The proliferating brown alga Sargassum polycystum in Tuvalu, South Pacific: assessment of the bloom and applications to local agriculture and sustainable energy

Antoine De Ramon N'Yeurt & Viliamu Iese

Journal of Applied Phycology

ISSN 0921-8971

Volume 27

Number 5

J Appl Phycol (2015) 27:2037-2045

DOI 10.1007/s10811-014-0435-y

**JOURNAL OF APPLIED
PHYCOLOGY**

October 2015

Volume 27 no. 5

Editor-in-chief
M.A. Borowitzka

Founding Editor
B.A. Whitton

Guest Editors
Kirsten Heimann
Stephen O'Leary
Dagmar Stengel
Pia Winberg

5th Congress of the
International Society
for Applied Phycology

Springer
ISSN 0921-8971

Your article is protected by copyright and all rights are held exclusively by Springer Science +Business Media Dordrecht. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your article, please use the accepted manuscript version for posting on your own website. You may further deposit the accepted manuscript version in any repository, provided it is only made publicly available 12 months after official publication or later and provided acknowledgement is given to the original source of publication and a link is inserted to the published article on Springer's website. The link must be accompanied by the following text: "The final publication is available at link.springer.com".

The proliferating brown alga *Sargassum polycystum* in Tuvalu, South Pacific: assessment of the bloom and applications to local agriculture and sustainable energy

Antoine De Ramon N'Yeurt · Viliamu Iese

Received: 11 August 2014 / Revised and accepted: 12 October 2014 / Published online: 26 October 2014
© Springer Science+Business Media Dordrecht 2014

Abstract Since 2011, the small South Pacific atoll nation of Tuvalu has been affected by algal blooms, the most recent being a large growth of the brown alga *Sargassum* on the main atoll of Funafuti. The gravity of the situation led to an invitation to the authors from the Tuvalu Government to conduct an initial survey of the problem in November 2013. The bloom was seen to be localized on the lagoon side of the main populated island of Fongafale, distributed in a variably dense belt up to 100 m from the shoreline. A total of 19 species of macroalgae were found in the survey area, the dominant one being the phaeophyceae alga, *Sargassum polycystum* C. Agardh, with individual plants reaching up to 2 m in length with a cover ranging between 16 and 23 % of the substratum. For seven transects laid from the southern tip of the island to the end of the populated area, wet biomass ranged between 0.45 and 3.56 kg m⁻², with an average of 1.68 kg m⁻². There was a correlation noticed between the density of human population on the shore and algal biomass, with the highest biomass figures opposite a school and a hotel. Water quality tests also showed nutrient levels almost twice as high in front of populated areas than in unpopulated areas of the island. The algal belt was seen to be concentrated in water less than 1 m deep, becoming sparser as depth increased. The high amount of *Sargassum* biomass available makes it a good candidate for use as a fertiliser additive for agricultural practices in Tuvalu. Benefits from seaweed-based fertilisers are numerous, and individual farmers have already reported success with the blooms species on the atoll. Additionally, the *Sargassum* biomass could be converted into biogas using the process of anaerobic digestion in simple household digesters, to meet the need for renewable energy in lighting and cooking.

Keywords *Sargassum* · Tuvalu · Phaeophyceae · Biofertiliser · Macroalgae · Biofuel · Bloom · Proliferation · Invasive species

Introduction

The small atoll nation Tuvalu in the South Pacific (Fig. 1) has a land area of 26 km², consisting of three reef islands and six atolls, with a total population of 10,837 persons in 2012 (Government of Tuvalu 2012) mostly living on the main island of Fongafale. Owing to its low profile with the highest point only 4.6 m above sea level, it is very prone to the effects of climate change, especially rising sea levels. Because of the porous nature of the sandy soil, nutrients rapidly leach out into the surrounding lagoon, prompting farmers to rely heavily on imported phosphate-based fertiliser, pig manure and green compost to augment the soil qualities; these chemicals and high nutrient inputs also find their way into the lagoon, causing eutrophication. Organic pollution of the lagoon is also a major concern on the atoll, with only about 10 % of the population owning a flush toilet; moreover, because of the porous soil, septic tanks inevitably leach their contents into the water table and lagoon.

In 2011, local inhabitants of the main island of Fongafale on the atoll of Funafuti reported a sudden bloom of a filamentous alga in the lagoon surrounding the main populated area. From available pictures shown to us by the Tuvalu Fisheries Department, it appeared to have been caused by unattached, benthic mats of a filamentous cyanobacterium, although no samples were taken at the time. Around 2012, this population subsequently was replaced entirely by a proliferating, attached species of *Sargassum*. The situation became so serious that about 30 truckloads of the brown alga had to be removed from the beaches at one stage by volunteers in Funafuti (L. Paeniu, personal communication). At this point, the Government of

A. De Ramon N'Yeurt (✉) · V. Iese
Pacific Center for Environment and Sustainable Development, The
University of the South Pacific, Private Mail Bag, Suva, Fiji
e-mail: nyeurt_a@usp.ac.fj

Fig. 1 Map of the Tuvalu Archipelago and its location within the Pacific Ocean. Island names follow those in Motteler (2006)

Tuvalu requested the University of the South Pacific in Fiji for a research team to investigate the issue, resulting in the present survey by the authors.

Previous works on Tuvalu marine algae Aside from nineteenth and early twentieth century records of coralline algae (Foslie 1899, 1900), the earliest known inventory of the marine algae of Tuvalu was by Chapman (1955) who listed some 50 taxa (8 Cyanophyceae, 24 Chlorophyceae, 6 Phaeophyceae and 12 Rhodophyceae). No previous records of the genus *Sargassum* in Tuvalu could be found from the literature, but that genus occurs in Wallis Island, to the southeast of Tuvalu (N'Yeurt and Payri 2004); although because it was only found at the port of entry, indications are that it is probably not native to that island. Unfortunately, no previous records of Wallis marine algae existed before the 2004 survey by N'Yeurt and Payri, and no records of the cultural use of this alga are known, such as has been reported in the isolated

Polynesian island of Rotuma to the southwest of Wallis, where *Sargassum* is used as an ingredient in traditional garlands for dancing (N'Yeurt 1993, 1996). Recent surveys of the marine biodiversity of Funafuti (Job and Ceccarelli 2012) contain a cursory account of *macroalgae* but do not make mention of any *Sargassum*.

Materials and methods

Standing biomass assessment A total of seven transects were laid (Fig. 2), starting from the sparsely populated southern end of Fongafale islet up to the front of the Government Building, hotel, Funafuti meeting place and primary school. Each transect was between 30 and 110 m long, starting from the shoreline and going seaward. At every 10-m interval, a 1-m² quadrat was laid on the transect line and all algal covers were

Fig. 2 Aerial view of Fongafale Island, Tuvalu, showing transects (T1–T7) within the *Sargassum* belt area (inset)

recorded as an estimated percentage cover. For the last two quadrat points in each transect, all *Sargassum* plants were collected, drip dried by shaking in the field and put into black garbage bags in order to obtain their wet weight and assess the average biomass per square metre. Wet weight was measured about 1 h after collecting on a precision balance in the Funafuti JICA Foram-Sand Laboratory. The lengths of haphazardly selected plants from those collected for wet weight determination were also assessed in the field by laying them extended at the bottom of the boat and using a measuring tape to obtain an idea of the vertical distribution of the biomass.

Algal biodiversity and distribution patterns In addition to assessing the biomass and extent of the *Sargassum* populations, other macroalgae present in the quadrats were also estimated for their percentage cover and distribution patterns once the overlaying *Sargassum* plants were first removed or displaced. These macroalgae were collected for taxonomic identification in the laboratory. Representative specimens of all macroalgae identified were processed into dried herbarium vouchers and brought back to the University of the South Pacific, Fiji, where they were deposited in the algal collections of the South Pacific Regional Herbarium (SUVA-A). Distribution data were statistically analyzed applying a one-way ANOVA to test for significant differences among the seaweeds making up the dominant cover (e.g. *Sargassum*, *Halimeda* and *Dictyota*) along the individual transect line sites. Tukey's test was then used to identify which species cover was different from the others. Both tests were carried out using the statistical software package 'R'.

For comparative purposes to the heavily populated areas of the lagoon in Fongafale, algal cover estimates were also made at the Funafuti Conservation Area (FCA) which covers a total land area of about 33 km². This area was the first marine protected area declared in Tuvalu in 1996 (Job and Ceccarelli 2012); it accounts for about 20 % of the reef area of the atoll.

Water quality measurements At each site, water quality was measured with a precision instrument (AquareadTM AquameterTM) which automatically recorded the GPS position, pH, temperature, salinity, dissolved oxygen (DO), nitrate and total dissolved solids (TDSs). The results were directly exportable into Google Maps with transect points.

Results

Standing *Sargassum* biomass assessment

The only species of *Sargassum* found was *Sargassum polycystum* C. Agardh, with individual thalli attached to the rocky substratum. Individuals reached between 1 and 2 m in length. In shallower waters, plants typically spread horizontally floating on the water surface, blocking much of the light to organisms below. Figure 3 shows that the highest mean *Sargassum* percentage covers were recorded in transects T3 (48 %) and T6 (23 %), followed by T7 (19 %); these were in front of heavily populated areas. Transects T6 and T7 had mean total biomass values for *Sargassum* of 1.94 and

Fig. 3 Graph showing the average biomass of *Sargassum* within the surveyed transects. Vertical lines indicate standard error ($n=8$)

1.52 kg m⁻², respectively. The lowest mean covers for *Sargassum* were in transects T1 (0 %) and T2 (5.5 %), both from sparsely populated areas of the island.

Algal biodiversity and distribution patterns

Figure 4 summarizes the distribution of macroalgae species for transects T1 to T7. A total of 15 taxa were found in the transect areas (Table 1), with *Sargassum* as the most dominant

Fig. 4 Graph showing the percentage covers of the dominant macroalgae found within the transect area. Vertical lines indicate standard error ($n=8$)

Table 1 List of algal species from transects at Fongafale lagoon

Voucher	Class	Taxa
TV13-12	Cyanophyta	<i>Schizothrix</i> sp.
TV13-13	Chlorophyta	<i>Caulerpa bikiensis</i> W.R. Taylor
TV13-14	Chlorophyta	<i>Caulerpa cupressoides</i> (Vahl) C. Agardh
TV13-24	Chlorophyta	<i>Caulerpa serrulata</i> (Forsskål) J. Agardh
TV13-19	Chlorophyta	<i>Dictyosphaeria versluysii</i> Weber-van Bosse
TV13-16	Chlorophyta	<i>Halimeda taenicola</i> W.R. Taylor
TV13-18	Chlorophyta	<i>Microdictyon okamurai</i> Setchell
TV13-20	Chlorophyta	<i>Neomeris vanbosseae</i> M.A. Howe

overall. The *Sargassum* belt extended from transects T3 to T7 and beyond; in those areas, it was very dense and clearly visible from the air (Fig. 5). Within the beds, plants assumed a columnar growth pattern and tended to float out on the surface in shallower areas (Fig. 5c, d). It was also noticed that the density of *Sargassum* plants decreased in waters deeper than about 1 m, while near the shore, plants tended to grow in parallel bands corresponding to the ridges in the sandy substratum caused by parallel shore currents. *Sargassum* was totally absent from T1 and little represented in T2 which were both facing sparsely populated areas. The green alga *Halimeda minima* and the brown alga *Dictyota bartayresiana* were the most abundant species in transects T1 and T2, while the green alga *Caulerpa racemosa* was most abundant within the *Sargassum* beds of transects T3 and T4. *Padina boryana*, a brown alga, was most abundant in transect T4. Both *D. bartayresiana* and *H. minima* were absent, or nearly so, in transects where *S. polycystum* was present.

No *Sargassum* plants were seen in the Funafuti Conservation Area despite a thorough survey at sites in Fualopa, Fuafatu and Tefala islets. The most abundant macroalgae at the FCA (Table 2) were the green alga *Microdictyon okamurai* (23 % mean cover) followed by *Neomeris vanbosseae* (10 %); both taxa are typical of atoll algal floras and conspicuously absent from the Fongafale lagoon area. No *Sargassum* plants were seen growing on the ocean side of Fongafale Island, even in the highly populated areas. The ocean-side fringing reef was mostly dominated by cyanobacteria and the green algae *Boodlea composita* and *Dictyosphaeria versluysii*. Combining the above surveys, a total of 19 taxa of macroalgae were noted and processed into herbarium vouchers for further study.

Water quality results

Seawater temperature at all sites varied between 30.3 and 31.7 °C, while pH varied between 8.08 and 8.65. Nitrate levels were highest at transect T7, near the shore of the heavily populated area (0.30 mg L⁻¹) which was twice more than that observed at transect T2 in the sparsely populated area

Fig. 5 Morphology of the algal beds at Fongafale. **a** Aerial view of the lagoon coastline showing the extensive *Sargassum* beds (*sb*). **b**, **e** View of the algal beds as they appear from the surface of the lagoon. **c**, **d** Underwater

view of *Sargassum* plants showing their columnar growth and fanning out of the thalli at the surface. **f** Habit of the freshly pressed top half of a *Sargassum polycystum* plant from the study area (scale in centimetres)

(0.14 mg L^{-1}) and higher than that in the Tuvalu Conservation Area (Fualopa 1, 0.18 mg L^{-1}). The daytime, late afternoon, DO levels were highest at transects T4 and T7 (175.3 and 163.4 % Sat, respectively).

Discussion

Ecosystem phase shift to algal dominance

From information given to us by local authorities, the over-abundant seaweeds established themselves in the Fongafale lagoon following a severe period of drought in 2011, also an El Niño year, when current patterns in the lagoon were likely disrupted, and very favourable nutrient conditions existed (it was noted to us that at the time, much of the population of Funafuti resorted to the lagoon for washing, cleaning and defecating). Similar sudden algal blooms caused by

anthropogenic eutrophication and high seawater temperatures occurred in other parts of the world; for instance, there was a massive *Ulva* bloom in Qingdao, China, prior to the 2008 Olympic sailing events (Leliaert et al. 2009); large red algal blooms in Florida, USA, in 2006 (Lapointe and Bedford 2007); and a very persistent *Gracilaria* bloom in many parts of Fiji (Buresse 2013). It appeared that the initial bloom population in Funafuti lagoon consisted of blue-green algae dominated by *Phormidium* sp., which was entirely replaced sometime in 2012 by the brown alga *S. polycystum*.

The reason for this sudden population shift is still unclear, but since no previous records of *Sargassum* in Tuvalu could be found prior to this study, including the only known algal checklist for Funafuti (Chapman 1955), preliminary evidence suggested that *S. polycystum* was an introduced invasive species from a nearby regional source, whose geographic boundaries were extended due to stochastic changes in local conditions. There are several ways for brown algae such as

Table 2 List of algal species from transects at the Tuvalu Conservation Area (TCA)

Voucher	Class	Taxa
TV13-08	Chlorophyta	<i>Caulerpa racemosa</i> (Forsskål) J. Agardh var. <i>lamourouxii</i> (Turner) Weber-van Bosse
TV13-26	Chlorophyta	<i>Caulerpa racemosa</i> (Forsskål) J. Agardh var. <i>typica</i>
TV13-28	Chlorophyta	<i>Halimeda discoidea</i> Decaisne
TV13-03	Chlorophyta	<i>Halimeda macroloba</i> Decaisne
TV13-10	Chlorophyta	<i>Halimeda minima</i> (W.R. Taylor) Hillis-Colinvaux
TV13-31	Chlorophyta	<i>Halimeda opuntia</i> (Linnaeus) J.V. Lamouroux
TV13-29	Chlorophyta	<i>Halimeda taenicola</i> W.R. Taylor
TV13-22	Chlorophyta	<i>Ulva flexuosa</i> Wulfen
TV13-25	Chlorophyta	<i>Ulva intestinalis</i> Linnaeus
TV13-23	Cyanophyta	<i>Lyngbya majuscula</i> Harvey ex Gomont
TV13-05	Phaeophyta	<i>Dictyota bartayresiana</i> J.V. Lamouroux
TV13-06	Phaeophyta	<i>Padina boryana</i> Thivy in W.R. Taylor
TV13-01	Phaeophyta	<i>Sargassum polycystum</i> C. Agardh
TV13-27	Phaeophyta	<i>Turbinaria conoides</i> (J. Agardh) Kützting
TV13-04	Rhodophyta	<i>Galaxaura divaricata</i> (Linnaeus) Huisman & R.A. Townsend

Sargassum to disperse across vast expanses of the open ocean, the most documented being by floating rafts (Stiger and Payri 1999), with vegetative thalli remaining viable for up to 4 months (Zubia 2003). The main factors favouring this dispersal method would be ocean drift by currents from another island bearing populations of *Sargassum* (Martinez et al. 2007), for instance borne on the prevailing south-east trade winds. The island of Wallis, some 700 km to the southeast of Funafuti, is a likely source for *Sargassum*, the primary vector being floating rafts or even entangled with international shipping, since a substantial population of the same species of tall *Sargassum* existed in Mata Utu harbour as far back as 2002 (N'Yeurt and Payri 2004). The Wallisian *Sargassum* plants, interestingly, only occurred at that island's port of entry, despite extensive algal surveys of the island's reefs. Some of the results of the initial algal survey of Wallis Island by N'Yeurt and Payri (2004), including *S. polycystum*, were later depicted on a special stamp issue released on the 26th of June 2004 by the Wallis and Futuna philatelic bureau. There exists a fortnightly commercial shipping link (Pacific Direct Line PDL/TRANSAM) between Fiji, Futuna, Wallis and Funafuti, with a transit time of only 48 h between Wallis and Funafuti; the observation that the *Sargassum* outbreak in Funafuti first occurred at the port of entry where container ships' berth would add weight to the

hypothesis of shipping as a vector (either entangled or released with bilge water). The actual method of transmission of viable thalli, either on the hull of vessels, caught in propellers or in anchors and anchor chains, remains debatable and would need to be studied in detail in collaboration with shipping companies. Future genetic studies on the Tuvalu *Sargassum* population, combined with ocean current model investigations, could enable verification of these hypotheses and pinpoint the origin and dispersal route of this prolific alga.

Algal blooms and nutrients

The *Sargassum* bloom in Funafuti had a positive correlation with high nitrate levels in the lagoon, opposite densely populated areas such as the *borrow pit* settlements (living within areas excavated by the US military during WWII to procure material to construct the Funafuti airstrip), schools, the hospital and hotels. These highly populated areas have improper latrines, combined with leaking sewer systems, leaching nutrients into the lagoon and promoting luxurious algal growth. The *Sargassum* also preferred shallow areas, less than 1 m deep, with a hard substratum. A similar link between high nutrient levels in coastal areas and algal blooms was observed in Fiji by Mosley and Aalbersberg (2005) and also Tamata (2007). In the latter study mostly dealing with *Sargassum* on Fijian polluted coastal areas, it was noticed that the plants very quickly absorbed nutrients such as dissolved nitrates, in a matter of minutes. This 'nutrient sink' effect by these opportunistic plants implied that proper assessment of nutrient levels in the water column needs to be carried out upstream from algal beds or combined with radio-isotope analyses of dried plant thalli in order to determine the actual amount of nutrients assimilated in the tissues (Lamb et al. 2012). Of particular interest were the nitrate levels, which were much higher in the heavily populated areas of Fongafale (e.g. transect T7, up to 0.30 mg L⁻¹), as compared to the unpopulated conservation area (Fualopa 1, 0.18 mg L⁻¹). Nitrates are derived from sewage and other effluents and are excellent nutrients for algal growth, as shown by the high daytime DO levels in these areas due to the higher photosynthetic activity by the abundant seaweed forests.

Inputs of nutrients into water masses with restricted movement such as lagoons leading to eutrophication and algal blooms can have multiple origins (Liu et al. 2013). For a small atoll nation such as Tuvalu, faced with poor porous soils, overpopulation and a largely absent and/or highly deficient sewer system, the consequences can be disastrous. The high use of chemical fertilisers rich in nitrates and phosphates to enable some sort of agriculture inevitably leads to these elements leaching out into the lagoon through the porous sandy soils. Similarly, poorly contained sewage tanks can leach their contents into the surrounding ground, freshwater lens and seawater. Possible solutions would entail reducing the use of chemical fertilisers and

replacing them with sustainable organic ones as well as redirecting sewage for use as compost and/or renewable energy using anaerobic digesters (N'Yeurt and Iese 2014). Simple organic digesters are low-cost devices that can cater for the energy need of individual households, as demonstrated by the ongoing project-based use of household and animal waste to generate biomethane in Tuvalu (Woods et al. 2006; Hemstock 2008). Extensive seaweed forests such as that found in the Tuvalu lagoon not only absorb organic and chemical nutrients but also provide a climate service by removing a substantial amount of carbon dioxide from the atmosphere during photosynthesis; harvesting these plants for renewable energy use and using carbon capture and storage (CCS) technology to store the resulting CO₂ would effectively mitigate climate change through an appreciable reduction in global greenhouse gases (N'Yeurt et al. 2012).

Health issues from algal blooms

Algal blooms such as that of the toxic cyanobacteria *Lyngbya* have been known to cause health problems (respiratory, dermatitis and respiratory symptoms) in the human populations in localities such as tropical Australia and the Cook Islands (Osborne et al. 2001; Hope and Eason 2005). The brown alga *Sargassum muticum* has been reported to cause contact allergy as well (Angelini 2000), and in Tuvalu, families reported to the authors that their children experienced irritant syndromes after swimming in the *Sargassum*-infested lagoon.

The use of marine algae as seaweed fertilisers

Advantages of using seaweed-derived fertilisers in agriculture include increased nutrient uptake, deeper root development, enhanced growth rates and increased resistance to diseases, pests and climatic stress (Kuwada et al. 2006). In French Polynesia (Zubia 2003; Zubia et al. 2003), an analysis of the

invasive brown algae *Turbinaria ornata* and *Sargassum mangarevense* (*Sargassum pacificum*) found them to be rich in potassium, nitrates, calcium, iron and polyunsaturated fatty acids, with low levels of heavy metals. Similarly, liquid seaweed fertiliser made from *Sargassum wightii* at diluted levels was found to elicit shoot and root growth in mung bean or green gram (*Vigna radiata*) plants (Kavipriya et al. 2011; Kumar et al. 2012). Drift seaweed biomass may be turned into organic compost through aerobic composting methods and, when applied to plants, was found to be comparable to that of cow dung and commercial fertilisers (Wosnitza and Barrantes 2006; Haq et al. 2011); in Argentina, compost from green algae was found to be beneficial in improving growth, soil water retention capacity and stress resistance in tomato plants (Eyras et al. 1998). Additional benefits reported from the use of seaweed extracts as a foliar spray include a reduction in the number of insect pests (Hankins and Hockey 1990), protection against oxidative and thermal stress to improve nutritional qualities in leafy vegetables such as spinach (Fan et al. 2011) and enhanced photosynthetic rates and growth due to higher chlorophyll level in leaves (Blunden et al. 1997).

Most farmers in Tuvalu use inorganic chemical fertilisers to grow vegetables, but after understanding the negative impacts of inorganic fertilisers on coastal waters especially in atolls, many are shifting back to organic farming using compost and animal manures. Two farmers interviewed for this study mentioned that they used seaweed as an organic fertiliser. In one instance, the seaweeds were soaked for 3 days before being mixed with composts. Another farmer used *Sargassum* plants washed up on the beaches which were applied to various crops including tomatoes, cabbage, watermelons and long bean. The algae were soaked in water before application, the water being reused for hydrating the plants. The washed, dried seaweed was manually applied to the base of the plants at regular intervals. After 3 to 6 months of using this method, positive

Fig. 6 Schematic diagram of a typical household-sized anaerobic digester (adapted from N'Yeurt and Iese 2014)

growth results were seen, notably a faster growth of cucumber and water melons that were fertilised with seaweed compared to other farmers who were not using seaweed fertiliser. Following these anecdotal positive results by Tuvaluan farmers, ongoing systematic studies at the University of the South Pacific by a regional Masters student are looking at the effects of both liquid and solid seaweed-derived fertilisers (including *Sargassum*) on common Pacific food and cash crops, with the objective of producing a 'best practice guide' for regional agriculturists.

Seaweeds as a renewable energy source

The possibility of using marine biomass for energy generation through anaerobic digestion by methanogenic bacteria is a simple and proven technology readily accessible to the developing world (Chynoweth 2002; Vergara-Fernández et al. 2008; Migliore et al. 2012; N'Yeurt et al. 2012). Digester systems already exist in Tuvalu (Hemstock 2008) and would require little or no modification to switch to using marine biomass such as *Sargassum* to generate biogas for lighting and cooking at the household and community level. Figure 6 shows the basic design of a simple anaerobic digester that is suitable for use in the context, with starter bacteria derived from lagoon marine sediments and/or fish guts. The real possibility of converting the current *Sargassum* bloom in the Funafuti lagoon into renewable energy that does not contribute to climate change could be an incentive for regular mass culling efforts by the local community, for as long as the issue persists (or through controlled integrated multi-trophic aquaculture (IMTA) of the species). Moreover, the by-product of the anaerobic digesters is an organic slurry that can be readily applied to crops as a fertiliser, complementing the poor nutrient levels in the soils of the atoll.

Future outlook

The sudden algal bloom of *S. polycystum* currently being faced by the atoll nation of Tuvalu is of grave concern to the local communities, with implications for human health, livelihoods, changes in biodiversity and tourism. However, through proper management of the likely causes, eventual recovery of the ecosystem could be possible. Immediate action to alleviate the symptoms could include appropriate biosecurity checks for algae on incoming shipping vessels, raising the awareness of the local population to remove sources of nutrients that could enter the lagoon such as water's edge piggeries and chicken sheds, improving sanitary practices and harvesting in a controlled manner the standing biomass for use as organic compost fertiliser and biofuel generation through anaerobic digestion.

Acknowledgments The European Union Global Climate Change Alliance (EU GCCA) at the Pacific Center for Environment and Sustainable Development (PaCE-SD) of the University of the South Pacific is duly acknowledged for financial assistance enabling this work to have been carried out. The authors are grateful to the Falekaupule Funafuti, the President and Members of the Funafuti Island Council (Kaupule Funafuti), the Director and Fisheries Department of Tuvalu, the Director and Agriculture Department of Tuvalu, Mr. Semese Alefaio of Tuvalu Fisheries Department, the Director of the USP Campus in Tuvalu Mr. David Manuella and Ms. Teuleala Manuela-Morris for facilitating our work while in Tuvalu. We sincerely thank Ms. Andra Whiteside for her skilled assistance with statistical analyses on algal distribution data.

References

- Angelini G (2000) Occupational aquatic dermatology. In: Kanerva I, Elsnér P, Wahlberg JE, Maibach HI (eds) Handbook of occupational dermatology. Springer, Berlin, pp 234–247
- Blunden G, Jenkins T, Liu YW (1997) Enhanced leaf chlorophyll levels in plants treated with seaweed extract. J Appl Phycol 8:535–543
- Burese I (2013) Too much seaweed. <http://www.fijitimes.com/story.aspx?id=222905>. Accessed 9 July 2013
- Chapman VJ (1955) Algal collections from Funafuti atoll. Pac Sci 9:354–356
- Chynoweth DP (2002) Review of biomethane from marine biomass. Department of Agricultural and Biological Engineering, University of Florida, p. 76
- Eyras MC, Rostagno CM, Defossé GE (1998) Biological evaluation of seaweed composting. Compost Sci Util 6:74–81
- Fan D, Hodges DM, Zhang J, Kirby CW, Ji X, Steven J, Locke SJ, Critchley AT, Prithiviraj B (2011) Commercial extract of the brown seaweed *Ascophyllum nodosum* enhances phenolic antioxidant content of spinach (*Spinacia oleracea* L.) which protects *Caenorhabditis elegans* against oxidative and thermal stress. Food Chem 124:195–202
- Foslie M (1899) Notes on two lithothamnia from Funafuti. Kong Norsk Vidensk Selsk Skr 1899: 1–5
- Foslie M (1900) Calcareous algae from Funafuti. Kong Norsk Vidensk Selsk Skr 1900: 1–12
- Government of Tuvalu (2012) Population and housing census. Preliminary Analytical Report. Central Statistics Division, Government of Tuvalu, p. 11
- Hankins SD, Hockey HP (1990) The effect of a liquid seaweed extract from *Ascophyllum nodosum* (Fuciales, Phaeophyta) on the two-spotted red spider mite *Tetranychus urticae*. Hydrobiologia 204/205:555–559
- Haq T, Khan FA, Begum R, Munshi AB (2011) Bioconversion of drifted seaweed biomass into organic compost collected from the Karachi coast. Pak J Bot 43:3049–3051
- Hemstock SL (2008) The potential role of biomass energy in the sustainable development of small island economies: the case for Tuvalu. In: Pillarisetti JR, Teo SYJ, Lawrey R, Siddiqui SA, Ahmad A (eds) Small economies and global economics. Nova Science Publishers, p. 19.
- Hope V, Eason CT (2005) A detailed risk assessment of potential causes of the irritant syndrome in Titikaveka November 2003–July 2004. Contract report for the Prime Minister's Office, Rarotonga, Cook Islands. Landcare Research, Auckland, p. 33
- Job S, Ceccarelli D (2012) Tuvalu, marine life scientific report. Alofa Tuvalu, Funafuti, p. 213
- Kavipriya R, Dhanalakshmi PK, Jayashree S, Thangaraju N (2011) Seaweed extract as a biostimulant for legume crop, green gram. J Ecobiotechnol 3:16–19

- Kumar NA, Vanlalzarzova B, Sridhar S, Baluswami M (2012) Effect of liquid seaweed fertilizer of *Sargassum wightii* grev. on the growth and biochemical content of green gram (*Vigna radiata* (L.) R. Wilczek). Recent Res Sci Tech 4:40–45
- Kuwada K, Kuramoto M, Utamura M, Matsushita I, Ishii T (2006) Isolation and structural elucidation of a growth stimulant for arbuscular mycorrhizal fungus from *Laminaria japonica* Areschoug. J Appl Phycol 18:795–800
- Lamb K, Swart PK, Altabet MA (2012) Nitrogen and carbon isotopic systematics of the Florida reef tract. Bull Mar Sci 88:1–27
- Lapointe BE, Bedford BJ (2007) Drift rhodophyte blooms emerge in Lee County, Florida, USA: evidence of escalating coastal eutrophication. Harmful Algae 6:421–437
- Leliaert F, Zhang X, Ye N, Malta EJ, Engelen AH, Mineur F, Verbruggen H, De Clerck O (2009) Identity of the Qingdao algal bloom. Phycol Res 57:147–151
- Liu F, Pang S, Chopin T, Gao S, Shan T, Zhao X, Li J (2013) Understanding the recurrent large-scale green tide in the Yellow Sea: temporal and spatial correlations between multiple geographical, aquacultural and biological factors. Mar Environ Res 83:38–47
- Martinez E, Maamaatuaiahutapu K, Payri C, Ganachaud A (2007) *Turbinaria ornata* invasion in the Tuamotu Archipelago, French Polynesia: ocean drift connectivity. Coral Reefs 26:79–86
- Migliore G, Alisi C, Sprocati AR, Massi E, Ciccoli R, Lenzi M, Wang A, Cremisini C (2012) Anaerobic digestion of macroalgal biomass and sediments sourced from the Orbetello Lagoon, Italy. Biomass Bioenerg 42:69–77
- Mosley L, Aalbersberg WGL (2005) Nutrient levels and macro-algal outbreaks in Fiji's coastal water. Institute of Applied Sciences Technical Report 2005/01, The University of the South Pacific, Suva, p. 25
- Motteler LS (2006) Pacific island names, a map and name guide to the new Pacific. Bishop Mus Bull Cult Environ Stud 2:1–95
- N'Yeurt ADR (1996) A preliminary floristic survey of the benthic marine algae of Rotuma Island. Aust Syst Bot 9:361–490
- N'Yeurt ADR, Payri CE (2004) A preliminary annotated checklist of the marine algae and seagrasses of the Wallis Islands (French overseas territory of Wallis and Futuna), South Pacific. Aust Syst Bot 17: 367–397
- N'Yeurt ADR, Chynoweth DP, Capron ME, Stewart JR, Hasan MA (2012) Negative carbon via ocean afforestation. Process Saf Environ 90:467–474
- N'Yeurt ADR (1993) A Floristic survey of the intertidal and shallow benthic marine algae of Rotuma. MSc Thesis, the University of the South Pacific, Suva, p. 270.
- N'Yeurt ADR, Iese V (2014) Marine plants as a sustainable source of agrifertilizers for Small Island Developing States (SIDS). In: Ganpat WG (ed.) Impacts of climate change on food security in small island developing states. The University of the West Indies, Trinidad and Tobago/IGI Global (in press).
- Osborne NJT, Webb PM, Shaw GR (2001) The toxins of *Lyngbya majuscula* and their human and ecological health effects. Environ Int 27:381–392
- Stiger V, Payri CE (1999) Spatial and seasonal variations in the biological characteristics of two invasive brown algae, *Turbinaria ornata* (turner) J. Agardh and *Sargassum mangarevense* (Grunow) Setchell (Sargassaceae, Fucales) spreading on the reefs of Tahiti (French Polynesia). Bot Mar 42:295–306
- Tamata UB (2007) Studies of nutrient variability and the consequences for benthic communities on the coral coast fringing reefs, Fiji. PhD Thesis, University of Wollongong, Australia, p. 331.
- Vergara-Fernández A, Vargas G, Alarcon N, Velasco A (2008) Evaluation of marine algae as a source of biogas in a two-stage anaerobic reactor system. Biomass Bioenerg 32:338–344
- Woods J, Hemstock SL, Bunyeat J (2006) Bio-energy systems at the community level in the South Pacific: impacts & monitoring greenhouse gas emissions and abrupt climate change: positive options and robust policy. Mitig Adapt Strat Global Change 11:461–492
- Wosnitza T, Barrantes J (2006) Utilization of seaweed *Ulva* sp. in Paracas Bay (Peru): experimenting with compost. J Appl Phycol 18:27–31
- Zubia M (2003) La valorisation industrielle des algues brunes invasives (Fucales) de Polynésie française: étude prospective pour lutter contre leur prolifération et contribuer à la gestion durable de l'environnement récifal. PhD Thesis, University of French Polynesia, Tahiti, p. 359.
- Zubia M, Payri CE, Deslandes E, Guezennec J (2003) Chemical composition of attached and drift specimens of *Sargassum mangarevense* and *Turbinaria ornata* (Phaeophyta: Fucales) from Tahiti, French Polynesia. Bot Mar 46:562–571