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1 Acknowledgments

We acknowledge the input of the governments and people of Kiribati, Samoa and Fiji. We also acknowledge the engagement of farmers and community members, particularly the Women's Council of Kiribati, and women's groups in community management plans in Samoa. We thank the diverse range of Pacific businesses for their contributions and their involvement in project outputs. We highlight the broader contributions of Secretariat of the Pacific Community and international donors that are working on seaweed development in the region including the Markey Development Facility. We thank our seaweed colleagues Dr Joe Zuccarello (Victoria University Wellington), Dr Rebecca Lawton (University of Waikato) and Dr Andrew Cole (James Cook University) for their technical input and insights.

2 Executive summary

Seaweeds are produced for food and as industrial products throughout the Pacific and many communities rely on this production for significant portions of their income. This industry is diverse in the types of seaweeds produced, whether they are cultured or harvested from the coastline, the way that they are processed and in the final use of the seaweeds. However, the production of seaweed is fragmented across the Pacific region, and the range of opportunities is not well understood and has rarely been evaluated. The overarching aim of this project was to diversify the activities and, correspondingly, the opportunities available to the seaweed industry in the Pacific Islands. The project conducted a diverse range of research for development activities relating to seaweed production and bioproduct evaluation in three partner countries (Fiji, Samoa and Kiribati) working with government fisheries departments, university researchers, community groups and the private sector.

The first research objective of the project was to improve production levels and post-harvest quality of carrageenan gel-producing red seaweed *Kappaphycus* in Fiji and Kiribati. During the project, partners identified bottlenecks in the production of this commodity seaweed, evaluated technical barriers for expansion of seaweed production into new communities and how to sustain these efforts, and conducted scientific analyses of the quality of the seaweed biomass produced with a view to understanding how the value of the seaweed can be maximised. This work included activities such as environmental monitoring of the key production sites in each country, reporting on the volumes and value of seaweed in the domestic supply chains, empirical investigations of growth of different seaweed strains and insights from the communities regarding the socio-economic importance of seaweed farming.

In Fiji, 15 *Kappaphycus* production sites were studied across the Central, Western and Northern divisions, working with the Ministry of Fisheries and Forests and the University of the South Pacific. Through a concurrent effort by government, a number of farm clusters were established and communities were producing seaweed in 2014 (35 tonnes) and 2015 (39 tonnes), with the majority of production in the Yasawa Islands (70% of national volume). Environmental monitoring of key sites was not able to differentiate any effects of the main physical variables (temperature, current speed, light levels, nutrients - nitrogen and phosphorus), nor any distinction in terms of the culture methods and drying techniques on production volume and quality. Our insights suggest that it is likely a combination of singular environmental events and human factors that contributed to variation in output, including that many sites were pre-selected that had previously been farming sites. This was confirmed by social studies that highlighted most of the current crop of farmers had farmed seaweed before, as well as other insights including that 2/3 of farmers were male, many were over 50 years old (30%), most conducted seaweed farming as a family activity (95%), and identified weather and transportation as the main barriers for production. National production in Fiji was halted by Cyclone Winston in 2016 (one of the strongest cyclones to hit Fiji), and recovery has been slow (2016 - 4 tonnes; 2017 ~9 tonnes). Data and analysis from project activities were submitted and presented to the Fijian government and shared through the National Seaweed Taskforce which included members of the project team. Efforts in Fiji continue for the export production of *Kappaphycus*, but farming remains heavily dependent on government support and initiatives.

In Kiribati, 4 *Kappaphycus* production sites were studied on 3 islands in the Gilbert Group (Tarawa, Aranuka and Abaiang) with project scientists from the Ministry of Fisheries & Marine Resources Development. Production of seaweed from Kiribati is primarily from Fanning Island, in the Line Islands, however dried seaweed is typically stockpiled by the Central Pacific Producers Ltd (CPPL) on Tarawa as the supply chain is broken and sales to Asian processors are sporadic. On the capital Tarawa, seaweed farming had not occurred for many years and seaweed strains had to be sourced from other locations for project trials. These trials were run with two strains – one of the original *Kappaphycus* strains (collected from Fanning Island) and one of the new temperature-tolerant strains ("maumere") imported by MFMRD from Indonesia. Cyclone Winston in 2016 led to significant wave damage to the coastline, including the study sites. Small seaweed farms have continued after the project with farmers affiliated with Fisheries continuing to produce, dry and sell to the CPPL company. The key findings for this objective mirrored in many ways those of Fijian efforts, which are a narrative of environmental challenges (storms, sedimentation of the seaweed, and high temperatures), supply chain challenges (intermittent buyers that question product quality) and issues around the value of seaweed farming for farmers, especially those on the outer islands with the competition from copra with its regulated prices. Kiribati Fisheries and the CPPL have developed a taskforce to address these concerns, focussing on the potential of short supply chains and local use of the seaweed product to diversify the end use away from export in the near term.

For its second research objective, the project sought to consolidate production and post-harvest strategies for edible sea grapes *Caulerpa* in Samoa and Fiji for domestic and export markets. Project partners addressed fundamental issues in the supply of edible seaweed from wild-harvest fisheries by assessing the opportunity for domestication and aquaculture production of multiple species of sea grapes found across the countries.

Trials of sea grape farming used commercial aquaculture trays deployed for sea grape production in Australia. In Samoa, these were initially community-based trials working with women's groups at 3 sites on Upolu Island and 3 sites on Savai'i Island. However, cultures were only successful at 1 site on Upolu. Follow up trials in Samoa focussed on domesticating the sea grape seedstock from Upolu in the Taloa Hatchery, developing protective cages to exclude herbivores and successfully deploying this new design at village sites on Upolu and Savai'i. In Fiji, trials were conducted with the University of the South Pacific at 5 sites on Viti Ievu, Mamanuca and Yasawa Islands. However, cultures were only successful at 1 site on Mana Island, Mamanucas. The key outcome of the trials in Samoa and Fiji was that there are both biological and environmental constraints for production. The scientific impact of the project activities on sea grapes has been the formal identification, using DNA barcoding, of the sea grapes across the partner countries. This work identified for the first time that there are 5 species of *Caulerpa*, not the single *Caulerpa racemosa* and variants as previously described. For Samoa, this information helped to resolve why trials of sea grapes worked only with Upolu seed stock (*C. racemosa*) and not with the Savai'i seedstock (*C. chemnitzia*). Similarly, Fiji had three species of *Caulerpa* (*C. chemnitzia*, *C. macra* and *C. oligophylla*), all of which were sold as "nama" in the market. Notably no *Caulerpa racemosa* was identified. The lack of *Caulerpa racemosa* in Fiji is a limitation for the sea grape aquaculture as this was the most amenable to culture of all 4 species evaluated.

Project partners evaluated the ability to value-add to existing sea grape supply chains by investigating alternative methods for handling of fresh product and for processing into new products with export potential. The value chain of the seaweed fishery in Fiji was characterised, highlighting that sea grapes are the main edible seaweed, that up to 16 villages contribute into the major market in Suva but are dominated by 3 collection sites (Gunu village [Yasawa Islands], Rakiraki [Viti Ievu] and Mana [Mamanuca Islands]), and that the supply chain is almost exclusively women, from harvesting through to sales. The value of the sea grape fishery in Fiji is ~ FJD$80,000 per annum. Alternative ways to process the fresh sea grapes were evaluated, focussing on preservation in brine [for export] and on use in new recipes. Methods to preserve sea grapes were developed using brine, and the reconstitution of processed samples into products was evaluated. A small start-up company Pacific Seaweed was supported for some of its research needs. The final activity in this objective was a peer-led training workshop with seaweed harvesters/processors and project partners from Samoa training 25 representatives from the national associations of women's groups in Kiribati. Training included the collection, handling and use of recipes for sea grapes from Kiribati. This seaweed resource (*Caulerpa chemnitzia* and *C. racemosa*) is not widely utilised in Kiribati. Evaluation of the training workshop revealed that health and nutrition were the key reasons Kiribati people would be interested in eating seaweed, and that most were interested in participating across the supply chain with the motivation of financial benefit for personal savings.

In its third Objective (to assess opportunities for new seaweed bioproducts in Pacific Island Countries), the project has addressed the need to identify new commercial species of seaweeds and new applications for existing species. This is a common need across all partner countries, with a view to diversify the products available to seaweed farmers and to processors. The objective was to create new opportunities and pathways for adoption by leveraging the existing government and industry interest in the sector.

The project identified that there is a considerable opportunity to modernise and expand the seaweed industry, including the introduction of new products and applications, and this can be done with the support of government, fisheries departments, researchers and the private sector. Some examples of the activities conducted during the project include: creating seaweed compost (the utilisation of beach wrack – essentially seaweed waste – as a base nutrient in compost: Kiribati – focused on *Acanthophora*, Fiji – focussed on *Hydropuntia/ Gracilaria*, and Samoa – focused on *Sargassum*); utilising seaweed compost (the use of seaweed compost to grow crops: Kiribati – tomatoes and cabbages, Fiji – herbs); using seaweed as a feedstock for biochar (biological charcoal from pyrolysis of *Kappaphycus* from Kiribati); identifying the value chain of edible seaweed in the Suva Market in Fiji (*Caulerpa* spp. – FJ$13/kg, >6,000 kg p.a.; *Hypnea cornuta*/lumi cevata - FJ$17/kg, >500 kg p.a.; *Hydropuntia edulis (Gracilaria)*/lumi wawa – FJ$9/kg, >100 kg p.a.; and *Ulva meridionalis*/lumi boso - FJ$10/kg, >50 kg p.a.); using seaweed as a functional food (demonstration of the health benefits of consuming *Kappaphycus* from Fiji and its high-potassium salt); and, using seaweed cosmetics (the use of sea grapes in the development of a new product line for Essence of Fiji focussed on important minerals). In Kiribati, a series of training workshops on creating and using seaweed composts was run at Nanikaai, Tarawa, with 24 participants growing and then selling/bartering their products (both the compost and the crops). This training was evaluated, highlighting the motivators (learning new skills) and barriers (lack of ongoing support, materials and space) for the uptake of the training in the future, which is particularly important given a high rate of attrition in follow on activities.

Overall, the diverse range of technical activities conducted by the project are new opportunities for the Pacific, but notably many of these opportunities have not yet been translated into sustainable industries elsewhere either. The project identified sustainability issues for the seaweed industry that spans technical, cultural and economic aspects of working on an export-oriented business in the Pacific region. What the project has documented across the objectives, and across countries, is that the best way to make the local seaweed industry more resilient to both external and internal factors is to actively link seaweed production and processing to broader social, economic and environmental goals. However, it is likely that the industry will remain subsistence until domestic production first matures and diversifies. In this way a renewed focus on short supply chains for modernising and growing the seaweed industry on the domestic front would provide the platform to launch export-orientated ventures in due course.

3 Background

Global Seaweed Industry

Seaweeds are a diverse bioresource with a broad range of applications from food products to gelling agents, as fertilisers and in feeds, and specialty chemicals such as pharmaceuticals and nutraceuticals. Correspondingly, at the time of developing the project proposal in 2012, seaweeds represented one of the largest aquaculture crops in the world, with more than 15 million tonnes per annum in production, predominantly in Asia (Paul & Tseng 2012). Growth of the industry since 2000 has been strong, increasing by >5% per year, meeting demands for existing products and also new applications. The majority of global aquaculture production is from China and Korea for food – accounting for more than 2/3 of production or >10 million tonnes of kelp and nori together – and the remainder is for hydrocolloid production (carrageenan and agar), predominantly from the Philippines and Indonesia.

Seaweed Production in Pacific Island Countries

In contrast to global trends, seaweed production in Pacific Island Countries (PICs) has declined since 2000, with commercial production in the region remaining around ~1500 tonnes per annum (Ponia 2010). A stark comparison is that other tropical nations, such as Indonesia and the Philippines, have increased annual output above 1,000,000 tonnes (Paul & Tseng 2012). The potential remains for seaweed as an important crop for remote coastal communities in Pacific Island countries where it can deliver large livelihood impacts as income and food security (SPC Aquaculture Action Plan 2007). However, stimulation of the industry will require diversification of seaweed production in PICs because of the significant past focus on aquaculture production of a single type of seaweed (*Kappaphycus*) for a single product stream (colloids).

The production of *Kappaphycus alvarezii*, known as “cottonii”, for the hydrocolloid carrageenan is the key to the revitalisation of the core seaweed industry in Fiji and Kiribati. *Kappaphycus* production has declined significantly in Kiribati (from >1400 t of dried seaweed in 2000 to 0 tonnes in 2007) and in Fiji (from 420 t in 2000 to <50 tonnes in 2007). The major technical issues relate to productivity declines, for which the use of more robust varieties of *Kappaphycus* that deal with warming water temperature, and better farm management practices, are options for the industry (McHugh 2006). A second constraint on production referred to on a scoping mission was product quality, both in terms of the quantity and type of carrageenan and also in terms of the consistency of product pooled from different villages or seasons. A number of socio-economic factors were likely involved in the retraction of the industry around the year 2000 (McHugh 2006), for example, some villagers have switched to a more valuable use of the same shoreline (such as Bêche-de-mer). Together these factors affect production capacity which in turn creates uncertainty in the market chain. However, the *Kappaphycus* crop remains critical for remote coastal communities in Kiribati and for this reason production continues to be subsidised by the government and managed by the government-controlled company Central Pacific Producers Ltd. (K. Tonganibeia *pers. comm.*, Vice Chairman CPPL in 2012). Similarly in Fiji there is renewed interest in *Kappaphycus* production from private industry with a focus on a more consistent and refined product for shipment rather than a raw form.

Opportunity for industry-focussed R&D

An earlier scoping study and past ACIAR projects and regional reviews (e.g. McHugh 2006, SPC Aquaculture 2007) have identified opportunities for diversification of seaweed industries. These broadly relate to R&D opportunities to revitalise existing *Kappaphycus* industries in Fiji and Kiribati, to consolidate the emerging sea grape production in Samoa and Fiji, and to establish new opportunities for seaweed bioproducts in Pacific Island Countries (PICs).

Firstly, ACIAR-funded and regional reviews (McHugh 2006, SPC Aquaculture 2007) have provided clear recommendations for the *Kappaphycus* seaweed industry, highlighting the need for improved production methods to create a high-quality product and for diversification of products as value-adding opportunities. The desire for a consistent quality of product through standardised farm management practices, and the evaluation of new strains, were recurring themes in recent discussions with industry representatives on a scoping study. One strategy is to identify common technical constraints in *Kappaphycus* production and – at the same time - to delineate these from socio-economic factors that may have influenced past declines in production. By providing a regional standard protocol for production to deliver a relatively consistent supply and grade for carrageenan processing, the seaweed industry can build confidence in the marketability of their product. Furthermore, where acceptable grades cannot be consistently met, an alternative product stream (or streams) for *Kappaphycus* (for example biochar or other soil applications) can create an opportunity to retain the commercial viability of the crop.

Secondly, *Caulerpa*, known as sea grapes, have recently been a focus for sustainable harvests of fisheries products in Fiji (ACIAR PARDI 2010/002) and aquaculture production in Samoa (FIS/2006/138 mini-project). There is an opportunity to build upon the successful demonstration of a sea grape production system in Samoa by expanding village-based production. Sea grapes are typically stored and served fresh, and preservation methods to increase shelf life are important for domestic consumption and critical to access international export markets. There is also an opportunity to build upon the technical R&D for shelf life extension conducted by an earlier ACIAR project to meet these market requirements (PARDI 2010/002).

Thirdly, Pacific Island countries are well placed to take advantage of new seaweed bioproduct opportunities, such as nutraceutical, animal feeds, fertiliser or bioenergy, because of their pristine water, shallow and accessible coastal environments and diversity of seaweed flora. Together with value-adding through product diversification of *Kappaphycus* and sea grapes, the identification of new bioproducts sources could create additional markets and provide opportunities for expansion of seaweed production in remote communities of PICs.

Research questions and strategy: Three general research questions were formulated after a scoping mission to Fiji, Kiribati and Samoa: 1) what are the critical constraints for *Kappaphycus* production and product quality? 2) what are the biomass productivities and post-harvest options for sea grape production; and 3) can existing seaweed products, by-products or new sources of biomass be used in alternative applications? A series of specific research questions is detailed in the methodology section.

The research strategy for FIS/2010/098 was to focus on field-based research in selected PICs which have a strong history of seaweed production and existing capacity in both government agencies and private industry. The project maintained a close link with fisheries agencies and industry partners, and strong community engagement through village-based trials. There was a sharp focus on the two major seaweed crops, *Kappaphycus* and *Caulerpa*, complemented by targeted R&D on new bioproduct applications with these same species and additional seaweeds identified in the scoping study (*Gracilaria*, *Hypnea*, *Acanthophora, Ulva, Sargassum* spp.).

Specific activities varied depending on industry status and in-country R&D capabilities, but all activities and outputs have potential impact for any partner country.

4 Objectives

The overall aim of this project was to provide the technological basis for diversification and revitalisation of seaweed industries in Pacific Island Countries, focussing in on Fiji, Samoa and Kiribati. The specific objectives were to:

1. Improve production levels and post-harvest quality of *Kappaphycus* in Fiji and Kiribati
2. Consolidate production and post-harvest strategies for edible sea grapes *Caulerpa* in Samoa and Fiji for domestic and export markets
3. Assess opportunities for new seaweed bioproducts in Pacific Island Countries

4.1 Objective 1

Improve production levels and post-harvest quality of *Kappaphycus* in Fiji and Kiribati

- Assess the critical factors for year-round production of *Kappaphycus* and their relationship with biomass quality and other biochemical traits;
- Determine the influence of post-harvest treatment processes and shelf-life on biomass quality and biochemical traits;
- Assess the properties of new seaweed strains introduced into Fiji;
- Provide a quantitative evaluation of existing product grades in relation to farming method and biomass quality; and,
- Develop strategy for standardised production and post-harvest methods in PICs to produce a consistent high-quality product.

4.2 Objective 2

Consolidate production and post-harvest strategies for edible sea grapes *Caulerpa* in Samoa and Fiji for domestic and export markets

- Identify which types of sea grapes are compatible with aquaculture production;
- Determine on-farm productivities and harvest cycles for village-based production of sea grapes;
- Generate technical information on the physical characteristics and nutritional benefits of sea grapes;
- Trial post-harvest methods for shelf-life extension to meet domestic and export specifications; and,
- Engage with government, farmers and processors in workshops and training, with a particular focus on involvement of women.

4.3 Objective 3

Assess opportunities for new seaweed bioproducts in PICs

- Identify and evaluate sources of biomass from existing seaweed products, by-products or new sources of biomass seaweeds for new applications; and,
- Evaluate the production of new seaweed bioproducts by integrating with existing industry capacities.

5 Methodology

The methodology of the project focused on field-based research in selected PICs which have a strong history of seaweed production and existing capacity in both government agencies and private industry. The project maintained a close link with fisheries agencies and industry partners, and strong community engagement through village-based trials. The relative priorities of the objectives were reflected in heavier weightings for particular country activities where seaweed aquaculture or bioresource potential for that species was already established. The location of work for specific activities in each objective varied depending on industry status and in-country R&D capabilities. We note where outputs developed in one country were deployed in another country during the project.

5.1 Improve production levels and post-harvest quality of *Kappaphycus* in Fiji and Kiribati

Study sites: Fiji and Kiribati

Key personnel and participants: Led by government agencies and working with farming families in Fiji (community groups; seaweed clusters), University of the South Pacific [USP]. Secretariat of the Pacific Community [SPC] and FAO.

- Mr Tentaku Teata (ACIAR project officer in Kiribati)
- Ms Shirleen Bala (ACIAR project scientist from USP)
- Fisheries extension officers in both countries (Fiji: Western, Central and Northern Divisions; Kiribati: Tarawa, Abaiang, Aranuka)
- Graduate Research Students: USP Masters - Ms Verenaisi Lewatoro, Mr Albert Whippy, Ms Ashmeeta Shalvina; JCU Graduate Certificate – Mr Ian Tuart
- Mr Ian Tuart and Ms Ana Wegner, project scientists at the University of the Sunshine Coast (Ian Tuart formerly JCU)
- Dr Ruth Garcia-Gomez, collaborating scientist SPC and FAO (at various times during project)

Methods: One of the most attractive propositions for farming *Kappaphycus* for carrageenan gel production is that the culture methods of propagation by fragmentation lends themselves to year-round production under the right environmental conditions. The project scientists from Fiji and Kiribati assessed the **critical factors for year-round production of *Kappaphycus*** in their respective regions, tying together production data with information on **biomass quality and the biochemical traits** of the seaweed. Efforts were first made to quantify the annual production, starting with export values. However, upon starting the project, because export had ceased in both countries (see Results), we instead had to evaluate production at the trader scale. Seaweed was scaling up in Fiji and sites were selected to monitor the state of the industry in the farming clusters that were supported by the regional fisheries officers. Five sites were monitored from 2015 till early 2017, while some were added later upon request from Fisheries Department and monitoring was discontinued at some sites due to no seaweed production (Table 5.1).

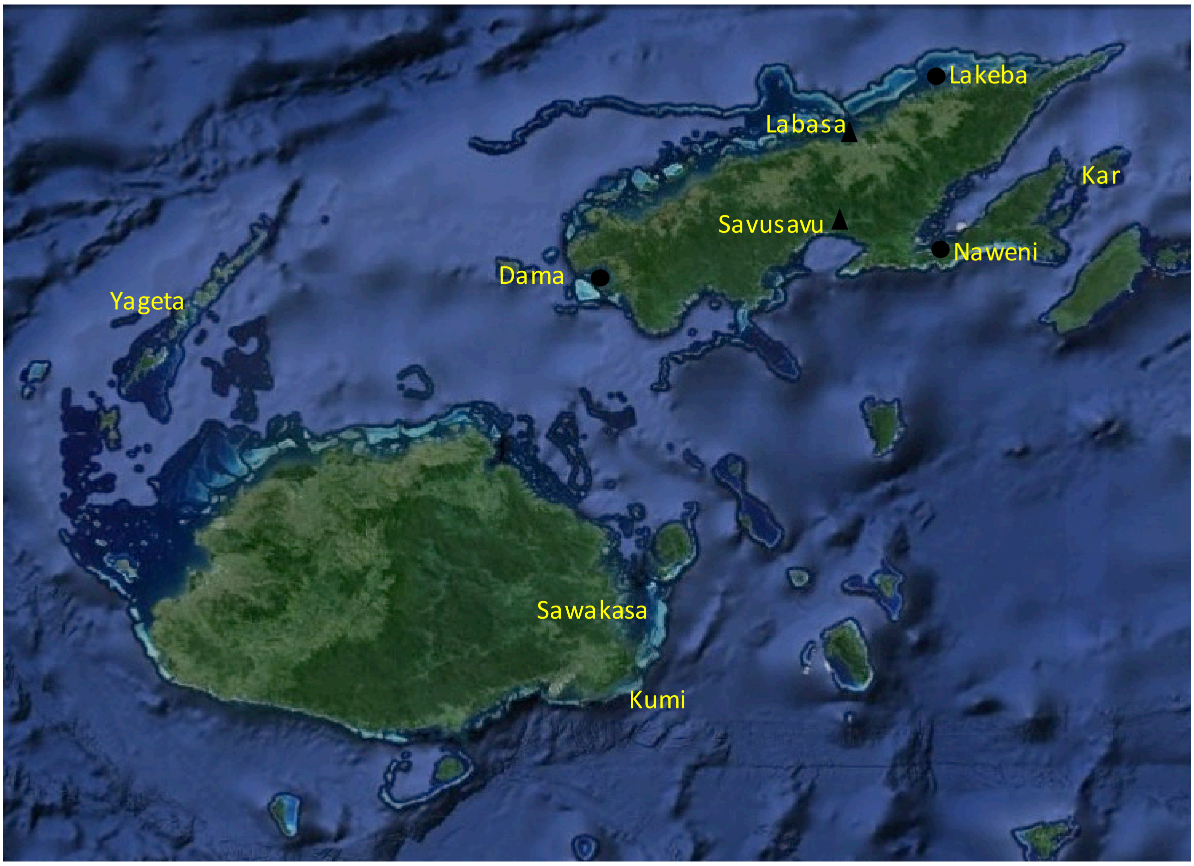


Figure 5.1. Main Fijian sites for *Kappaphycus* production.

Table 5.1 Fijian sites monitored from 2015-2017

Village	Area	Variety	Sampling duration	Status at July 2017
Sawakasa	Tailevu, Vitilevu	Sacol	Mar 15- Jan 17	Not active
Kumi	Tailevu, Vitilevu	Sacol	Mar 15-Sept 15	-
Lakeba	Vanua Levu	Tambalang	Mar 15- Sept 15	-
Dama	Bua, Vanua Levu	Tambalang	Mar 15- June 17	Active
Druadrua	Vanua Levu	Tambalang	Aug 15- June 17	Active
Kavewa	Vanua Levu	Tambalang	Mar 15- Feb 17	Not active
Karoko	Savusavu, Vanua Levu		Mar 15-Jun 15	-
Naweni	Savusavu, Vanua Levu	Tambalang	Mar 15-Jun 15	-
Yageta	Yasawa	Tambalang	Apr 15- June 17	Active
Vuaki	Yasawa	Tambalang	Apr 15- June 17	Active
Nabautini	Coral Coast, Viti Levu	Sacol	Sept 15-Feb 16	Not active

Village	Area	Variety	Sampling duration	Status at July 2017
Nayavu-i-ra	Rakiraki, Viti Levu	Tambalang	May 15- Oct 15	Not active
Nakalau	Vanua Levu	Tambalang	Nov 15-June 17	Active
Navidamu	Vanua Levu	Tambalang	March 17- June 17	Active
Kaba	Tailevu	Tambalang	Sept 16-May17	Active

In contrast, no village-based production occurred in the Gilbert Islands (including the capital Tarawa) in Kiribati for the duration of the project. Community-led farming was documented on Fanning Island, however, flights into Fanning were not possible for the duration of the project. Mr Tentaku Teata did visit the island later in the project cycle to deliver the new maumere strain (see below). Seaweed production R&D in Kiribati focussed on MFMRD extension officer-led trials in the Gilbert Islands focussed on a number of sites in Tarawa and surrounding islands.

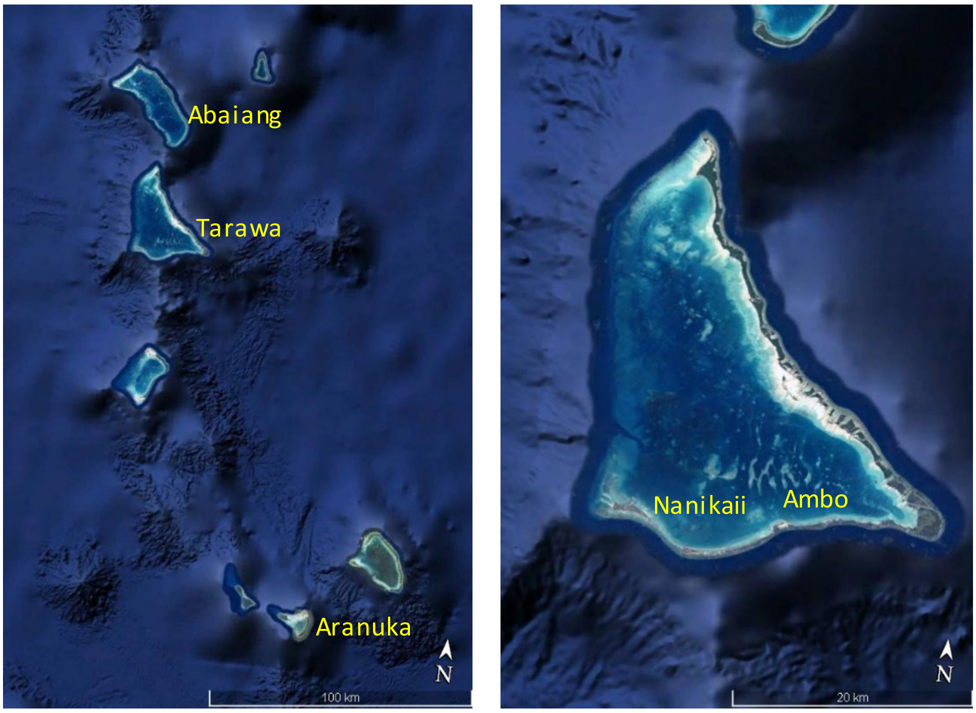


Figure 5.2. Main Kiribati sites for *Kappaphycus* production. Gilbert Islands group sites (left) and Tarawa sites (right).

At all farming sites a suite of environmental monitoring methods were utilised. Hobo pendant loggers (model number: UA-002-64) were used to measure water temperature and light intensity every 10 minutes. YSI meters were used to record water temperature and salinity when project partners were in the field for individuals sampling points. HACH (DR 900) were used to analyse nutrient levels (nitrate and phosphate) for water samples collected at each sampling point. Current speed and direction were recorded for some selected sites using a Marotte HS drag-tilt current meters (developed by James Cook University/Marine Geophysics Lab). Raw seaweed production data was collected from seaweed buyers and sorted by sites and divisions from 2014 to 2017 in both Fiji and Kiribati.

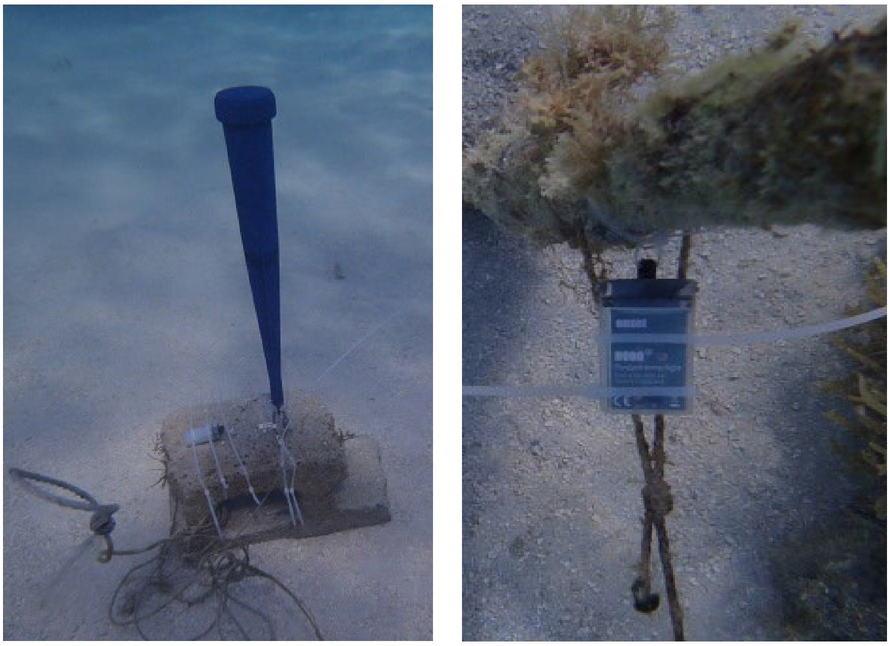


Figure 5.3. Deployment of environmental loggers. Marrote current logger (left) and Hobo Temperature-Light Pendant (right).

At the same time as conducting environmental monitoring, biomass sampling was also conducted. Dried seaweed samples were collected haphazardly from the larger shipments (a handful from each bag, where possible) and analysed for moisture content. Samples were packed and shipped to Australia for further nutritional content analysis. All the data for biomass production and quality samples were captured in a database. These sampling times relied on access to seaweed buyers' inventories and were therefore only sporadically collected (it was rarely possible to link the final analysed sample back through the supply chain to the harvest date and handling conditions thereafter – raw data is therefore as received by the project partners at the major traders in Fiji and sites as reported).

Actual production data was collated from buyer data. Data was collected from Wee Kong Marine Ltd, who was the only buyer of *Kappaphycus* seaweed in Fiji from 2014 till Jan 2017. In 2017 data was collected from Wee Kong and another new company Soluk Fiji Ltd which started buying in 2017. For Kiribati, samples were taken from project culture activities and from seaweed stockpiled at the Central Pacific Producers Ltd. Biochemical data sheets were made for each country.

Variation in the quality of dried *Kappaphycus* for export is one of the main limitations for supply of high value biomass into the commodity market. Traders, such as Wee Kong Enterprises in Fiji and Central Pacific Producers Ltd in Kiribati are wary of purchasing seaweed that is low quality as this is, at best, a low value commodity and at worse, difficult to move. The key steps in quality control at the farm level are sufficient drying of the seaweed (so that carrageenan degradation does not occur) and ensuring that the level of impurities is low and that the carrageenan content is high. Methods were developed to assess the **influence of post-harvest treatment on biomass quality and biochemical traits** of *Kappaphycus* that is farmed and dried at Fijian villages and transported to traders in the main cities of Suva and Lautoka. Specifically, the project examined the variation in the moisture content (indicator of drying quality) and in the ash content (high ash or mineral content is a sign of impurities (sand) and/or low organic (carrageenan) content). These measurements provided the project team with an objective way to **evaluate existing**

product grades, as determined by the buyer, that which dictated the price of the seaweed that went to the farmer. The farm gate price was recorded and relationships between the price and the biomass quality and biochemical traits were assessed. See Objective 3 for a more complete analysis of the biochemical composition of *Kappaphycus* samples collected from Fiji and Kiribati.

The project supported the Secretariat of the Pacific Community to assess the **properties of new seaweed strains** (*Kappaphycus alvarezii,* variety 'maumere') that was imported from Indonesia (Dr Ruth Garcia-Gomez). The original goal of the project was to conduct trials with the maumere strain in Fiji, however three failed attempts by the Fisheries at domesticating the introduced strain meant that the intended ACIAR-related activities were omitted from the project planning. Towards the end of the project maumere was successfully introduced into Kiribati, but only through to the domestication stage. No formal trials were run comparing production to the existing tambalang strain.

The formal identification of red seaweed farmed for carrageenan from the *Kappaphycus* and *Eucheuma* genera is sometimes difficult as strains vary in colour and shape, and common names do not necessarily equate to the current taxonomy. For example, *Kappaphycus alvarezii* was previously called *Eucheuma cottonii*, which in turn was commonly referred to as 'cottonii' by farmers. The "cottonii" common name still stands. Likewise *Kappaphycus striatum* is commonly known as "sacol". Both have been introduced into Fiji but it was unclear whether they were still cultured. Molecular barcoding was used to assess the species and, where possible, the strain of seaweed under cultivation in Fiji and Kiribati. This was done by A/Prof Joe Zuccarello from Victoria University Wellington using the Cox1-2 spacer for red seaweed. Comparisons could then be made of the biomass quality and biochemical traits of samples of known taxonomy. Importantly, sampling protocols to preserve the seaweed for DNA barcoding were developed through trial and error, settling on dehydrating a short (<2cm), apical section of the fresh seaweed sample in ample silica in a sealed container. A second step included replacing the indicator gel as required and storing in a cool, dark site prior to shipment to molecular laboratories.

The synthesis of the results relating to seaweed production in the villages (environmental variation and also the influence of natural disasters such as cyclones and related wave), post-harvest processes for drying and storing seaweed prior to shipment, biomass quality and biochemical properties, and ultimately sale prices were synthesised. Additional information from socio-economic work on the farming culture in Fiji were also incorporated through Masters students, Verenaisi Lewatoro and Albert Whippy from USP. These results were discussed in the final workshop, at which a strength-weakness-opportunity-threat analysis was done with participants including project scientists, industry and farmers. A series of recommendations relating to developing **a strategy for standardised production of *Kappaphycus* in Pacific Island Counties** were made and delivered to the National Seaweed Taskforce in Fiji.

5.2 Consolidate production and post-harvest strategies for edible sea grapes *Caulerpa* in Samoa and Fiji for domestic and export markets

Study sites: Samoa and Fiji

Key personnel and participants:

- Ms Ulusapeti Tiitii – Principal Fisheries Officer, Ministry of Agriculture and Fisheries, Samoa
- Inshore Fisheries & Aquaculture team, Ministry of Agriculture and Fisheries, Samoa
- Ms Cherie Morris – ACIAR project scientist from USP

- USP Masters Student: Mr Tomasi Tikoibua
- JCU Masters Student: Ms Tereere Tioti (also of Ministry of Fisheries and Marine Resource Development, Kiribati)
- Mr Ian Tuart, project scientist at the University of the Sunshine Coast
- Dr Libby Swanepoel, University of the Sunshine Coast
- Taati Eria – Fisheries Training Unit, Ministry of Fisheries and Marine Resource Development, Kiribati
- Kiribati Council of Women's Groups

Methods: For sea grape production, the project expanded on previous work relating to aquaculture production of sea grapes in Samoa begun as an ACIAR mini-project (FIS/2006/138, Paul et al. 2012). For sea grape post-harvest work, these built upon the activities of the ACIAR PARDI project (PARDI 2010/002) by continuing work to extend shelf-life and export potential using fresh product and introduced new methods of long-term preservation through brine. The strategy for this objective was to focus on the strengths of each country in either production (Samoa) and processing (Fiji), working closely with fisheries agencies on farm techniques in village-based experiments in Samoa, and, with the University of the South Pacific and small businesses (including Pacific Seaweed) on post-harvest techniques to meet domestic and export requirements. Trials of farm techniques were also conducted in Fiji through a USP Masters project.

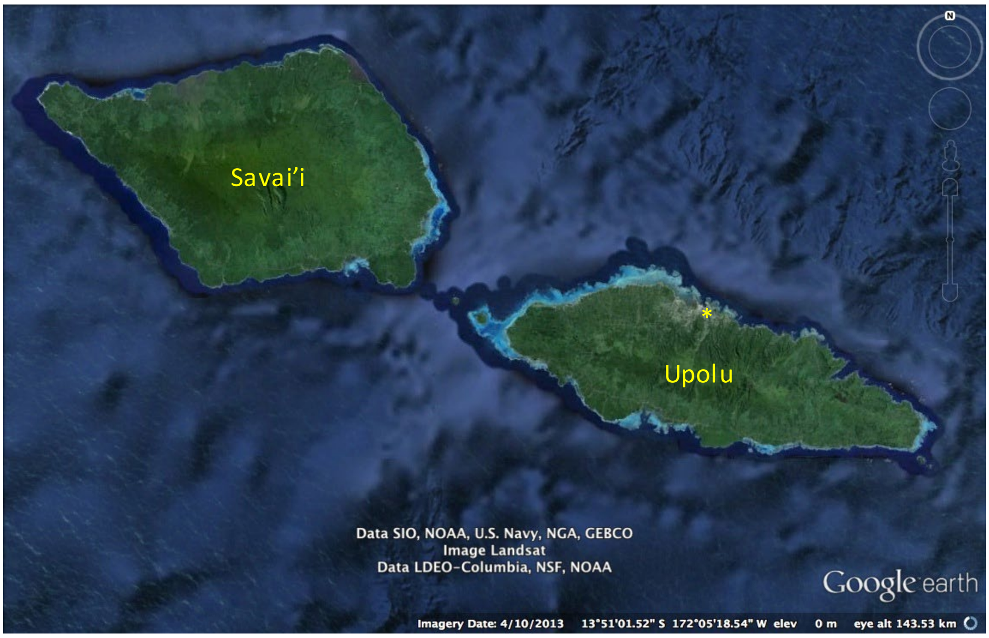


Figure 5.3. Main island of Samoa. Upolu hosts the capital Apia (*). Key village sites for production trials were on Upolu (Savaia, Faleula and Salua Monono tai) and on Savai'i (Asaga, Vaisala and Salelologa).

The first steps towards identifying **which types of sea grapes are compatible with aquaculture production** was to source and freight aquaculture trays from Australia to Samoa and Fiji. These activities were based upon low-technology culture methods using fragmentation to promote re-growth which have been successfully trialled in short-term tests of village-based production in Samoa (ACIAR FIS/2006/138 mini-project). The assembly of systems for sea grape trials focussed on shallow subtidal areas (Figure 5.4). The aquaculture trays, or "aquatrays", are 1m x 2m comprising of 8 compartments covered by a lid with a ~5cm deep cavity (Tooltech Pty Ltd, XL8 Aquatray). Trays containing 10kg of sea grapes were deployed and monitored for growth and environmental conditions over a 6 week period. The approach for this sub-objective was to collect data on the productivities and harvest cycles of sea grapes in culture. The R&D focused on the continual production of stock in the system over multiple harvest cycles, measuring seasonal changes in productivity and in morphology of the sea grapes. Comparisons were made between the two local varieties of sea grapes in Samoa assessing different stocking densities of sea grapes in the first instance.

Figure 5.4. Site selection and preparation for culture of sea grapes on sandy reef flats in the shallow subtidal in Samoa. This photo shows the experimental set up at Vaisala village on Savai'i island, with a fisheries staff member securing the posts for cultivation. (March 2014)

The next step was to expand production trials into other sites in Samoa and also trial the same aquaculture set up in Fiji (Figure 5.5). Productivities were measured as changes in biomass over time, noting the relative amounts of biomass in different parts of the tray (inside tray, above tray or below tray). Different configurations of tray set ups were assessed. In all cases the tray was suspended above the substrate in coastal areas that were permanently submerged. Trays were secured from each corner to a rebar (reinforcing bar) using fishing line (Figure 5.5 A). At some sites a double layer of trays was trialled (Figure 5.5B). At the same time as conducting biomass productivity trials, environmental conditions were monitored similar to Objective 1 above.

A.

B.

Figure 5.5. Aquaculture production trials of sea grapes (*Caulerpa* spp.) at Mana Island, Fiji. (September 2014)

One of the questions relating to expanding sea grape production is how the aquaculture product would compare to wild-harvest product. In order to do this **baseline technical information on the physical characteristics and nutritional benefits of sea grapes** was required for both Samoa and Fiji. Data sets of physical characteristics and biochemical composition of sea grapes were collated using samples collected from the main marketplaces in both countries for each variety of sea grapes. At the same time as collecting information on sea grapes, other edible seaweed sold in the markets were also monitored over time (Figure 5.7). Price and volume sold were collected for all seaweeds where possible. Additional dried biomass samples were taken for molecular (DNA) barcoding in Samoa, Fiji and Kiribati were as per Objective 1. **Technical product sheets** on the physical characteristics and nutritional composition of sea grapes from Fiji and Samoa were produced.

More specifically for Fiji sea grape and edible seaweed sampling resulting in technical product sheets, monthly sampling of sea grapes (with the exception of March 2016: consequence of Cyclone Winston – no market sales) sold in Suva market ran from April 2015 to May 2017. Approximately 1kg samples were purchased at around the same time each sampling day from the same vendors from all sea grape village sources. Initially, samples were taken on Saturday as this was the main day of sale. Additional edible seaweed species such as *Hydropuntia edulis, Hypnea cornuta* and *Ulva meridionalis* from each source were purchased from July 2015 onwards after a decision was made to include all edible seaweeds in the monitoring to enable greater context for any changes in sea grape availability (see Figure 5.7 for typical seaweed vendor set up). Data collected on the main market day (Saturday) included the: number of vendors; number and size (kg) of bags per vendor; number plates per sample; price per plate (FJD, plate is the standard way the seaweed is sold); mean fresh weight per kg; fresh and dry weights (g); ratio of fresh weight to dry weight; date of harvest; date received by seller; and, data packed. In August 2016, the number of sampling days per week increased to 4 (Wednesday to Saturday) to enable a better estimate of national production.

For biochemical analysis, each cleaned seaweed sample from the market was placed in a clean plastic bag and returned directly to the laboratory. After placing each sample in a tray (30x43x5cm), wet weights and photos (for assessment of impurities) of each sample were taken before being placed into an Ezidri Ultra FD1000 dehydrator for 30-60 hours depending on humidity. Weights were taken after drying with a calibrated Ohaus NVL2100 balance scale. From November 2016, about 5g wet weight samples of all 4 edible seaweed species from each source were dried with silica gel. About 0.02g of each dried seaweed species was transferred to a conical tube, labelled and stored in the freezer for DNA analysis at a later stage. All dried samples were packed and sealed using a Sunbeam Vacuum sealer, labelled accordingly and sent to the University of the Sunshine Coast for biochemical analysis (see Objective 3 – methods for analysis details). The seasonal product quality measurements of water content (calculate from the FW: DW ratio) and ash content of the dried matter (mineral content; with the difference being the dry matter organic content) is expressed for each species in a time series.

Fijian production statistics are presented for two years from June 2015 to May 2017 for all 4 species of edible seaweed from the 8 villages across Fiji which were regularly supplied and sold in Suva market. There were 2 villages irregularly supplying Nadi & Lautoka markets, although these were excluded from time series comparisons due to low number of samples. However, for national production calculations, the production statistics from the occasional suppliers, including 5 other villages and 1 island resort, were included in the overall quantities per region. Similarly, Samoan production statistics for 2 years from January 2016 to June 2017 for sea grapes from 19 villages across Samoa in Apia market are present.

A key limitation for expanding the market of sea grapes is developing technologically appropriate post-harvest techniques that can be used to extend shelf-life. The steps required in this were **developing preparation and packaging options for transport to reduce spoilage** and also evaluating these packaging options and transport in different settings. This component focused on developing village-based treatment of sea grapes across the partner countries for shelf-life extension. In Fiji, this work was begun initially with the industry partner, Pacific Seaweeds, who have a regular shipment of preserved product to New Zealand (using preservatives such as brine). Research students in Fiji, Kiribati and Australia continued this work on shelf-life extension of fresh product using traditional materials. This work formed the basis for subsequent training exercises with women's groups in Kiribati.

Figure 5.7. Edible seaweeds of Fiji from the fresh food market in Suva. Lumi wawa (*Gracilaria* sp., far left, eaten fresh), Lumi (*Hypnea* sp., second from left, eaten after cooking in coconut milk), Nama (*Caulerpa* spp., sea grapes, eaten fresh with chilli and fermented coconut) and *Ulva* (far right, eaten fresh).

The final activities in this objective related to **engagement with government, farmers and processors in workshops and training**, with a particular focus on involvement of women. Initial workshops were conducted with sea grape farmers in Samoa with women's groups on Savai'i Island. At the end of the project, a peer to peer workshop was conducted with Samoan women experts in sea grape training Kiribati women in the collection, processing and sales of sea grapes using traditional methods. The aim of this workshop was to engage with people in Kiribati participating in a 2-day seaweed training workshop, to explore their perceptions of their potential role in local seaweed harvesting and utilisation. The specific objectives were to: describe the characteristics of people taking part in a seaweed training in Kiribati; determine people's barriers to participating in various activities associated with seaweed harvesting and processing; determine opportunities and enablers to support their participation in local seaweed harvesting and processing; and, to explore the role that seaweed harvesting, and processing could play in improving the wellbeing of participants.

A cross-country peer-led approach was used to introduce women in Kiribati to the potential benefits of seaweed harvesting, processing and consumption. Local community members (18 years of age and over) were invited to take part in a 2-day seaweed training workshop on June 12-13th 2018, facilitated by a group of Samoan women who were proficient in seaweed harvesting and processing. The Samoan peers travelled to Kiribati to conduct the training workshop in collaboration with the University of the Sunshine Coast project team, Samoan Fisheries team members (Samoa Ministry of Agriculture and Fisheries), and Kiribati Fisheries team members (Ministry of Fisheries and Marine Resource Development). Participatory research principles underpinned the training workshop where participants took ownership of recipe development, price and marketing strategies.

Figure 5.8: Women participants developing sea grape recipes as part of the 2-day training workshop in 2018.

In-person structured interviews were conducted with all participants (n=24) to evaluate their interest, barriers and enablers, and expected costs and benefits from potential future engagement in seaweed activities. In-country researchers (interviewers) were briefed on the ethical considerations for data collection and trained in the interview process. Participants were aware that their responses would remain confidential, and that they were welcome to skip questions or withdraw from the interview at any time without penalty or repercussions. Questions were translated into e-Kiribati and piloted in-country for face validity. Interviews took place at the workshop venue and took between 45-60 minutes to complete. The interviewer recorded responses by hand at the time of the interview. A summary of each response was provided to the participant after each question to verify that the researchers had captured and understood what the participant has said to be correct. Conventional content analysis of interview responses was conducted to uncover common themes. Content analysis additionally focussed on outlier themes that may be culturally specific and particularly relevant to the aims of this study.

5.3 Assess opportunities for new seaweed bioproducts in Pacific Island countries

Study sites: Kiribati, Fiji

Key personnel and participants: University of the Sunshine Coast, University of the South Pacific,

- Mr Ian Tuart and Ms Ana Wegner, project scientists at the University of the Sunshine Coast (previously at James Cook University)

- Mr Tentaku Teata and Mr Karibanang Tamuera, Ministry of Fisheries and Marine Resource Development, Kiribati
- Mr Routan Tongaiaba, Ministry of Agriculture, Kiribati
- Nanikaai Women's Groups and Disabled Group (4 community groups in total)
- Dr Libby Swanepoel, University of the Sunshine Coast
- Ms Taati Eria, Training Unit, Ministry of Fisheries and Marine Resource Development, Kiribati
- Ms Debra Sedranu, Essence of Fiji, Nadi, Fiji
- Associate Professor Jimaima Lako, Fiji National University
- USP Masters Students: Ms Ashmeeta Shalvina, Ms Jagruti Chuahan

The project addressed two interrelated research questions relating new bioproduct opportunities: Can existing seaweed products, by-products or new sources of biomass be used in alternative applications? And, what are the unique biochemical and morphological traits of these seaweeds and their by-products?

New opportunities for seaweed bioproducts in Pacific Island Countries will be **assessed for existing seaweed products, by-products and new sources of biomass**. A scoping exercise firstly identified potential sources of biomass in each of the countries, with a particular focus on seaweed blooms and beach wrack as "waste" material. Two main soil applications were evaluated (Question 1): compost production and biochar (Bird et al. 2012). Biochar – a biological charcoal produced via pyrolysis – was made from Kiribati seaweed using cultured *Kappaphycus* and its chemical profile compared to other commercially available seaweeds (as per methods in Roberts et al. 2014). Compost needed additional proof of concept development, pot trials of composts and community-scale evaluation (see subsequent paragraphs in this section for details). The main bioactive application was evaluating cultured seaweed in an animal health model for use as a functional food. This work was done in collaboration with the University of Southern Queensland (as per methods in Wanyonyi et al. 2017). This study evaluated use of *Kappaphycus* from Fiji as a "whole" functional food additive for reversal of diet-related metabolic syndrome.

A significant amount of effort was spent quantifying the **biochemical and morphological traits** of *Kappaphycus*, *Caulerpa* and other Pacific seaweeds. Comparisons were also made to some Australian samples from cultivated seaweed. Comprehensive analyses were done on samples used for particular bioproduct assessments, such as those used for compost trials, the main edible seaweeds in the food markets, and for those tested in functional assessment of bioactivity. For example, specific quality measures required for applications relating to functional food, such as fibre and mineral content, were measured for Wanyonyi et al. (2017). More than 1000 individual data entries on the biochemical properties of seaweed were made for samples collected during the project to assess the composition and quality of different species from Fiji, Kiribati, Samoa and Australia. While samples from the Pacific Islands (Fiji, Kiribati and Samoa) were wild harvested, Australians samples were from recirculating aquaculture systems with controlled temperature and nutrients (nitrogen and phosphorous).

DNA barcoding: Identification of seaweed can be difficult due to morphological variation (plasticity) or that species are yet to be formally classified. DNA barcoding was used to provide a molecular identification for seaweeds from Fiji, Samoa, Kiribati and Australia to complement the common names used in the region. DNA barcoding of the red algae was completed by Dr Joe Zuccarello of Victoria University of Wellington, New Zealand; and that of the green algae by Dr Rebecca Lawton from James Cook University. Samples taken for DNA barcoding were collected specifically for this purpose and handled as follows. When collecting the seaweed, the sample was rinsed thoroughly in water from the sampling site to remove any other algae attached to it or contaminants. After removing excess water by shaking it, the sample was put in a labelled zip lock bag to be transported. In a dry and clean space (e.g. laboratory), the sample is pat dry with paper towel of excess water and then sufficient growing tips (up to 3cm long) of the sample are broken and placed into a 250ml clean plastic vial. In order to dry the sample, the algae is covered with ample silica gel bids, the container covered with a lid and left for approximately 12hrs (or until completely dry). Once dry, a minimum of 200mg dry weigh is transferred to a 1.5ml Sarstedt micro tube and kept in the freezer until submission of samples.

Methods for biochemical analysis used to produce the product sheets are following:

- *Moisture content analysis of dried samples.* Water strongly affects the microbiological and chemical stability, and physical properties of dried seaweed. Therefore, to increase shelf life and maintain high quality of dried samples, it is crucial to keep the moisture content of the biomass low. Low moisture content can be challenging to maintain when the biomass is stored outdoors, as it is vulnerable to daily weather variations (humid and dry conditions). During the project, samples were either harvested or purchased fresh from the market and then dried, or taken previously dried from seaweed distributors' storage centres (e.g. CPPL in Tarawa). Several of these samples had the moisture content measured by a moisture analyser (MS-70 moisture analyser, A&D Company Ltd.). Moisture content was also measured as a procedural step after dehydration and prior to biochemical analysis. These results are reported as the moisture content in the product data sheets. If stored in air tight recipients (e.g. sealed bags or containers/vials), moisture content can be kept between 2-10% depending on species and drying method. The moisture analyser uses a built-in set of scales and a halogen lamp to weigh and dry samples. It calculates the moisture content (%) by comparing the difference between the initial moist weight and final dry weight obtained by the heating of the halogen lamp to 105°C. A minimum of 1, 5 or 10 grams of the dry sample is needed for the analysis for low (0.05%/min), medium (0.02%/min) or high (0.01%/min) accuracy results respectively. The analyser dries the sample until the sample weigh stabilises according to the accuracy program chosen. The analyser will then display the moisture content in percentage (%). Most samples were dried in a food dehydrator and packed in sealed containers or vacuum sealed bags prior to being analysed. However, to compare the moisture content of samples dried in food dehydrator with local drying methods (e.g. air drying), moisture analyses were done on samples purchased from the local market in Fiji, as received.
- *Ash content analysis.* To determine composition and properties of a specific sample, it is important to assess its ash (= inorganic) content. Inorganic non-volatile matter (such as metals, ions and salts, for example) is crucial to quantify to assess the suitability of a specific product to a targeted end-product. A muffle furnace (Yokogawa model UP150) was used to determine the ash content of algae samples obtained during the project. The furnace has a maximum temperature of 1500°C, heated by a Kanthal A1 resistance wire spiral element wound on the outside of the refractory muffle. The high temperature (maximum of 550°C for ashing) burns all organic matter, leaving the inorganic/ash. A minimum 1 gram of dry algae is placed in a pre-weighted crucible, which is then re-weighted (using a scale with 0.0001g precision). Three replicates of each sample were weighted to be averaged out. The crucibles – with a lid each – are placed in a metal tray which in turn is put into the muffle furnace. Once turned on, the oven will follow its selected program. For ash content evaluation, the furnace heats up to 550°C over 1h 45min, maintaining at 550°C for 6 hours and cooling down to 100°C over 3 hours. After the program has completed, the crucibles (containing the ash) are removed from the furnace and

placed into a desiccator. Once they reach room temperature, the crucibles are re-weighed and the ash percentage can be calculated.

- *Lipid extraction.* The method used for lipids extraction from seaweeds followed the protocol of Folch et al. (1957) to extract lipids from animal brain tissue, adapted by Gosch et al. (2012), to extract lipids from algae. The lipids are extracted by adding an inorganic solvent to a dried and milled sample and heating it on a hot plate for 1 hour.
- *Protein.* Protein content was calculated based the concentration of Nitrogen. Protein content in algae biomass can be estimated following the use of a nitrogen-to-protein conversion factor of 5 from Angell et al. (2016.)
- *Fibre content.* Fibre content includes both total dietary fibre and insoluble dietary fibre. The supplier for this was Australian Export Grains Innovation Centre (AEGIC), Australia (http://aegic.org.au). A minimum of 8g of the sample dried (in a food dehydrator) and milled (in a small food blender) was put into a 25ml plastic test tube with a silica gel bag inside, closed tight with a lid and sealed with a plastic paraffin film (Parafilm) to be sent for analyses. AEGIC followed standard methods for analyses (AOAC Official Method 985.29 total dietary fibre in Foods, and AOAC Official Method 993.19 soluble dietary fibre in food and food products). Samples were analysed for total dietary fibre and insoluble dietary fibre, thereafter, soluble dietary fibre were calculated by difference.
- *Elemental composition (CHONPS).* Different species of seaweed differ on its concentrations of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorous (P) and sulfur (S). Furthermore, the concentration of some of these elements in the water where the seaweed grows will influence the algae composition. To explore new seaweed bio-products it is crucial to learn the proportion of these elements in the seaweed. The suppliers used were OEA Laboratory Ltd., UK (http://www.oealabs.com) for CHON and the Advanced Analytical Centre (AAC), James Cook University for P and S together with metal analyses (see heading 2.7 Metal composition). A minimum of 1g of the sample dried (in a food dehydrator) and milled (in a small food blender) was put into a 25ml plastic test tube with a silica gel bag inside, closed tight with a lid and sealed with a plastic paraffin film (Parafilm) to be sent for analyses. The laboratory uses an elemental analyser that converts carbon, nitrogen, hydrogen and sulfur from the sample into carbon dioxide, elemental nitrogen, water vapour and/or sulphur dioxide by combustion in pure oxygen. Oxygen analysis involves conversion of oxygen to carbon monoxide by high temperature catalysed pyrolysis. These gases are carried through the analytical system by helium, separated by a gas chromatography column and quantified using thermal conductivity or flame photometric detectors. If the amounts of C, H, N, S and ash are available (in %) Oxygen can also be estimated by difference as: $O\% = 100 - \Sigma(C, H, N, S, ash)$.
- *High Heating Value (HHV).* The gross energy content of the biomass (MJ kg^{-1}), expressed as the higher heating value (HHV), can be calculated based on the results of ash content and the elemental composition using the following equation (detailed in Appendix 11.6):
  HHV (MJ/kg)=(0.3491*C)+(1.1783*H)+(0.1005*S)-(0.1034*O)-(0.0151*N)-(0.0211*ash)
- *Metal and remaining elemental composition.* The mineral content of seaweed has important positive and negative implications for potential role in nutrition for animals and plants. Multiple suppliers were used: Advanced Analytical Centre (AAC) at James Cook University, Australia, Advanced Analytical Australia (http://www.aaapl.com.au) and A2 Analises Quimicas, Portugal (http://a2analisesquimicas.webs.com). A minimum of 5g of the sample dried (in a

food dehydrator) and milled (in a small food blender) was put into a 25ml plastic test tube with a silica gel bag inside, closed tight with a lid and sealed with a plastic paraffin film (Parafilm) to be sent for analyses. The mineral content of the biomass was measured by inductively coupled plasma mass spectrometry (ICP/MS) (Varian 820-MS, Australia) as described in Appendix 11.6.

- *Water content of fresh samples (Fresh to Dry ratios).* When fresh, different species of seaweed differ in the average amount of water they hold within their cells. Water content of the same species will also fluctuate depending on the growing conditions. For example, fast growth can result on higher water content, giving misleading values when measuring production only on fresh weight if the biomass value is on its dry weight. To know the amount of water seaweed holds within its cells, the weight of the fresh algae is divided by the weight of the dried algae, thus giving a fresh-to-dry ratio (FW:DW). To obtain fresh weight, the sample must be taken from the water and have its excess over the surface water removed. One way of removing the excess water is by gentle centrifuge/spin. Small samples that had their FW:DW taken, were spun in a salad spinner, weighted, dried for at least 24 hours (or until fully dried) in a food dehydrator and re-weighted in the same balance. The FW:DW will be the sample's fresh weight divided by the sample's dry weight.

Compost for soil health in country: One of the key activities conducted by the project was the production, evaluation and community-based training in use of seaweed compost in Kiribati. This production of composting methods was possible because of a partnership created between Ministry of Fisheries and Ministry of Agriculture in Tarawa. One particular variety of seaweed – the red seaweed *Acanthophora spicifera* - is highly abundant and washed up on the beach to form a "wrack" (Figure 5.9). This beach wrack is sometimes removed by the community and buried or disposed of, as it is unsightly and can degrade and cause an offensive smell. This seaweed became the primary focus for composting work in Kiribati after initial trials revealed it was most suitable.

Figure 5.9. Seaweed beach wrack at Nanikaai community on South Tarawa, Kiribati.

- *Compost production and pot trials*. A range of different seaweed species, different ratio of seaweed:leaves (from 1:10 to 10:10), and a range of different inclusion rates in pot trials (from 20% to 80%) for 4 different crops were evaluated during the project. A manual was subsequently written (Appendix 11.3) for the community workshop on the production of compost using the *Acanthophora* seaweed.

- *Community compost training workshop*. Tarawa on 16-17 August 2016. A community-level trial of compost was conducted in Nanikaai, Sth Tarawa, focussed on four village groups. Nanikaai community was selected for this workshop because the four villages are active in cleaning their beachfront of seaweed but, as yet, do not use this seaweed for any applications. They presently bury the seaweed or dispose of it. The workshop participants will primarily focus on women from each of the four villages that are already engaged in cleaning and maintaining the beachfront. This community trial was run by Fisheries staff from the Ministry of Fisheries and Marine Resources Development (MFMRD) and University of the Sunshine Coast project scientists from ACIAR, in partnership with staff from the Kiribati Ministry of Agriculture. Each village group (~ 5 people) created their own compost mix, and this compost was maintained for the duration of the trial with regular support from Fisheries and Agriculture staff. Additional training was provided during the workshop for the Fisheries Training Officer, and to two Fisheries Assistants that are involved in seaweed farming on Abaiang and Aranuka, to support additional extension activities on Tarawa and the outer islands. The workshop participants from Nanikaai learnt the methods required to produce and manage compost in a hands-on workshop and were be supported by Fisheries and Agriculture staff for the duration of a 3-month trial, at which point another workshop was conducted for the use of compost in planting crops, again supported by Agriculture and Fisheries staff. An evaluation of the compost training workshop was conducted a year later through participant interviews (see Appendix 11.4).

- *Compost training evaluation*. This activity was a 12-month follow-up evaluation of the training program to describe the characteristics of people taking part in composting groups in Kiribati, determine people's barriers and enablers to ongoing involvement in composting groups, and, to evaluate the role membership of the seaweed composting group played in improving the wellbeing of members involved. Seaweed composting groups were established in Tarawa as a cost-effective and environmentally friendly method of generating compost and producing vegetable gardens. Current and past members of the composting groups were invited by local researchers to take part in a face-to-face interview to share their experience and involvement in the group. Structured interviews were conducted 12-months after training with 18 of the original 24 participants. Questions were translated into e-Kiribati and reviewed by a local researcher to check for ambiguity, appropriateness of wording and cultural acceptability. Participants completed the interview in e-Kiribati with the use of a local translators (Figure 5.10).

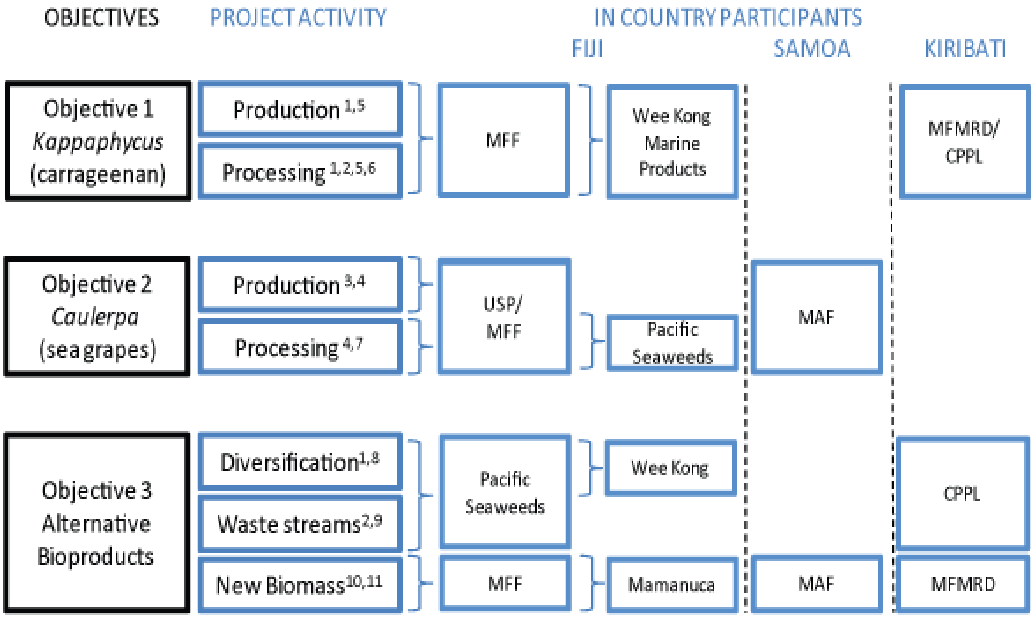
Figure 5.10: Debriefing session with local translators following initial interviews.

Product sheets: Ultimately, the technical data sheets were used to engage with existing local industry groups, from small business developing new seaweed-based products to environmental groups interested in the nutrient removal from coastal waters. Sheets were made for individual seaweed species collected from each country. A separate sheet was also made tomatoes produced during the compost evaluation.

5.4 Project Framework

The original relationship framework (from 2013) amongst partners for the project is detailed in Figure 5.11. As the project activities developed during the project, additional industry and donor partners included:

- FAO (Dr Ruth Garcia Gomez) – supply of maumere *Kappaphycus* strain from Indonesia and associated training of ACIAR-funded project scientist from Fisheries in Kiribati
- Market Development Facility – Cardno, Suva
- Essence of Fiji – Nadi, Fiji (cosmetic and wellness company)
- Mamanuca Environment Society, Nadi, Fiji
- Mana Island, Navini Island, Treasure Island and Tokoriki Island resorts in the Mamanuca Islands, Fiji
- Fiji National University (FNU)
- Soluk Trading – Seaweed trader, Fiji
- Ministry of Agriculture, Kiribati
- Women's Council of Kiribati



Past ACIAR Activities
1 McHugh 2006
2 SMAR/2008/025
3 FIS/2006/138
4 PARDI 2010/002

Key Publications
5 SPC Aquaculture Plan 2007
6 Pickering & Mario 1999
7 Paul & de Nys 2010
8 Bird et al. 2012
9 Craigie 2011
10 Pickering 2005a & 2005b
11 Holdt & Kraan 2011

In Country Participants – Government/University
MFF – Ministry of Fisheries and Forests, FIJI
MAF – Ministry of Agriculture and Fisheries, SAMOA
MFMRD – Ministry of Fisheries & Marine Resource Development, KIRIBATI
USP – University of the South Pacific, Institute for Marine Resources, FIJI
CPPL – Central Pacific Producers Ltd, Betio, KIRIBATI

In Country Participants – Private Industry
Wee Kong Marine Products & Exporters Co Ltd – Private Company, Suva, FIJI
Pacific Seaweeds – Private Company, Suva, FIJI
Mamanuca Resort Islands – Private resorts, Nadi, FIJI

Figure 5.11. Relationship between project partners (government, university and private industry) in conducting project activities, highlighting past ACIAR projects and key publications at the start of the project in 2013.

6 Achievements against activities and outputs/milestones

6.1 Objective 1: Improve production levels and post-harvest quality of Kappaphycus in Fiji and Kiribati

no.	activity	outputs/ milestones	completion date Y = Year, M = Month Y1, M1: October 2013	comments
1.1	Assess the critical factors for year-round production of *Kappaphycus* and their relationship with biomass quality and biochemical traits	Develop methods for chemical and physical traits of *Kappaphycus*	Y1, M12	Technologically appropriate methods for the analysis of the chemical and physical traits of *Kappaphycus* were developed. These involved in-country analysis using project-supplied equipment at the partner institutions (moisture content, fresh weight: dry weight ratio) and was complemented by additional fine-scale analyses at the commissioned organisation and other Australian contract research laboratories.
		Define the state of the industry in Fiji and Kiribati	Y1, M12	In 2015, production statistics for *Kappaphycus* production were sourced from both government and company export data for 2014/2015. Export of seaweed had, in that period, resumed for both countries after a number of years of no sales. However, since then Fiji suffered major setback in production due to Cyclone Winston in 2016 and Kiribati had supply chain/customer issues that meant neither country had substantial export production. These problems remain current. Project team also contributed to national seaweed taskforce discussions in Fiji and similar in Kiribati. Formal presentations regarding the state of the industry were made each year from 2015.

no.	activity	outputs/ milestones	completion date Y = Year, M = Month Y1, M1: October 2013	comments
		Documented data sets of *Kappaphycus* production	Y2, M12	Seaweed production has been documented for farming clusters around Fiji. The main production area is the Western division (>50% of production, focussed on the Yasawa group), followed by the Eastern division (Gau and Ono-i-Lau), then Central (eastern portion of Viti levu) and Northern (Vanua levu) divisions. Yasawa Islands has had no production since Cyclone Winston. Seaweed production remains at an R&D scale in the Gilbert Islands, Kiribati, with small trials on Tarawa, Abaiang Tabiteuea North, Abemama Island, Aranuka Island, Marakei Island and Butaritari Island. Fanning Island (Line Islands) accounts for the entire commercial production at this time. Both countries were heavily affected by natural disasters in this reporting period. Production in Fiji has been significantly reduced, with many villages not reprising production after the cyclone. These data sets were two sequential milestones for 2015 and 2016.
		Documented data sets of biomass quality and other biochemical traits	Y2, M12	Biochemical data for *Kappaphycus* farmed in Fiji and Kiribati was generated through sampling of dried material from both export companies. Biomass quality was also analysed for a limited number samples taken from experimental plots. These data sets were two sequential milestones for 2015 and 2016.
		Create database capturing the productivity, post-harvest methods, and the seasonality of biochemical traits for *Kappaphycus*	Y4, M9	A database has been assembled for the entire project using a pivot table format. Because of the intermittent biomass available for production and post-harvest methods, the data largely comprises of biochemical traits. Datasets from across the three objectives have been synthesised into a single file containing geographic and temporal information.
		Product quality sheets for *Kappaphycus* that detail variation in biochemical traits	Y4, M9	Product quality sheets have been produced for *Kappaphycus* farmed in Fiji and Kiribati. In Fiji, individual data sheets have also been produced for the main producing areas (Western and Eastern Divisions), documenting within country variation.

no.	activity	outputs/ milestones	completion date Y = Year, M = Month Y1, M1: October 2013	comments
1.2	Determine the influence of post-harvest treatment processes and shelf-life on biomass quality and biochemical traits	Assess the influence of processing and storage on biochemical traits	Y2, M6	The first set of analyses for the key traits of *Kappaphycus* (moisture content and ash content) was completed for the small amount of exported material available in 2014/2015 for both Fiji and Kiribati. Note that more comprehensive analyses were planned but were not feasible because of limited supply of seaweed.
		Documented data sets of biomass quality and biochemical traits	Y2, M12	There is considerable variation in the moisture content and the amount of impurities in traded seaweed. "Quality" (as described by buyers and their price points) was amorphous and the limited insights we had found that it was based on subjective interpretations regarding impurities and moisture content. These insights are anecdotal as there was insufficient data on quality and price to identify any objective quality traits.
1.3	Assess the properties of new seaweed strains	Establish sampling protocols for SPC lead trial(s) of new *Kappaphycus* strains	Y1, M12	Protocols for production of the 'maumere' strain were developed by SPC for both Fiji and Kiribati. However, no new seaweed strains were available for the future. Effort was re-directed to production of the existing strains of *Kappaphycus* in both Fiji and Kiribati.
		Molecular barcoding of *Kappaphycus* strains in PICs complete	Y5, M6	DNA barcoding was completed for *Kappaphycus* samples of the existing strains and the new strain using the Cox 2-3 spacer region. The results identified that the main type of seaweed cultured was *Kappaphycus alvarezii* haplotype 3 (which is the most widely cultured haplotype in SE Asia). This was the same strain in both Fiji and Kiribati, for different colour morphs and for the "new" maumere strain as well. One sample of *Kappaphycus* from Tai levu, Fiji was the "sacol" variety – *Kappaphycus striatum* haplotype 89. From our knowledge, this was the first time that Pacific Islands samples had been analysed at this level.

no.	activity	outputs/ milestones	completion date Y = Year, M = Month Y1, M1: October 2013	comments
1.4	Provide a quantitative evaluation of existing product grades in relation to farming method, biomass quality and biochemical traits	Documented data set of farming methods, biomass quality and product quality	Y3, M12	Biochemical data sets have been produced for *Kappaphycus* for sites across the Pacific and is the first complete characterisation of product quality for the region. Product grades could not be formally analysed nor linked back to farming methods as there was limited consistency in the sources and frequency of samples in the supply chain. The final "product sheets" generated will now be used by stakeholders to aid in their commercial negotiations and to develop alternative products and applications.
1.5	Develop strategy for standardised production and post-harvest methods in PICs to produce a consistent high-quality product	Tailored operating procedures for specific end-uses in PICs	Y4, M9	The project identified that the socio-economic and cultural factors influencing production and post-harvest may be as (or more) important to consistently high-quality products than technical interventions. Tailored operating procedures for end-uses was not possible. However, recommendations were made at the final project meeting and are recorded in the discussion and Appendix 11.
		Conduct workshop with key participants, farmers and processors	Y4, M9	Nadi, July 2017

6.2 **Objective 2:** Consolidate production and post-harvest strategies for edible sea grapes Caulerpa in Samoa and Fiji for domestic and export markets

no.	activity	outputs/ milestones	completion date	comments
2.1	Identify which types of sea grapes are compatible with	Source and freight aquaculture kits from Australia to Samoa & Fiji	Y1, M6	All partner countries (Samoa, Fiji and Kiribati) received project materials and infrastructure for conducting trials on time.

no.	activity	outputs/ milestones	completion date	comments
	aquaculture production	Complete production trials of different sea grape varieties in Samoa	Y1, M12	Production trials of the two varieties of sea grapes (limu fuafua) in Samoa are completed. Trials with the Upolu variety continue into Year 2/3 in the hatchery rather than village-based trials. Trials with the Savai'i variety were discontinued after multiple attempts to domesticate this species (see note subsequent regarding different species). A new seedstock system was constructed at the Samoa Fisheries hatchery facility to aid in domestication. The construction of a seedstock facility at the hatchery in Samoa was not originally earmarked and represented a big accomplishment by the project team. The existence of seaweed-specific infrastructure was important for raising the profile of work with limu at the Ministerial level.
		Complete testing of different stocking densities and harvest cycles of sea grapes in Samoa	Y2, M12	Harvest cycles have been evaluated in Samoa, indicating that cycles of 4 weeks are optimal. The project intent was to continue to evaluate harvest cycles and stocking density in Samoa with a view to optimising the system in the latter part of the project. However, this milestone relied upon the successful scale up of production of different sea grapes in Samoa. Only one species was successful (see subsequent milestone) and the project team opted to do this under controlled conditions in the recently constructed hatchery, prior to returning to village-based production trials.

no.	activity	outputs/ milestones	completion date	comments
		Complete production trials of different sea grape varieties in Fiji	Y3, M12	The first production trials of the edible sea grapes *Caulerpa* using technology from Australia have been completed at six production sites around the Western and Central Divisions of Fiji. This work identified the environmental parameters and trialled new production configurations at the most promising sites for year-round production in the Mamanuca and Yasawa Islands. There was significant variation in the growth of the sea grapes that could not be explained by bio-physical parameters. Subsequently, the molecular barcodes of the different types of sea grapes has for the first time been determined, identifying at least four cryptic species that are all sold as "sea grapes' in Samoa and Fiji. This has changed the focus in Samoa, with the domestication now relying on hatchery production of one species (*Caulerpa racemosa*). In Fiji, for example, none of the species evaluated have proven to be successful for intensive culture – this species was not found in Fiji to date.
2.2	Determine productivities and harvest cycles for village-based production of sea grapes	Documented data sets for sea grape production and the environmental conditions	Y3, M12	The extension of sea grape production in Samoa and Fiji has not been straightforward because of genetic effects associated with cryptic species. The project instead focussed on seasonal monitoring of fisheries production in both Samoa and Fiji through market surveys. Environmental data was collected at some harvest sites and seasonal data from the *Kappaphycus* monitoring sites were used to complement these collections. The influence of environmental disasters on supply in the marketplace was also noted.

no.	activity	outputs/ milestones	completion date	comments
		Standard operating procedures for village-based production of sea grapes	Ongoing	There are considerable limitations for sea grape aquaculture more broadly in the Pacific Islands if the dominant species in Fiji and Samoa (i.e those familiar to people and used in the marketplace) are not amenable to domestication. The pilot trials at villages in both countries was intended to be performed with local species from each village production area. However, there has been a substantial change in knowledge relating to the use of the common term "sea grapes". Our molecular barcoding investigation identified that there are at least four different species in Fiji and Samoa, and only one of these, *Caulerpa racemosa* in Samoa, is readily domesticated. The project recommendations for sea grapes in the Pacific include aspects on: (1) hatchery seed production (2) deployment in cages in villages (away from freshwater) (3) whole tray harvest over time – then replace with new seed from hatchery
		Report on the productivity and quality comparisons of sea grapes from different sites in Samoa and Fiji	Y4, M9	Completed only for Fiji. Report is based upon quality data obtained from seasonal market data (Appendix 11.2). Mr Tomasi Tikoibua Masters thesis is another output from this section of the work. Project funds were used in addition to the USP ACIAR scholarship to deliver on this objective in Fiji.
2.3	Generate technical information on the physical characteristics and nutritional benefits of sea grapes	Documented data sets of physical characteristics of sea grapes	Y2, M12	Biochemical data sets have been produced for *Caulerpa* from wild harvests in Samoa and Fiji. These document the fresh weight to dry weight ratios and ash content.
		Documented data sets of nutritional benefits of sea grapes	Y3, M12	Biochemical data sets for *Caulerpa* were updated to include the main biochemical components (including the mineral content related to its nutritional benefits) as well as the nutrient status of the seaweed (C, N and P contents). The data on the nutritional and biochemical profiles of sea grapes were taken from biomass sampled during the market surveys (2.2). Separate "product data sheets" have been produced for each country and, in some instances, separate production regions. These product sheets are in the same format as the *Kappaphycus* outputs.

no.	activity	outputs/ milestones	completion date	comments
2.4	Trial post-harvest methods for shelf-life extension to meet domestic and export specifications	Develop preparation and packaging options for transport to reduce spoilage	Y1, M12	A decision was made earlier in the project to prioritise research support for the post-harvest processing of sea grapes for export rather than fresh. This involved work with the small business Pacific Seaweed (Ms Shamron Pickering).
		Complete trial of packaging options and transport	Y2, M12	Initial assessments of the existing preparation and packaging options for sea grapes in Fiji (nama) were completed and alternative methods were developed as a partnership between USP (Ms Cherie Morris) and Dr Jimaima Lako (FNU).
		Technical product sheets on the physical characteristics, shelf-life and nutritional benefits of sea grapes for domestic and export requirements	Y4, M6	Full technical product sheets have been developed for domestic fresh product. Export requirements will now be assessed for brine products – a comparative assessment of an existing commercial product from Vietnam has been completed. This was undertaken in Australia by Mr Imran Lapong (Masters student).
2.5	Engage with government, farmers and processors in workshops and training, with a particular focus on involvement of women	Conduct workshop with key participants, farmers and processors in Fiji and in Samoa	Y5, M9	Training for the project activities related to preservation was not relevant to Fiji and Samoa. However, a niche opportunity was identified, and training was instead run in Kiribati for the national council of women's groups. A variation in project end date was granted. This was the last activity of the project.

6.3 Objective 3: Assess opportunities for new seaweed bioproducts in Pacific Island countries

no.	activity	outputs/ milestones	completion date	comments
3.1	Identify and evaluate sources of biomass from existing seaweed products, by-products or new sources of biomass	Identify target biomass sources for seaweed bioproducts	Y1, M12	During the first year of the project, seaweed targets for bioproduct evaluation were identified in each country. These include: the red seaweed *Gracilaria* in Fiji (problem seaweed on the Mamanuca Islands; preliminary investigations in compost and cosmetic applications – now reclassified as *Hydropuntia*); the red seaweed *Acanthophora* in Kiribati (prominent beach cast on Tarawa; preliminary investigation as compost); the brown seaweed *Sargassum* in Samoa (beach cast on Upolu Island; preliminary investigation as compost). In subsequent years the potential for expanding bioproducts from existing market seaweed was investigated for the food products of lumi, lumi wawa and other lumi in Fiji. Insights from the market analysis in Fiji provide a compelling story to focus on expanding the production and breadth of applications for existing natural resources rather than through introduction of non-native species such as *Kappaphycus*.
		Quantify the biochemical and morphological traits of biomass sources	Y2, M12	To complement the biochemical and morphological traits of the sea grapes and *Kappaphycus* from the two objectives above, additional species have also been evaluated in each country. This focussed on *Acanthophora* (from Kiribati), *Hydropuntia*, *Hypnea* and *Ulva* (from Fiji), and *Halymenia* (from Samoa).
		Produce biochar and co-products from target species	Y2, M12	Biochar was produced from *Kappaphycus* collected from Kiribati (grown on Fanning Island).
		Evaluate bioactivity of targeted biomass to test product applications	Y3, M12	Potential bioactives from the red seaweed *Kappaphycus*, including its high-potassium salt, have now been evaluated in animal models for the reversal of metabolic syndrome using functional food. This is a collaboration with the University of Southern Queensland.

no.	activity	outputs/ milestones	completion date	comments
		Evaluate soil health applications in country	Y4, M6	The development of seaweed compost has had a clear scientific impact, both inside and outside of the project. The work on seaweed compost in Kiribati has motivated a number of villages to begin to use the seaweed in compost formulations, based on project extension activities and also word of mouth from participants in a project-run community training program in 2016/17. There has similarly been some outside uptake of the compost work in the Mamanuca Islands of Fiji, where seaweed has become invasive on the small islands scattered throughout the island chain.
		Scientific publication on biochemical traits and bioactivity of new bioproducts for PICs	Y5, M2	A publication on biochar from *Kappaphycus* farmed in Kiribati was published in 2015. A publication on *Kappaphycus* bioactivity was published in 2017. Another on health applications for bioactives from *Kappaphycus* is in preparation
3.2	Evaluate the production of new seaweed bioproducts by integrating with existing industry capacities	Produce technical data sheets for new seaweed bioproducts in PICs	Y3, M12	Technical (product) data sheets have been produced for *Acanthophora* (from Kiribati), *Hydropuntia*, *Hypnea* and *Ulva* (from Fiji). The existing data sheets for *Kappaphycus* and *Caulerpa* are also being used in determining the potential for development of new applications and bioproducts.
		Engage with Australian industry to determine interest in new bioproducts and create awareness of opportunities	Y3, M12	The Australian algal company (formerly known as MBD Energy Ltd) trialled the native species of sea grapes which were being used in Australia for pilot experiments as part of the methods development of shelflife Objective 2.
		Engage with PIC industry to determine interest in new bioproducts and create awareness of opportunities	Y4, M6	The Nadi-based cosmetic company Essence of Fiji has translated research findings on the biochemical properties of sea grapes (nama) into a range of new products.
		Conduct workshop to promote uptake and leverage investment opportunities	Y4, M9	Workshop session at final project meeting was run for private partners including Essence of Fiji, Cardno Markey Development Facility, Mamanuca Environment Society, Treasure Island Resort, Navini Island Resort.

7 Key results and discussion

The overarching aim of this project was to diversify the activities and the opportunities available to the seaweed industry in the Pacific Islands. The project conducted a diverse range of research for development activities relating to seaweed production and bioproduct evaluation in three partner countries (Fiji, Samoa and Kiribati) working with government fisheries departments, university researchers, community groups and the private sector.

*The key results and discussion for **Objective 1** (improve production levels and post-harvest quality of carrageenan gel-producing red seaweed Kappaphycus in Fiji and Kiribati) were:*

7.1 *Kappaphycus* production in Fiji

In 2014, production was 35 tonnes and, in 2015, this slightly increased to 39 tonnes. The resolution of site-specific data from the 5 project sites was only available from 2014-2017 (Fig. 7.1A; full details Appendix 11.1) with the majority of production from the Yasawa Islands (this equated to ~70% of national volume). National production in Fiji was halted by Cyclone Winston in 2016 (one of the strongest cyclones to ever hit Fiji), and recovery has been slow (2016 - 4 tonnes; 2017 - ~9 tonnes). The wholesale prices were difficult to collate as they intermittently came through the sole seaweed trader in Suva; however, there was considerable variation in price paid to farmers across the years (Figure 7.1B). Overall the total farmgate value of seaweed for the peak production year of 2015 was FJ$40,051 (Table 7.1). Data and analysis from project activities were submitted and presented to the Fijian government and shared through the National Seaweed Taskforce which included members of the project team from MFF, USC and USP. Government efforts in Fiji continue for the export production of *Kappaphycus*, but farming remains heavily dependent on government support and initiatives.

Figure 7.1A. Production for selected sites over 4 years in Fiji

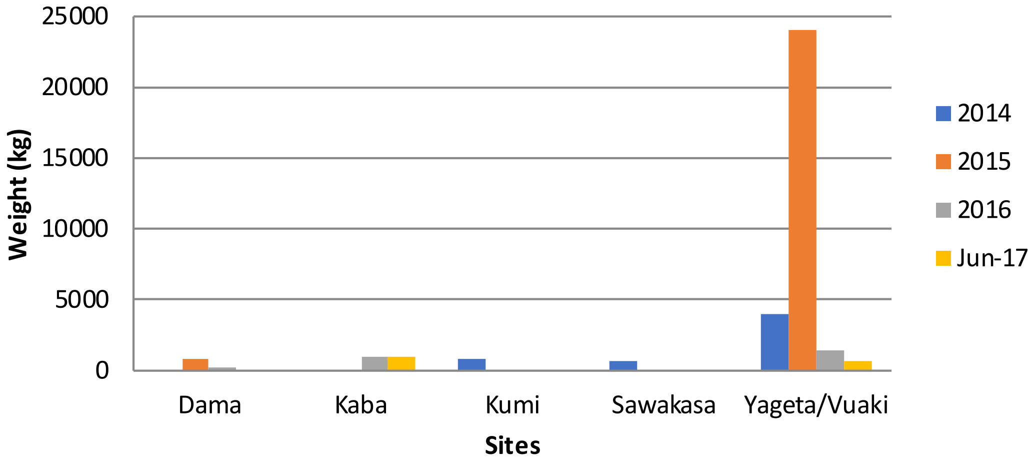


Figure 7.1B. Price Fluctuation per kg of *Kappaphycus* in Fiji

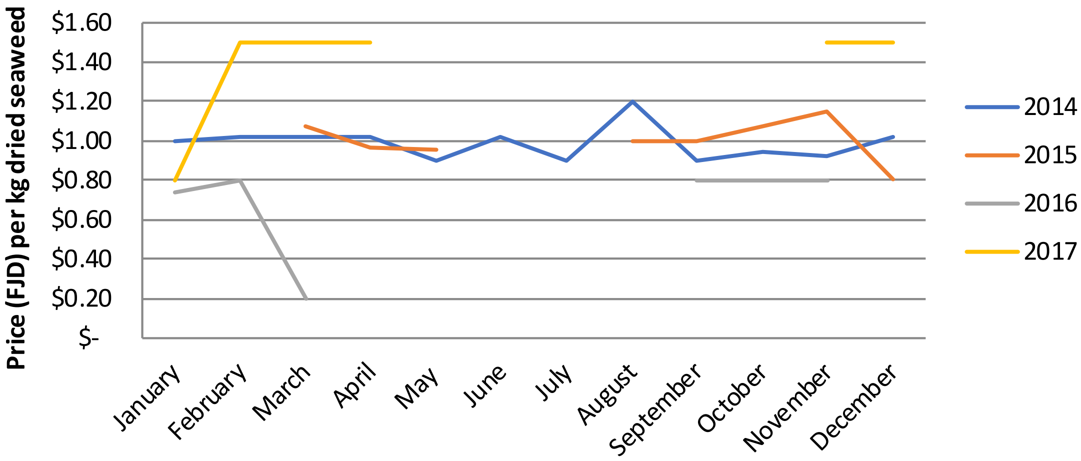


Table 7.1: Seaweed production and total value. Source: Wee Kong Marine Ltd and Soluk Fiji Ltd.

Years	Actual Production (Kg)	Total Value (FJD)	
2014	35,331.90	$	34,985.66
2015	39,375.90	$	40,051.59
2016	3,964.95	$	3,123.86
2017	6,726.15	$	9,878.42

7.2 Environmental variation at *Kappaphycus* project sites in Fiji

We were unable to determine any clear effects of the main physical variables (temperature, current speed, light levels, nutrients - nitrogen and phosphorus), nor any distinction in terms of the culture methods and drying techniques, on the production volume and quality from the project areas. The environmental analysis included 3 additional sites that were not producing saleable product (Drua drua, Kavewa and Nakalou). Full data profiles are available in Appendix 11.1; however, taking the highest production year of 2015 as an example, the variation in temperature of the adjacent Yageta/Vuaki sites in the Yasawas (main producing area) has similar mean temperature to low productivity sites of Kumi and Sawakasa. The logged temperature data in Figure 7.2A are displayed as box plots with 25th to 75th percentiles, median (line), mean (x) and whiskers minimum and maximum values of weekly averages. Overall the annual mean water temperature of sites ranged between 26.8°C – 30.3 °C from 2015-2017. Current speed loggers were also deployed (Figure 7.2B) which was more variable between sites that the temperature data, but - like temperature – did not have any clear relationship. Salinity, light and nutrient (nitrate/phosphate) were measured intermittently during site visits. There was considerable variation in salinity measured (2015 to 2017 ranges from 27.4 to 36.8ppt) with sites away from the mainland maintaining salinity higher than 34.5 ppt (Appendix 11.1). Light and nutrient levels were variable and of less confidence, as discussed in Appendix 11.1. In summary, it was not possible to compare and contrast production of *Kappaphycus* with the environmental variables due to the intermittent nature of sales of seaweed product to the traders. This will remain a challenge for future work; unless there is more consistency and scale in production and sales at the granular level required to correlate to key logged variables such as temperature and current.

Figure 7.2A. Temperature profiles of key Fijian sites for *Kappaphycus* production in 2015

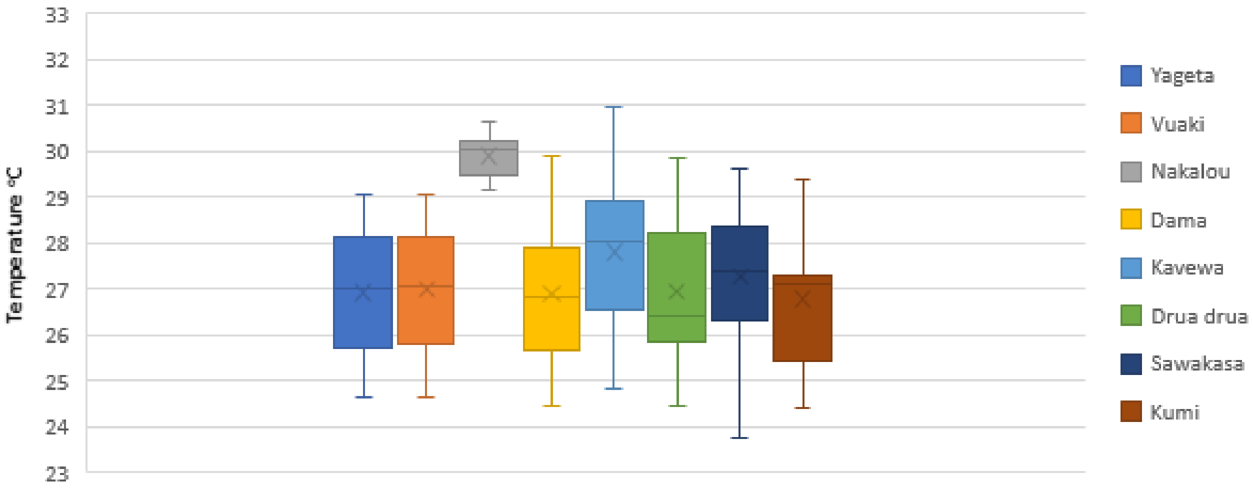
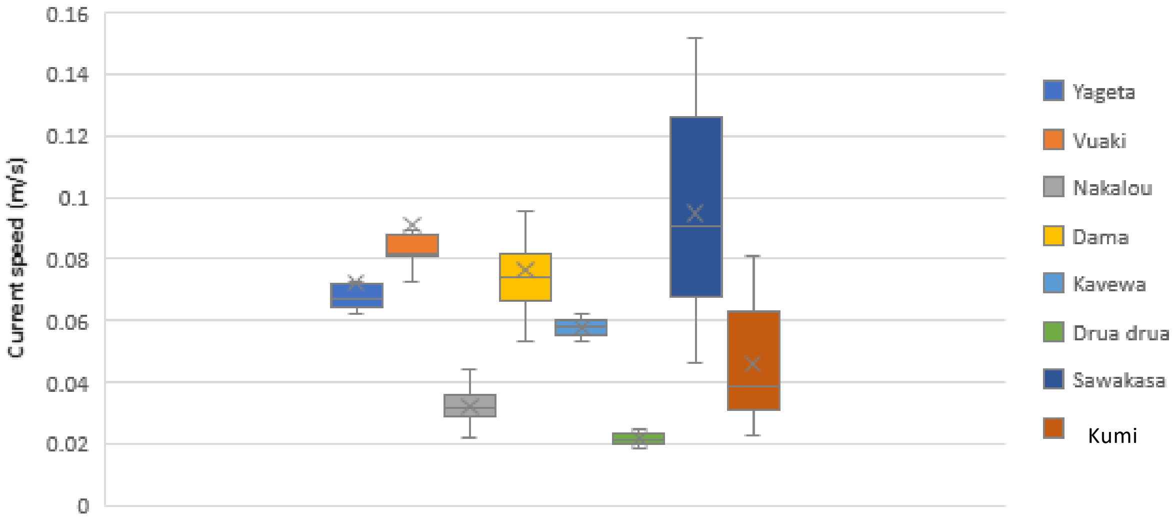


Figure 7.2B. Current profiles of key Fijian sites for *Kappaphycus* production in 2015



7.3 Socio-economic factors for *Kappaphycus* in Fiji

The insights from the environmental data and production statistics suggest that a combination of singular environmental events (cyclones) and human factors contributed to variation in *Kappaphycus* output. One observation was that many current sites were pre-selected because they had previously been farming sites of seaweed in the past. This was confirmed by social studies that highlighted most of the current crop of farmers had farmed seaweed before, as well as other insights including that 2/3 of farmers were male, many were over 50 years old (30%), most conducted seaweed farming as a family activity (95%), and identified weather and transportation as the main barriers for production (Appendix 11.7; Figure 7.3A & B). Out of all the major sites monitored, Yasawa and Druadrua farms were located within walking distance from the beach, while other farms such Dama, Kaba, Sawakasa, Nakalou were only accessible by boats (see Appendix 11.1). Accessibility was reported as an issue, as was transportation of the product. The low prices on offer by seaweed traders also appeared to contribute to the unwillingness to continue farming and/or revive farms after Cyclone Winston especially in Yageta and Vuaki which prior to the cyclone were the major production sites. From the trader's perspective, not enough seaweed is being produced, what is being produced is not done so consistently, and it is costly store dried seaweed until a sufficient volume to export is achieved. All of these socio-economic factors are contributing to the ongoing issues for the industry in Fiji. Industrialisation of the seaweed industry in Fiji may be a solution by moving away from rural development initiatives and towards more self-sufficient and large-scale commercial farms.

Figure 7.3A. Problems faced during cultivation from farmers (Lewatoro, USP Masters Thesis, Appendix 11.7).

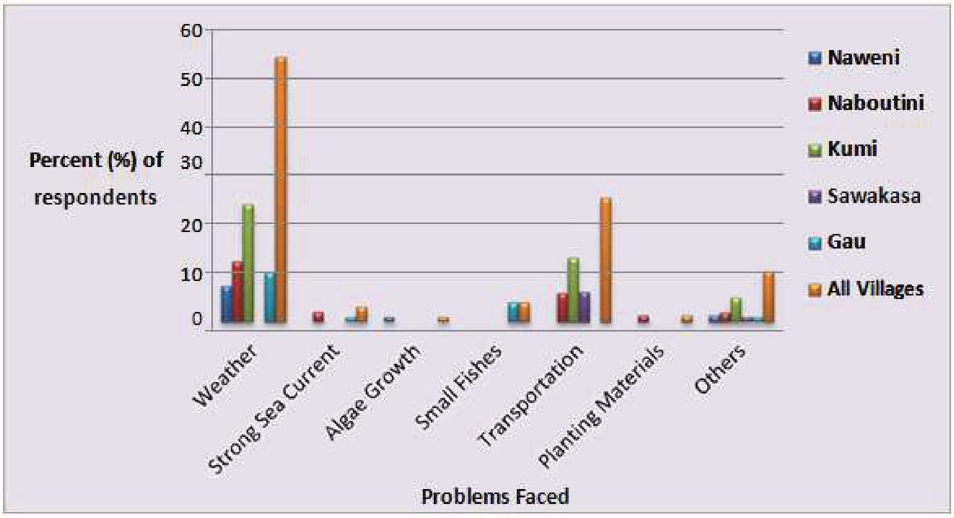


Figure 7.3B. Seedling bundles ready for deployment at the farm site at Yageta village, Yasawa Islands, Fiji. Farming families attaching new seedlings of the seaweed *Kappaphycus alvarezii* onto lines. This is one of the key sites monitored for production and environmental data in Fiji.

7.4 *Kappaphycus* production in Kiribati

Four *Kappaphycus* production sites were studied on 3 islands in the Gilbert Group (Tarawa, Aranuka and Abaiang) with project scientists from the Ministry of Fisheries & Marine Resources Development. Production of seaweed from Kiribati is primarily from Fanning Island, in the Line Islands; however, dried seaweed is typically stockpiled by the Central Pacific Producers Ltd (CPPL) on Tarawa as the supply chain is regularly broken and sales to Asian processors are sporadic. On the atoll of Tarawa, seaweed farming had not occurred for many years and seaweed strains had to be sourced from surrounding islands for project trials. These acclimation trials were run with two strains – one of the original *Kappaphycus* strains (collected from Fanning Island) and one of the new temperature-tolerant strains (*maumere*) imported by MFMRD from Indonesia. Unfortunately, Cyclone Winston in 2016 led to significant wave damage to the coastline, including the study sites, from which the farm-scale production activities never recovered. Some small seaweed farms continued after the project with farmers affiliated with Fisheries continuing to produce, dry and sell to CPPL. The key findings for this objective mirrored in many ways those of Fijian efforts, which are a narrative of environmental challenges (storms, sedimentation of the seaweed, and high temperatures), supply chain challenges (intermittent buyers that question product quality) and issues around the value of seaweed farming for farmers, especially those on the outer islands with competition from copra production due to its regulated prices. Kiribati Fisheries and the CPPL have developed a taskforce to address these concerns, focussing on the potential of short supply chains and local use of the seaweed product to diversify the end use away from export in the near term.

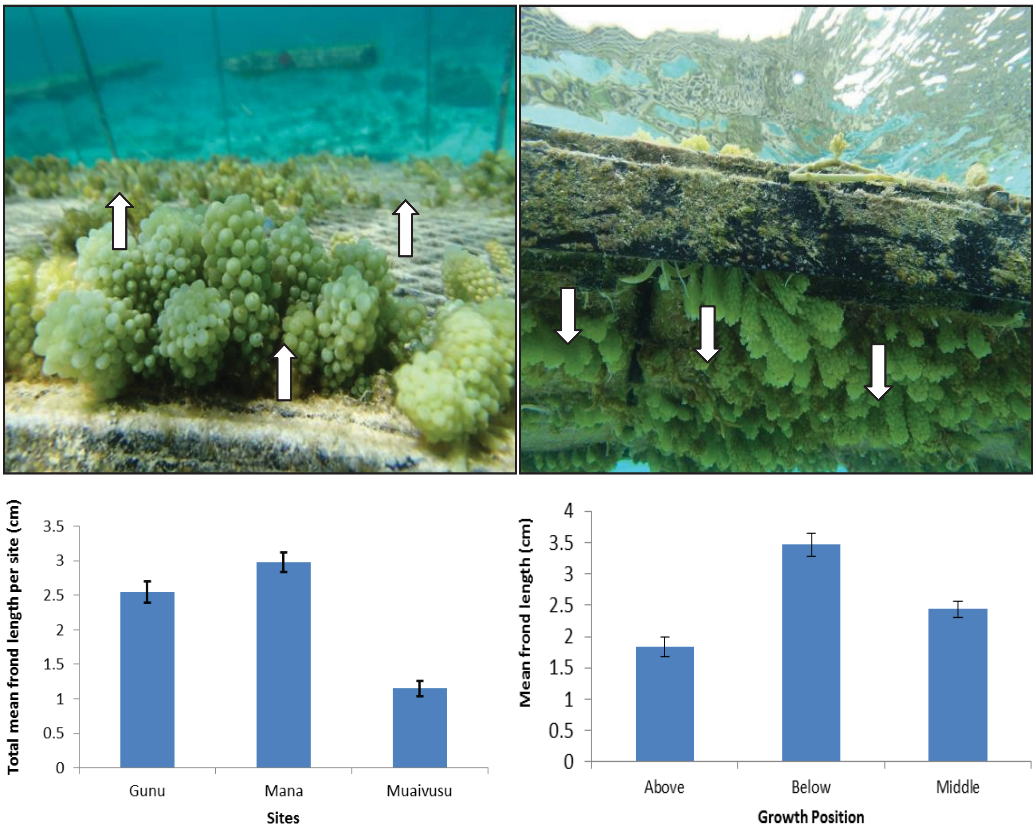
The key results and discussion for ***Objective 2*** *(consolidate production and post-harvest strategies for edible sea grapes Caulerpa in Samoa and Fiji) were:*

7.5 Production trials of sea grape farming in Samoa and Fiji

We used commercially available oyster aquaculture trays previous utilised for sea grape production in Australia. Initially in Samoa, community-based trials were run working with women's groups at 3 sites on Upolu Island and 3 sites on Savai'i Island. However, cultures were only successful at 1 site on Upolu. Follow up trials in Samoa focussed on domesticating the sea grape seedstock from Upolu in the Taloa Hatchery, developing protective cages to exclude herbivores and deploying this new design at village sites on Upolu and Savai'i. In Fiji, trials were conducted with the University of the South Pacific at 5 sites on Viti Ievu, Mamanuca and Yasawa Islands through the Master's research of Mr Tomasi Tikoibua (Appendix 11.7). New growth protruding through the tray provided a clean and readily harvestable yield, and was ironically mostly below the tray for Fijian trials (Figure 7.5; shallow and very clear water). However, overall growth of cultures (minus stocking weight) were only successful at 1 site on Mana Island, Mamanucas. The key outcome of the trials in Samoa and Fiji was that there are biological and environmental constraints for production. The scientific impact of the project activities on sea grapes has been the formal identification, using DNA barcoding, of the sea grapes across the partner countries. This work identified for the first time that there are 5 species of *Caulerpa*, not the single *Caulerpa racemosa* and variants previously described. For Samoa, this information helped to resolve why trials of sea grapes worked only with Upolu seed stock (*C. racemosa*) and not with the Savai'i seedstock (*C. chemnitzia*). Similarly, Fiji had three species of *Caulerpa* (*C. chemnitzia*, *C. macra* and *C. oligophylla*), all of which were sold as "nama" in the market. Notably no *Caulerpa racemosa* was identified in Fiji. The lack of *Caulerpa racemosa* is a limitation for the sea grape aquaculture in Fiji as this was the most amenable to culture of all

4 species evaluated. Full list of DNA barcoding for all species of seaweed studied in the project is available in Paul et al. (2020) and additional detail outlined below in Activity 7.15 below.

Figure 7.5. *Caulerpa* spp. (sea grape) growth trials in Fiji showing new growth protruding "above" tray growth (top left) and "below" tray (top right). Arrows show direction *of Caulerpa* growth. Mean frond length compared separately between 3 sites and amongst growth position (above, below or within tray).



7.6 Production of sea grapes in Samoa

Project scientists from the Ministry of Agriculture & Fisheries monitored the main markets monthly from January 2016 to July 2017 on both Upolu (Fugalei) and Savai'i (Salelologa), as well as roadside markets in front of villages. The market sales of sea grapes (limu fua fua) is entirely sourced from wild-harvest fisheries gleaning from the reef flat. The average monthly production was 319 kg of *Caulerpa*; however, this was highly varied over the 18 months (standard deviation of 204 kg), from a low of 26 kg in October 2016 and highs of > 600 kg in May 2016 and June 2017 (Figure 7.6A). The average price of sea grapes was $20.98 (Tala) / kg, equivalent to AU$12 / kg. We found a significant trend relating to decreasing price with increasing availability ($R^2 = 0.354$, $P < 0.01$, Figure 7.6B). At a finer scale, there was considerable variability in the price based upon the weight of the bundle, given that there was a fixed price of 10 tala per bundle. The average portion size of seaweed in the bundle was 468 g (SD - 181 g). The estimates of sea grape volume traded can also be made by factoring in the weight of the breadfruit leaves used to make the bundle, i.e. the average weight of seaweed was 65% of the overall bundle weight (n = 38 samples across 2 years). Complete annual volumes and prices were also estimated (Table 7.6) highlighting that production and price is relatively stable for the main Fugalei market but less so for the

Salelologa fish market on Savai'i and the roadside sales. The average volume of sea grapes traded in Samoa is >5.5 tonnes per annum, slightly less than that from Fiji (see Activity #10). In Samoa, 4 villages accounted for >70% of annual production, with Satapuala village the largest and most consistent producer with 30% of total production in both monitoring years.

Figure 7.6. A. Estimated volume of sea grapes traded in Samoa based on market sampling from January 2016 to June 2017. **B.** Trend in price (Samoan tala) related to changes in supply (AUD:Tala is 0.54:1).

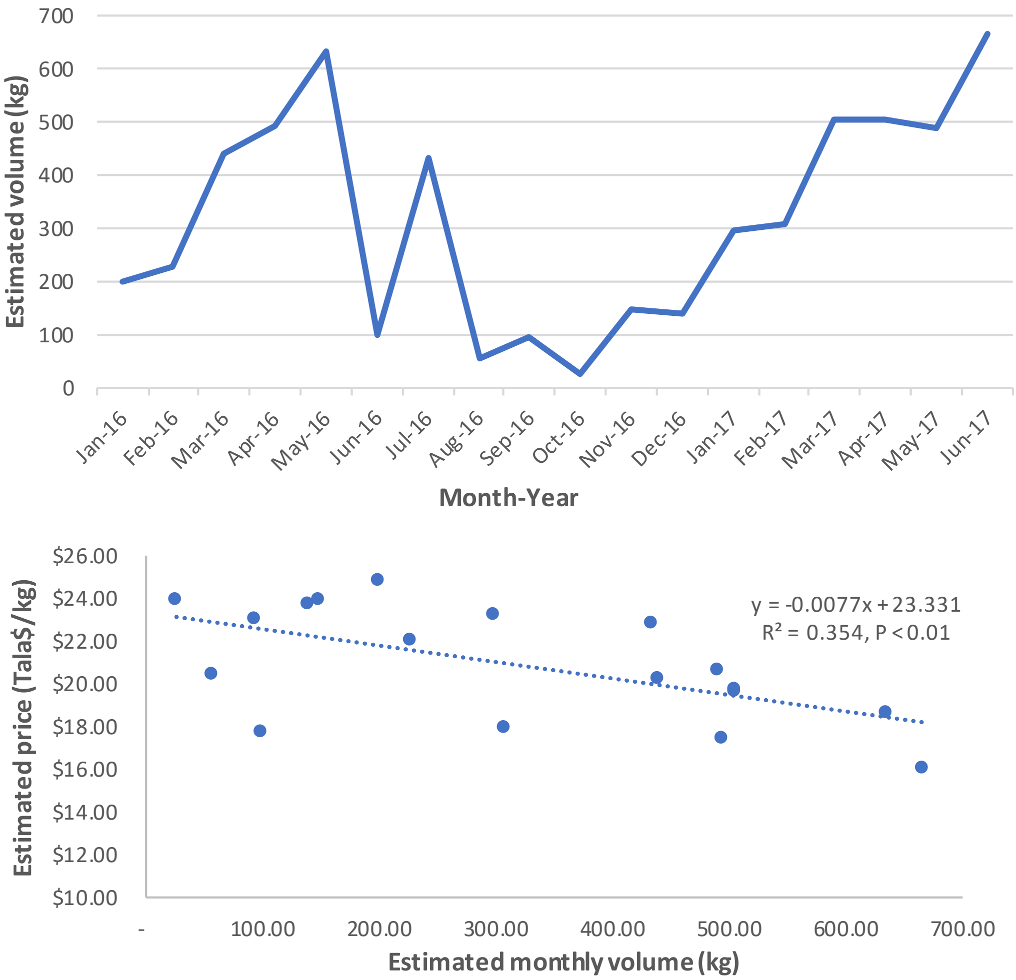


Table 7.6. Production volumes and price of sea grapes in Samoa from January 2016 to July 2017. The volumes produced by the top 4 villages (out of a total of 19) are also provided. Data collected by Ministry of Agriculture & Fisheries, Samoa.

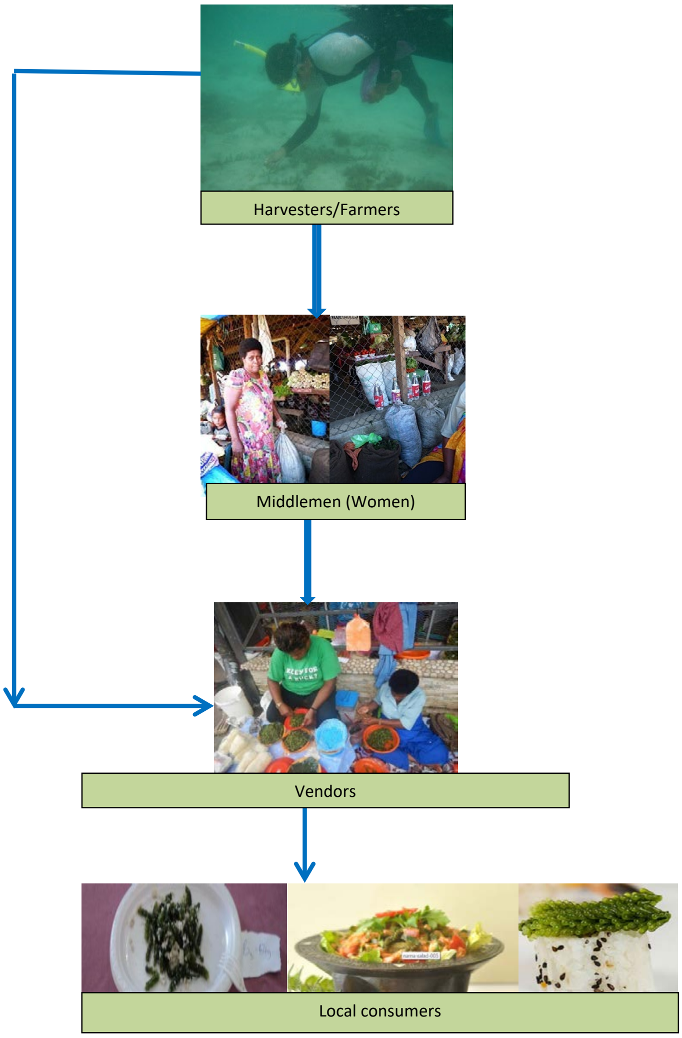
	Volume (tonnes)		**Price** (Tala, $/kg)	
	2016	*2017*	*2016*	*2017*
Market location				

	Volume (tonnes)		Price (Tala, $/kg)	
	2016	*2017*	*2016*	*2017*
Fugalei Market (Apia, Upolu)	2.99	2.77	$20.62	$19.14
Salelologa Fish Market (Savai'i)	2.44	1.60	$15.35	$15.38
Roadside	1.12	0.43	$19.26	$19.29
Top village production sites				
Satapuala	1.987	1.367		
Lano	0.625	1.074		
Satuimalufilufi	1.162	0.518		
Leauva'a	0.620	0.360		
Total	6.55	4.79		

7.7 Supply chain and alternative processing for sea grapes in Fiji

Project partners evaluated the ability to value-add to existing sea grape supply chains by investigating methods for handling of fresh product and methods for extending the shelflife for export. The value chain of the seaweed fishery in Fiji was characterised, highlighting that sea grapes are the main edible seaweed, that up to 16 villages contribute into the major market in Suva but are dominated by 3 collection sites (Gunu [Yasawa Islands], Rakiraki and Mana [Mamanuca Islands]), and that the supply chain is almost exclusively women, from harvesting through to sales (Figure 7.7 and Appendix 11.2). From walking the chain from the Yasawa sites (Naviti island in the Northern Division) it was determined that 41 women from 3 villages harvested *Caulerpa* spp. and sold to 2 women who acted as middlewomen in Suva and to women vendors in Lautoka; the *Caulerpa* was transported to Lautoka by sea and transported to Suva by road; the these 2 middlewomen retailed seaweed themselves and sold wholesale in Suva; sea grapes were shipped from Yasawa to Lautoka and Suva markets once a week. Long-term trends in the volume and value of sea grapes in the local markets of Fiji have highlighted some worrying trends relating to natural disasters and also the continued increase in price and the existence of large annual and/or seasonal swings in production volumes. The project team documented a clear influence of cyclone Winston on the supply of sea grapes in subsequent weeks and months after the event, with a corresponding increase in prices of 25-100%. This was further investigated through a comparative analysis of *Caulerpa* value chain with the 3 other seaweed species consumed in Fiji (Activity 7.10). Alternative ways to process the fresh sea grapes were evaluated, focussing on preservation in brine and on use in new recipes. Methods to preserve sea grapes were developed using brine, and the reconstitution of processed samples into products was evaluated at USP and through Master's research in Australia (Mr Imran Lapong, Appendix 11.7). The small start-up company Pacific Seaweed was supported for some of its research needs relating to optimal brine concentration for export, but it was no longer in business at the end of the project. Commercial products are available for future comparison, including those from Tritin Pty Ltd from Vietnam.

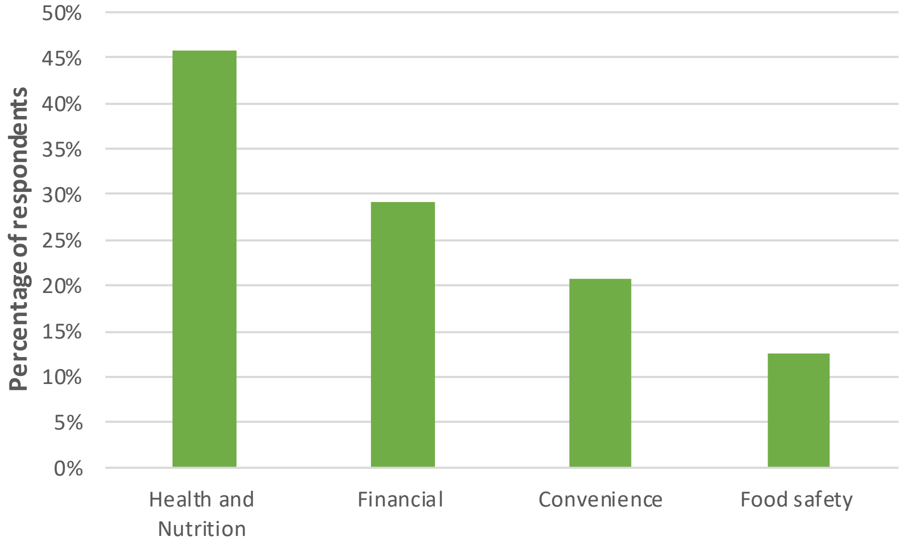
Figure 7.7. Supply chain of *Caulerpa* (sea grapes/nama) in Fiji from the Yasawa Islands to Lautoka and Suva markets. The two most preferred methods of preparation were combining with canned tuna in a salad and as plain with/without coconut cream.

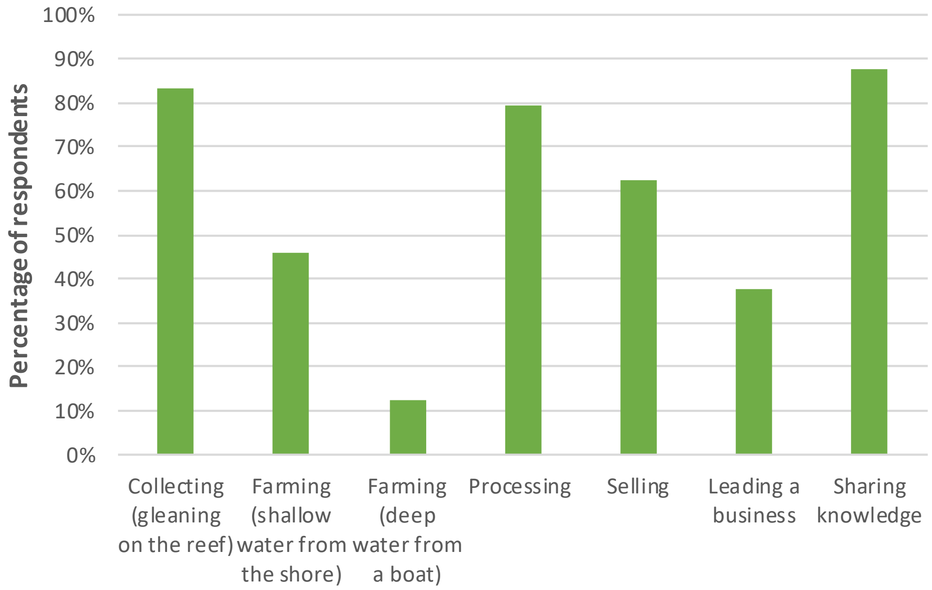


7.8 Sea grape training for women's groups in Kiribati

The final activity in this objective was a peer-led training workshop with seaweed harvesters/processors and project partners from Samoa training 25 representatives from the national associations of women's groups in Kiribati, including 12 church groups from across Tarawa and the outer islands. Training included the collection, handling and recipes for sea grapes from Kiribati. This seaweed resource (*Caulerpa chemnitzia* and *C. racemosa*) is not widely utilised in Kiribati. This project took a peer-led approach to engage women in Kiribati in participating in seaweed activities through a 2-day training workshop that explored perceptions of their potential role in local seaweed harvesting and utilisation. The participants took ownership of recipe development, price and marketing strategies. Evaluation of the training workshop revealed that health and nutrition were the key reasons Kiribati people would be interested in eating seaweed, followed by financial reasons (saving money on food and/or earning money by selling seaweed), the convenience of growing, collecting and preparing seaweed, and recognising that it's safe to consume (Figure 7.8A). Most were interested in participating across the supply chain with the motivation of financial benefit for personal savings. All but two women (92%) felt they had time to dedicate to a diverse range of seaweed-related activities (Figure 7.8B). The amount of time women felt they could contribute ranged from 2 hours per week to 3 days per week. Many women could even specify which days seaweed activities would fit into their weekly schedule. Full details of this activity are found in Appendix 11.5.

Figure 7.8. A. Keys reasons people in Kiribati would be interested in eating seaweed. **B.** Participant interest in taking part in seaweed-related activities.



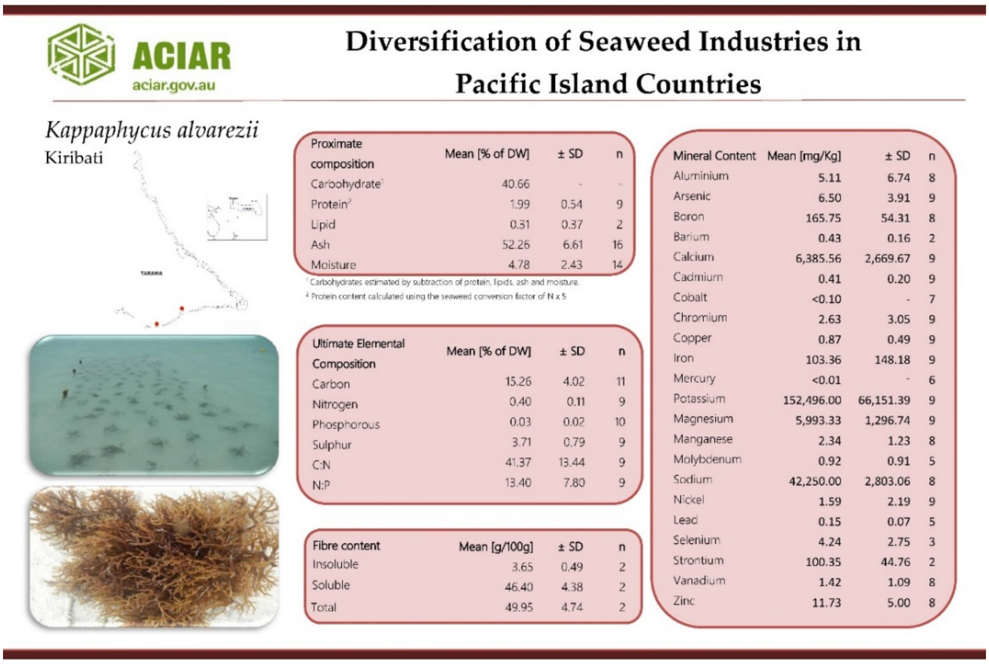


*The key results and discussion for **Objective 3** (assess opportunities for new seaweed bioproducts in Pacific Island Countries) were:*

7.9 Seaweed product sheets and biochemical database

The nutritional quality and biochemical profiles of Pacific seaweeds were formulated into product sheets (Appendix 11.8) and available as a citable DOI in Paul et al. (2020). Some of the key findings relating to the mineral contents amongst the different species from different sites were that the red seaweed *Kappaphycus* from Fanning Island, Kiribati and the Yasawa Islands in Fiji had very high potassium content (over 15% dry weight; Figure 7.9A); green seaweed *Ulva* from Tarawa lagoon in Kiribati had high nitrogen content (1.24% dry weight [dw]), the beach-wrack red seaweed *Acanthophora* from Tarawa, Kiribati had relatively high boron (413 mg/kg dry weight) and potassium (13% dw) and the red seaweed *Gracilaria (*now *Hydropuntia)* from the Mamanucas in Fiji also had high boron (560-590 mg/kg dry weight) and potassium (13% dw; Figure 7.9B). Full details of the biochemical variation are available in Appendix 11.8. These complete biochemical profiles also highlight other proximate components of 8 genera of seaweeds investigated across the 3 countries. Highlights include the relatively high lipid content of *Caulerpa* species (Fiji – 2.49% dw and Samoa – 2.05 % dw), the high protein content of *Ulva meridionalis* (Fiji – 6.97 % dw and Kiribati – 6.20 % dw), the low protein content (Fiji – 1.46 % dw and Kiribati – 1.99 % dw; so low that it is difficult to believe that this seaweed is alive with a C/N ratio of >200 in Fiji and 61 for Kiribati). Overall, the findings provide a basis for product diversification through the development and testing of new applications. The use of contemporary data from sustainable biomass sources will be critical for promoting investment in any emerging seaweed industries in the Pacific Islands. We believe that this is the first complete characterisation of product quality for many of these seaweeds. These "product sheets" can be downloaded and used by stakeholders to aid in their commercial negotiations and to develop alternative products and applications.

Figure 7.9. A. *Kappaphycus* from Kiribati. **B**. *Gracilaria/Hydropuntia* from Fiji. Full product sheets available in Appendix 11.8 and from Paul et al. (2020). All data is dry weight (dw).



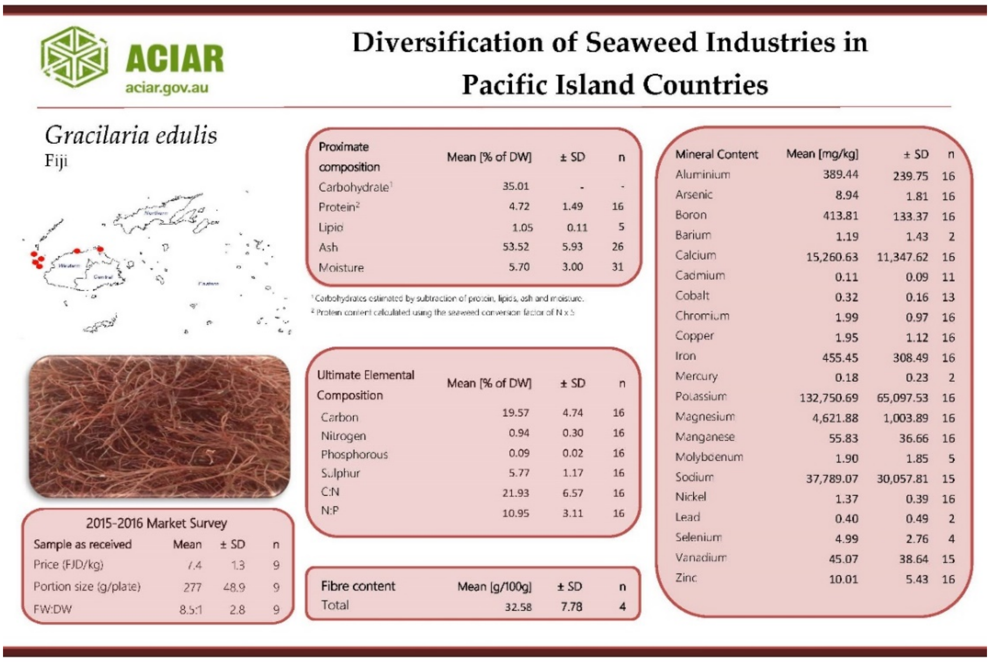
Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	40.66	-	-
Protein[2]	1.99	0.54	9
Lipid	0.31	0.37	2
Ash	52.26	6.61	16
Moisture	4.78	2.43	14

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture.
[2] Protein content calculated using the seaweed conversion factor of N x 5

Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	15.26	4.02	11
Nitrogen	0.40	0.11	9
Phosphorous	0.03	0.02	10
Sulphur	3.71	0.79	9
C:N	41.37	13.44	9
N:P	13.40	7.80	9

Fibre content	Mean [g/100g]	± SD	n
Insoluble	3.65	0.49	2
Soluble	46.40	4.38	2
Total	49.95	4.74	2

Mineral Content	Mean [mg/Kg]	± SD	n
Aluminium	5.11	6.74	8
Arsenic	6.50	3.91	9
Boron	165.75	54.31	8
Barium	0.43	0.16	2
Calcium	6,385.56	2,669.67	9
Cadmium	0.41	0.20	9
Cobalt	<0.10	-	7
Chromium	2.63	3.05	9
Copper	0.87	0.49	9
Iron	103.36	148.18	9
Mercury	<0.01	-	6
Potassium	152,496.00	66,151.39	9
Magnesium	5,993.33	1,296.74	9
Manganese	2.34	1.23	8
Molybdenum	0.92	0.91	5
Sodium	42,250.00	2,803.06	8
Nickel	1.59	2.19	9
Lead	0.15	0.07	5
Selenium	4.24	2.75	3
Strontium	100.35	44.76	2
Vanadium	1.42	1.09	8
Zinc	11.73	5.00	8



Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	35.01	-	-
Protein[2]	4.72	1.49	16
Lipid	1.05	0.11	5
Ash	53.52	5.93	26
Moisture	5.70	3.00	31

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture.
[2] Protein content calculated using the seaweed conversion factor of N x 5

Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	19.57	4.74	16
Nitrogen	0.94	0.30	16
Phosphorous	0.09	0.02	16
Sulphur	5.77	1.17	16
C:N	21.93	6.57	16
N:P	10.95	3.11	16

Fibre content	Mean [g/100g]	± SD	n
Total	32.58	7.78	4

Mineral Content	Mean [mg/kg]	± SD	n
Aluminium	389.44	239.75	16
Arsenic	8.94	1.81	16
Boron	413.81	133.37	16
Barium	1.19	1.43	2
Calcium	15,260.63	11,347.62	16
Cadmium	0.11	0.09	11
Cobalt	0.32	0.16	13
Chromium	1.99	0.97	16
Copper	1.95	1.12	16
Iron	455.45	308.49	16
Mercury	0.18	0.23	2
Potassium	132,750.69	65,097.53	16
Magnesium	4,621.88	1,003.89	16
Manganese	55.83	36.66	16
Molybdenum	1.90	1.85	5
Sodium	37,789.07	30,057.81	15
Nickel	1.37	0.39	16
Lead	0.40	0.49	2
Selenium	4.99	2.76	4
Vanadium	45.07	38.64	15
Zinc	10.01	5.43	16

2015-2016 Market Survey

Sample as received	Mean	± SD	n
Price (FJD/kg)	7.4	1.3	9
Portion size (g/plate)	277	48.9	9
FW:DW	8.5:1	2.8	9

7.10 Value chain of edible seaweed in the Suva market in Fiji

Project scientists from the University of the South Pacific (led by Ms Cherie Morris) monitored the Suva fresh food market and captured data on the 4 main seaweeds traded (price and volume; Appendix 11.2) and took samples for subsequent biochemical analyses used in the generation of the product sheets. A high-level summary of the main findings in Table 7.10 are as follows: *Caulerpa* spp. (common name nama)– FJ$13/kg, >6,000 kg p.a.; *Hypnea cornuta* (lumi cevata) - FJ $17/kg, >500 kg p.a.; *Hydropuntia edulis (*formerly *Gracilaria edulis*/lumi wawa) – FJ$9/kg, >100 kg p.a.; and *Ulva meridionalis* (lumi boso) - FJ $10/kg, >50 kg p.a.. Monthly production of seaweed species varied but was generally higher during the cooler months particularly May, June and October (cooler weather extends from May to October), and during the festive season from November to December. Zero or very low quantities were reported after adverse weather such as Cyclone Winston in February 2016 and floods in December 2016. Variation in monthly sales of *Caulerpa* (nama) can be seen in Figure 7.10A, including the drop in February 2016 from Cyclone Winston. However, these edible seaweed species seem to be resilient and recover quickly from disturbance, especially *Hypnea* (lumi cevata). Vendors remained at the market until all seaweed was sold (up to 6 hours; Figure 7.10B).

Figure. 7.10. A. Quantify of *Caulerpa* (nama, sea grapes) sold in Suva market, Fiji, from 2015-2017.

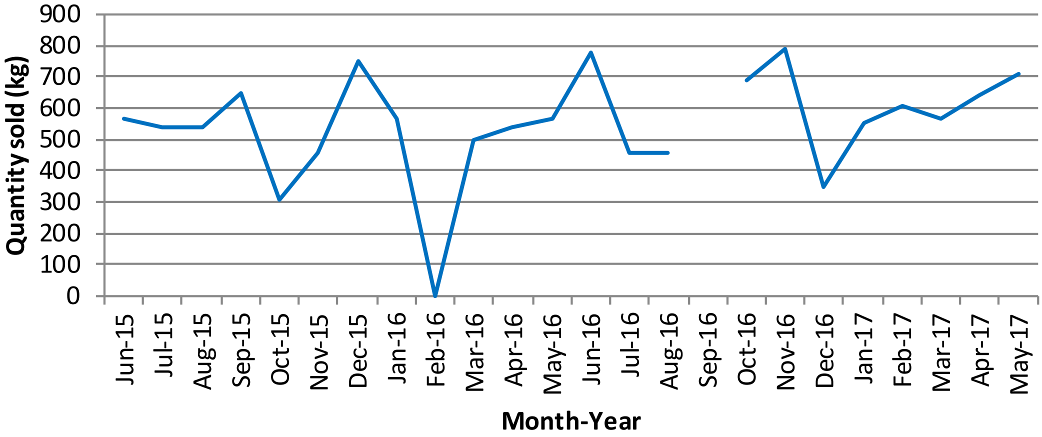


Table 7.10. Estimated annual production (kg fresh weight) and price (FJD/kg) of edible seaweed species from Suva market from April 2015- May 2017.

Species	Main regions	Year 1	Year 2	Price
Caulerpa spp.	Yasawas, Rakiraki	6,000	6,610	$13/kg
Hypnea cornuta	Tailevu, Rakiraki	585	435	$17/kg
Hydropuntia (Gracilaria) edulis	Rakiraki	90	140	$9/kg
Ulva meridionalis	Rakiraki	90	55	$10/kg

Figure 7.10B. Seaweed vendors in the Saturday fresh food market in Suva, Fiji. Existing supply chains see multiple vendors selling 200g portions of sea grapes (known as nama) in the weekend markets of Suva and Nadi (often with chilli and fermented coconut accompaniment, right). Sea grapes are sold for FJ$2 per plate which ranges from 150-250 g of fresh seaweed per plate (equivalent to approx. AU$6/kg) (December 2014).

7.11 Creating and evaluating seaweed-based composts

This component of the project utilised beach wrack (i.e. waste seaweed) as a base nutrient for production of compost. Most of the initial R&D on seaweed compost was done in Kiribati focused on *Acanthophora*. Subsequent work was done in Fiji focussed on *Hydropuntia/ Gracilaria* and a small trial was conducted in Samoa using *Sargassum*. In Kiribati from 2014-2016, project scientists ACIAR conducted scientific trials on the production of compost from different seaweed resources (wild harvests of *Acanthophora*, *Ulva* and *Gelidium* as well as the farmed *Kappaphycus*). The most abundant and free source of seaweed in Kiribati was the beach-wrack red seaweed *Acanthophora*. The composts were produced over ~3 months by blending seaweed with available leaf matter measuring the carbon to nitrogen ratio of the blend (details in Appendix 11.3). Biochemical analyses of the seaweed and leaves demonstrated that the seaweed is rich in nitrogen (N, 1% of the dry weight) and also in essential trace elements (including potassium [K] and other minerals). For example, the NPK ratio of the red seaweed *Acanthophora* is approximately 14:1:85 and, when blended with dried leaves in a weight ratio of between 5:1 and 9:1 can be used to produce a unique compost for Tarawa that can reduce the reliance on sourcing animal manure. The different seaweed-based composts were monitored over time with a temperature probe (Figure

7.11A, first measurements began a few days after starting the compost). The initial temperatures of the composts are indicative of the rate of decomposition by the microbial flora. Most of the compost activity was within the first 3 weeks. From 2 months onward the composts remained at the ambient temperature of ~30°C. The *Gelidium*, *Ulva* and *Acanthophora* composts (with 24:1 carbon:nitrogen [C:N] ratio; and an additional C:N treatment of *Acanthophora* of 30:1) were more active initially (i.e. higher temperatures) than the compost with *Kappaphycus* (73:1 C:N, because there was so little nitrogen in *Kappaphycus*). Subsequent pot trial testing of the seaweed-based composts were done across a range of blends with soil (from 0% compost to 100% compost). The inclusion rate of *Acanthophora* compost that yielded the most tomatoes (~60 g per pot, i.e. per plant) was from 20% through to 60% inclusion of compost, with a minimal effect of the initial compost ratio of seaweed:leaves (Figure 7.11B). These tomatoes had higher levels of potassium (+30%), magnesium (+40%), manganese (+70%), iron (+50%), zinc (+40%) calcium (+50%) and boron (+40%) than those tomatoes purchased from the local market, as well as lower levels of sodium (-35%) (Figure 7.11C). Cabbages and eggplants were also evaluated in pot trials (September 2015) to assess what crops could be used for subsequent community training workshop in August 2016.

Figure 7.11A. Compost production trial November 2014 - January 2015

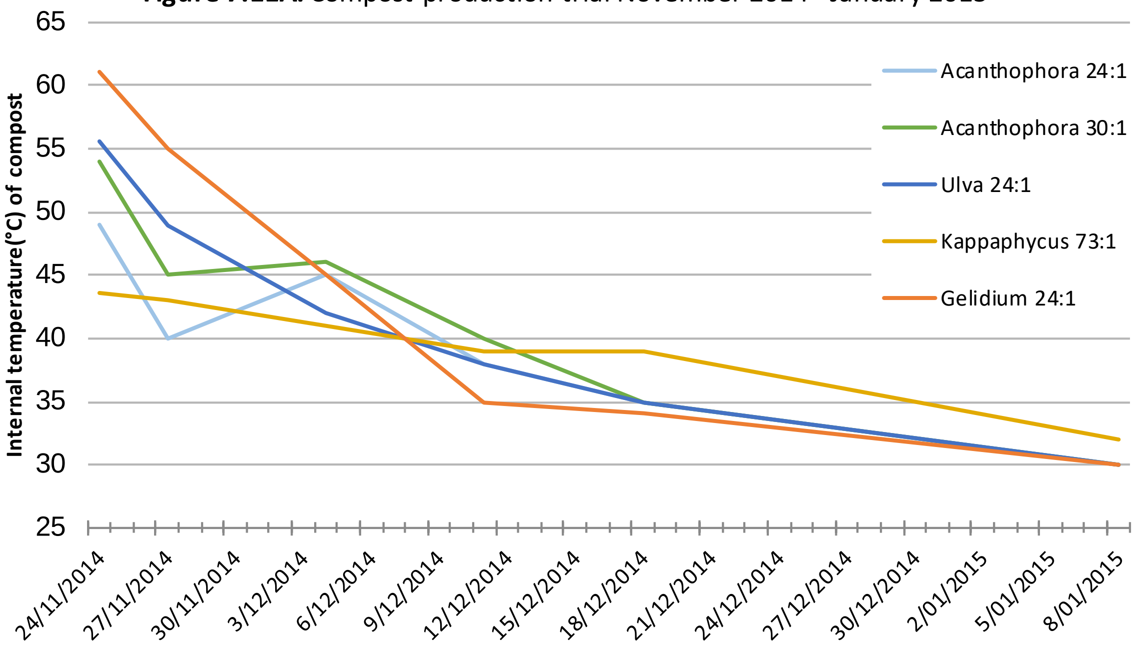


Figure 7.11B Tomato trial with different seaweed composts in May 2015

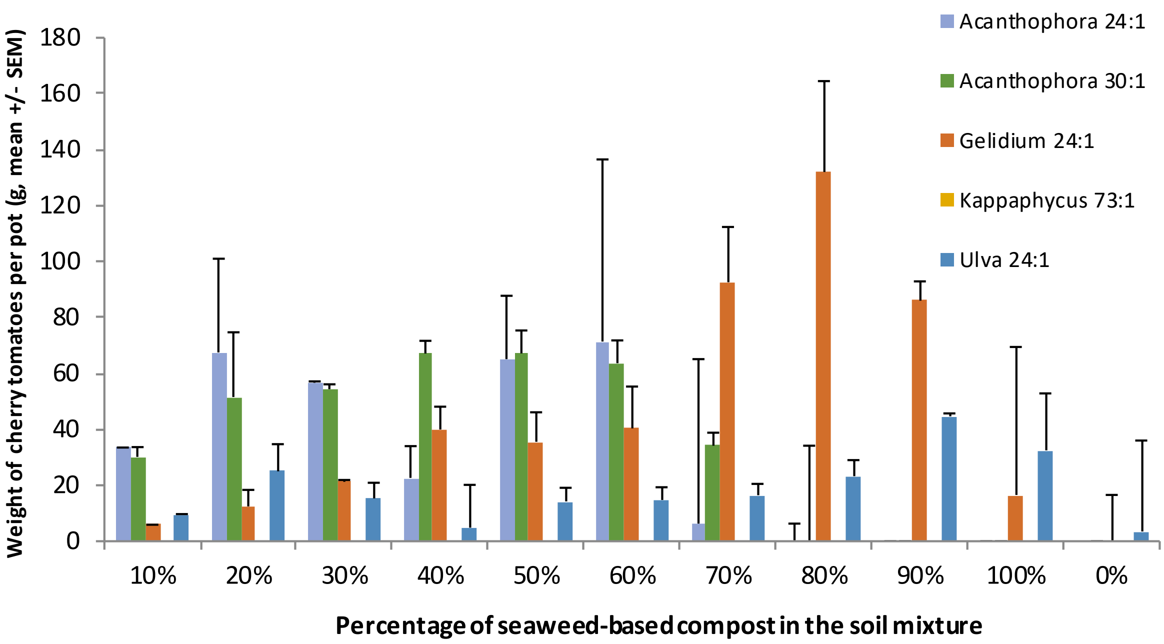
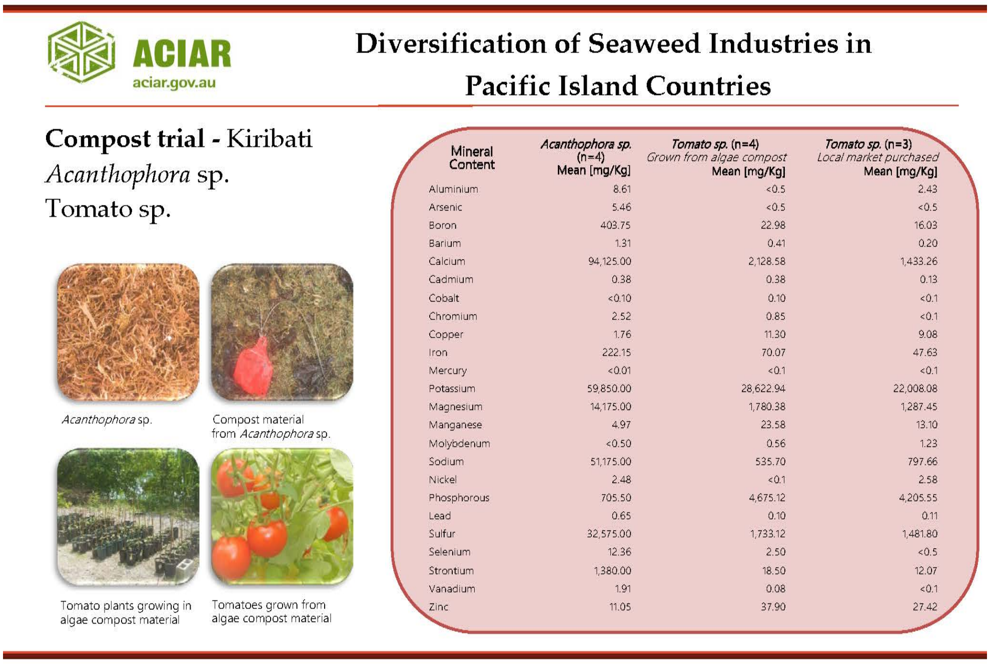


Figure 7.11C. *Acanthophora* – compost grown tomatoes product sheet comparing the mineral content of the original seaweed source to tomatoes grown with seaweed compost and those from the local market. Full product sheets available in Appendix 11.8.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Diversification of Seaweed Industries in Pacific Island Countries

Compost trial - Kiribati
Acanthophora sp.
Tomato sp.

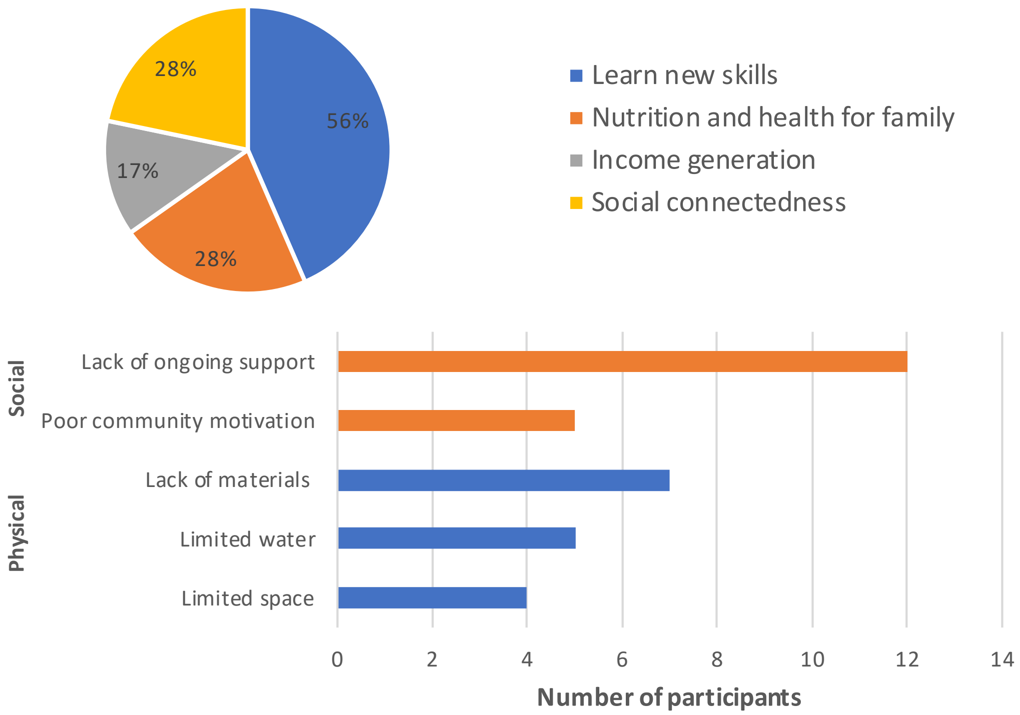
Acanthophora sp.
Compost material from *Acanthophora* sp.
Tomato plants growing in algae compost material
Tomatoes grown from algae compost material

Mineral Content	*Acanthophora sp.* (n=4) Mean [mg/Kg]	*Tomato sp.* (n=4) *Grown from algae compost* Mean [mg/Kg]	*Tomato sp.* (n=3) *Local market purchased* Mean [mg/Kg]
Aluminium	8.61	<0.5	2.43
Arsenic	5.46	<0.5	<0.5
Boron	403.75	22.98	16.03
Barium	1.31	0.41	0.20
Calcium	94,125.00	2,128.58	1,433.26
Cadmium	0.38	0.38	0.13
Cobalt	<0.10	0.10	<0.1
Chromium	2.52	0.85	<0.1
Copper	1.76	11.30	9.08
Iron	222.15	70.07	47.63
Mercury	<0.01	<0.1	<0.1
Potassium	59,850.00	28,622.94	22,008.08
Magnesium	14,175.00	1,780.38	1,287.45
Manganese	4.97	23.58	13.10
Molybdenum	<0.50	0.56	1.23
Sodium	51,175.00	535.70	797.66
Nickel	2.48	<0.1	2.58
Phosphorous	705.50	4,675.12	4,205.55
Lead	0.65	0.10	0.11
Sulfur	32,575.00	1,733.12	1,481.80
Selenium	12.36	2.50	<0.5
Strontium	1,380.00	18.50	12.07
Vanadium	1.91	0.08	<0.1
Zinc	11.05	37.90	27.42

7.12 Utilising seaweed compost in Kiribati communities

A series of training workshops on creating and using seaweed composts was run at Nanikaai, Tarawa, with 24 participants growing and then selling/bartering their products (both the compost and the crops). This training was evaluated, highlighting the motivators (e.g. learning new skills) and barriers (e.g. lack of ongoing support, materials and space) for the uptake of the training in the future, which is particularly important given a high rate of attrition in follow on activities. Participants represented the 4 villages that were involved in the compost training program. Participants were mainly women (83%, n=15), married (83%, n=15), and aged between 23-55 years. All participants were confident they had learnt new skills in seaweed composting, however they identified a need for ongoing support and input from facilitators in order to sustain their involvement. Participants were highly satisfied (mean score 9.3/10) with their overall involvement in the compost training program. Participants shared that their key motivators for engaging with training were financial (money from selling vegetables), to improve nutrition for their families, skill development, social connectedness with fellow group members, and the cleanliness of their community and beach from the collection of dried leaves and beach-cast seaweed (see Figure 7.12A). Participants identified the key physical barriers as limited space to grow a family garden, brackish water and lack of materials needed for composting activities, for example a wheel barrow for collecting seaweed and leaves, spade and fence to protect the garden (Figure 7.12.B). These findings reinforce that the success of short supply chain initiatives, such as community composting, are reliant on collaboration and ongoing encouragement and support, which should be factored in to any future compost initiatives on Tarawa. Full details of this activity are captured in Appendix 11.4.

Figure 7.12. A. Key motivators for ongoing involvement in composting activities. **B**. Physical and social barriers to ongoing involvement in composting activities.



7.13 Seaweed as a feedstock for biochar

Biological charcoal (biochar) was produced from pyrolysis of *Kappaphycus* farmed in Kiribati. The C/N of 74 is much higher than any of seaweed. Full profile of biochar produced from *Kappaphycus* from Kiribati includes 1.1% H, 15.6% O, 5.5% S, 13.0 MJ/kg (HHV). The full characterisation is available in Roberts et al. (2015) including other measures of the physico-chemical properties of the different chars. It is also useful to compare the biochar composition to the raw material seaweed in the product sheet (Appendix 11.8, or 7.9 above). Overall, *Kappaphycus* and other seaweeds from Kiribati may be used as feedstock for long term sequestration of carbon in soils with the added benefit of bring other elements (NPK) as a slow release fertiliser.

Table 7.12. Yield and elemental composition of seaweed biochar comparing *Kappaphycus* from Kiribati to other commercially available seedstock. All data are mean values of three independent biochar samples from each sample origin for each species. Data from Roberts et al. (2015).

Seaweed source	Yield (%)	C (%)	N (%)	P (%)	K (%)	C/N
Kappaphycus (Kiribati)	54.1	31.3	0.3	0.50	158.0	46
Eucheuma (South Sulawesi)	61.7	26.5	0.8	1.78	119.0	31
Gracilaria (South Sulawesi)	59.8	30.9	2.8	1.35	51.2	11
Saccharina/Laminaria (China)	49.7	28.0	2.2	4.69	8.9	13
Sargassum (Indonesia)	49.0	28.9	1.0	1.30	31.1	29
Undaria (China)	62.4	34.8	2.4	3.91	5.1	15

7.14 Seaweed as a functional food

Demonstration of the health benefits of consuming *Kappaphycus* from Fiji highlights that products can be produced with minimal effort (drying and milling seaweed) for use as functional food. While the next steps in developing functional claims require clinical studies in humans to verify the animal study, it is clear from the data presented in Table 7.14 that the BMO and fat mass are reduced in the seaweed treatment (HR) compared to the high fat diet fed rats (H), to a point where there are no significant differences between the seaweed fed rats and the control diet (C). Lower blood glucose concentrations and systolic blood pressure were also recorded. There was no effect on cholesterol however.

Table 7.13. Effect of dried-milled *Kappaphycus* from Fiji on metabolic, body composition, and physiological variables at 5% dietary inclusion (from Wanyonyi et al. 2018). Values are mean ± SEM, n = 8–10. Means in a row with unlike superscripts (a, b, or c) differ and no superscript indicates no significant difference between the groups, $p < 0.05$; C, corn starch diet-fed rats; H, high-carbohydrate, high-fat diet-fed rats; HR, high-carbohydrate, high-fat diet-fed rats supplemented with dried and milled whole *Kappaphycus*.

Variables	C	H	HR
Body mass index, g/cm^2	0.57 ± 0.02 ^{b}	0.70 ± 0.03 ^{a}	0.58 ± 0.01 ^{b}
Total fat mass, g	49.4 ± 5.0 ^{b}	98.7 ± 8.3 ^{a}	53.4 ± 6.5 ^{b}
Basal blood glucose concentrations, mmol/L	3.7 ± 0.3 ^{b}	4.7 ± 0.2 ^{a}	3.6 ± 0.2 ^{b}
Total cholesterol, mmol/L	1.50 ± 0.08	1.61 ± 0.09	1.76 ± 0.14
Systolic blood pressure, mmHg	120 ± 2 ^{c}	136 ± 1 ^{a}	127 ± 3 ^{b}

7.15 Molecular characterisation of Pacific seaweed resources

DNA barcoding identified cryptic species of sea grapes and taxonomically problematic red seaweeds in the Pacific Islands. As the project proceeded the need for molecular identification of seaweeds became clearer, to both aid in the interpretation of the findings and for communication amongst project partners and stakeholders. This was particularly important for *Caulerpa*, because of the highly plastic nature of the sea grape morphology; however, we also provided new insights into the nomenclature of the seaweed resources in each country using currently accepted names provided by molecular taxonomy (a total of 190 samples were processed for DNA barcoding across the partner countries: Appendix 11.6). As an example, sea grapes in Fiji are collectively known as nama, and the main production sites for the nama sold in Suva market are Gunu (Yasawa Islands) and Rakiraki. A total of 37 samples were collected from 9 village sources and the project team identified 3 different species of *Caulerpa* in Fiji: *Caulerpa oligophylla*, *Caulerpa macra* and *Caulerpa chemnitzia*. The difficulty that arises here is that some sites, including the major producers Gunu and Rakiraki, sell multiple species of sea grapes. The main species by volume consumed in Fiji is *Caulerpa oligophylla* (Table 7.15), however, every 3rd sample from both Gunu and Rakiraki was *Caulerpa macra*. *Caulerpa chemnitzia* is the least common species in Fiji but is one of the main ones consumed in Samoa. The differences in species will potentially have impact on their harvest management, farming suitability and also for quality control for consumers.

Table 7.15. Percentage of sea grape species in Fiji identified using DNA barcoding. Samples of nama were collected from the marketplace in Suva and the Fijian villages from which they were sourced identified.

Location	Samples taken	*C. oligophylla*	*C. macra*	*C. chemnitzia*
Gunu	16	56%	38%	6%
Rakiraki	12	67%	33%	0%
Tai levu	2	0%	100%	0%
Kesi	1	0%	100%	0%
Somosomo	2	0%	50%	50%
Mana	1	0%	0%	100%

Location	Samples taken	*C. oligophylla*	*C. macra*	*C. chemnitzia*
Tavua levu	1	100%	0%	0%
Waiganake	1	100%	0%	0%
Namuimada	1	0%	100%	0%
Total Fiji	37	51%	41%	3%

7.16 Additional insights for *Kappaphycus* and sea grapes

In 2014 there was considerable effort spent sourcing and acclimating the new strains of *Kappaphycus* for Fiji and Kiribati. The first two attempts of transfer of stock failed during 2013 in Fiji. A third attempt was successful for acclimation (and trials began on Kadavu Island: Figure 7.16A) yet later in 2015 the 'maumere' strain of *Kappaphycus* introduced by SPC from Indonesia was no longer in culture in Fiji or in Kiribati. The milestones relating to this strain were modified for the project which instead focussed on monitoring production of existing seaweed strains in Fiji and Kiribati. Large scale production kicked off in 2015 at farm clusters in the Yasawa Islands and Rakiraki (Western Division) and on Vanua levu (Northern Division), with the project team providing technical support for production with instrumentation deployed at 10 village sites across the country. Regular monitoring of product quality through the sole distribution centre (Wee Kong Enterprises) in the capital of Suva (Appendix 11.1). In 2015, a final effort was made by SPC/FAO and MFMRD to introduce the new temperature-tolerant strain of *Kappaphycus* known as 'maumere'. Trials began on two islands in Kiribati (Tarawa and Abaiang), led by SPC, where there has not been seaweed activity since disease and other factors caused a halt to the industry over the last decade. This strain however is no longer in culture as a large swell and storm event affected both production sites and all material has been lost. One more effort was made to introduce the new strain and this was cultured at the Ambo site.

Figure 7.16A. New temperature-tolerant strains of *Kappaphycus* ("maumere" variety) are being evaluated in Fiji and Kiribati as part of the project in collaboration with the Secretariat of the Pacific Community. **i)** Production trials were conducted by project staff from the Ministry of Fisheries and Marine Resources Development on Tarawa and Abaiang Islands in the Gilbert Islands group. Mature seaweed (*Kappaphycus alvarezii*) harvested by Fisheries staff at Ambo village, South Tarawa (April 2015). **ii)** Line cultivation of the red seaweed *Kappaphycus alvarezii* ("tambalang" variety) in Fiji. Mr Albert Whippy (USP MSc student) is inspecting the lines from a recent transfer of seedstock from Gau Islands by Fijian Fisheries to the island of Kadavu (January 2014).

Production trials of sea grapes *Caulerpa* in 2015 were conducted at Samoan village sites on Upolu (Savaia, Faleula and Salua Monono tai) and on Savai'i (Asaga, Vaisala and Salelologa). This work identified that the main variety of sea grape on each island of Upolu and Savai'i responds differently to long-term production and that there is a mix of environmental factors that need to be understood before the system will provide year-round production, including understanding if there are times when stock may need to be protected from fish grazing or environmental extremes. A new seedstock system was constructed at the Fisheries hatchery facility using project funds to domesticate multiple isolates for redeploying at the production sites (see Figure 8.1 above). Propagation of one of the two varieties was not successful with multiple attempts, indicating that this variety is not amenable to aquaculture via fragmentation. Therefore this variety (the Savai'i Island variety) was no longer being evaluated in the project, and we only later realised that this was in fact an entirely different species *Caulerpa chemnitzia* to that of the Upolu variety (*C. racemosa*). Propagation of the more promising Upolu Island variety has also suffered some setbacks during the extension work. Project effort then consolidated on further domesticating strains of the Upolu variety at the newly constructed, purpose-built system at the MAF hatchery as seedstock for subsequent trials. These field trials in turn focused on the most promising culture site at Savaia village on Upolu where multiple runs of sea grape production were done, including for the Samoan Agricultural Show.

Market sampling of the price and volumes of sea grapes sold in the main market in Apia and on road-side stalls has continued throughout the second year of the project. Sea grape bundles range in price from WST$5 – 15 each which range from 300-650 g of fresh seaweed (equivalent to approx. AU$12/kg). Monitoring of the weekly production by Fisheries continued for the duration of the project with an additional monthly sampling of the quality of the product assessed (Figure 7.16B; see Results above in Activity 7.6).

Figure 7.16B. Market assessment of sea grapes in Samoa. Sea grapes or "limu fuafau" are a staple in the fish markets of Apia (top right). The product is packaged in breadfruit leaves (bottom) and can be stored at ambient temperature prior to consumption. Sea grape bundles range in price from WST$5 – 15 each which range from 300-650 g of fresh seaweed (equivalent to approx. AU$12/kg) (January 2015).

7.17 Additional country-specific insights

Fiji is the most diverse country for seaweed activity in the Pacific Islands, having provided significant government support to *Kappaphycus* since its introduction in 1985 from Tonga, and more recently as an epicentre for production of sea grapes and diversification of existing seaweed products into new applications, such as fertiliser, by the company Pacific Seaweeds. Fiji was therefore represented in each project objective including some unique insights following:

a) Prior to the project commencing, commercial production of two different strains occurred, *Kappaphycus alvarezii* var. *tambalang* focussed on Gau Islands and *Kappaphycus alvarezii (striatum)* variety "sacol" outside of Suva on Viti Levu (the latter is a more freshwater tolerant strain). There was a strong history of government support to small farmers, however, market forces and environmental stress (cyclones and disease) have reduced production. The main commercial buyer at the beginning of the project was Wee Kong Marine Products & Exports Ltd. The company attempted, over the project lifespan, to expand production by supplying farmers with additional materials. Furthermore, Wee Kong was interested in value-adding to exports by producing a processed product ("seaweed flour") at their facility in Suva to reduce freight volume. The influence of processing on product quality requires technical R&D to support the premise of establishing a higher value product.

b) Village-based sea grape production occurs through wild harvest fisheries on the Yasawa Islands and at Rakiraki on Viti Levu (see activities on sea grapes above for more detail). The previous ACIAR PARDI project (run through the University of the South Pacific) identified a number of post-harvest techniques, which in combination with existing processes for Australian sea grapes (Paul & de Nys 2010) were investigated to extend shelf-life of fresh product for domestic consumption (JCU Masters students, Appendix 11.7). The ACIAR PARDI project also investigated post-harvest treatment and storage for exports to New Zealand, including salting and brine. There is considerable interest in export production into New Zealand and Australia, which requires technical R&D to ensure that fresh product poses no biosecurity risks, in addition to shelf-life and presentation requirements. The commercial viability of this enterprise appears to be challenging.

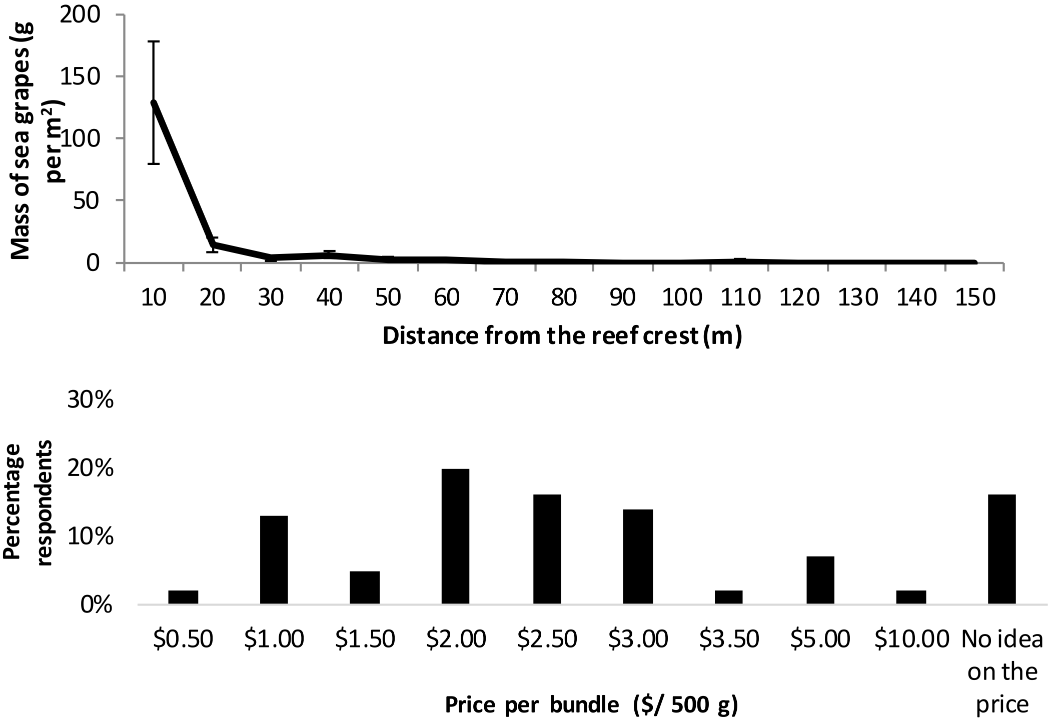
c) Other food gel products could be produced from native seaweeds in the Pacific, including Australia. A USP Masters student (Ms Ashmeeta Shalvina) assessed effect of environmental culture conditions on carrageenan in Fijian red seaweeds and its application in pineapple jelly and found that it was possible to get a high yield of semi-refined carrageenan from Fijian grown *Kappaphycus* with good gel strength and viscosity. Trade-offs were evaluated between carrageenan yields, environmental conditions and growth. Ms Jagruti Chuahan studied the agar extraction steps for *Gracilaria* species from Fiji to make vanilla and cinnamon pastes, uniquely blending the agar gels with carrageenan from Kappaphycus to make a mixed gel system. These pastes were used as toppings on biscuits and were assessed in sensory panels (Figure 7.17A, Appendix 11.7). In Australia, for which *Kappaphycus* is not native, the environmental effects on growth and carrageenan/agar gel yields were comparatively assessed by Mr Ian Tuart as part of his Graduate Certificate of Research. Similar to the USP study the salinity effects influence growth and carrageenan yields outside of marine salinity, with *Gracilaria* (agar producer) a more robust candidate for use in Australia than *Sarconema* (carrageenan producer).

Figure 7.17A. Sensory evaluation being carried out for vanilla and cinnamon seaweed pastes on products. This was a USP Master's project aligned with the project with supervision from Associate Professor Jimaima Lako from FNU.

Samoa was the second most populous partner country with its main seaweed crop sea grapes, *Caulerpa racemosa*, of which there are two varieties harvested in village-based production, both of which are called "limu fua fua". The project showed that the main Upolu variety was *Caulerpa racemosa* and that the main Savai'i variety was *Caulerpa chemnitzia*. Wild harvests have been in decline and correspondingly prices have increased and the project team from the Ministry of Agriculture and Fisheries collected this information during the project (see Activity 7.6 above). The Samoan Government Aquaculture Plan 2012 highlighted sea grapes specifically as a priority target species, and Ms Ulusapeti Tiitii (project scientist) has continued on with this data collection and community-based market assessment of Samoa sea grapes in a Masters of Science. In addition to this, through the market surveys, the project team identified that another edible seaweed is sporadically available. This seaweed is called limu a'au (seaweed of the reef crest) and is a species of red seaweed from the genus *Halymenia*. Ms Tiitii is studying both the sea grapes and the *Halymenia* in her MSc at the University of the Sunshine Coast.

Kiribati was the smallest partner country by land area and population but has the longest history of seaweed aquaculture out of all the partners. The seaweed crop of Kiribati is *Kappaphycus alvarezii*, as currently no other seaweeds are farmed and locals do not consume any of the local seaweeds. Fanning Island is the major production centre, with more than 90% of the Kiribati 1437 tonnes in 2000 (Sulu et al. 2004). Small operations also exist on the most populous island Tarawa (~2 tonnes per annum) that are linked to fisheries-supported operations. The original controlling company Atoll Seaweed Company, which was government-owned, has been consolidated into Central Pacific Producers Ltd (CPPL, Fig. 1), also a state-owned enterprise, which deals primarily with tuna exports. There is some household use of seaweeds in fertiliser (through composting of local strains of beach wrack, most likely of the common species of *Acanthophora* identified in the scoping study), which was covered in Activities 7.10 and 7.11 above. A significant success relating to seaweed in Kiribati was the introduction of edible sea grapes to the women's group (Activity 7.7). Prior to the sea grape training workshop, Ms Tereere Tioti from Kiribati assessed the abundance and availability of *Caulerpa* on Tarawa through her Master's research component (details in Appendix 11.7). She captured the first information of its kind on the distribution and stock of sea grapes in South Tarawa, the availability of traditional packaging method (breadfruit leaves) and the willingness of the people to harvest, consume and/or purchase sea grapes in the future as a foundation for the community workshops. The sea grape distribution was not uniform on the reef flat across the South Tarawa atoll. It was on average highest just back (~10m back) from the reef crest from which >100 g/m^2 could be collected here. This means that most of the stock is only accessible at low tide. Furthermore, on average, people were willing to pay AU$4 per kg for the sea grapes (or $2 per 500 g bundle in breadfruit).

Figure 7.17. **B**. The mean density (grams/m^2 ± SE) of sea grapes at 10 different sites in South Tarawa, Kiribati (Bonriki, Temaiku, Bikenibeu, Eita, Taborio, Ambo, Teaoraereke, Nanikaai, Bairiki and Betio). **C**. Percentage of respondents with willingness to pay various prices for 500 grams of sea grapes.



8 Impacts

8.1 Scientific impacts – now and in 5 years

The following changes in **scientific practice** resulted from the project activities:

- Government agencies are now familiar with the use of molecular barcoding as a taxonomic tool for difficult-to-identify species. There has been a substantial change in knowledge relating to the use of the common term "sea grapes". Our molecular barcoding work identified that there are at least four different species in Fiji and Samoa, and only one of these, *Caulerpa racemosa* (only from Samoa and Kiribati), is readily domesticated;
- Because of the scientific evaluation of sea grape production at the village scale by the Inshore Fisheries & Aquaculture sections of the Ministry of Agriculture & Fisheries, Samoa (with bespoke additions of cages to minimise grazing and maximise frond growth: Figure 8.1), MAF has in turn become the contact point to for sea grape developments in other Pacific nations (including French Polynesia), SPC has commissioned consultants from the project to evaluate the same in Tokelau and new developments are being assessed in PNG with other ACIAR projects;
- Peer-reviewed publications on new product applications (Objective 3, three submissions), 5 Masters of Sciences theses (from the University of the South Pacific) and 3 postgraduate research papers (from James Cook University) were produced, and 1 published database of Pacific seaweed resource provide a broad range of outputs from the project activities; and,
- The Fijian National Seaweed Taskforce was established early 2015 and project staff from Australia (USC) and Fiji (USP) were "Research & Scientific Advisors" on the taskforce. The project members presented information from the scientific outputs of the project on *Kappaphycus* and the edible seaweeds from the market. Seaweed remains one of the priority areas of Fisheries departments in the Pacific.

Five years from now, the scientific impacts and novel research outcomes for the seaweed industry and in the area of bioresources more generally will continue to underpin innovation in the Pacific seaweed industry. There will be more opportunities to build on the project findings and deliver international peer-reviewed articles. One of the most prominent opportunities is to continue with the utilisation of seaweed as a feedstock for compost and biochar and their use in crop production, which can be developed and tested in collaboration with other ACIAR projects in the Pacific and other community-based initiatives in food security. Island nations such as Fiji and Kiribati are compelling settings for integrated mariculture-agriculture activities, and the collaborations built between fisheries and agriculture officers will provide a platform to evaluate and develop sustainable products at scale. Similarly, the identification of the potential nutritional benefits of edible seaweeds in the Pacific represents a new and rapidly expanding field of interest for human health. The product sheets are the first step towards demonstrating low-level health claims of nutritional content in edible seaweed (e.g. fibre and specific minerals). This information will be the foundation for future studies by researchers and students in each country.

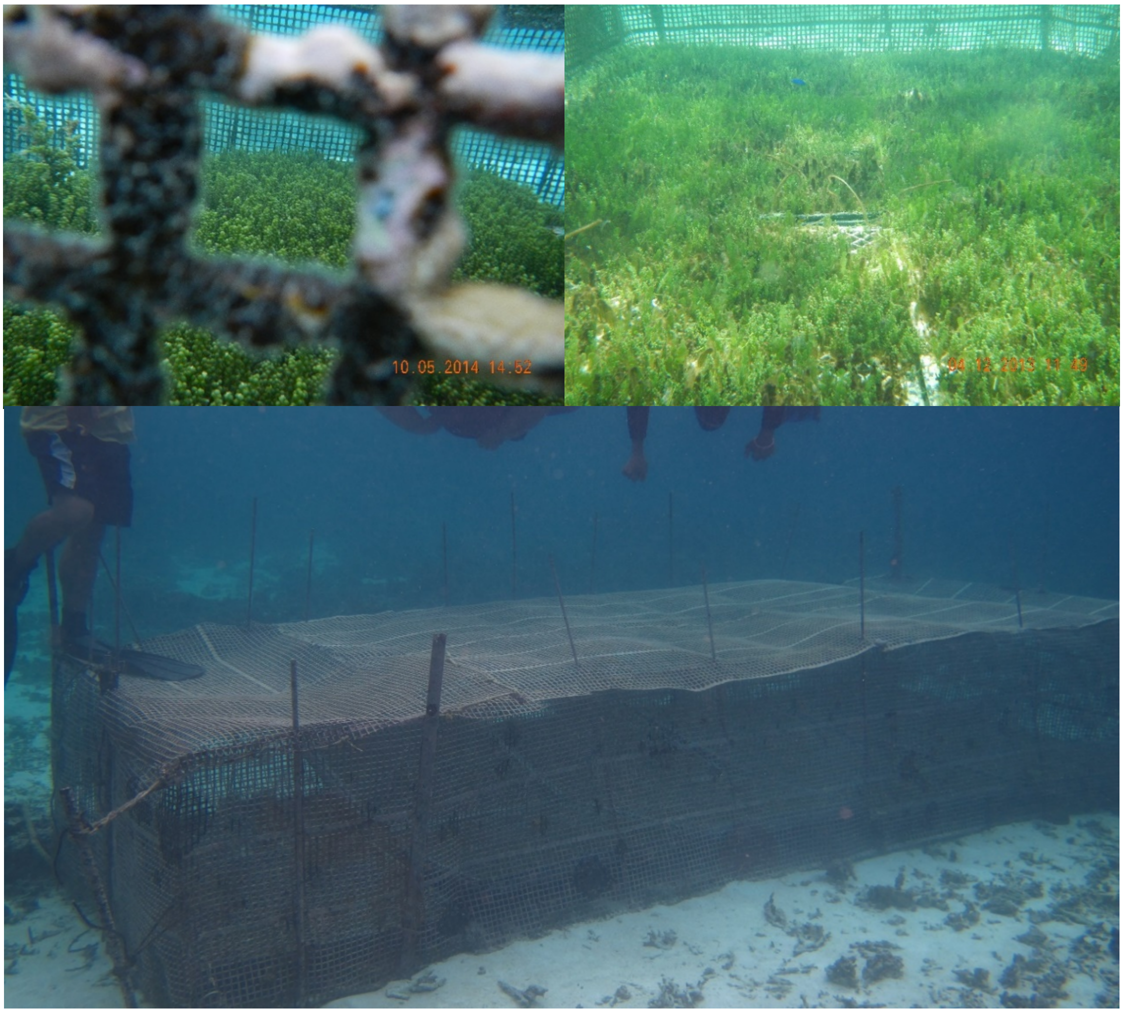


Figure 8.1. New method development of cage culture of sea grapes in Samoa to protect against herbivory. Two images on top show cultures inside cage, taking on a very different elongated form to the shape of fronds in open systems (December 2013 - May 2014).

8.2 Capacity impacts – now and in 5 years

The project has increased the **knowledge and skills** of researchers and staff in Fiji, Kiribati and Samoa through their participation in the following project activities and specific training elements:

- *Environmental monitoring of water quality*: Project scientists from the Institute of Marine Resources, University of the South Pacific, Masters students from the University of the South Pacific, Fisheries and Extension Officers from the Ministry of Agriculture & Fisheries (Samoa), Ministry of Fisheries and Forests (Fiji) and the Ministry of Fisheries and Marine Resources Development (Kiribati) were trained in site selection, deployment of probes and data loggers, extraction and synthesis of data. The use of environmental data loggers and probes represent transferable skills and knowledge within their departments related to water quality and environmental monitoring in marine science more broadly;
- *Biological sample collection and processing*: Fisheries Officers from the Ministry of Fisheries and Marine Resources Development (Kiribati) and Ministry of Agriculture &

Fisheries (Samoa) and project scientists from the Institute of Marine Resources, University of the South Pacific, were trained in use of equipment for measuring fresh-dry ratios, drying and vacuum sealing, preparation and collation of samples for DNA analysis (counterintuitively for those used to taking specimen samples, it requires a very small amount of young tissue with lots of silica);

- *Aquaculture system design and construction*: Fisheries Officers from the Ministry of Agriculture & Fisheries (Samoa) were trained in the construction, monitoring, maintenance and trouble shooting of a flow through aquaculture system for seaweed production at the Taloa Hatchery (Figure 8.3);
- *Evaluation of training activities*: The Training Unit of the Ministry of Fisheries and Marine Resources Development (Kiribati) were trained in the process of evaluation of training activities, interview techniques and data handling;
- *Seaweed compost production and evaluation*: Fisheries Officers from the Ministry of Fisheries and Marine Resources Development (Kiribati) were trained in the technical methods of compost production, monitoring and evaluation, and the translation of this to the community compost workshops (Figure 8.2). This training provided a platform for cross-ministry collaboration between Fisheries and Agriculture;
- *Village-based farming of sea grapes*: Women's groups from community-based fisheries management clusters in Samoa were trained in the deployment, harvest and maintenance of aquaculture systems (Figure 8.2). Fisheries Officers from the Ministry of Agriculture & Fisheries (Samoa) were involved in the workshop planning and were able to operate independently thereafter for community training activities; and,
- *Village-based collection of sea grapes*: Women's groups from Kiribati were trained by Samoan peers and Fisheries Officers from the Ministry of Agriculture & Fisheries (Samoa) in sea grape harvesting and preparation. Fisheries Officers from the Ministry of Fisheries and Marine Resources Development (Kiribati) were involved in the workshop planning, gave presentations to the women and recorded participant feedback.

The project has enabled **practice change** by refining and evolving their approach to seaweed production and post-harvest practices through the following examples:

- Equipment (data loggers, multi-parameter probes, sample processing) were provided to each of the partners and are available for future use in seaweed and other related activities;
- Specialised seaweed infrastructure was provided to the Ministry of Samoa that enables Fisheries officers to continue R&D beyond the scope of the project. This facility has already been used for additional seaweed-related work since project completion. However, just as importantly, the infrastructure development has significantly expanded the footprint of operations at the facility and, with this, redundancy in the system through the addition of new pumps to support other project activities;

Figure 8.2 Seaweed compost trials in Kiribati were possible by facilitating a cross-department collaboration between the Ministry of Fisheries and Marine Resources Development and the Ministry of Agriculture. Seaweed composts were made using different seaweeds and combinations of leaf material to produce composts with a carbon to nitrogen ration of between 20:1 and 30:1. The composts were tended over 3 months (top left) and were then trialled in various blends with soil to grow tomatoes. The yields of ripe tomatoes and their mineral contents were the first assessment of seaweed-supplemented crops in Kiribati (November 2014).

Figure 8.3. New seaweed seedstock facility for sea grapes in Samoa. The project has identified a need to develop the domesticated seedstock in a hatchery setting at the Samoan Fisheries facility to be deployed to village-based trials and provide stock security throughout the year (January 2015).

- The knowledge and skills described above (and in the scientific impacts) have led to practice change in:
  - the government monitoring of seaweed market sales in Samoa that now includes more granular details of saleable portions of edible sea grapes for more accurate reporting of volume and value, with the spreadsheets recording and reporting the data evolving accordingly. These data analysis methods represent generic skills that are applicable to any future project;
  - the culture and handling of additional species of seaweed in Samoa including *Halymenia* (red seaweed, limu a'au); and,
  - the engagement with village-based enterprises and private industry, where possible, to ensure that uptake pathways are identified early in the project and up-scaling is fast-tracked. Project participants benefited from identifying and discussing the commercialisation requirements of companies working on seaweeds which, in turn, have led to new interactions between researchers and private enterprise and donors (for example, the Market Development Facility, Suva).
- ACIAR Soil health program published an article that referred to our *Kappaphycus* seaweed-mineral work on compost (How food gardens based on traditional practice can improve health in the Pacific https://theconversation.com/how-food-gardens-based-on-traditional-practice-can-improve-health-in-the-pacific-75858) and Kiribati government agriculture officers have since been assessing the availability of seaweed as a nutrient source for composts on the outer islands where there are insufficient numbers of animals to provide manure.

Five years from now, the knowledge, skills and practice change across the partner countries should allow the institutions to provide immediate support to new initiatives from the *Kappaphycus* industries in Fiji and Kiribati through an understanding of the importance of standardised production and post-harvest treatments of seaweed, including the analysis and monitoring of farm production and product quality. Future activities in *Kappaphycus* will have clearer adoption pathways because of the direct involvement of seaweed farmers and private industry in project activities, and collaboration between countries can be built on the relationships between researchers, fisheries officers and associated government agencies. The increased technical capacity of government scientists and farmers in the production of sea grapes (*Caulerpa*) in Samoa, Fiji and Kiribati will enable them to maintain and report on cropping trials, measuring growth rates, assess growth patterns and develop extension programs. The project partners will use, and add to, the seaweed product databases that, creating new product sheets from the templates provided with details required by government or donors. Lastly, because of the foundation of inter-disciplinary research and collaboration, the Fisheries officers will have the confidence to think outside of the box in terms for new opportunities that sit at the intersection of Fisheries and sustainable development.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

This project did not set out to formally capture economic impacts within the project cycle; however, there were a number of changes that resulted from community training workshops and new business developments including:

- Kiribati women that were trained in the production of seaweed-based compost were able to sell and barter the crops produced from their workshop efforts and, after the uptake of this training, through compost runs thereafter;

- The cosmetic and wellness company Essence of Fiji in Nadi produced a new line of cosmetics based upon the sea grape (nama) product sheets (see the Managing Director Debra Sedranu speaking about this in the communication section). The product line is now available and known "Namase" (https://www.essencegroupfiji.com/namase-health-skin/nama-of-fiji/). The company is gearing up for export growth and have identified the need for sustainable production of the nama sea grapes at project sites in the Yasawa Islands. The Cardno Market Development Facility in Suva has supported these business efforts to date;
- A Philippines seaweed company is now selling Pacific Sea Moss citing the health properties described in the project using Pacific *Kappaphycus* (Wanynoni et al. 2019: Figure 8.3A). There is minimal processing needed as it involves dried and milled carrageenophyte seaweed. Similar products could be evaluated from Pacific *Kappaphycus* production (https://bioseahealth.com/sp_faq/nutrients-in-pacific-sea-moss-we-can-get/).
- Hotel groups of the Mamanuca Islands in Fiji (such as Navini Island) used the workshop recipe to create compost and grow food groups for guests. This means that they can reduce the reliance on fresh food trade from the mainland and from overseas imports that are, on occasion, needed to support the tourist sector.

Figure 8.3A. Project scientists have evaluated the use of whole *Kappaphycus* seaweed (including its high potassium salt that can be seen crystallising on the outside of the plant). The carrageenan fibre and high mineral content could be the basis for health supplements (Wanyoni et al. 2018).

At the beginning of the project we predicted that it would be a number of years before the downstream effects of the project are seen but that there would be improved livelihood opportunities and stability of income, particularly in remote coastal communities, as well as improved livelihoods through minimising fishing time and physical activities of seaweed harvesters by having farming alternatives. For Objective 1, the return of *Kappaphycus* industries in Fiji and Kiribati to previous levels in 2000 would equate to income of AUD$840,000 per annum in Kiribati (at $0.60/kg) and $160,000 per annum in Fiji (at $0.38/kg). The gross domestic product per capita in 2011 for Kiribati was $1,840 per annum and for Fiji was $3840, effectively supporting more than 450 people in Kiribati and more than 40 in Fiji. The long-term value growth rate of 7% per annum for the global seaweed industry (Paul & Tseng 2012). The revitalised production of *Kappaphycus* in remote coastal communities, potentially with strains that were evaluated as part of the project, would act to discourage drift to the population centres and to provide self-respect among income earners.

For Objective 2, the development of sea grape farming activities for uptake by coastal communities in Samoa over the next 5 years will have direct economic impact for individual farmers and also the broader population. A single village-based production area of only 100m^2 can yield up to 3000 bundles every 6 weeks, equating to ~ AU$23,000 per annum. Given that gross domestic product per capita in 2011 for Samoa was ~AU$3400, this equates to supporting ~7 people in a village. There are at least 20 sites that would be suitable for sea grape production (Figure 8.3B), which together would generate more than AU$400,000 per annum. Furthermore, sea grape supply has contracted, and at the same time bundle price has increased while the bundle size has decreased. The average price in 2005 was AU$2.30/kg, in 2010 it was worth around AU$6/kg, and our most recent data in 2017 show the price is now doubled again at AU$12/kg. The economic impacts, in this instance, should be downward or stabilising pressure on market prices and greater domestic accessibility.

For Objective 3, the identification of novel bioproducts should provide additional support and funding from private enterprise or donors, which would act to further catalyse growth of the industries. The scientific outputs on the health benefits will have broad interest with potential applications extending beyond the partner countries to benefit Australia and abroad.

Figure 8.3B. Village-based production trials and training of sea grape aquaculture in Samoa. This photo shows the local women's group at Vaisala village on the island of Savai'i assessing sea grapes that have been cultured with support from Samoan Fisheries and project staff. Sea grapes are being re-stocked for a 6-week culture period (April 2014).

8.3.2 Social impacts

Many of the project activities, and the majority of the community training opportunities, were focussed on women as they are more active than men across the seaweed value chain from wild-harvest production through to market sales. The community training for compost production and its utilisation in Kiribati, and the peer-to-peer community training for sea grape production and processing in Kiribati, were both accompanied by training evaluation exercises led by USC's Dr Libby Swanepoel. These evaluations provided direct insights into perceived changes in equity, culture, gender roles or status of the participants. Complete details of the feedback are provided in Appendix 11.4 and Appendix 11.5. The women's ownership of the capacity building was highlighted by the consensus name that they arrived at for the Kiribati species of sea grapes, "kuraben taari", which now sits alongside the "nama" of Fiji and "limu fuafua" of Samoa. We also noted the empowerment of the trainers that came from Samoa to conduct the workshop; for one seaweed harvester it was the first time that she had left the country. Some of the direct quotes from the Kiribati participants of training workshop highlight how the project worked to ensure equal participation and empowerment (additional can be found in the short video below):

> *"The training program was useful when we were able to go to the field and take part with the practical exercise. Watching the Samoan women allowed me to learn and remember the know-how. They show me it is so easy." [Participant, age 35]*
>
> *"I will be popular, and when I share my new skills it will join the community together, some neighbours are shy so we can include them to join in. And it will mean food for health, for all." [Participant, age 45]*
>
> *"We get what our body needs from the sea grapes, all the health and nutrition. Vegetables from the store are very expensive, so collecting sea grapes will save us money." [Participant, age 45]*

Figure 8.3C: Women taking part in roadside marketing of sea grapes during the training workshop in Kiribati.

8.3.3 Environmental impacts

The anticipated environmental impacts and benefits of this project in years to come are:

- The molecular identification of the natural seaweed resources of the Pacific Islands highlighted that there is a higher biodiversity of taxa than previously recognised (e.g. *Caulerpa* sea grapes). This will impact on the way that these resources are managed and utilised at a regional scale.

- Reduced pressure from wild harvest industries on sea grape production and concentrated farming activities in coastal areas will minimise environmental footprints. Previous reports from Samoan Ministry of Agriculture and Fisheries have identified that over-harvesting of sea grapes from fisheries has led to decreased supply to market, which potentially be compounded by environmental change. The same is a concern for Fiji, especially as supply and price fluctuates substantially around to natural disasters.
- Environmental groups (e.g. Mamanuca Environment Society), NGOs or donors can use the technical data sheets to quantify nutrient (nitrogen and phosphorus) extraction rates for biomass removal (Figure 8.3C), especially when nutrients move from catchments to coast due to release of fertilisers, stormwater runoff and wastewater discharge. The seaweeds captured in the project provide quantifiable ecosystem services from any farming or wild harvest activity through nutrient removal (from 3-14 kg of nitrogen and 0.3-1.4 kg of phosphorus) and carbon dioxide draw down (up to 930 kg of CO_2) for every dried tonne of seaweed biomass produced:

  Carbon (*Kappaphycus* = 15.3-16.4%; *Caulerpa* = 22.11-22.68%; *Hypnea* = 16.7%; *Gracilaria* = 19.57%; *Acanthophora* = 16.25%; *Ulva* = 17.9-25.4%);

  - Multiply by 3.67 to get CO_2 equivalents per tonne of seaweed – ranging from 560 kg to 930 kg CO_2 per tonne dried seaweed across the species evaluated.

  Nitrogen (*Kappaphycus* = 0.29-0.40%; *Caulerpa* = 0.83-1.00%; *Hypnea* = 0.96%; *Gracilaria* = 0.94%; *Acanthophora* = 0.98%; *Ulva* = 1.24-1.39%);

  Phosphorus (*Kappaphycus* = 0.03%; *Caulerpa* = 0.08-0.09%; *Hypnea* = 0.10%; *Gracilaria* = 0.09%; *Acanthophora* = 0.07%; *Ulva* = 0.10-0.14%).

Figure 8.3D. Waste to resource. Community composting of problematic seaweed blooms on the Mamanuca Islands (Treasure Island shown; snorkelers collecting and loading *Gracilaria*, a red seaweed).

8.4 Communication and dissemination activities

The following key activities were undertaken by the project team to disseminate the results and outputs, with a focus on creating a platform for achieving long lasting impacts of the work.

Written communication and dissemination

1. Presentation and recommendation paper to Fiji National Seaweed Taskforce meeting in Suva (May 2017). Meeting was chaired by Ministry of Forests and Fisheries and included senior government officials from the Prime Minister's Office and the Ministry for Women's Affairs.

   Key recommendations from the project team were:
   - develop strategy for rehabilitation of production following cyclone including seedstock management;

- anecdotal evidence is that there are multiple, and possibly interacting, factors involved in why seaweed farming stops at particular sites (including natural disasters and socio-economic drivers);
- *Kappaphycus* production statistics remain at levels well below sustainable to compete in the international marketplace and well below levels that would be required for carrageenan processing;
- strong scientific basis for developing new products from *Kappaphycus* and other seaweed in the Fiji market place (Nama [*Caulerpa*] and Lumi [*Gracilaria, Hypnea*] – see Appendix 11.8: Product data sheets);
- analysis of the market volume and value for each of the main seaweeds produced in Fiji (aquaculture or wild-harvest) are that nama and lumi are significantly more important than *Kappaphycus* with respect to volume and value;
- integrated seaweed production could be explored through *Kappaphycus* farming and lumi harvesting (two commodities have compatible infrastructure and harvesters typically collect lumi from *Kappaphycus* farming ropes and poles);
- possibility to develop a broader integrated aquaculture approach using seaweed and pearls (this system design would require relatively deep water and additional research & development).

2. Presentation to the Pacific Heads of Fisheries Meeting "*ACIAR Seaweed Projects in the Pacific: Feasible, Sustainable and Commercial*" (SPC Noumea, February 2015)
3. Annual workshops culminating in Project Final Review, Nadi (June 2017). SWOT Analysis conducted with 35 participants (full description in Appendix 11.9). Word cloud summary (Figure 8.4) highlighted key considerations from project stakeholders in the future development of seaweed in the Pacific Islands. Notably there was a desire to focus on diversity of products, government and donor support, managing natural disasters such as cyclones, capacity building of skills, links with community, markets and price.

Figure 8.4. Word cloud generated from a SWOT analysis at the final project meeting and review (4 groups, 6-8 participants each; from Appendix 11.9).

4. Community based composting in Kiribati - instruction manual (Appendix 11.3)
    - Instruction manual for the Community Workshop conducted on August 16-17 2016 in Tarawa was distributed to 30 participants from women's and disabled groups involved in the training exercise. One of the women from the Kiribati compost training still had the instruction manual 1 year later kept "on the top shelf" in her home. Issues related to practice change for community impact are highlighted in Appendix 11.4.

Online communication and dissemination

5. Product data sheets were developed as a means to identify key features of seaweeds produced in the region. These professional 1-page documents have been shared with all the project partners to be distributed to private enterprise, donors and others are required.
    - Product sheets are hosted on the USC Research Bank (Biochemical Database and Product Sheets for Seaweeds from Fiji, Samoa and Kiribati. http://dx.doi.org/10.25907/5e13b12523e43) and analytics of use can be monitored over time as requested by ACIAR.

Video communication and dissemination

6. USC commissioned Mr Benjamin King (Oxigeno Production) to produce a series of short video stories covering the project activities. A long format (12 min.) whole of project video has been shared with ACIAR communications team. The short videos (2-3 min. duration) have been shared on YouTube under the links provided below and through social media posts (LinkedIn, Twitter) where they already received >4500 views and 100s of interactions:

I. **Seaweed farming in the Pacific Islands** (3:11) https://youtu.be/BdJELCD172Y: A collage of seaweed farming on the remote atolls of Kiribati in the middle of the Pacific Ocean. This 3 min film shares recent developments on seaweed farming in and around Tarawa through work led by the University of the Sunshine Coast in Queensland, Australia, funded by the Australian Centre for International Agricultural Research. The focus is on the carrageenan gel-producing seaweed known as "*Kappaphycus*". This gel is used as a natural thickener in all sorts of food and drink products (including ice cream and even toothpaste). In this film you will gain insights from government and university researchers working on seaweed, hear from community members involved in farming, and see the next frontiers for seaweed production in the turquoise waters of the coral atoll.

II. **Seaweed superfood of the Pacific Islands** (2:30) https://youtu.be/kgSoTsiOhMI: Its crunchy, salty and spicy – what's not to like about sea grapes from Samoa, Kiribati and Fiji? Just when you thought it couldn't get any more exciting, we hear from our Australian Centre for International Agricultural Research partners that it is also sustainable, healthy and nutritious and can even be used as a cosmetic ingredient. This delicacy in the Pacific Islands is a type of seaweed known as "*Caulerpa*" and has different common names in different p laces. In Samoa, it is called 'limu fuafua', in Fiji it is called nama" and in Kiribati it is called "kuraben taari". One thing that they all agree on is that seaweed is an important part of their culinary heritage that is crucial to preserve in these times of environmental change. Researchers in nutrition and dietetics at the University of the Sunshine Coast are working with government scientists on just that.

III. **Peer to peer seaweed training in the Pacific Islands** (2:57) https://youtu.be/JhysbGxHfcI: Sharing their knowledge of seaweed (limu) harvesting and recipes, this film documents a training workshop run by Samoan seaweed harvesters and Fisheries staff. The Samoan team travel to Tarawa Island in the middle of the Pacific to spend time with women from the coral atolls of Kiribati. With support from the University of the Sunshine Coast and the Australian Centre for International Agricultural Research, the Kiribati women's groups were trained in the traditional Samoan ways of collection and preparation. The trainees share their own seaweed stories, some reflecting on their youth and others on why seaweed harvesting could well be an important part of their future livelihoods. The women also put some Kiribati spin on the seaweed recipes using toddy (fermented coconut juice) and name their own seaweed resource "kuraben taari" – grapes of the sea! Watch them as they take their new found skills out into the marketplace. Keep an eye out for the incredible and ancient heart-shaped fish traps on the reefs. These conveniently double up as seaweed gardens for the women to harvest from.

IV. New and sustainable applications for seaweed in the Pacific (3:07) https://youtu.be/mRYle7y_ojk: We are constantly looking for new and sustainable opportunities to use the incredibly diverse seaweed resources of our coastlines. This film builds on the knowledge generated from research on seaweed farming and edible seaweeds in the Pacific Islands. We see that

the same mineral and nutrient properties of seaweed that allows them to grow fast and make them a healthy food, are also the critical components for making organic compost and for use in cosmetics. On Tarawa, the most populous island of Kiribati, soil and water resources are scarce. Innovative approaches to agriculture are needed for these low nutrient sandy soils. Producing compost by using seaweed that is washed up on their beaches is one way for communities to turn a problematic waste into a useful resource. By focusing on how seaweed production and use can benefit regional economies, we will be able to move towards a more sustainable, “circular economy” approach to coastal resources and development that addresses food security and also creates opportunities for small business.

9 Conclusions and recommendations

9.1 Conclusions

Seaweed production remains one of the few industries in the Pacific Islands which is potentially export-oriented, culturally and technologically appropriate, and able to provide substantial livelihood benefits to men and women in remote communities. Seaweed is also ranked by the Secretariat of the Pacific Community as one of the highest priority commodities for aquaculture in the region. The *FIS/2010/098* project brought together researchers from universities in Australia and the Pacific, fisheries and agriculture officers from ministries in Fiji (Ministry of Fisheries & Forests), Samoa (Ministry of Agriculture & Fisheries), Kiribati (Ministry of Fisheries and Marine Resources Development), the Secretariat of the Pacific Community and representatives of the community and private sector (Figure 9.1). This project was the first ACIAR-funded project on seaweed in the Pacific and hence there was little opportunity to capitalise on previous work. However, the project activities provide a valuable foundation of knowledge, skills, capacity building and community engagement for the future needs of the industry that are captured in the final report, the Appendix and scientific outlets.

The overall aim of the project was to provide the technological basis for diversification and revitalisation of seaweed industries in Pacific Island Countries, focused on Fiji, Samoa and Kiribati. The project developed and delivered new technology for each of the objectives, and linked this, where possible, to community and economic impacts, disseminating the findings broadly. The strategy was to focus on field-based research in each country, with a sharp initial focus on the red seaweed *Kappaphycus* and the green seaweed *Caulerpa* in Objectives 1 & 2, but notably expanding the breadth of seaweed activities to five other genera as opportunities arose under Objective 3 (*Acanthophora*, *Gracilaria*, *Hypnea*, *Ulva* and *Sargassum*). The research approach was to maintain a close link with fisheries agencies and industry partners, with strong community engagement through village-based trials, training and workshops. In the end, we found that there was a strong community and business interest around utilisation of the seaweed for new products and applications, which in some cases will justify future work on seaweed farming but in other cases will require more research effort on sustainable harvesting and market development. The breadth of activities and the adaptability of the project partners were clear strengths of the project and the key learnings arising from the project were:

- Pacific countries participating in *Kappaphycus* production still require significant government support for seaweed farming communities to retain their export-orientated goals. However, these countries are competing with the established production centres of Indonesia and the Philippines. Given the Pacific supply chain remains precarious, any disturbances in production or sales (natural disasters, reduction in price, inconsistent supply) sometimes enough to disrupt seaweed production in the community.

- Edible sea grapes are an important part of the culinary heritage of Samoa and Fiji, and the fishery in each country is important for women's livelihoods in coastal communities. Supply of sea grapes is heavily influenced by environmental conditions and the market price of sea grapes continues to rise. The taxonomic identification of different species of sea grapes was an important learning for fisheries staff, and will be critical to manage the resource and preserve the supply chain in future times of environmental change, including knowledge of where and what species to farm. Project scientists in Samoa also identified, and began monitoring, an emerging edible species of red seaweed *Halymenia*. Because of the project training, Kiribati is now looking towards developing a market for their own species of sea grapes.

- Diversification of the uses of the existing seaweed is feasible because it is a multi-species resource with a broad range of commercial applications, from food products to gelling agents, as fertilisers and in feeds, and for functional ingredients in nutraceuticals and cosmetics. Pacific Island countries are well placed to take advantage of new seaweed bioproduct opportunities because of their pristine water, shallow and accessible coastal environments and diversity of seaweed flora. Together with value-adding through product diversification of existing *Kappaphycus* and sea grapes, the identification of new seaweed resources could create additional markets and opportunities for expansion of seaweed production in remote communities. More than 1000 separate biochemical analyses were run for samples collected during the project to assess the composition and quality of different warm-water seaweed species from Fiji, Kiribati, Samoa and Australia as a foundation for future product development.
- Seaweeds with high levels of nutrients and essential minerals can be harvested from the Pacific Island coastlines (essentially extracting nutrients from the water adjacent to communities), turned into compost at a large-scale, which in turn can be blended with existing soil to grow crops. For Kiribati, seaweed compost will effectively convert coral sand into fertile soil for the production of fresh food. Our analyses of the nutrients in the crops indicate that there is an added benefit through biofortification of certain minerals. These technical findings were complemented by socio-economic insights into the key barrier and drivers for community uptake of composting including ongoing support from government and availability of equipment and space.

In 5 years' time, the extension of activities of the current project will provide the foundation for creating the next set of research priorities, pursuing new bioproducts and markets, expanding the involvement of participants in collaborative research teams and further developing integrated approaches for mariculture and agriculture. The diverse range of technical activities conducted by the project are new opportunities for the Pacific, but notably many of these opportunities have not yet been translated into sustainable industries elsewhere either. The project identified sustainability issues for the seaweed industry that span technical, cultural and economic aspects of working on an export-oriented business in the Pacific region. We believe that the best way to make the local seaweed industry more resilient to both external and internal factors is to actively link seaweed production and processing to broader social, economic and environmental goals. However, it is likely that the export industry will remain nascent and subsistent until domestic production and processing of wild-harvest fisheries first matures and diversifies. In this way a renewed focus on short supply chains for modernising and growing the seaweed industry on the domestic front would provide the platform to launch export-orientated ventures in due course.

Figure 9.1. Participants at the FIS/2010/098 project review in Nadi, July 2017. In attendance were contributors from the University of the Sunshine Coast, University of the South Pacific, James Cook University, Fiji Ministry of Fisheries & Forests, the Secretariat of the Pacific Community (SPC), Samoa Ministry of Agriculture & Fisheries, Kiribati Ministry of Fisheries and Marine Resources Development and representatives of the private sector from respective countries.

9.2 Recommendations

The following recommendations are made:

- There is a need to reconnect with existing hydrocolloid buyers who are interested to develop longer term supply relationships, even for smaller volumes of *Kappaphycus* such as those from Kiribati and Fiji (e.g. global colloid businesses that have worked in the Pacific previously). The price of carrageenan continues to rise and is now over US$2,000/tonne for dried seaweed; however, this value is not yet flowing back to the farmers in the Pacific. This surge in price will likely drive renewed interest in exports and will hopefully avoid stockpiling (e.g. Figure 9.1) as the intermittent sales of dried seaweed requires significant government support and marketing effort if buyers are lost and the supply chain is disrupted in Kiribati with its significant geographical area. The project highlighted that the quality characteristics required by the industry for dried *Kappaphycus* need to be defined unequivocally and that the importance of these quality factors is communicated to farmers;
- Edible seaweeds are important small-scale fisheries in the Pacific Islands focused on endemic species and local consumption. There is a need to continue to invest in community-based sea grape production in the Pacific through technical innovations in hatchery seed production and the deployment of sea grape trays in cages in villages (for protection from herbivores, noting the need to be away from freshwater). In the short term a mixed model approach to sea grape farming could be done via ranching and ongoing harvesting of stock, with new stock deployed by government fisheries officers upon request. Adopting traditional seaweeds and recipes used in other Pacific countries can be facilitated by supporting country to country peer-to-peer training workshops that were successful in the current project;

- There is an opportunity to develop new products that builds upon traditional knowledge, and recent research by ACIAR, to deliver healthy, plant-derived nutrients to consumers. By raising the profile and increasing government support of existing short supply chains of edible seaweed, it may be possible to ride out the boom-bust cycles of export-orientated development of *Kappaphycus* for carrageenan (noting this seaweed is not native to the region). The focus on traditional seaweeds would also increase the involvement of women because they are leaders across the entire wild-harvest supply chains in each country for *Caulerpa*, *Hypnea*, *Ulva* and *Gracilaria* (*Hydropuntia*). A new ACIAR Small Research Activity has evolved from *FIS/2010/098* with Dr Libby Swanepoel (University of the Sunshine Coast) leading a new project entitled “Improving nutrition through women’s and men’s engagement in the seaweed food chain in Kiribati and Samoa”. The direction of work is grounded in the notion of “nutrition-sensitive” agriculture, which is the sustainable production of nutritious, affordable and safe foods to meet the dietary requirements of populations. The goal is to shift the focus of seaweed production in the Pacific from a low-value export to domestic use as “food for health”;
- In the final workshop and project review of *FIS/2010/098* (July 2017), delegates identified common issues across the three partners countries that may help to prioritise research effort for further developing the seaweed value chain. These include a lack of knowledge and skills for value adding, a lack of business skills to identify and deliver greater value, and broken supply chains for its export commodities. The project reviewers also highlighted that “further value-adding research is becoming an imperative to maximise worth and to expanding production”. The full SWOT analysis, including technical opportunities and threats, is available in Appendix 11.9;
- Seaweed beach-wrack is an under-utilised resource in the Pacific. This waste seaweed is nutrient-rich and could be integrated into a circular economy approach that links nutrient capture from eutrophic coastal systems with village-based food systems through seaweed compost production. Future ACIAR research on seaweed composting should address technical needs for including the characterisation of nutrients captured in harvested seaweed, assmeent of the potential of seaweed-based composts to improve production of diverse food crops, and quantification of the changes in key nutrients within these food crops. This should be done using medium- to long-term trials to allay any perceived negative effects of high salt levels; and,
- ACIAR could plan for an ex-ante benefit-cost analysis to independently assess the economic benefits of the seaweed project in years to come and estimate success and scale-up of industries developed by the project team. ACIAR could also encourage, and contribute into, a new SPC Aquaculture Plan for the region. Seaweed remains a priority item for Fiji, Samoa and Kiribati, but is not necessarily reflected in donor facing material.

Figure 9.1. Dried seaweed stock (~150 tonnes) in the trading warehouse of Central Pacific Producers Ltd in Betio, South Tarawa, Kiribati. Seaweed was cultured on Fanning Island in the Line Islands and freighted to Tarawa prior to sales into Asian markets.

Seaweed production has vast potential as an export industry in the tropics yet, outside of Indonesia, is characterised by sporadic farming effort and broken supply chains due to the logistics of exporting raw material overseas for processing. Here we have highlighted that alternative products from endemic seaweeds in the Pacific Islands could be developed, building upon each country's natural advantages by targeting value-added processing and health applications. These endemic species are primarily fished by women and sold in local food markets and, ironically, in most Pacific Islands the harvested seaweeds have a higher market value than farmed exports. Future projects will provide an opportunity to complete most of the unfinished aspects of the current project. More generally, for all seaweed resources, the future sustainability of production would benefit from nursery and seed distribution centres. It would be beneficial to assess the model of the Government of Indonesia given its success in scaling seaweed production over the last 30 years (leveraging existing collaborations and partnerships from other ACIAR projects, e.g. *FIS/2015/038*) but should also look to integrate with regional initiatives, for example, efforts in Fiji to consolidate seaweed farmers through a cluster-style system. Effort should be directed towards securing additional funding for infrastructure, training and extension activities for these purposes. There remains a significant opportunity for value-adding by developing new products from both the farmed product and the harvested seaweeds as “pull” factors for industry development to complement any “push” initiatives from efforts to scale up farming in communities.

To transform the seaweed industry in the Pacific, future work should build upon the existing project partnerships, and to introduce new partners and next users, that will enable stakeholders to focus on the unique nutritional properties of seaweed, the crucial roles for women in small-scale fisheries, institutional capacity building and the importance of marketing for the adoption of healthy food options.

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10.2 List of publications produced by project

Published

Paul, N. A., Wegner, A., Tuart, I., Tamuera, K., Teata, T., Tioti, T., ... & Tanielu, E. (2020). Biochemical Database and Product Sheets for Seaweeds from Fiji, Samoa and Kiribati. http://dx.doi.org/10.25907/5e13b12523e43

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Arbita, A. A., Paul, N. A., Cox, J., & Zhao, J. Isolation and Biochemical Characterisation of a Protease from the Red Seaweed *Gracilaria edulis* with Identical Cleavage Site on κ-casein as Calf Rennet. Submitted to *Food Chemistry*.

11 Appendixes

11.1 Appendix 1: *Kappaphycus* production in Fiji

Authors: Shirleen Bala, Institute of Marine Resources, University of the South Pacific, and, Ian Tuart, University of Sunshine Coast.

Executive Summary

Kappaphycus farming in Fiji has been practiced for the past 30 years, but the industry is far from reaching full commercial stage. Production was picking up in 2014 and 2015, and then dropped due to cyclone damages in 2016 and to date the industry is still struggling to recover. The success of the industry is not solely limited by environmental conditions and natural disasters, but also socio-cultural issues. Most farmers are heavily dependent on the Fisheries Department for farming items, seed stock, boats, fuel, technical/extension service and transport to market and may not produce if such services are withdrawn. Additionally, challengers faced by seaweed buyers also needs to be understood and addressed. There is a need to study the whole supply chain, understand and identify problems faced by stakeholders at each stage and then analyse the viability of the industry. Commercialisation of the seaweed industry in Fiji may mean moving away from rural development initiatives and move towards expanding viable self-sustained large-scale farms.

1. Introduction

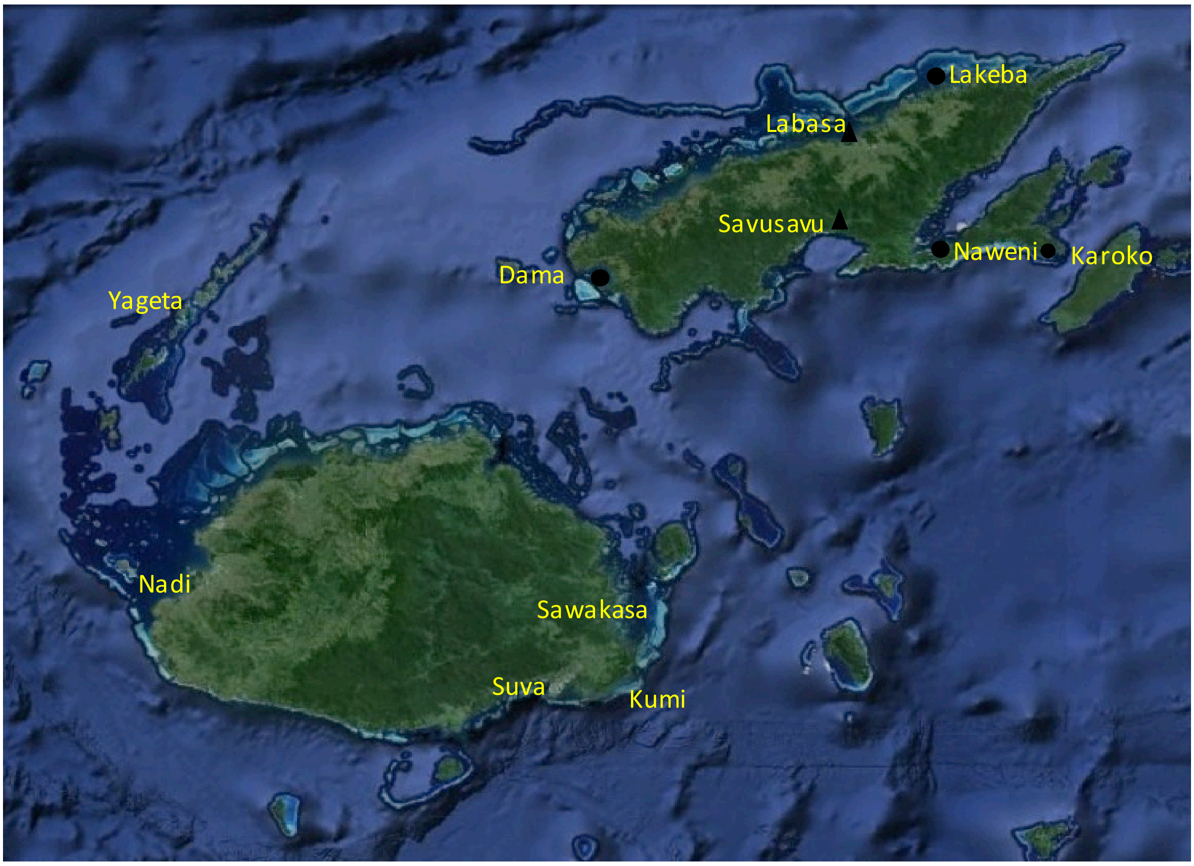
Commercial seaweed aquaculture in Fiji has being practiced in Fiji for the past 30 years; however there has been lapse of several years with no production and ups and downs (Lal and Vuki, 2010). There are various reasons that have supposedly being identified for the unsuccessful nature of the industry, such as unfavourable environmental conditions at some sites, market access and market price (Lal and Vuki, 2010), in-country logistics, supply of materials and social issues (Namudu and Pickering, 2006). The Fiji Fisheries department is hopeful that seaweed farming will serve as an alternative livelihood for coastal communities and are providing assistance to communities to boost seaweed production in Fiji, which includes planting materials, seed stock as well as services of extension officers. The department is also addressing the issue of marketing by securing buyers in-country. In addition transportation cost to market mainly from Vanua Levu, Lau groups and Yasawa is also being subsidised by the Fiji Fisheries Department.

Currently there are two strains of *Kappaphycus* (tambalang and sacol) being farmed in Fiji. Seaweed production data collated from the Fiji Fisheries Annual Reports for respective years shows that production was fairly consistent from 2008 to 2012 ranging between 40-60 metric tons per annum. In 2013 there was a huge drop in production to approximately 18 metric ton. This ACIAR project assisted the Fiji Fisheries Department in collecting long term scientific data which will help better understand the water quality parameters of selected seaweed farms in Fiji and to see if there is any difference in environmental conditions between high and low production sites.

2. Methodology

2.1. Sampling sites

Several *Kappaphycus* farming sites (Fig. 1) were selected for monitoring purpose around Viti Levu and Vanua Levu after consultation with the Fiji Fisheries Department. While efforts were made to have a good representation of areas around Fiji, most areas could not be



monitored due to inconsistent farming and/or logistics.

Figure 1. Map of Seaweed farming sites monitored under the project.

Five sites were monitored from 2015 till early 2017, while some were added later upon request from Fisheries Department and monitoring was discontinued at some sites due to no seaweed production (Table 1).

Table 1. Sites monitored since start of project

Village	Area	Variety Farmed	Sampling duration	Current Farm Status as of July 2017
Sawakasa	Tailevu, Vitilevu	Sacol	Mar 15- Jan 17	Not Active
Kumi	Tailevu, Vitilevu	Sacol	Mar 15-Sept 15	Unknown
Lakeba	Vanua Levu	Tambalang	Mar 15- Sept 15	Unknown
Dama	Bua, Vanua Levu	Tambalang	Mar 15- June 17	Active
Druadrua	Vanua Levu	Tambalang	Aug 15- June 17	Active
Kavewa	Vanua Levu	Tambalang	Mar 15- Feb 17	Not active
Karoko	Savusavu, Vanua Levu		Mar 15-Jun 15	Unknown

Village	Area	Variety Farmed	Sampling duration	Current Farm Status as of July 2017
Naweni	Savusavu, Vanua Levu	Tambalang	Mar 15-Jun 15	Unknown
Yageta	Yasawa	Tambalang	Apr 15- June 17	Active
Vuaki	Yasawa	Tambalang	Apr 15- June 17	Active
Nabautini	Coral Coast, Viti Levu	Sacol	Sept 15-Feb 16	Not active
Nayavu-i-ra	Rakiraki, Viti Levu	Tambalang	May 15- Oct 15	Not active
Nakalau	Vanua Levu	Tambalang	Nov 15-June 17	Active
Navidamu	Vanua Levu	Tambalang	March 17- June 17	Active
Kaba	Tailevu	Tambalang	Sept 16-May17	Active

2.2. Data Collection

Long term scientific data from selected seaweed farming sites in Fiji were collected throughout the duration of this project. Hobo pendant logger (model number: UA-002-64) was used to measure water temperature and light intensity every 10 minutes. Current meters designed by James Cook University's Marine Geophysics Lab were also deployed at some sites to record current direction and speed. A YSI meter was used to record water temperature and salinity on actual sampling dates. HACH (DR 900) was used to analyse nutrient levels (Nitrate and Phosphate) for water samples collected from each sampling period. Current speed was also recorded for selected sites using a *Marotte HS* drag tilt current meter developed by James Cook University. All environmental data was subsequently broken down into weekly averages and converted into box and whisker plots to compare between sites over years.

Actual seaweed production data was collected from seaweed buyers and sorted by sites and divisions from 2014 to 2017.

Dried seaweed were also collected randomly and analysed for moisture (2015 & 2016). Samples were sent to James Cook University for further nutritional content analysis.

3. Results

3.1. Water Quality Data

3.1.1. Water temperature

Overall mean water temperature ranged between 26.8°C – 30.3 °C from 2015-2017. In 2015, Kumi recorded the lowest mean temperature of 26.8°C and Nakalau recorded the highest of 29.9°C. Sawakasa recorded the lowest (27.9) mean temperature in 2016 and Nakalau again recorded the highest (29.1°C). Temperature data for 2017 was only recorded until June and Dama recorded the lowest mean of 29.7°C while Vuaki recorded the highest (30.2°C) for this period.

3.1.2 Salinity

Salinity data was sorted into mean quarterly reading per year. Overall salinity from 2015 to 2017 ranges from 27.4 to 36.8ppt. Quarterly means for 2015 ranges from 32.1ppt to 35.7ppt, with Sawakasa recording the lowest salinity of 32.1ppt in the first quarter and Yasawa (Yageta and Vuaki) recording the highest (35.7) in the second quarter.

For 2016, salinity ranged from 32.2ppt to 36.8ppt with Sawakasa recording the lowest in the first quarter and Northern sites (Nakalau, Dama and Kavewa) recording the highest in the third quarter. Sampling was done only once in 2017 and salinity ranged from 27.4ppt-35.7ppt with Nakalau recording the lowest and Yageta recording the highest.

Overall, salinity reading was generally higher than 34.5 ppt for sites which are situated away from main land, such as Yageta, Vuaki, Dama, Kavewa and Druadrua.

3.1.3 Nutrients

Nitrate and phosphate readings were sorted into quarterly means per year per site (Fig. 3 & 4).

Nitrate readings ranged from 0.02-1.5mg/l in 2015, with Sawakasa and Kavewa recording the highest (1st and 3rd quarter respectively) and Yasawa (Yageta and Vuaki) recorded the lowest in the first quarter. In 2016 nitrate ranged from 1-1.8mg/l, with the highest being recorded in Nakalau (3rd quarter) and lowest in Sawakasa (1st Quarter). In 2017 only one reading was done for all sites and it ranged from 0.8-1.9mg/l, where Vuaki recorded the highest and Druadrua recorded the lowest.

Phosphate readings for 2015 ranged from 0-0.32mg/l, with Dama recording the highest in the 2nd quarter and Druadrua recording the lowest in the 4th quarter. In 2016, reading ranged from 0-0.37mg/l with Sawakasa recording the highest in the 1st quarter and Kavewa recording the lowest in 2nd quarter. In 2017, reading ranged from 0-0.07mg/l with Yageta recording the highest in quarter 1 and Vuaki and Nakalau recorded the lowest in quarter 1 and 2 respectively.

No major trend was detected for different sites and overall nutrient reading varied between sites and years.

3.1.4 Current Speed

Long term current speed data was summarized into yearly means for three years (Fig.6). In 2015, current speed readings ranged between 0.02m/s to 0.09m/s with Sawakasa recording the highest and Druadrua recording the lowest mean current speed. Similarly in 2016 Vuaki recorded the highest (0.08 m/s) and Druadrua recorded the lowest (0.02 m/s). Only three site's data was available for 2017, where Yageta recorded the highest mean current speed of 0.08 m/s and Druadrua again recording the lowest mean of 0.04 m/s.

3.1.5 Light Intensity

Light data used in this analysis was only from2-4 weeks after deployment, as beyond this time data was compromised due to irregular cleaning of the light sensor. Light intensity data was summarized into yearly means for three years (Fig. 7). In 2015, Kavewa recorded the highest at approximately 92,000 lux followed by Yageta and Vuaki at approximately 88,000 lux. Dama recorded the highest light intensity for 2016 and Sawakasa the lowest at 78,000 lux and 12,000 lux respectively. In 2017, Yageta recorded the highest (approx. 81,000 lux) and Duradrua recorded the lowest (15,000 lux).

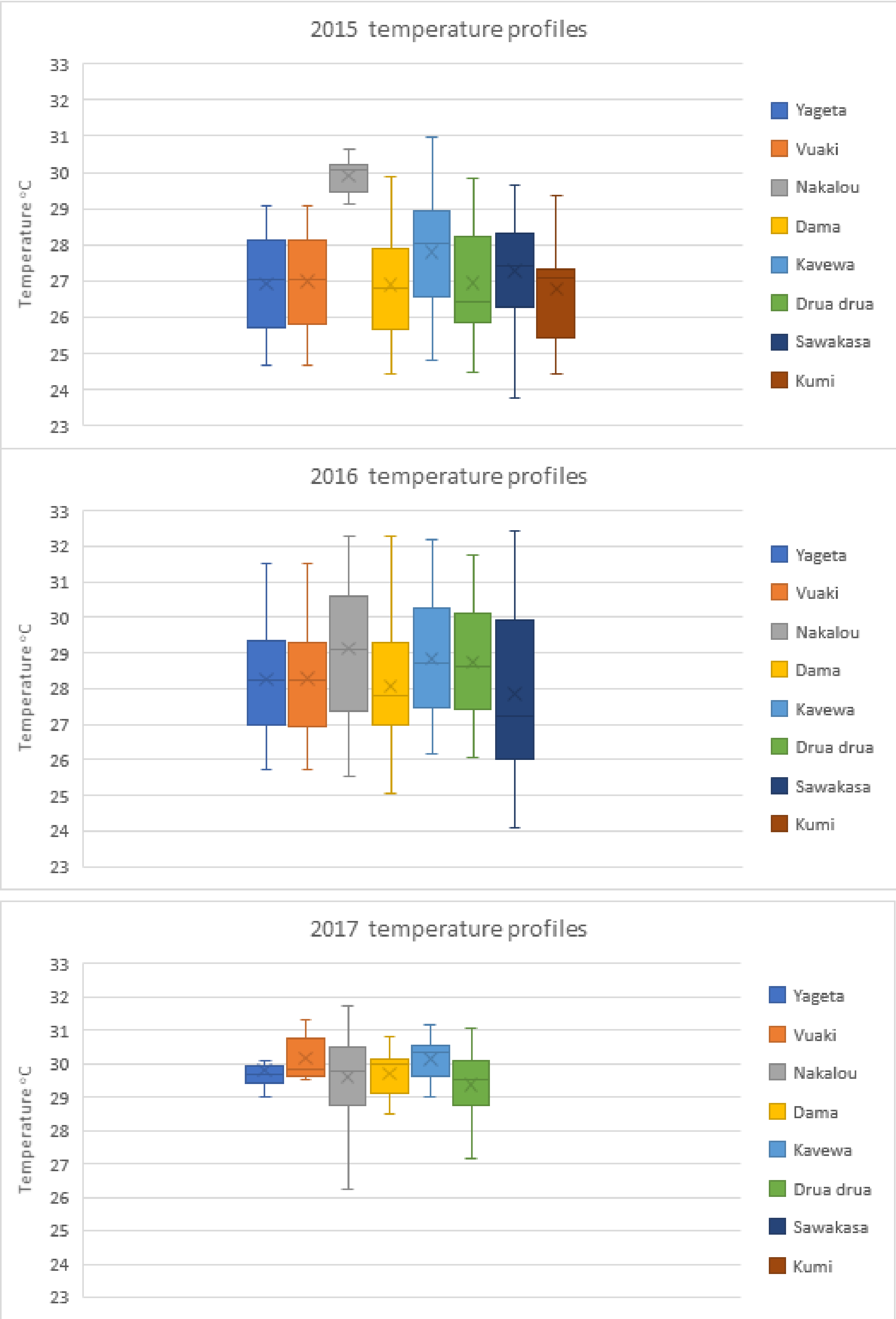
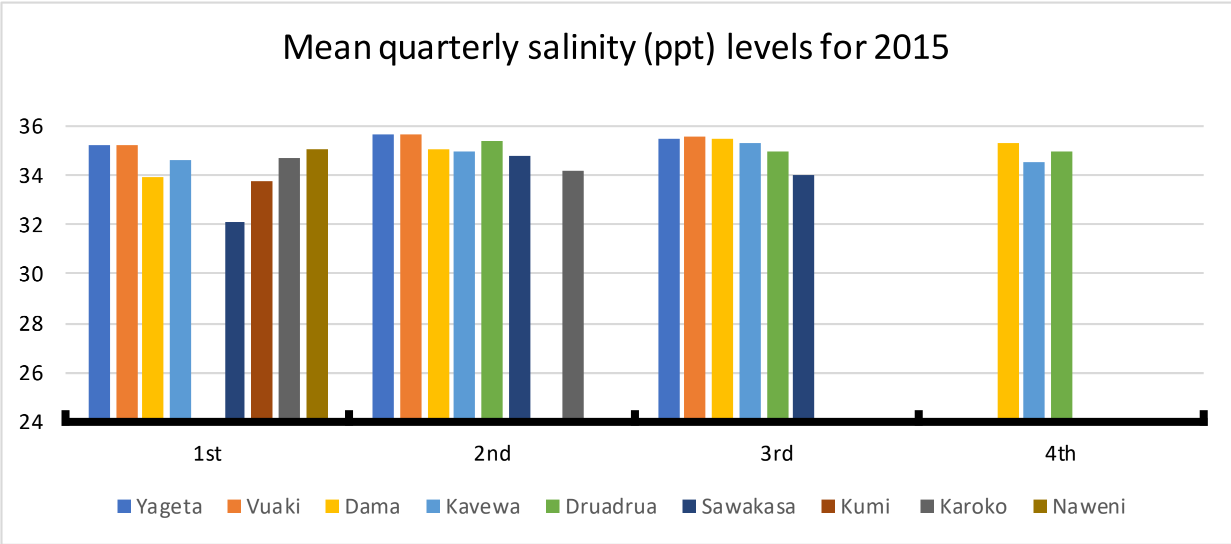
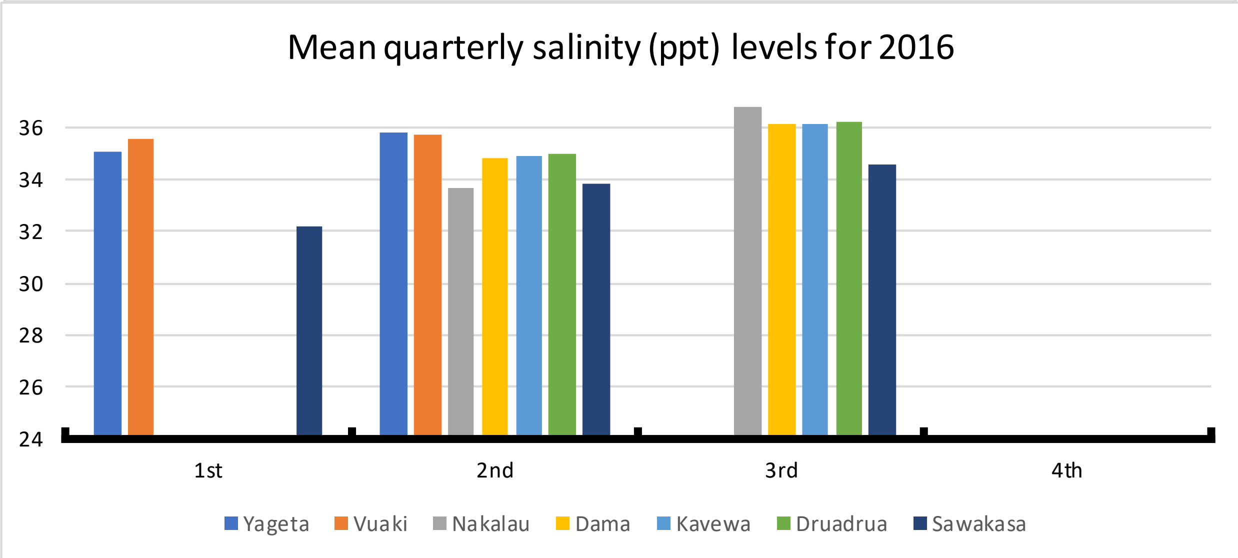


Figure 2. Temperature profiles for selected sites from 2015 to June 2017. Box plots show 25th to 75th percentiles, median (line), mean (x) and whiskers minimum and maximum values of weekly averages.





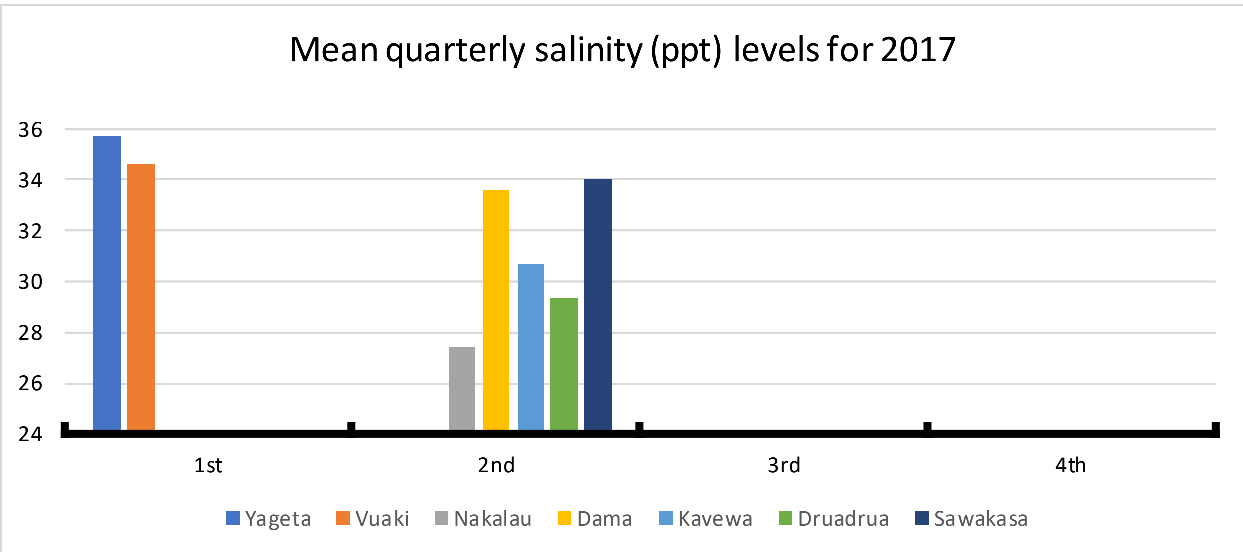


Figure 3. Mean quarterly salinity from 2015- June 2017

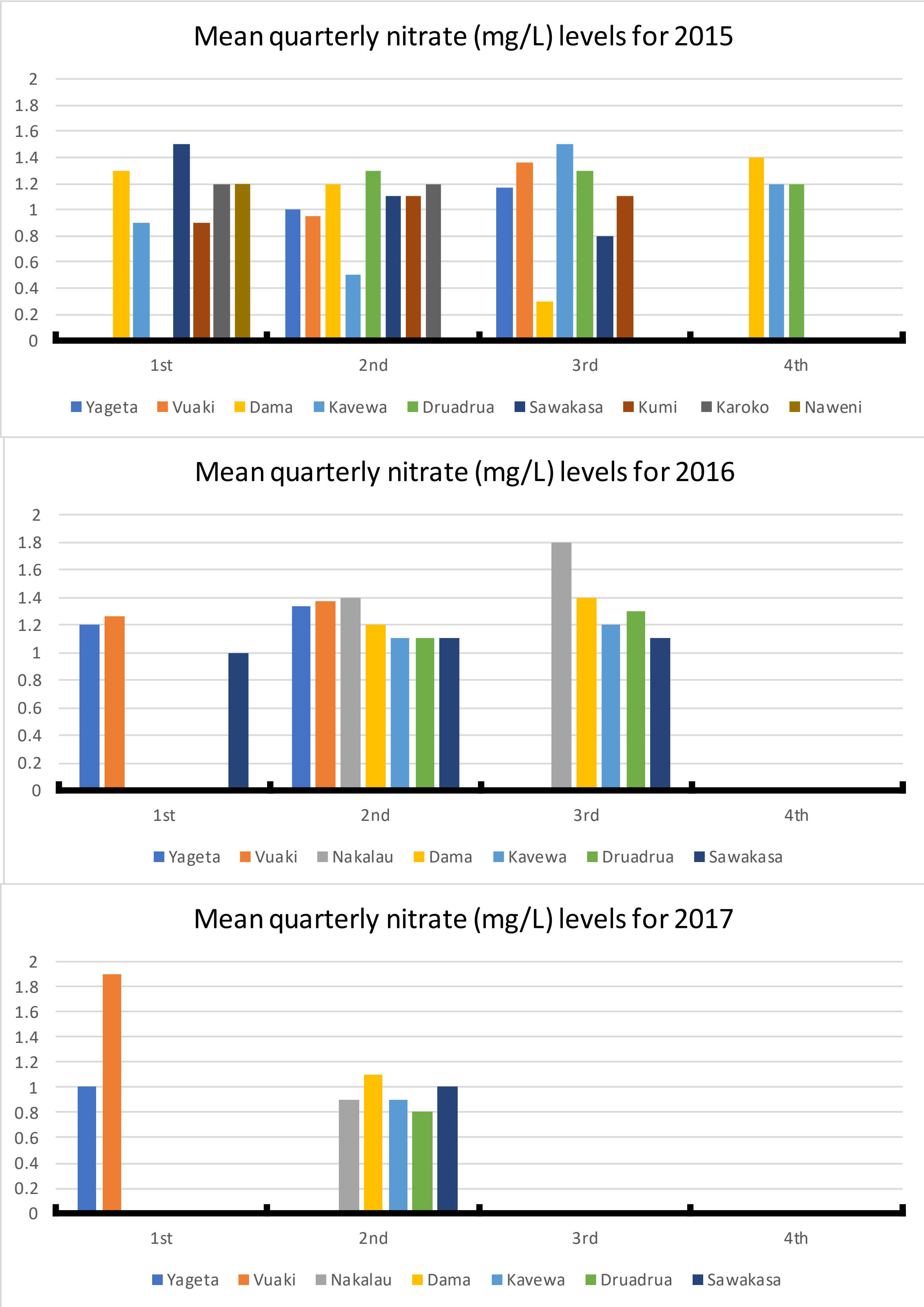


Figure 4. Mean quarterly nitrate from 2015- June 2017

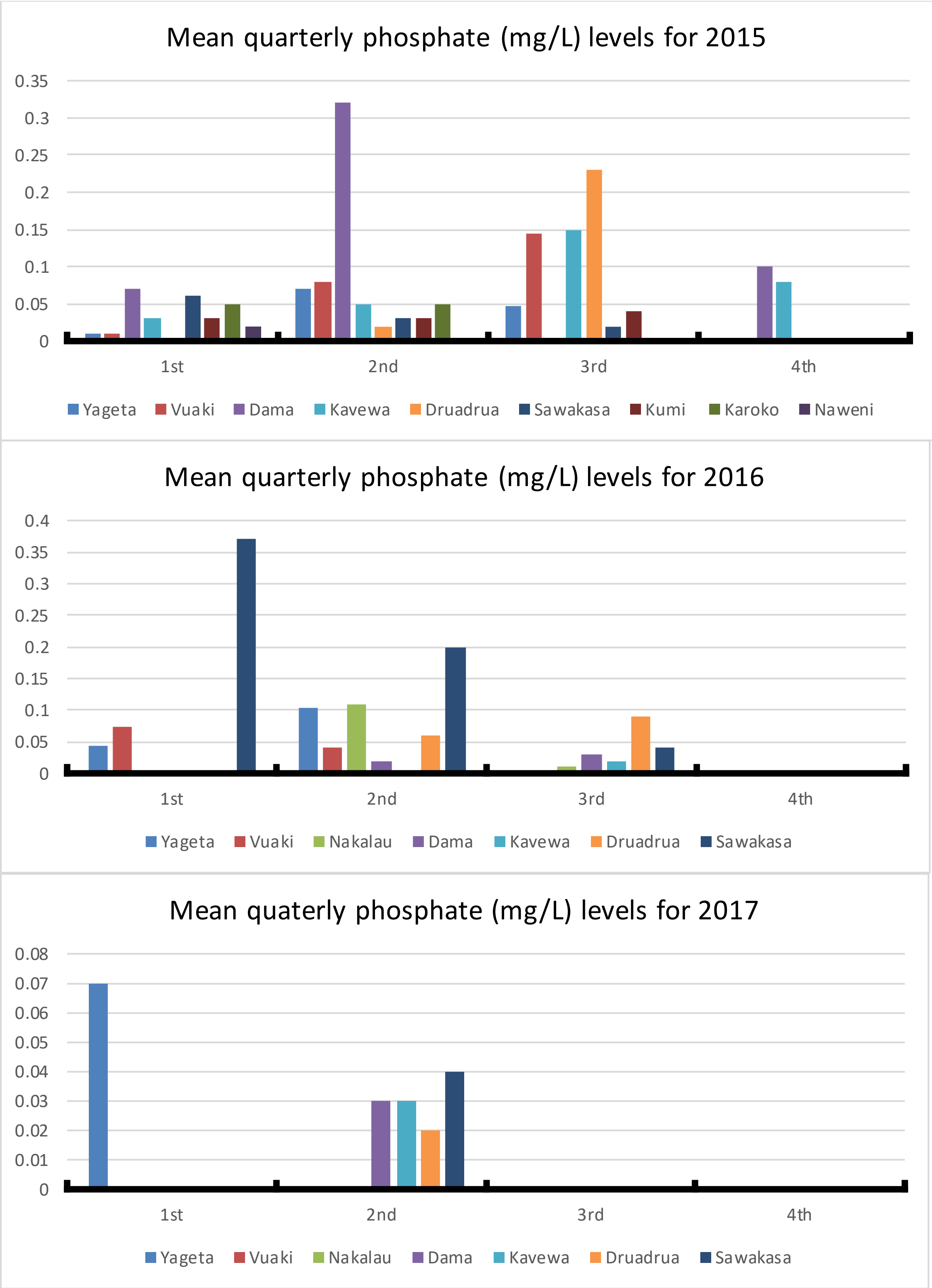


Figure 5. Mean quarterly phosphate from 2015- June 2017.

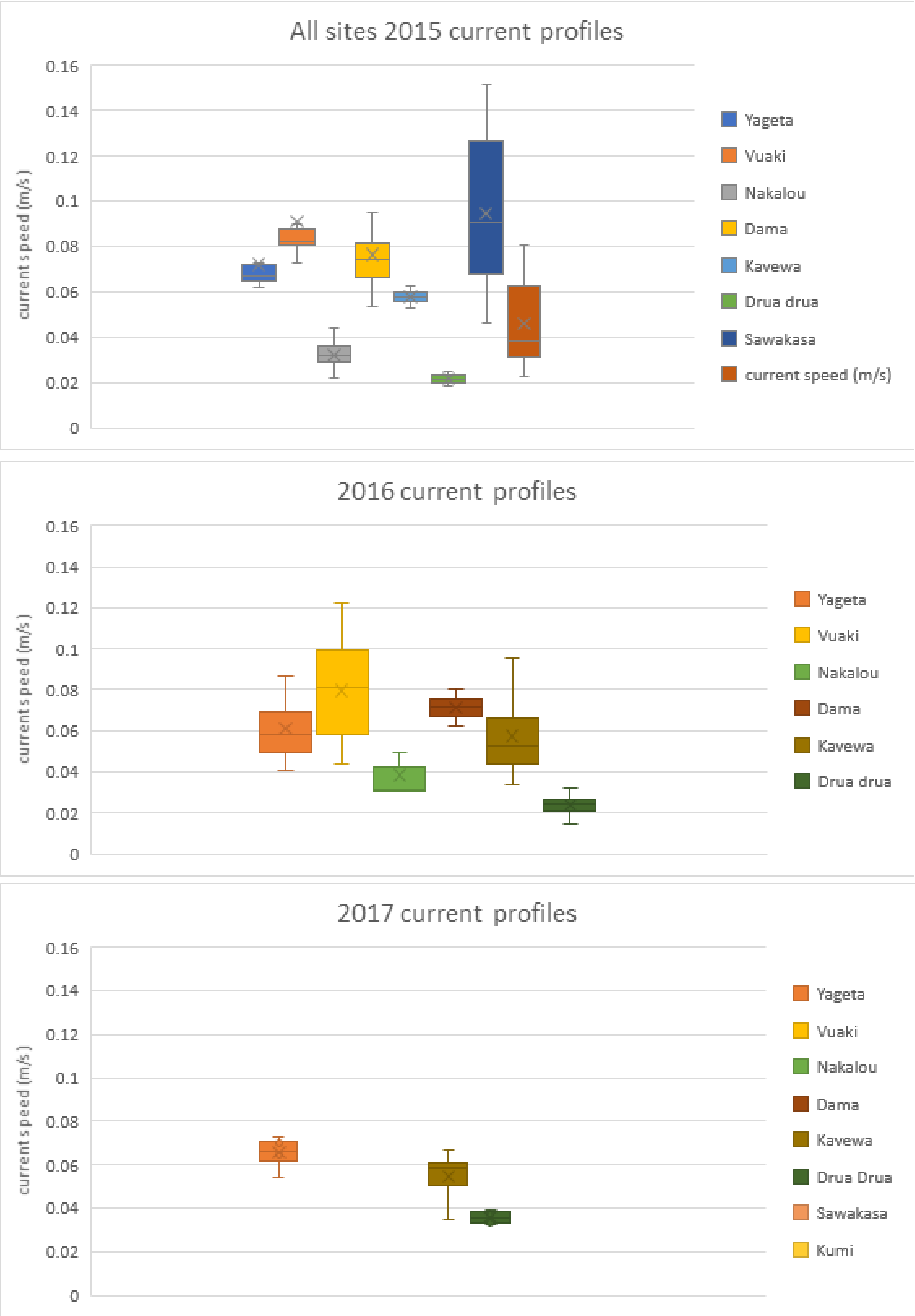


Figure 6. Current speed profiles for selected sites from 2015- June 2017. Box plots show 25th to 75th percentiles, median (line), mean (x) and whiskers minimum and maximum values of weekly averages.

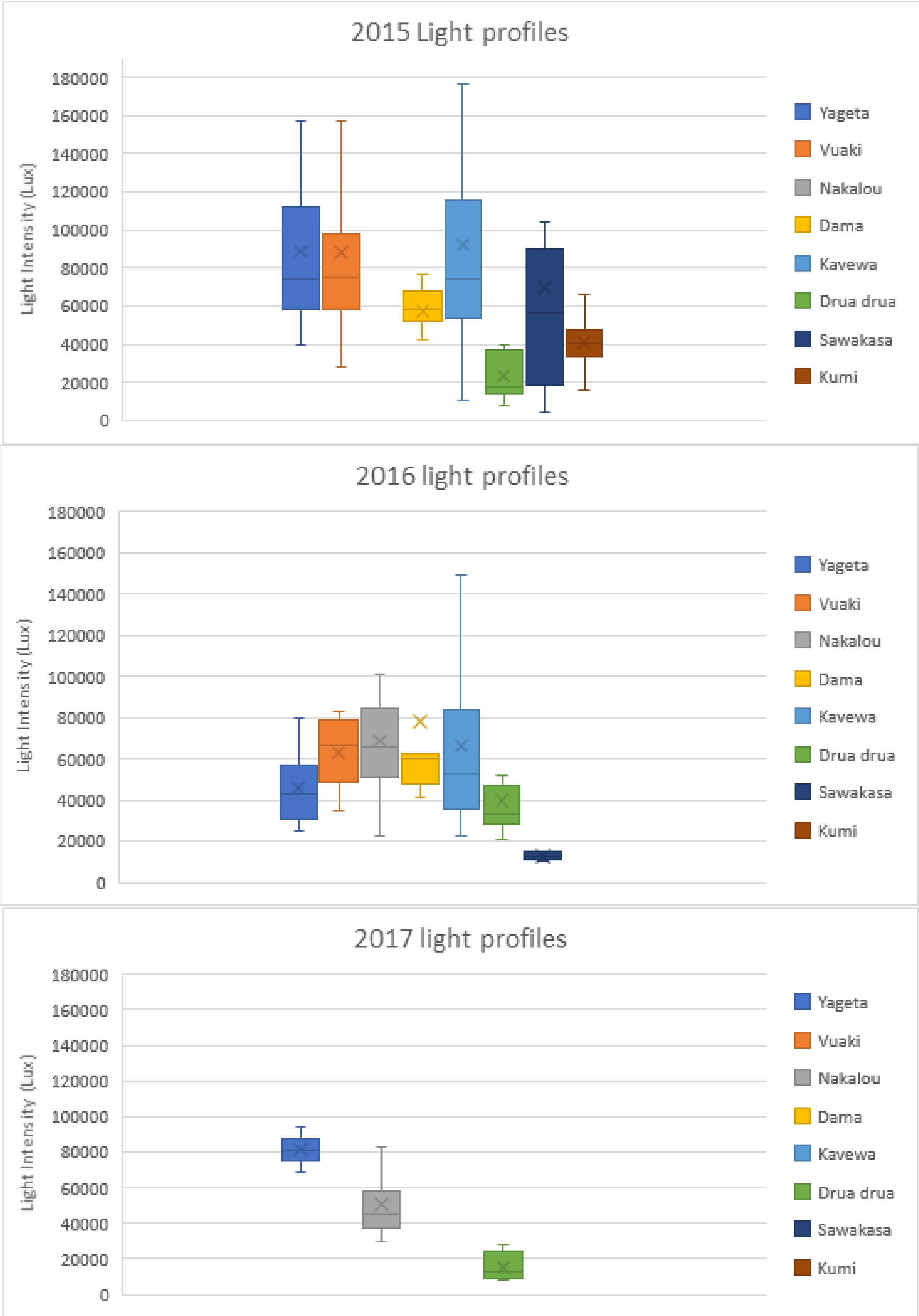


Figure 7. Light profiles for selected sites from 2015 to June 2017. Box plots show 25th to 75th percentiles, median (line), mean (x) and whiskers minimum and maximum values of weekly averages.

3.2 Production and Post-Harvest Quality

Actual production data was collated from buyer data. Data was collected from Wee Kong Marine Ltd, who was the only buyer of *Kappaphycus* seaweed in Fiji from 2014 till Jan 2017. In 2017 data was collected from Wee Kong and another new company Soluk Fiji Ltd which started buying in 2017.

Actual production (Table 2) of *Kappaphycus* was approximately 35 tons in 2014 and 39 tons in 2015, valued at FJD34, 985 and FJD 40, 051 respectively. There was a huge drop in production (3.9 tons only) in 2016 due to major damages sustained by most seaweed farms during Tropical Cyclone Winston. Most of 2017 was recovery of nursery areas, thus the production for this year was low (6.7 tons).

Table 2: Actual seaweed production and total value

(Source: Wee Kong Marine Ltd and Soluk Fiji Ltd).

Years	Actual Production (Kg)	Total Value (FJD)
2014	35,331.90	$ 34,985.66
2015	39,375.90	$ 40,051.59
2016	3,964.95	$ 3,123.86
2017	6,726.15	$ 9,878.42

Out of all the sites monitored during the project, five sites were continuously active/monitored. Production figures of these selected sites shows (Fig. 7) that Yasawa (Yageta/Vuaki) sites were most productive especially in 2014 and 2015. All sites were severely affected by cyclone Winston in 2016. Production in Kaba and Yasawa slowly picked up in 2017, while there was no production recorded for the other three sites.

The price of dried seaweed also fluctuated over the years (Fig. 8). Overall the price sought per kg of dried seaweed generally ranged from $0.80 to $1.20 from 2014 to Jan 2017. However there were some instances where the buyer's price went down to $0.20/kg and this was attributed to low quality seaweed. In 2017, the new seaweed buyer (Soluk Ltd) started buying at $1.50 per kg and this price has been consistent so far.

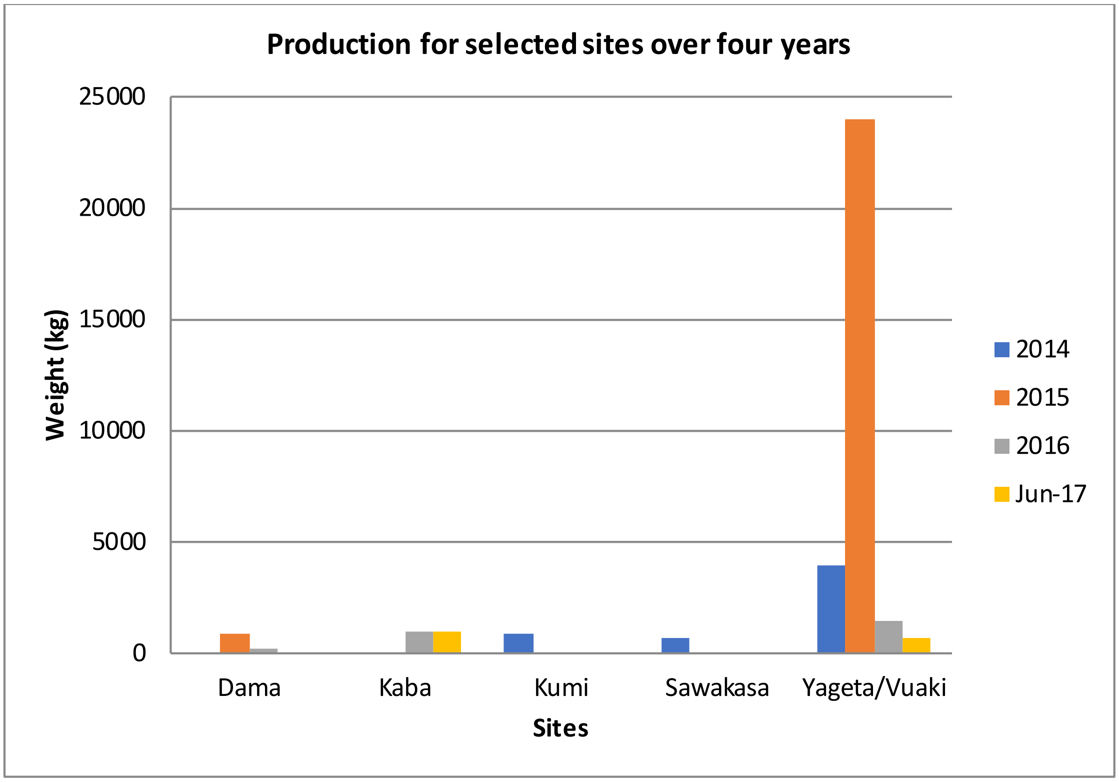


Figure 8. Actual production figures for selected sites.

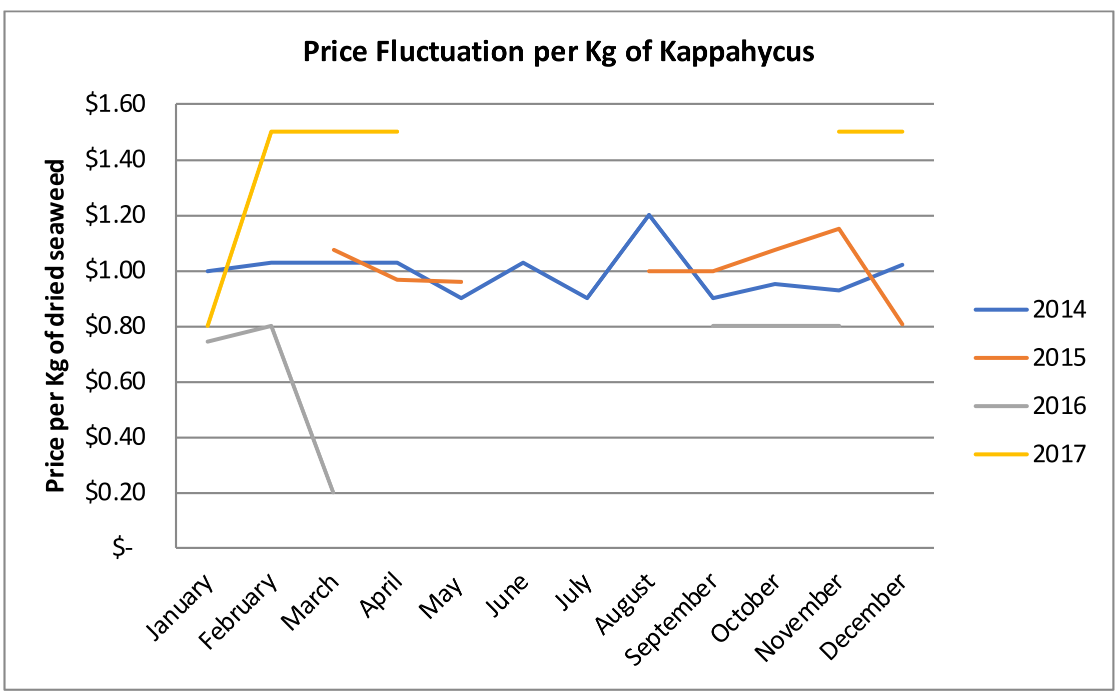


Figure 9: Price fluctuation for dried seaweed ($/kg) over four years

Actual production trend cannot be deduced from the buyer data, as purchase data is the collective weight of seaweed bought from one farm/area at one point in time. The weight bought may be total seaweed produced by the area over a six month period.

3.3 Nutrient Content Analysis

Samples collected (n=17) from various farmers were analysed for moisture and nutritional content and a nutritional content information sheet was produced (Fig. 7). The mean moisture content (% of dry weight) was 22.3 ± 6.2. Results of the mineral content analysis shows a significantly high amount of Potassium (171,681.94 mg/kg) followed by Sodium (35,536.56 mg/kg), Magnesium (5,188.44 mg/kg) and Calcium (4,310.50 mg/kg).

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Diversification of seaweed industries in Pacific Island Countries

Kappaphycus sp.
Country: Fiji

Samples per region
Central:1
Eastern: 5
Northern: 3
Western: 7

Sample as received	Mean [% of DW]	± SD	n
Moisture content	22.3	6.2	17

Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	42.23	9.07	7
Protein[2]	1.46	0.50	16
Lipid	0.43	0.38	8
Ash	54.52	8.53	12
Moisture	3.81	1.50	12

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture in individual samples.
[2] Protein content calculated using the seaweed conversion factor of N x 5 (Angell et al. 2016)

Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	16.88	3.35	16
Nitrogen	0.29	0.10	16
Phosphorous	0.03	0.01	13
Sulphur	3.82	0.63	14
C:N	67.77	42.60	16
N:P	10.76	2.98	13

Fibre content	Mean [g/100g]	± SD	n
Insoluble	2.55	0.49	2
Soluble	34.60	3.11	2
Total	37.15	2.62	2

Mineral Content	Mean [mg/Kg]	± SD	n
Aluminium	153.00	248.46	14
Arsenic	4.81	1.82	14
Boron	141.86	38.58	14
Barium	0.18	0.08	3
Calcium	3,645.71	1,814.25	14
Cadmium	0.14	0.12	10
Cobalt	1.64	1.88	14
Chromium	5.75	5.75	13
Copper	1.98	2.05	14
Iron	436.19	419.92	13
Mercury	<0.01	-	9
Potassium	167,636.00	44,913.15	14
Magnesium	5,116.43	1,028.32	14
Manganese	8.69	8.99	14
Molybdenum	2.88	4.20	11
Sodium	35,228.57	9,386.03	14
Nickel	9.43	10.56	13
Lead	<0.50	-	14
Selenium	<1.00	-	11
Strontium	50.20	18.35	14
Vanadium	1.45	1.10	14
Zinc	14.46	15.91	13

Figure 10. Nutritional Information sheet for *Kappaphycus alvarezii*.

4. Discussion

While there were no substantial differences in water quality parameters between sites, there were some minor differences observed for some sites. Sawakasa recorded the lowest salinity readings (2015 and 2016), which may be due to the site being located in the central division with high rainfall and being within close vicinity of at least two river mouths.

Light intensity was generally lower for sites with turbid waters such as Sawakasa, Kumi and Druadrua. Sawakasa and Kumi are located close to mainland which explains turbid water due to land runoffs, Druadrua on the other hand is located off the mainland, but seems to have low water exchange as it recorded the lowest mean current speed for all three years.

Sites situated away from mainland generally had better environmental conditions, clearer waters, sufficient light intensity, sufficient water exchange and optimum salinity for seaweed growth.

Seaweed production data shows staggered production from most sites. Site visits also confirmed inconsistent farming activity at all sites except Yasawa (Yageta and Vuaki) for 2014 and 2015. This may have been due to difference in ownership of seaweed farms. All other farms monitored were communally owned by the village while Yasawa farms were owned by individual farmers. A similar trend can be noticed for Kaba seaweed farm which was setup in 2016 and had individual farmers. Their production appear to be consistent for 2016 and 2017.

Accessibility to farming sites may also be a factor hindering production. Out of all the major sites monitored, Yasawa and Druadrua farms were located within walking distance from the beach, while other farms such Dama, Kaba, Sawakasa, Nakalou were only accessible by boats.

Natural disasters such as floods and tropical cyclones also affected most farms. Seaweed production was slowly increasing from 18mt in 2013 to 35mt in 2014 and then 39mt in 2015. Cyclone Winston destroyed most of the farms in February 2016 which is the reason there was huge drop in production, however post cyclone site visits confirmed all farms had seed stock to start over.

The price of seaweed is also a factor that influences farmers' willingness to farm. In 2016, Wee Kong Ltd decided to reduce the price to seaweed from $1.00/ kg dry weight to 80 cents per kg and at some instances going as low as 20 cents/kg. This was evident in the unwillingness to continue farming and/or revive farms after Cyclone Winston especially in Yageta and Vuaki.

Since most seaweed farms in Fiji are part of Fisheries Department's rural development project, a good understanding of social issues in community owned projects is vital. In this study we noticed the majority of the farms were heavily dependent on the Fisheries Department for farming items, seed stock, boats, fuel, technical/extension service and transport to market. A village's/ farmer's enthusiasm to farm and the amount of effort put into farming depends on the availability of such subsidy and services.

Most of the factors discussed above has been pre-existing for some years and has been previously documented in a study by Namudu and Pickering (2006), where the authors also pointed out that technical factors were often outweighed by social factors in the success of any rural development projects.

On the other hand, the seaweed buyers have their own set of concerns which are often not understood by all stakeholders. Upon discussion with the Manager of Wee Kong Marine Ltd, who were the sole buyer of seaweed from 2014-2016, not enough seaweed is being produced consistently to ensure the viability of the industry (Pers. Com. Allan Cheung). Their export data for 2014- 2015 shows that it may take them 6 to 10 months to reach the quantity (20-25 tonnes) to fill a container and export. This doesn't only affect the company in maintaining its market share with their buyers overseas, but also costs the company to store dried seaweed until the required quantity is reached. Additionally some farmers were selling seaweed which was not dried properly, thus they had to dry it further at the warehouse which incurs more cost. Seaweed with high moisture tends to degrade in storage. This was the reason behind the buyer reducing the price in 2016 (Pers. Com. Allan Cheung - 2015-2017). In 2017 the Ministry of Fisheries secured a new seaweed buyer (Soluk Ltd) who is currently buying seaweed at $1.50 per kg (DW). Similar concerns were also voiced by the company's manager, who pointed out that quantity and consistency is an issue and will affect their relationship with their investor company (Pers. Com. Mikaele Radrodro- 2017-2018). He also pointed out that they need at least 15 to 20 tonnes to export. And exporting such quantities is still difficult and expensive.

In summary, the growth of the seaweed industry may not be limited by environmental parameters, but more so by social-cultural issue. There is a need to study the whole supply chain, understand and identify problems faced by stakeholders at each stage and then analyse the viability of the industry. Commercialisation of the seaweed industry in Fiji may mean moving away from rural development initiatives and move towards expanding viable self-sustained large-scale farms.

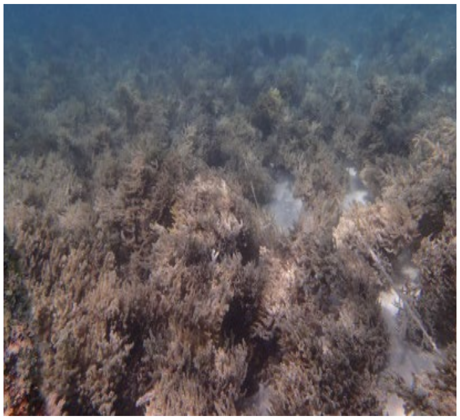
5. References

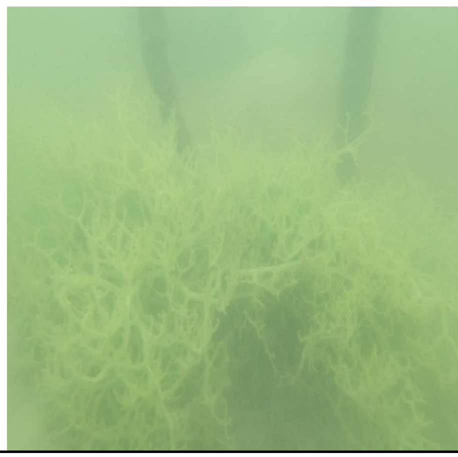
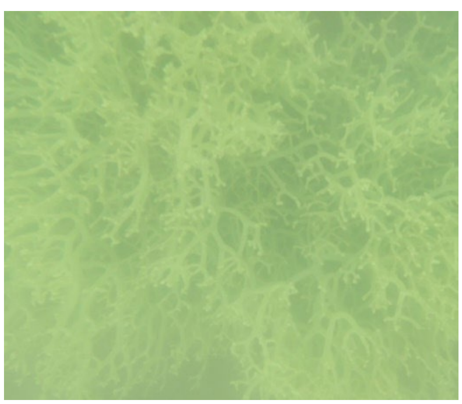
Lal, A. and Vuki, V. 2010. The historical development of seaweed farming, including roles of men and women, and prospects for its future development in Fiji. SPC Women in Fisheries Information Bulletin #21- Dec 2010

Namaudu, M and Pickering, T. 2006. Rapid survey technique using socio-economic indicators to access the suitability of Pacific Island rural communities for *Kappaphycus* seaweed farming development. Journal of Applied Phycology 18: 241-249

6. Supporting information

Hobo and current loggers deployed at sites		
Farmers tying new seaweed lines in Yasawa		

Seaweed growing in farms, a) Tambalang in Yasawa and b) Sacol in Sawakasa		
Seaweed drying method, either on ground or on drying racks		
Bulk storage of seaweed at Wee Kong		

Cyclone Winston Damage (before and after (Yageta – Yasawa)	Before 	After 
Cyclone Winston Damage (before and after (Sawakasa – Tailevu)	Before 	After 
Flood damage- Dec 2016 (Sawakasa farm)	Before 	After 

11.2 Appendix 2: Edible seaweed production in Fiji

Author: Cherie Morris, Institute of Marine Resources, University of the South Pacific

Executive Summary:

Prior to evaluating opportunities to enhance production and processing of edible seaweeds (such as sea grapes), market analyses were done to characterise the production, value and supply chain of edible seaweeds in Fiji. There are four species of edible seaweed harvested from a total of 16 villages across Fiji for sale in Suva, Nadi, Lautoka and Nausori markets. These comprised of two green seaweed genera, *Caulerpa* spp. (common name "nama" or sea grapes) and *Ulva meridionalis* (common name "lumi boso" or sea lettuce) as well as two red seaweeds *Hypnea cornuta* (common name "lumi cevata") and *Hydropuntia edulis* (common name "lumi wawa", formerly known as *Gracilaria*). Both green seaweeds and *lumi wawa* are consumed fresh, whereas *lumi cevata* is traditionally cooked in coconut cream and consumed as a gelatinous food once cooled and set.

Long-term monitoring over a period of 2 years allowed us to estimate that a combined seaweed volume of 20.6 tonnes were supplied, equivalent to ~10 tonnes per annum. The total annual value of edible seaweed traded in the marketplace was ~ FJD100,000. Out of the 16 production villages, 8 supplied a combined volume of about 7 tonnes per annum, 90% of which were sea grapes (*Caulerpa* spp.) to Suva market on a regular basis. The work to date focused on the supply chain for the Suva market, with sex disaggregated data in particular. Harvesting is mostly done by females (93%; 55 out of 59 reported) and most of the vendors are female in the markets examined (>95%), all middlemen were in fact women. Most of the harvesting activities require boats to travel to the harvest site, up to 5 km away from the village. Transportation to market is by sea or road. Quantities of edible seaweed sold monthly in Suva, although variable, typically peaked during the "winter" months of May and June and during the festive season (November to December). There was evidence that the seaweed portion varied as a result of disasters such as cyclone and floods. In addition, dried *Caulerpa* sp. had an average ash content of 61% with seasonal variation.

Seaweed prices range from FJD9.00 to FJD17.00 per kilogram depending on the type of species and are consumed by locals at their homes, most preferably as tuna salad and plain salad with/without coconut cream to compliment other dishes.

1. Introduction

Edible seaweed, including seagrapes, is sold in a number of Fiji markets, with the main municipal market located in Suva. Seaweed are sold for FJ$2 per plate which ranges from 100-400 g of fresh seaweed per heap (equivalent to approx. AU$6/kg). Like Samoa, although the price doesn't change, the portion size does. This makes it difficult for consumers to understand that there may be supply issues and seasonal price fluctuations (eg. during adverse weather conditions). In Fiji, seaweed is generally offered to customers on plastic plates, usually accompanied by a small plastic bag of fermented coconut and fresh chilli. The peak marketing days of seafood are Fridays and Saturdays to prepare for consumption on Saturday and Sunday. Fresh, harvested stock arrives in the main markets Wednesday and Friday mornings. On Viti Levu, some harvesters do their own retailing and some sell wholesale to market vendors in Lautoka, Nadi, Nausori and Suva (Paul, N. et al. 2011; Morris et al. 2014).

Following a 6-month preliminary assessment of sea grape production through the Suva market from 2014 to 2015, it was determined that monitoring of the production and quality of the fresh product would continue with monthly sampling capturing a total of 1.5 years of additional data. Socioeconomic information was documented later for the main edible seaweed (sea grapes) from the two main supply regions, Rakiraki and Yasawa, to complement the production statistics in order to get a better understanding of the value chain of edible seaweed industry in Fiji.

2. Methods

2.1. Estimating edible seaweed production and biochemical analysis

A monthly sampling of sea grapes (with the exception of March 2016: consequence of Cyclone Winston – no market sales) sold in Suva market began from April 2015 to May 2017. Approximately 1kg samples were purchased at around the same time each sampling day from the same vendors from all sea grape village sources. Initially, samples were taken on Saturday as this was the main day of sale. Additional edible seaweed species such as *Hydropuntia edulis, Hypnea cornuta* and *Ulva meridionalis* from each source were purchased from July 2015 onwards. In August 2016, sampling days increased to 4 from Wednesday to Saturday to enable a better estimate of national production. Data collected on Saturday and after the sampling period included the following:

- Number of vendors
- Photo code
- Number and size (kg) of bags per vendor
- Sample number
- Number plates per sample
- Price per plate (FJD)
- Fresh and dry weights (g)
- Ratio of fresh weight to dry weight
- Mean fresh weight per kg
- Dates of: harvest, received by seller, sampled & packed
- No. hours drying & temperature

Adjustments were made to the number of vendors observed on each sampling day to avoid duplication since vendors remained at the market until all seaweed was sold (up to 6 hours). Each cleaned seaweed sample was placed in a clean plastic bag and taken to IMR for measurements. After placing each sample in a tray (30x43x5cm), wet weights and photos (for assessment of impurities) of each sample were taken before being placed into an Ezidri ultra FD1000 dehydrator for 30-60 hours depending on humidity. Weights were taken after drying with a calibrated Ohaus NVL2100 balance scale. Dried samples were packed and sealed using a Sunbeam Vacuum sealer, labelled accordingly and sent to the University of the Sunshine Coast for biochemical analysis. The seasonal product quality measurements of water content (calculate from the FW: DW ratio) and ash content of the dried matter (mineral content; with the difference being the dry matter organic content) is expressed for each species in a time series.

For ease of referencing, production statistics are presented for two years from June 2015 to May 2017 for all 4 species of edible seaweed from the 8 villages across Fiji which were regularly supplied and sold in Suva market. There were 2 villages irregularly supplying Nadi & Lautoka markets, although these were excluded from time series comparisons due to low number of samples. However, for national production calculations, the production statistics from the occasional suppliers, including 5 other villages and 1 island resort, are included in the overall quantities per region (Table 2).

2.2. Preparation for DNA analysis

From November 2016, about 5g wet weight samples of all 4 edible seaweed species from each source were dried with silica gel. About 0.02g of each dried seaweed species was transferred to a conical tube, labelled and stored in the freezer for DNA analysis at a later stage.

2.3. Value Chain analysis

A preliminary value chain analysis (VCA) using a questionnaire was conducted in 5 villages (Namuaimada, Vunitogaloa, Gunu, Somosomo and Nasoqo) and at Suva market to complement the production data from market sampling. The questionnaire was divided into 4 parts for each of the groups identified.

3. Results and Discussion

3.1. Estimating edible seaweed production and biochemical analysis

Overall, the total combined edible seaweed production (4 species) was ~7 tonnes per annum with a value of ~FJ$86,000. The highest combined production and value occurred during the months of May (910kg; FJ$11,148), June (830kg; FJ$10,168), November (820kg; FJ$10,045) and December (845kg; FJ$10,351) (Figures 4a & b). Out of the 4 edible seaweed species, *Caulerpa* spp. dominated production (6 tonnes) and value (~FJ$78,000) per annum which equated to 90% of the total combined production. The other species comprised, about 0.5 tonnes *Hypnea cornuta* (7.5% of total) around 100kg *Hydropuntia edulis* (previously *Gracilaria edulis*, 1.5% of total) and about 70 kg *Ulva meridionalis* (1% of total) per annum (Table 1, Figures 3-6).

Monthly production of seaweed species varied but was generally higher during the cooler months particularly May, June and October (winter months extend from May to October, (Kumar et al., 2014)) and during the festive season from November to December. Zero or very low quantities corresponded to adverse weather such as Cyclone Winston in February 2016 and floods in December 2016 and seaweed arriving late on a couple of sampling days. However, edible seaweed species seems to be resilient and recover fairly quickly from a disturbance, some (e.g. *Caulerpa* and *Hypnea*) faster than others (Figures 5 & 6).

Four villages (Gunu, Somosomo, Nasoqo and Namuaimada) in 2 regions (Yasawa & Rakiraki) regularly supply Suva market with *Caulerpa* spp. with the majority being supplied from the 3 villages on Naviti Island in Yasawa (Figures 1 & 2; Table 2). Additional smaller quantities of *Caulerpa* spp. were supplied occasionally from 5 villages and 1 island resort. The quantity of *Caulerpa* spp. from Mana island, although traded only 4 times over 17 months, was close to the quantity supplied from Rakiraki traded over 2 years. The *Caulerpa* fronds from Mana were much wider and held more water (FW:DW ratio is 17 compared to 15 for others) (Table 2).

Although price per portion of edible seaweed was standard at FJ$2.00, the price per kilogram differed for each species. Overall, *Hypnea cornuta* had the highest price (FJ$17.00) and *Hydropuntia edulis* the lowest price (FJ$9.00) per kilogram (Table 3). This was attributed to the differences in the amount of water each species retained (Table 5, Figure 8) and the portion per plate which was influenced by the market vendors' handful size and number. The variation in the portion size shows that there is evidence of supply issues and therefore seasonal price fluctuations which are not well understood by the consumer. *Hypnea cornuta* showed the highest variation in portion size (Table 4).

The measurements of ash and water content of *Caulerpa* spp. (n=42) showed that seasonal variations occurred. Ash content varied and was particularly high (average 61%) compared to that of other studies (Bhuiyan et al. 2016), (Darmawati et al. 2016), Setthamongkol (2015) (Figure 8). According to Bhuiyan et al (2016), high level of ash was generally associated with the amount of mineral elements.

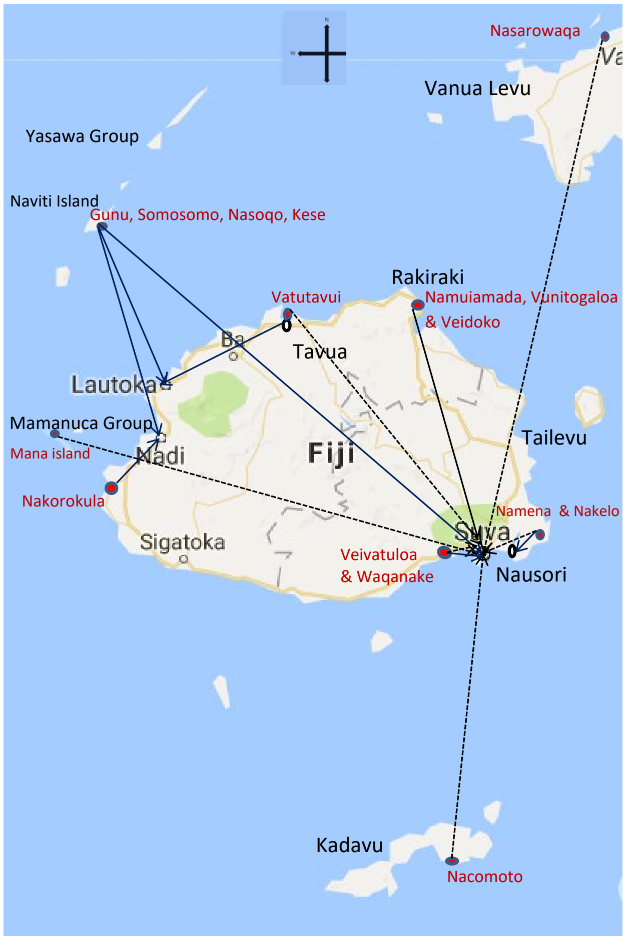


Figure 1. Location of all sources and markets for 4 species of edible seaweed: (*Caulerpa* spp., *Hypnea cornuta, Hydropuntia edulis & Ulva meridionalis*) in Fiji. Dotted lines are the villages which supply *Caulerpa* spp. occasionally.

Table 1. Estimated annual production (kg fresh weight) of edible seaweed species from Suva market

Species	Year 1	Year 2
Caulerpa spp.	6,000	6,610
Hypnea cornuta	585	435
Hydropuntia (Gracilaria) edulis	90	140
Ulva meridionalis	90	55

Figure 2. Fresh and dried edible seaweed samples: A. *Caulerpa* spp. B. *Hypnea cornuta* C. *Hydropuntia edulis* D. *Ulva meridionalis*. E. Plates of *Caulerpa* spp. being sold at Suva market. F. Dried *Caulerpa* spp. samples.

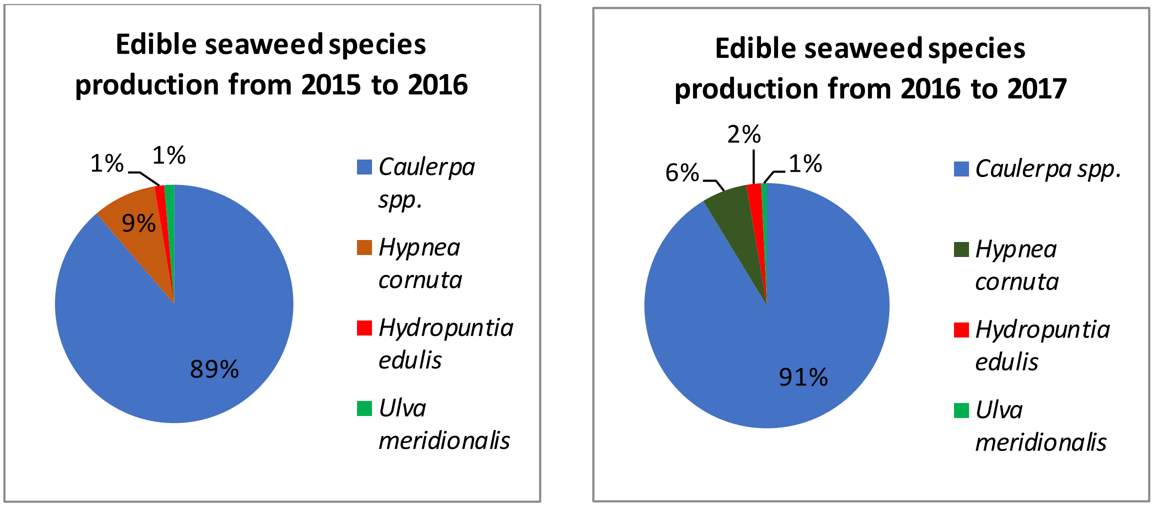


Figure 3. Annual proportions of edible seaweed species from Suva market.

Table 2 Overall production (kg fresh weight) of edible seaweed species per region at Suva and Nadi markets

	Caulerpa spp.	***Hypnea cornuta***	***Hydropuntia edulis***	***Ulva meridionalis***
Rakiraki	5,230	435	205	145
Yasawa	7,610			
Tailevu		545	25	
Veivatuloa		70		
Nadroga		2	2	
Mana isl *	5,180			
Waqanake*	60			
Kadavu*	80			
Bua*	1,040			
Tailevu*	20			
Tavua*		10		
Total	**19,220**	**1,062**	**232**	**145**

Regions marked with an asterisk * are occasional suppliers which supplied seaweed between 1 to 4 times in 17 months from 2014 to 2016.

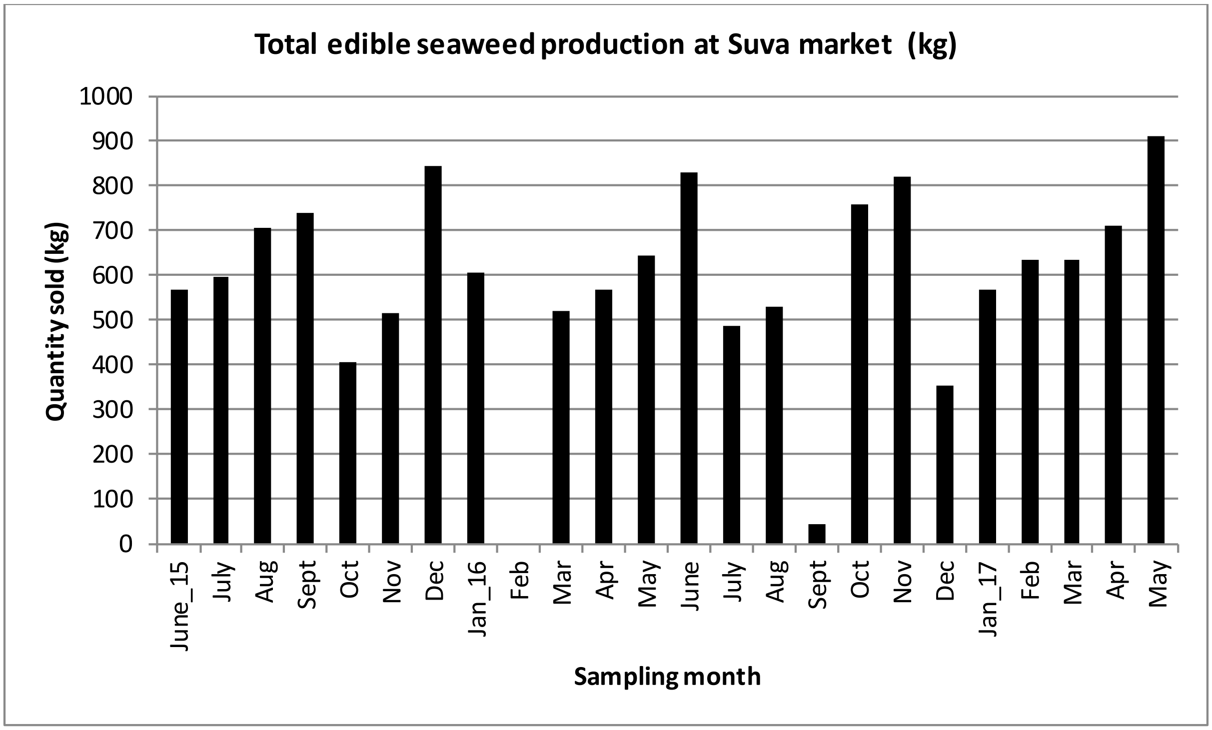


Figure 4a. Total edible seaweed production at Suva

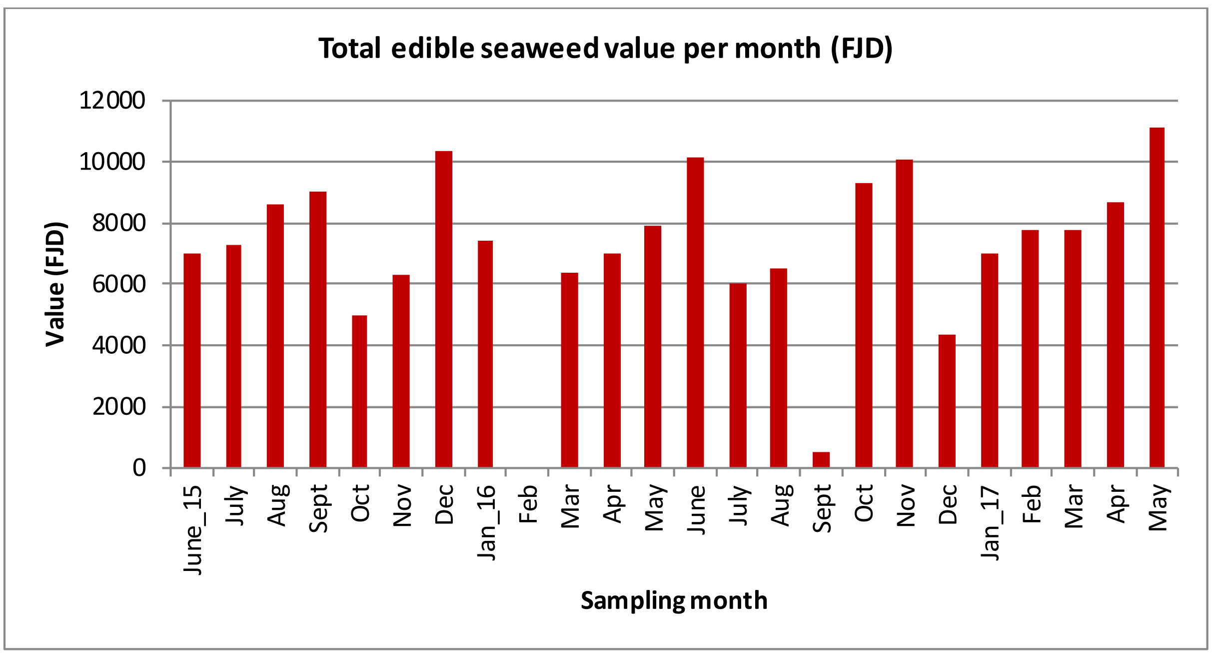


Figure 4b. Total edible seaweed value

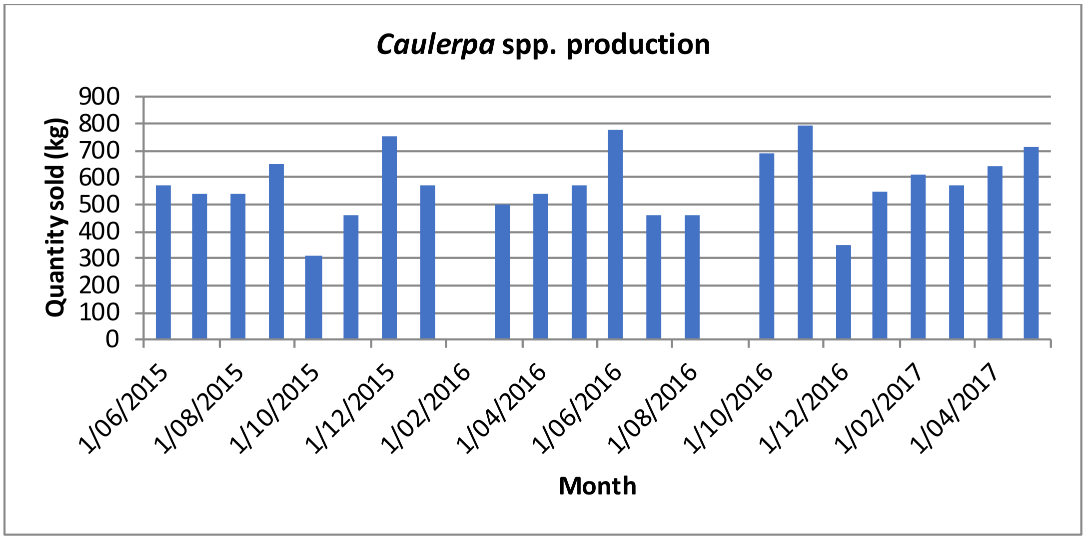


Figure 5a. *Caulerpa* spp. production at Suva.

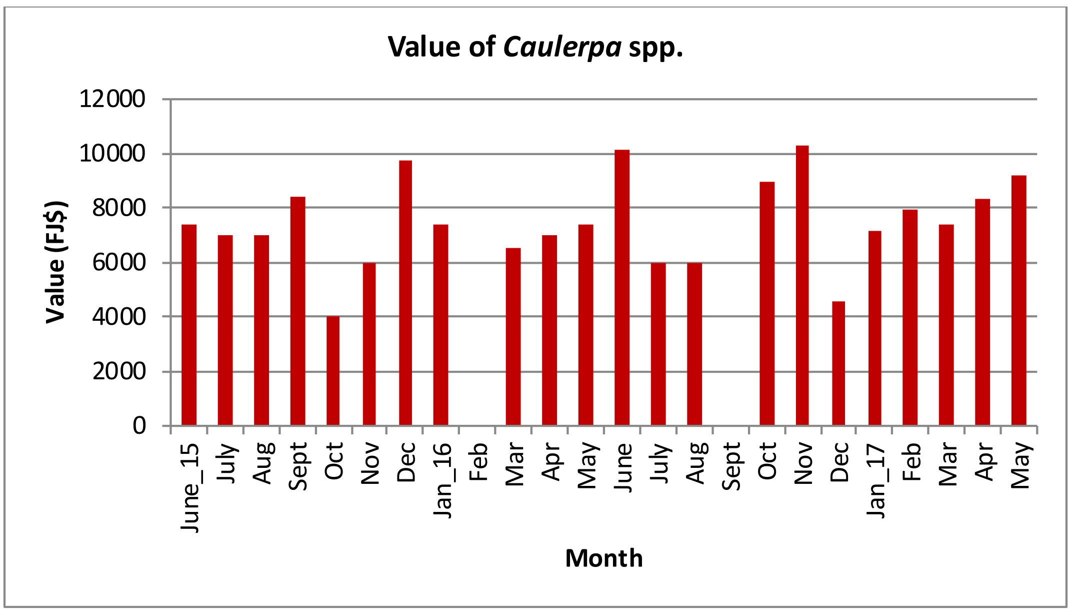


Figure 5b. Total *Caulerpa* spp. value.

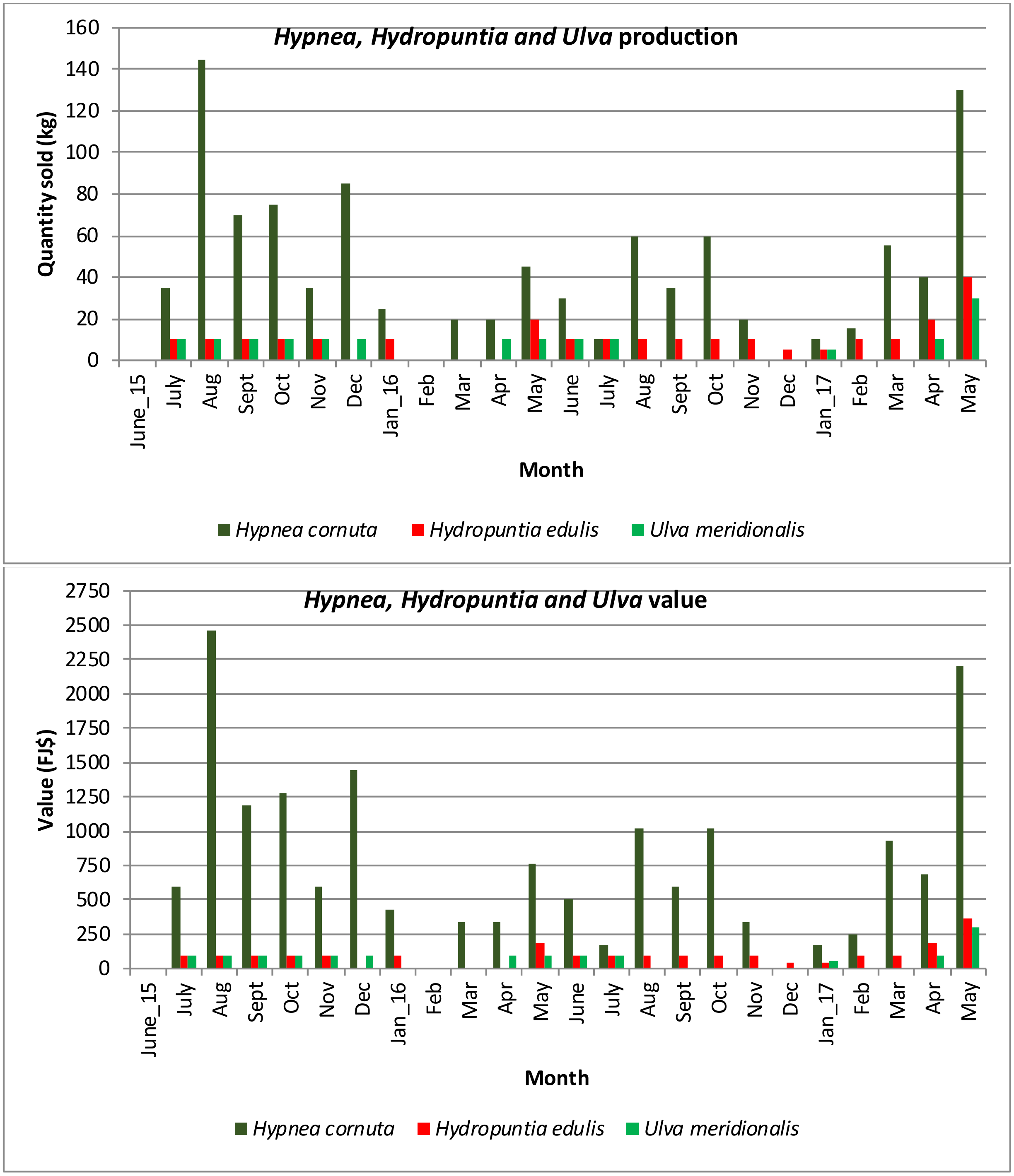


Figure 6. Other edible seaweed species production and value at Suva.

Table 3. Overall species price per kilogram

Species	Price/kg (FJD)
Caulerpa spp.	13
Hypnea cornuta	17
Hydropuntia edulis	9
Ulva meridionalis	10

Table 4. Overall variation in portion size (n=7 plates)

Species	F/Wgt. per plate	F/Wgt. per plate (H)	F/Wgt. per plate (L)
Caulerpa spp.	182.38	298.10	101.19
Hypnea cornuta	208.62	445.00	71.93
Hydropuntia edulis	212.65	392.00	165.00
Ulva meridionalis	213.90	387.93	204.82

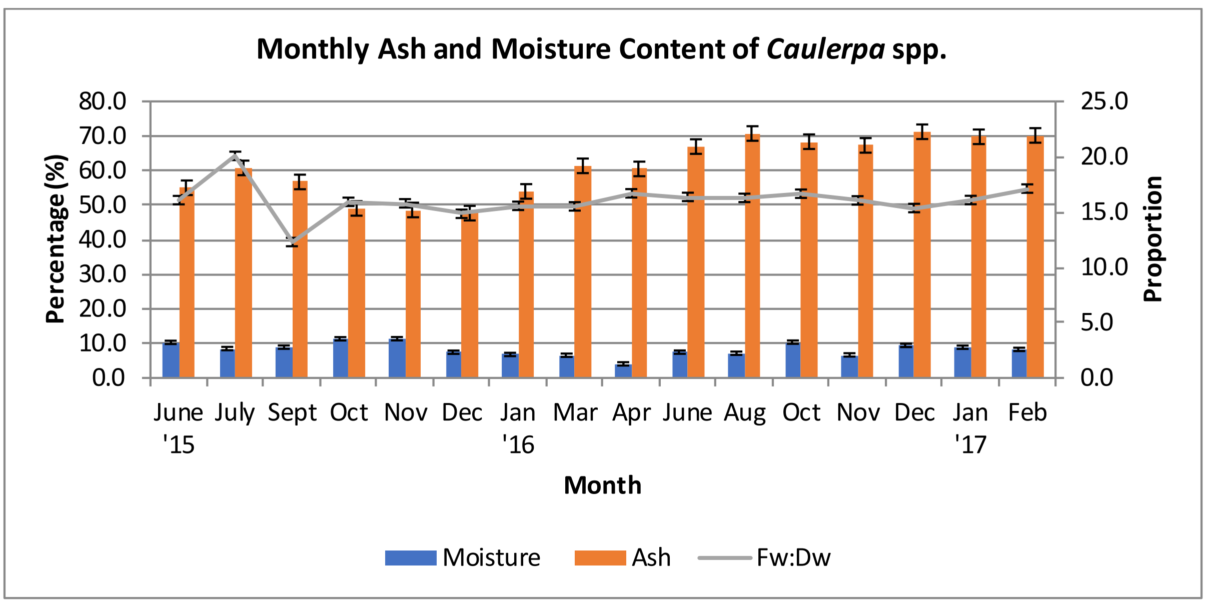


Figure 8. Seasonal variation of ash and moisture content of *Caulerpa*. Error bars show ±SD.

3.2. Supply chain analysis

The flow of edible seaweed and associated activities from the source to final market involves 4 main groups; harvesters (farmers), middle sellers (all women), vendors and local consumers (Figure 5). Transporters who are all male are involved in pre-harvest (to harvest site) and post-harvest (to market). A total of 55 women and 4 men aged between 20 and 59 years regularly harvested 4 species of edible seaweed from the 5 villages surveyed. Harvesters travelled to the harvest site mostly by boat or on foot during the falling tide and spend from 4 to 6 hours a day, 2-3 days a week collecting seaweed. Harvesting was usually carried out throughout the year except during adverse weather conditions. Harvested seaweed was generally stored in potato or flour sacks within the harvesters' house and kept from 1 to 3 days before transferring to market. Out of a total of 7 vendors in Suva, two of these women were also middlesellers.

With respect to the two main village producers: Rakiraki (Northern Division): 14 women harvested *Caulerpa* spp. from one village and *Ulva meridionalis* from another village. These and other women also bought *Gracilaria edulis* and *Hypnea cornuta* from female and male harvesters in a nearby village. Rakiraki harvesters sold directly to market vendors and a middleman (woman) in addition to transporting the seaweed to market by road to sell themselves. Edible seaweed from Rakiraki supplied Nausori and Suva markets 2-3 times per week.

Yasawa (Naviti island in the Northern Division): 41 women from 3 villages harvested *Caulerpa* spp. and sold to two other women who acted as middlemen in Suva as well as other women vendors in Lautoka. *Caulerpa* was transported to Lautoka by sea and the 2 middlemen in Suva transported the seaweed to market by road. These sellers retailed seaweed themselves in addition to selling wholesale in Suva. Edible seaweed from Yasawa supplied Lautoka and Suva markets once a week. This value chain has been previously analysed by Morris et al. (2014). Comparing this analysis to the previous one, similarities include; Yasawa remains the major supplier of *Caulerpa* spp., presentation of seaweed, price, days seaweed arrive at Suva market and unsustainable harvesting practices at some sites remain the same. The main differences of the current analysis compared to that of the previous one are that more data has been collected over time although there were less sites and active harvest sites were updated. In the current analysis, data included, long-term seaweed production (over 2 years), a more detailed supply chain including sex disaggregated data, production of 3 additional edible seaweed species and biochemical and DNA analysis conducted.

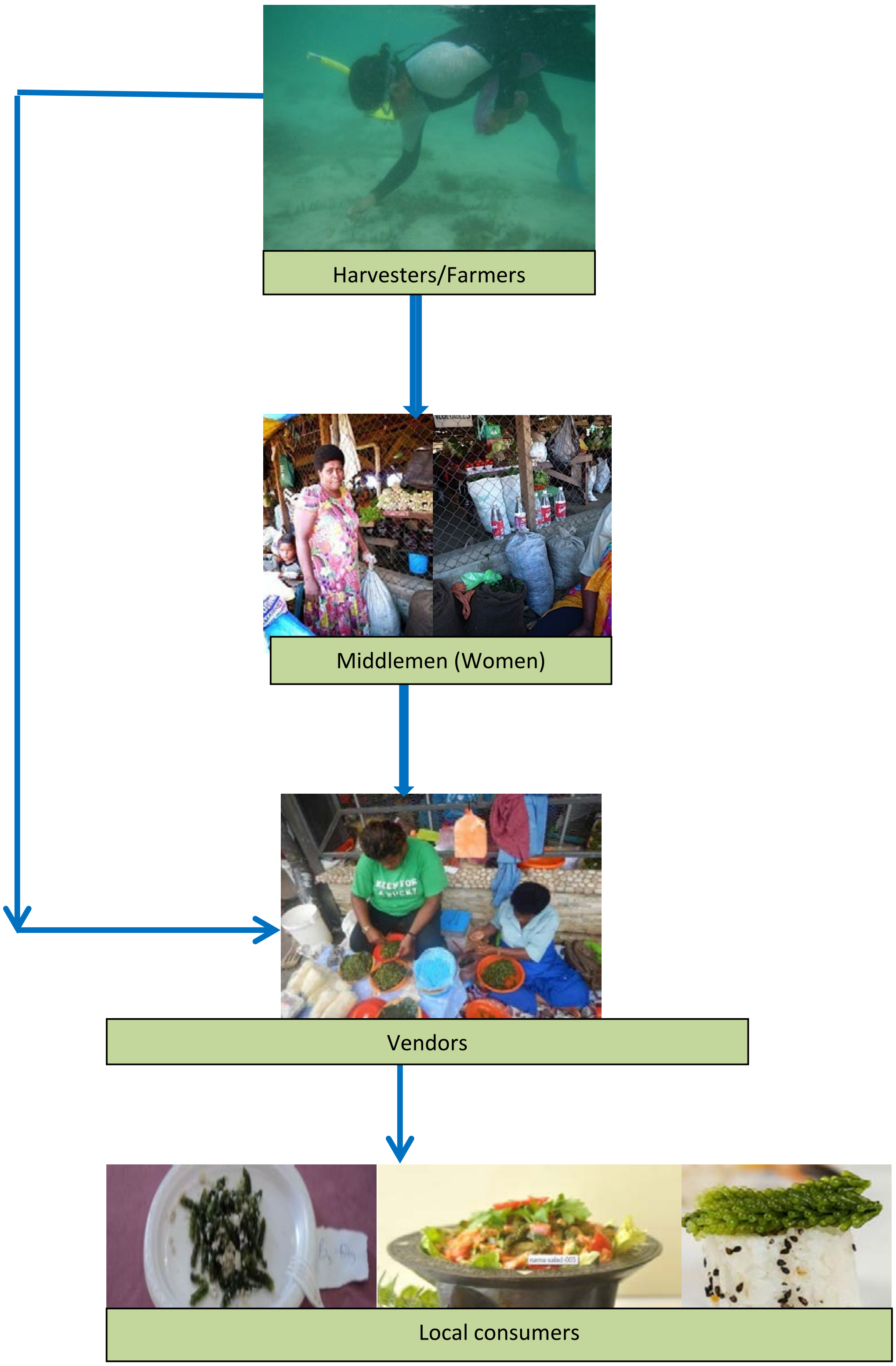


Figure 8. The value chain of edible seaweed through 4 groups.

A small amount of seaweed is consumed by villagers and majority is sold in local markets or restaurants. All 4 edible seaweed species are usually sold fresh and *Hypnea cornuta* is also sold cooked. Out of twenty-one consumers interviewed, majority were female (n=18), of Fijian descent (n=14), ate seaweed since childhood (n=19), purchased 1 to 2 species at a time (n=9; n=8), consumed seaweed in the home (n=19) and purchased seaweed once a week (n=10). In terms of portion, two plates of fresh edible seaweed were most commonly purchased by the consumer at one time. In addition, the two most preferred methods of preparation were canned tuna salad and plain salad with/without coconut cream.

Edible seaweeds are nutritious and provide a source of protein, fiber, vitamins, polyunsaturated fatty acids, macro and trace elements, as well as important bioactive compounds (Setthamongkol et al. 2015). However, it is important to understand that since portions of edible seaweeds are often small, these do not necessarily satisfy dietary intake of trace elements for adults (Paul et al. 2013).

4. Conclusion

An estimated combined edible seaweed volume of 20.6 tonnes were supplied to the three main markets in Fiji, equivalent to 10 tonnes per annum. Out of the 16 production villages, 8 supplied a combined volume of about 7 tonnes per annum, 90% of which were sea grapes (*Caulerpa* spp.) to Suva market on a regular basis. The other species comprised, about 0.5 tonnes *Hypnea cornuta* (7.5% of total) around 100kg *Hydropuntia edulis* (1.5% of total) and about 70 kg *Ulva meridionalis* (1% of total) per annum The total annual value of edible seaweed traded in the marketplace was ~ FJD100,000.

Harvesting is mostly done by females (93%; 55 out of 59 reported) and most of the vendors are female in the markets examined (>95%), all middlemen were in fact women. The main consumers of seaweed are of Fijian descent who purchased two plates of up to 2 species at a time for home consumption. Seaweed is generally eaten as a salad either with canned tuna or plain and with or without coconut cream.

5. Recommendations

Further studies are required on the following:

1. Linking the local names of *Caulerpa* spp. with the confirmed scientific names
2. Growth trials of individual *Caulerpa* spp. to determine the most suitable species for commercial production
3. Growth trials of *Hypnea cornuta*
4. Effect of the environment on biochemical production in the most suitable *Caulerpa* sp. (from 2) and in *Hypnea cornuta*

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11.3 Appendix 3: Seaweed compost manual – Community workshop August 2016 Tarawa, Kiribati

Authors and key staff:
Nicholas Paul and Ian Tuart, University of the Sunshine Coast
Karibanang Tamuera, Tentaku Teata, Fisheries, Kiribati
Routan Tongaiaba, Ministry of Agriculture, Kiribati

Executive Summary

This manual was the written material provided for a workshop on the production of compost using seaweed conducted in Tarawa on 16-17 August 2016. A community-level trial of compost will be conducted in Nanikaai, Sth Tarawa, focussed on four village groups. This community trial was run by Fisheries staff from the Ministry of Fisheries and Marine Resources Development (MFMRD) and University of the Sunshine Coast project scientists from ACIAR, in partnership with staff from the Kiribati Ministry of Agriculture. The workshop participants from Nanikaai learnt the methods required to produce and manage compost in a hands-on workshop and were be supported by Fisheries and Agriculture staff for the duration of a 3-month trial, at which point another workshop was conducted for the use of compost in planting crops, again supported by Agriculture and Fisheries staff. An evaluation of the compost training workshop was conducted a year later through participant interviews (see following Appendix).

Background

Seaweed is an abundant resource on the reef flat on Tarawa. There are many different types of seaweed in the shallow coastal environment, however, one particular variety – the red seaweed *Acanthophora spicifera* - is highly abundant and washed up on the beach to form a "wrack". This beach wrack is sometimes removed by the community and buried or disposed of, as it is unsightly and can degrade and cause an offensive smell. In 2015-2016, project scientists from MFMRD/ACIAR conducted scientific trials on the production of compost from this seaweed resource, producing a compost over 3 months and subsequently testing this compost as a blend in soil (20% compost:soil) for a range of different crops including tomatoes, cabbages and eggplant. These studies found that the seaweed is rich in nitrogen (N, 1% of the dry weight) and also in essential trace elements (including potassium [K] and other minerals). The NPK ratio of the seaweed is approximately 14:1:85 and, when blended with dried leaves in a weight ratio of between 5:1 and 9:1 can be used to produce a unique compost for Tarawa that can reduce the reliance on sourcing animal manure.

Location & Participants

Nanikaai community was selected for this workshop because the four villages are active in cleaning their beachfront of seaweed but, as yet, do not use this seaweed for any applications. They presently bury the seaweed or dispose of it. The workshop participants will primarily focus on women from each of the four villages that are already engaged in cleaning and maintaining the beachfront.

Each village group (~ 5 people) created their own compost mix, and this compost was maintained for the duration of the trial with regular support from Fisheries and Agriculture staff. Additional training was provided during the workshop for the Fisheries Training Officer, and to two Fisheries Assistants that are involved in seaweed farming on Abaiang and Arunuka, to support additional extension activities on Tarawa and the outer islands.

Instruction manual

1. Collect seaweed

Fresh and dried seaweed can be collected from the beach using flour (yellow) bags

Care should be taken to sort rubbish into green bags

2. Dry seaweed

Fresh and dried seaweed can be laid out to dry (avoid rain)

Continue to sort rubbish into green bags (transfer to tip)

Rake seaweed into pile and then compress into 50kg bag for storage (~10kg dried seaweed per bag)

3. Collect leaves

Collect leaves from surrounding area regularly. Store leaves in pile close to compost. Add leaves to 50 kg flour bags (4 kg dried leaves per bag)

4. Mix seaweed and leaves

Mix seaweed and leaves in compost area:

Seaweed: 5x 50kg bags (total of 50kg)

Leaves: 4 x 50kg bags (total of 8kg)

5. Start compost

Start compost by wetting until water runs out at the base

Feel inside compost pile to ensure moist

6. Cover compost

Cover compost with 50kg flour bags. Put weights on top of cover to stop evaporation

7. Check compost weekly

<u>From 0 to 1 month</u>: Check moisture with hands – if dry in middle add water.

Check temperature with hands – if it is not hot in the middle, then mix through more seaweed (record how much is added, for example ½ bag).

Turn and tend once per week.

<u>After 2 months</u>: Continue to add water if needed (to stay moist).

8. Finish compost

The compost will shrink in size

When the compost looks like soil (**see photo on right**), it is ready

Cover until use for planting

Conclusion of Compost Trial and Start of Crop Trial

At the conclusion of the trial after 3 months, a subsequent workshop was run for the use of the compost in planting. This workshop adopted learnings from the earlier trials with a range of fruit and vegetables, such as these tomatoes produced in experimental pot trials using seaweed compost (below). The planting workshop trial ran for another 3 months. Note: total time to create compost and harvest crop (e.g. tomatoes) is 6 months.

11.4 Appendix 4: Evaluation of community workshop on compost training

Authors and key staff:

Libby Swanepoel, Silva Larson and Nicholas Paul, University of the Sunshine Coast

Taati Eria and the Fisheries Training Unit, Ministry of Fisheries and Marine Resource Development

Background

Food supply chains are essential to food security in developing countries. The Republic of Kiribati has seen a rapid transformation of its food system away from a traditional diet and towards imported foods. The development of short supply food chains through home gardening promotes traditional, locally embedded and sustainable diets. Remoteness and poor soil quality in Tarawa, Kiribati limits the cultivation of fresh fruit and vegetables in home gardens.

Substantial amounts of red seaweed *Acanthophora* can be found as wrack on the beaches adjacent to villages on Tarawa, Kiribati. Collecting this beach-cast seaweed acts to improve environmental quality of the coastline whilst being utilised in the cost-effective production of nutrient-rich organic compost. Seaweed compost is particularly important for water security on Tarawa as synthetic fertilisers are banned to protect the freshwater lens of the coral atoll. A training program conducted in four communities in Tarawa aimed to develop women's ability to prepare seaweed compost to support home gardening. This project reports on the 12-month follow-up evaluation of the training program. The specific objectives were to:

1. Describe the characteristics of people taking part in composting groups in Kiribati.
2. Determine people's barriers and enablers to ongoing involvement in composting groups.
3. Evaluate the role membership of the seaweed composting group played in improving the wellbeing of members involved

Method

Seaweed composting groups were established in Tarawa as a cost-effective and environmentally friendly method of generating compost and producing vegetable gardens. Current and past members of the composting groups were invited by local researchers to take part in a face-to-face interview to share their experience and involvement in the group. Structured interviews were conducted with 18 of a total of 24 participants 12-months after training. Questions were translated into e-Kiribati and reviewed by a local researcher to check for ambiguity, appropriateness of wording and cultural acceptability. Participants completed the interview in e-Kiribati with the use of a local translators.

Figure 1: Debriefing session with local translators following initial interviews

The interviewer recorded participant responses directly during the interview. Responses were summarised back to participants throughout the discussion to verify that an accurate representation of their response was captured. Individual interviews took between 45-60 minutes to complete. Conventional content analysis of interview responses was conducted to uncover common themes. Content analysis also focused on outlier themes that may be culturally specific relevant to the aims of this study.

Results

Participants represented the four villages that were involved in the compost training program. Participants were mainly women (83%, n=15), married (83%, n=15), and aged between 23-55 years. All participants were confident they had learnt new skills in seaweed composting, however they identified a need for ongoing support and input from facilitators in order to sustain their involvement. Participants were highly satisfied (mean score 9.3/10) with their overall involvement in the compost training program as shown in Figure 2.

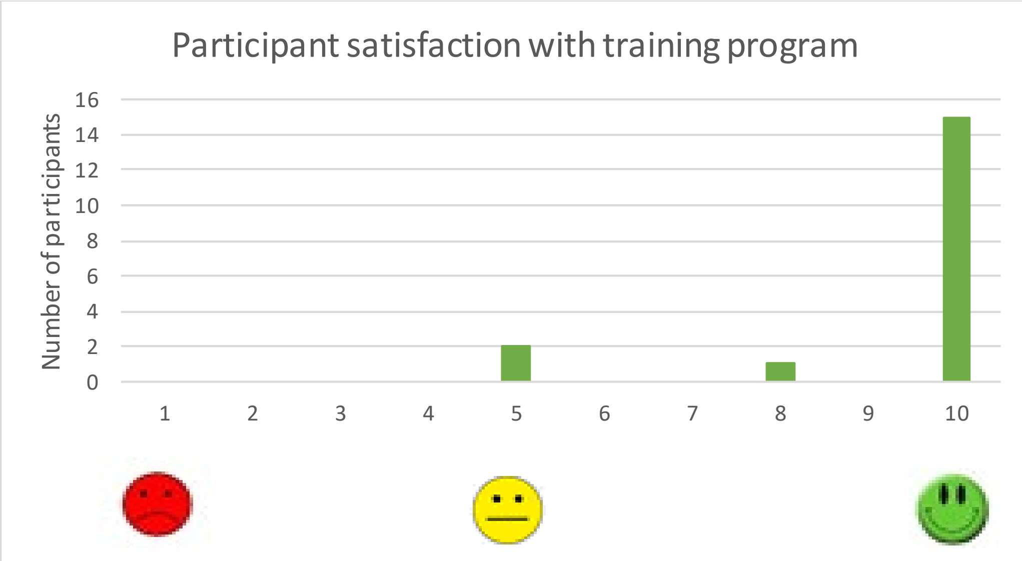

Figure 2: Participant's overall satisfaction with attending the compost training program

There was a high rate of attrition in those involved in composting activities over time, as illustrated in Figure 3.

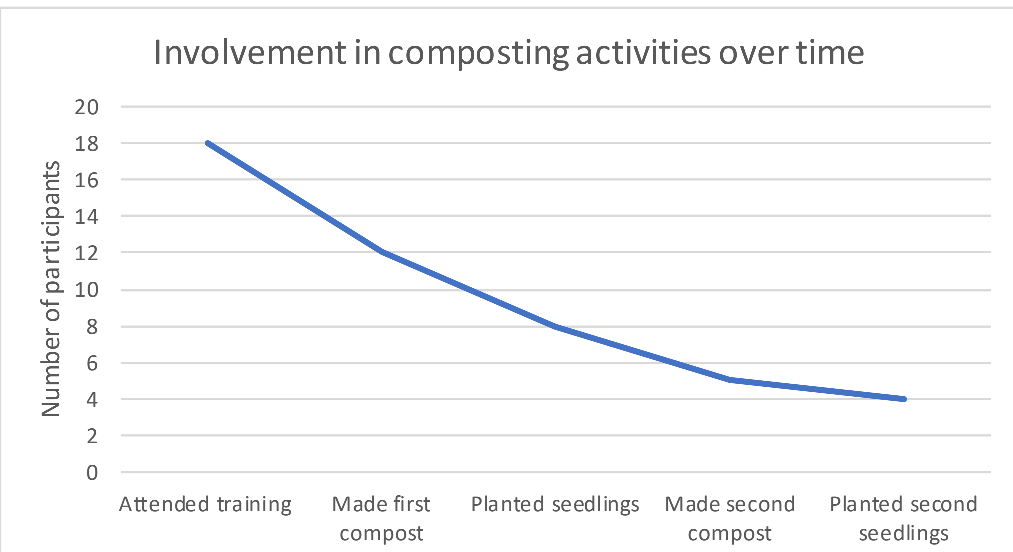

Figure 3: Declining participation in composting activities over time

All participants identified benefits of seaweed composting, these ranged from financial (money from selling vegetables), to improved nutrition for their families, skill development, social connectedness with fellow group members, and the cleanliness of their community and beach from the collection of dried leaves and beach-cast seaweed (see Figure 4).

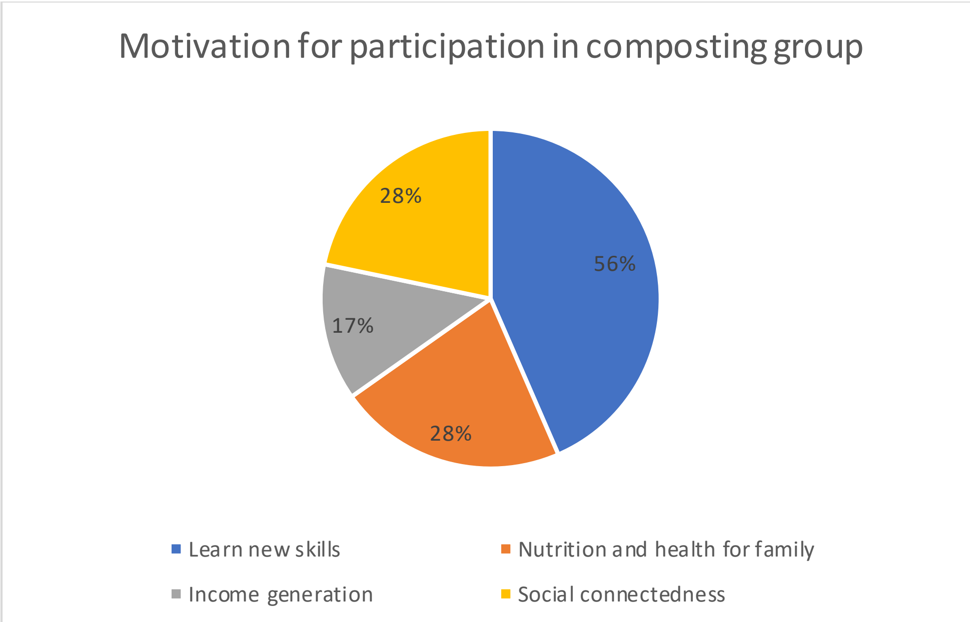

Figure 4: Key motivators for ongoing involvement in composting activities

Elements of the workshop that were most valued by participants included opportunities for practical application of skills, engaging nature of workshop facilitators, and the reliable accessibility of organic materials needed for composting (beach cast seaweed and dry leaves) (see Figure 5).

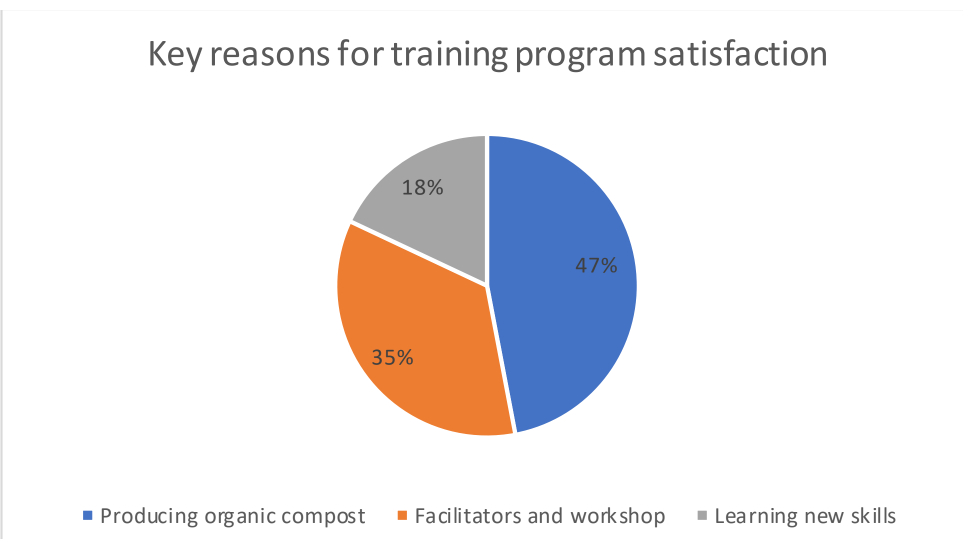

Figure 5: Content analysis of key reasons for satisfaction with the training program

Content analysis of qualitative responses (Figure 6) revealed two key barriers to ongoing participation; physical barriers and social barriers.

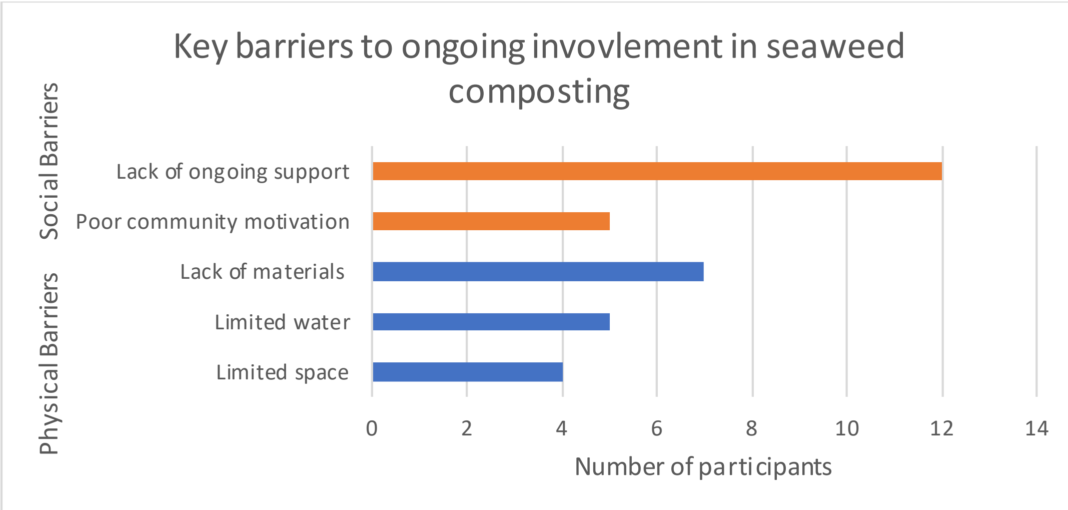

Figure 6: Physical and social barriers to ongoing involvement in composting activities

Participants identified the key physical barriers as limited space to grow a family garden, brackish water and lack of materials needed for composting activities, for example a wheel barrow for collecting seaweed and leave, spade and fence to protect the garden. The following quotes illustrate these common themes.

"I'm really interested in growing my own cabbages using seaweed compost, but not having a wheelbarrow to collect the seaweed, or a spade to dig means I can't have my own garden."

"I need a fence around my garden to keep the chickens from eating all the vegetables."

Social barriers included poor community drive and motivation, and the continued need for follow-up support from project facilitators, as illustrated through the following participant quotes;

"We require a project officer to be involved at all points from the making of seaweed compost, to planting seedlings. We require monitoring and need encouragement."

One third (n=6) of participants identified the need for the composting manual to be re-distributed to support their re-engagement in composting activities.

"I need the manual to remind me of the compost recipe."

Extrinsic motivation was common for participants who did not have continued involvement in composting activities.

"Encouragement of the community to be more involved in composting through rewards."

Whereas the few participants who successfully continued composting were motivated for intrinsic reasons.

"My whole family is involved in composting, the boys collect the seaweed from the beach, I tidy the garden and collect dried leaves and my daughter does the watering. We all eat the vegetables, and I sometimes sell them for money."

Discussion

Despite high motivation, in most cases engagement in composting activities was not sustained. Findings from this evaluation suggest that women are eager to engage in subsistence gardening, and in some cases can identify strategies to overcome the barriers to sustained composting. Members who successfully sustained composting and gardening activities realised both nutritional and social benefits such as involving the whole family. These findings reinforce that the success of short supply chain initiatives, such as community composting, are reliant on collaboration and ongoing encouragement and support. Insight into the barriers and motivational factors of community composting can be used to inform future efforts for improved nutritional and socio-economic outcomes of women and communities.

An added success of this project was increasing the research capacity of staff from the MFMRD training unit (see Figure 7). Although this capacity building strategy was not formally evaluated, staff involved in conducting face-to-face interviews expressed an eagerness to develop their research skills further. Staff recognised the importance of evaluation to inform improvements in their daily activities.

Figure 7: Dr Libby Swanepoel and the MFMRD training unit staff, Tarawa, Kiribati

11.5 Appendix 5: Evaluation of seaweed harvesting and processing workshop in Tarawa, Kiribati

Authors and key staff:

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Taati Eria and the Fisheries Training Unit, Ministry of Fisheries and Marine Resource Development

Background

Food and nutrition security is challenged by persistent undernutrition and micronutrient deficiencies alongside ever-increasing obesity rates (the triple burden of malnutrition). Traditionally a subsistence culture, Small Island Developing States (SIDS) have become increasingly dependent on imports and relief due to globalisation, urbanisation and the changing environment. Transition away from typical fisher and farmer activities have impacted on personal economics and income, and additionally effected nutrition and diet. An unhealthy diet, underpinned by poor access to and availability of fruit and vegetables, is endemic to SIDS. Edible seaweeds are traditional food in several SIDS, such as Samoa. They are highly nutritious, low cost and easy to harvest and therefore provide an alternative to fruit and vegetables. However, other countries such as Kiribati do not have a strong traditional culture for using seaweed in their diets.

This project took a peer-led approach to engage women in Kiribati in participating in seaweed activities. The aim of this project was to engage with people in Kiribati participating in a 2-day seaweed training workshop, to explore their perceptions of their potential role in local seaweed harvesting and utilisation. The specific objectives were to:

1. Describe the characteristics of people taking part in a seaweed training in Kiribati.
2. Determine people's barriers to participating in various activities associated with seaweed harvesting and processing.
3. Determine opportunities and enablers to support their participation in local seaweed harvesting and processing.
4. Explore the role that seaweed harvesting, and processing could play in improving the wellbeing of participants.

Method

A cross-country peer-led approach was used to introduce women in Kiribati to the potential benefits of seaweed harvesting, processing and consumption. Local community members (18 years of age and over) were invited to take part in a 2-day seaweed training workshop on June 12-13th 2018, facilitated by a group of Samoan women who were proficient in seaweed harvesting and processing. The Samoan peers travelled to Kiribati to conduct the training workshop in collaboration with the University of the Sunshine Coast project team, Samoan Fisheries team members (Samoa Ministry of Agriculture and Fisheries), and Kiribati Fisheries team members (Ministry of Fisheries and Marine Resource Development). Participatory research principles underpinned the training workshop where participants took ownership of recipe development, price and marketing strategies.

Image 1: Women participants developing sea grape recipes as part of the 2-day training workshop

In-person structured interviews were conducted with all participants (n=24) to evaluate their interest, barriers and enablers, and expected costs and benefits from potential future engagement in seaweed activities. In-country researchers (interviewers) were briefed on the ethical considerations for data collection and trained in the interview process. Participants were aware that their responses would remain confidential, and that they were welcome to skip questions or withdraw from the interview at any time without penalty or repercussions. Questions were translated into e-Kiribati and piloted in-country for face validity. Interviews took place at the workshop venue and took between 45-60 minutes to complete. The interviewer recorded responses by hand at the time of the interview. A summary of each response was provided to the participant after each question to verify that the researchers had captured and understood what the participant has said to be correct. Conventional content analysis of interview responses was conducted to uncover common themes. Content analysis additionally focussed on outlier themes that may be culturally specific and particularly relevant to the aims of this study.

Results

Participants represented 12 church groups from diverse locations across Tarawa. All participants (n=24) were women aged between 24-71 years and 87% (n=21) were married. The number of people living in the household ranged from one to 19 people. The main source of household income was a small shop (54%, n=13) selling cigarettes, vegetables, or hand sewn products.

Seven (30%) households income was from government jobs, five (21%) from remittance, and two (8%) from fishing.

All women felt that if promoted, the people of Kiribati would be interested in eating seaweed. Content analysis of qualitative responses revealed four key reasons motivating people to eat seaweed; health and nutrition, financial (saving money on food and/or earning money by selling seaweed), the convenience of growing, collecting and preparing seaweed, and recognising that it's safe to consume (see Figure 1).

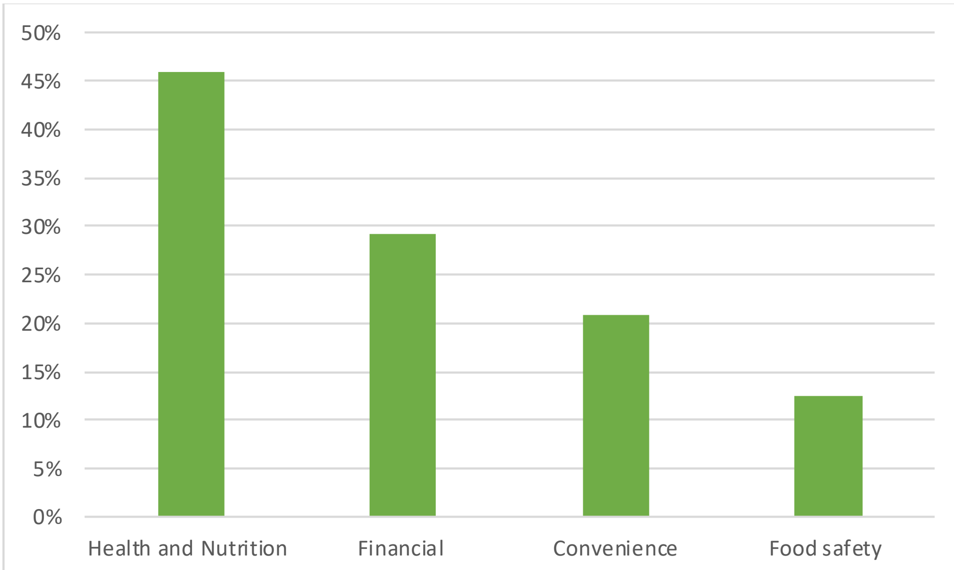

Figure 1: Keys reasons people in Kiribati would be interested in eating seaweed

Women noted that watching the Samoan seaweed farmers in the field filled them with confidence to collect sea grapes from the reef at low tide (see Image 2). This common theme is illustrated through the following quote:

> *"The training program was useful when we were able to go to the field and take part with the practical exercise. Watching the Samoan women allowed me to learn and remember the know-how. They show me it is so easy." [Participant 7, age 35]*

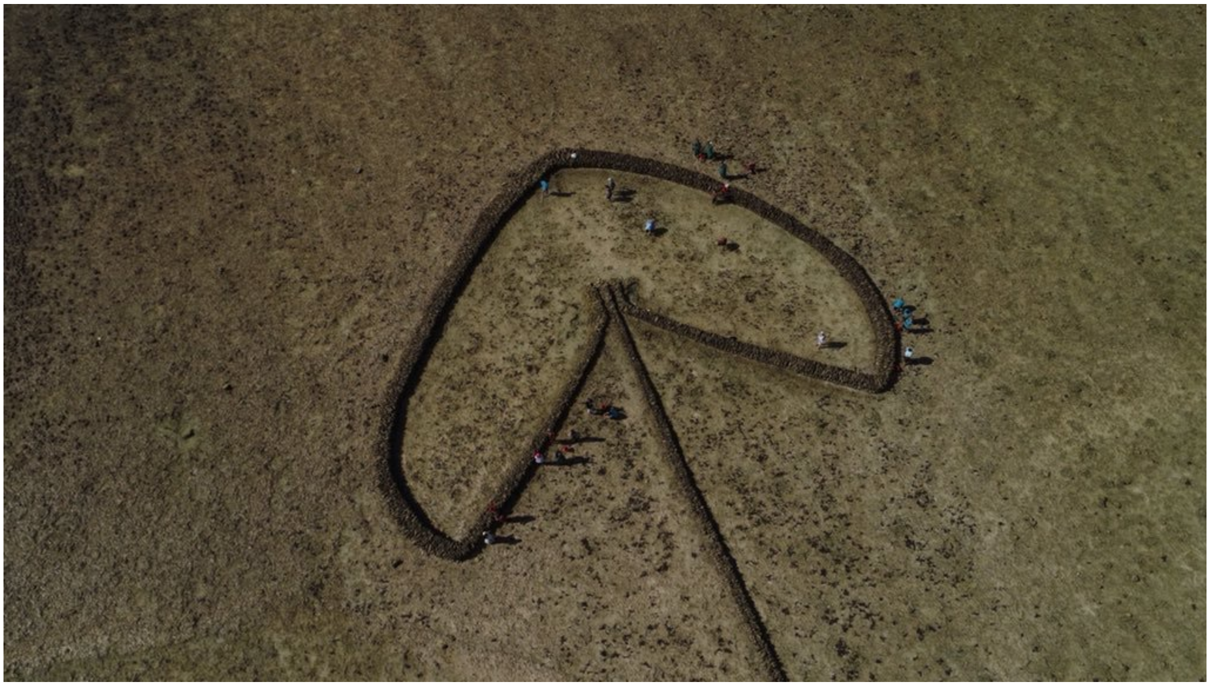

Image 2: Samoan seaweed farmers demonstrating the gleaning process to workshop participants on the Tarawa reef at low tide. Collection in this image is around the base of the rock walls of an intertidal fish trap.

There was high interest in being involved in most seaweed activities (See Figure 2). Only three younger participants (aged 29, 33 and 39) displayed an interest in farming seaweed in deep water from a boat. All but two women (92%) felt they had time to dedicate to seaweed-related activities. The amount of time women felt they could contribute ranged from 2 hours per week to three days per week. Many women could specify which days seaweed activities would fit in their weekly schedule.

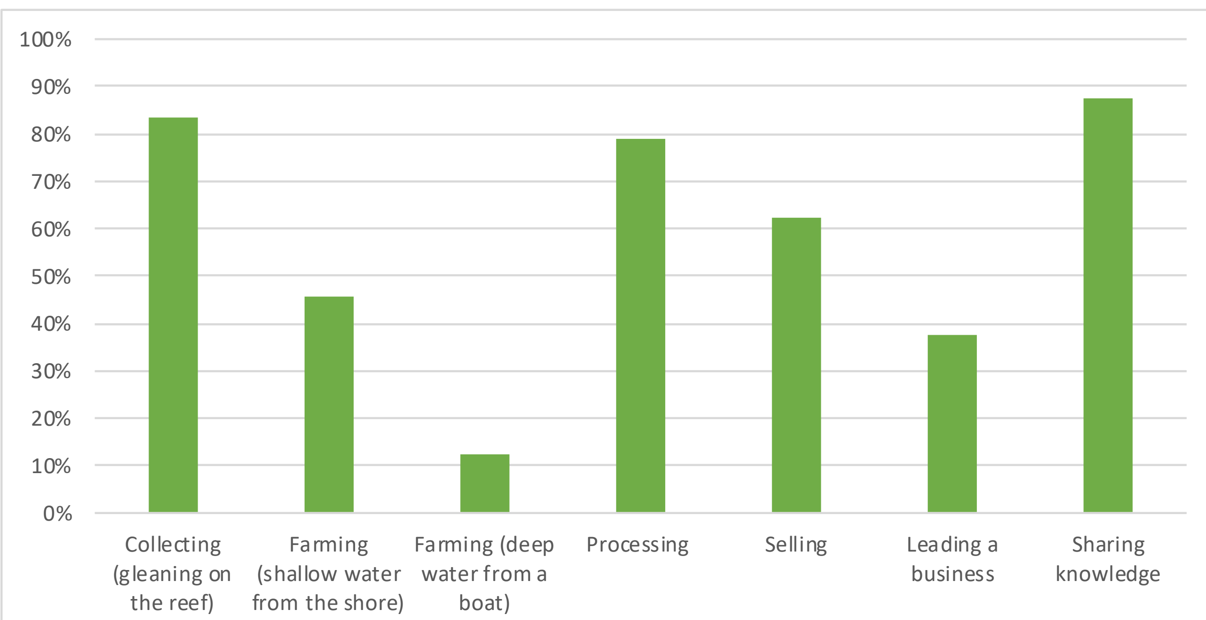

Figure 2: Participant interest in taking part in seaweed-related activities

Common enablers to ongoing participation in seaweed activities included; further training, social support, equipment (including safety boots to walk on the reef), recipes, and promotion and awareness raising in the community. These themes are illustrated through the following quotes.

> *"I request some training and skills on how to market seaweed, what business things need to be planned for before marketing." [Participant 2; age 39]*
>
> *"If I can go with someone I will feel safer, so maybe I will go with my niece or neighbour." [Participant 21; age 54]*
>
> *"Awareness and promotion on the radio on the importance of eating sea grapes for your health." [Participant 8; age 39]*

All women recognised the income generating opportunity that selling seaweed offers. The recommended asking price varied between $1 and $5 per bundle.

Image 3: Women taking part in roadside marketing of sea grapes during the training workshop

One quarter of women in this study (n=6) were not involved in decisions relating to how money was spent. In these cases, financial decisions were made by the woman's son or husband. For those women who made financial decisions themselves or in collaboration with their husband, they intended to use and financial benefits from selling sea grapes to go towards personal savings, children's education, buying food from the store, personal enjoyment (e.g. bingo), church donations, and contributing to daily needs such as bus fare and soap (see Figure 3).

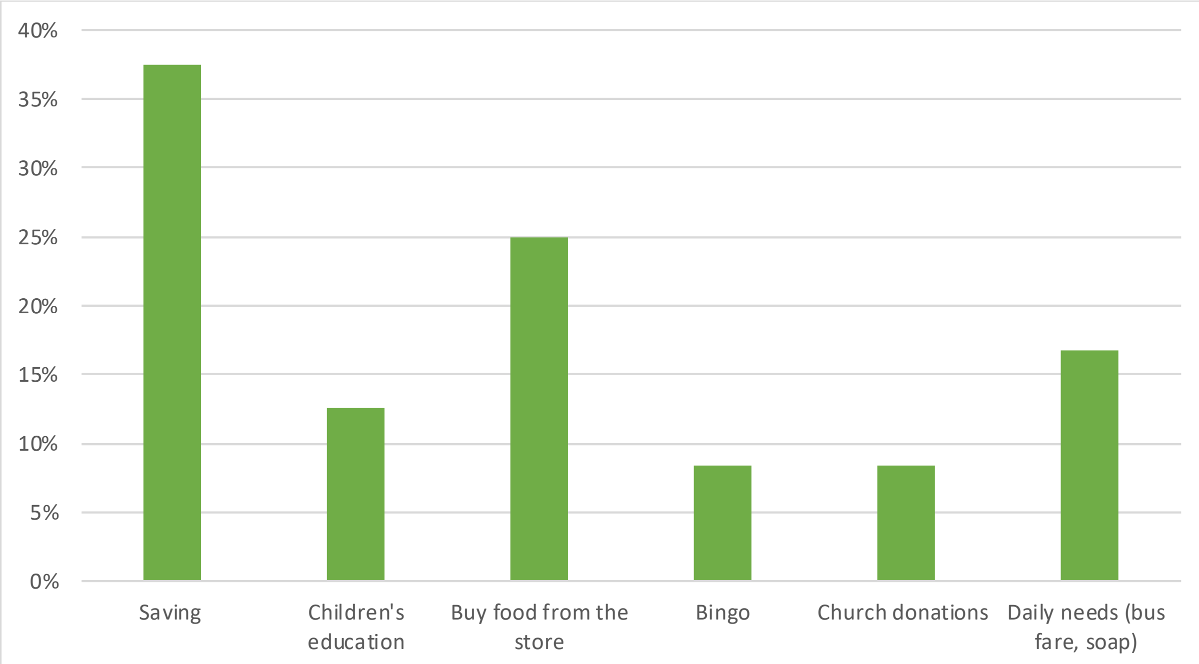

Figure 3: Expectations for financial benefits from selling seaweed

In most cases women did not choose to be part of the training workshop, but rather were nominated by their church leader to be a representative of their church group. Women felt honoured to be included in the training session and were eager to share their learning with their friends and family. In addition to income generating opportunities, other personal and social benefits that women identified included improved community cohesion, and access to a healthy and nutritious food source. These common themes are illustrated through the following quotes.

> *"I will be popular, and when I share my new skills it will join the community together, some neighbours are shy so we can include them to join in. And it will mean food for health, for all." [Participant 4, age 45]*

> *"We get what our body needs from the sea grapes, all the health and nutrition. Vegetables from the store are very expensive, so collecting sea grapes will save us money." [Participant 24, age 45]*

Discussion

This project provides a baseline understanding of the motivations, barriers and enablers to participating in seaweed harvesting and production for a group of women in Kiribati. Women expressed a keen desire to be involved in seaweed harvesting from adjacent reefs. Some individuals were entrepreneurial whereas others were more community focussed. Taking a bottom-up approach, as done in this case, allows health to directly link back to women and families through consumption of fresh food or by enhancing wealth and wellbeing.

Deeper insight into community and church structures in Kiribati is necessary. Nomination of selected community members to take part in this training does not automatically mean that learnings will be transferred to the rest of the community. Understanding the minutia of church and community hierarchies is needed to inform targeted approaches that support all women and families, rather than a select few.

This project highlights the need to increase the capacity of some women to participate in financial (and other) decision making. Engaging whole communities, both men and women, from all socioeconomic backgrounds, is needed to empower women and their families to establish sustainable food supply chains. Further participatory research to gain in-depth understanding of how to accommodate women's diverse needs and address issues at the beginning of the food supply chain is warranted. Such gender inclusive activities are needed to explore and build roles that are sustainable for women and their families.

Food supply chains including production, distribution and consumption are underpinned by small-scale farmers and fishers. Recognising women's role and motives in food supply chains and addressing their barriers and enablers to participation is central to developing sustainable food systems and combatting food and nutrition insecurity. The cross-country peer-led model used in this project successfully provided culturally appropriate, low cost education that promotes long-term results through the empowerment of a group of women in Kiribati.

11.6 Appendix 6: Biochemical analysis methodology and results

Authors and key staff:

Ana Wegner, Ian Tuart and Nicholas Paul, University of the Sunshine Coast

1. Background

The information contained in this section relates to the "documented data sets of biomass quality and other biochemical traits" activities across all three objectives. Details of methods used for each variable are provided.

2. Methods

More than 1000 individual data entries on the biochemical properties of seaweed were made for samples collected during the project to assess the composition and quality of different species from Fiji, Kiribati, Samoa and Australia. While samples from the Pacific Islands (Fiji, Kiribati and Samoa) were wild harvested, Australians samples were from recirculating aquaculture systems with controlled temperature and nutrients (nitrogen and phosphorous).

The number and type of analyses done on samples from each country are presented in Table 1. Moisture content, ash content and lipid analysis were undertaken at James Cook University by ACIAR employed staff and the methodology. All other analysis (DNA barcoding, nitrogen, carbon, hydrogen, minerals and fibre) were outsourced to laboratories in Australia, New Zealand and UK (as detailed below).

Table 1: Number and type of analysis done for samples from each country.

	DNA	Moisture	Ash	Lipids	Fibre	Carbon	Nitrogen	Metals
Fiji	61	181	176	33	13	65	65	64
Kiribati	8	42	48	10	5	21	19	19
Samoa	11	60	60	9	2	15	15	15
Australia	7	5	5	0	5	5	5	5
Total	**87**	**375**	**289**	**52**	**25**	**106**	**104**	**102**
Grand Total		**1,140**						

2.1. Sample collection for DNA barcoding

Rationale: Identification of seaweed can be difficult due to morphological variation (plasticity) or that species are yet to be formally classified. DNA barcoding was used to provide a molecular identification for seaweeds from Fiji, Samoa, Kiribati and Australia to complement the common names used in the region.

Supplier: DNA barcoding of the red algae was completed by Dr Joe Zuccarello of Victoria University of Wellington, New Zealand; and that of the green algae by Dr Rebecca Lawton from

James Cook University. Samples taken for DNA barcoding were collected specifically for this purpose and handled as follows.

Methods: When collecting the seaweed, the sample was rinsed thoroughly in water from the sampling site to remove any other algae attached to it or contaminants. After removing excess water by shaking it, the sample was put in a labelled zip lock bag to be transported. In a dry and clean space (e.g. laboratory), the sample is pat dry with paper towel of excess water and then sufficient growing tips (up to 3cm long) of the sample are broken and placed into a 250ml clean plastic vial. In order to dry the sample, the algae is covered with ample silica gel bids, the container covered with a lid and left for approximately 12hrs (or until completely dry). Once dry, a minimum of 200mg dry weigh is transferred to a 1.5ml Sarstedt micro tube and kept in the freezer until submission of samples.

2.2. Proximate analyses

We used proximate analyses to provide a standardised means of comparing the overall biochemical properties of seaweed species in the region using simple protocols for ash, lipid and moisture content, a conversion factor for protein based upon nitrogen content, and then calculating the carbohydrate by difference. Other common measurements are also included in the following section.

2.2.1. Moisture content analysis of dried samples

Rationale: Water strongly affects the microbiological and chemical stability, and physical properties of dried seaweed. Therefore, to increase shelf life and maintain high quality of dried samples, it is crucial to keep the moisture content of the biomass low. Low moisture content can be challenging to maintain when the biomass is stored outdoors, as it is vulnerable to daily weather variations (humid and dry conditions).

During the project, samples were either harvested or purchased fresh from the market and then dried, or taken previously dried from seaweed distributors' storage centres (e.g. CPPL in Tarawa). Several of these samples had the moisture content measured by a moisture analyser (MS-70 moisture analyser, A&D Company Ltd.).

Moisture content was also measured as a procedural step after dehydration and prior to biochemical analysis. These results are reported as the moisture content in the product data sheets. If stored in air tight recipients (e.g. sealed bags or containers/vials), moisture content can be kept between 2-10% depending on species and drying method.

Method: The moisture analyser uses a built-in set of scales and a halogen lamp to weigh and dry samples. It calculates the moisture content (%) by comparing the difference between the initial moist weight and final dry weight obtained by the heating of the halogen lamp to 105°C. A minimum of 1, 5 or 10 grams of the dry sample is needed for the analysis for low (0.05%/min), medium (0.02%/min) or high (0.01%/min) accuracy results respectively. The analyser dries the sample until the sample weigh stabilises according to the accuracy program chosen. The analyser will then display the moisture content in percentage (%).

Most samples were dried in a food dehydrator and packed in sealed containers or vacuum sealed bags prior to being analysed. However, to compare the moisture content of samples dried in food dehydrator with local drying methods (e.g. air drying), moisture analyses were done on samples purchased from the local market in Fiji, as received.

2.2.2. Ash content analysis

__Rationale:__ To determine composition and properties of a specific sample, it is important to assess its ash (= inorganic) content. Inorganic non-volatile matter (such as metals, ions and salts, for example) is crucial to quantify to assess the suitability of a specific product to a targeted end-product.

__Method:__ A muffle furnace (Yokogawa model UP150) was used to determine the ash content of algae samples obtained during the project. The furnace has a maximum temperature of 1500°C, heated by a Kanthal A1 resistance wire spiral element wound on the outside of the refractory muffle. The high temperature (maximum of 550°C for ashing) burns all organic matter, leaving the inorganic/ash.

A minimum 1 gram of dry algae is placed in a pre-weighted crucible, which is then re-weighted (using a scale with 0.0001g precision). Three replicates of each sample were weighted to be averaged out. The crucibles – with a lid each – are placed in a metal tray which in turn is put into the muffle furnace. Once turned on, the oven will follow its selected program. For ash content evaluation, the furnace heats up to 550°C over 1h 45min, maintaining at 550°C for 6 hours and cooling down to 100°C over 3 hours. After the program has completed, the crucibles (containing the ash) are removed from the furnace and placed into a desiccator. Once they reach room temperature, the crucibles are re-weighed and the ash percentage can be calculated.

2.2.3. Lipid extraction

__Methods:__ The method used for lipids extraction from seaweeds followed the protocol of Folch et al. (1957) to extract lipids from animal brain tissue, adapted by Gosch et al. (2012), to extract lipids from algae. The lipids are extracted by adding an inorganic solvent to a dried and milled sample and heating it on a hot plate for 1 hour.

2.2.4. Protein

Protein content was calculated based the concentration of Nitrogen (Section 2.3). Protein content in algae biomass can be estimated following the use of a nitrogen-to-protein conversion factor of 5 from Angell et al. (2016.)

$$\%Protein = \%Nitrogen * 5$$

2.2.5. Fibre content

__Rationale:__ Fibre content includes both total dietary fibre and insoluble dietary fibre.

__Supplier:__ Australian Export Grains Innovation Centre (AEGIC), Australia (http://aegic.org.au)

__Methods:__ A minimum of 8g of the sample dried (in a food dehydrator) and milled (in a small food blender) was put into a 25ml plastic test tube with a silica gel bag inside, closed tight with a lid and sealed with a plastic paraffin film (Parafilm) to be sent for analyses. AEGIC followed standard methods for analyses (AOAC Official Method 985.29 total dietary fibre in Foods, and AOAC Official Method 993.19 soluble dietary fibre in food and food products). Samples were analysed for total dietary fibre and insoluble dietary fibre, thereafter, soluble dietary fibre were calculated by difference.

2.2.6. Elemental composition (CHONPS)

Rationale: Different species of seaweed differ on its concentrations of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorous (P) and sulphur (S). Furthermore, the concentration of some of these elements in the water where the seaweed grows will influence the algae composition. To explore new seaweed bio-products it is crucial to learn the proportion of these elements in the seaweed.

Supplier:

- OEA Laboratory Ltd., UK (http://www.oealabs.com) for CHON;
- Advanced Analytical Centre (AAC), James Cook University for P and S together with metal analyses (see heading 2.7 Metal composition).

Methods: A minimum of 1g of the sample dried (in a food dehydrator) and milled (in a small food blender) was put into a 25ml plastic test tube with a silica gel bag inside, closed tight with a lid and sealed with a plastic paraffin film (Parafilm) to be sent for analyses. The laboratory uses an elemental analyser that converts carbon, nitrogen, hydrogen and sulphur from the sample into carbon dioxide, elemental nitrogen, water vapour and/or sulphur dioxide by combustion in pure oxygen. Oxygen analysis involves conversion of oxygen to carbon monoxide by high temperature catalysed pyrolysis. These gases are carried through the analytical system by helium, separated by a gas chromatography column and quantified using thermal conductivity or flame photometric detectors.

If the amounts of C, H, N, S and ash are available (in %) Oxygen can also be estimated by difference as: $O\% = 100 - \Sigma(C, H, N, S, ash)$.

2.2.7. High Heating Value (HHV)

The gross energy content of the biomass (MJ kg^{-1}), expressed as the higher heating value (HHV), can be calculated based on the results of ash content (Section 2.2.2) and the elemental composition (Section 2.3) using the following equation (Channiwala & Parikh 2002):

HHV (MJ/kg)=(0.3491*C)+(1.1783*H)+(0.1005*S)-(0.1034*O)-(0.0151*N)-(0.0211*ash)

2.2.8. Metal and remaining elemental composition

Rationale: The mineral content of seaweed has important positive and negative implications for potential role in nutrition for animals and plants.

Supplier(s):

- Advanced Analytical Centre (AAC) at James Cook University, Australia;
- Advanced Analytical Australia (http://www.aaapl.com.au);
- A2 Analises Quimicas, Portugal (http://a2analisesquimicas.webs.com).

Methods: A minimum of 5g of the sample dried (in a food dehydrator) and milled (in a small food blender) was put into a 25ml plastic test tube with a silica gel bag inside, closed tight with a lid and sealed with a plastic paraffin film (Parafilm) to be sent for analyses. The mineral content of the biomass was measured by inductively coupled plasma mass spectrometry (ICP/MS) (Varian 820-MS, Australia) as described in Saunders et al. (2012).

2.2.9. Water content of fresh samples (Fresh to Dry ratios)

Rationale: When fresh, different species of seaweed differ in the average amount of water they hold within their cells. Water content of the same species will also fluctuate depending on the growing conditions. For example, fast growth can result on higher water content, giving misleading values when measuring production only on fresh weight if the biomass value is on its dry weight.

Methods: To know the amount of water seaweed holds within its cells, the weight of the fresh algae is divided by the weight of the dried algae, thus giving a fresh-to-dry ratio (FW:DW).

To obtain fresh weight, the sample must be taken from the water and have its excess over the surface water removed. One way of removing the excess water is by gentle centrifuge/spin. Small samples that had their FW:DW taken, were spun in a salad spinner, weighted, dried for at least 24 hours (or until fully dried) in a food dehydrator and re-weighted in the same balance. The FW:DW will be the sample's fresh weight divided by the sample's dry weight.

3. Results

The primary results for the FIS/2010/098 are stored on USC accessible as a pivot table at the following link: "Biochemical Database and Product Sheets for Seaweeds from Fiji, Samoa and Kiribati" http://dx.doi.org/10.25907/5e13b12523e43

Following are some additional insights from the analyses conducted, including a summary of the main findings in the relevant sections. At the end of the report are the individual **product sheets** for different species and countries (Appendix 11.8).

3.1. DNA Barcoding

Some methodological issues arose during the project, including impurities from bacteria and epiphytes, that led to the establishment of the procedures described in Section 2.1, which we found were more important for red algae than for green algae. A total of 190 samples were sent for DNA barcoding, however, only 87 were successfully identify. Red algae were barcoded with Cox2-3 spacer. Green algae were barcoded with tufA/ITS. The following results for the molecular identification of seaweed in the region have been presented to the relevant agencies in each country.

Location	***Caulerpa oligophylla***	***Caulerpa macra***	***Caulerpa chemnitzia***
Fiji (n=37)	51%	41%	3%
Gunu (n=16)	56%	38%	6%
Rakiraki (n=12)	67%	33%	0%
Tai levu (n=2)	0%	100%	0%
Kesi (n=1)	0%	100%	0%
Somosomo (n=2)	0%	50%	50%
Mana (n=1)	0%	0%	100%
Tavua levu (n=1)	100%	0%	0%
Waiganake (n=1)	100%	0%	0%

Location	*Caulerpa oligophylla*	*Caulerpa macra*	*Caulerpa chemnitzia*
Namuimada (n=1)	0%	100%	0%

Barcoding results for different countries. Revision of taxonomy indicated by underline with current ID. Number of individual collections in brackets (n).

Country	Collection site	Current ID	Number of collections	Common name	Previous ID
Fiji	Gunu	*Caulerpa oligophylla* *Caulerpa macra* *Caulerpa chemnitzia*	9 6 1	Nama	*C. racemosa*
	Rakiraki	*Caulerpa oligophylla* *Caulerpa macra*	8 4	Nama	*C. racemosa*
	Tai levu	*Caulerpa macra*	2	Nama	*C. racemosa*
	Kesi	*Caulerpa macra*	1	Nama	*C. racemosa*
	Somosomo	*Caulerpa chemnitzia* *Caulerpa macra*	1 1	Nama	*C. racemosa*
	Mana	*Caulerpa chemnitzia*	1	Nama	*C. racemosa*
	Tavua levu	*Caulerpa oligophylla*	1	Nama	*C. racemosa*
	Waiqanake	*Caulerpa oligophylla*	1	Nama	*C. racemosa*
	Namuimada	*Caulerpa macra*	1	Nama	*C. racemosa*
Fiji	Veivatuloa	*Gracilaria* sp.	1	Lumi cevata	*Hypnea sp.*
Fiji	Rakiraki	*Kappaphycus alvarezii*	1	Lumi cevata	*Hypnea sp.*
Fiji	Tai levu	*Ceramium* sp.	1	Lumi cevata	*Hypnea sp.*
Fiji	Mana Island	*Hydropuntia edulis*	1	Lumi wawa	*Gracilaria edulis*
Fiji	Treasure Island	*Hydropuntia edulis*	1	Lumi wawa	*Gracilaria edulis*
Fiji	Tokoriki Island	*Hydropuntia edulis*	1	Lumi wawa	*Gracilaria edulis*
Fiji	Navini Island	*Hydropuntia edulis*	1	Lumi wawa	*Gracilaria edulis*

Country	Collection site	Current ID	Number of collections	Common name	Previous ID
Fiji	Treasure Isl.	*Hydropuntia edulis*	1	Lumi wawa	*Gracilaria edulis*
Fiji	Tai levu	*Solieriaceae*	1	Lumi wawa	*Gracilaria edulis*
Fiji	Tai levu	*Solieriaceae*	1	Lumi wawa	*Gracilaria edulis*
Fiji	Rakiraki	*Ulva meridionalis*	3	Lumi boso	*Ulva spp.*
Fiji	Namuimada	*Ulva meridionalis*	1	Lumi boso	*Ulva spp.*
Fiji	Drua drua	*Kappaphycus alvarezii*	1	Tambalang	*K. alvarezii*
Fiji	Yaqeta	*Kappaphycus alvarezii*	3	Tambalang	*K. alvarezii*
Fiji	Dama	*Kappaphycus alvarezii*	1	Tambalang	*K. alvarezii*
Fiji	Nakalou	*Kappaphycus alvarezii*	2	Tambalang	*K. alvarezii*
Fiji	Navini	*Kappaphycus alvarezii*	1	Tambalang	*K. alvarezii*
Fiji	Tai Levu	*Kappaphycus alvarezii*	1	Tambalang	*K. alvarezii*
Fiji	Sawakasa	*Kappaphycus striatum*	1	Sacol	-
Samoa	Taloa	*Caulerpa racemosa* *Caulerpa chemnitzia*	2 1	Limu fuafua	*C. racemosa*
Samoa	Satui	*Caulerpa racemosa*	1	Limu fuafua	*C. racemosa*
Samoa	Maulifanua	*Caulerpa racemosa*	1	Limu fuafua	*C. racemosa*
Samoa	Asaga	*Caulerpa chemnitzia*	1	Limu fuafua	*C. racemosa*
Samoa	Satapuala	*Caulerpa racemosa*	3	Limu fuafua	*C. racemosa*
Samoa	Faleula	*Caulerpa racemosa*	1	Limu fuafua	*C. racemosa*
Samoa	Taga	*Caulerpa chemnitzia*	1	Limu fuafua	*C. racemosa*
Kiribati	Temaiku	*Caulerpa racemosa*	2	Kuraben taari	-

Country	Collection site	Current ID	Number of collections	Common name	Previous ID
Kiribati	Abaiang	*Caulerpa chemnitzia*	1	Kuraben taari	-
Kiribati	Ambo	*Kappaphycus alvarezii* (haplotype 3)	1	Cottonii, maumere	*Eucheuma cottonii*
Kiribati	Abaiang	*Kappaphycus alvarezii* (haplotype 3)	1	Cottonii,	*Eucheuma cottonii*
Kiribati	Aranuka	*Kappaphycus alvarezii* (haplotype 3)	1	Cottonii, green tambalang	*Eucheuma cottonii*
Kiribati	Aranuka	*Kappaphycus alvarezii* (haplotype 3)	1	Cottonii, brow n tambalang	*Eucheuma cottonii*
Kiribati	Nanikaai	*Gelidium sp.* (cox2-3)	1		*Gellidium* sp.

3.2. Proximate composition - Moisture, ash, lipids, protein, fibre/carbohydrates

The biomass composition can be divided into carbohydrates, protein, lipid, ash (inorganic material) and moisture (water content), totaling 100%. When ash, lipids, protein and moisture values are available, then the carbohydrate percentage can be estimated by subtraction. Dietary fibres are the main form of carbohydrates; therefore, their values are similar.

3.3. Ash

Ash content ranged from 18.2-85.8% across all species and locations. Higher values (e.g. 85.78% for *Ulva sp.* from Kiribati and 85.04% for *Caulerpa sp.* From Samoa) were likely due to salt accumulated on the seaweed when samples were collected from intertidal locations during low tide, and not cleaned/rinsed in the sample water before drying.

3.4. Lipid

Green seaweeds contained higher levels of lipids than reds. For example; *Caulerpa sp.* presented the highest levels ranging from 1.37-3.83% in samples from Fiji, and from 1.23-3.02% in samples from Samoa, and *Acanthophora sp.*’s values (from Kiribati) ranged from 0.10-0.54%, and *Kappaphycus sp.*’s values ranged from 0.05-0.57% in Kiribati and 0.05-0.85% in Fiji.

3.5. Dietary fibre

Ulva sp. and *Kappaphycus sp.* had the highest amount of fibre across all species in Fiji and Kiribati, while *Caulerpa sp.* presented the lowest with consistent values in Fiji and Samoa (18.00% average in Fiji and 18.85% average in Samoa)

3.6. Protein

Kappaphycus sp. had low levels of protein compared to all other species with values ranging from 0.50-2.58% in Fiji and 1.57-3.06% in Kiribati, while *Ulva sp.* protein values ranged from 5.89-8.30% in Fiji and 1.63-9.61% in Kiribati.

Table 2 Proximate composition (% of dry weight) and total fibre content of seaweed species from Australia. Number of samples in brackets ().

	AUSTRALIA				
	Caulerpa lentillifera	***Hydropuntia edulis (Gracilaria)***	***Gracilaria eucheumatoides***	***Halymenia* sp.**	***Sarconema* sp.**
Carbohydrates %	-	-	-	-	-
Ash %	62 (1)	55.00 (1)	45.00 (1)	39.00 (1)	51.00 (1)
Moisture %	9.79 (1)	5.86 (1)	5.55 (1)	9.45 (1)	6.38 (1)
Lipids %	-	-	-	-	-
Protein %	6.31 (1)	10.97 (1)	5.24 (1)	11.68 (1)	11.47 (1)
Total Fibre (g/100g)	16.10 (1)	26.00 (1)	39.90 (1)	32.70 (1)	24.40 (1)
Insoluble fibre (g/100g)	10.70 (1)	-	-	-	-
Soluble fibre (g/100g)	5.40 (1)	-	-	-	-

Table 3 Elemental composition (% of dry weight) of seaweed species from Australia. Number of samples in brackets ().

	AUSTRALIA				
	Caulerpa lentillifera	***Hydropuntia edulis (Gracilaria)***	***Gracilaria eucheumatoides***	***Halymenia* sp.**	***Sarconema* sp.**
C %	10.45 (1)	20.99 ± 3.15 (2)	18.00 (1)	24.70	24.32 ± 6.16 (2)
H %	-	-	-	-	-
N %	1.26 (1)	2.45 ± 0.22 (2)	1.05 (1)	2.34 (1)	2.84 ± 0.77 (2)
S %	0.53 (1)	5.90 (1)	2.80 (1)	5.00 (1)	5.20 (1)
O % (*calculated)	-	-	-	-	-
P %	0.07 (1)	0.25 (1)	0.37 (1)	0.50 (1)	0.19 (1)
C:N	8.27 (1)	8.55 (1)	17.19 (1)	10.57 (1)	8.71 (1)
N:P	18.14 (1)	8.77 (1)	2.83 (1)	4.67 (1)	12.07 (1)

Table 4 Proximate composition (% of dry weight), total fibre content and HHV of seaweed species from Fiji, Kiribati and Samoa. Number of samples in brackets ().

	FIJI					KIRIBATI				SAMOA	
	Caulerpa sp.	*Hydropuntia edulis (Gracilaria)*	*Hypnea sp.*	*Kappaphycus sp.*	*Ulva meridionalis*	*Acanthophora sp.*	*Gelidium sp.*	*Kappaphycus alvarezii*	*Ulva sp.*	*Caulerpa sp.*	*Sargassum sp.*
Carbohydrates %	22.68	37.72	29.28	39.62	44.71	27.52	-	41.01	17.71	25.41	-
Ash %	62.23 ± 7.5 (73)	53.52 ± 5.9 (26)	55.57 ± 5.4 (35)	51.12 ± 11.1 (28)	32.42 ± 2.5 (14)	63.49 ± 4.8 (10)	50.00 (1)	52.26 ± 6.6 (16)	73.65 ± 9.7 (10)	66.43 ± 7.1 (58)	67.53 (1)
Moisture %	7.59 ± 2.4 (72)	5.70 ± 3.0 (31)	6.07 ± 2.1 (36)	3.64 ± 2.0 (28)	10.18 ± 2.0 (14)	4.69 ± 1.1 (9)	5.02 (1)	4.78 ± 2.4 (14)	3.68 ± 0.7 (7)	5.30 ± 2.8 (58)	4.77 (1)
Lipids %	2.49 ± 0.9 (6)	1.05 ± 0.1 (6)	0.6 ± 0.7 (4)	0.47 ± 0.4 (10)	1.41 ± 1.1 (8)	0.31 ± 0.2 (3)	-	0.31 ± 0.4 (6)	0.81 ± 0.4 (5)	2.05 ± 0.6 (9)	-
Protein %	5.01 1.51 (21)	4.72 ± 1.5 (16)	4.78 ± 0.7 (9)	1.46 ± 0.5 (16)	6.97 ± 1.22 (3)	4.91 ± 0.7 (4)	3.97 ± 0.3 (2)	1.99 ± 0.5 (2)	6.20 ± 3.5 (4)	4.14 ± 1.5 (14)	3.43 (1)
Total Fibre (g/100g)	18.00 ± 2.4 (2)	32.58 ± 7.8 (4)	32.63 ± 0.6 (3)	37.15 ± 2.6 (2)	49.10 (1)	25.05 ± 0.2 (2)	40.80 (1)	49.95 ± 4.7 (2)	-	18.85 ± 6.7 (2)	-
Insoluble fibre (g/100g)	-	-	-	2.55 ± 0.5(2)	-	-	-	3.65 ± 0.5 (2)	-		
Soluble fibre (g/100g)	-	-	-	34.60 ±3.1 (2)	-	-	-	46.40 ± 4.4 (2)	-	-	-
HHV	-	8.91 ± 1.9 (2)	-	5.23 ± 1.2 (2)	-	5.69 (1)	-	4.48 ± 1.5 (9)	-	-	-

Table 5 Elemental composition (% of dry weight) of algae species from Fiji, Kiribati and Samoa. Number of samples in brackets ().

	FIJI					KIRIBATI				SAMOA	
	Caulerpa sp.	*Hydropuntia edulis (Gracilaria)*	*Hypnea sp.*	*Kappaphycus sp.*	*Ulva meridionalis*	*Acanthophora sp.*	*Gelidium sp.*	*Kappaphycus sp.*	*Ulva sp.*	*Caulerpa sp.*	*Sargassum sp.*
C %	11.61 ± 3.6 (21)	19.57 ± 4.7 (16)	16.74 + 0.8 (9)	16.44 ± 3.6 (16)	25.37 ± 0.5 (3)	16.25 ± 0.4 (4)	17.75 ± 2.6 (2)	15.26 ± 4.0 (11)	17.91 ± 1.9 (4)	9.51 ± 3.3 (14)	15.85 (1)
H %	1.93 ± 0.4 (10)	3.17 ± 0.9 (2)	-	2.58 ± 0.9 (2)	-	2.21 (1)	1.21 (1)	2.52 ± 0.5 (3)	2.39 ± 1.2 (2)	1.41 ± 0.5 (10)	1.61 (1)
N %	1.00 ± 0.3 (21)	0.94 ± 0.3 (16)	0.96 ± 0.2 (9)	0.29 ± 0.1 (16)	1.39 ± 0.2 (3)	0.98 ± 0.1 (4)	0.79 ± 0.1 (2)	0.40 ± 0.1 (9)	1.24 ± 0.7 (4)	0.83 ± 0.3 (14)	0.69 (1)
S %	1.78 ± 1.1 (11)	5.77 ± 1.2 (16)	6.79 ± 0.7 (9)	3.73 ± 0.7 (16)	4.67 ± 0.5 (3)	3.26 ± 0.4 (4)	0.74 (1)	3.71 ± 0.8 (9)	2.01 ± 1.2 (2)	0.89 ± 0.2 (4)	-
O % (*calculated)	-	*19.32 ±4.2 (2)	-	20.00 ± 4.0 (2)	*25.37 ± 0.5 (3)	*18.34 (1)	*17.75 ± 2.6 (2)	18.25 ± 3.2 (2)	-	*9.51 ± 3.3 (14)	-
P %	0.08 ± 0.03 (20)	0.09 ± 0.02 (16)	0.10 ± 0.01 (9)	0.03 ±0.01 (13)	0.14 ± 0.02 (3)	0.07 ± 0.02 (4)	0.09 ± 0.00 (2)	0.03 ± 0.02 (8)	0.10 ± 0.02 (4)	0.09 ± 0.02 (14)	0.10 (1)
C:N	11.64 ± 1.22 (21)	21.93 ± 6.57 (16)	17.90 ± 3.13 (9)	67.77 ± 42.60 (16)	18.54 ± 2.96 (3)	16.77 ± 2.07 (4)	22.27 ± 1.82 (2)	41.37 ± 13.44 (9)	21.82 ± 18.82 (4)	11.55 ± 1.16 (14)	23.08 (1)
N:P	12.46 ± 4.80 (19)	10.95 ± 3.11 (16)	9.40 ± 1.62 (9)	10.76 ± 2.98 (13)	9.72 ± 0.70 (3)	14.82 ± 5.23 (4)	8.70 ± 0.33 (2)	13.40 ± 7.80 (9)	13.74 ± 7.64 (4)	9.78 ± 4.12 (14)	7.06 (1)

Table 6 Proximate composition (% of dry weight), fibre content and elemental composition (% of dry weight) of *Kappaphycus sp.* in Fiji, compared to samples from Eastern and Western regions of the country. Number of samples in brackets ().

	Kappaphycus sp.		
	Fiji All Regions	Fiji Eastern region	Fiji Western region
Carbohydrates %	39.62	-	-
Ash %	54.17 ± 8.3 (12)	46.25 ± 7.7 (4)	58.04 ±5.1 (5)
Moisture %	4.28 ± 2.2 (13)	4.35 ± 0.7 (4)	2.80 ± 1.4 (4)
Lipids %	0.47 ± 0.4 (10)	0.46 ± 0.4 (4)	0.79 (1)
Protein %	1.46 ± 0.5 (16)	1.32 ± 0.5 (5)	1.47 ± 0.4 (7)
Total Fibre (g/100g)	37.15 ± 2.6 (2)	-	37.15 ± 2.6 (2)
Insoluble fibre (g/100g)	2.55 ± 0.5(2)	-	2.55 ± 0.5(2)
Soluble fibre (g/100g)	34.60 ±3.1 (2)	-	34.60 ±3.1 (2)
Moisture % (market sample as received)	22.30 ± 6.2 (17)	19.37 ± 5.7 (10)	25.14 ± 4.34 (5)
C %	16.44 ± 3.6 (16)	18.09 ± 3.1 (5)	16.92 ± 2.8 (7)
H %	2.58 ± 0.9 (2)	-	2.58 ± 0.9 (2)
N %	0.29 ± 0.1 (16)	0.26 ± 0.1 (5)	0.29 ± 0.1 (7)
S %	3.73 ± 0.7 (16)	4.30 ± 0.6 (5)	3.56 ± 0.5 (5)
O % (*calculated)	20.00 ± 4.0 (2)	-	20.00 ± 4.0 (2)
P %	0.03 ±0.01 (13)	0.03 ± 0.01 (4)	0.03 ± 0.01 (5)
C:N	67.77 ± 42.60 (16)	88.56 ± 70.6 (5)	61.94 ± 22.3 (7)
N:P	10.76 ± 2.98 (13)	10.64 ± 3.1 (4)	10.18 ±1.5 (5)

Table 7 Metal composition (mg/kg) of *Kappaphycus sp.* in Fiji, compared to samples from Eastern and Western regions of the country. Number of samples in brackets ().

	Kappaphycus sp.		
	Fiji All Regions	Fiji Eastern region	Fiji Western region
Aluminium	153.00 ± 248.46 (14)	30.17 ± 20.26 (5)	108.04 ± 123.38 (5
Arsenic	4.81 ± 1.82 (14)	5.00 ± 2.21 (5)	4.94 ± 1.93 (5
Boron	141.86 ± 38.58 (14)	147.60 ± 26.05 (5)	158.40 ± 47.4 (5
Barium	0.18 ± 0.08 (3)	0.15 (1)	0.20 ± 0.10 (2
Calcium	3,645.71 ± 1,814.25 (14)	4,180.00 ± 2,712.38 (5)	2,748.00 ± 418.06 (5
Cadmium	0.14 ± 0.12 (10)	0.07 ± 0.02 (3)	0.16 ± 0.16 (5
Cobalt	1.64 ± 1.88 (14)	0.57 ± 0.41 (5)	2.53 ± 2.71 (5
Chromium	5.75 ± 5.75 (13)	7.43 ± 6.30 (5)	3.78 ± 2.71 (5
Copper	1.98 ± 2.05 (14)	0.73 0.21 (5)	2.67 ± 2.8 (5
Iron	436.19 ± 419.92 (13)	457.96 ± 380.67 (5)	274.14 ± 298.02 (5
Mercury	<0.01 (9)	<0.01 (4)	<0.50 (5
Potassium	167,636 ± 44,913.15 (14)	155,978.20 ± 46,025.88 (5)	176,194.60 ± 52,780.33 (5
Magnesium	5,116.43 ± 1,028.32 (14)	4,404.00 ± 809.99 (5)	5,802.00 ± 1,002.51 (5
Manganese	8.69 ± 8.99 (14)	4.19 ± 2.07 (5)	6.93 ± 5.37 (5
Molybdenum	2.88 ± 4.20 (11)	1.27 ± 0.62 (5)	1.99 ± 1.99 (4
Sodium	35,228.57 ± 9,386.03 (14)	27,600.00 ± 9,813.26 (5)	42,640.00 ± 5,457.84 (5
Nickel	9.43 ± 10.56 (13)	11.29 ± 8.05 (5)	5.72 ± 5.83 (5
Lead	<0.50 (14)	<0.50 (5)	<0.50 (5
Selenium	<1.00 (11)	<1.00 (4)	<1.00 (3
Strontium	50.20 ± 18.35 (14)	35.60 (1)	57.50 ± 18.81 (2
Vanadium	1.45 ± 1.10 (14)	1.04 ± 0.43 (5)	1.32 ± 0.98 (5
Zinc	14.46 ± 15.91 (13)	10.16 ± 7.66 (5)	24.90 ± 26.62 (4

Table 8 Mineral composition (mg/kg) of seaweed species from Fiji, Kiribati and Samoa. Number of samples in brackets ().

	FIJI					KIRIBATI				SAMOA
	Caulerpa sp.	*Hydropuntia edulis (Gracilaria)*	*Hypnea*	*Kappaphycus sp.*	*Ulva meridionalis*	*Acanthophora sp.*	*Gelidium sp.*	*Kappaphycus sp.*	*Ulva sp.*	*Caulerpa sp.*
Aluminium	239.00 ± 307.84 (20)	389.44 ± 239.75 (16)	1,354.11 ± 428.18 (9)	147.38 ± 231.83 (16)	1,991.67 ± 351.96 (3)	8.61 ± 3.57 (4)	22.38 ± 22.1 (2)	5.11 ± 6.74 (8)	43.47 ± 65.30 (4)	489.10 ± 745.87 (14)
Arsenic	11.57 ± 4.88 (20)	8.94 ± 1.81 (16)	7.73 ± 1.80 (9)	4.74 ± 1.71 (16)	2.27 ± 0.49 (3)	5.46 ± 1.60 (4)	2.94 ± 0.62 (2)	6.50 ± 3.91 (9)	9.57 ± 3.32 (4)	12.89 ± 5.54 (14)
Boron	47.79 ± 35.99 (11)	413.81 ± 133.37 (16)	217.78 ± 23.86 (9)	138.88 ± 36.86 (16)	206.67 ± 15.28 (3)	403.75 ± 121.89 (4)	310.00 (1)	165.75 ± 54.31 (8)	225.50 ± 30.40 (2)	44.25 ± 17.50 (4)
Barium	0.31 (1)	1.19 ± 1.43 (2)	-	0.61 ± 0.61 (5)	-	1.31 (1)	-	0.43 ± 0.16 (2)	3.09 ± 0.55 (2)	-
Calcium	22,987.50 ± 12,357.46 (20)	15,260.63 ± 11,347.62 (16)	16,022.22 ± 9,626.24 (9)	4,310.50 ± 2,485.24 (16)	10,000 ± 0.00 (3)	94,125.00 ± 46,580.35 (4)	125,600.00 ± 62,791.08 (2)	6,385.56 ± 2,669.67 (9)	136,750.00 ± 49,748.50 (4)	45,414.29 ± 34,776.03 (14)
Cadmium	0.05 ± 0.01 (20)	0.11 ± 0.09 (11)	0.2 ± 0.09 (9)	0.13 ± 0.11 (12)	<0.50 (3)	0.38 ± 0.11 (4)	0.51 ± 0.22 (2)	0.41 ± 0.20 (9)	0.49 ± 0.56 (4)	0.09 ± 0.04 (13)
Cobalt	0.40 ± 0.45 (11)	0.32 ± 0.16 (13)	0.55 ± 0.22 (9)	1.51 ± 1.78 (16)	1.80 ± 0.44 (3)	<0.10 (4)	<0.10 (1)	<0.10 (7)	0.28 ± 0.07 (2)	0.83 ± 0.81 (3)
Chromium	3.56 ± 3.95 (19)	1.99 ± 0.97 (16)	3.22 ± 1.40 (9)	8.36 ± 8.98 (15)	8.33 ± 1.30 (3)	2.52 ± 0.72 (4)	3.73 ± 0.18 (2)	2.63 ± 3.05 (9)	5.36 ± 2.81 (4)	7.61 ± 5.61 (14)
Copper	1.37 ±1.14 (20)	1.95 ± 1.12 (16)	3.32 ± 1.04 (9)	1.97 ± 1.93 (16)	7.57 ± 2.12 (3)	1.76 ± 0.39 (4)	1.88 ± 0.40 (2)	0.87 ± 0.49 (9)	5.36 ± 3.04 (4)	1.77 ± 0.91 (14)
Iron	322.42 ± 376.68 (19)	455.45 ± 308.49(16)	1,494.44 ± 523.76 (9)	434.63 ± 388.80 (15)	2,666.67 ± 513.16 (3)	222.15 ± 87.23 (4)	121.85 ± 39.81 (2)	103.36 ± 148.18 (9)	439.15 ± 342.07 (4)	1,026.34 ± 1,433.52 (14)
Mercury	<0.01 (20)	<0.01 (13)	0.02 ± 0.01 (9)	<0.01 (11)	<0.01 (3)	<0.01 (4)	<0.01 (2)	<0.01 (6)	<0.50 (4)	<0.01 (13)
Potassium	9,040.56 ± 2,387.45 (18)	132,750.69 ± 65,097.53 (16)	35,666.67 ± 5,722.76 (9)	171,681.98 ± 43,258.01(16)	32,666.67 ± 5,507.57 (3)	59,850.00 ± 8,038.86 (4)	5,705 ± 1,845.55 (2)	152,496.00 ± 66,151.39 (9)	36,000.00 ± 15,411.9 (4)	8,930.71 ± 2,122.72 (14)
Magnesium	9,113.50 ± 3,653.20 (20)	4,621.88 ± 1,003.89 (16)	6,288.89 ± 419.66 (9)	5,188.44 ± 978.81 (16)	24,000.00 ± 2,645.75 (3)	14,175.00 ± 665.21 (4)	11,205 ± 2,538.51 (2)	5,993.33 ± 1,296.74 (9)	16,052.50 ± 6,788.30 (4)	6,420.71 ± 1,618.58 (14)
Manganese	12.34 ± 8.57 (11)	55.83 ± 36.66 (16)	28.39 ± 8.45 (9)	8.19 ± 8.48 (16)	132.47 ± 40.87 (3)	4.97 ± 1.07 (4)	3.51 (1)	2.34 ± 1.23 (8)	6.92 ± 3.85 (2)	37.31 ± 35.31 (4)
Moly bdenum	<0.50 (8)	<0.50 (11)	0.52 ± 0.01 (9)	2.88 ± 4.20 (11)	<0.5 (3)	<0.50 (4)	<0.50 (1)	0.92 ± 0.91 (5)	2.84 ± 3.63 (2)	<0.50 (4)
Sodium	161,764.64 ± 74,340.91 (11)	37,789.07 ± 30,057.81 (15)	142,229.89 ± 9,955.85 (9)	35,536.56 ± 8,778.57 (16)	26,333.33 ± 7,767.45 (3)	51,175.00 ± 7,636.92 (4)	22,000 (1)	42,250.00 ± 2,803.06 (8)	37,300.00 ± 3,111.30 (2)	234,271.00 ± 38,389.67 (4)
Nickel	0.82 ± 0.43 (16)	1.37 ± 0.39 (16)	1.77 ± 0.66 (9)	9.21 ± 9.86 (15)	7.17 ± 1.00 (3)	2.48 ± 1.19 (4)	1.64 ± 0.05 (2)	1.59 ± 2.19 (9)	4.45 ± 2.40 (4)	2.96 ± 3.05 (14)
Lead	0.10 ± 0.09 (9)	<0.50 (15)	<0.50 (9)	<0.50 (14)	2.28 ± 2.43 (2)	0.65 ± 0.12 (4)	0.80 ± 0.42 (2)	0.15 ± 0.07 (5)	3.10 ± 3.03 (4)	0.55 ± 0.43 (11)
Selenium	7.53 ± 2.61 (20)	<1.00 (12)	<1.00 (9)	<1.00 (13)	<1.00 (3)	12.36 ± 12.64 (4)	2.89 ± 2.67 (2)	4.24 ± 2.75 (3)	5.54 ± 2.38 (4)	8.95 ± 1.22 (10)
Strontium	-	93.75 ± 5.6 (2)	-	50.20 ± 18.35 (14)	-	1,380.00 (1)	-	100.35 ± 44.76 (2)	2,745.00 ± 558.61 (2)	-
Vanadium	1.34 ± 1.21 (11)	45.07 ± 38.64 (15)	4.52 ± 1.20 (9)	1.78 ± 1.37 (16)	7.20 ± 1.15 (3)	1.91 ± 0.72 (4)	1.90 (1)	1.42 ± 1.09 (8)	5.05 ± 3.66 (2)	3.97 ± 3.37 (3)
Zinc	3.96 ± 3.59 (14)	10.01 ±5.43 (16)	7.04 ± 5.71 (9)	13.75 ± 15.52 (14)	9.63 ± 1.58 (3)	11.05 ± 5.12 (4)	11.50 ± 2.69 (2)	11.73 ± 5.00 (8)	16.34 ± 9.39 (4)	6.42 ± 4.44 (7)

3.7. Elemental composition

- *Ulva sp.* presented the highest concentrations of carbon, nitrogen and phosphorous. Carbon concentrations in *Ulva* samples from Fiji were higher (24.86-25.86%) than in samples from Kiribati (16.29-20.15%), while nitrogen and phosphorous levels were more consistent.
- *Caulerpa sp.* had the lowest concentration of Sulphur across all species sampled in Fiji, Samoa and Australia.
- *Kappaphycus sp.* had the greatest ratios of carbon-to-nitrogen (C:N), with a maximum of >200 in Fiji, and 61 in Kiribati; compared to *Caulerpa sp.* which had a maximum C:N ratio of 15.05 and 13.68 in Fiji and Samoa respectively.

3.8. Mineral composition

- Species from Kiribati had lower concentration levels of aluminum (5 - 44mg/kg) than species from Samoa and Fiji (147 – 1,992mg/kg). *Ulva sp.* and *Hypnea* sp. samples. from Fiji had the highest concentrations at 1,991.67mg/kg and 1,354.11mg/kg respectively.
- *Caulerpa* consistently presented the highest levels of arsenic and sodium, and the lowest levels of boron in Fiji and Samoa, compared to all other species. In Australia, *Caulerpa* levels were consistent with Fiji and Samoa for sodium (high) and boron (low), however had the lowest values of arsenic (0.56mg/kg) compared to all other species analysed (the highest being 6.40mg/kg for *Gracilaria*).
- *Ulva* samples from Fiji had the highest levels of aluminium, cobalt, copper, iron, magnesium and manganese compared to all other species. However, except for magnesium and lead, these levels were not consistent with the Ulva samples from Kiribati. In the other hand, Ulva from Kiribati presented the highest levels of barium, calcium, molybdenum, strontium and zinc compared to all other species analysed throughout Fiji, Kiribati and Samoa.
- *Kappaphycus* samples presented the highest averages of potassium in Fiji and Kiribati, with maximums of 234,887.00mg/kg and 259,735.00/kg respectively.
- *Hydropuntia* (previously *Gracilaria*) samples from Fiji also had high levels of potassium with a maximum of 201,070.00mg/kg and had the highest levels of boron and vanadium compared to other species in Fiji, Kiribati and Samoa. *Hydropuntia* and *Sarconema*, grown in a stable recirculating aquaculture system in Australia had similar high levels of potassium: 235,811.00mg/kg and 200,820.00mg/kg respectively.

3.9. Moisture content of dried samples

Samples that were dried in a food dehydrator and kept in sealed containers/bags held their moisture content typically around 5%. This measurement was used to standardise the dry matter content of samples processed for biochemical analyses. However, for samples purchased from the market and air-dried *Kappaphycus*, the moisture content analysed without further drying, moisture ranged from 19-26%.

4. References

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11.7 Appendix 7: Abstracts of student theses aligned with FIS/2010/098

1. Ms Verenaisi Lewatoro, University of the South Pacific. Masters of Science, Thesis title: "The effects of the cultivation of *Kappaphycus alvarezii* (common name *cottonii*) in improving the socio-economic conditions of the community of Fiji".

   http://digilib.library.usp.ac.fj/gsdl/collect/usplibr1/index/assoc/HASHe164.dir/doc.pdf

2. Mr Tomasi Tikoibua, University of the South Pacific. Masters of Science, Thesis title: "Growth and morphology of local sea grapes (*Caulerpa* spp.) in Fiji"

   http://digilib.library.usp.ac.fj/gsdl/collect/usplibr1/index/assoc/HASHa8f6.dir/doc.pdf

3. Ms Ashmeeta Shalvina, University of the South Pacific. Masters of Science, Thesis title: "Effect of environmental culture conditions on carrageenan in Fijian red seaweeds and its application in food jelly". http://digilib.library.usp.ac.fj/
4. Mr Albert Whippy, University of the South Pacific. Masters of Science, Thesis title: "Comparison of farming and drying methods for the red seaweed *Kappaphycus alvarezii* '*tambalang'* in Galoa, Kadavu, Fiji Island". *Submitted.* http://digilib.library.usp.ac.fj/
5. Ms Jagruti Chuahan, University of the South Pacific. Masters of Science, Thesis title: "The application of Fiji's carrageenan and agar in the physicochemical and rheological properties of vanilla bean and cinnamon pastes products". *Submitted.* http://digilib.library.usp.ac.fj/
6. Ms Tereere Tioti, James Cook University. Masters of Science, Minor Project: "Exploring a potential new seafood product (*Caulerpa*) for the coral atolls in Kiribati".
7. Mr Imran Lapong, James Cook University. Masters of Science, Special Topics: "Evaluation of the brine preservation method of sea grapes (*Caulerpa lentillifera*)".
8. Mr Ian Tuart, James Cook University. Graduate Certificate of Research Methods, Title: "Environmental tolerances for production of the commercially important red seaweed *Gracilaria edulis* and *Sarconema filiforme* in tropical Australia".

Note: Project leader Prof. Nicholas Paul was an associate supervisor of USP students and principal supervisor of the Australian students.

Verenaisi Lewatoro: The effects of the cultivation of *Kappaphycus alvarezii* (common name *cottonii*) in improving the socio-economic conditions of the community of Fiji

Abstract: The study was carried out in five (5) different *Kappaphycus* growing areas in Fiji namely Kumi, Sawakasa, Naboutini, Naweni and Gau Island. The general objective of the study was to examine the socio-economic effects of the cultivation of seaweeds in Fiji and it has four specific objectives which was to examine the interrelationship between the social and economic variables in the cultivation of *Kappaphycus* seaweed; to analyse the contribution of seaweeds in the household economy of rural communities; to assess the women's contribution in the production and marketing of seaweeds and to identify the problems faced by seaweed farmers over the years and their underlying reasons. Altogether a total of 74 farmers were interviewed during the survey. These include those farmers that were once involved in the seaweed cultivation process. In addition to this, a field officer from the Department of Fisheries and one officer from the market (Wee Kong Marine & Exports Company Ltd) were also interviewed for the progress of seaweed industry in Fiji.

The study found that 68% of the farmers engaged in seaweed cultivation were male whilst 32% were female. The majority of these farmers were married and over the age of 50 years. The average family size of seaweed farming household is around 3.1 people with 59 percent of the farmers having reached secondary level of education. In addition to this, 50 percent of the farmers interviewed have been cultivating *Kappaphycus* seaweed for a period of four to six years. The study also found that the most common profile of a seaweed farmer in Fiji is a male farmer aged between 41 and 50, he is educated to secondary level and has been involved in seaweed farming for 4 years, and finally that he is married, with a family network of three people. This family spends about 42% of their time working on their seaweed farm doing a small amount of work every day, then often planting root crops and fishing in their spare time. During one harvest, the family produces 50kgs of the dried biomass with an overall income of $300, and they could do up to 6 harvests per year. The farmer has strong reliance on the community network for crucial activities such as planting and management of farms to maximise production and more income opportunities.

Income generated from the sale of seaweed assisted the farmers in many ways including education needs, food, catering for household needs and village or community obligations. The womens' role in the production and marketing of *Kappaphycus* seaweed were very important as they deal mostly with the quality control of the produce. However, farmers have experienced problems in cultivation throughout the years such as change in weather patterns, strong currents, algae growth or even presence of small fishes which greatly affects the production of *Kappaphycus alvarezii*.

The following recommendations were made based upon the results of this study. Firstly, the government through the Department of Fisheries, should encourage people to be engaged in *Kappaphycus* cultivation through conducting more training sessions and supplying or facilitating the purchase of materials where needed for individual farmers and villages. Secondly, there is a need for more support from the government to promote seaweed industry nationally, developing marketing strategies and installing processing equipment in the country. Lastly, there is a need to develop longer term policy for the seaweed industry, after an increased and stable production is reached, to safeguard the farmers and allow for an open market to increase competition between buyers.

Selected figures:

Figure 1. Gender involvement in Seaweed Farming**;**

Figure 2. Age Groups of Seaweed for All Villages;

Figure 3. Family members involvement in cultivation;

Figure 4. Problems Faced During Cultivation

Figure 1

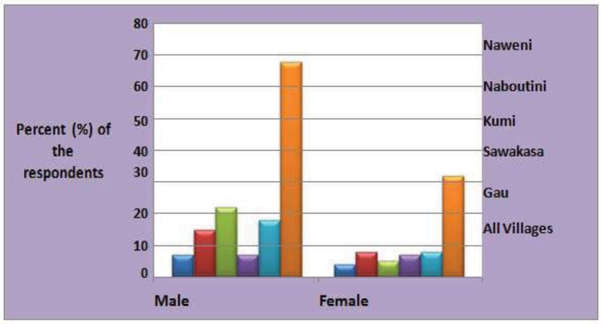


Figure 2

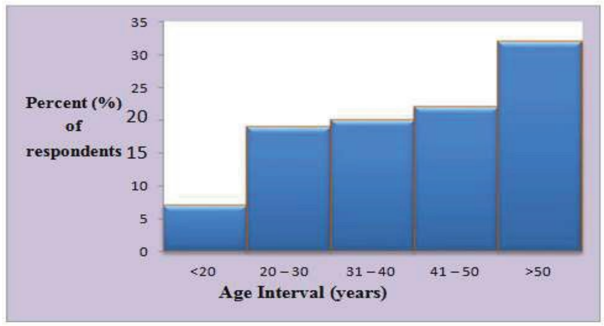


Figure 3

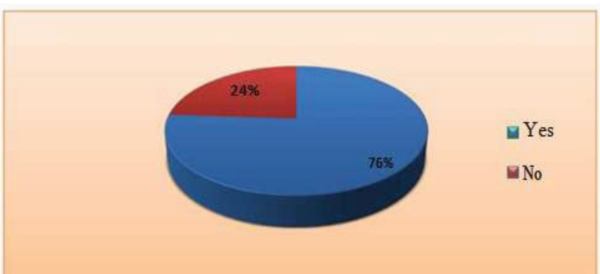
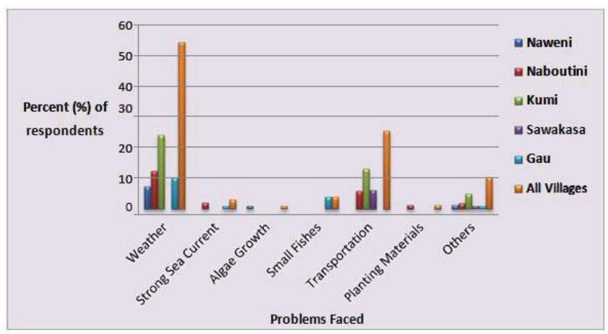


Figure 4.6 Family Members Involvement in Cultivation

Figure 4



Tomasi Tikoibua: Growth and morphology of local sea grapes (*Caulerpa* spp.) in Fiji

Abstract: Scientific research plays a crucial role in the development of seaweed harvesting, cultivation, processing and utilization. There is a clear and ongoing need for research and development to enable an economically and environmentally sustainable seaweed industry in the Pacific, including Fiji. The major focus of this study was to assess the growth and morphology of cultured *Caulerpa* species in the field and to determine the effect of key environmental parameters (temperature, light intensity and salinity) on its growth in the laboratory.

The first research aspect was field experiment which focused on assessing the growth and morphology of *Caulerpa* species at five different sites (Veivatuloa, Muaivusu, Namuaimada, Mana and Gunu). Six single trays with two treatments (three trays with 7 kilograms of rubble as a substrate and three without rubble) were placed in five sites. Biomass fresh weight and biomass attributes (frond length, width and grape size) of *Caulerpa* spp. were assessed based on site (five sites), substrate (with and without rubble) and growth position (protruding above, within or below tray). Overall, there was poor growth of *Caulerpa* spp. after 9 weeks. However, there was a significant difference in the biomass fresh weight of *Caulerpa* spp. between sites, whereby growth at Mana was significantly higher than that at other sites. Tray growth position in the water column (above, middle or below tray position) had no effect on *Caulerpa* spp. biomass weight. There was no overall statistical difference of biomass weight detected between any of the three factors. However, there was an interaction between site and substrate, driven by an effect of no rubble (1.12 kg ± 0.1 SE) on biomass weight. At Mana, it was significantly higher than that with rubble (0.84 kg ± 0.01 SE). Results showed that there were significant differences between biomass attributes and sites. Both frond width and grape size were also significantly higher at Mana than other sites (Frond width - Mana: 0.86 cm ± 0.02 SE, Gunu: 0.65 cm ± 0.02 SE), (Grape size – Mana: 0.24 cm ± 0.004 SE, Gunu: 0.21 cm ± 0.005 SE). Furthermore, frond length was greater at Mana and Gunu than at Muaivusu. The frond length and width results were strongest on biomass culture in the bottom position of tray. There was a trend for larger grape size on the above position (0.25 cm ± 0.009 SE versus 0.24 cm ± 0.009 SE for below position), however this was not significantly different. There was no significant differences between treatments in any of the main effects, both frond length and grape size. Differences only existed with frond width when compared between substrate treatments. For the environmental variables monitored (temperature, light intensity and salinity), temperature appeared to have the strongest association with the growth of *Caulerpa* spp. in the field.

The second aspect of the study was focused on determining the influence of key environmental parameters (temperature, light intensity and salinity) on *Caulerpa* spp. growth in the laboratory. The study was conducted at USP Seawater Wet Laboratory from June to August 2015. *Caulerpa* spp. seedlings were collected from Volivoli in Rakiraki, Western Division. There were five experimental trials carried out consecutively for duration of ten days of culture. In each trial, growth was investigated at temperatures of 25, 30 and 35°C, light intensities of 1000, 10 000 and 20 000lx and salinities of 29, 32 and 35 ppt. Results revealed that *Caulerpa* spp. growth was best at the medium temperature of 30°C, the medium light intensity of 10 000lx and with a salinity range of 29-35 ppt.

This study highlights that the growth and morphological variation of *Caulerpa* spp. are highly variable. The empirical and monitoring data presented indicates that multiple environmental and biological factors will influence the domestication and aquaculture of *Caulerpa* in Fiji, primarily temperature and substrate for the attachment of individuals. Any future research should firstly focus on understanding the genetic variation of *Caulerpa* spp. at the different sites, as the environmental factors evaluated in the present study could not explain the majority of the variation

observed in the system, which could be due to presence of more than one species of different strains of the one species.

Selected figures:

Figure 1. *Caulerpa* spp. growth position. (a). protruding "above" tray growth (b). protruding "below" tray growth. Arrows show *Caulerpa* spp. growth direction.

Figure 2. *Caulerpa* spp. mean frond length compared separately; (a). between sites (b). between growth position (above, in the middle or below tray).

Figure 3. Caulerpa spp. mean grape size compared separately; (a). between sites (b). between growth position (above, in the middle or below tray).

Figure 4. Mean specific growth rate (% d-1) of *Caulerpa* spp. seedling. (a) under different temperatures irrespective of light intensities and salinities; (b) under different light intensities irrespective of temperatures and salinities; (c) under different salinities irrespective of temperatures and light intensities

Figure 1

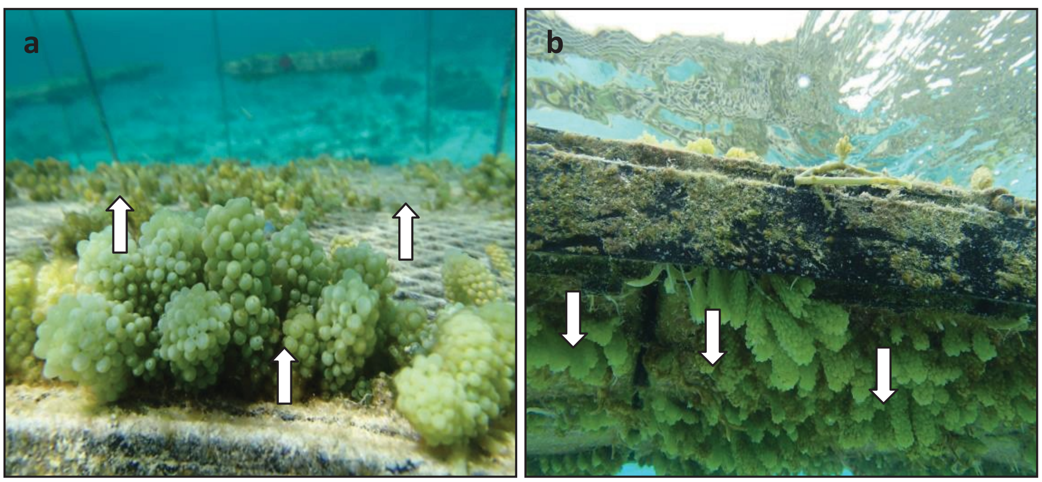


Figure 2

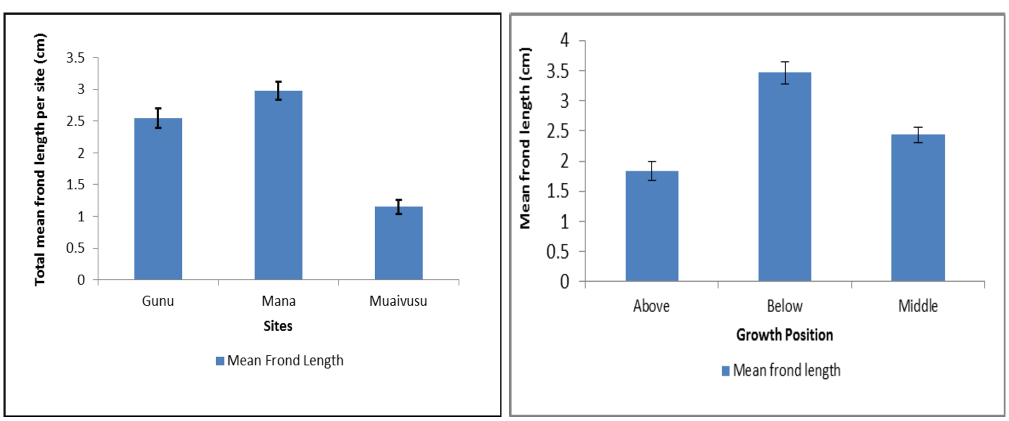


Figure 3

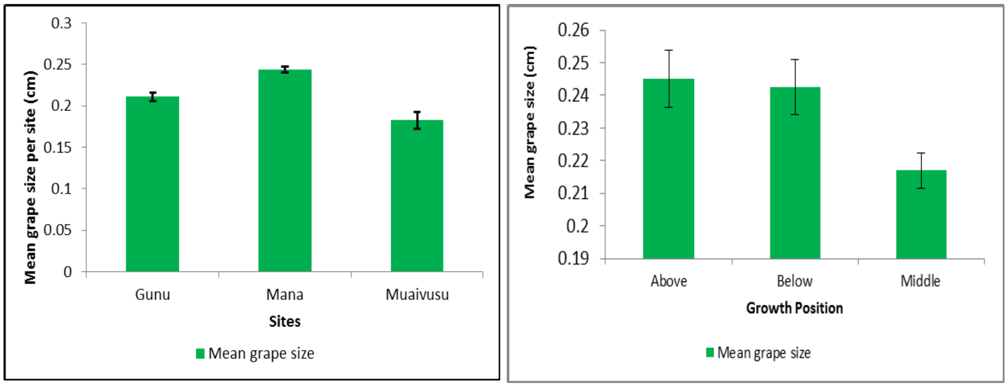
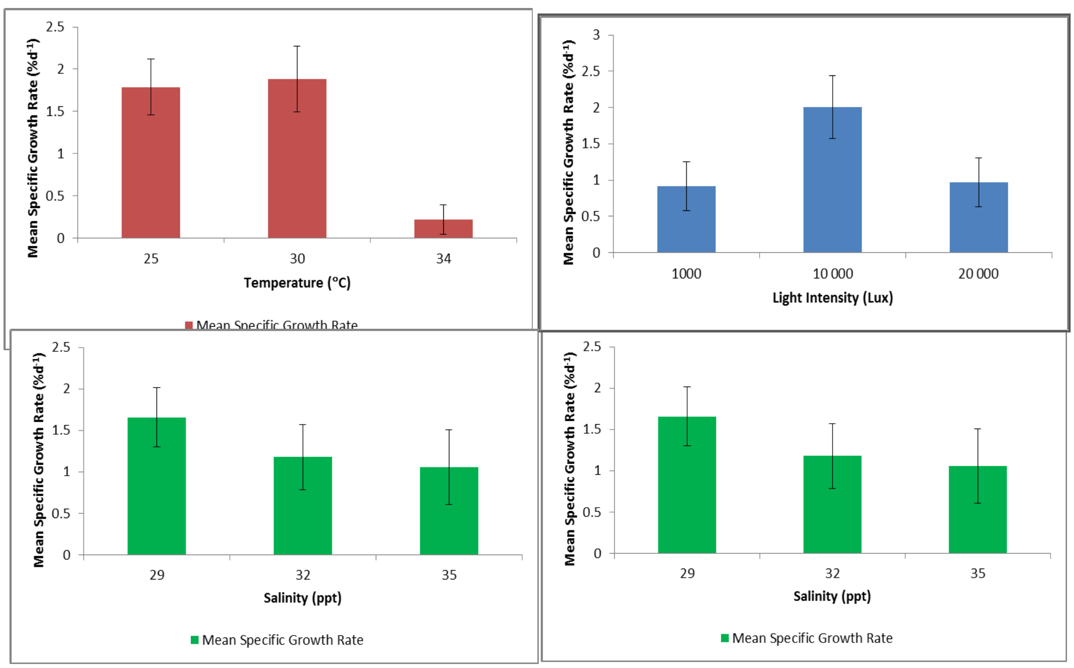


Figure 4



Ashmeeta Shalvina: Effect of environmental culture conditions on carrageenan in Fijian red seaweeds and its application in food jelly

Abstract:

This thesis focuses on the impacts posed by the environmental conditions on the culture of seaweed species namely *Kappaphycus alvarezii*, *Hypnea cornuta* and *Halymenia durvillei.* The growth, semi refined carrageenan yield, gel strengths such as gel compression and penetration strength and viscosity of the gels were measurement of interest of the seaweed species in culture. After which an application of fruit jellying abilities were undertaken using semi refined carrageenan.

The purpose of the study is to fill the information gap in Pacific Island Countries regarding the effects of environmental culture conditions on *K. alvarezii*, *H. cornuta* and *H. durvillei* and what is happening to seaweed communities with changing climate. Information acquired will inform the local seaweed industries for best seaweed species to aquaculture for high biomass growth and carrageenan.

Research methodology was that *K. alvarezii*, *H. cornuta* and *H. durvillei* were randomly collected from Kaba, Vunitogaloa village and Fish Patch near Suva respectively after which it was acclimatized and then introduced to culture conditions. The factorial design was used to culture seaweeds with two levels of temperature, salinity and nutrient concentration combinations. The specific growth rate was measured and carrageenan was extracted. The semi refined carrageenan extracted was used to measure gel strength and viscosity after which the carrageenan was mixed with pineapple juice to note the behaviour changes of gel strength and viscosity.

It was found out that *K. alvarezii* was the best species to be cultured giving higher biomass growth and it preferred to grow well at high temperature. There were high semi refined carrageenan yield obtained from *K. alvarezii* at low salinity but *H. cornuta* displayed high carrageenan yield at high salinity. As for gel strength, the compression and penetration strengths were relatively higher for *K. alvarezii* than *H. cornuta* both in distilled water and pineapple juice. The same observation was made for viscosity as well when in distilled water and pineapple juice.

Selected figures:

Figure 1. Mean specific growth rate (%/day) of *Kappaphycus alvarezii* in four different treatments at two different temperatures that is 30°C (H-High) and 24°C (A-Ambient). Bars represent the range of SRG in each treatment. The mean SGR is obtained from 12 replicates of *K. alvarezii* cultured in each treatment for 15 days. S1N1 = 25 ppt, 0.1 mg/l N, S1N2 = 25 ppt, 0.5 mg/l N, S2N1 = 40 ppt, 0.1 mg/l N and S2N2 = 40 ppt, 0.5 mg/l N.

Figure 2: Mean SRC yield of *Kappaphycus alvarezii* cultured at 30°C and 24°C with different combinations of salinity and nutrients. The error bars represent the scale SRC yield. S1 = 25 ppt, S2 = 40 ppt, N1 = 0.1 mg/l and N2 = 0.5 mg/l.

Figure 1

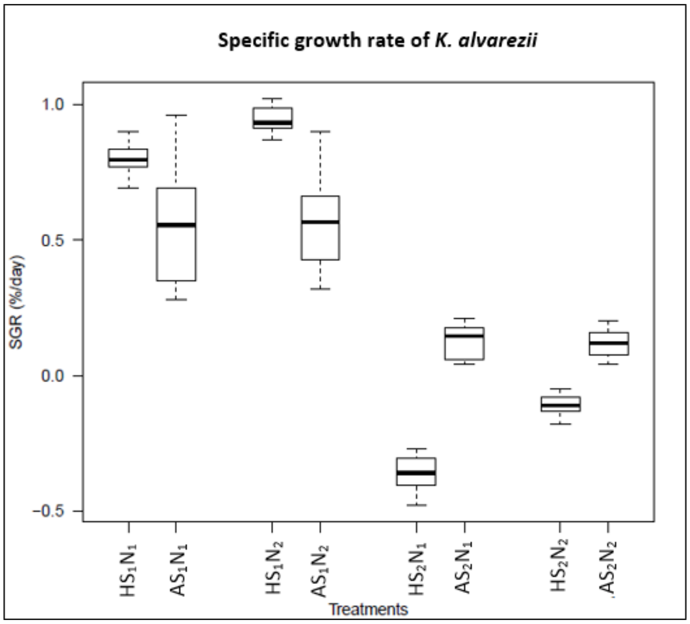
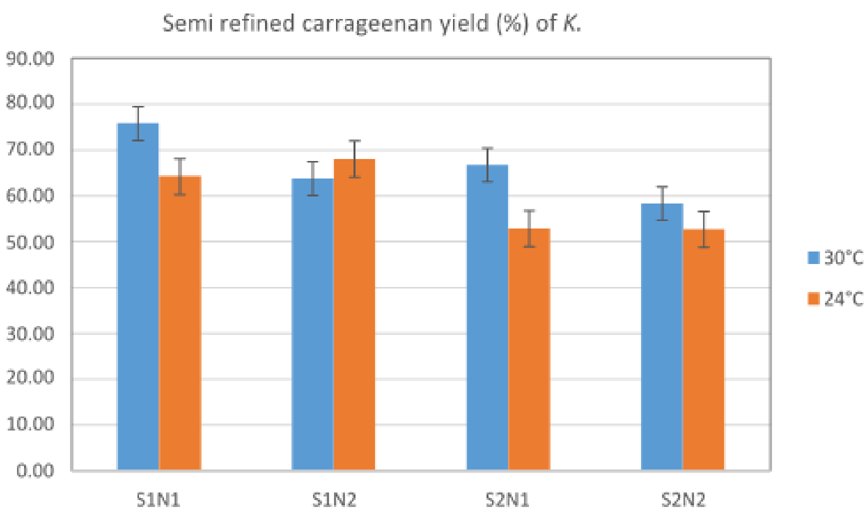


Figure 2



Albert Whippy: Comparison of farming and drying methods for the red seaweed *Kappaphycus alvarezii* "*tambalang*" in Galoa, Kadavu, Fiji Island

Abstract:

This thesis presents the findings of research based on seaweed farming conducted from January to June of 2015. The research was in three different categories, the socio-economic survey, the field studies which compared two different farming methods and the two different drying methods and the lab experiment with a more controlled environment. The socio-economic survey found that the respondents are willing to take up seaweed farming due to the geographical location of the island and also due to their high dependence on marine resources especially the sea for survival. The study identified that the respondents were also earning income from farming *yaqona* but not as much as what they earn from the sea because farming *yaqona* depends on the weather.

The research results show that with the farming of *Kappaphycus alvarezii* production depends on the water salinity, the water temperature, surface temperature and other environmental factors including water disturbance by the people. The *K. alvarezii* with the variety *tambalang* was introduced to Galoa, Kadavu from the Yasawas for my master's research work and this was not an easy transition as it required a lot of care and patience and skills as well. The site selection was carried out first in the research site so that it allows growth of the *K. alvarezii* when it arrived in the island. Even though seaweed farming may be a new activity to many, it has been proven as a major source of money in some coastal communities.

Climate change and unstable weather events affect the growth of the *K .alvarezii* and at times could destroy the entire stock, especially when it is in its transition stage, moving it from one location to another. The packing and handling process by humans can also be a major drawback if they do not know the proper protocol or the skills of taking care of the seedlings as it is transported from one location to the other by boat or by vehicle.

The monitoring process in the field is a very important component of the research as the seedlings and the whole farm needs daily cleaning up to allow light to reach the seedlings for growth and fouling to be removed. The idea of having seaweed farming in the coastal communities is a step forward to minimize exploitation of fishing grounds and over fishing. The willingness of farmers to carry out seaweed farming is a way forward towards building resilience and reducing vulnerability of households to the impact change and constraints that affect the marine resources. The farmers or fishing communities need assistance from Government and Non-governmental Organizations to aid in the equipping of these seaweed farmers and also solutions to climatic associated impacts that affects them. The research found out that the off bottom farming method is the best method of farming *K. alvarezii* and the either drying on rack or hanging method can be used to dry seaweed after harvesting. If only the coastal villagers begin to realize the importance of taking up seaweed farming the marine resources would not be as exploited as it is now.

Selected figures:

Figure 1. Box Plots for Final Weight for Off Bottom and Floating Farming Method

Figure 2. Box Plots for Initial Weight and Final Weight for Hot and Cold Seasons

Figure 3. Hang dry method and rack drying method

Figure 1

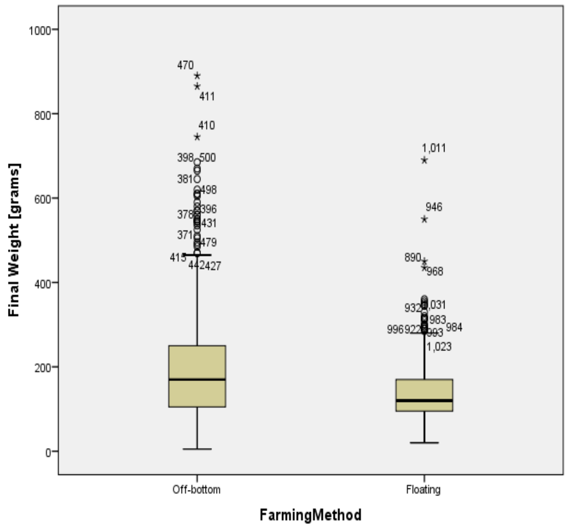


Figure 2

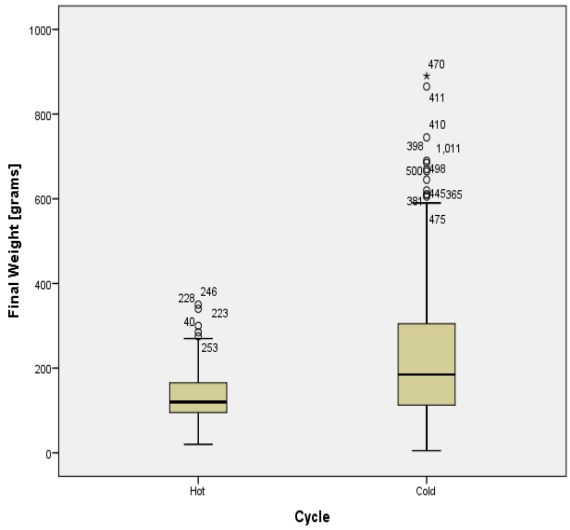


Figure 3

Jagruti Chuahan: The application of Fiji's carrageenan and agar in the physicochemical and rheological properties of vanilla bean and cinnamon pastes products

Abstract: Hydrocolloids are colloidal system with non-crystalline molecules which dissolve in water to give a thickened or viscous gel like solution. This class of compounds acts as an important ingredient and additives in food industries, cosmetic, pharmaceutical and agricultural industries due to their unique physicochemical and gelling properties. In food industry, hydrocolloids are used for functional food applications such as a thickening, gelling, emulsifying agents, or other production of meat and dairy products and may be extracted from seaweeds. In this study, two hydrocolloids, agar and carrageenan were extracted from red sea weeds. Agar was extracted from, *Gracilaria maramae* and *Gracilaria edulis*, while carrageenan from *Kappaphycus alvarezii.*

The agar was extracted from *Gracilaria maramae* and *Gracilaria edulis* with sodium hydroxide, followed by filtration, drying and blending while carrageenan was extracted from *Kappaphycus alvarezii* in sodium bicarbonate, with isopropanol, followed by oven dried and blending. The physicochemical analysis was carried out for the two hydrocolloids and of the mixed-gel system of agar and the carrageenan. The mixed-gel-systems of these hydrocolloids were used in the preparation of vanilla and cinnamon paste and the paste quality was investigated.

The results show that the yield of carrageenan increases with the soaking time with isopropanol during precipitation. The agar from *Gracilaria edulis* gave a higher and better yield using citric acid. The chemical structure of the extracted carrageenan and agar was confirmed using Fourier transform infrared spectroscopy.

Both carrageenan and agar formed gels without the addition of any other cations; however carrageenan formed softer gels then agar gels. Viscosity of agar and carrageenan both increased with increasing temperature. The young's modulus of compression of carrageenan indicated soft gels formation and greater gel strength. Texture analysis of agar gel from *Gracilaria edulis* and *Gracilaria maramae* both showed that the gels were soft and easily ruptured. Agar gels from *Gracilaria edulis* are softer then agar from *Gracilaria maramae*. Mixed–gel system of different ratios of the agar and carrageenan gels was also analyzed. The samples with a greater composition of agar has a stronger gelling profile compared to the larger ratio of carrageenan indicating that the gel strength increases with increasing percentage of agar, thus increasing the viscosity.

The cinnamon and the vanilla paste was made using the mixed-gel system of different ratios of the extracted carrageenan and agar. It was seen that the viscosity of the pastes were greater with higher percentage of agar. Sensory evaluation also showed acceptance of the vanilla and the cinnamon paste and its products. This study reveals the application of mixed gel systems in food additive and food preparation.

Selected figures:

Figure 1 Viscosity of Mixed Gel System of Agar from *Gracilaria edulis* and *Gracilaria maramae* with Carrageenan in ratios

Figure 2. A) 10 vanilla and cinnamon paste prototypes, B) Ms Ashika Pillay, Technical Baker at Punjas during product preparation, C) Product made with Paste Flavours

Figure 3. Sensory evaluation being carried out for vanilla and cinnamon Pastes and its products by the professional panellist at Punjas Flour.

Figure 1

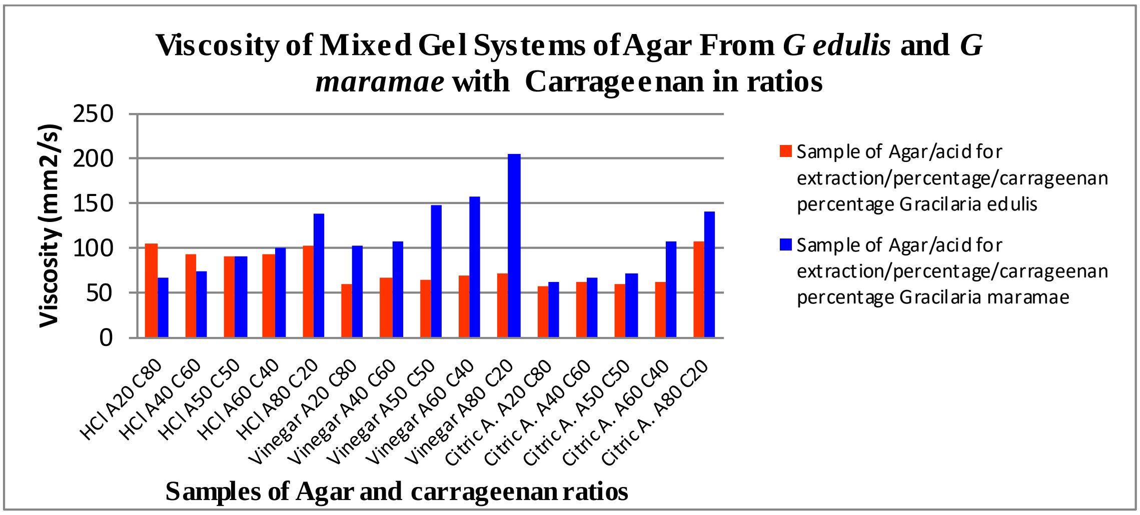


Figure 2

A  B  C 

Figure 3

Tereere Tioti: Exploring a potential new seafood product (*Caulerpa*) for the coral atolls in Kiribati

Abstract: People of the Pacific Island nation of Kiribati are highly dependent on fisheries resources as part of their daily consumption as well as their income earnings. However, most of these fisheries resources are declining because of the increasing population and other anthropogenic impacts such as climate change and overfishing. Seaweeds from the genus *Caulerpa,* known as sea grapes, could become a source of food and income for the people living in South Tarawa in Kiribati, if the market is established.

At this stage, there is no data on the distribution and stock of sea grapes, and there appears to be limited local knowledge that sea grapes can in fact be harvested and consumed. Therefore, the aims of this study were to: (1) evaluate the stock of sea grapes in South Tarawa; (2) examine which packaging method (traditional breadfruit leaves vs modern plastic containers) provide the longest shelf life; and (3) survey people's opinion and willingness to harvest, consume and/or purchase sea grapes in the future.

Results indicate that the distribution of sea grapes in South Tarawa is not uniform on the reef flat across the atoll, although sea grapes are abundant at some sites and this stock is sufficient to supply a small local market. For post-harvest processing, the plastic container with an absorbent pad will extend the shelf life of sea grapes to 5 days, while locally available breadfruit leaves only preserve sea grapes for 1 day. Finally, the survey results indicate that 95% of the people in South Tarawa were willing to harvest, consume and purchase sea grapes if a market was established. The willingness to pay for sea grapes (on average people would pay $4/kg) could offset the price of packaging materials.

Selected figures:

Figure 1. A. Location of Tarawa in Kiribati (modified from World Health Organisation map A). B. The Map of Tarawa in Kiribati with the 10 study sites, Bonriki, Temaiku, Bikenibeu, Eita, Taborio, Ambo, Teaoraereke, Nanikaai, Bairiki and Betio highlighted in red oval circles.

Figure 2. The mean density (grams/m^2 ± SE) of sea grapes at 10 (Bonriki, Temaiku, Bikenibeu, Eita, Taborio, Ambo, Nanikaai, Bairiki and Betio) different sites in South Tarawa, Kiribati.

Figure 3. Percentage of people interviewed on the different prices willing to pay various prices for 500 grams of sea grapes in South Tarawa, Kiribati.

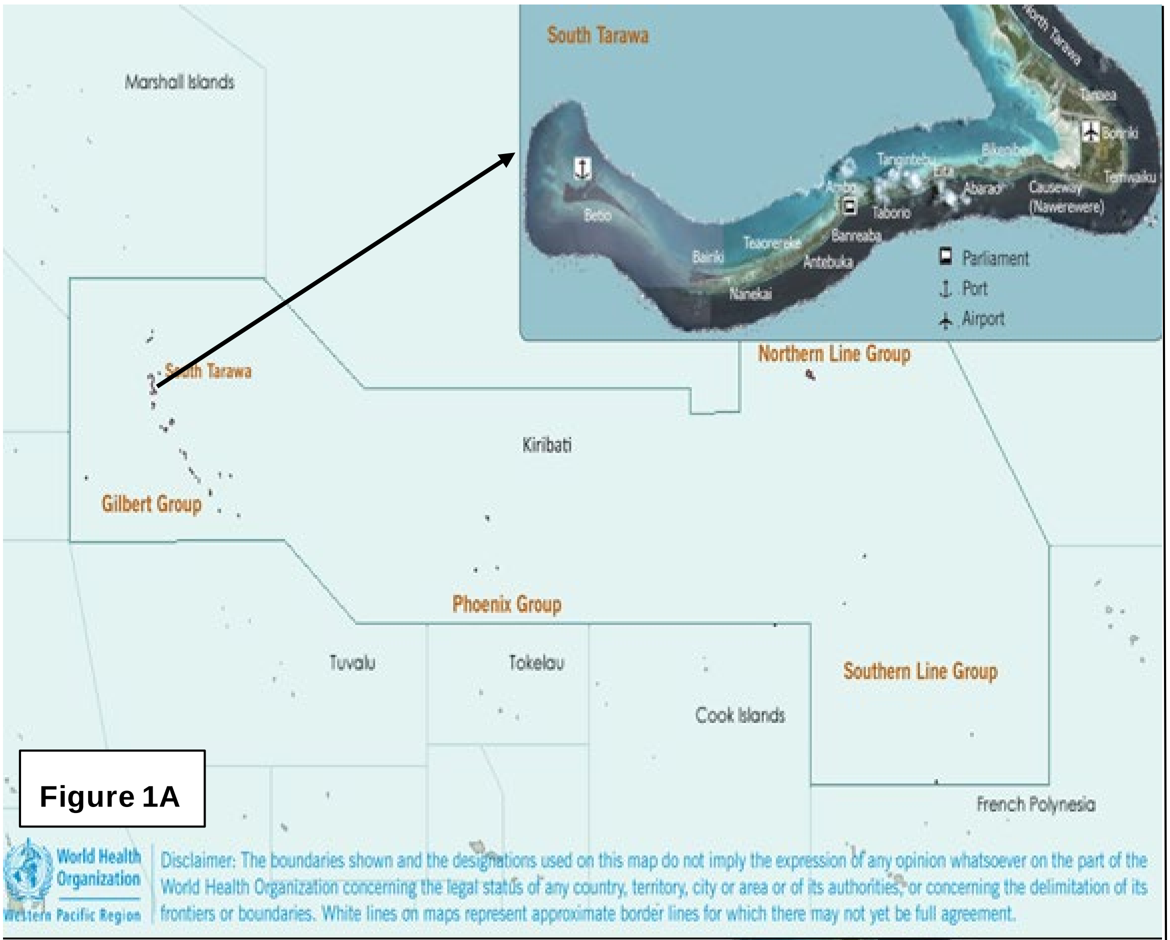


Figure 1A

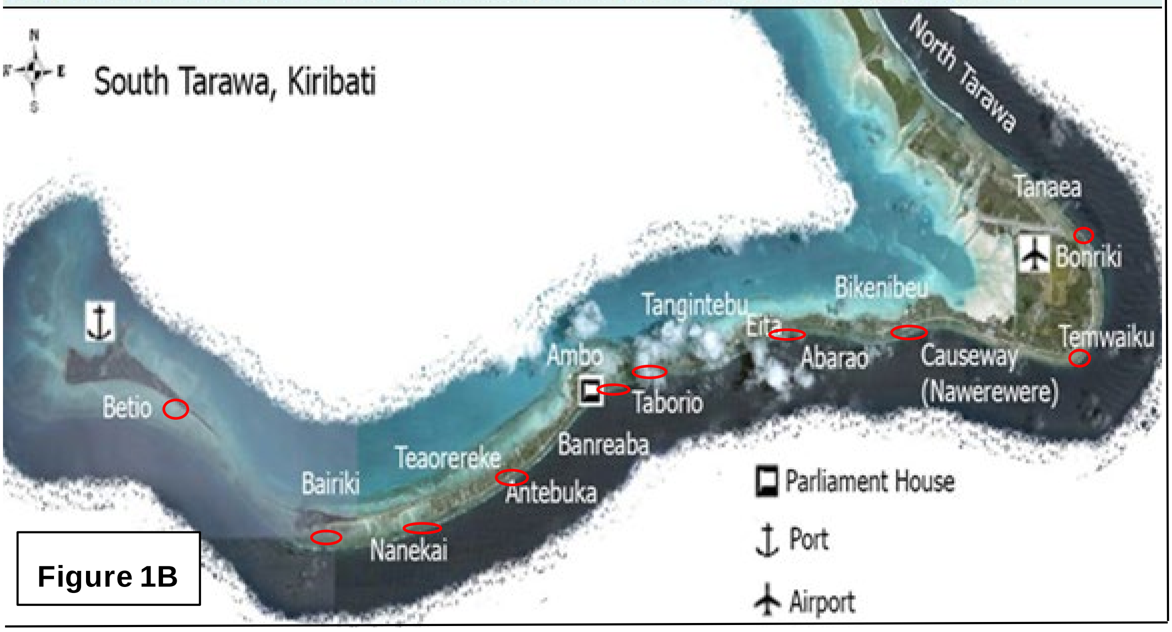


Figure 1B

Figure 2

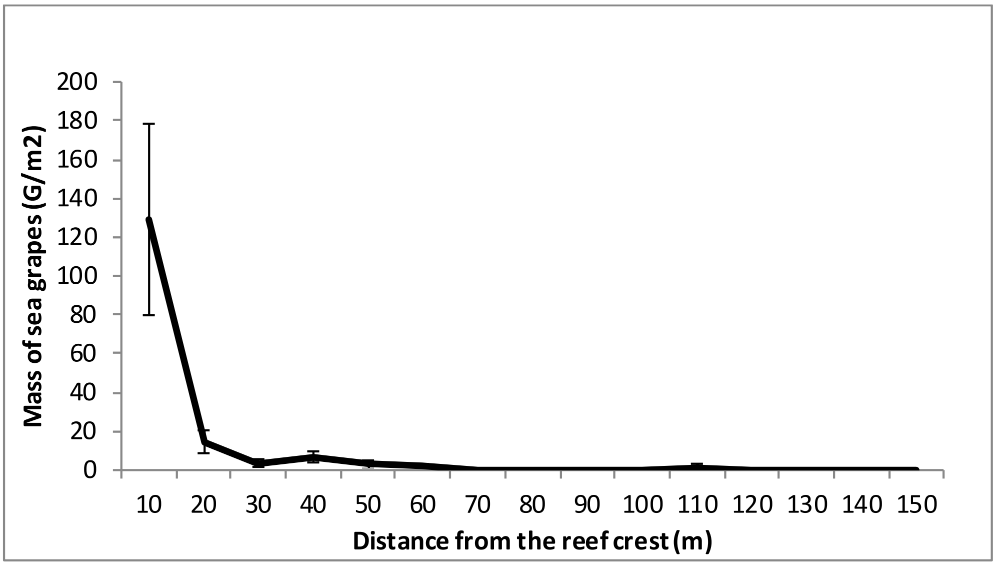
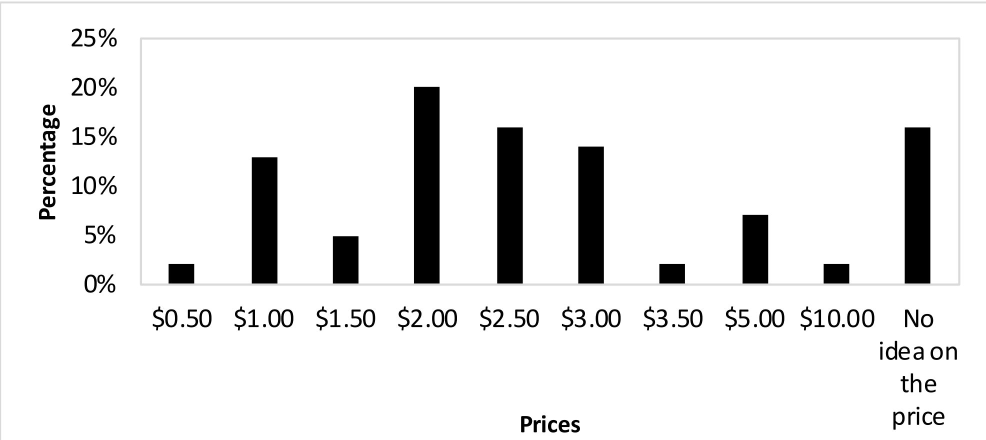


Figure 3



Imran Lapong: Evaluation of the brine preservation method of sea grapes (*Caulerpa lentillifera*)

Abstract: Species of sea grapes (*Caulerpa* spp.) are consumed broadly in many regions such as in Southeast Asia and Pacific areas. However, it damages easily if packed incorrectly and may only last for couple of days. One of the options to extend the shelf life of *Caulerpa* is using brine as a preservation method, and a company in Vietnam (Tritin Pty Ltd) has developed a preservation technique for sea grapes that enables export to many countries. The first aim of this study is to evaluate this commercial product in relation to the preservation materials, the preserved product biomass, individual weight and length of the fronds, and the effect of soaking time and water temperatures on the frond "crispiness". The second aim of this study is to evaluate two different brine concentration 10% (100 g/L) and 15% (150 g/L) for the preservation of *Caulerpa* including their effects on the weight of the preserved fronds (the edible portion), the physical characteristics of the fronds over preservation time (frond "crispiness"), and finally the mineral content analysis of the brine solutions used compared to a commercial product.

The study found that the commercial product based on a 10% brine concentration (114.33 g/L ±2.30 SD). The average weight of each sachet package is 22.47 g ±0.37 containing 65 fronds of *Caulerpa lentillifera*. The average weight and length of the fronds is 0.73 g ±2.30 SD and 7.27 cm ±1.59 SD. There was a significant relationship between the weight and the length of the fronds during the rehydration process in freshwater ($R^2=0.35$, $p<0.01$), with rehydration of weight and length complete after x seconds. However, there was no significant difference between different soaking times (from 30s to 2 minutes) on the weight and the length of the fronds ANOVA ($p=0.88$) and ($p=0.81$) after the initial period. Furthermore, tap water and ice water treatments during rehydration process had no significant effect on the fronds crispiness (ANOVA $p=0.560$).

There were significant differences between the initial and final weights of the fronds, with the weight loss of the fronds using 10% brine decreasing between 1, 5, 10, and 20 days of preservation respectively by 2.55%, 11.61%, 25.57%, and 40.23% of the initial weight. Similarly, in 15% brine, the weight loss of the fronds respectively are 2.37%, 12,38%, 24.03%, and 39.25%, and there were no differences between the two brine treatments. There was a significant different between 10% and 15% brine on the crispiness of the product, as determined by the rigidity of the fronds, but there was no effect of preservation time on this same characteristic.

These results show that the preserved product using high concentration of brine produces a product with consistent biomass, size, and amount of the fronds. However, the temperature of the freshwater used in rehydration has no effect on the quality of the product, in contrast to the claims made by the company on the packaging instructions. The second experiment showed that brine solutions of 10% and 15% had similar physical effects on *Caulerpa* preservation, and that the higher brine concentration was better suited for "crispiness" of the fronds.

Selected figures:

Figure 1. The weight and length of the fronds with the frequency.

Figure 2. The weight of the fronds in the different soaking time (mean ±SE)

Figure 3. a. The angle formed by a frond (preserved at 10% brine) at 5 minutes after soaked in the tap water. b. The angle formed by a frond (preserved at 15% brine) at 5 minutes after soaked. Frond in figure **a** has a smaller angle (flaccid) than a frond in figure **b** (rigid).

Figure 4. The angles formed by the fronds in the different times after 3 minutes soaked in the tap water and 3 minutes in the tap plus 3 minutes in the ice water (mean ±SE). Column with the same letters are not significant.

Figure 5. Frond weight loss from preservation days in two different brine solutions

Figure 1

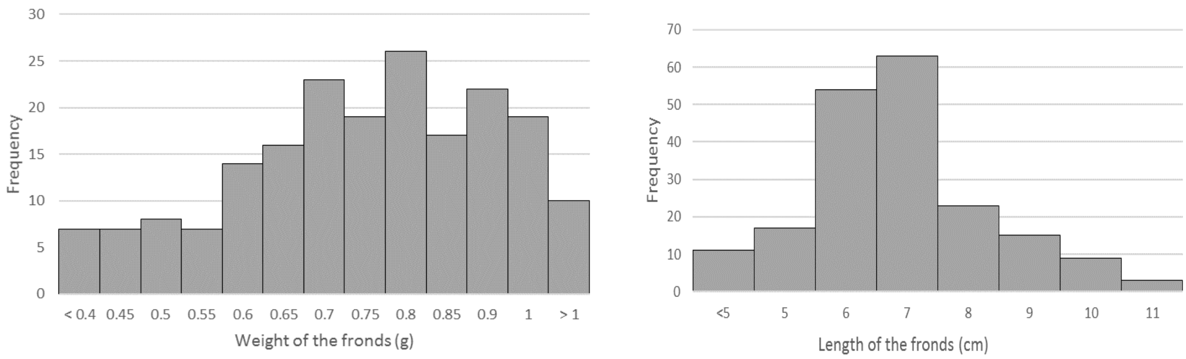


Figure 2

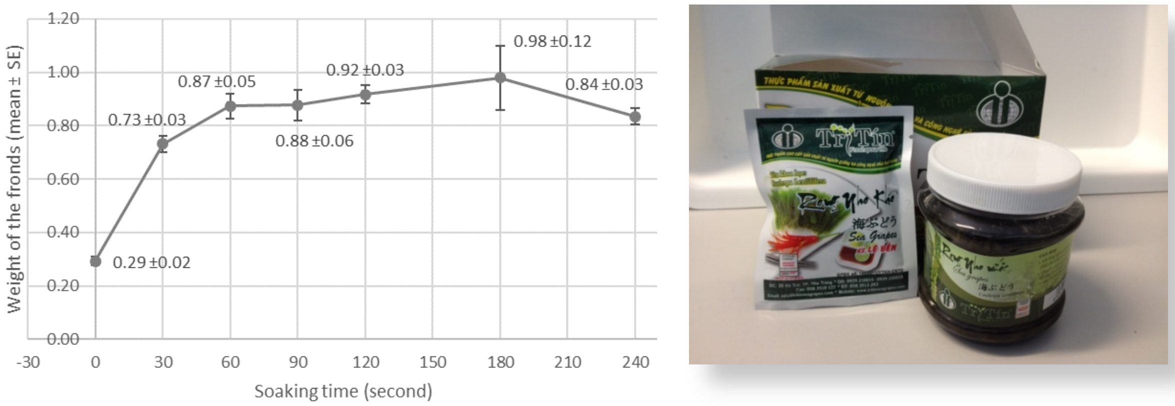


Figure 3

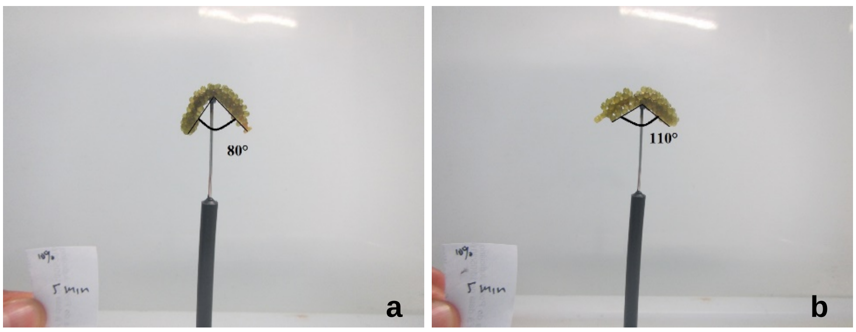


Figure 4

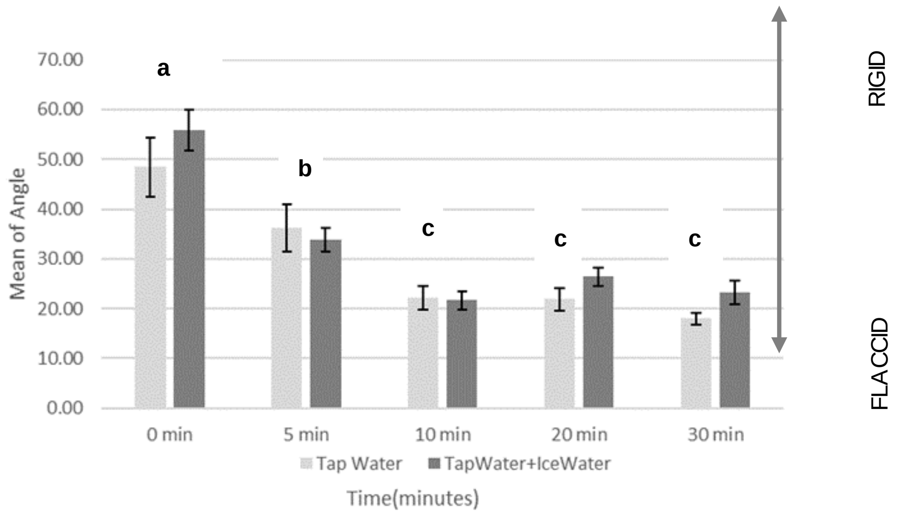
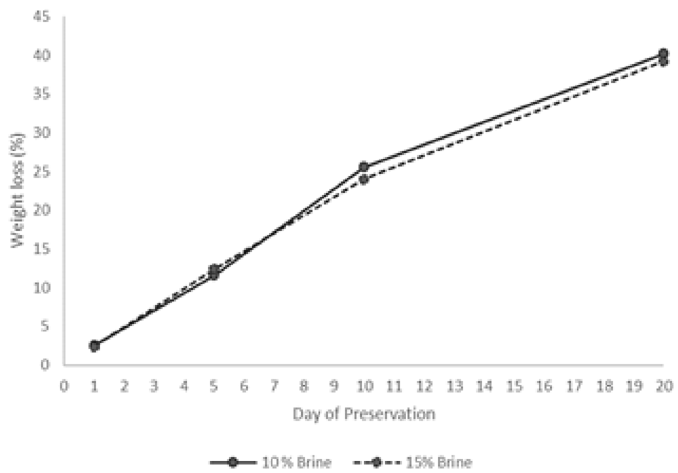


Figure 5



Mr Ian Tuart, James Cook University.

Environmental tolerances for production of the commercially important red seaweed *Gracilaria edulis* and *Sarconema filiforme* in tropical Australia

Abstract

Agar and carrageenan gels (hydrocolloids) from red seaweeds are critical in the food industry to maintain the functional properties of processed foods. In coastal marine environments of tropical Australia, where such seaweeds could be cultured, the environment is highly variable. This therefore requires robust seaweeds to be selected. *Gracilaria edulis* and *Sarconema filiforme* are potential candidates because their hydrocolloids (agar and carrageenan, respectively) have established markets, however, fundamental knowledge of the influence of salinity and temperature upon their growth and the biochemistry is lacking. This study evaluates the effects of environment on the production of these seaweeds and their hydrocolloid content. *Gracilaria* had a peak biomass productivity of 7.44g dry weight (dw) m^{-2} d^{-1} 30 ppt, more than 50% higher than *Sarconema*. *Sarconema* was less affected by salinity, with a relatively stable biomass production between 20 and 40 ppt. Both species were negatively affected by extreme salinities, 15 ppt and 45 ppt. Aside from species-specific differences, the biochemical composition of both species was reasonably stable, although there were some effects of low salinity on protein and ash contents. Under these conditions, *Sarconema* had a higher hydrocolloid content (54% dw, experiment-wide) than *Gracilaria* (45% dw). Neither salinity nor temperature influenced hydrocolloid content. Relatively stable biomass production (within 20 and 40 ppt) and stable hydrocolloid contents are desirable properties for domestication and aquaculture production. Furthermore, the content of nitrogen was also stable which enables other applications of seaweed to be considered simultaneously, such as bioremediation of nutrient-rich waste water. Most of the future potential for Australian aquaculture is in land-based aquaculture of prawn and fish, where there is a pressing need to provide economically viable treatment of waste water. This could be achieved with the production of a high value seaweed yielding >$500 per hectare from seaweed gels with potential an additional value of >$50 per hectare from waste water treatment.

Selected figures:

Figure 1. Mean Hydrocolloid productivity for *Gracilaria* = blue and *Sarconema* = red, during week 3, for all temperature treatments combined.

Figure 2. Mean bioremediation potential for *Gracilaria* (blue) and *Sarconema* (red) during week 3. Note both temperature treatments are pooled.

Figure 1

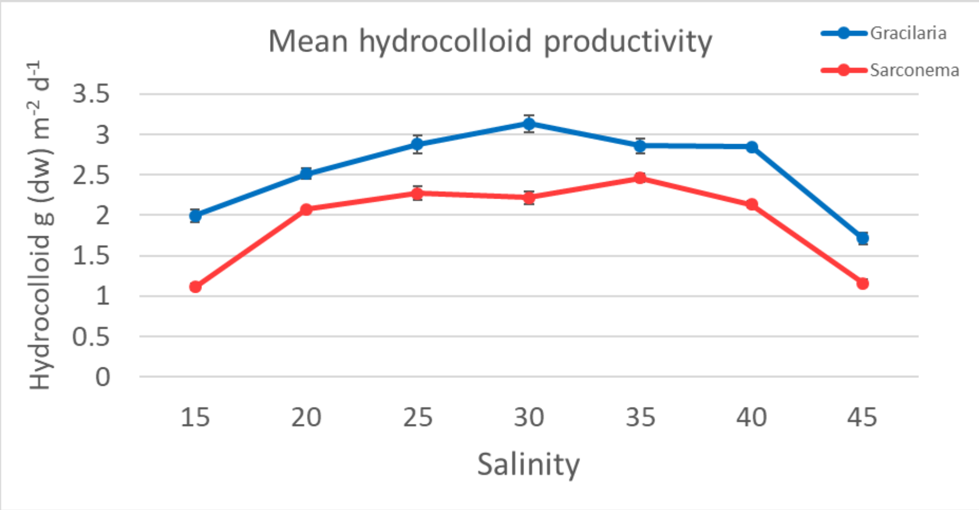
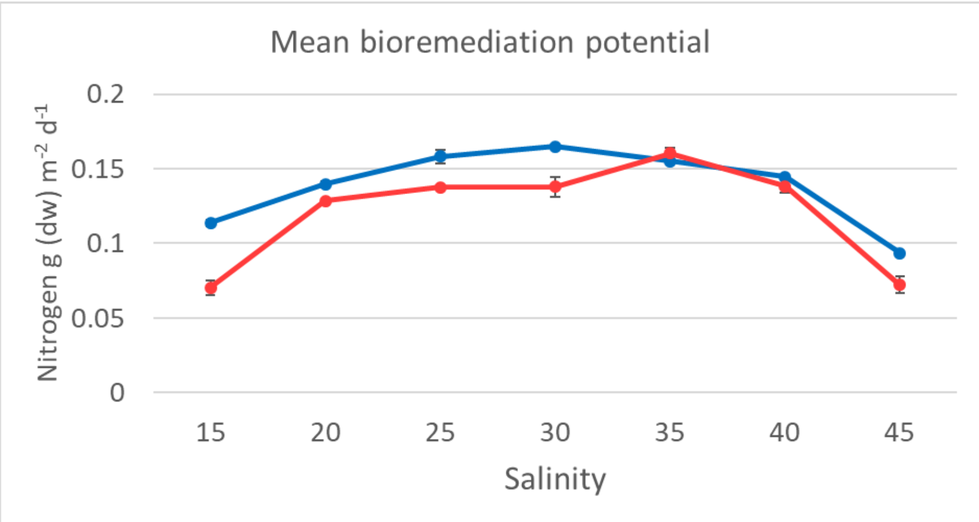


Figure 2



11.8 Appendix 8: Product data sheets

The following product data sheets have been assembled from the pivot table of biochemical composition and biomass quality for the project across all countries. Full database including additional information on sites, collection dates, handling methods and individual replicates is open access at: http://dx.doi.org/10.25907/5e13b12523e43

1. *Kappaphycus* Fiji (2 pages)
2. *Kappaphycus* Kiribati
3. *Caulerpa* Fiji
4. *Caulerpa* Samoa
5. *Hypnea* Fiji

6. *Gracilaria* (*Hydropuntia*) Fiji
7. *Ulva* Fiji
8. *Ulva* Kiribati
9. *Acanthophora* Kiribati
10. Tomatoes – seaweed compost trial - Kiribati

Diversification of Seaweed Industries in Pacific Island Countries

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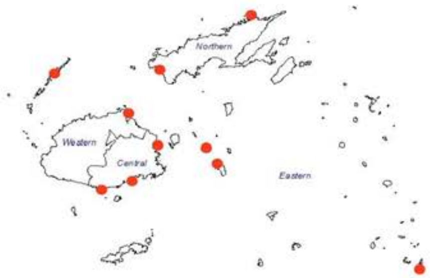
Kappaphycus alvarezii
Fiji



2015-2016 Market Survey			
Sample as received	**Mean**	**± SD**	**n**
Moisture content (% of DW)	22.3	6.2	17

Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	40.09	-	-
Protein[2]	1.46	0.50	16
Lipid	0.47	0.35	10
Ash	54.41	11.02	29
Moisture	3.57	2.02	29

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture.
[2] Protein content calculated using the seaweed conversion factor of N x 5

Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	16.44	3.59	16
Nitrogen	0.29	0.10	16
Phosphorous	0.03	0.01	15
Sulphur	3.73	0.69	16
C:N	67.77	42.60	16
N:P	10.76	2.98	13

Fibre content	Mean [g/100g]	± SD	n
Insoluble	2.55	0.49	2
Soluble	34.60	3.11	2
Total	37.15	2.62	2

Mineral Content	Mean [mg/kg]	± SD	n
Aluminium	147.38	231.83	16
Arsenic	4.74	1.71	16
Boron	138.88	36.86	16
Barium	0.61	0.61	5
Calcium	4,310.50	2,485.24	16
Cadmium	0.13	0.11	12
Cobalt	1.51	1.78	16
Chromium	8.36	8.98	15
Copper	1.97	1.93	16
Iron	434.63	388.80	15
Mercury	<0.01	0.13	11
Potassium	171,681.94	43,258.01	16
Magnesium	5,188.44	978.81	16
Manganese	8.19	8.48	16
Molybdenum	2.88	4.20	11
Sodium	35,536.56	8,778.57	16
Nickel	9.21	9.86	15
Lead	<0.5	0.03	14
Selenium	<1.00	1.18	13
Vanadium	1.78	1.37	16
Zinc	13.75	15.52	14

Amino Acids	Mean [mg/kg]	± SD	n
Histidine	0.09	0.01	2
Serine	0.80	0.01	2
Arginine	0.83	0.01	2
Glycine	0.80	0.02	2
Aspartic acid	1.71	0.03	2
Glutamic acid	1.80	0.03	2
Threonine	0.84	0.01	2
Alanine	0.92	0.01	2
Proline	0.70	0.01	2
Lysine	0.61	0.01	2
Tyrosine	0.20	0.01	2
Methionine	0.21	0.00	2
Valine	1.06	0.02	2
Isoleucine	0.79	0.01	2
Leucine	1.25	0.03	2
Phenylalanine	0.82	0.01	2

Fatty Acids	Mean [mg/kg]	± SD	n
C14:0	0.25	0.02	2
C16:0	1.25	0.09	2
C16:1	0.35	0.01	2
C16:3	0.68	0.06	2
C18:3	0.39	0.02	2
Sum fatty acids	**2.92**	**0.10**	**2**

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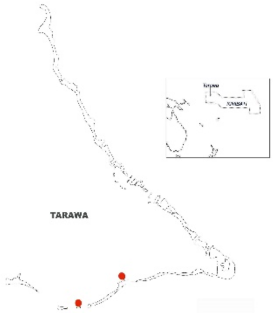
Kappaphycus alvarezii

Kiribati



Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	40.66	-	-
Protein[2]	1.99	0.54	9
Lipid	0.31	0.37	2
Ash	52.26	6.61	16
Moisture	4.78	2.43	14

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture.

[2] Protein content calculated using the seaweed conversion factor of N x 5

Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	15.26	4.02	11
Nitrogen	0.40	0.11	9
Phosphorous	0.03	0.02	10
Sulphur	3.71	0.79	9
C:N	41.37	13.44	9
N:P	13.40	7.80	9

Fibre content	Mean [g/100g]	± SD	n
Insoluble	3.65	0.49	2
Soluble	46.40	4.38	2
Total	49.95	4.74	2

Mineral Content	Mean [mg/Kg]	± SD	n
Aluminium	5.11	6.74	8
Arsenic	6.50	3.91	9
Boron	165.75	54.31	8
Barium	0.43	0.16	2
Calcium	6,385.56	2,669.67	9
Cadmium	0.41	0.20	9
Cobalt	<0.10	-	7
Chromium	2.63	3.05	9
Copper	0.87	0.49	9
Iron	103.36	148.18	9
Mercury	<0.01	-	6
Potassium	152,496.00	66,151.39	9
Magnesium	5,993.33	1,296.74	9
Manganese	2.34	1.23	8
Molybdenum	0.92	0.91	5
Sodium	42,250.00	2,803.06	8
Nickel	1.59	2.19	9
Lead	0.15	0.07	5
Selenium	4.24	2.75	3
Strontium	100.35	44.76	2
Vanadium	1.42	1.09	8
Zinc	11.73	5.00	8

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Caulerpa sp.

Fiji

2015-2016 Market survey			
Sample as received	**Mean**	**± SD**	**n**
Price (FJD/kg)	12.25	2.33	55
Portion size (g/plate)	168.11	27.67	55
FW:DW	15.8:1	2.45	55

Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	22.68	-	-
Protein[2]	5.01	1.51	21
Lipid	2.49	0.89	6
Ash	62.27	7.48	74
Moisture	7.55	2.41	73

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture.
[2] Protein content calculated using the seaweed conversion factor of N x 5

Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	11.61	3.55	21
Nitrogen	1.00	0.30	21
Phosphorous	0.08	0.03	20
Sulphur	1.78	1.13	11
C:N	11.64	1.22	21
N:P	12.46	4.80	19

Fibre content	Mean [g/100g]	± SD	n
Total	18.00	2.43	3

Mineral Content	Mean [mg/Kg]	± SD	n
Aluminium	239.00	307.84	20
Arsenic	11.57	4.88	20
Boron	47.79	47.79	11
Barium	0.31	0.31	1
Calcium	22,987.50	12,357.46	20
Cadmium	0.05	0.01	12
Cobalt	0.40	0.45	10
Chromium	3.56	3.95	19
Copper	1.37	1.14	20
Iron	322.42	376.68	19
Mercury	<0.10	-	19
Potassium	9,040.56	2,387.45	18
Magnesium	9,113.50	3,653.20	20
Manganese	12.34	8.57	11
Molybdenum	<0.50	-	8
Sodium	161,764.64	74,340.91	11
Nickel	0.82	0.43	18
Lead	0.10	0.09	9
Selenium	7.53	2.61	10
Vanadium	1.34	1.21	11
Zinc	3.96	3.59	14

Diversification of Seaweed Industries in Pacific Island Countries

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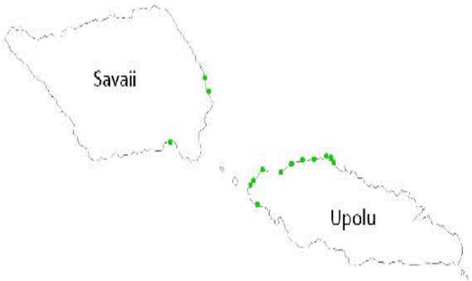
Caulerpa sp.

Samoa



Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	22.11	-	-
Protein[2]	4.14	1.48	14
Lipid	2.05	0.59	9
Ash	66.37	7.02	59
Moisture	5.33	2.80	59

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture in individual samples.
[2] Protein content calculated using the seaweed conversion factor of N x 5

Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	9.51	3.28	14
Nitrogen	0.83	0.30	14
Phosphorous	0.09	0.02	14
Sulphur	0.89	0.18	4
C:N	11.55	1.16	14
N:P	9.78	4.12	14

Fibre content	Mean [g/100g]	± SD	n
Total	18.85	-	1

Mineral Content	Mean [mg/Kg]	± SD	n
Aluminium	489.10	745.87	14
Arsenic	12.89	5.54	14
Boron	44.25	17.50	4
Calcium	45,414.29	34,776.03	14
Cadmium	0.09	0.04	13
Cobalt	0.83	0.81	3
Chromium	7.61	5.61	14
Copper	1.77	0.91	14
Iron	1,026.34	1,433.52	14
Mercury	<0.01	-	13
Potassium	8,930.71	2,122.72	14
Magnesium	6,420.71	1,618.58	14
Manganese	37.31	35.31	4
Molybdenum	<0.50	-	4
Sodium	234,271.00	38,389.67	4
Nickel	2.96	3.05	14
Lead	0.55	0.43	11
Selenium	8.95	1.22	10
Vanadium	3.97	3.37	3
Zinc	6.42	4.44	7

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Hypnea cornuta

Fiji

2015-2016 Market Survey

Sample as received	Mean	± SD	n
Price (FJD/kg)	14.8	7.3	24
Portion size (g/plate)	173.0	97.8	24
FW:DW	8.4:1	1.6	24

Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	32.98	-	-
Protein[2]	4.78	0.73	9
Lipid	0.60	0.73	4
Ash	55.57	5.40	35
Moisture	6.07	2.11	36

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture.
[2] Protein content calculated using the seaweed conversion factor of N x 5 (Angell et al. 2016)

Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	16.74	0.76	9
Nitrogen	0.96	0.15	9
Phosphorous	0.10	0.01	9
Sulphur	6.79	0.71	9
C:N	17.90	3.13	9
N:P	9.40	1.62	9

Fibre content	Mean [g/100g]	± SD	n
Total	32.63	0.59	3

Mineral Content	**Mean [mg/kg]**	± SD	**n**
Aluminium	1,354.11	428.18	9
Arsenic	7.73	1.80	9
Boron	217.78	23.86	9
Calcium	16,022.22	9,626.24	9
Cadmium	0.20	0.09	9
Cobalt	0.55	0.22	9
Chromium	3.22	1.40	9
Copper	3.32	1.04	9
Iron	1,494.44	523.76	9
Mercury	0.02	0.01	9
Potassium	35,666.67	5,722.76	9
Magnesium	6,288.89	419.66	9
Manganese	28.39	8.45	9
Molybdenum	0.52	0.01	9
Sodium	142,229.89	9,955.85	9
Nickel	1.77	0.66	9
Lead	<0.5	-	9
Selenium	<1	-	9
Vanadium	4.52	1.20	9
Zinc	7.04	5.71	9

Diversification of Seaweed Industries in Pacific Island Countries

Gracilaria edulis

Fiji

Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	35.01	-	-
Protein[2]	4.72	1.49	16
Lipid	1.05	0.11	5
Ash	53.52	5.93	26
Moisture	5.70	3.00	31

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture.
[2] Protein content calculated using the seaweed conversion factor of N x 5

Mineral Content	Mean [mg/kg]	± SD	n
Aluminium	389.44	239.75	16
Arsenic	8.94	1.81	16
Boron	413.81	133.37	16
Barium	1.19	1.43	2
Calcium	15,260.63	11,347.62	16
Cadmium	0.11	0.09	11
Cobalt	0.32	0.16	13
Chromium	1.99	0.97	16
Copper	1.95	1.12	16
Iron	455.45	308.49	16
Mercury	0.18	0.23	2
Potassium	132,750.69	65,097.53	16
Magnesium	4,621.88	1,003.89	16
Manganese	55.83	36.66	16
Molybdenum	1.90	1.85	5
Sodium	37,789.07	30,057.81	15
Nickel	1.37	0.39	16
Lead	0.40	0.49	2
Selenium	4.99	2.76	4
Vanadium	45.07	38.64	15
Zinc	10.01	5.43	16

Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	19.57	4.74	16
Nitrogen	0.94	0.30	16
Phosphorous	0.09	0.02	16
Sulphur	5.77	1.17	16
C:N	21.93	6.57	16
N:P	10.95	3.11	16

2015-2016 Market Survey

Sample as received	Mean	± SD	n
Price (FJD/kg)	7.4	1.3	9
Portion size (g/plate)	277	48.9	9
FW:DW	8.5:1	2.8	9

Fibre content	Mean [g/100g]	± SD	n
Total	32.58	7.78	4

Diversification of Seaweed Industries in Pacific Island Countries

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Ulva meridionalis

Fiji

2015-2016 Market Survey

Sample as received	Mean	± SD	n
Price (FJD/kg)	7.8	1.6	9
Portion size (g/plate)	269.3	65.0	9
FW:DW	13.5:1	3.0	9

Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	49.02	-	-
Protein[2]	6.97	1.22	3
Lipids	1.41	1.11	8
Ash	32.42	2.50	14
Moisture	10.18	1.96	14

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture.

[2] Protein content calculated using the seaweed conversion factor of N x 5

Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	25.37	0.50	3
Nitrogen	1.39	0.24	3
Phosphorous	0.14	0.02	3
Sulphur	4.57	0.46	3
C:N	18.54	2.96	3
N:P	9.72	0.70	3

Fibre content	Mean [g/100g]	± SD	n
Total	49.10	-	1

Mineral Content	Mean [mg/Kg]	± SD	n
Aluminium	1,991.67	351.96	3
Arsenic	2.27	0.49	3
Boron	206.67	15.28	3
Calcium	10,000.00	0.00	3
Cadmium	<0.5	-	3
Cobalt	1.80	0.44	3
Chromium	8.33	1.30	3
Copper	7.57	2.12	3
Iron	2,666.67	513.16	3
Mercury	<0.01	-	3
Potassium	32,666.67	5,507.57	3
Magnesium	24,000.00	2,645.75	3
Manganese	132.47	40.87	3
Molybdenum	<0.5	-	3
Sodium	26,333.33	7,767.45	3
Nickel	7.17	1.00	3
Lead	2.28	2.43	2
Selenium	<1	-	3
Vanadium	7.20	1.15	3
Zinc	9.63	1.58	3

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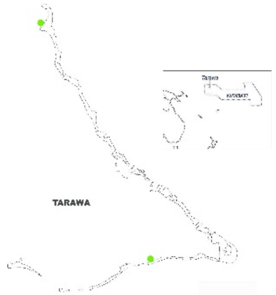
Ulva sp.

Kiribati



Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	17.71	-	-
Protein[2]	6.20	3.54	4
Lipid	0.81	0.39	5
Ash	71.88	9.78	8
Moisture	3.40	0.61	6

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture.
[2] Protein content calculated using the seaweed conversion factor of N x 5

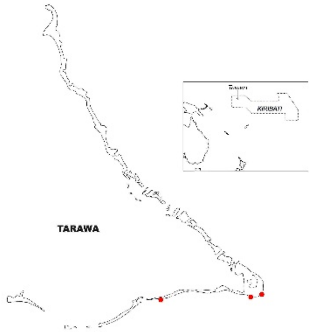
Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	17.91	1.93	4
Nitrogen	1.24	0.71	4
Phosphorous	0.10	0.02	4
Sulphur	2.01	1.15	2
C:N	21.82	18.82	4
N:P	13.74	7.64	4

Mineral Content	Mean [mg/Kg]	± SD	n
Aluminium	43.47	65.30	4
Arsenic	9.57	3.32	4
Boron	225.50	30.4	2
Barium	3.09	0.55	2
Calcium	136,750.00	49,748.50	4
Cadmium	0.49	0.56	4
Cobalt	0.28	0.07	2
Chromium	5.36	2.81	4
Copper	5.36	3.04	4
Iron	439.15	342.07	4
Mercury	<0.50	-	4
Potassium	36,000.00	15,411.90	4
Magnesium	16,052.50	6,788.30	4
Manganese	6.92	3.85	2
Molybdenum	2.84	3.63	2
Sodium	37,300.00	3,111.30	2
Nickel	4.45	2.40	4
Lead	3.10	3.03	4
Selenium	5.54	2.38	4
Strontium	2,745.00	558.61	2
Vanadium	5.05	3.66	2
Zinc	16.34	9.39	4

Diversification of Seaweed Industries in Pacific Island Countries

Acanthophora sp.

Kiribati



Proximate composition	Mean [% of DW]	± SD	n
Carbohydrate[1]	27.26	-	-
Protein[2]	4.91	0.66	4
Lipid	0.31	0.22	3
Ash	62.93	4.70	9
Moisture	4.59	1.08	8

[1] Carbohydrates estimated by subtraction of protein, lipids, ash and moisture.

[2] Protein content calculated using the seaweed conversion factor of N x 5

Ultimate Elemental Composition	Mean [% of DW]	± SD	n
Carbon	16.25	0.41	4
Nitrogen	0.98	0.13	4
Phosphorous	0.07	0.02	4
Sulphur	3.26	0.44	4
C:N	16.77	2.07	4
N:P	14.82	5.23	4

Fibre content	Mean [g/100g]	± SD	n
Total	25.05	0.21	2

Mineral Content	Mean [mg/kg]	± SD	n
Aluminium	8.61	3.57	4
Arsenic	5.46	1.60	4
Boron	403.75	121.89	4
Barium	1.31	-	1
Calcium	94,125.00	46,580.35	4
Cadmium	0.38	0.11	4
Cobalt	<0.10	-	4
Chromium	2.52	0.72	4
Copper	1.76	0.39	4
Iron	222.15	87.23	4
Mercury	<0.01	-	4
Potassium	59,850.00	8,038.86	4
Magnesium	14,175.00	665.21	4
Manganese	4.97	1.07	4
Molybdenum	<0.50	-	4
Sodium	51,175.00	7,636.92	4
Nickel	2.48	1.19	4
Lead	0.65	0.12	4
Selenium	12.36	12.64	4
Strontium	1,380.00	-	1
Vanadium	1.91	0.72	4
Zinc	11.05	5.12	4

Diversification of Seaweed Industries in Pacific Island Countries

Compost trial - Kiribati

Acanthophora sp.

Tomato sp.

Acanthophora sp.

Compost material from *Acanthophora* sp.

Tomato plants growing in algae compost material

Tomatoes grown from algae compost material

Mineral Content	*Acanthophora sp.* (n=4) Mean [mg/Kg]	*Tomato sp.* (n=4) *Grown from algae compost* Mean [mg/Kg]	*Tomato sp.* (n=3) *Local market purchased* Mean [mg/Kg]
Aluminium	8.61	<0.5	2.43
Arsenic	5.46	<0.5	<0.5
Boron	403.75	22.98	16.03
Barium	1.31	0.41	0.20
Calcium	94,125.00	2,128.58	1,433.26
Cadmium	0.38	0.38	0.13
Cobalt	<0.10	0.10	<0.1
Chromium	2.52	0.85	<0.1
Copper	1.76	11.30	9.08
Iron	222.15	70.07	47.63
Mercury	<0.01	<0.1	<0.1
Potassium	59,850.00	28,622.94	22,008.08
Magnesium	14,175.00	1,780.38	1,287.45
Manganese	4.97	23.58	13.10
Molybdenum	<0.50	0.56	1.23
Sodium	51,175.00	535.70	797.66
Nickel	2.48	<0.1	2.58
Phosphorous	705.50	4,675.12	4,205.55
Lead	0.65	0.10	0.11
Sulfur	32,575.00	1,733.12	1,481.80
Selenium	12.36	2.50	<0.5
Strontium	1,380.00	18.50	12.07
Vanadium	1.91	0.08	<0.1
Zinc	11.05	37.90	27.42

11.9 Appendix 9: Communication and Dissemination

SWOT Analysis – Seaweed Industry in the Pacific Islands (Project Workshop and Final Review; June, 2017). Groups 1 – 4 indicated (7-9 participants in each group from 5 different countries: Fiji, Samoa, Kiribati, Australia, PNG). See summary word cloud in Section 8.4.

STRENGTHS		**WEAKNESSES**	
Group 1	***Group 2***	***Group 1***	***Group 2***
1. Excellent environment 2. Availability of a variety of species 3. Government support 4. History of traditional uses of seaweed and culturing (kappa) 5. Low technology 6. Community inclusive e.g. higher age and gender 7. No need for cold storage	1. Source of income and livelihood 2. Community based project 3. Quick turnover 4. Knowledge and skills available 5. Support from national govern 6. Opportunities for private sector in post-harvest production 7. Simple technology for growing 8. Improved natural habitat 9. Used as part of diet 10. Potential to make bi-products 11. Bring communities together 12. Capacity building 13. Access to resources - coastal areas 14. Traditional edible resource 15. Resource availability e.g. planting material, seed	1. Vulnerable to natural disasters 2. Volatile global market 3. Low market price for unprocessed products 4. Remoteness from major market 5. Bulky products transportation and storage issues 6. High value species cannot be cultured 7. No disaster preparation capability (seed, secure standing stock) 8. Overexploitation of seaweed fishery	1. Price fluctuation 2. Upscaling issues 3. Insufficient nurseries 4. Isolation 5. Freight cost 6. Lack of interest 7. Lack of awareness and production skills 8. Lack of knowledge and skills for value adding 9. Lack of funding 10. Short shelf life for some species e.g. *Caulerpa* 11. Lack of research on indigenous species 12. Poor processing and handling to produce high quality product
Group 3	***Group 4***	***Group 3***	***Group 4***
1. Seaweed is an existing commodity 2. Low cost farming techniques and infrastructure 3. Fast growing crop	1. Community interest 2. Gov. support opportunity 3. Easy to grow 4. Low effort 5. Women empowerment 6. Income generation	1. Sustainability of industry without external (government, donors) support 2. Price fluctuations 3. High transportation cost	1. Transport constraints 2. Limited availability of edible algae products in Nadi 3. Low production

STRENGTHS		WEAKNESSES	
4. Goog water quality (seawater) 5. Seed stock ready available 6. Easily manageable and diversity 7. Expertise and skills available 8. Less post-harvest/labour work 9. Environmentally friendly means of storage	7. Support coastal livelihood and food security 8. Resilient/quick recover post-disaster 9. Multi applications 10. Readily available – wild harvest 11. Historically used and consumed 12. Health benefits 13. Easy to research	4. Lack of Business skills 5. Poor natural disaster/emergency response plan 6. Low volume and Inconsistent market	4. Weather constraints – harvest 5. Cost of importing equipment for culturing 6. Price fluctuation 7. Post-harvest loses Perishable
OPPORTUNITIES		**THREATS**	
Group 1 1. Increasing consumer demand 2. Value adding e.g. new products 3. Clean and green 4. Opportunities for training	***Group 2*** 1. Trade 2. Healthy food 3. Source of food 4. Can develop new products locally Carbon and environmental credit	***Group 1*** 1. Climate change 2. New diseases 3. Non-tariff barriers to trade, especially live fresh seaweed	***Group 2*** 1. Natural disaster 2. Disease 3. Market and competition 4. Other income source 5. Marine tenure
Group 3 1. Novel value adding (e.g. nama vodka) 2. Bioproducts (e.g. organic fertiliser to improve other crops) 3. Growing seaweed industry 4. Maximise income for communities/farmers 5. Employment opportunities	***Group 4*** 1. New product development and export e.g. preserved nama 2. Preserved product (nama) can make more seaweed dishes: hotel and resort menus, seaweed tourism 3. New bio-products e.g. biochar (health, wellness, and agriculture)	***Group 3*** 1. Natural disasters 2. Global warming 3. Pollution 4. Reluctance of private sectors to be involved 5. High dependency on government and donors' support (financial and monitoring)	***Group 4*** 1. Natural disasters 2. Disease and pests 3. Unsustainable harvesting practices 4. Global market price – export 5. Government policies 6. Food safety