fertilizer	1498.3 ± 209.7	998.25 ± 209.7	200
Octuple fertilizer	1382.5 ± 166.2	836.1 ± 166.2	167

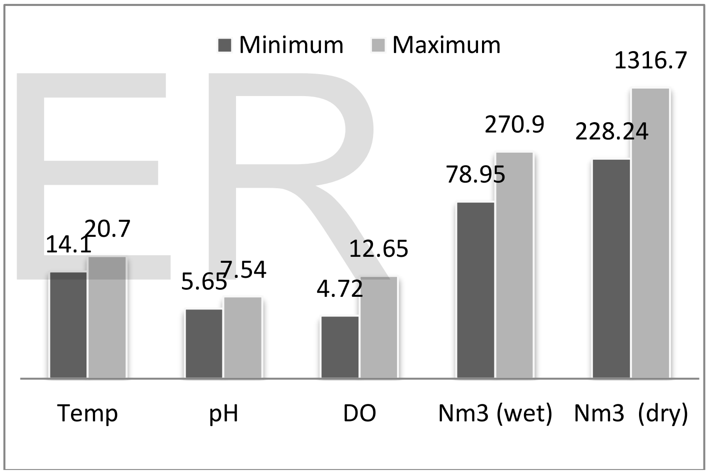

Figure 1: Comparative maximum and minimum values of physico-chemical parameters and gas yield. Minimum values were recorded. during the dark phase (night), while maximum values were recorded during the light phase (day) excluding gas production values (just minimum and maximum values are illustrated).

In aquaculture, biomass accumulation are generally dependent on both on external factors (pH, salinity, inorganic and organic complex molecules) and on physico-chemical parameters (temperature, light, dissolved oxygen and nutrients) that control the metabolic rate.

Figure 1 illustrates the maximum and minimum values of physico-chemical variables experienced in the ponds, the mean and standard deviation were as follows; temperature (17 ± 2.03), pH (6.53 ± 0.39), DO (8.07 ± 2.32), light (910 ± 2.32) there was no significant different $(p < 0.05)$ in these variables at the different treatments. Temp, pH, DO and light show a diurnal variation (Figure 1). Similar ranges were previously reported on by [30] for *Ulva spp* production in similar systems. Other research showed that *Ulva lactuca* could be cultured at 15– 20 °C and 400 – 1000 $\mu Es^{-1}m^{-2}$ [35] [36] [37]. The lower values of pH 5.65, DO 4.72 mgl^{-1} and $0.0\mu Es^{-1}m^{-2}$ were recorded during the dark phase at night when the biochemical activities was minimal due to the absence of sunlight and photosynthesis. These values similarly agree with the results and findings of [31]. Light range values in the pond were recorded as 0 – 1800 $\mu Es^{-1}m^{-2}$. This result falls within the range of results reported in similar research [38]. The wet to dry weight for the samples was 36.48 ± 21.35; this figure is within the range noted in earlier research [30].

Table 2: Composition and biogas yield from *Ulva*

Element	Unit of Measure	Biogas
Methane	CH_4%	53
Carbon Dioxide	CO_2 %	47
Hydrogen	H_2 %	1
H_2S	ppm (Vol)	325
NH_3	ppm (Vol)	75
Water	Dew point, °C	3
Gas yield	Nm^3 Biogas/t FM	77.4
Gas yield	Nm^3 Biogas/t DM	691

FM=fresh matter, DM= dry matter

Biogas is primarily a mixture of methane (53 %) and CO_2 (47 %), while the CO_2 was the initial atmospheric CO_2 absorbed by *Ulva* during culture. This result is comparable to 60 – 70 % for LPG, but better than LPG on major harmful emission like CO_2, hydrocarbon and nitrogen oxide (No_x) produced [39].

CONCLUSION

Energy supply in South Africa is primarily coal-based. South Africa is therefore a CO_2 intense economy, with the country's major energy requirement sourced from fossil fuels. It is necessary, at an industrial scale, to shift the dependence on fossil fuel-based energy to that of renewable and sustainable practices. The seaweed aquaculture industry as a biomass source for the production of biomethane gas is feasible in South Africa and could help promote this needed shift. The fact that fossil fuel prices are increasing and that macroalgae production costs will inevitably fall as algal production expands, make large scale macroalgae cultivation financially feasible. Unlike the first generation biofuels, macroalgae have additional advantages that make them environmentally sustainable. The high oxygen (by-product of photosynthesis) amounts dissolved in the paddle ponds enable the water to be reused for integrated polyculture with aquatic animals. Utilizing cultivated seaweed as a sustainable and renewable feedstock for biogas production would be a great advantage for South Africa and could potentially lead the way in renewable energy development. Additional benefits from such projects might include: capturing industrially emitted CO_2 to use for enhanced seaweed growth to mitigate climate change, decreasing ocean acidification through carbon sequestration, as well as uptake of excess nutrients from industrial and agricultural effluent discharges; and reducing coastal eutrophication. All these practices ultimate support change towards more environmentally sound practices.

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