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ARTICLE *in* JOURNAL OF APPLIED PHYCOLOGY · OCTOBER 2008

Impact Factor: 2.56 · DOI: 10.1007/s10811-008-9385-6

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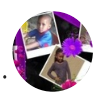
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J Appl Phycol
DOI 10.1007/s10811-008-9385-6

Growing *Ulva* (Chlorophyta) in integrated systems as a commercial crop for abalone feed in South Africa: a SWOT analysis

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Received: 24 July 2008 / Revised and accepted: 3 October 2008

Abstract Over 1,000t fresh weight of *Ulva* was cultivated on South African abalone farms in 2007, primarily for feed, but in one case to allow partial re-circulation by nutrient removal. The potential of this new commercial crop is analysed. Material is collected from natural free-floating populations and at least four species are commonly grown, with different ecophysiological characteristics. A brown epiphyte, *Myrionema strangulans*, causes a disease of the *Ulva*, which is currently managed by farmers by re-stocking. The main potential threat is that some farmers are wary of integrated systems, fearing they may promote disease in abalone, although *Ulva* has been grown in abalone effluent and fed back to the abalone on one farm for 6 years without adverse effects. Opportunities exist for the expansion of *Ulva* cultivation via further spread of the abalone industry, the inclusion of seaweed raceways in proposed fish-farming activities, or the potential for the inclusion of high quality cultivated *Ulva* as a constituent in aquafeed. A conservative estimate of production over a full year from these raceway systems was 26.1 g dw m^{-2} day^{-1} (2006) and 19.7 g dw m^{-2} day^{-1} (2007), similar to maximum figures for total annual microalgal biomass production in outdoor systems.

Keywords Abalone · Algae · Aquaculture · Biomass · Production · *Ulva*

Presented at the 3rd Congress of the International Society for Applied Phycology, Galway.

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Introduction

Species of the genus *Ulva* ('sea lettuce') are grown for human food in eastern countries (e.g. as 'aonori' in Japan; Ohno 1993), and since 1990 have been authorised for human food in France (Marfaing and Lerat 2007). *Ulva* species have also been grown in many parts of the world in pilot commercial systems (e.g. Parker 1981; De Busk et al. 1986; Neori et al. 1991, 2000, 2003; Israel et al. 1993), including integrated multi-trophic systems where *Ulva* culture is combined with aquaculture of marine animals (Cohen and Neori 1991; Jimenez del Rio et al. 1996; Neori et al. 1996, 1998, 2000; Neori and Shpigel 1999; Schuenhoff et al. 2003). A major reason for the widespread use of *Ulva* is that many species of this genus can thrive unattached in sheltered marine waters and estuaries, and have particular affinities for growth in high nitrogen concentrations. Seaweed species that grow naturally unattached are particularly suitable for aquaculture, a good example being the wide-spread commercial culture of the red seaweed *Gracilaria* for agar (Friedlander and Levy 1995; Oliveira et al. 2000). It appears that only if a seaweed is grown for a high price product can more sophisticated aquaculture, with control of the spore or gamete stages of the life history, be commercially worthwhile (e.g. large-scale culture of *Laminaria* and *Porphyra* for human food). For growth to produce large

Published online: 22 November 2008

biomass easily, thereby removing large amounts of dissolved nutrients, unattached *Ulva* species are perfect aquaculture candidates, and much research has been carried out on their growth in various systems (e.g. Ryther et al. 1984; Henley 1992). Despite this, *Ulva* is not grown commercially outside Asia (where it is grown for human food), because there is no market for it.

In South Africa, large-scale cultivation of the local abalone, *Haliotis midae*, has grown rapidly from its beginnings in the mid-1990s, and South Africa is currently the largest producer of cultured abalone outside Asia (Troell et al. 2006; Robertson-Andersson et al. 2008), producing ca. 1,100 t in 2007 (Robertson-Andersson 2007). Abalone are herbivores, and much of the early cultivation was carried out using freshly harvested kelp (mostly *Ecklonia maxima*) as feed (Troell et al. 2006; Anderson et al. 2007). From a peak of 6,000 t kelp harvested in 2004, the kelp usage has reduced to around 3,000 t in 2006 (Anderson et al. 2007), being replaced largely by compound feed (mostly the locally produced Abfeed®, Britz et al. 1994). Almost all South African abalone farms (ca. 20) are west of Cape Agulhas, the southernmost point of Africa, and close to the site of the easternmost kelp beds on the continent (see map in Troell et al. 2006). Two farms occur much further east: Marine Growers near Port Elizabeth, and Wild Coast Abalone at Haga Haga near East London. In the 1990s, the former farm began experimental studies in the cultivation of initially *Gracilaria* (Fourie 1994; Smit 1997; Hampson 1998) and later *Ulva* (Steyn 2000) for feed addition. Since then, Wild Coast Abalone have become world leaders in *Ulva* cultivation. In 1992, the farm built a series of 32 large-scale raceways growing seaweed in effluent from the flow-through abalone tanks, and using paddle wheels for water movement, with dimensions of 40 m×10 m and a depth of 0.5–0.75 m. These are similar to *Gracilaria* paddle raceways used by Lipkin and Friedlander (1998). It appears that the first to use such paddle raceways for seaweeds were Neish et al. 1977 (according to Friedlander and Levy 1995). Initially both *Gracilaria* and *Ulva* were cultivated, but for the last few years they have been used to grow *Ulva*. This integrated abalone/*Ulva* system produces ca. 2.5 t *Ulva* per working day thoughout the year (Richard Clark, personal communication; Bolton 2006a, b; Robertson-Andersson et al. 2008).

A further advance in the cultivation of *Ulva* on South African abalone farms came in early 2006, with the setting up of an integrated abalone/*Ulva* system with partial re-circulation on a farm on the southwest coast (I & J West Coast Abalone in Gansbaai). This was built as a separate extension to the farm's previous abalone cultivation. The effluent from the abalone tanks (after sediment is removed) flows through four paddle raceways, similar to those at Wild Coast Abalone. After passing through the seaweed raceways, ca. 50% of the effluent water is re-circulated back to the abalone tanks. This system has been running commercially since January 2006. The system was modelled using data from scientists working with smaller experimental systems on the farm (Potgieter 2005; Flodin 2005; Hansen 2005; Brandt 2006; Lindstrom 2006; Robertson-Andersson 2003, 2007, Robertson-Andersson et al. 2008). Extrapolating from these experimental data, a target of 2.5 t per pond per month in summer and 1.5 t per raceway per month in winter was proposed. This system has been running since January 2006, and the average production figures per raceway per month from January 2006 until May 2008 are shown in Fig. 1. It can be seen that production has been increasing, and is approaching proposed target production. The average monthly yield per raceway throughout 2006 was 1,877 kg and for 2007 was 1,419 kg. (Fig. 1). Yields fall below target particularly in the early months of the year (January–March). This problem is associated with an epiphyte growth on the *Ulva*, which will be discussed later.

In addition, three other farms produce smaller amounts of *Ulva* in one or more paddle raceways, for feed addition. The estimated figure of 1,100 t wet weight of *Ulva* currently produced in South Africa for abalone feed (Marine & Coastal Management, personal communication) is the same figure as the current estimated annual abalone production.

The rationale for this paper is that commercial cultivation of *Ulva* for abalone feed has been successfully carried out for a number of years in South Africa. We will discuss this venture, structuring the discussion using the format of a SWOT (strengths, weaknesses, opportunities, threats) analysis of *Ulva* cultivation on South African abalone farms. This SWOT analysis was carried out by seaweed biologists, using their experience in working with industry over a number of years. Much research has been carried out on *Ulva* cultivation in many countries without the initiation of a successful long-term commercial venture. This contribution is thus specifically aimed at the perceived attributes of *Ulva* cultivation, to investigate why this commercial seaweed cultivation has been successful in South Africa.

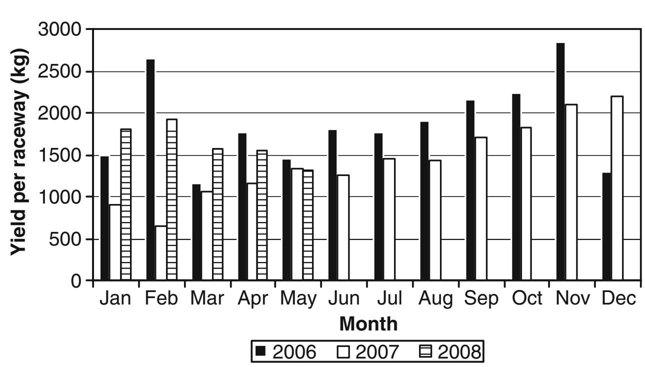

Fig. 1 Monthly yields of *Ulva* in paddle raceways at I&J Abalone Farm, Gansbaai, South Africa from January 2006 to May 2008

Strengths

The most obvious strength (Fig. 2) of *Ulva* cultivation is that it has proved easy to grow. *Ulva* and *Gracilaria* have been considered the most likely candidates for large-scale seaweed biomass production for many years (see, e.g. Ryther et al. 1984). There was some initial local research growing *Gracilaria* on rope rafts in the sea both in neighbouring Namibia (Dawes 1995; Molloy and Bolton 1996) and in South Africa (Anderson et al. 1996, 2003; Wakibia et al. 2001). Thus, when initial studies to grow seaweeds for feed began, at Marine Growers farm in Port Elizabeth, *Gracilaria* was an obvious candidate. These farms were assisted scientifically by a group from the University of Port Elizabeth, now the Nelson Mandela Metropolitan University (Fourie 1994; Smit 1997; Hampson 1998; Smit et al. 2003). During these experiments, difficulties were experienced with clumping of the seaweed and epiphytic growth of diatoms and filamentous brown algae, and *Ulva* grew spontaneously in some of the tanks and proved useful abalone feed. Interest was switched to growing *Ulva* (Steyn 2000). Consequently, when the paddle raceways at Wild Coast Abalone were initially set up, both *Ulva* and *Gracilaria* were grown. Over a number of years, South African farmers have shown that *Ulva* is much easier to produce in these systems than *Gracilaria*. Interestingly, studies on a European Union project to find new seaweeds for aquaculture had little success with *Ulva*, having problems with fertility and consequent disintegration of thalli (Klaus Lüning, personal communication). This has not proved a problem on South African abalone farms. The *Ulva* has shown itself to be particularly amenable to growth in large shallow raceways, with water motion provided by energy-efficient paddles. There is much less attached seaweed and other growth on the edges of tanks and raceways of *Ulva* compared to those with *Gracilaria*, presumably because the *Ulva* plants are suspended efficiently by the water motion, and thus reduce light throughout the ponds.

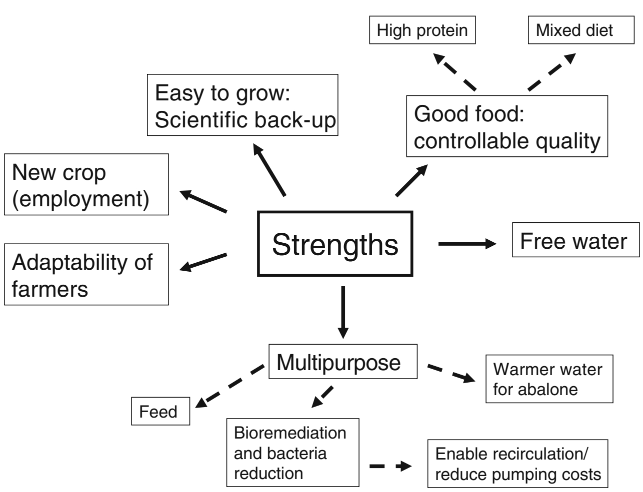

Fig. 2 Strengths of commercial *Ulva* cultivation in South Africa

Another critical strength in this system is the fact that pumped water to culture the seaweed is available without cost in this system. The abalone farming is commercially successful in its own right and, given the correct infrastructure planning, the abalone effluent is available for seaweed cultivation. The socio-economic factors have also proved very important. A number of entrepreneurs and farm managers who have so successfully initiated abalone farming in South Africa appear to be open to new ideas, and have been willing to try new aquaculture products and systems. Although they have been assisted by the availability of scientific expertise, it is clear that the success of seaweed cultivation has been dependent on innovative and outward-thinking farmers. Currently around 15 people are employed full-time to grow *Ulva* in South Africa. This compares with 388 people employed in the commercial collection of kelp for abalone feed (Robertson-Andersson 2007).

Many experimental studies using seaweeds as animal feed collect seaweeds from natural populations. It is critical in this context that cultured seaweed can be produced that is of much better quality, as feed, than natural stocks. For example, the protein content of *Ulva* has been increased to over 30% of dry weight in South African systems (Robertson-Andersson 2003, 2007), and experimental trials showed that kelp plus cultured seaweed addition (*Gracilaria* and *Ulva*) produced as much abalone growth as compound feed (Naidoo et al. 2006). Thus, cultivated seaweed is of a better and more controllable quality than feeds such as kelp (local *Ecklonia maxima* has around 11–12% of dry weight crude protein throughout the year; Smith 2007).

The success of the re-circulating system at I&J has proved to be due to the multipurpose role of the *Ulva* ponds in the system. The *Ulva* not only provides abalone feed and reduces ammonia and bacteria levels (Flodin 2005) in the effluent, allowing partial re-circulation (thus slightly reducing pumping costs due to reduced pumping height) but also, especially due to the enhanced light-absorbing properties of the seaweed, increases the temperature of the abalone culture tanks. As most farms in South Africa (including I&J) occur where ambient seawater temperatures are sub-optimal for abalone, this thus increases the growth rate of the abalone, and hence increases profits (Robertson-Andersson 2007; Robertson-Andersson et al. 2008),

Weaknesses

As with all new aquaculture ventures, the novelty of the system means that some farmers will prove sceptical and not all will make the necessary commitment to make seaweed cultivation possible. A considerable buy-in from the farmers and their backers to the idea of seaweed cultivation is necessary, as the infrastructure for this integrated abalone/seaweed system has to be planned in advance. This is because land has to be available for seaweed culture that can be fed by gravity from abalone systems on higher ground. The commercial benefit of seaweed production is 'invisible' in that it does not appear on balance sheets. The seaweed is not sold, and this has the additional drawback that *Ulva*—one of the major products, in terms of fresh weight, in current South African aquaculture—does not appear in any aquaculture summaries from industry or Government sources. It is clearly much easier for a farmer to buy and feed dry compound abalone feed (mostly the locally produced Abfeed®; Britz et al. 1994; Anon. 2008), than to construct and maintain large systems for seaweed production.

Other main weaknesses of the systems currently in operation concern the biology of the *Ulva* itself, and are related to our increasing knowledge of it but also many knowledge-gaps (Fig. 3). Taxonomic studies on South African Ulvaceae have begun (Joska 1992; Stegenga et al. 1997; Kandjengo 2002), but the genus *Ulva* (now including the former genus *Enteromorpha*; Hayden et al. 2003) is taxonomically very complicated. At least four different species of *Ulva* have been grown commercially on South African abalone farms. The morphological taxonomy of local Ulvaceae has been studied for the coastline west of Cape Agulhas, where most of the abalone farms occur. However, *Ulva* species have few morphological characters, and those grown in aquaculture systems almost always lack holdfast tissue, thus reducing potentially useful identification characteristics still further. The source of aquacultured *Ulva* has been sheltered bays and harbours, often close to the farm (e.g. Gansbaai harbour for I&J, or Saldanha Bay for farms on the west coast, such as Jacobsbaai Sea Products). There is, however, evidence that what eventually grows in the system may be material that is present at the farm locality, which dominates in the local pond conditions. For example, material cultivated in the early years at Wild Coast Abalone (Haga Haga) fitted the morphological description of South African *U. rigida*, whereas the material currently grown (sent to the authors in May 2008) was rather *U. linza* (according to the description in Stegenga et al. 1997, verified by Herre Stegenga). Material grown at I&J, according to its morphological attributes, has included *U. rigida*, *U. capensis*, and *U. lactuca*, with the latter currently predominating. Local material of most of these species is taxonomically problematic. South African *U. lactuca* is not identical in its rbcL sequences with European *U. lactuca* (the source of the type), and will thus be likely to need a new name once studies are completed (L.K., unpublished data).

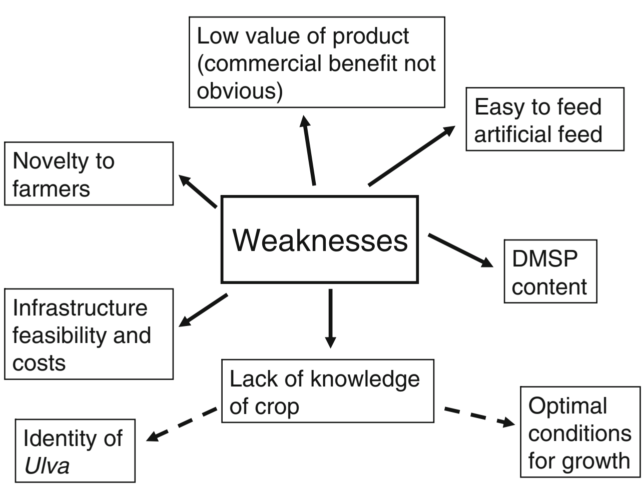

Fig. 3 Weaknesses of commercial *Ulva* cultivation in South Africa. *DMSP* Dimethyl sulphonio-proprionate

The critical matter to South African *Ulva* growers concerns whether these different taxonomic entities have different ecological growth requirements, and these are currently being studied in the laboratory. An example concerns *U. lactuca* and *U. rigida*, which were both present in pilot commercial tank cultures on a west coast farm (Jacobsbaai Sea Products: Robertson-Andersson 2003). Figure 4 shows the relative numbers of pieces of the two species of *Ulva* in these tanks over the course of a year (July 2001 to July 2002). These tanks were subjected to 80% shadecloth in the summer (December), at which point the *Ulva* composition changed rapidly from a dominance of *U. lactuca* to *U. capensis*. On gradual removal of the shadecloth, this dominance reversed. There is clearly much work to be done on selection of species and strains of *Ulva* for cultivation in different geographical regions and ecological conditions, and this requires a thorough taxonomic treatment of available genetic material, using molecular methods. This has relevance wherever *Ulva* is commercially cultivated, especially as much of it is described as *Ulva lactuca* wherever it is grown around the world, almost always without convincing taxonomic evidence.

Another weakness specific to *Ulva* as feed is the high concentration of dimethyl sulphonio-proprionate (DMSP) in the plants (Smit et al. 2007). *Ulva*-fed abalone concentrate large amounts of DMSP in their tissues. This can prove to be a problem if the abalone are canned, when the DMSP is converted by heat to dimethyl sulphide (DMS), creating odour problems. This problem can be managed by feeding the abalone for the last 3–6 months on other feeds (Smit et al. 2007). Taste tests have, however, suggested that smaller amounts of DMSP may enhance the taste of wild and cultured abalone (Robertson-Andersson 2007).

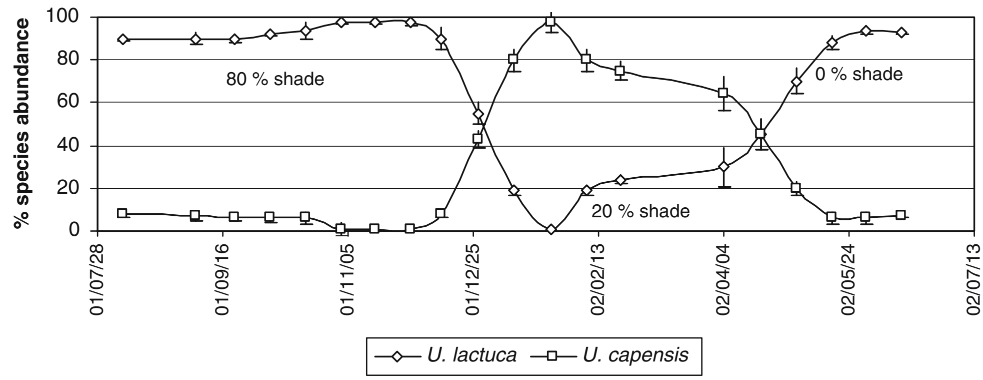

Fig. 4 Percentage of plants of *Ulva lactuca* and *Ulva capensis* in tank cultures in abalone effluent at Jacobsbaai Sea Products abalone farm, South Africa from July 2001 to July 2002. 80% shadecloth was added in September 2001, reduced to 20% shadecloth in February 2002, and shadecloth was removed in May 2002

Opportunities

The South African abalone industry is predicted to double in the next 5 years (Robertson-Andersson 2007). There is clearly potential for the cultivation of *Ulva* to increase correspondingly (Fig. 5). In addition, there are many initiatives for fish farming in South Africa, including some involving production in land-based systems. As *Ulva* cultivation in aquaculture effluent is successfully carried out locally, the opportunity exists to incorporate seaweed production into future aquaculture initiatives. Aquaculture is given high priority by the South African Government, with a new policy for marine aquaculture gazetted on 7 September 2007 (Anon 2007). In this policy document, proposed research and technology development programmes include: abalone culture support programme, integrated aquaculture, seaweed research, nutrition. There is clearly strong government support for integrated systems such as those growing abalone/seaweed.

As large amounts of seaweed can be grown in these systems there may be the opportunity to use the seaweed in some way other than as fresh feed. As seaweeds are the natural diet of abalone and other commercially important seafood products such as sea urchins (Vasserot 1990; Unuma 2002; Shpigel et al. 2005) it may be feasible and useful to include seaweeds such as *Ulva* as components in compound aquafeed. Apart from the relatively high protein content of cultured *Ulva*, there is evidence that the presence of seaweed extracts increases feeding in sea urchins (Dworjanyn et al. 2007), and there is the possibility that seaweeds could at least partially replace fishmeal/fish oil in aquafeeds prepared for herbivores and omnivores. Apart from its potential as an aquafeed component, further markets for seaweed biomass may become available in the future, perhaps in the burgeoning biofuel industry (Ryther et al. 1984; Raiko et al. 2003).

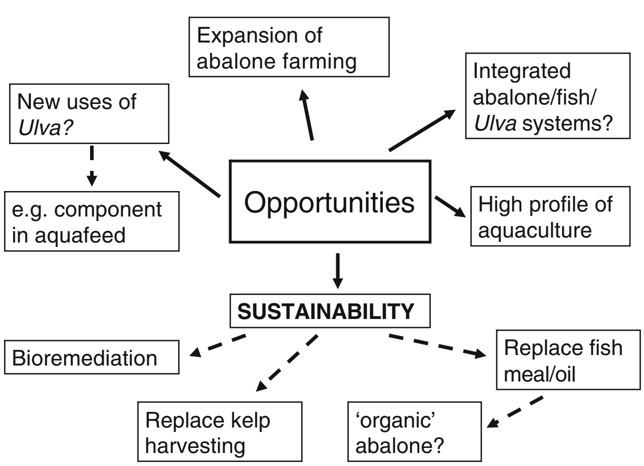

Fig. 5 Opportunities for commercial *Ulva* cultivation in South Africa

A particularly important aspect of opportunity for seaweeds in aquaculture concerns the drive for sustainability of aquaculture systems. Much has been written on the importance of integrated multi-trophic systems (IMTA) in enhancing aquaculture sustainability in the future (Troell et al. 1999, 2003; Chopin et al. 2001; Neori et al. 2004, 2007). In such systems, the seaweeds contribute bioremediation capacity by removing dissolved nutrients from the effluent. The potential for seaweeds as components of aquafeed could be a further contribution towards sustainability of the system (Nakagawa et al. 1987; Hashim and Maat-Saat 1992). It is possible that this could become a marketing tool for abalone, as abalone fed on seaweed as opposed to those fed on compound feed containing fishmeal/oil could be marketed on the basis of the sustainability of the operation—perhaps as 'organic' abalone? In addition, the cultivation of seaweed as feed on South African abalone farms has the potential to reduce the harvesting of natural kelp beds (Troell et al. 2006; Anderson et al. 2007), offering another potential contribution towards sustainability of natural resources.

Threats

The cultivation of seaweeds on abalone farms will always be subject to financial threats, as coastal land is at a premium and farmers may not see a commercial benefit in seaweed production on land that could be producing more profitable abalone. The outcome depends on how individual farmers see the balance between feed, price, seaweed feed production, and other benefits and drawbacks associated with the integrated systems.

Many grazer species appear in the *Ulva* aquaculture systems, with the most problematic being the keyhole limpet, *Fissurella mutabilis* (Hansen et al. 2006). It has proved possible to reduce the loss of production from these grazers by washes with fresh water. Some species of *Ulva* are particularly tolerant of lowered salinity, with South African *Ulva rigida* discs surviving 2 weeks in distilled water plus one-third Provasoli ES nutrients (D. S., unpublished data). This procedure has also been used successfully against amphipod growth in South African *Gracilaria* aquaculture (Smit et al. 2003).

There are, however, two major threats to the successful continuation of *Ulva* aquaculture in South Africa (Fig. 6). Firstly, production drops due to poor health and fragmentation of the seaweed in the I&J systems in late spring/early summer, associated with large amounts of epiphytic growth of the brown crustose seaweed *Myrionema strangulans* (Robertson-Andersson 2003, 2007; Robertson-Andersson et al. 2008). This species grows widely in temperate seas, and can produce profuse growth on *Ulva* elsewhere (e.g. see infestation on *Ulva lactuca* in Abb. 28 of Kornmann and Sahling 1983). For the last few years, *Myrionema* growths have been seasonal in the systems at I&J, growing on both *Ulva lactuca* and *U. capensis*. They generally appear in late winter (July/August), reaching a peak in December (Robertson-Andersson 2007). The infestation coincides with a general weakening of the thalli, with lowered nitrogen content. Many perforations appear in the thalli, at least some of which are associated with the disintegrating centres of the circular discs of *Myrionema*. Eventually, the *Ulva* disintegrates and loses pigment, and cultures need to be re-stocked, either from stock tanks, which are grown more slowly and shaded, which apparently reduces *Myrionema* growth, or from field populations. *M. strangulans* can grow very quickly, with Kornmann and Sahling (1983) producing fertile plants from spores in 11 days in the laboratory. From preliminary experiments, low salinity treatment may also be efficacious with this problem, as it appears that the *Myrionema* is less resistant that the *Ulva*. In short-term experiments in the laboratory, it has also been shown that culturing of *Myrionema*-infected discs of *Ulva* in high nutrient media causes the epiphytes to disappear within 2 weeks (D.S., unpublished data). It is likely that low nutrients in the *Ulva* at I & J farm are implicated in the onset of the observed spots of *Myrionema*. Detailed studies are in progress.

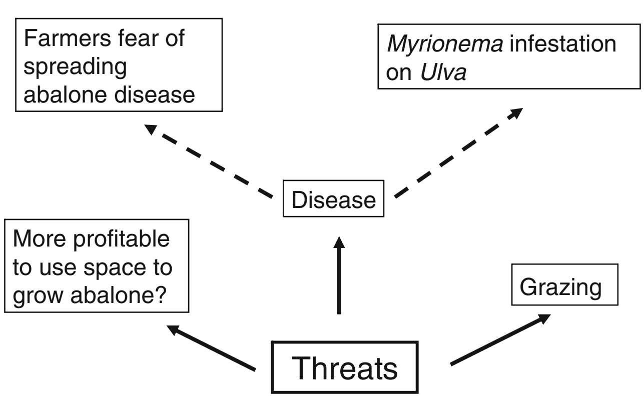

Fig. 6 Threats to commercial *Ulva* cultivation in South Africa

A ‘perforation disease’ of *Ulva* has been reported previously in Israel (Colorni 1989), but in that case there was no biological agent that appeared to be associated with disease symptoms. Colorni (1989) studied other organisms associated with their diseased *Ulva*, and does illustrate a crustose epiphyte (see Fig. 6 in Colorni 1989), but the epiphytes were not thought to contribute to the disease symptoms. These epiphyte crusts were not identified, but appear from the illustration to be a species of the green alga *Ulvella*. Ryther et al. (1984) report that their *Ulva* “occasionally fragmented in isolated tanks”. Very similar occasional fragmentation of *Ulva* in individual raceways without *Myrionema* infestation also occurs in the I&J recirculation system.

The most important threat to the commercial culture of *Ulva* probably concerns farmers’ perceptions rather than any immediately testable scientific phenomenon. Diseases of abalone have caused great problems in aquaculture industries around the world (for recent examples, see Miner et al. 2006; Hooper et al. 2007; Sawabe et al. 2007). The main disease problem in South Africa is the sabellid worm *Terebrasabella heterouncinata* (Ruck and Cook 1998). The latter is managed and contained in the South African industry, although feeding with formulated feed can exacerbate sabellid infestation, and requires greater water flow in the abalone tanks than kelp-fed abalone to reduce this (Anon 2008). Despite the fact that *Ulva* has been cultured in abalone waste and fed back to the abalone for around 6 years at Wild Coast Abalone without any increase in disease, other farmers and potential farmers express misgivings about the possibility of spreading some as yet unknown disease between abalone and seaweed tanks in integrated systems. This is a particular problem with integrated systems such as these, where one product is re-introduced elsewhere in the system.

Conclusions

The adaptability of South African abalone farmers, particularly their willingness to try new species, and the availability of the scientific knowledge to grow *Ulva* cheaply and successfully have combined to produce the current commercial abalone/seaweed integrated systems, which appear to be unique worldwide (Neori et al. 2007). Most weaknesses of and threats to the system are being managed adequately. It is apparent from the Wild Coast abalone system, that the lack of available kelp, and the real or perceived benefit of feeding live seaweed, has produced a commercial successful integrated abalone/seaweed system. In the case of the I&J recirculation system, the bioremediation aspect of the seaweed has added to the economic benefits, by both reducing pumping costs and increasing water temperature in the abalone tanks (Robertson-Andersson 2007). One weakness (seaweed quality) is solved to an extent by controlled cultivation, and a specifically problematic aspect of the seaweed cultivation system (the *Myrionema* infestation) is being successfully managed. The main threat to the continuing success of this seaweed cultivation is a perception of the possible transfer of disease organisms within re-circulating systems, or systems in which components are transferred between the multi-trophic levels of the system. So far these fears have proved unfounded, but they could be solved in the future either by finding a market for the *Ulva* produced, or by the introduction of a seaweed that grows as easily as *Ulva* but which has an intrinsic market value. There is clearly an opportunity to investigate the use of seaweed as a component of compound aquafeed.

It is important that studies of IMTA need to differentiate between three types of IMTA:

1. IMTA in the sea (e.g. Chopin et al. 1999; Whitmarsh et al. 2006)
2. IMTA on land in flow-through systems (e.g. Wild Coast Abalone abalone/*Ulva* system)
3. IMTA on land involving re-circulation of water and/or feed produced in the system (e.g. I&J abalone/*Ulva* system).

The cultivation of *Ulva* in raceway ponds in South Africa has produced the first continuous commercial production data available over an annual period. A conservative figure for daily yield (as dry weight per area, using 90% water content) for 2006 would be as follows:

- 1.877 t month^{-1} raceway^{-1}=6.26 kg day^{-1} (wet)
- At 90% water content=6.26 kg dry day^{-1} raceway^{-1}
- Raceways 30 m×8 m=240 m^{-2}
- Production=6,260 g day^{-1} on 240 m^{-2}=26.1g dw m^{-2} day^{-1}

Similarly, the figure for 2007 would be 19.71 g dw m^{-2} day^{-1}. These are very high figures for continuous algal biomass production over a year. Figures in the literature for smaller tank systems are generally higher, as are figures calculated over shorter time periods in optimal seasons. These South African figures are of the same order of magnitude as those presented by Ryther et al. (1984) for similar large scale production of *Ulva*. In 'non-energy intensive conditions' (no aeration, short seawater residence times) Ryther et al. (1984) attained a production figure of 6.8 g dw m^{-2} day^{-1} over a 250-day period, increasing to 18.8 g dw m^{-2} day^{-1} under 'more energy intensive conditions' (continuous aeration, short seawater residence time). The yield from the South African systems, and the top yields obtained by Ryther et al., are very similar to figures for microalgae grown throughout the year in similar systems. Borowitzka (1999) gives a figure of 25 g dw m^{-2} day^{-1} for *Chlorella* grow in open systems over a long period in Western Australia, and similar figures (24–35 g dw m^{-2} day^{-1}) are generally quoted in the literature on cultivating microalgae in open systems over the whole year for biofuel (e.g. Chisti 2007; Patil et al. 2008). If *Ulva* were to prove a useful source of biomass for, e.g. bioethanol production (see Ryther et al. 1984), these pond systems in South Africa would appear to be competitive to outdoor microalgal raceways for year-round biomass production.

Acknowledgements The authors would like to thank I&J Cape Abalone and their seaweed production team for excellent assistance and permission to publish production data, Wild Coast Abalone, as well as the National Research Foundation and the Department of Environmental Affairs and Tourism for funding.

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