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Production and Uses of Ulva armoricana: The South African Perspective

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***Abstract—* *Ulva* is currently South Africa's largest aquaculture product by weight, its production having developed steadily using integrated multitrophic aquaculture (IMTA) paddle wheel ponds as the preferred method of production. *Ulva* spp are exciting prospects for energy efficiency as demonstrated by biotransformation to Liquefied Petroleum Gas (LPG) studies, and by utilizing cultivated *Ulva* as feedstock for CH_4. *Ulva* has also been developed as a protein substitute in aquaculture feeds such as Abfeed™ and Midae Meal™. Still other farmers use cultivated *Ulva* spp as a fresh feed supplement in abalone farming. We have also shown that fishmeal can readily be replaced with *Ulva* as a source of protein in experimental diets for the production of abalone, catfish and sea urchins. The South African seaweed industry provides raw materials for other sectors of the economy, such as feedstock for phycocolloid production, and the production of Phloroglucinol, Eckol, Kelpak® and Afrikelp®, which are plant-growth stimulants. *Ulva armoricana* has shown prospects as a plant-growth stimulant for crop production. *Ulva* species efficiently remove dissolved inorganic nutrients as they have high uptake rates that can be applied in developing wastewater treatment for agro-allied industries within the safe limits prescribed by the FAO/WHO. pH toxicity tests are useful for assessing the health of macroalgae grown under aquaculture conditions. With increasing ocean acidification caused by higher CO_2 concentrations that lower water pH (4.71 - 6.67), the use of IMTA systems can mitigate acidification. Other benefits from *Ulva* production include: capturing industrially emitted CO_2 to use for enhanced seaweed growth; decreasing localized ocean acidification; and the uptake of excess nutrients from industrial and agricultural effluent.**

A. *Keywords— aquaculture, biogas, feed,* CO_2 *, Integrated Multitrophic Aquaculture (IMTA)*

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II. Introduction

Of about 9800 species of seaweed worldwide (http://www.seaweed.ie/), over 900 species are found around the South African coastline, making the region one of the richest marine floras in the world, with a high level of endemism [1] [2]. Cultivation of seaweeds from the genus *Ulva* has developed steadily since the early 1990's mainly as a feed supplement for the east coast abalone farms, which were unable to use formulated diets in summer [3] [4]. Wild Coast Abalone®, Abagold® and Irvin and Johnson® Cape cultured abalone, currently cultivates most of South Africa's *Ulva* [5]. The current estimated figure of *Ulva* production in South Africa is about 2884 t wet weight in flow-through, double ended, D paddle ponds usually integrated with abalone cultivation [5] [6]. This is the preferred method for growing *Ulva* [6]. Of all *Ulva* species, *U. armoricana* is grown commercially (Figure 1) around the west to east coast of South Africa due to its high growth rate, ease of harvesting and resistance to contamination by other algal species [4].

As a third-world country with many first-world technologies, South African seaweed aquaculture provides many important lessons for less developed coastal African nations [7]. This review summarizes the production, uses and innovation in research on *Ulva* spp in South Africa over the past two decades.

Fourteen species of *Ulva* are known to occur along the Southern African coastline within latitude 33°58′S and longitude 25°36′E, namely: *U. armoricana* P.Dion, B.de Reviers & G.Coat, *U. atroviridis* Levring, *U. compressa* Linneaeus, *U. capensis* Areschoug, *U. fasciata* Delile, *U. flexuosa* Wulfen, *U. intestinalis* Linneaeus, *U. linza* Linneaeus, *U. marginata* (J.Agardh) Le Jolis, *U. minima* Vaucher, *U. prolifera* O.F.Müller, *U. rigida* C.Agardh, *U. rhacodes* (Holmes) Papenfuss and *U. uncialis* (Kützing) Montagne [8] [9] [10] [19] [12] [13]. Previously thought to be *U. lactuca*, molecular evidence (L. Kandjengo & J.J. Bolton, unpublished data) has shown that the main species of *Ulva* grown in South Africa is the free-floating *U. armoricana* (Figure 2). Other South African specimens reported to be "*U. lactuca*" are different from those reported from other parts of the world and will require an indepth (taxonomic and molecular) assessment to determine their taxonomic status [10].

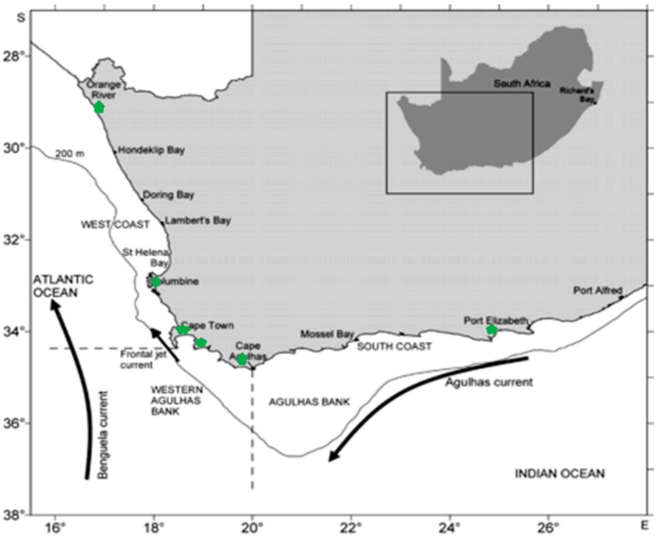

Figure 1. Location of abalone farms where *Ulva armoricana* is grown commercially in SA. (★ Sites showing cities and towns of abalone farms)

Figure 2. *Ulva armoricana* grown in South Africa (Photo source: Dr. Deborah V. Robertson-Andersson)

III. *Ulva* Utilization History

Although there is evidence that indigenous people from the Western Cape, South Africa ate seaweeds more than 10 000 years ago [14], we have been unable to determine if species of *Ulva* were specifically consumed. Seaweed recipes from the Hout Bay Museum (Western Cape Province) show that it was likely picked with *Porphyra* spp, washed in fresh water and dried over tree branches, and then eaten as a crispy chip [15]. The use of seaweeds as a food source by early humans is not surprising as seaweeds are known to be one of the healthiest foods on the planet, containing vitamins, more than 90 minerals and many antioxidants [16] [17], and have a high calorific value [14]. Coastal communities, who have historically consumed large quantities of seaweed, live longer and have a lower incidence of hypertension and arteriosclerosis than their inland counterparts who do not include seaweeds in their diets [18]. Seaweed salt (Cerebos salt industry/Cape Treasure, South Africa), Seaweed Rib Rub (Caviart®) and Roasted Seaweed Dukkah (Seas Gift Seaweed snacks, Health Island, South Africa) are just some of the current seaweed food products using local species of seaweed that exist in South Africa.

Figure 3. South African women from an economically disadvantaged coastal community collecting beach-cast kelp as feed for an aquaculture farm (Photo source: Prof. M. Troell)

The South Africa species of *Ulva* has been well studied [7]. Commercial *Ulva* production has grown by 448 percent from 2006 to 2012 [5] [6]. *Ulva* species are currently South Africa's largest aquaculture products by volume and are predominately used as feed in the abalone (*Haliotis midae* L) aquaculture industry [19] [20]. *Ulva* cultivation has occurred as part of Integrated Multitrophic Aquaculture (IMTA) in abalone seaweed systems and there is a wealth of knowledge on its cultivation within these ecologically friendly aquaculture systems [19] [21] [22]. Research has shown that abalone farms incorporating an IMTA seaweed-abalone system can significantly reduce their green-house gas (GHG) emissions [21] [22] and increase nutrient filtration for aquaculture benefits [23].

Current global production efficiencies for seaweed biomass production range from US$0.60/kg to US$7.00/kg [24]. The South African seaweed sector is small in comparison to similar fisheries, worth only about US$4.6 million, generating approximately US$2.5 million per year. Nevertheless, the SA seaweed sector employs well over 400 people, the majority of whom are women (Figure 3) who earn an average annual salary of US$5,000 (as at 2012) [5]. Economically, the SA seaweed sector has also impacted on previously disadvantaged coastal communities, where any increase in employment is valuable largely because such communities are generally characterized by high rates of unemployment (85.7 percent) and low skill levels (50 percent) [3] [22]. Employment in the seaweed aquaculture sector is smaller compared to other fisheries sectors, but jobs are more permanent and salaries are generally higher [19].

IV. Major Uses and Benefits of *Ulva* in South Africa

A. Biogas

As far as we know, South Africa is the first African country with the capacity for large-scale seaweed production and its subsequent biotransformation to LPG, being both economically viable and as an additional economic benefit from farming activities [20]. Biogas produced from bacterial digestion is primarily a mixture of methane (53 percent) and CO_2 (47 percent). Our studies (Table 1) demonstrated that it is comparable to LPG (60-70 percent methane), but better than LPG on major harmful emissions like CO_2, hydrocarbon and nitrogen oxide (No_x) [25]. The South African government, since 2013, has mandated that 20-50 percent of biofuel renewable energy, using sugar cane and sugar beet as bioethanol feedstocks, rely on locally cultivated maize and sugarcane in the initial period of development [26]. *Ulva* as a methane source is better than traditional biogas feedstocks and its potential as a bioethanol feedstock is being investigated in developed countries.

TABLE 1: COMPOSITION AND BIOGAS YIELD FROM *ULVA ARMORICANA*

Element	Unit of Measure	Biogas
Methane (CH_4)	%	53
CO_2	%	47
Hydrogen	%	1
H_2S	ppm (Vol)	325
NH_3	ppm (Vol)	75
Water (H_2O)	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

Source: [26]

B. Dried and Fresh Animal Feed.

In South Africa there is a market for fresh seaweeds used as feed in the production of abalone. Most farmers use large quantities of kelp as fresh abalone feed and supplement this with cultivated *Ulva* spp [3] [27]. *Ulva* is fed to *Haliotis midae* either as a fresh diet or is supplied as a feed fortification in compound feeds. Feeding trials incorporating cultured *Ulva* showed that abalone growth was improved [21] [28] [29] [30] [31], most likely a result of the higher protein content of the cultivated *Ulva*, which was attained by culturing the seaweed under high ammonia levels [19] [21]. Research on the sea urchin *Tripneustes gratilla* L [32] [33], the African Catfish *Clarias gariepinus* (Table 2) and the dusky kob *Argyrosomus japonicas* [5] demonstrated that an inclusion of a protein-enriched *Ulva* diet significantly outperforms the control diets. In the latter investigation, the *Ulva* enriched diet also resulted in a higher n-3 fatty acid content in fillet tissues. This finding is in contrast to a previous investigation [34] that stated that *Ulva* is more beneficial for algivorous fish species than carnivorous fish.

TABLE 2: CUMULATIVE GROWTH RATES OF *CLARIAS GARIEPINUS* FINGERLINGS FED DIFFERENT DIET COMPOSITIONS

	Diet composition			
Growth indices	Commercial FeedX	*Ulva armoricana* –non enriched	*Ulva armoricana* – enriched	Control - 35% Crude protein diet
Mean body weight g	2.40±0.28[a]	3.72±1.21[b]	3.88±1.36[b]	3.90±1.22[b]
Weight gain g	0.13±0.05[a]	0.49±0.17[b]	0.56±0.22[b]	0.52±0.2 3[b]
% weight gain	5.46±1.72a[a]	17.35±8.83[b]	18.25±5.6[b]	18.72±7.80[b]
Specific Growth Rate	0.32±0.07[a]	0.12±0.06[b]	0.09±0.06[b]	0.11±0.08[b]
Food Conversion Ratio	8.18±3.08[a]	3.23±2.17[b]	1.75±1.34[c]	0.79±2.39[c]
Gross Feed Conversion Ratio	6.86±1.7 8[a]	14.96±8.30[b]	41.60±24.39[c]	62.72±21.68[c]
Nitrogen metabolism	0.11±0.07[a]	0.40±0.67[b]	0.45±0.55[b]	0.42±0.75[b]

Measurements in the same row with the same superscript are not significantly different ($p > 0.05$). Data are presented as means ± Standard Error.

C. Plant-growth stimulants

About 1000 t of plant concentrates made from seaweed and worth US$5 million, is used worldwide as growth stimulants and hormones for several agricultural crops [23]. These plant concentrates (growth regulators) contain active ingredients such as Abscisic Acid, Auxins, Brassinosteriods, Cytokinins, Ethylene, Gibberellins and polymines responsible for growth [35]. Most of these growth regulators have been extracted from brown seaweeds [36]. Today there are several products and brand names on the market, including Maxicrop® (United Kingdom), Goëmill® (France), Algifert® (Norway), Kelpak®, Afrikelp® (South Africa) and Seasol® (Australia) [37]. The naturally occurring biostimulant extracts from seaweeds for the production of Kelpak®, Afrikelp®, and more recently Phloroglucinol and Eckol [38] [39], are commercial plant-growth stimulants used worldwide in the agricultural sector. These are liquid seaweed concentrates extracted from freshly harvested South African giant brown kelp *Ecklonia maxima* (Osbeck) Papenfuss, commonly known as sea bamboo. This kelp dominates the west coast of South African with an estimate of 530,000 t fresh weigh [40]. About 100 t (dry weight) of *E. maxima* is harvested annually for the commercial production of Kelpak® [41] alone. Recent research on *U. armoricana* has successfully demonstrated the use of this seaweed as a plant-growth stimulant in some African leafy vegetables. Ongoing work is being conducted to investigate the inclusion of cultivated *Ulva* spp into existing kelp liquid seaweed concentrates [20].

D. Integrated Multitrophic Aquaculture (IMTA)

In South Africa, much research has demonstrated the technical and economic feasibility of using *Ulva* spp as biofilters for removing excess ammonium (90 percent removal efficiency) and other inorganic nutrient uptake in IMTA units [19] [22] [42]. *Ulva* spp grown in shellfish wastewater have an increased nitrogen content, resulting in value-added seaweeds with over 40 percent protein dry weight content [19] and hence their value as a feed source. Our findings on biofiltration and uptake of dissolved nutrients by *Ulva armoricana* in a land-based aquaculture system (Table 3) revealed that double fertilized (200 $g.m^2$) *U. armoricana* had high Cd, Cu and Zn, although these values were still lower than the South African permissible limits for lettuce. This is in spite of the fact that *Ulva* species are known for their ability to bioaccumulate heavy metals [23] and that heavy metals, such as cadmium (Cd), tend to be elevated in marine environments because of their persistent nature [43]. Thus, if *Ulva* spp were to be used for human consumption, monitoring of theses metals would be required.

TABLE 3: HEAVY METALS AND NUTRIENT COMPOSITION OF *U. ARMORICANA*

	Experimental Treatments			**Standards**	
Heavy metals/Nutrient	Control (Seawater + fertilizer)	Seawater + double fertilizer	Seawater + Quadruple fertilizer	*SA Permissible Limit ($mg.kg^{-1}$) (Lettuce)	**FAO/WHO Permissible Limit ($mg.kg^{-1}$)
Cd	0.639 ± 0.023^a	1.166 ± 0.360^b	0.8451 ± 0.566^b	0.1	0.2
Cu	4.619 ± 1.193^a	5.676 ± 1.367^a	4.687 ± 1.148^a	30.0	0.1
Pb	ND	ND	ND	0.5	0.3
Zn	18.640 ± 4.814^a	20.244 ± 2.011^a	22.158 ± 8.991^a	40.0	.015 - .030 ***
% N	2.122±0.862a	3.220 ± 0.494^b	2.350 ± 1.039^b	-	GMP
% P	1.789 ± 0.082^a	1.711 ± 0.318^a	1.700 ± 0.269^a	-	2200

Measurements in the same row with the same superscript are not significantly different ($p > 0.05$),* South Africa Government Gazette, 9 September, 1994, metals in foodstuffs, cosmetics and disinfectants act, (Act no. 54 of 1972), **FAO/WHO (2001) [44]. standard for seaweed/vegetable, ***Australia recommended leaf nutrient concentrations, GMP = Good manufacturing practices (GMP) must be followed (hygiene, low temperature, and disinfection) as in packaging gas. ND=None detected. Data are presented as means ± Standard Error.

E. Ocean acidification

Ocean acidification could seriously effect molluscs [44] [45] because a decrease of carbonate reduces the calcium carbonate ($CaCO_3$) saturation state [45], potentially leading to aragonite shell dissolution [46]. It has been predicted that the oceans will become under-saturated with respect to aragonite by the year 2050 [47] [48], from a preindustrial value of 8.2, resulting in a 30 percent increase in acidity [49] [50].

Several projects have been proposed to mitigate ocean acidification. These revolve around three broad themes: 1) reducing anthropogenic CO_2 emissions; 2) maximizing biotic resilience and adaptation by increasing the number of marine protected areas; and 3) reducing pollution [53]. Seaweeds are known to lock away atmospheric CO_2, a process now referred to as blue carbon [54] [55]. Research has demonstrated, however, that they do not only fix dissolved inorganic carbon but, in the process, they alter the local seawater chemistry [55] and raise the pH [56]. Local research has shown that *U. armoricana* can increase the pH from 7.9 – 8.1 in both small and commercial-sized abalone-seaweed IMTA systems [18] [57], demonstrating this seaweed's ability to be a strong local candidate for mitigation against seawater acidification.

V. Conclusion

The development of the seaweed aquaculture industry in South Africa has been successful and sustainable largely due to a bilateral technology transfer and innovation between commercial abalone farms and research institutions. The South African seaweed aquaculture industry is well researched and has developed steadily as a result of many commercial drivers. The industry provides raw materials for several sectors of the economy, creates employment opportunities and provides several environmentally friendly opportunities for aquatic organisms.

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