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Review

South African seaweed aquaculture: A sustainable development example for other African coastal countries

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The green seaweed *Ulva* is one of South Africa's most important aquaculture products, constituting an important feed source particularly for abalone (*Haliotis midae* L.), and utilized as a bioremediation tool and other benefits such as biomass for biofuel production and for integrated aquaculture. Besides *Ulva* spp, *Gracilaria* spp. are also cultivated. Wild seaweed harvest in South Africa totals 7,602 mt, compared to 2,015 mt of cultivated *Ulva*. To mitigate for the reliance on wild harvesting, the South African seaweed aquaculture industry has grown rapidly over the past few decades. On-land integrated culture units, with paddle-wheel raceways, are now widely viewed as the preferred method of production for the industry. The success of seaweed aquaculture in South Africa is due to a number of natural and human (industrial) factors. The development of the seaweed aquaculture industry has paralleled the growth of the abalone industry, and has been successful largely because of bilateral technology transfer and innovation between commercial abalone farms and research institutions. In South Africa seaweeds have been used commercially as feedstock for phycocolloid production, for the production of abalone feed, and the production of Kelpak® and Afrikelp®, which are plant-growth stimulants used in the agricultural sector. Additionally, *Ulva* is being investigated for large-scale biogas production. The South African seaweed industry provides a template that could be used by other coastal African nations to further their undeveloped aquaculture potential.

Key words: Aquaculture, resources, seaweed, *Ulva*, South Africa.

INTRODUCTION

Fisheries and aquaculture provide significant food and income for the world's coastal countries, constituting the livelihoods of over 3 billion people (FAO, 2009; Smith et al., 2010; Amosu et al., 2012). Fisheries rely upon renewable harvest from the aquatic environment, while aquaculture is the cultivation of desirable aquatic organisms in open, closed, or semi enclosed bodies of water (Lorentzen et al.,2001). Aquaculture is currently the fastest growing primary industry (FAO, 2009) and is likely to overtake wild capture fisheries, providing a source of

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animal protein and food fish (FAO, 2010a, 2012). Active coastal aquaculture development has been practiced in Asia, Europe and South America for several decades, whereas only minimal production has thus far been achieved in Africa (FAO, 2012). Currently the African continent accounts for less than 1% of the annual total global aquaculture production (FAO, 2010a, 2012) and the vast majority of Africa's aquaculture is in freshwater.

Seaweed is currently the most significant aquatic plant that has contributed to the development of fisheries and the aquaculture industry (FAO, 2010b). Since 1970, the production of aquatic plants (seaweed and angiosperm) worldwide has consistently increased at an annual rate of 7.7%; 93.8% of the total world seaweed production is now from aquaculture (McHugh, 2001; FAO, 2003, 2009, 2010b, 2011), a higher figure than for any other group of marine organism. Globally, the production of seaweed increased from 11.66, 16.83 and 19.9 million mt in 2002, 2008 and 2010 respectively, while seaweed biomass accounted for 23% of the world aquaculture output in 2007 (FAO, 2012; Paul and Tseng, 2012). In recent years the total global annual seaweed harvest, produced by over 30 countries, ranges from 3.1 to 3.8 million mt (FAO, 2010b). Aquaculture production of aquatic plants in 2008 was estimated at US$7.4 billion (99.6% quantity and 99.3% value) (FAO, 2009). Even though Africa is the second largest continent and has a shoreline of about 30,000 km, it has yet to contribute significantly to the development of the seaweed industry despite its rich seaweed diversity (FAO, 2002, 2010b). Abalone farming in South Africa has developed rapidly and the country is now the largest producer outside Asia, partly achieved due to seaweed production. From a seaweed perspective, *Eucheuma* farming is well established in Zanzibar where commercial interests have assisted the establishment and development of the industry (FAO, 2002), making Tanzania the largest seaweed producing country in Africa, and among the top ten producers and one of only a few countries around the world producing more than 8,000 mt of seaweed per annum (FAO, 2012).

Africa offers numerous aquaculture opportunities, including integrated seaweed aquaculture production, which has been on the increase since 2001 (Table 1). The continent produced 138,989 mt of farmed seaweeds in 2010, with Tanzania (mainly Zanzibar), Madagascar, South Africa, Mozambique, and Namibia as the leading producers (FAO, 2012). This paper examines the current status of seaweed aquaculture in South Africa, the philosophy behind the country's achievements, prospects for the future, and the lessons for other African coastal countries.

THE SOUTH AFRICAN SEAWEED INDUSTRY

South Africa has had a seaweed industry for over 60 years. The commercial exploitation of seaweeds in South Africa is based largely on beach-cast collecting and cutting of kelp. Harvesting of *Ecklonia maxima* (Osbeck) Papenfuss and *Laminaria pallida* Greville ex J. Agardh started in the 1940's as a result of the scarcity of kelp during the Second World War (McHugh, 1987). When supplies of agar from Japan became unavailable, various potential resources were identified. However, commercial exploitation only began in the early 1950s (McHugh, 1987), followed by hand-picking of *Gelidium* sp. in the Eastern Cape since 1957. Most of this harvest was shipped to Europe, North America, and Asia for alginate extraction (Anderson et al., 1989). South African kelps yield alginate concentrations of between 22 and 40% (Anderson et al., 1989). Some trade figures showed that powdered kelp was also exported to Japan for use in formulated fish-feed (Zhang et al., 2004). Since 1975, wet kelp has been harvested from Concession Area 9 along the west coast solely for the production of Kelpak®, which is a plant-growth stimulant[1] and soil conditioner (Khan et al., 2009). Similar harvesting of wet kelp in small quantities started in 1979 on the west coast and later on the south coast for the production of Afrikelp®, which is also a plant-growth stimulant. This harvesting continues today (Anderson et al., 1989, 2003; Robertson-Anderson et al., 2006; Troell et al., 2006).

The bulk of the wet harvested kelp forms the major fresh feed ingredient for cultured abalone in South Africa. The use of kelp for abalone feed has fluctuated since 2005 (Table 2), but in 2010a total of 5,542 mt of fresh kelp fronds were supplied to farmers (DAFF, 2011a). Despite the large quantities of kelp supplied for use as abalone feed, some farmers also use formulated feeds, such as Abfeed™ and Midae Meal™, and some do not use kelp at all.

In 2010 commercial quantities of *Gelidium* were collected only from Concession Area 1; *G. pristoides* (Turner) Kuetzing comprises more than 90% of the harvest. Abundant endemic species such as *Gelidium pristiodes*, *Gelidium pteridifolium* Norris, Hommersand & Fredericq and *Gelidium abbottiorum* R. E. Norris have been harvested from Eastern Cape intertidal areas since the mid 1950s and have been identified for possible exploitation from other Concession Areas[2] (viz. 1, 20, 21, 22 and 23). Yields vary with demand from a few to about 120 mt dry weight annually. The sheltered waters of *Gracilaria gracilis* (Stackhouse) Greville wash-ups from Saldanha Bay on the west coast were exported for extraction of agar. Although some Gracilaria cultivation was attempted in the 1990's in Saldanha Bay and St Helena Bay, these commercial ventures failed (Anderson

[1] Kelp contains active ingredients (cytokinins and auxins) that have been shown to improve the growth performance and efficacy of many food and agricultural crops.

[2] The coastline between the Orange and Mtamvuna Rivers is divided into 23 seaweed rights areas. In each area, the rights to each group of seaweeds (e.g. kelp, *Gelidium*, or Gracilarioids) can be held by only one company, to prevent competitive overexploitation of these resources. Different companies may hold the rights to different resources in the same area (Figure 2).

Table 1. World aquaculture production of aquatic plants by producers in 2010**.**

Country		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
World total	Q	9,715,105	10,597,528	11,401,733	12,664,638	13,518,933	14,091,266	14,993,619	15,877,626	17,355,766	19,007,053
	V	3,042,257	3,127,449	3,352,420	3,850,013	3,916,781	3,985,305	4,262,670	4,377,832	4,961,197	5,651,167
China	Q	7,167,171	7,720,529	8,580,314	9,374,297	9,494,591	9,502,403	9,752,745	9,933,885	10,495,905	11,092,270
	V	1,361,096	1,487,034	1,809,558	2,099,267	2,038,868	2,027,812	2,072,273	2,311,139	2,357,839	2,533,196
Indonesia	Q	212,473	223,080	231,900	410,570	910,636	1,170,000	1,728,475	2,145,061	2,963,556	3,915,017
	V	21,247	36,636	17,059	32,846	127,489	210,600	392,980	300,309	811,822	1,268,367
Philippines	Q	785,795	894,857	988,889	1,204,808	1,338,597	1,468,905	1,505,070	1,666,556	1,739,995	1,801,272
	V	58,017	62,664	67,674	93,863	109,801	173,963	136,850	291,039	201,154	256,715
Korea Rep	Q	373,538	497,557	452,054	547,108	621,154	765,595	792,953	921,024	858,659	901,672
	V	127,981	156,797	169,819	231,917	262,523	269,657	332,524	311,305	252,112	327,823
Korea D P Rp	Q	444,295	444,295	444,295	444,295	444,295	444,300	444,300	444,300	444,300	444,300
	V	244,362	244,362	244,362	244,362	244,362	244,365	244,365	66,645	66,645	66,645
Japan	Q	511,448	557,951	477,705	484,389	507,742	490,062	513,964	456,337	456,426	432,796
	V	1,169,140	1,073,392	987,696	1,105,796	1,097,189	969,620	1,005,664	1,020,354	1,121,388	1,138,184
Malaysia	Q	18,863	18,871	25,000	30,948	40,000	60,000	80,000	111,298	138,857	207,892
	V	1,986	1,986	2,632	4,072	1,584	2,454	3,492	6,686	7,884	17,444
Zanzibar	Q	81,860	111,830	94,640	71,860	73,620	76,760	84,850	107,925	102,682	125,157
	V	963	1,086	697	542	638	740	579	1,265	1,327	1,781
Viet Nam	Q	20,000	25,000	30,000	30,000	30,000	36,000	38,000	35,700	33,600	35,000
	V	10,000	12,500	15,000	15,000	15,000	18,000	19,000	17,850	16,800	17,500
Chile	Q	65,538	71,648	40,079	20,273	15,493	38,219	26,387	27,703	88,193	12,179
	V	29,492	46,571	32,098	14,200	11,621	61,660	43,307	46,731	114,678	15,841
Solomon Is	Q	...	6	400	2,140	3,260	1,690	1,080	1,440	5,100	8,000
	V	...	...	11	57	87	33	21	58	253	397
Tanzania	Q	1,000	2,000	2,000	3,000	3,000	3,200	4,000	5,000	5,520	6,885

Table 1. Contd.

	V	9	18	14	21	24	31	27	65	168	196
China, Taiwan	Q	15,628	16,799	12,250	9,164	2,438	5,949	9,390	6,879	4,383	4,888
	V	15,177	2,235	2,200	1,461	502	447	8,311	1,206	5,161	3,158
Kiribati	Q	9,264	4,248	3,904	3,904	5,000	8,837	1,112	1,083	1,788	4,745
	V	287	139	153	156	200	353	44	91	139	428
South Africa	Q	12	1,050	2,824	2,845	3,000	3,000	3,000	1,834	1,900	2,015
	V	49	525	1,065	1,252	1,340	1,265	1,208	756	807	744
Timor-Leste	Q	...	...	...	...	...	...	370	1,000	1,500	1,500
	V	...	...	...	...	...	...	28	75	113	113
Brazil	Q	...	...	...	...	...	...	...	320	520	730
	V	...	...	...	...	...	...	...	26	39	62
Mozambique	Q	...	1,570	5,230	920	560	150	690	700	700	700
	V	...	31	120	18	11	3	14	14	14	14
Russian Fed	Q	504	143	67	216	245	818	300	260	739	614
	V	1,260	286	101	259	294	982	360	312	887	737
Fiji	Q	3,200	800	250	450	450	1,190	650	660	440	560
	V	176	44	14	25	25	65	36	46	31	56
Myanmar	Q	...	...	...	...	...	...	...	36	150	262
	V	...	...	...	...	...	...	...	11	45	79
Namibia	Q	20	38	67	67	67	70	27	132	130	130
	V	10	35	62	62	62	65	25	97	93	107
France	Q	35	38	37	37	45	32	35	53	125	120
	V	2	2	2	16	16	17	16	30	66	61
Burkina Faso	Q	...	...	...	...	10	20	20	70	70	70
	V	...	...	...	...	5	10	10	37	37	37

Table 1. Contd.

Cent Africa Rep	Q	...	...	...	...	...	...	...	...	...	30
	V	...	...	...	...	...	...	...	...	...	15
Ireland	Q	...	...	...	...	...	...	3	...	...	3
	V	...	...	...	...	...	...	2	...	...	2
Senegal	Q	...	...	...	...	1	...	...	...	...	2
	V	...	...	...	...	...	...	...	...	...	6
St Lucia	Q	3	2	2	1	1	1	1	1	1	2
	V	12	8	8	13	10	16	5	7	9	13
Spain	Q	...	...	...	...	0	1	25	14	5	1
	V	...	...	...	...	0	678	951	1,009	943	746
Other countries	Q	3,590	3,860	7,850	16,870	18,080	6,810	...	...	1	...
	V	895	996	1,955	4,216	4,516	1,703	...	...	6	

V = Value in USD 1 000; Q = Quantity.

Table 2. Annual yields of commercial seaweeds in South Africa, 2000-2010.

Year	Gelidium (kg dry wt)	Gracilaria (kg dry wt)	Kelp Beach cast (kg dry wt)	Kelp fronds harvest (kg fresh wt)	Kelp fresh beach cast (kg fresh wt)	Kelpak (kg fresh wt)
2001	144 997	247 900	845 233	5 924 489	0	641 375
2002	137 766	65 461	745 773	5 334 474	0	701 270
2003	113 869	92 215	1 102 384	4 050 654	1 866 344	957 063
2004	119 143	157 161	1 874 654	3 119 579	1 235 153	1 168 703
2005	84 885	19 382	590 691	3 508 269	126 894	1 089 565
2006	104 456	50 370	440 632	3 602 410	242 798	918 365
2007	95 606	600	580 806	4 795 381	510 326	1 224 310
2008	120 247	0	550 496	5 060 148	369 131	809 862
2009	115 502	0	606 709	4 762 626	346 685	1 232 760
2010	103 903	0	696 811	5 336 503	205 707	1 264 739
Total	1 140 374	633 089	8 034 189	45 494 533	4 903 038	10 008 012

Kelp beach cast' (column 4) refers to material that is collected in a semi-dry state, whereas 'kelp fresh beach cast' (column 6) refers to clean wet kelp fronds that, together with 'kelp fronds harvest' are supplied as abalone feed. 'Kelp fresh beach cast' was only recorded separately since 2003. Source: DAFF 2011a.

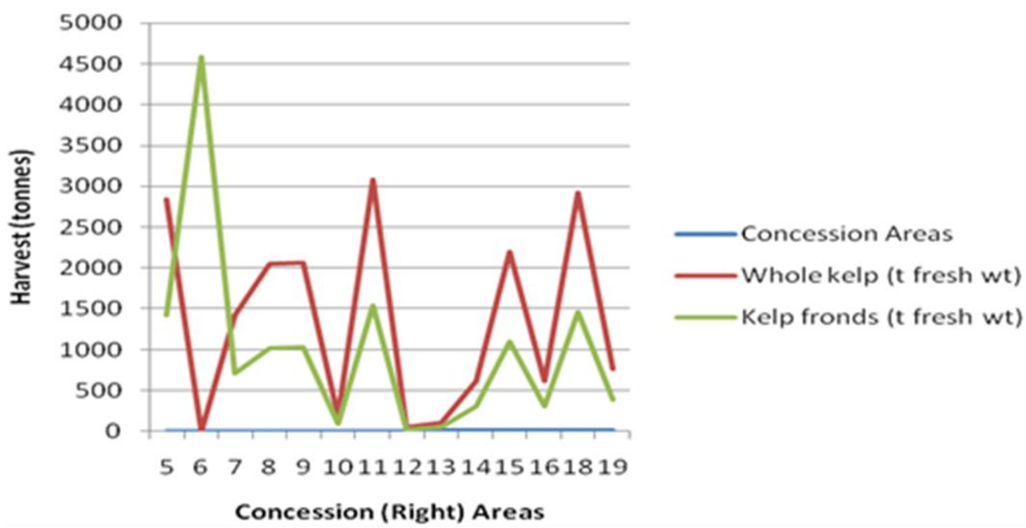

Figure 1. Maximum sustainable yield (MSY) of harvested kelp for all areas for 2010.

et al., 1989, 2003). Only beach-cast *Gracilaria* material may be collected commercially, because harvesting of the living beds is not sustainable. In Saldanha Bay, large yields (up to 2,000 mt dry weights in 1967) were obtained until the construction of the iron ore jetty and breakwater in 1974, after which yields fell dramatically. Occasional small wash-ups are obtained in St Helena Bay. Because total annual yields of Gracilarioids range from zero to a few hundred tonnes dry weight, this resource is regarded as unreliable. Accordingly, no gracilarioids have been collected commercially since 2007. From the start of commercial seaweed exploitation in South Africa in the 1950's, only six seaweed genera (*Ecklonia*, *Laminaria*, *Gracilaria*, *Gelidium*, *Gigartina* and *Porphyra*) have been harvested, with most of this material being exported for use in the phycocolloid industry. *Ulva* has also been harvested in small amounts, but mostly for seaweed salt.

Seaweed aquaculture in South Africa started as an offshoot of the abalone (*Haliotis midae* L.) farming industry in the 1990's and has increased accordingly. Within South Africa twelve seaweed species are currently being exploited: *Ulva* sp., *Porphyra* sp., *E. maxima*, *Laminaria pallida*, *Gracilaria gracilis*, *Gracilariopsis longissima* (S. G. Gmelin) M. Steentoft, L. M. Irvine & W. F. Farnham, *G. abbottiorum*, *G. pteridifolium*, *G. pristoides*, *G. capense* (S.G. Gmelin) P. C. Silva, and *Plocamium corallorhiza* (Turner) Harvey (ESS, 2005; Troell et al., 2006; Robertson-Andersson, 2007).

South Africa's seaweed resources are well protected under the Marine Living Resources Act of 1998 and are conserved from a concessional perspective[3] (Anderson et al., 1989, 2003; GPR, 2005; Anderson et al., 2006). In certain Concession Areas, limitations are placed on the quantity that can be harvested. These sustainable limits are termed Maximum Sustainable Yields (MSY) and equate to 10% of the estimated kelp accessible (non-reserve) biomass, a value that was estimated to equal the annual mortality rate for the kelp *E. maxima* (Simons and Jarman, 1981). A large amount of this harvested seaweed is exported for the extraction of gums and 42.7% of the total harvest of fresh kelp fronds was supplied to abalone farmers as feed, this harvested kelp fetching a market value of R6 million (~ US$750 000) in 2010 (DAFF, 2012). Within the 23 Concession Areas, currently 14 areas are for kelp rights (Figure 1); no commercial activity was reported in five of these areas (DAFF, 2012).

[3]The seaweed resources is managed in terms of both a Total Applied Effort (TAE) and a Total Allowable Catch (TAC)

IMPORTANCE, USES AND BENEFITS

Seaweed is produced in 25 countries globally, comprising 145 species used in food production and 101 species used in phycocolloid production (Dhargalkar and Verlecar, 2009). There are 20 commercial seaweed species being cultivated in each of the main genera, which includes *Caulerpa*, *Chondrus*, *Eucheuma* and *Kappaphycus*, *Gracilaria* and *Gracilariopsis*), *Palmaria*, *Pyropia* (formerly *Porphyra*), *Monostroma*, *Saccharina* (formerly *Laminaria*), *Ulva* and *Undaria* (Zemke-White et al., 1999, Fleurence, 2004; Bruton et al., 2009; Klaus et al., 2009; Mohammad and Chakrabarti, 2009; Pia et al., 2009; FAO, 2010b; Paul and Tseng, 2012).

Agar and carrageenan are commercially valuable substances. The best quality agar, and its associated derivative agarose, comes from red algae belonging to the family Gelidiaceae, while lower-quality agars are mainly found in other families, mainly the Gracilariaceae. Globally agarose is used extensively in gels for electrophoresis in molecular biology. Carrageenans are generally employed for their viscous properties in

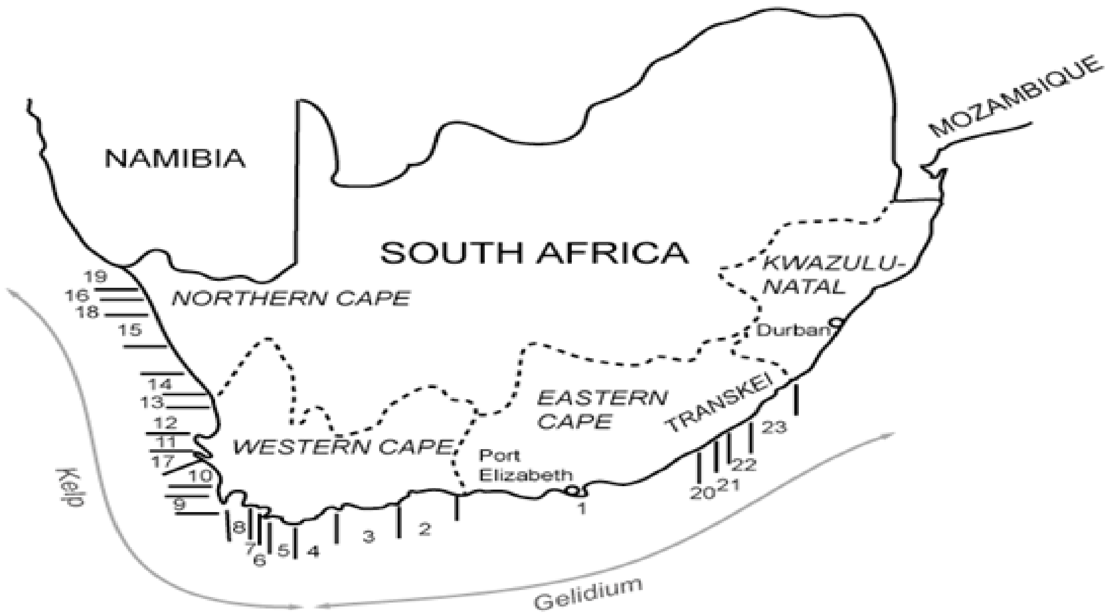

Figure 2. Map of South Africa showing area of potential commercial seaweed concession right areas (Anderson et al., 2003).

gelation, as stabilization of emulsions, in suspensions and foams, and in the control of crystal formation in dairy products and frozen foods. Seaweeds have been called the medical food of the 21st century (Khan and Satam, 2003). According to the World Health Organization (WHO) seaweed are among the healthiest foods on the planet as they contain vitamins, over 90 minerals and many antioxidants (FAO, 2003). Historic evidence shows that seaweeds have been eaten by coastal communities of many countries since ancient times (FAO, 2002) and according to re**s**earch, such communities who have historically consumed large quantities of seaweed, on average lived longer and had a lower incidence of hypertension and arteriosclerosis (Tietze, 2004).

Seaweeds are also used in the manufacture of pharmaceuticals and cosmetic creams (Bhakuni and Rawat, 2005; Leonel, 2011; Lewis et al., 2011). For example, *Digenea* spp (Rhodophyta) produce an effective vermifuge (kainic acid) (Smit, 2004). *Laminaria* and *Sargassum* species have been used for the treatment of cancer (Khan and Satam, 2003). Anti-viral compounds discovered in *Undaria* spp have been used to inhibit the Herpes simplex virus (Barsanti and Gualtieri, 2006). Research is now being carried out into using seaweed extracts to treat breast cancer and HIV (Schaeffer and Krylov, 2000; Synytsya et al., 2010). Several calcareous species of *Corallina* have been used in bone-replacement therapy (Stein and Borden, 1984). *Asparagopsis taxiformis* and *Sarconema* spp. are used to control and cure goiter while heparin, a seaweed extract, is used in cardiovascular surgery (Khan and Satam, 2003).

GLOBAL SEAWEED TRADE

Globally the seaweed industry is estimated to have an annual value of some US$6 billion (McHugh, 2003) and the largest share of this is for food products. Currently there are 42 countries across the world with reports of commercial seaweed activity (Khan and Satam, 2003; Bixler and Porse, 2011). The primary wild-harvested genera include *Chondrus*, *Furcellaria*, *Gigartina*, *Sarcothalia*, *Mazzaella*, *Iridaea*, *Mastocarpus*, and *Tichocarpus* (Bixler and Porse, 2011). As already mentioned, seaweeds are an important food source, especially in Japan (FAO, 2003). Popular seaweed food stuffs include Wakame, Quandai-cai (*Undaria pinnatifida*), Nori (*Porphyra* spp), Kombu or Haidai (*Laminaria japonica*), Hiziki (*Hizikia fusiforme*), Mozuku (*Cladosiphon okamuranus*), Sea grapes or Green caviar (*Caulerpa lentillifera*), Dulse (*Palmaria palmata*), Irish moss or Carrageenan moss (*Chondrus crispus*), Winged kelp (*Alaria esculenta*), Ogo, Ogonori or Sea moss (*Gracilaria* spp), Carola (*Callophyllis variegata*), Leafy sea lettuce (*Ulva* spp), Arame (*Eisenia bicyclis*), and Kanten (agar-agar). Seaweed products for human consumption contribute about US$ 5 billion of which nori is worth US$ 2 billion per annum (FAO, 2003).

The production of seaweeds and other aquatic algae reached 19.9 million mts in 2010, of which aquaculture produced 19 million mt. Japanese kelp was the most cultivated seaweed species (5.1 million mt) in 2010 and most of it was grown in China (FAO, 2012). Major seaweed aquaculture production come from China, Indonesia, Philippines, North Korea, South Korea, Japan, Malaysia, Chile, India, and Tanzania (Barsanti and Gualtieri, 2006; Bixler and Porse, 2011; FAO, 2010b, 2012). The most cultivated seaweed is the kelp *Saccharina japonica*, which accounts for over 60% of the total cultured seaweed; species from the genera *Porphyra*, *Kappaphycus*, *Undaria*, *Eucheuma*, and *Gracilaria* make up the majority of the remaining total (Barsanti and Gualtieri, 2006). The most valuable among the seaweed is the red alga (*Porphyra yezoensis*), an important constituent of sushi (FAO, 2010, 2012; Bixler and Porse, 2011).

High demand for carrageenan has similarly triggered the development of *Kappaphycus alvarezii* and *Eucheuma denticulatum* farming in several countries, the largest producers being the Philippines, Indonesia, Malaysia, Tanzania, Kiribati, Fiji, Kenya, and Madagascar (Bixler and Porse, 2011). World carrageenan production exceeded 50,000 mt in 2009, with a value of over US$527 million (Bixler and Porse, 2011). About 32,000 to 39,000 mt of alginic acid per annum is extracted worldwide from approximately 50,000 mt (wet weight) annual production of kelp (Barsanti and Gualtieri, 2006). Agar is relatively cheap, usually around US$18 per kg. In 2009, about 86,100 mt of hydrocolloids were traded comprising 58% of carrageen, approximately 31% alginates, and approximately 11% agar (10,000 mt with a value of $175 million); the major genera included *Ahnfeltiopsis*, *Gelidium*, *Gelidiella*, *Gracilaria*, *Pterocladiella* and *Pterocladia* (Bixler and Porse, 2011).

AFRICA REGIONAL SEAWEED AQUACULTURE DEVELOPMENT

The African continent comprises 29 coastal countries and five island nations, few of which are practicing some form of seaweed aquaculture (Machena and Moehl, 2001). However, the biogeographical features and shore characteristics in several of these countries suggest a high potential for seaweed resources exploitation, culture and utilization**.**

West Africa

Excluding Ghana (200 species), Senegal (241 species), and Sierra Leone (112 species), which have high seaweed diversities associated with upwelling events and rocky shores (Bolton et al., 2003), West Africa generally has a low seaweed diversity (John and Lawson, 1991). Nigeria (49 species), Benin (16 species), Togo (37 species) and Guinea Bissau (12 species) have coastlines characterized by sandy beaches and extensive mangroves, deltas, estuaries, and lagoons with correspondingly low algal diversity (John and Lawson, 1997). Recent research (Fakoya et al., 2011; Abowei and Tawari, 2011) has shown the potential of seaweed resources for exploitation, culture and utilization for Nigeria but as yet, no targeted commercial harvesting and cultivation has commenced.

North Africa

North Africa (Morocco – 197 species, Libya – 178 species, Tunisia – 87 species, Western Sahara – 81 species, Sudan – 18 species) has a variable seaweed species richness. The Moroccan coast, however, has been most studied, due to its proximity to European countries (Gallardo et al., 1993) and this may explain the high species numbers. None the less, Morocco has a well-established seaweed industry based on the extraction of agar from wild *Gelidium* species. Steps are also being taken to identify suitable protected natural sites for seaweed cultivation, presumably with a view to cultivating *Gracilaria* to supplement the natural resources of *Gelidium* for agar production (FAO, 2003).

East Africa

The East African coastline is about 9500 km long and comprises the tropical coasts of Somalia (211 species), Kenya (403 species), Tanzania (428 species), Mozambique (243 species) and Madagascar (207 species). Seaweed aquaculture is a recent development in East Africa, occurring in all East African countries except Somalia. Tanzania's aquaculture production has increased steadily to become the largest producer of aquaculture products in Africa (FAO, 2012). *Eucheuma denticulatum* (previously *E. spinosum*) and *Kappa-phycus alvarezii* (previously *E. cottonii*) have been farmed in the region since 1989. These two species are found naturally in East Africa, and were previously collected from the wild for export to USA and Europe. Although the species are found locally, the farmed strains are mainly imported from the Philippines. Madagascar currently accounts for a very small proportion (about 4,000 mt of seaweed per year) of global seaweed production, despite the fact that much of its 5,000 km coastline provides perfect conditions for seaweed cultivation (FAO, 2012). With assistance from commercial sources, seaweed cultivation is proving to be promising in Mozambique. This will make Mozambique only the fourth seaweed producing nation in Africa (FAO, 2012). To support this industry and to promote aquaculture, the Mozambique government recently (2011) approved a decree establishing the marine aquaculture reserve. Approximately 10,600 ha have been set aside for seaweed aquaculture, potentially yielding 641,000 mt of seaweed (Nkutumula, 2011). The seaweeds of Kenya are well-studied relative to other East African/Indian Ocean countries (Bolton et al., 2003). However, Kenya does not present good prospects for a seaweed industry. None of the pilot studies carried out have produced any promising results that would encourage investors to venture into seaweed farming for Kenya.

Southern Africa

Namibia's proximity to South Africa greatly influenced the documentation of the former country's seaweed resources. Both countries have developed through technology sharing, but the seaweed aquaculture industry in Namibia is still not as developed as in South Africa. The 196 seaweed species of Namibia have been studied and documented (Engeldow, 1998; Rull Lluch, 1999, 2002; Engeldow and Bolton, 2003). As in South Africa, Namibian seaweed harvesting companies operate under a system of Concessions Areas. The industry provides employment opportunities for over 250 people in an area where job opportunities are severely lacking. Investment in polyculture of seaweeds and crustaceans has also been promoted in Namibia (Hasan and Chakrabarti, 2009). Of the 196 Namibian species of seaweeds, nine have shown potential use as animal feed supplements. Beach-cast *Gracilaria* is also collected and cultivation is being developed by a local company; the current market, however, is depressed.

The seaweeds of South Africa have been extensively detailed (Stegenga et al., 1997; De Clerck et al., 2005; Maneveldt et al., 2008). The known seaweed diversity of South Africa has increased from 547 species in 1984 to around 900 species in 2012, making the region one of the richest marine floras in the world, with a high level of endemism (Payne et al., 1989; Bolton, 1999; Bolton et al., 2003; Maneveldt et al., 2008, pers. obs.). South African seaweed aquaculture is focused on the abalone industry, particularly the abalone, *Haliotis midae* (Bolton et al., 2006; Troell et al., 2006). By far the most cultivated seaweed species is *Ulva* spp. The aquaculture of *Ulva* spp occurs on many abalone farms (DAFF, 2010) and here paddle-wheel raceways have proven to be the most suitable device for growing *Ulva* spp in large quantities (Chopin et al., 2008).

The South African abalone aquaculture industry has grown rapidly over the past few decades along the west coast of South Africa where suitable rocky habitat exists (Troell et al., 2006). On-land integrated culture units, which use shallow raceways, are the preferred method of production for the abalone industry (Bolton et al., 2006). There is growing evidence that suggests a mixed diet of kelp and other seaweeds can induce growth rates that meet or exceed those attained with artificial feed (Naidoo et al., 2006, Dlaza et al., 2008; Francis et al., 2008; Robertson-Andersson et al., 2011). Moreover, a natural diet can improve abalone quality and reduce parasite loads (Robertson-Andersson, 2003; Naidoo et al., 2006; Al-Hafedh et al., 2012).

PROBLEMS AND PROSPECTS OF SEAWEED AQUACULTURE IN AFRICA

Failures of some ill-conceived pilot projects (e.g. South-west Madagascar – De San, 2012) continue to remain a major constraint in convincing farmers and investors of the economic viability of seaweed aquaculture in most African coastal countries.

Several other constraints have prolonged the development of the industry in many African countries, and these can be summarized as: weak economies; *poor aquaculture development policies*; inappropriate technologies; weak extension services; weak impact of research institutions; inadequate information management systems; limited coordination between research and production sectors; scanty reliable production statistics and the high value/cost of coastal land; and the associated competition for this land from other coastal industries. In the countries (South Africa, Tanzania, Madagascar, Mozambique, Namibia, Burkina Faso, Central Africa Republic and Senegal) where thriving seaweed cultivation practices have been achieved, these industries provide a meaningful form of income for communities that might otherwise not be employable in the traditional sense.

LESSONS FOR OTHER COASTAL NATIONS

The general benefit of integrated multitrophic aquaculture[4] (IMTA) is the reduction of nutrient release to the environment (Neori et al., 2004, Bolton et al., 2009). This phenomenon is also true for integrated seaweed-abalone culture in South Africa. The technical and economic feasibility of IMTA using seaweeds as biofilters is already well established in South Africa (Nobre, 2010). Seaweeds grown in abalone effluent have an increased nitrogen content (sometime as much as 40% protein dry weight content), resulting in value-added seaweeds of excellent quality to feed abalone (Naidoo et al., 2006; Robertson-Andersson, 2007; Robertson-Andersson et al., 2011). Not only in South Africa but elsewhere, the increasing demand for abalone feed has seen the need for sustainable production of seaweed in IMTA aquaculture with aquatic animals (Brzeski and Newkirk, 1997, Troell et al., 1999, Buschmann et al., 2001), especially with abalone (Neori et al., 1991, 1996, 1998, 2004). To improve seaweed biomass estimations and to document the relative seaweed distributions, GIS mapping and diver-based sampling of the resource is regularly undertaken in South Africa as a government requirement. Monthly harvests of fresh kelp are routinely checked against the prescribed MSY as set in the annual permit conditions of all rights holders. Visual inspections by South African government officials, and reports received from right-holders, show that the kelp resource is stable and healthy (DAFF, 2011a).

Although, the South African seaweed sector is small in comparison to similar fisheries, it is currently worth

[4] Integrated Multitrophic Aquaculture (IMTA) is defined as an ecosystem based management approach that effectively mitigates the overabundance of nutrients introduced by fish farming.

US$3.7 million, generates approximately US$2 million[5] per year, but nevertheless employs up to 400 people, the majority of whom are women who earn an average annual salary of US$ 5 000 (Payne et al., 1989; DAFF, 2011a, b, 2012). More importantly, high proportions (92%) of the employees in the sector are classified as historically disadvantaged persons[6] (DAFF, 2011a). The South African aquaculture sector thus has an important local impact within 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%) and low skill levels (50%) (Nobre et al., 2010).

South Africa is currently spearheading a number of other research innovations. Research has shown that abalone farms incorporating an IMTA seaweed-abalone system can significantly reduce their green-house gas (GHG) emissions (Nobre et al., 2010; Troell et al., 2011). Due to their high carbohydrate contents, seaweeds can be fermented to CH_4 (biogas) and have subsequently been considered a potential CO_2-neutral and renewable energy supply (Bartsch et al., 2008; Roesijadi et al., 2008; Bruhn et al., 2011, Chung et al., 2011). Furthermore, recent research findings have shown that *Laminaria* and *Ulva* species are important prospects from an energy point of view (Bruton et al., 2009; Klaus et al., 2009; Abowei and Tawari, 2011; Bruhn et al., 2011, Chanakya et al., 2012). This important benchmarking knowledge could propel the commencement of research on seaweed as a substitute for liquefied petroleum gas (LPG). Aside from being a renewable resource and reducing CO_2 emissions (especially if seaweed cultivation is incorporated with a source of CO_2 production), seaweed cultivation could potentially have a major positive impact on global warming and ocean acidification. As a consequence of these findings, South Africa is currently investigating large-scale anaerobic digestion of methane gas from seaweed as well as the local species of seaweeds' potential for mitigation of ocean acidification.

CONCLUSION

Despite the fact that South Africa is currently not Africa's highest seaweed aquaculture producer, the country has the highest regional seaweed diversity and one of the richest in the world. As a third-world country with many first-world technologies, South Africa provides many important lessons for less developed coastal African nations. The South African seaweed aquaculture industry is well researched and has developed steadily due to the need for sustainable production of seaweed in IMTA. Presently the South African seaweed aquaculture industry provides raw materials for other sectors of the economy, as well as the potential for bioremediation of both the atmospheric and aquatic environment.

[5] 1US$(US dollar) equals R9.55 (SA Rand) as at 22 May 2013.
[6] Historically disadvantaged persons are persons so classified as underdeveloped populations targeted by the SA Government for accelerated development (www.polity.org.za/html/govdocs/rd/rdp2.html. 2013).

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REFERENCES

Abowei JFN, Tawari CC (2011). A Review of the Biology, Culture, Exploitation and Utilization Potentials Seaweed Resources: Case Study in Nigeria. Res. J. Appl. Sci. Eng. Technol. 3(4):290-303.

Al-Hafedh YS, Alam A, Buschmann AH, Fitzsimmons KM (2012). Experiments on an integrated aquaculture system (seaweeds and marine fish) on the Red Sea coast of Saudi Arabia: efficiency comparison of two local seaweed species for nutrient biofiltration and production. Rev. Aquacult. 4:21–31.

Amosu AO, Bashorun OW, Babalola OO, Olowu RA, Togunde KA (2012). Impact of climate change and anthropogenic activities on renewable coastal resources and biodiversity in Nigeria. J. Ecol. Nat. Environ. 4(8):201-211.

Anderson RJ, Rothman MD, Share A, Drummond H (2006). Harvesting of the kelp *Ecklonia maxima* in South Africa affects its three obligate, red algal epiphytes. J. Appl. Phycol. 18:343–349.

Anderson RJ, Bolton JJ, Molloy FJ, Rotmann KW (2003). Commercial seaweeds in southern Africa. In: Chapman ARO, Anderson RJ, Vreeland VJ, Davidson I (Eds) Proceedings of the 17th International Seaweed Symposium. Oxford University Press, Oxford, pp. 1–12.

Anderson RJ, Simons RH, Jarman NG (1989). Commercial seaweeds in southern Africa: A review of utilization and research. South Afr. J. Marine Sci. 8:277-299.

Barsanti L, Gualtieri P (2006). Algae Anatomy, Biochemistry, and Biotechnology Taylor and Francis Group LLC. Boca Raton London New York CRC Press.

Bartsch I, Wiencke C, Bischof K, Buchholz CM, Buck BH, Eggert A, Feuerpfeil P, Hanelt D, Jacobsen S, Karez R, Karsten U, Molis M, Roleda MY, Schumann R, Schubert H, Valentin K, Weinberger F, Wiese J (2008). The genus *Laminaria* sensu lato: recent insights and developments. Eur. J. Phycol. 43(1):1-86.

Bhakuni DS, Rawat DS (2005). Bioactive marine natural products. Anamaya Publishers, New Delhi, India.

Bixler HJ, Porse H (2011). A decade of change in seaweed hydrocolloids industry. J. Appl. Phycol. 23:321-335.

Bolton JJ (1999). Seaweed systematic and diversity in South Africa: An historical account. Trans. Royal Soc. South Afr. 54(1):167-177.

Bolton JJ, De Clerck O, John DM (2003). Seaweed diversity patterns in Sub-Saharan Africa. Proceedings of the Marine Biodiversity in Sub-Saharan Africa: The Known and the Unknown, 23-26 September, Cape Town, South Africa, pp. 229-241.

Bolton JJ, Robertson-Andersson DV, Shuuluka D, Kandjengo L (2009). Growing *Ulva* (Chlorophyta) in integrated systems as a commercial crop for abalone feed in South Africa: a SWOT analysis. J. Appl. Phycol. 21:575-583.

Bolton JJ, Robertson-Andersson DV, Troell M, Halling C (2006). Integrated systems incorporate seaweeds in South African abalone culture. Global Aquacult. Advocate 9:54-55.

Bruhn A, Dah J, Nielsen HB, Nikolaisen L, Rasmussen MB, Markager S, Olesen B, Arias C, Jensen PD (2011). Bioenergy potential of *Ulva lactuca*: Biomass yield, methane production and combustion. Bioresour. Technol. 102:2595-2604.

Bruton T, Lyons H, Yannick Lerat, Y, Rasmussen MB (2009). A Review of the Potential of Marine Algae as a Source of Biofuel in Ireland. Sustainable Energy Ireland, Glasnevin, Dublin 9. Ireland. www.sei.ie

Brzeski V, Newkirk G (1997). Integrated coastal food production systems — a review of current literature. Ocean Coast. Manage. 34:66–71.

Buschmann A, Troell M, Kautsky N (2001). Integrated algal farming: a review. Cah. Biol. Mar. 43:615–655.

Chanakya HN, Mahapatra DM, Ravi S, Chauhan SV, Abitha R (2012). Sustainability of large-sScale aAlgal bBiofuel pProduction in India. India Inst. Sci. 92(1):63-98.

Chopin T, Robinson SMC, Troell M, Neori A, Buschmann AH, Fang J (2008). Multitrophic integration for sustainable marine aquaculture. In: Jørgensen SE, Fath BD (eds) Encyclopedia of ecology, vol 3, Ecological engineering. Elsevier, Oxford. pp 2463–2475.

Chung IK, Beardall J, Mehta S, Sahoo D, Stojkovic S (2011). Using marine macroalgae for carbon sequestration: a critical appraisal. J. Appl. Phycol. 23:877–886.

Department of Agriculture, Forestry and Fisheries DAFF (2010). Marine Aquaculture Annual Farm Operation Report 2010.

DAFF (2011a). Status of the South African Marine Fishery Resources, 2010. Unpublished report, South African Department of Agriculture, Forestry and Fisheries.

DAFF (2011b). Aquaculture annual report 20011 South Africa. South African Department of Agriculture, Forestry and Fisheries.

DAFF (2012). Agriculture, Forestry and Fisheries- Integrated Growth and Development Plan 2012. . South African Department of Agriculture, Forestry and Fisheries.

De Clerck O, Bolton JJ, Anderson RA, Copperjans E (2005). Guide to the seaweeds of KwaZulu-Natal. Scripta Botanica Belgica 33:1–294.

De San M (2012). The farming of seaweeds. Implementation of a regional fisheries strategy for the eastern - southern Africa and India Ocean Region. Report: SF/2012/28.

Dlaza TS**,** Maneveldt GW, Viljoen C (2008). The growth of post-weaning abalone (*Haliotis midae* Linnaeus) fed commercially available formulated feeds supplemented with fresh wild seaweed. Afr. J. Mar. Sci. 30(1):199-203.

Engeldow HE (1998). The biogeography and biodiversity of the seaweed flora of the Namibian intertidal seaweed flora. PhD thesis, University of Cape Town, South Africa.

Engledow HE, Bolton JJ (2003). Factors affecting seaweed biogeographical and ecological trends along the Namibian coast. Proceedings of the 17th International Seaweed Symposium. Oxford University Press. pp. 285-291

ESS (2003). Mather D, Britz P J, Hecht T, Sauer, WH H (2003). An economic & sectoral study of the South African Fishing Industry. V .1. Economic & regulation principles, survey results, transformation and socio-economic impact. Report prepared for Marine and Coastal Management, Department of Environmental Affairs and Tourism by Rhodes University, Grahamstown, South Africa. P. 300.

Fakoya KA, Owodeinde FG, Akintola SL, Adewolu MA, Abass MA, Ndimele PE (2011). An Exposition on Potential Seaweed Resources for Exploitation, Culture and Utilization in West Africa: A Case Study of Nigeria. J. Fish. Aquat. Sci. 6:37-47.

FAO (2002). Prospects for seaweed production in developing countries, FAO Fisheries Circular No. 968 FIIU/C968 (En). FAO Rome.

FAO (2003). A guide to the seaweed industry, FAO fisheries technical paper 44, Rome.

FAO (2009). The state of world fisheries and aquaculture 2008. FAO fisheries and aquaculture department. Food and Agriculture Organization of United Nations, Rome. 2009.

FAO (2010a). The State of World Fisheries and Aquaculture. FAO Fisheries and Aquaculture Department. Food and Agricultural Organization of the United Nations: Rome.

FAO (2010b). FishStat fishery statistical collections: aquaculture production (1950–2008; released March 2010). Rome, Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/fishery/statistics/software/fishstat/en.

FAO (2011). FAO Fisheries Department, Fishery Information, Data and Statistics Unit. FishStatPlus. Universal Software for fishery statistical time series. Version 2.3 in 2000. Last database update in April 2011 http://www.fao.org/docrep/013/i1820e/i1820e00.htm, Cited 10 Oct 2011.

FAO (2012). The State of World Fisheries and Aquaculture. ISBN: 978-92-5-107225-7. ftp://ftp.fao.org/FI/brochure/SOFIA/2012/english_flyer.pdf.

Fleurence J (2004). Seaweed proteins, in: R.Y. Yada (Ed.), Proteins in Food Processing, Woodhead Publishing, pp. 197-210.

Francis TL, Maneveldt GW, Venter J (2008). Growth of market-size abalone (*Haliotis midae*) fed kelp (*Ecklonia maxima*) versus a low-protein commercial feed. Afr. J. Aquat. Sci. 33(3):279-282.

Gallardo T, Garreta GA, Ribera MA, Cormaci M, Furnari G, Giacconi G, Boudouresque CF (1993). Checklist of Mediterranean seaweeds. II Chlorophyceae. Bot. Marina 36:399-421.

GPR (2005). General reasons for the decisions on the allocation of rights in the seaweed sector. DEAT publication. Available at http: www.mcm-deat.gov.za.

Hasan MR, Chakrabarti R (2009). Use of algae and aquatic macrophytes as feed in small-scale aquaculture: a review. FAO Fisheries and Aquaculture Technical. Rome, FAO. 2009. 531:123.

John DM, Lawson GW (1991). Littoral ecosystems of tropical western Africa. In: Mathieson, A.C. & Nienhuis, P.H. (eds) Intertidal and Littoral Ecosystems. Ecosys. World 24:297-322.

John DM, Lawson GW (1997). Seaweed biodiversity in West Africa: a criterion for designating marine protected areas S.M. Evans, C.J. Vanderpuye, A.K. Armah (Eds.), The Coastal Zone of West Africa: Problems and Management, Penshaw Press, Sunderland UK (1997), pp. 111-123.

Khan SI, Satam SB (2003). Seaweed Mari culture. Scope and Potential in India. Aquaculture Asia, 8(4):26-29.

Khan W, Rayirath UP, Subramanian S, Jithesh NM, Rayorath P, Hodges DM, Critchley AT, Craigie JS, Norrie J, Prithiviraj B (2009). Seaweed Extracts as Biostimulants of Plant Growth and Development. J. Plant. Growth Regul 28:386-399.

Klaus JH, Uwe F, Rocio H, Anja E, Morchio R, Suzanne H, Boosya B (2009). Aquatic Biomass: Sustainable Bio-energy from Algae? - Issue Paper -,The workshop is co-funded by two German research projects “bio-global” (sponsored by the Federal Ministry for Environment, BMUthrough the Federal Environment Agency, UBA) and “conCISEnet”(sponsored by the Federal Ministry for Education and Research, BMBF) Bio-global / conCISEnet.www.oeko.de.

Leonel P (2011).A Review of the Nutrient Composition of Selected Edible Seaweeds. In: Seaweed (Ed) by Vitor H. Pomin. Nova Science Publishers, Inc.

Lewis J, Salam F, Slack N, Winton M, Hobson L (2011). ‘Product options for the processing of marine macro-algae – Summary Report’.The Crown Estate, P. 44.

Lorentzen K, Amarasinghe US, Bartley DM, Bell JD, Bilio M, de Silva SS, Garaway CJ, Hartman WD, Kapetsky JM, Laleye P, Moreau J, Sugunan VV, Swar DB (2001). Strategic review of enhancement and culturebased fisheries. pp. 211-237 In Subasinghe, RP, Bueno, PB., Phillips, MJ. Hough C, McGladdery, SE, Arthur JR. (eds.). Aquaculture in the third millennium. Technical proceedings of the conference on aquaculture in the thirdmillennium, Bangkok, Thailand. 2025 February 2000. NACA, Bangkok and FAO, Rome.

Machena C, Moehl J (2001). Sub-Saharan African aquaculture: regional summary. In R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur, eds. Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000. pp. 341-355. NACA, Bangkok and FAO, Rome.

Maneveldt GW, Chamberlain YM, Keats DW (2008). A catalogue with keys to the non-geniculate coralline algae (Corallinales, Rhodophyta) of South Africa. South African Journal of Botany 74: 555-566.

McHugh DJ (1987) (ed.), 1987. Production and utilization of products from commercial seaweeds. FAO Fish. Tech. Pap. 288:189.

McHugh, DJ (2001). Prospects for Seaweed Production in Developing Countries. Food and Agriculture Nations, Rome.Organization, Rome, Italy.

McHugh DJ (1987) (ed.). Production and utilization of products from commercial seaweeds. FAO Fish. Tech. Paper 288:189.

Mohammad RH, Chakrabarti R (2009).Use of algae and aquatic macrophytes as feed in small-scale aquaculture: A review. FAO, Fisheries and aquaculture technical P. 531. Rome.

Naidoo K, Maneveldt G, Ruck K, Bolton JJ (2006). A comparison of various seaweed-based diets and artificial feed on growth rate of abalone in land-based aquaculture systems. J. Appl. Phycol. 18:437-443.

Neori A, Chopin T, Troell M, Buschmann AH, Kraemer GP, Halling C, Shpigel M, Yarish C (2004). Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern aquaculture. Aquaculture 231:361–391.

Neori A, Krom M, Ellner S, Boyd C, Popper D, Rabinovitch R, Davison P, Dvir O, Zuber D, Ucko M, Angel D, Gordin H (1996). Seaweed biofilters as regulators of water quality in integrated fish-seaweed culture units. Aquaculture 141:183–199.

Neori A, Ragg NLC, Shpigel M (1998). The integrated culture of seaweed, abalone, fish and clams in modular intensive land-based systems: II. Performance and nitrogen partitioning within an abalone (*Haliotis tuberculata*) and macroalgae culture system. Aquacult. Eng. 17:215–239.

Neori A, Cohen I, Gordin H (1991). *Ulva lactuca* biofilters for marine fish pond effluents. II. Growth rate, yield and C: N ratio. Bot. Mar. 34:483–489.

Nkutumula A (2011). Mozambique: Government Promotes Aquaculture, Fisheries Ministry, National Aquaculture Development Institute (INAQUA), http://allafrica.com/stories/201109141399.html.

Nobre AM, Robertson-Andersson DV, Neori A, Sankar K (2010). Ecological–economic assessment of aquaculture options: comparison between abalone monoculture and integrated multi-trophic aquaculture of abalone and seaweeds. Aquaculture 306:116–126.

Paul NA, Tseng CK (2012). Seaweed and Microalgae .Aquaculture: Farming Aquatic Animals and Plant, Second edition, edited by John S Lucas. C South gate. Blackwell Publishing Ltd.

Payne AIL, Crawford RJM, Van Dalsen A (1989). Oceans of Life off Southern Africa. Vlaeberg Publishers, Cape Town.

Pia W, Ghosh D, Tapsell L (2009). Seaweed Culture in Integrated Multi-Trophic Aquaculture: Nutritional Benefits and Systems for Australia, Rural Industries Research and Development Corporation. Project No. PRJ-000162.

Robertson-Andersson DV, Maneveldt GW, Naidoo K (2011). Effects of wild and farm-grown macroalgae on the growth of juvenile South African abalone *Haliotis midae* (Linnaeus). Afr. J. Aquatic Sci. 36(3):331-337

Robertson-Andersson DV (2007). Biological and economical feasibility studies of using seaweeds *Ulva lactuca* (chlorophyta) in recirculation systems in abalone farming. PhD Dissertation, University of Cape Town, South Africa.

Robertson-Andersson DV, Leitao D, Bolton JJ, Anderson RJ, Njobeni A, Ruck K (2006). Can kelp extract (KELPAK™) be useful in seaweed mariculture. J. Appl. Phycol. 18:315–321.

Robertson-Andersson DV (2003). The cultivation of *Ulva lactuca* (Chlorophyta) in an integrated aquaculture system, for the production of abalone feed and the bioremediation of aquaculture effluent. MSc Dissertation, University of Cape Town, South Africa.

Roesijadi G, Copping AE, Huesemann MH, Forster J, Benemann JR (2008). Techno-economic feasibility analysis of offshore seaweed farming for bioenergy and biobased products. Independent research and development report IR # PNWD-3931, Battelle Pacific Northwest Division, P. 115.

Rull Lluch JR (1999). Algues benthõniques marines de Namibia. Ph.D. thesis, University of Barcelona, Spain.

Rull Lluch JR (2002). Marine benthic algae of Namibia. Sci. Marina 66(3):5-256.

Schaeffer DJ, Krylov VS (2000). Anti-HIV activity of extracts and compounds from algae and cyanobacteria. Ecotoxicol. Environmental Safe. 45:208-227.

Simons RH, Jarman NG (1981). Subcommercial harvesting of kelp on a South African shore. Proceedings of the Tenth International Seaweed Symposium. De Gruyter, Berlin. pp. 731–736.

Smit AJ (2004). Medicinal and pharmaceutical uses of seaweed natural products: A review. J. Appl. Phycol. 16:245–262.

Smith MD, Roheim CA, Crowder LB, Halpern BS, Turnipseed M, Anderson JL, Asche F, Bourillón L, Guttormsen AG, Kahn A, Liguori LA, McNevin A, O'Connor M, Squires D, Tyedemers P, Brownstein C, Carden K, Klinger DH, Sagarin R, Selkoe KA (2010) Sustainability and Global Seafood. Science 327:784-786.

Stegenga H, Bolton JJ, Anderson RJ (1997). Seaweeds of the South African west coast. Contributions from the Bolus Herbarium University of Cape Town, 8: 655.

Stein JR, Borden CA (1984). Causative and beneficial algae in human disease conditions: A review. Phycologia 23:485-501.

Synytsya A, Kim W, Kim S, Pohl R, Synytsya A (2010). Structure and antitumour activity of fucoidan isolated from sporophyll of Korean brown seaweed *Undaria pinnatifida*. Carbohydr. Polym. 81(1):41–48.

Tietze HW (2004). Spirulina - Micro Food Macro Blessing, Harald W. Tietze Publishing, Bermagui NSW 2546 Australia.

Troell MD, Robertson-Andersson DV, Anderson RJ, Bolton JJ, Maneveldt G, Halling C, Probyn T (2006). Abalone farming in South Africa: An overview with perspectives on kelp resources, abalone feed, potential for on-farm seaweed production and socio-economic importance. J. Appl. Phycol. 257(4):266-281.

Troell M, Ronnback P, Halling C, Kautsky N, Buschmann A (1999). Ecological engineering in aquaculture: use of seaweeds for removing nutrients form intense mariculture. J. Appl. Phycol. 11:89-97.

Troell M, Hecht T, Beveridge M, Stead S, Bryceson I, Kautsky N, Mmochi A, Ollevier F (eds.) (2011) Mariculture in the WIO region - Challenges and Prospects. WIOMSA. Book Series No. 11:8-59.

Zemke-White WL, Clements KD, Harris PJ (1999). Acid lysis of macroalgae by marine herbivorous fishes: myth or digestive mechanism. J. Exper. Mar. Biol. Ecol. 233:95–113.

Zhang G, Que H, Liu X, Xu H (2004). Abalone mariculture in China. J. Shellfish Res. 23:947-950.