The Mauritian Seaweed Flora: Diversity and Potential for Sustainable Utilisation

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The Mauritian Seaweed Flora: Diversity and Potential for Sustainable Utilisation

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Abstract

The world seaweed industry is currently worth over US$7.4 billion, and the potential for increased seaweed use exists in many countries. The species diversity of seaweeds in Mauritius has been extremely well documented in comparison with many local islands and regions, largely due to the work of the Danish phycologist Dr F. Boergesen, published from 1940-1957. The recorded seaweed flora is currently 435 species (59 brown algae, 108 green algae and 268 red algae), which is more than have thus far been recorded in either Kenya or Tanzania, and many more than for any other similar islands in the Indian Ocean. The world seaweed industry is growing rapidly, particularly the aquaculture sector, and possibilities for sustainable seaweed utilisation in Mauritius are discussed. Most seaweed culture for human food occurs in temperate regions, and current successful industries in tropical environments, especially the culture of *Eucheuma* / *Kappaphycus* for carrageenans, are in developing countries with low average incomes, often

involving the importation of non-indigenous species. Possibilities exist in the aquaculture of seaweeds including in integrated systems for bioremediation and/or as animal feed, as well as the potential for utilisation of abundant species as feed or fertiliser or in small value-added industries. As an example, the worldwide uses of *Sargassum*, perhaps the most abundant local genus, are discussed.

**For correspondences and reprints*

1. INTRODUCTION

Seaweeds (marine macroalgae) are economically utilised in many countries, and the current value of the world seaweed industry is estimated at more than US$7 billion (FAO 2010). Many countries are considering the potential for a local seaweed industry and this contribution summarises what is known about Mauritian seaweeds, and discusses their potential for sustainable use.

2. MAURITIUS AND ITS MARINE ENVIRONMENT

The island of Mauritius, covering an area of about 2040 km^2 and located at latitudes 19°59'S-20°32'S and longitudes 57°18'E-57°47'E in the Western Indian Ocean is about 800 km east of Madagascar. The mean sea surface temperature is 25.7°C and normally varies between 23°C in winter and 27°C during summer. Semidiurnal tides with a very small tidal range of 0.6 m at springs and 0.5 m at neaps occur around the island. The south east trade winds are prevalent throughout the year, especially during the cooler season of May to November. On the south coast the mean wave heights range between 1.67 m in the summer to 2.86 m in the winter (Fagoonee 1990). Annual rainfall varies from 1200 mm on to 3600 mm on the north coast and the central plateau, respectively.

A large submarine platform surrounds the island. This 25 km platform has allowed the development of extensive coral reefs that covers an area of 300 km^2 (Montaggioni and Mahe 1980). Lagoons are generally shallow (2-3 m) (Turner *et* *al.* 2000) reaching depths of 6 m in the north. Because of the low tidal range of 0.5 m and related topographical features the Mauritian intertidal is narrow. The island has a coastline of 177 km and 243 km^2 area of lagoon water surrounds the island. The lagoons extend from a few meters in width in the Petite Rivière Noire region to some 7 km in Bay of Mahébourg.

3. HISTORY OF SEAWEED STUDY IN MAURITIUS

The Mauritian seaweed flora is arguably the best known in the Indian Ocean, with regard to the documentation of the species present. This was largely due to the work of one man, Dr Frederik Boergesen of Denmark, who began working on Mauritian seaweeds in 1939 at the age of 70, and wrote 15 detailed papers describing the seaweed flora (Boergesen 1940-1957). He described the species based on specimens sent to him over many years by Dr RE Vaughan, a terrestrial botanist based in Mauritius. The correspondence from Boergesen to Vaughan over almost two decades was kept by Vaughan, and is archived in the Herbarium of the Mauritius Sugar Research Institute (which also houses the only well-maintained herbarium collection of seaweeds on the island). Boergesen never visited Mauritius, and Boergesen and Vaughan never met. According to De Clerck *et al.* (2004), 311 species of seaweeds were recorded for the island of Mauritius prior to their work. The only notable more recent publications recording additional species for the Mauritian islands are two papers on the seaweeds of the island of Rodrigues (Coppejans *et al.* 2004, De Clerck *et al.* 2004). Occasional visits of seaweed biologists have resulted in lists of species from various localities (e.g. Mshigeni 1985, Jagtap 1993).

In contrast, much less is known about the distribution and ecology of seaweeds on Mauritius. Jagtap (1993) provides data on abundance and ecological dominance of seaweed species at a number of sites around the island.

4. MAURITIAN SEAWEED DIVERSITY

The algal website www.Algaebase.com includes global distributions of all seaweed species, taken from the scientific published literature. A list of the species of Mauritius downloaded from the site (Guiry and Guiry 2011) includes 435 currently accepted species names (59 Phaeophyceae, 108 Chlorophyceae and 268 Rhodophyceae). Most of this information is taken from the catalogue of Indian Ocean seaweeds (Silva *et al.* 1996). This is a remarkable figure for a small Island state, and is about the same as have been recorded from the entire coastline of Tanzania (Table 1) and more than have been recorded for any of the countries of the East African coastline (with the exception of South Africa, which has 2,900 km of coastline including portions of three marine realms (Bolton and Stegenga 2002, Bolton *et al.* 2004, Spalding *et al.* 2007). Seaweed species richness in the flora of a region on a global scale correlates with the log of the coastline length (Santelices *et al.* 2009). The high diversity on Mauritius reflects extremely high species diversity on Mauritius and also the extremely detailed nature of Vaughan's collecting and Boergesen's documentation. Jagtap (1993) collected 127 species of seaweeds (including 5 Cyanobacteria) in transects at 10 sites around Mauritius over a period of two months. Jagtap (1993) was of the opinion that "the poor representation of marine algae and seagrasses reflects the degradation of the marine ecosystem". This view was apparently based on a comparison with the much larger number of species listed by Boergesen, although the latter were collected at many sites over almost two decades. Although there is no doubt that human activities have reduced marine species numbers at many specific sites, as evidenced by the high biomass of 'weedy' seaweeds such as *Ulva* spp., it would be difficult to demonstrate that the seaweed diversity as a whole has been reduced.

The only detailed information available on seaweed species abundance in Mauritius is in the work of Jagtap (1993) who estimated seaweed abundance in a single transect at 10 sites around the island. Most of the biomass occurred in the intertidal zone and in lagoons, with the dominant genera being *Ulva*, *Cladophora*, *Boodlea*, *Sargassum*, *Turbinaria*, *Gracilaria*, *Hypnea*, *Digenea* and

Palisada(formerly *Laurencia*). In the subtidal region associated with corals, only a few genera were abundant, such as *Asparagopsis*, *Halimeda*, *Turbinaria* and coralline red algae.

Table 1. The number of seaweed species recorded in Mauritius, and in other countries in East and Southern Africa.

Region	**Number of species**	**Source**
Mauritius (including Rodrigues)	435	Guiry and Guiry (2011)
Rodrigues	139	De Clerck *et al.* (2004), Coppejans *et al.* (2004)
Somalia	211	Bolton *et al.* (2003)
Kenya	386	Bolton *et al.* (2007)
Tanzania	428	Bolton *et al.* (2003)
Mozambique	243	Bolton *et al.* (2003)
South Africa	850	Bolton and Stegenga (2002)
Namibia	196	Rull Lluch (2002)
Angola	169	Anderson *et al.* (*in press*)

5. POTENTIAL FOR SUSTAINABLE UTILISATION OF SEAWEEDS IN MAURITIUS

World seaweed aquaculture production is currently estimated at a worth of US$7.4 billion per annum, representing 93.8% of world seaweed production in 2008. Seaweed aquaculture production grew at an average annual rate of 7.7% from 1970 to 2008 (FAO 2010). These remarkable facts cause society representatives and marine scientists in many coastal countries to consider the possibility of a seaweed industry (e.g. recently in Nigeria: Abowei and Tawari 2011). Mauritius has an Exclusive Economic Zone (EEZ) of 1.9 million km^2 of sea (Mauritius Oceanography Institute, 2002-2009), and thus possesses great potential for similar industries. In May 2011, the Mauritius Research Council (MRC) brought together research and industry stakeholders to discuss the potential for local seaweed use in the future. The MRC for the last few years have invested in generating scientific information to foster the potential seaweed industry in Mauritius and Rodrigues (Republic of Mauritius Portal 2011).

World seaweed aquaculture is mainly based on species for human food and the colloid industry. Of the 15.8 million fresh tons produced in 2008 (FAO 2010), more than half of this material was of three groups of temperate algae which could not grow in Mauritian natural sea temperature conditions: *Saccharina* (formerly *Laminaria*) *japonica*, *Porphyra* spp., and *Undaria pinnatifida* (often known by the Japanese names kombu, nori and wakame). These could only be produced commercially in Mauritius if some engineering system was introduced to bring up cooler, deeper seawater for some other purpose (Mauritius Research Council Brochure 2007). The other main products globally are *Eucheuma* (species of *Eucheuma* and *Kappaphycus*) for carrageenan, and *Gracilaria* (species of *Gracilaria* and *Gracilariopsis*) mostly for agar. The prices of dry seaweeds for colloids are much lower than for human food, and the vast majority of seaweed produced for colloids in aquaculture is grown by coastal villagers in areas where per capita incomes are not high (Wakibia *et al.* in press). The world *Eucheuma* industry is based on the introduction of cultured material of a number of strains which were originally from the Philippines, and have been selected over many years for aquaculture potential. These have been introduced across the entire Indo-Pacific, although only in a few countries have these systems been successful. The key factors in this success have been reported as careful site selection, as well as "*a well-designed and funded cultivation and development programme, with a management plan and an assured market*" (Ask *et al.* 2003). The major success story in the Western Indian Ocean has been the *Eucheuma* industry in Tanzania: 5000-6000 tons of dry *Eucheuma* were produced on the island of Zanzibar in 2000 (Oliveira *et al.* 2005). If plans were introduced to import commercial *Eucheuma* into Mauritian waters, much thought should be given as to whether the price of the product and the potential aquaculture area available are sufficient to make an industry viable, as well as potential ecosystem consequences of the introduction of alien seaweed cultivars (Pickering *et al.* 2007). In contrast, in the *Gracilaria* industry many different local species are grown around the world. Most of the species which are successfully aquacultured are finely branched, terete ('stringy') species, which generally grow loosely attached in sheltered bays or estuaries (Oliveira *et al.* 2000), e.g. *Gracilaria chilensis* in Chile, or *Gracilaria gracilis* in Namibia (Dawes 1995). Boergesen (1950) records *Gracilaria confervoides* for Mauritius, which could be a species of either *Gracilaria* or *Gracilariopsis* (see Iyer*et al.* 2005), and which would make a good likely candidate for aquaculture on rope systems (see Anderson *et al.* 2003).

There are numerous niche markets for small industries based on seaweeds around the world. Many of these are in places where seaweeds are traditionally eaten (e.g. Asian countries, Polynesia etc.), but also include the cosmetic, health and nutraceutical industries. Other possibilities are as fertiliser or animal feed additions. The benefits of seaweeds in the latter industries are based generally on the mineral content, although high-value agricultural products are made from some seaweeds (generally large brown algae) by cold extraction methods based on the content of plant hormones (Stirk and Van Staden 1996).

Fish aquaculture has already begun in Mauritius (e.g. The Mahébourg Marine Farm has been operational since 2005, and employs some 120 people), and similar activities are increasing in many countries. Fed aquaculture (e.g. finfish, crustaceans and non-filter feeding molluscs) tends to release excess nitrogen into the natural environment which can cause eutrophication. An alternative is to grow more than one organism, including other organisms lower in the food chain which are extractive, such as filter-feeding molluscs which extract nutrient-rich particles, and seaweeds which extract dissolved nutrients (known as IMTA: integrated multi-trophic aquaculture: Chopin *et al.* 2008). Such systems have been set up on abalone farms in South Africa (Bolton *et al.* 2009) and fish farms in Tanzania (Msuya *et al.* 2006), using the green seaweed *Ulva*. In farms growing herbivores or omnivores, the seaweed can be used as extra feed as well as to allow partial re-circulation of seawater in land-based systems, which can make aquaculture facilities more economically and environmentally sustainable (Bolton *et al.* 2009, Nobre *et al.* 2010). If *Ulva* or *Gracilaria* is to be utilised in such systems, it is best initiated from locally collected material growing loose lying in sheltered lagoons, as such material tends to grow well vegetatively without losing material through spore production. The red seaweed *Asparagopsis* is also common on Mauritius, and has been recommended as excellent seaweed for bioremediation (nutrient removal) of aquaculture effluent (Schuenhof *et al.* 2006), among many other potential uses (Kraan and Barrington 2005, Bolton *et al.* 2011).

6. AN EXAMPLE: POTENTIAL USES OF SARGASSUM

Few seaweeds are present in large amounts in Mauritius (Jagtap 1993), which would be a requirement if a small industry were to be based on natural populations. Perhaps the most abundant seaweeds are large brown algae in the genus *Sargassum*.

Fucales are ecologically important because they often represent the major component of warm temperate, subtropical and tropical marine forests (Nizamuddin 1962). In tropical and subtropical coral reef ecosystems such as in

Mauritius, benthic marine beds formed primarily by *Sargassum* spp. represent the equivalent of marine forests structured by *Fucus* spp. and *Cystoseira* spp. in temperate regions of the northern hemisphere (Nizamuddin 1962, Yoshida 1989, Phillips 1995, Thiebault *et al.* 2005). These natural *Sargassum* beds, with a canopy not usually exceeding 2 m high, play an essential role in the biological cycles of numerous marine species by providing substrate, food, and protection against difficult environmental conditions (e.g. desiccation, high wave action) and predation (McClanahan *et al.* 1994, Rossier and Kulbicki 2000, Godoy and Coutinho 2002, Leite and Tura 2003). *Sargassum* forests are inhabited by a wide variety of invertebrates (amphipods, polychaetes, molluscs, etc.) and represent nurseries for numerous fish species (Mukai 1971, Ornellas and Coutinho 1998, Barrabe 2003, Tanaka and Leite 2003, Aburto-Oropeza *et al.* 2007).

Seaweeds are used in numerous countries for food, agro-food and other industries (Prud'homme van Reine 2002). *Sargassum* spp. in particular are collected and used in a number of Asiatic countries for their medicinal properties (Hong *et al.* 2007), food (Wondimu *et al.* 2007), fertilizers (Sivasankari *et al.* 2006), or their alginate contents (textile or agro-food industries) (Saraswathi *et al.* 2003). *Sargassum* spp. may also be a source of compounds with anti-inflammatory properties (Dar *et al.* 2007). In a review of medicinal and pharmaceutical uses of seaweed natural products, Smit (2004) underlines the various properties attributed to *Sargassum* spp.: antiviral, stimulant for the genesis of vascular tissues, anti-cancer, and reduction of cell proliferation, fibrinolytic, anti-thrombic and anti-coagulant. As an example, de Sousa *et al.* (2007) demonstrated that alginate from *Sargassum* spp. has considerable anti-tumour activity, and also has considerable renal effects (de Sousa *et al.* 2008). *Sargassum* species also contain phenolic compounds (Stiger *et al.* 2004, Plougerné *et al.* 2006) with anti-oxidant and antimicrobial properties interesting for the cosmetic and pharmaceutical industries. Also a *Sargassum* species from South Africa has been shown to inhibit the *in vitro* growth of the malaria parasite (Afolayan 2008).

Other studies have shown that the incorporation of up to 25% of *Sargassum* in animal feed leads to a good overall growth and makes it possible to lower the final coast of the feed (Casas-Valdez *et al.* 2006a). Addition of *Sargassum* in the feed for cultured shrimps has also been shown to protect them against certain viruses and lower their cholesterol contents (Chotigeat *et al.* 2004, Casas-Valdez *et al.* 2006b). *Sargassum* spp. may also be used as fertilizers and a variety of organic brands may be found for sale on the internet. They are advertised as rich natural fertilisers, non-toxic, non-polluting, and containing trace elements as well as growth hormones. In French Polynesia, a study has demonstrated the benefit of using *Sargassum mangarevense* (formerly known as *S. pacificum*) for enhancing the growth of maize crops (Zubia 2003).

Various *Sargassum muticum* extracts have shown activity against micro-organisms responsible for marine micro-fouling (Plougerné *et al.* 2008). According to Plougerné *et al.* (2008), the dichloromethane extract, which is the most active, could replace toxic chemical products currently used in anti-fouling paints to protect hulls of ships. Numerous studies have demonstrated or underlined *Sargassum* spp.'s adsorption capacities (i.e. biosorption) for heavy metals such as Cd^{2+}, Cu^{2+}, Zn^{2+}, Pb^{2+} and Ni^{2+} (Davis *et al.* 2003, Sheng *et al.* 2004). Dead drift *Sargassum* biomass could thus become an efficient biosorbant at low cost for, as an example, the treatment of industrial effluents (Davis *et al.* 2000, Stirk and van Staden 2000, Pinto Padhilha *et al.* 2005).

As a general trend, the economic potential of *Sargassum* is underlined in numerous studies documenting their properties and uses. However, each individual species might represent distinct potentials, and stocks might be limited (Prud'homme van Reine 2002). Moreover, the harvesting of marine macrophytes may have important ecological consequences, especially when the species of interest structures one of the major habitats of the area. An in depth study of their ecology and sustainable harvesting is essential before any harvesting / exploitation of their biomass. Considering the low prices of seaweed biomass on the international market, harvesting costs in some countries may also render the exploitation of the available biomass not economically viable.

It is important to keep in mind that *Sargassum* spp. structure important habitat which may represent essential nurseries for economically important fish species. As an example, in the Gulf of California, Aburto-Oropeza *et al.* (2007) have shown that the abundance in recruitment of fish juveniles of economic interest is dependent on the availability and abundance of *Sargassum* spp. beds. Similarly, in Brazil, Ornellas and Countinho (1998) have shown that the density of fish observed is linked to the *Sargassum* bed biomass / canopy. The authors list 42 species of fish belonging to 32 families of which the abundance varies with season and *Sargassum* biomass. In New Caledonia, Rosier and Kulbicki (2000) have underlined that the fish species diversity is more important in *Sargassum* beds (202 species) than on coral reefs (187 species) or *Halimeda* spp. beds (96 species). Mellin *et al.* (2007) have also underlined the importance of algal beds in the recruitment of coral reef fish juveniles. In this context, protecting seaweed beds would mean protecting fish nurseries and thus contribute towards the maintenance and good recruitment of commercial fish species diversity. According to Aburto-Oropeza *et al.* (2007), the disappearance or regression of *Sargassum* spp. beds in the Gulf of California would have heavy consequences on local fisheries. In Mauritius, a study of the presence and ecology of commercial fish species in *Sargassum* beds would be necessary to understand their economic importance for fisheries.

7. CONCLUSIONS

Mauritius has a coastline of 177 km and a great diversity of species but low natural biomass of seaweeds. The potential for developing a seaweed industry exists, and will require direct investment. Successful initiatives are likely to be on a small-scale, preferably for a high-value product, or based on aquaculture. Integrating seaweed cultivation with animal aquaculture in an IMTA system could minimise environmental perturbation and increase sustainability. Careful planning should be taken to study the real potential for a sustainable industry before any non-indigenous species such as *Eucheuma* were to be imported for the production of a relatively low-price material. Future research should involve the selection of suitable local species for aquaculture, surveys and testing of potential aquaculture sites (Anderson *et al.* 2003, Wakibia *et al.* 2006), and surveys of biomass and possibly experiments towards sustainable harvesting of more abundant seaweeds such as species of *Sargassum*.

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