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Final report

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Acronyms and abbreviations

ACIAR	Australian Centre for International Agricultural Research
AMAFRAD	Agency for Marine and Fisheries Research and Development (Ministry of Marine Affairs and Fisheries, Indonesia) [previous agency – BaLitBang]
AMFRHR	Agency for Marine and Fisheries Research and Human Resources (duration of project, Ministry of Marine Affairs and Fisheries, Indonesia) [agency for duration of project]
ASPERLI	Asosiasi Pembudidaya Rumput Laut - Indonesian Seaweed Farmers and Processors Association
ASTRULI	Asosiasi Industri Rumput Laut - Indonesian Seaweed Industry Association
ARLI	Asosiasi Rumput Laut - Indonesian Seaweed Association
BBRP2BKP "Biotek"	Balai Besar Riset Pengolahan Produk dan Bioteknologi Kelautan dan Perikanan - Research Institute for Marine and Fisheries Product Competitiveness and Biotechnology (Jakarta, Indonesia) [Biotek for duration of project]
BPBAP	Balai Perikanan Budidaya Air Payau - Brackishwater Aquaculture Development Centre (two centres: Takalar, South Sulawesi and Ujung Batee, Aceh)
BRIN	Badan Riset dan Inovasi Nasional (National Agency for Research and Innovation, Indonesia)
COVID-19	coronavirus disease
GoI	Government of Indonesia
KKP	Kementrian Kelautan dan Perikanan (Ministry of Marine Affairs and Fisheries, Indonesia)
LPPBRL "Loka"	Loka Riset Budidaya Rumput Laut - Centre for Seaweed Research (Gorontalo, Indonesia)
P3DPSB "Biotek"	Research & Development Center for Marine & Fisheries Product Competitiveness & Biotechnology [Biotek at inception of project]
R&D	research and development
R4D	research for development
SDG	Sustainable Development Goal
SGR	specific growth rate
SRA	small research activity
SME	small or medium enterprise
STITEK	Sekolah Tinggi Teknologi Kelautan - College of Marine Technology (Makassar, Indonesia)
UNHAS	Hasanuddin University (Makassar, South Sulawesi, Indonesia)
UniSC	University of the Sunshine Coast (Queensland, Australia)
VUW	Victoria University Wellington (Wellington, New Zealand)

Contents

1 Acknowledgments

We thank the Australian Centre for International Agricultural Research (ACIAR) for supporting this project. In particular we thank both the current and past Fisheries Research Program Managers Prof. Ann Fleming and Dr Chris Barlow for their support and guidance from inception through to completion, and for help in navigating the constraints and flow on effects from COVID-19.

We also thank our partners in the participating agencies. The project collaborated with four research concentrations within the Ministry for Marine Affairs and Fisheries and one national university, with ~30 core staff across the five partner organisations, which over the time of project operations were:

- Research Institute for Marine and Fisheries Product Competitiveness and Biotechnology (“Biotek”) at Jakarta;
- Research Centre for Seaweed Culture at Gorontalo (“Loka”);
- Brackishwater Aquaculture Development Centre at Takalar, South Sulawesi (Balai Takalar);
- Brackishwater Aquaculture Development Centre at Ujung Batee, Aceh (Balai Ujung Batee);
- Hasanuddin University, Makassar, South Sulawesi.

We also thank our collaborators from:

- College of Marine Technology, Makassar; and,
- Victoria University Wellington, New Zealand.

The project team would like to thank the individual seaweed farmers across Indonesia, and specifically the seaweed farming communities in South Sulawesi and the three industry associations that engaged with the project activities:

- Indonesian Seaweed Industry Association (ASTRULI);
- Indonesian Seaweed Farmers and Processors Association (ASPERLI); and,
- Indonesian Seaweed Association (ARLI).

Lastly, we would like to thank the in-country project support from the Makassar administration officers Suliyanti Hakim and Nur Samsul and centrally through ACIAR in Jakarta.

2 Executive summary

Seaweed ('rumput laut') farming in Indonesia is carried out through much of the archipelago, and mainly by smallholder farmers. Indonesia is the largest global producer of the red seaweeds *Kappaphycus alvarezii* and *Eucheuma denticulatum* (colloquially 'cottonii' and 'spinosum') which are used to produce carrageenan, and is a major producer of *Gracilaria*, used to produce agar. Seaweed farming is attractive to farmers in rural coastal communities because capital and operating costs are low, farming techniques are not technically demanding, labour requirements are relatively low (allowing farmers to engage in other livelihoods), and production cycles are short (~45 days) with the potential to provide regular income throughout much of the year. Using the reported values for seaweed-farming income we do emphasise that the farming of seaweeds can, but does not always, lift rural households above the Indonesian poverty line. This economic rationale is a major driving force behind much of the international interest in small holder farming of seaweed across tropical countries, and this finding early in the project provided important context for all subsequent work with farming communities.

In addition to the direct financial benefits of seaweed production, the project team provided new insights on the broader impacts of seaweed farming, specifically that farming contributes to human and social capitals within households and communities. Continued delivery of economic and social benefits from seaweed farming will require additional policy development, as well as technical research and development to support improved and more consistent seaweed productivity, improved product quality at farm level, provision of effective extension and technical support services, and diversification of the existing value chains to reduce the impacts of price fluctuations associated with global commodity chains. The work that the Indonesian project partners continue to conduct across these broad themes will be crucial for long-term sustainable development of the industry and the communities that rely upon them.

Seaweed innovations can provide opportunities to enhance economic, environmental and social wellbeing impacts on Indonesian coastlines and across the country. Project publications and outputs are described herein, focusing on analysing the value chains for established red seaweeds *Kappaphycus* and *Eucheuma*, understanding the socio-economic benefits for women from community-scale processing, identifying existing and emerging species of seaweed using molecular barcoding techniques and improving the quality of seaweed produced at the farm level to enhance gel yields for global commodity markets. The project also identified new product opportunities for seaweeds that can be developed domestically, developed new processing techniques and, importantly for waste management, identified innovative methods to manage processing waste streams. For example, the solid waste from agar extraction of *Gracilaria* consists of micronutrients and growth hormones with now demonstrated use as plant fertiliser, and high-value pigments and bio-salt can be pre-extracted from *Kappaphycus* at the farm prior to shipment and processing for carrageenan. These and other value-adding product innovations from the project are now being evaluated in a circular economy approach, with numerous publications and intellectual property being developed.

One of the most important contributions of the project was the provision of fundamental taxonomic information on the seaweeds being farmed in Indonesia, and the associated capacity-building provided through molecular workshops on DNA barcoding techniques. The results established, in many instances for the first time, which species are under cultivation in Indonesia, as the origins of most of the cultivars are obscure. This work confirmed that seaweed taxonomy must be based on molecular investigations, as morphological characteristics are not useful for seaweeds due to their inherent phenotypic plasticity. The outcome of this component of the project is the surety on the species being produced that is essential for marketing and for selecting superior seed stocks for farming.

A series of large and logistically challenging experiments was conducted on the farming of *Kappaphycus* across Indonesia. Discussions between the project team and farmers in some locations provided anecdotes and a perceived general trend of decreasing seaweed production. The seminal research conducted by the Loka Gorontalo (Seaweed Centre) team demonstrated inherent variability in growth rates and chemical composition of seaweeds when farmed in a standardised manner at their source locations. Furthermore, when seedstock were translocated from throughout Indonesia to a single ‘common garden’ experimental trial site in South Sulawesi, there were significant source by environment interactions with different cultivars performing differently, some better and some worse than the local cultivar over multiple cycles and across different environmental conditions. Similar insights were gained in ‘reciprocal transplant’ farm trials of *Gracilaria* cultivars from different locations (pond and sea) and of transplants of *Caulerpa* cultivars from different pond sites in South Sulawesi. To reiterate, research of this type has not been reported elsewhere in Indonesia and rarely done at scale around the world. The results and the methods developed by the project teams are fundamental for establishing effective processes for improving the growth rates and quality of the seaweed, and utilising the full breadth of cultivars available in Indonesia.

One of the main objectives of the project was to quantitatively document the socio-economic benefits of seaweed farming for communities with a focus on women. The publication outputs from this package of work are already important contributions to the global literature on seaweed farming, and being cited accordingly. These journal articles are complemented by the soon to be released ‘Makassar Seaweed Recipe’ book which provide instructions in both Bahasa and English on recipes selected by the interviewed women’s groups. This monograph has been designed to enhance the standing and growth of the women’s groups in South Sulawesi, which were both active contributors and beneficiaries in the project. Importantly, the project has identified next steps to ensure the sustainability and further development of the women’s groups.

Overall, the project was a productive, multi-disciplinary and collegial effort to understand and enhance seaweed farming and processing in Indonesia. Upon reflection, perhaps the end of project reviewers captured the essence of the team work best through their written comment that ‘the project has been perceived by stakeholders as one of Australia’s most significant contributions to Indonesian people’. The project created collaborations that are sustained to this day, as articles continue to be published and connections across the partner organisations expand through student exchange and mobility to other agencies. The disruption of COVID over the last year of operations hampered the activities on the ground, and ultimately the ability to bring farmers together to workshop the project results. However, this did provide the opportunity to publish a significant number of articles publications in national and international journals in both English and Bahasa. Members of the Biotek product team also received an Innovation Award and had a patent registered.

At the time of writing there are many global voices and relentless coverage of seaweed in the futuristic context of solving some of the most significant environmental challenges of our time. Some commentary is well founded, but most is over-simplified and makes assumptions about scale that even China and Indonesia have not achieved, with decades of learnings across business and research domains. In contemplating the next steps for seaweed initiatives, an Indonesian phrase that is relevant to fisheries comes to mind:

Tong kosong nyaring bunyinya (an empty vessel makes the most noise)

The ACIAR Indonesian Seaweed Project leaves a full vessel of rumput laut knowledge as its legacy, with 24 publications spread across all three Objectives. The outputs include 20 journal articles (15 with Indonesian first authors and 15 open access), 2 publications in Bahasa in the ‘Proceedings of the Annual National Seminar on Fisheries and Marine Products’ and significant impact through participation in national and international conferences and workshops during the project and since its completion (Appendix 1, and elsewhere). Many insights and lessons have been shared on the world stage and, at the same time, with the farmers, processors and communities within which the work took place. We look forward to the uptake of this research and helping to shape the future of global seaweed investments with the multidisciplinary lens that directed this project.

3 Background

At the time of project initiation in 2015, Indonesia was the world's second-largest producer of seaweeds, and seaweed culture is one of the few available income-generating opportunities for coastal communities in eastern Indonesia. There has been little growth in volume since this time, with approximately 10 million tonnes live weight each year, but seaweed remains a valuable commodity for Indonesia worth around US$2 billion (Appendix 2, 2019/20). The main production regions are still in eastern Indonesia: Sulawesi is responsible for over 50% of Indonesian seaweed production and Nusa Tenggara Timur province about 20%. Seaweed farming was seen as a significant income-generating option for coastal communities in eastern Indonesia: a 2008 survey indicated that there were more than 20,000 smallholder farms involved in seaweed production, and this figure has at least doubled since then, in line with production increases. Figures in 2014, were that 40,000 smallholder farms with around 120,000 people directly involved in seaweed farming (Neish 2013).

Production was predominantly of the red seaweeds *Kappaphycus* and *Eucheuma* (for carrageenan gel) and *Gracilaria* (for agar gel). Both of these products are international commodities, so the Indonesian industry suffers from the vagaries of international supply and demand. Consequently, seaweed farmers are subject to dramatic and often short-term price fluctuations, which means that they need to diversify along the value chain, i.e. in terms of types of seaweed produced, as well as processed products. It is recognized that to do this requires a fundamental understanding of the taxonomy and diversity of established and emerging species. There was both inconsistency in the reporting of species names and a limited understanding of the genetic variability of cultured strains, both of which could be addressed by molecular barcoding to enable species and strain delimitation across the major production areas.

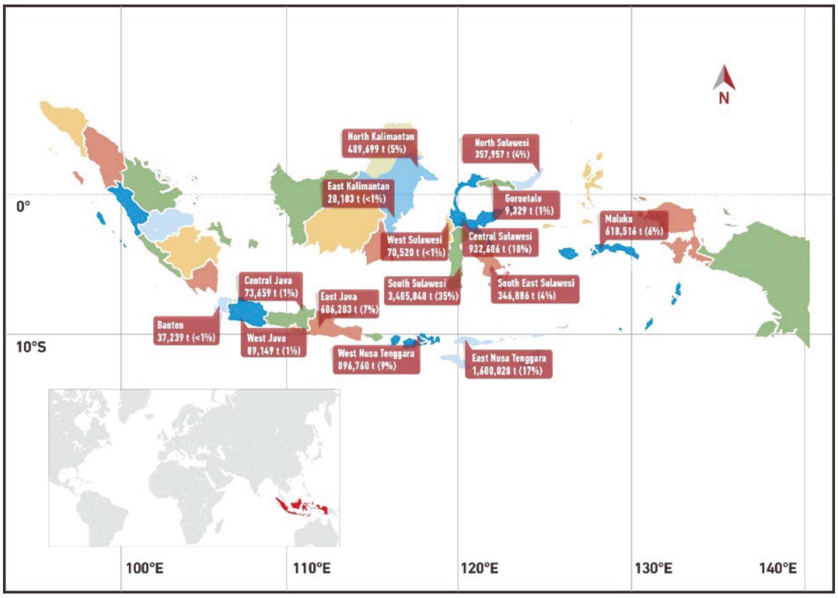


Figure 1. Map of Indonesia showing 2019 province-level seaweed production in tonnes (wet weight), and as proportion of total national volume of production. Data source: https://statistik.kkp.go.id, 2019 data for seaweed. Note that the different seaweed types are not differentiated in this data set. Provinces producing <0.1% of the national total were omitted from the map.

In August 2015, a scoping study of the Indonesian seaweed industry was undertaken to identify industry research and development needs. At the production end of the value chain, processors identified an issue of declining quality of carrageenan-producing seaweeds, particularly reduced gel strength and problems with colour of the processed product. The causes of variation in product quality and production between farming sites, and across seasons, as well as the longer-term deterioration in gel strength, are currently unidentified, although it has been suggested that the continued vegetative propagation methods used by seaweed farmers have led to reduced genetic diversity of many seaweed cultivars. The Indonesian government at the time had clearly articulated that effort for seaweed development should focus on cultivating those species of seaweed with the ability to value-add, that processing be done as close to the production areas as possible, and that a range of new products be developed to enable further growth in the industry. This intent had the highest level of support with the President of the Republic of Indonesia in *Cabinet Secretary letter No.B-16/Seskab/3/2015* indicating that the priorities were to: cultivate seaweed species that are good for processing into value-added products; develop the trading market at places which have large potential, such as South Sulawesi, Nusa Tenggara Barat, Nusa Tenggara Timur and East Java [provinces]; develop the processing industry close to the source of raw materials; and, develop growth of industry using seaweed for cosmetics, body care, drug/food supplement and food in the next 3 – 4 years. The project was developed with these government research priorities front of mind, including ‘profitable smallholder aquaculture systems’, with a focus on diversification of food products from coastal aquaculture, and the creation of ‘profitable agribusiness systems for eastern Indonesia’ by improved farming, processing and marketing systems for seaweed.

One of the key issues identified during scoping was the variation in price of the product both at the globally traded commodity value and at the wholesale trade in Makassar (Appendix 2 A-C). As context and reported here, as it was not directly a research objective, the project team monitored the maximum and minimum prices from the start to the end of the project for *Kappaphycus*. Prices ebbed and flowed during this time with peaks of 20,000 IDR/kg in January 2014 and 25,000 IDR/kg in January 2018. This was punctuated with lows of 5,000 IDR/kg and less over the period of October 2015 to May 2016. In comparison, but over a shorter period of monitoring, the *Gracilaria* dried seaweed value ranged from a one off high of 6,000 IDR/kg in November 2015 through to 3,500-4,000 IDR/kg in March 2017 over 18 months of monitoring (Appendix 2 D). At the production end of the value chain, processors had also identified an issue of declining quality of carrageenan-producing seaweeds, particularly reduced gel strength and problems with colour of the processed product. Gel strength has fallen by 25–40% over the last decade, negatively affecting marketability. The causes of variation in product quality and production between farming sites, and across seasons, as well as the longer-term deterioration in gel strength, are currently unknown.

There was a clear intent and opportunity to explore innovative products from seaweeds and their processed waste streams. At the time of the project initiation, only about 20% of seaweed processing was performed in Indonesia with the remainder processed offshore (mainly in China). The Government of Indonesia had an industry development priority to increase the proportion of seaweed processing in country, and the development of secondary and tertiary products from seaweed processing had been identified as an approach to improve the overall profitability of seaweed processing. Value-adding opportunities first needed to be identified that could be adopted in the existing seaweed supply chain through strategic research alliances with processing businesses. The processing of different types of seaweed, as well as the development of and training in new uses, were clear opportunities for research that would in turn promote increased farm production. This research would be able to support a range of activities; from ‘high-tech’ nutraceutical, pharmaceutical or cosmetic applications through to ‘low-tech’ processing of food products in villages, particularly by women’s groups. For women in particular, it was identified that there were conflicting views of the purported benefits of seaweed farming.

Taken together, the research activities described would conceivably ensure that the growth of the industry is not capped by existing supply chains and would potentially enable access to broader markets for seaweed and benefits to seaweed farmers and associated communities. Not surprisingly, this was not the first investment by ACIAR in the Indonesian seaweed industry. The work herein builds upon previous ACIAR projects including FIS/2007/124 “*Diversification of smallholder coastal aquaculture in Indonesia*” and SMAR/2008/025 – *Improved seaweed culture and postharvest waste utilisation in South-East Asia*, although neither of these projects focussed exclusively on seaweed in Indonesia. The background scoping and development of the current FIS/2015/038 project led to a general view that this area for investment would be a perfect fit for ACIAR with its guiding principle of responding to partner country priorities, as well as goals around capacity building, food security and poverty reduction, gender equity and women's empowerment, human health and nutrition, inclusive value chains, and natural resources and climate change. The knowledge gaps and research opportunities outlined sat squarely within the ACIAR Indonesian priority areas of the time: strengthening the aquaculture subsector in eastern Indonesia; providing technical research for development to support the increased production of seaweeds by developing food ingredients and access to markets; improving food and nutritional security through enhanced food quality; developing market linkages for high-value products sourced from smallholder production systems; and aligning activities within value chains.

The project also built upon significant investment by Indonesia in seaweed research and development across the archipelago. The Ministry of Marine Affairs and Fisheries (MMAF, Appendix 3) had established a dedicated seaweed research institute, based at Gorontalo in Sulawesi in 2013 (Loka Riset Budidaya Rumput Laut). This along with other MMAF agencies and universities in eastern Indonesia, provided the institutional and personnel capacity to address the major research issues around seedstock, farming practices, increasing domestic processing, new products from waste streams, expanding and securing socio-economic benefits for smallholders and especially for women, and nutritional benefits of foods incorporating seaweeds. It was identified early on that both basic (contributing to fundamental knowledge) and applied (advancing industry practices and livelihoods) research would be required to achieve these goals. The multi-disciplinary research objectives were therefore devised to address key gaps across the entire value chain.

4 Objectives

The overall aim of the project was to provide the scientific basis to transform and modernise the Indonesian seaweed industry by taking a 'whole-of-value-chain' approach to solve the key production constraints and develop diverse product opportunities.

The specific research objectives of the project were to:

1. Analyse value chains to identify constraints and knowledge gaps for seaweed production in Indonesia;
2. Improve the quality of seaweeds produced at the farm level; and
3. Create innovative products from seaweeds and their processed waste streams.

5 Methodology

The overarching R&D strategy of this project was to integrate technical R&D along the entire value chain to develop new market opportunities for seaweeds in Indonesia by enhancing the quality of farmed seaweeds and facilitating the development of emerging species of seaweed with high-value applications. This includes both low-tech and high-tech approaches to the processing of established and emerging species into new products. Some of the methodology leveraged existing ACIAR seaweed R&D: FIS/2010/098 supported the farming of one of the same species of red seaweed, *Kappaphycus* in the Pacific Islands, and linking production with processing and post-harvest quality to enhance value chains; FIS/2007/124 had trialled culture *Caulerpa* ('lawi-lawi') in coastal ponds is South Sulawesi, demonstrating the profitability of this crop and several local farmers are now engaged in producing lawi-lawi for the local market; and, SMAR/2008/025 had worked on sea-based production of *Gracilaria* and postharvest waste utilisation from carrageenan processing. Furthermore, FIS/2007/124, working with two of the current project partners in South Sulawesi, Hasanuddin University (UNHAS) and the Brackishwater Aquaculture Development Centre (BBAP) Takalar, successfully developed farmer groups to trial new aquaculture commodities in coastal ponds and worked with women's processing groups, which the present methods will build upon. For the project partners more broadly, the priority areas for R&D for each participant is captured in Appendix 3, highlighting the partnerships with government agencies and industry groups for activities under each objective.

The project used different methodologies depending on the research questions at hand, that are summarised for each objective below (see project publications [Section 10.2] for specific details).

Overarching research questions for Objective 1 (relating to value chains) were:

1. How much seaweed is produced and processed in Indonesia, where is this occurring and how is it changing over time?
2. What are the constraints in the value chain for different seaweed species
3. What are the socio-economic implications of community-scale processing of seaweed by women's groups for local markets?

Industry processors and government representatives planning for future use of seaweed require an accurate assessment of the flows within the country (Question 1). Production of the major species *Kappaphycus* and *Eucheuma* was already regularly reported for different regions (see Figure 1 and Larson et al. 2021). This component of the project instead captured new information from buyers and processors further up the supply chain. It sought to identify ways for the industry to alter the production processes and activities associated with seaweed developments to enhance their long-term financial viability. The value chain work done led by Dr Heri Purnomo engaged closely with farmers and processors across the country. It mapped the physical links in the supply chain, documenting where the seaweed is produced, how it is farmed and processed, how long it is stored and how it is distributed along the chain. It captured additional information on the contribution of economic, social and institutional factors as the project develops using quantitative and qualitative approaches (e.g. accessing government and private industry data records and conducting surveys as required), characterising the different layers within each step of the chain including initial inputs, farmers (producers), farmer groups, traders/wholesalers, processors and exporters for each case study. The FIS/2015/038 project also monitored the price of seaweed for the value chains in each case study throughout the project, as price volatility influences profit and is considered to be one of the major hurdles for growth in the industry.

As the value chains of seaweed in Indonesia are relatively short, with a small number of steps from the farm to seaweed products, the expectation was that we would be able to define the entire value chain of a range of seaweeds (Question 2). Surveys and walking the chain were used to capture the history of the industry by surveying individual farmers, where feasible, and looking to understand the seasonality of production, competition with other income-generating activities, any changes that the farmers, households and communities have experienced as the seaweed industry has grown in recent times, and their expectations of seaweed farming in the future. This covered some new species being developed during the project as well as the major varieties. One area that had received little attention was the role of women's groups in the processing and sales of seaweed products in local markets as value-adding activities. Socio-economic evaluations of community-scale seaweed processing (Question 3) were undertaken in South Sulawesi as collaborative research by UNHAS (Dr Mardiana Fachry) and Australian researchers (Dr Silva Larson, Prof Natalie Stoeckl). A series of interviews (surveys) were conducted to quantify the contribution that seaweeds make to the lives and livelihoods of communities associated with seaweed production, focusing primarily on the ability of community-scale seaweed processing by women's groups to enhance the positive effects. The surveys sought to understand the seaweed business of the women's group (e.g. earnings, volumes, prices of products etc.) as well as qualitative information on the history of the women's groups, their involvement in seaweed processing more specifically, time commitments, and the nature of any community or governmental support. The metrics used within these surveys allowed researchers to quantify some of the broader social and economic impacts of seaweed farming and processing for coastal communities. These metrics are important to document as the isolated benefits of farming activities for individuals may not necessarily outweigh the human and social costs of what can be a time consuming and physically demanding enterprise at the farm-scale (Fröcklin et al. 2012).

Overarching research questions for Objective 2 (relating to production) were:

4. How do we delimit the taxonomy of established and emerging species and what is the genetic diversity of the existing farmed strains?
5. Can the quality of *Kappaphycus* and *Eucheuma*, in terms of growth and gel strength, be enhanced through managing production?
6. How does the production and quality of *Gracilaria* vary between the two production methods of pond and sea culture?
7. Can the production of *Caulerpa* be tailored to increase product quality for access to higher value markets?

Molecular barcoding was used to delimit species and strains of all of the seaweeds currently commercially cultivated as well as emerging species, including wild-harvest species identified during the project (Question 4). DNA barcoding is an alternative approach to species identification where phenotypic plasticity is an issue for traditional taxonomy based on morphological traits (Leliaert et al. 2014). By barcoding the existing species, we were able to provide an unambiguous record of the biomass from multiple sites. This work was led by Dr Bagus Utomo (Biotek) and Prof Joe Zuccarello (Victoria University of Wellington, New Zealand) who, in previous work, has demonstrated limited genetic diversity of commercially farmed seaweeds from *Kappaphycus* and *Eucheuma* (Halling et al. 2013). Prof Zuccarello ran molecular taxonomy and strain identification workshops during the project to build capacity in this area.

Comparative studies of seaweed strains of the main species of *Kappaphycus* and *Eucheuma* (Question 5) sourced from different production areas in Indonesia were undertaken at LPPBRL Gorontalo, Sulawesi, to better understand the reported variability in domestic production. In the first instance, this included the collection of growth and product quality data from strains that are cultured in the main production areas (see Figure 1 and Simatupang et al. 2019, 2021 for more details). Then a 'common garden' experiment using farm-scale procedures was run at the seaweed demonstration site in Pangkep, South Sulawesi to compare the productivity and product quality of these strain across three commercial scale production trials measuring growth rates, semi-refined carrageenan yield and gel strength. These growth and quality data were correlated to environmental variables. Furthermore, the physical habit of the seaweeds (their colour and form) and the general health status (presence of disease such as “ice-ice” and epiphytes) were recorded throughout the experimental periods. The relationship between growth, gel quality, seaweed health and physical attributes, and the potential environmental drivers behind all of these variables, were explored as this remains one of the most vexing issues in the large-scale production of seaweeds. This series of experiments were the first of their kind to differentiate between the relative influence of strain and environment on the key commercial traits using farm practices (Pong Masak 2011). This worked leveraged the considerable investment in infrastructure at LPPBRL Gorontalo.

The farm-level production of *Gracilaria* (Question 6) and *Caulerpa* (Question 7) in South Sulawesi were evaluated in multiple trials. Firstly, for *Gracilaria*, a reciprocal transplant trial was run for *Gracilaria* strains from three ponds and three sea sites using standardised methods for the sea propagation. Secondly, for *Caulerpa*, seasonal production trials in coastal ponds were conducted using methods to attach and deploy biomass (Paul et al. 2014). These components of the project were led by BBAP Takalar (Dr Lideman and Mr Iman Sudrajat, with support from Mr Imran Lapong [STITEK]). Both sets of experiments were unfortunately subject to extreme environmental conditions (uncharacteristic wind and waves impacted sea-based production of *Gracilaria*, and rainfall impacting salinity in ponds), although some data insights were possible and are reported in the Results. BBAP Ujung Batee, Aceh, undertook smaller scale trials of *Caulerpa* production systems by way of extension of project activities to other suitable growth areas in western Indonesia. Production trials of both *Gracilaria* and *Caulerpa* quantify seasonal and daily variation in the key environmental variables and water quality sampling to identify changes in nutrient concentration and salinity in these coastal areas.

Overarching research questions for Objective 3 (relating to products) were:

8. What is the complete biochemical profile and, therefore, product potential of the key seaweeds produced in Indonesia?
9. What are the unique biochemical and morphological traits of these seaweeds and their by-products?
10. Can the waste streams from carrageenan and agar processing be used to create new products and, at the same time, generate a treated waste stream for disposal?
11. Can edible *Caulerpa* be produced and processed into products that enable access to higher value markets and international markets?
12. What seaweeds should be targeted for high value food and health applications?

The product quality of the seaweed biomass (Question 8) was assessed in all production and product work from Objectives 1 and 2. Generally, these were done through standardised analyses of the biochemical components by various partners in relation to their specific project activities (carrageenan, agar, protein, lipid etc, covered in Results). The biochemical components and physical characteristics of agar and carrageenan producing seaweed (yield, gel strength, viscosity, colour) were also important variables to compared seaweeds grown in different production areas.

Innovative products (Question 9) were evaluated by Biotek with a particular focus on the development of nutraceutical extracts (health-related compounds); and areas that was a priority for the Indonesian government. The fundamental data on the biochemical components included pigments and trace minerals, and explored novel extraction methods, such as bio-salt condensation from *Kappaphycus* led by Dr Sinngih Wibowo as a diversification of products from seaweed. Downstream processing waste streams for carrageenan (liquid waste) and agar (solid waste) were characterised (biochemical and physically) prior to its evaluation in different product applications by Biotek (Question 10).

There had been considerable work done by Mr Jamal Basmal and colleagues at P3DPSB in Jakarta, primarily on the solid waste stream from agar production, working closely with commercial processors such as PT. AgarIndo in Jakarta. This work on agricultural products (soil conditioning and fertiliser) and industrial products (such as particle boards) was expanded by the project. The goal for P3DPSB was to develop and pilot products from processing waste streams.

New product research for the edible green seaweed *Caulerpa* included processing into drinks and non-perishable products based on brine preservation (Question 11). New processing methods were evaluated using techniques developed for sea grapes in Okinawa, Japan, to extend the shelf life of the product through brine and pickling. The final work on the products section addressed potential human health implications from inclusion of seaweed into cottage industry products, thereby diversifying the product base (Question 12). This information was captured in the Makassar Seaweed Recipe Book (Swanepoel et al. 2024).

6 Achievements against activities and outputs/milestones

COVID-19: The final milestones of the project need to be considered through a COVID-19 lens. A Business Continuity Plan (2020) extended the project from its original end date of 31 July 2020 to 31 January 2021 through a no-cost variation. Overall, there was reduced scope of field activities in the last year of operations. The Indonesian government regulations resulted in social distancing and no external work activities were possible from March through to July 2020. However, both Biotek Jakarta and Loka Gorontalo were able to finalise most activities, operating within their respective institutional guidelines ("new normal") and then modifying field work from August 2020. For example, Loka Gorontalo conducted seaweed seed transplants within South Sulawesi (three sites: Barru, Jeneponto, Wajo) whereas previously they were going to transplant to three other islands, and, Biotek Jakarta had to limit their seaweed value chain and bioproduct activities to Java (including West Java). Even within island movements resulted in 2 weeks quarantine prior to return to the office. All project partners, collaborators, industry representatives, community and farmer groups were impacted, in part, through the absence of a face-to-face meeting and workshops at the close of the project. While this was not a preferable way to end the project, the project teams were able to meet online and partners were able to workshop online with different audiences and to moderate events. For example, Prof Hari Irianto and colleagues from Biotek Jakarta conducted a seaweed (rumput laut) webinar in July 2020 through Zoom that had 635 attendees and >1500 views since uploading to YouTube https://www.youtube.com/watch?v=Q380xZTBtok&t=337s. The lessons learnt from the Australian perspective were ultimately captured in an article in *Transform: The Journal of Engaged Scholarship* in which the Australian CIs gave their perspectives of capacity building to engage foreign research partners in a post-COVID-19 world (Swanepoel et al. 2020).

Objective 1: To analyse value chains to identify constraints and knowledge gaps for seaweed production in Indonesia

No.	Activity	Outputs/ milestones	Completion date	Comments
1.1	**Analyse the value chains for the established red seaweeds *Kappaphycus*/ *Eucheuma*, produced for carrageenan, and *Gracilaria*, produced for agar**	Implementation workshop conducted in Jakarta with all project participants and members of ASTRULI	April 2017	Implementation workshop was conducted in Makassar, March 2017. The meeting was attended by more than 30 participants across three days. Representatives from the 3 Indonesian seaweed associations were also present. The workshop was opened by Mr Sulkaf Latief, head of Marine and Fishery Agency of South Sulawesi, and Ms Violet Rish, Vice Consul, Australian Consulate-General, Makassar
		Completed map and dataset of raw seaweed flows of carrageenan, diversity of species	July 2017	Completed. Project teams surveyed seaweed farmers (seed producers, cultivation), traders (collectors, small and large traders, exporters) and processors (carrageenan, agar and food). This map was part of the Report from P3DPSB after their first year of operation (below).

		Report on production statistics (as reported in national statistics) for fresh, raw and processed material completed	July 2018	Report comprising national level data on the main species completed early at same time of maps (above). The value chains of key species were identified, including root problems in production and processing. Results were presented at 12th Asian Fisheries & Aquaculture Forum. Production data from this report has been used in preparation of a manuscript on socio-economics from Activity 1.3 (Larson et al. 2021)
		Report published on future scenarios of changing degrees of production and processing in-country	July 2019	Two reports produced and now developed as manuscripts, one on improving the margins for seaweed farmers and producers in the supply chain (Purnomo et al. 2021) and the other on recommendations for improvements in quality of Indonesian farmed seaweed (Purnomo et al. 2020b).
		Workshops convened with policy paper and review paper developed	January 2021	Two workshops convened in October 2020 and January 2021 to progress the policy paper. The policy and review of existing production was published in the journal Sustainability (Rimmer et al. 2021).
1.2	**Identify value chains for emerging species, including the green seaweed *Caulerpa*, produced for food, and other red seaweed**	Report on existing *Caulerpa* production and processing methods in South Sulawesi and Aceh	January 2017	Completed. Described the existing species of *Caulerpa* under production in three main areas (Jeneponto district, Takalar district and Lantebung Makassar), the methods used, BPBAP efforts on processing to date, and existing distribution networks (roadside vendors, oleh oleh stores). Includes estimate of 250 kg of *Caulerpa* (lawi lawi) sold from Lantebung production.
		Report on existing *Halymenia* and other red seaweed production trials	July 2017	Completed. *Halymenia* production ceased in Bali shortly after project initiation (because of competition with tourism). However, small scale production trials were run for *Halymenia* at Gorontalo, and other new high-value red seaweeds (*Gelidium* species in Java). Trials to domesticate and scale new species to a farm-level were unsuccessful, so focus was shifted to village-based production of *Kappaphycus*. Publication on performance of Performance of seaweed *Gelidium* sp. which is grown by the bag method on three different substrates (Simatupang et al. 2019).

		Completed analysis where technical interventions in *Caulerpa* could be made to introduce new activities into the value chain	July 2017	Completed. Value chains for *Caulerpa* are short – mostly it is sold as fresh product. Key interventions identified by BPBAP Takalar related to trials of new methods for cultivating *Caulerpa*/ lawi lawi in ponds to enhance the quality by raising the biomass out of the pond sediment. A range of designs (baskets, trays, floating systems, cages) were created. This led to trials in *Activity 2.5* with comparison of production parameters for the two species of *Caulerpa*.
1.3	**Analyse socio-economic benefits for women from community-scale processing of established seaweed species**	Preliminary report on the products, scale of operations and demographics of women's groups in Sth Sulawesi working with processed seaweed products	July 2017	Completed. Insights into women's groups in coastal villages highlighted that very little data could be obtained about the production, costs, prices, or profitability of seaweed products produced. Three different questionnaires were developed to assess the socio-economic aspects indirectly through study of wellbeing. Results of this new method were presented at Gender in Aquaculture & Fisheries 2018 meeting in Bangkok.
		Compiled dataset of seaweed products and prices	July 2018	The products from 12 seaweed women's groups were compiled with 6 products commonly produced including chips, *bakso* and *dodol*. However, the economic benefits and costs of farming and processing seaweed in women's groups could not be identified from interviews. The intended "time series data" on products was not feasible due to the nature of the groups' record keeping.
		Completed socio-economic framework to describe the broader social and economic impacts (costs and benefits) of women's groups for processing seaweed	July 2019	Completed. First publication in Aquaculture (Larson et al. 2021) describes positive impacts on individual wellbeing and household benefits from seaweed farming in Indonesia. A follow up publication on the broader socio-economic framework and feedback between resources and wellbeing was published in Ambio (Larson et al. 2022)
		Workshop convened for training groups and developing support network for seaweed products	January 2021	Could not be undertaken due to COVID-19 pandemic (restricted travel within Indonesia). Efforts for project team in Makassar was to focus on recording interviews with women's groups, generating photo and video assets for the Makassar Seaweed Recipe Book, which captures the stories of the women's groups as well as their recipes (Swanepoel et al. 2024).

Objective 2: To improve the quality of seaweeds produced at the farm level in Indonesia

No.	Activity	Outputs/ milestones	Completion date	Comments

2.1	**Develop technical capacity for seaweed production and quality assessment at the Centre for Seaweed Culture Research and Development (LPPBRL) in Gorontalo**	Completed assembly of seedstock facility for *Kappaphycus/ Eucheuma*	July 2017	Completed. Seedstock facility (including the procurement of equipment) at LRBRL Gorontalo was resourced for collection and trials of seaweed. Subsequent effort established a new seedstock facility for red seaweeds at Pangkep, South Sulawesi.
		Procured analytical equipment for quality assessment	July 2017	
		Collected strains of red seaweed (*Kappaphycus, Eucheuma, Gracilaria, Halymenia, Gelidium*) from throughout Indonesia	July 2018	Completed. The *Kappaphycus* seedstock was sourced from sites spread over 2000km from North Sulawesi across to Lampung, Sumatra. Other strains of *Halymenia* and *Gelidium* were also assessed but efforts focussed on *Kappaphycus*. A second wave of collections was conducted for *Kappaphycus* from a further 10 sites. In addition to collections of seedstock, a manuscript has been prepared based on the *in situ* evaluation of growth and gel content of each strain at its existing production site prior to transfer to the common garden site (Simatupang et al. 2021, see crossover with 2.3.2 below). See also Simatupang et al 2019 on *Gelidium.*
		Completed strain assessment of *Kappaphycus/ Eucheuma* in “common garden” experiments	January 2019	Completed. The first “common garden” experimental trial of 10 different seedstock from across Indonesia was run at Pangkep in 2017. The identification of existing strains in Indonesia (including Mamuju strain) that can be transplanted to new sites means that LRBRL now has capacity as a national seed provider. One manuscript resulted from this work in 2017 evaluating growth and carrageenan gel characteristics (Pong-Masak et al. submitted). Importantly, the Mamuju strain performed better than the tissue culture strain, which until now had been the only alternative approach for enhancing diversity in production strains. A subsequent common garden trial in Pangkep was run in 2018 with new collections.
		Completed transplant experiment of superior strains into existing or new production areas	January 2021	Completed. Nationwide transplants could not be undertaken due to COVID-19 pandemic (restricted travel within Indonesia). Loka Gorontalo instead focused on transplanting to key local production areas in South Sulawesi only (activities completed by November 2020). Manuscript on common garden trial in preparation (Pong Masak et al.), see Appendix 1.6 for additional details.

2.2	**Identify established and emerging Indonesian species of seaweed using molecular barcoding techniques**	Completed initial collection and screening of DNA from commercial seaweeds	July 2017	Completed. Samples were collected and sourced from multiple sites across Indonesia for DNA barcoding by multiple partners. DNA was extracted from some samples using standard protocols, however, these proved to be ineffective for many of the red seaweeds and capacity building was deemed necessary to develop this activity. Workshops were subsequently convened (see following).
		Compiled database of molecular barcodes of red seaweed, including emerging and new species	July 2018	Completed. Most of the early effort in the project focussed on method development for molecular barcoding rather expansive processing samples. A small but useful database existed at this stage of project – with one key finding the identification of *Gracilaria changii* that had previously been formally identified with many incorrect names (*G. chilensis*, *G. gigas*) being ascribed. Other examples from project activities of improved clarity around nomenclature from samples taken include: *Eucheuma cottonii* -> *Kappaphycus striatus*, *Eucheuma cottonii* -> *Kappaphycus alvarezii*, and, *Eucheuma spinosum* -> *Eucheuma denticulatum*. Certainty is important for industry associations and trade in particular. See Appendix 11.1 (Utomo et al.)
		Convened workshop on training in the use of molecular barcoding for species and strain delimitation at P3DPSB in Jakarta	July 2019 (Workshop 1: March 2018, Workshop 2: March 2019)	Completed. Partners requested to run the molecular training earlier in the project and to start at first principles with DNA extraction. These workshop methods, from sample collection through to DNA extraction, have been adopted in subsequent work by P3DPSB and LRBRL Gorontalo. A second workshop was requested to focus specifically on the *Kappaphycus* barcoding related to the strain collection from common garden experiments from *Activity 2.1*. A publication resulted from the capacity building training: Zuccarello & Paul (2019).
		Report published on the phylogeny of Indonesian seaweeds focussed on the key commercial strains	July 2020	Completed. Findings on the phylogeny of *Kappaphycus* seaweeds from the common garden experiments was published in the Squalen journal (Ratnawati et al. 2020), highlighting almost the vast majority of farmed seaweeds were *Kappaphycus alvarezii* (13) with the exception of one sample of *K. striatus.* Additional existing and emerging commercial species were evaluated from samples taken across Indonesia. Common names and molecular identifications were added to the database (Appendix 11.1).

2.3	**Improve the quality of *Kappaphycus/ Eucheuma* produced at the farm level to enhance semi-refined carrageenan (gel) yields**	Completed surveys of farm practices for growth and drying of seaweed in major production areas	July 2018	Surveys were completed in 2017 and augmented by additional information during the second round of strain collection from production areas in 2018 (see 2.1.3, above).
		Report on the evaluation of different farm practices of *Kappaphycus* for processing	July 2020	Survey data on production methods, including environmental data from sites and morphological (colour/shape) characteristics, were incorporated into a publication in Aquaculture Reports. This was a comprehensive evaluation of the seaweed in situ, prior to transfer to common garden trials at Pangkep (Simatupang et al. 2021).
2.4	**Increase the production and quality of *Gracilaria* farmed in coastal areas and ponds in South Sulawesi province**	Completed surveys of farm practices for culture and drying of *Gracilaria* in pond and sea	July 2017	Completed. Meetings with farmers and site evaluations have were conducted in the Takalar region of South Sulawesi by BPBAP Takalar, identifying farmer sites for trials. Pilot trials of experimental systems for comparative growth assessments of the agar-producing *Gracilaria* in ponds (using line culture vs. bottom culture) were conducted.
		Report on the variability in individual growth rates between and within sites	July 2018	Completed. A reciprocal transplant growth trial comparing pond and sea-based sites originally started in December 2017. However, an extreme weather event early in 2018 destroyed the sea-based sites. Growth was reported but biochemical traits (next milestone) were not because of lost biomass.
		Report on the variability in biochemical traits between and within sites	July 2020	Completed. New reciprocal transplant trial started in July 2018. Results indicate that despite the differences in morphology, both sea and pond cultures are *Gracilaria changii*. Results of growth and agar highlighted that strains are locally adapted and perform best in their original culture area, however sea-seed could be used to supplement pond seedstock. Manuscript in preparation (Lideman et al. in prep, see Appendix 11.2 for additional details).
		Compiled standard operating procedures for *Gracilaria* production in ponds and sea	January 2021	Completed. There was considerable complexity in the data set and that standards are not suitable. Manuscript in preparation (Lideman et al. in prep, see Appendix 1.5 for additional details).
2.5	**Increase the production and quality of *Caulerpa* species farmed in ponds in South Sulawesi province**	Completed surveys of farm practices for culture and handling of *Caulerpa* in ponds	July 2017	Completed. Meetings with farmers and site evaluations have been conducted in the Laikang area of South Sulawesi. Trials have been conducted of culture vessels for *Caulerpa* experiments in ponds BPBAP Takalar and BPBAP Ujung Batee.

		Report on the growth trials of *Caulerpa* under different stocking densities and in different environments	July 2018	Completed. Scale up of biomass resulted in estimates of 1.4-2.6 tonnes fresh weight accumulated at the 3 study sites. However, the report was initially delayed because of extreme weather event in South Sulawesi. The growth trial started in December 2017, after which salinities dropped to 3ppt in Lantebung and to 8 ppt in Takalar, and Jeneponto. A follow up trial started in May 2018 after enough stock was accumulated of the two *Caulerpa* strains. This trial found that *Caulerpa racemosa* was more resilient to different environmental conditions than the more valuable *Caulerpa lentillifera* (lawi lawi).
		Compiled standard operating procedures for *Caulerpa* production in ponds	January 2021	Completed. Bottom and hanging basket procedures were evaluated (Appendix 11.3). Key focus on supply of sufficient biomass for stocking and understanding production procedures around environmental conditions. Environmental assessment facilitated by the transfer of monitoring equipment for spot measures of water quality (salinity, pH) based on observations of extreme weather.
		Workshop with seaweed farmers in South Sulawesi	January 2021	Face to face workshop could not be undertaken due to COVID-19 pandemic. Online event run instead by Biotek with >600 attendees.

Objective 3: To create innovative products from seaweeds and their processed waste streams

No.	Activity	Outputs/ milestones	Completion date	Comments
3.1	**Identify new product opportunities for seaweeds that can be developed domestically**	Compiled product sheets detailing the biochemical traits and applications of established species	July 2017	Completed. The majority of the samples collected for biochemical analysis were from *Kappaphycus*. This was planned as the first of two milestones relating to this activity, and data collection was expected to continue over subsequent years with benchmarking from Australia to develop product sheets for established species. An expansive product sheet was not possible because of difficulties gaining material transfer agreements for transfer of samples outside of Indonesia for benchmarking at UniSC and other international suppliers. Biochemical data has been limited to that produced at P3DPSB and other domestic research facilities (e.g. RICA Maros). A number of reports document the biochemical composition, for example *Gracilaria* (Appendix 11.2), *Caulerpa* (11.3), Kappaphycus (11.4), as well as publication of the collection strains (Simatupang et al. 2021) and fine scale elemental composition of *Kappaphycus* and *Gracilaria* (Fateha et al. 2021).

		Published report on seaweed from different production sites	January 2021	Completed. Activities were delayed due to COVID travel limitations in 1st half of 2020. Biotek Jakarta field-based activities were limited to Java-only travel (with 2-week home quarantine upon return to office). Field work in West Java identified wild-harvest fishery of seaweed, including molecular characterisation (Appendix 11.1). This led to a publication on *Sargassum* fertiliser from beach wrack (Kusumawati et al. 2021). Project reviewers noted that specific product data information would have been useful, but that the absence of the data has not significantly impeded project outputs in this objective.
3.2	**Develop new processing techniques for seaweeds by expanding the existing product R&D programs of the Research & Development Center for Marine & Fisheries Product Processing & Biotechnology (P3DPSB)**	Developed a business plan for new products from established seaweeds *Kappaphycus, Eucheuma* and *Gracilaria*	July 2017	No formal business completed. Effort focussed on developing technology for value-adding for the main seaweed *Kappaphycus*. Initial work identified the need for case studies based on process flow diagrams, such as pre-carrageenan processing steps of raw material seaweed "sap" into biosalt and biofertilizer. Reviewers noted that business plans were challenging with little background information and supported the present endeavours of P3DPSB on sap/biosalt and biofertilizer from the pre-carrageenan *Kappaphycus*. This work on "biosalt" received an Innovation Candidate Award for Wibowo et al. in 2020. A publication on gel preparation methods and gel strength measurements also resulted from this work (Fateha et al. 2021).
		Report on pilot tests of products from established seaweeds *Kappaphycus* and *Eucheuma*	July 2018	Completed. Report on production of biosalt (containing high value pigments) and biofertiliser detailed the trials from this new pre-processing technique for Kappaphycus/Eucheuma. A new process flow after pre-treatment has produced an alternative carrageenan product called "organic powdered cottonii" (OPC). One manuscript is now in preparation on sap process (Wibowo et al., see Appendix 11.5).
		Industry and government workshop on products from emerging and new species	January 2021	Completed. Online Zoom event run due to COVID pandemic.
3.3	**Identify innovative methods to manage processing waste streams from seaweeds**	Report on the characteristics of processing waste streams from carrageenan and agar production	July 2017	Completed. There were some challenges accessing processing/waste data from companies. High level data highlights >4,000 ML of liquid waste per annum and >30,000 tonnes of solid waste per annum. This information is captured in publication Basmal et al. 2020.

		Developed a business plan for using and/or treating processing waste streams	July 2018	Completed. A modified business plan was developed for a subset of companies that are sharing specific data. Of those, characterize the macro- and micro-nutrients and growth hormones in waste streams and identified alternative product potential, particularly relating to biofertilizer. Relating to the two milestones above, a manuscript has been prepared for publication on the identification and characterisation of solid waste from agar-agar extraction (Basmal et al. 2020).
		Report on pilot tests of products from processing waste streams	July 2019	Completed. Work to date has focused on application of solid waste as biofertilizer. National Patent submitted by Biotek.
		Industry and government workshop on products from processing waste streams of seaweed	January 2021	Completed. Online Zoom event due to COVID pandemic. Reviewers noted the benefits of making use of the solid waste streams would be a productive area of future research. The products which have been developed thus far (particle board, light weight bricks) and the raw materials for ceramics show promise.
3.4	**Develop and evaluate food and health products from established and emerging red seaweeds**	Report on the effect of processing (drying, extraction) on the products of *Kappaphycus*	January 2019	Completed. This work linked with Activity 3.2 and the extraction of the healthy biosalt/sap from the fresh *Kappaphycus* seaweed, in contrast to drying. Extracted biomass was subsequently dried and normal gel extraction processes evaluated. One publication resulted on optimising carrageenan extraction from sap-extracted biomass (Fateha et al. 2019).
		Published report on the efficacy of whole products of *Kappaphycus* on human health applications	January 2021	Completed. The nutritional value of incorporating *Kappaphycus* and other seaweeds into food and beverages was captured in the Makassar Seaweed Recipe Book (Swanepoel et al. 2024, ACIAR Monograph 215). This book focussed on the women's group products identified in Activity 1.3, showcasing the recipes based on different seaweeds (*Kappaphycus*, *Eucheuma*, *Gracilaria* and *Caulerpa*) and profiling the nutritional composition and potential dietary benefits of adding seaweed to recipes. Reviewers noted the book highlights the work of the women's groups and gives them public exposure.

7 Key results and discussion

The FIS/2015/038 project used biophysical and socio-economic methods to address research questions relating to understanding the priority technical and social issues for the seaweed industry in Indonesia. Indonesian project teams from each of the four main partners Research Institute for Marine and Fisheries Product Competitiveness and Biotechnology (‘Biotek’, Jakarta), Centre for Seaweed Research (‘Loka’, Gorontalo), Hasanuddin University (‘UNHAS’, Makassar), Balai Perikanan Budidaya Air Payau (BPBAP) Takalar (Makassar) and BPBAP Ujung Batee (Aceh).

Many of the findings have now been published in the literature, in either national or international journals, and in both English and Bahasa. Here we will summarise some of the key results and discussion from these published works, and cover some of the data insights from components of each Objective that are not yet published. In essence, the project explored questions relating to production, quality and socio-economics across the entire value chain of seaweeds.

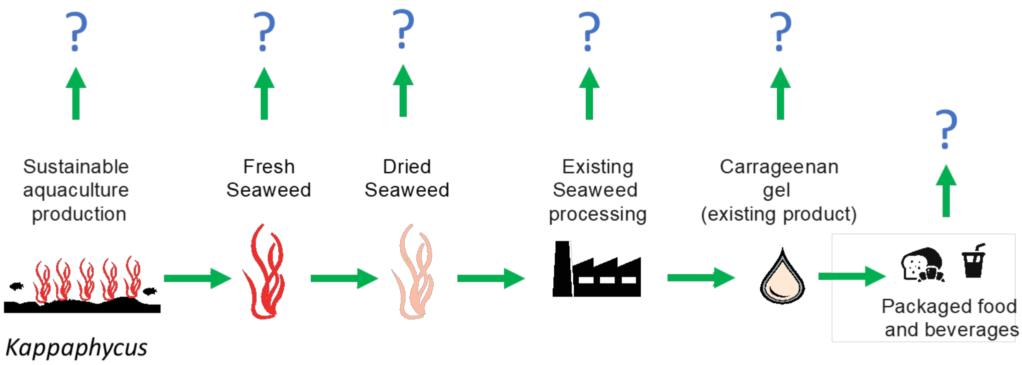


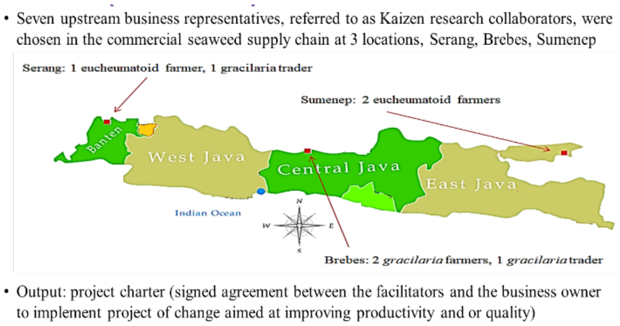
Figure 2. Existing supply chain of the main farmed seaweed seaweed *Kappaphycus*. Research questions covered elements in every step in the value chain with new products, opportunities or insights being evaluated and created .

Key results and discussion for Objective 1 – Value chains

The value chains of the key species of seaweed were characterised by Biotek (P3DPSB), providing insights into the flow of raw and processed material, and their respective values. It sought farmer, trader and processing insights on how much seaweed is produced and processed in Indonesia, where is this occurring and how is it changing over time. The quality was also queried, particularly moisture content and impurities, to understand the constraints in the value chain. By ‘walking the chain’, the Biotek project team surveyed seaweed farmers (seed producers and those in cultivation), traders (collectors, small and large traders, exporters) and processors (carrageenan, agar and food) across multiple sites. The main areas of study to date are the cities of Jakarta, Makassar, Malang and the regencies of Takalar, Maros, Sidoarjo, Pasuruan and Brebes in the provinces of West Java, East Java and South Sulawesi. By 2018, the value chains of the key species of seaweed have now been characterised by P3DPSB, providing insights into the flow of raw and processed material, and their respective values. The team quantified that production (tonnage) of raw material was growing rapidly at, on average, 28% per annum

in the last 5 years up to 10.1 million tonnes of landed (fresh) biomass. However, as the raw material moves between the main nodes in the supply chain, the added value was substantial – effectively from 2,000 – 10,000 Rp/kg dry weight at the farm gate through to a 250,000 Rp/kg of carrageenan. Furthermore, this work identified that more than 50% of the seaweed was processed overseas as a raw material, effectively a lost opportunity for Indonesia.

One key output was generated from this work on the biomass flows, specifically in relation to whether new areas are ready to expand seaweed operations and wholesale seaweed flows, for example, comparing the established areas of South Sulawesi to that of Java. Readiness index values of locations in Java were evaluated for development of similar "seaweed warehouse" system (Purnomo et al. 2020a). A warehouse receipt system practiced by seaweed players in South Sulawesi for *Gracilaria* in surveys done in 2018 (Purnomo et al. 2020b) was seen to have brought positive impacts through issuance of transferable certified proof of ownership, with guarantees of seaweed availability, quality and price. It was identified that the system could be adopted on Java to receive shipments from across Indonesia, but the main centres (Figure, right) need infrastructure (power, international shipping capacity) and institutional support (government and business participation). The three seaweed production centres on Java have an average readiness index of 'sufficient' with Sumenep the highest average index. If Sumenep is to be chosen as a seaweed receipt warehouse location then planning is needed for infrastructure. There are positives already including infrastructure for international shipping, area availability, institutional arrangement to handle environmental impacts, and pre-existing inter-sector cooperation. Lastly, more detailed work is covered in a publication on improving the margins of the upstream players in the Indonesian seaweed supply chain (Purnomo et al. 2021). This work took a Kaizen Approach with the philosophy of continuous 'change towards better'. It identified some simple ways to improve the upstream margin in the Indonesian commercial seaweed supply chain and motivate business development, specifically, related to drying (moisture content) and variation in culture productivity. It made recommendations for use of monofilament net to dry seaweed, optimization of cultivation spacing, and use of moisture analyser, which were – to date – irregularly used by the industry.



This was the first description of the value chain for some of the commodity dried products, which are processed in Indonesia or shipped as a raw ingredient overseas, and the identification of a short supply chain for local processing into food products. That is for the existing/established species. However, there are still many ongoing challenges for creating new or emerging species including: harvest is sporadic, farming is concentrated in a only few locations; export is limited to short time contracts, processing technology has not developed yet, the local market is limited to certain consumer groups and certain species, a lack of financial capital, and the climate / seasons that limit wild harvest. Some of these are addressed in subsequent work.

Research into the value of an emerging industry of seaweed processing at the village scale in women's groups was completed in collaboration with UNHAS, with the initial intent to partition the economic and social importance of these groups to the women. The project team in Makassar, South Sulawesi has captured for the first time the motivation behind the existence of seaweed processing groups for women in villages, of which there are more than 100 groups that value the social capital of the enterprise as much, if not more, than the economic value of its activities. A preliminary report on the products, scale of operations and demographics of women's groups in South Sulawesi working with processed seaweed products provided insight into seaweed processing groups (SPWG) and their activities in the Takalar Regency. The oldest group was formed in 1999 in the Tamale District, with the support of the Hasanuddin University, and is still an active group. Some of the groups produce more than 20 kg of seaweed products per month. The most common products are crackers (kerupuk), candy (gula-gula, dodol), jelly (selai), balls (bakso) and seaweed snacks (kue rumput laut). All are tasty. 136 women were reported as being involved with the production, generating on average almost 36 million IDR per month.

A comprehensive survey of the seaweed women's group followed that led to two publications (Larson et al. 2020, 2021) and the Makassar Seaweed Recipe Book (Swanepoel et al. 2024). Research into the value of an emerging cottage industry of seaweed processing at the village scale in women's groups was done by UniSC in collaboration with UNHAS to partition the economic and social importance of these groups to the women – this work highlighted that while the key products appear to be financially profitable, the well-being attributed to being part of the groups was a significant driver. In Larson et al. (2020) an analysis of the socio-economic benefits for women from community-scale processing was done, trialling new ways to collect socio-economic data in surveys with games. This provided unique insights into seaweed farming and processing benefits for women. This work found that, even though the industry grew at an unprecedented rate, the survey reported that the community perceptions were of positive economic and social impacts. Essentially, extra income earned meant positive change to wellbeing: transport, housing, basic needs, other needs and education. There were no negative changes, just reports of increasing life satisfaction, both by women who are and who are not engaged in farming. In a follow-on piece of work (Larson et al. 2021), the project went further into the feedback relationships between resources, functionings and wellbeing. Using this case study of seaweed farming and artisanal processing by women in Indonesia, and Sen's Capability Approach for wellbeing analysis, it asked whether there are feedback loops where a single item could be viewed as having a different role by different people, in different contexts. It found that the capability sets required for farming and for processing are in fact distinct, but that social networks and transportation (motorbikes) were important in almost all contexts. This is crucial for future policy development.

Dr Fachry (UNHAS) led a work component on the development of women's community enterprise through seaweed processing groups in Indonesian villages. She highlighted that there were more than 1,200 women involved in village-based seafood processing groups in South Sulawesi, Indonesia, alone. Of the 186 registered groups, 33 process seaweed exclusively. In-depth interviews of the group leaders of 12 groups in villages in the Takalar Regency close to Makassar revealed that almost all the groups were less than 5 years old (one exception being Sampulungan village initiated in 1998). They received support from government or NGOs in the form of equipment and assistance with writing applications. Respondents were of the impression they were supported for empowerment, to increase their processing capacity, and to supplement their family incomes. Lack of markets and capital funds and expensive packaging were perceived as the most important obstacles for growth. Of the 2 - 6 products made by each group, the most common were seaweed sticks, chips and bakso. Relating to financial breakdown on the costs for their most important products, ingredients were recorded as 58%, labour 22%, packaging 11% and the overheads (power, space) as 9%. Seaweed chips were the most profitable product. Reported use of seaweed was 550 kg for each tonne of chips produced, however, there was no evidence that profits increased with increased production quantity, perhaps because although seaweed was about half of the raw material per weight, it was reported as only a quarter of the costs. The existence and expanding number of groups highlighted that this is an important social policy supported by government, and that identifying where effort should be focussed for additional government support could avoid reliance on support from third parties.

In summary, the key points from the work done in Objective 1 and discussion at the project review related to the value chain included that:

- The value chain research was systematic in its approach and a major finding was that there is “information asymmetry” where traders and processors have information on the value chain but farmers do not; another finding was the need for improvement in the consistency and quality of production; and that a “warehouse receipt system” would provide greater incentive and fairer economic reward for farmers;
- The value chain research also indicated that there was little innovation in production processes, with farmers often repeating the methods of previous production cycles, highlighting the potential for improvement in the production systems; and,
- The socio-economic research related to the women’s groups was novel and the findings have relevance beyond Indonesia. There had been adequate “push” for the development of the women’s groups through government or third party support in establishment and operations, but now it was necessary for “pull” factors from the consumer end to drive future development.

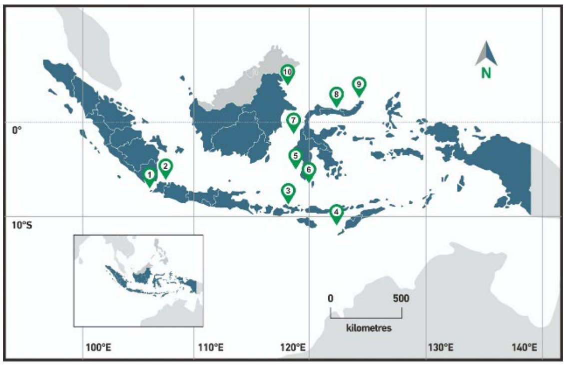
Key results and discussion relating to Objective 2 – Production

One of the frustrations of industry and researchers alike has been uncertainty about nomenclature of the seaweeds cultivated and used in Indonesia. Morphological methods for species identification in algae are complex or unreliable, and correct identification is crucial for species/varieties of commercial interest to compare growth and biochemical results, and to contrast between locations, across environments and over time. Many trade names do not reflect the evolutionary species and updated taxonomy of *Kappaphycus*. These Eucheumatoid seaweeds are highly variable in morphology and pigmentation, and the low genetic variation of COI gene contrasts with high phenotypic variation. The project teams at P3DPSB and Loka Gorontalo/BBAP Takalar were trained in seaweed molecular techniques (images, right), and processed the first set of samples of the different seaweed species using DNA barcoding at the P3DPSB facilities in Jakarta. A major achievement was the completion of the molecular barcoding workshop in Jakarta in March 2018 and repeated and expanded upon the subsequent year in Makassar in March 2019. The methods and discussion points from the workshops were integrated into a publication (Zuccarello & Paul 2019) ‘A Beginner’s Guide to Molecular Identification of Seaweed”. This was published in the Indonesian national journal - Squalen Bulletin of Marine and Fisheries Postharvest and Biotechnology and covered methodologies for sample collection, DNA preservation and extraction, PCR, and analyses of DNA sequence data. These workshops and publication

enabled staff working on live seaweed across the four partner organisations to identify the strains of *Kappaphycus* currently cultured (Ratnawati et al. 2020), as well as the nomenclature for *Gracilaria* (*G. changii*). This was an important accomplishment as it provides a standardised nomenclature for commercially produced seaweed and identify the genetic diversity throughout Indonesia. The results of the comprehensive sampling across the country using the methods taught is also available in Appendix 4.

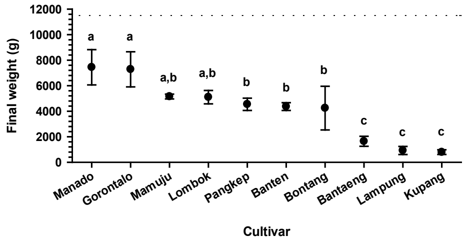
Common Garden Trials

The second objective was to improve the quality of seaweeds produced at the farm level, especially the quality of *Kappaphycus* produced at the farm level to enhance gel yields. The project invested significantly in the technical and human resource capacity for seaweed production and quality assessment at the Centre for Seaweed Research in Gorontalo (LPPBRL Gorontalo; Loka's official tag line is "Seaweed for life"). Firstly, they evaluated growth and product quality of the seaweed *Kappaphycus alvarezii* at the different farming locations in Indonesia (Simatupang et al. 2021, image right). Variability has not been systematically assessed in terms of production (growth and survival) and product quality (carrageenan content, gel strength and viscosity), and they demonstrated substantial seasonal and regional variation in production and product quality using standard techniques. Following this, Loka Gorontalo collected the strains from the major domestic production areas across Indonesia and evaluated these strains in a "common garden' experiment at Pangkep, Makassar over 3 growth periods in the second half of 2017. The common garden experimental trials compared 10 different strains of *Kappaphycus* at scale, with a view to whether "old" strains could be rejuvenated. These strains were sourced from cultivation areas in 9 provinces: Lampung (Lokal and Kuljar), Banten, West Nusa Tenggara (Lombok), East Nusa Tenggara (Kupang), East Kalimantan (Bontang), West Sulawesi (Mamuju), North Sulawesi (Minahasa Utara) and South Sulawesi (Bantaeng and the Pangkep cultivation area itself). Growth is assessed over a 45-day period. This work (Pong-masak in prep, below) identified faster growing strains and strains that are most tolerant to environmental variation. This work identified the "Mamuju" strain as the best-producing seaweed strain of those evaluated (see section following).

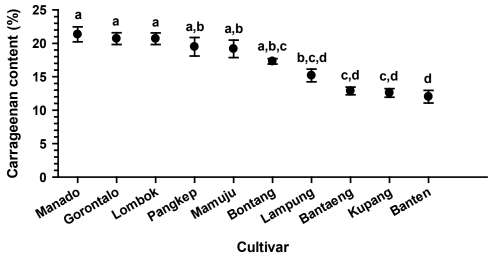


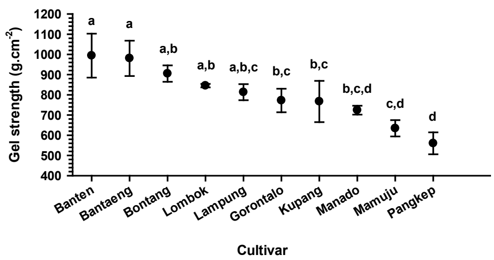
Mr Pong-Masak (Loka Gorontalo) led the work component on the evaluation of growth and product quality of seaweed *Kappaphycus alvarezii* cultivars from throughout Indonesia. The cultivars were collected from 10 locations and their performance (growth and survival) and product quality (carrageenan content and gel strength) parameters compared at Pangkep, South Sulawesi at the "seaweed estate" (Figure, below). The different cultivars showed substantial differences in performance. In the first cycle, the seaweed cultivar with the highest mean carrageenan content (Manado cultivar, 21.4% dry weight) had carrageenan content 70% higher than the cultivar with the lowest carrageenan content (Kupang cultivar, 12.6% dry weight). They found a significant negative relationship between carrageenan and gel strength data. These preliminary results are being prepared for publication. These differences could potentially be used to promote better-performing cultivars to farmers, supporting increased production, better product quality, and better farm performance for Indonesian seaweed farmers. After

three production cycles, the Mamuju cultivar was the last cultivar remaining under the local conditions. This cultivar was used by farmers in the Pangkep as it permitted them to farm outside of the normal season potentially due to heat tolerance. Another target strain from Saumlaki was identified in a subsequent year of trials and this was also "rejuvenated" for use by farmers.



Mean ± SE final weight (by rope, n=3) for 10 cultivars of seaweed evaluated in the **first** cycle of the common garden experiment. The dotted line represents the initial weight (by rope) of seaweed explants. Different letters denote significant differences between the cultivars (Fisher LSD, P<0.05).





Mean ± SE values (by rope, n=3) for carrageenan content and gel strength for ten cultivars of seaweed evaluated in the first cycle of the common garden experiment. Different letters denote significant differences between the cultivars (Fisher LSD, P<0.05).

Reciprocal Transplant Trials

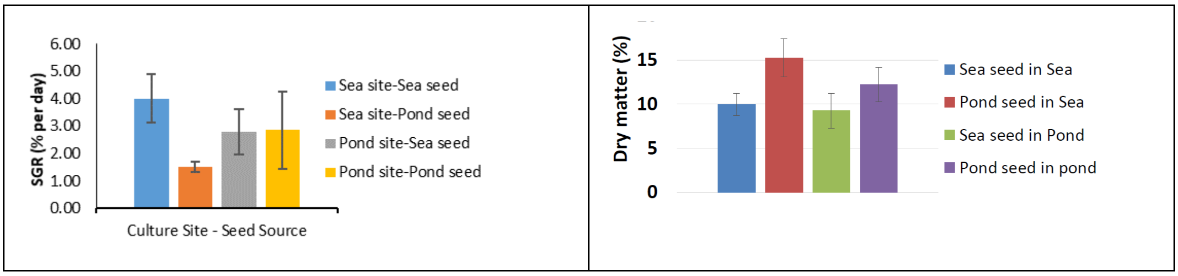
Two different species of seaweed (*Gracilaria* and *Caulerpa*) are also being investigated in Balai Budidaya Takalar and Balai Ujung Batee. Each set of trials have been designed to integrate the production data (individual growth rates, biomass yields) with the next stage of biochemical analysis to assess quality of different conditions and strains. The trials also highlighted the limitations of environmental variation in the scale up of the two, emerging species in *Gracilaria* for in-sea cultivation and *Caulerpa* (sea grapes) in pond cultivation.

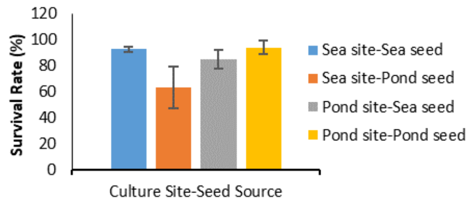
Gracilaria: Relating to *Gracilaria* production, firstly, farm surveys were conducted for culture and drying of *Gracilaria* in the pond and sea. Lagaruda village in Sanrabone was where there is large scale production of *Gracilaria* on long lines in the sea (image, right). The surveys revealed some key differences in productivity (2- to 3-times more production per unit area in the sea) and value (2- to 3-times higher price of dried *Gracilaria* from the sea). The negatives for production in the sea were purchasing infrastructure (although farmers didn't have to rent ponds in the sea) and susceptibility of production to rough seas (which also impacted the research program, image right). The surveys were followed by the first reciprocal transplant study (November to December 2017), at which one there was a

big sea wave ('thypon attack' aka typhoon, image right). The trial was reset and in 2018 it was completed between July and August. The work was presented at the International Conference of Aquaculture Indonesia 4th- 5th October 2019.

Description	Pond-based culture	Sea-based culture
Seed (wet weight)	2.0-3.0 tonnes /ha	4.8-5.6 tonnes /ha
Harvest (dry weight)	1.0-2.0 tonnes /ha/crop	2.0-5.6 tonnes /ha/crop
Crop/year	4-8	4-6
Culture period	1.0-1.5 months	1.5-2.0 months (need research)
Culture area	400 ha	250 ha
Main crop limitation	Salinity (5 –36 ppt), epiphyte	Salinity (15-36 ppt), high wave, epiphyte
Polyculture	Shrimp (10.000 pcs/ha) Milk fish (1.000 pcs/ha)	-
Seed price	rp1.200-1.500/kg	rp1.500-2.500/kg
Fertilizer	10 –30 kg/ha	-
Rope (25 m per line)	(spread out on bottom)	800 line/ha
Dried *Gracilaria* price	rp2.000-5.000/kg	rp4.000-6.000/kg

Dr Lideman (Balai Takalar) led the work component comparing the growth and survival rate of the *Gracilaria* species cultured in earthen pond and in the sea using a reciprocal transplant design. This work was done at Sanrabone in South Sulawesi, Indonesia where *Gracilaria* is mostly cultivated by spreading it on the bottom of earthen pond. However, since 2013, *Gracilaria* has also been cultivated in marine waters by being tied to a rope. Cultivating *Gracilaria* in the sea has benefits for farmers as they do not need to buy or rent an earthen pond to do the culture and they receive a higher value for their crop. Two types of *Gracilaria* seed were cultured at five sea-sites and five earthen ponds. Five replicate lines of 5 m polyethylene ropes were used with a clump of *Gracilaria* thallus (~50 g) tied to the rope every 20 cm. The clumps were cultivated for a total of 42 days at which point the specific growth rate and survival rate were measured (n = 5 ropes). The growth of sea-seed cultured in the sea was the highest, and survival rate was the highest for the pond-seed cultured in the pond. These findings demonstrate that the source of the seaweed is important for maximizing production. Importantly, DNA barcoding revealed that both sea and pond are the same species, *Gracilaria changii*, even though the empirical data suggests that seaweeds are selected for those conditions.





SGR (top) and SR (bottom) of sea and pond grown *Gracilaria* cultured in the sea or in earthen ponds for 42 days

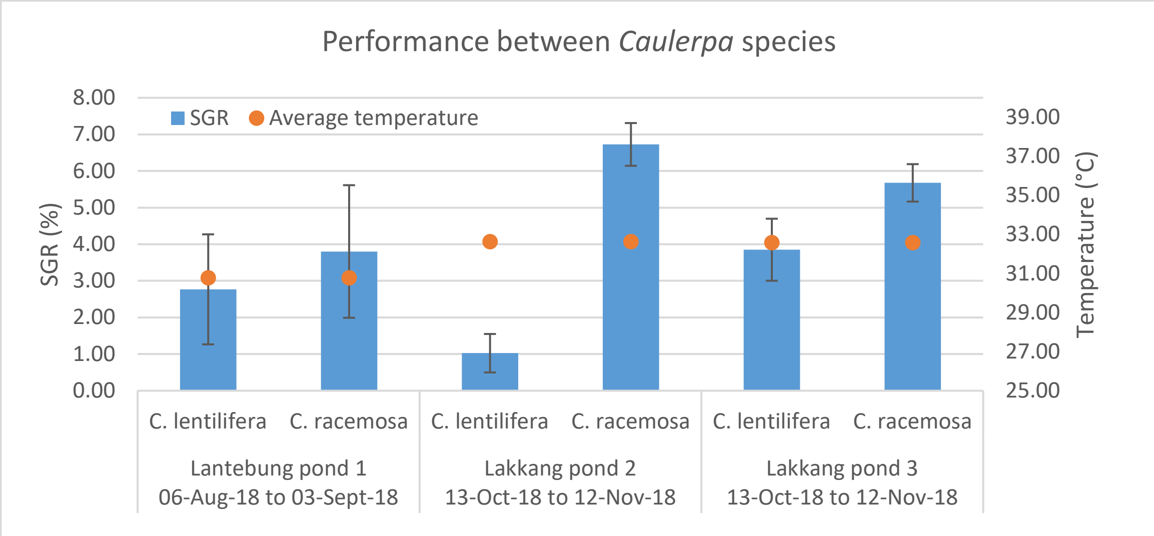
Agar content (% dry matter) of sea and pond grown *Gracilaria* cultured in the sea or in earthen ponds for 42 days

Caulerpa: Production trials of the edible seaweed *Caulerpa* at both Balai are underway comparing different basket culture systems in multiple ponds sites, including existing farmer sites at Jeneponto, Takalar. For these emerging species, new methods and infrastructure have since been evaluated. Growth trials are expanding to include new sites and new strain comparisons in the second year of operation, assessing the links between environment and growth.

Production trials of the edible seaweed *Caulerpa* at Balai Budidaya Takalar and Balai Ujung Batee have evaluated different culture systems (suspended versus bottom trays) and pond variation. The project team has identified a fit for purpose culture tray that will now be used as a standard system for evaluating sea grape growth across the region. As the trials crossed different seasons, the project team has found that the one of the target species of sea grape (*Caulerpa lentillifera*) is not salinity tolerant during extreme drops (<10 ppt); the lowest salinity occurred in December (peak of rainy season) where salinities in Lantebung dropped to 3 ppt and Takalar and Jeneponto both dropped to 8 ppt. However, in the process, the project team identified a new species (as yet unidentified, locally described as *C. racemosa*) that was able to grow throughout the same time. This new species may ultimately provide resilience for sea grape production throughout the year.

Site	**Lantebung pond 1 06-Aug-18 to 03-Sept-18**		**Lakkang pond 2 13-Oct-18 to 12-Nov-18**		**Lakkang pond 3 13-Oct-18 to 12-Nov-18**	
Variable	***C. lentilifera***	***C. racemosa***	***C. lentilifera***	***C. racemosa***	***C. lentilifera***	***C. racemosa***
SGR (%)	2.77	3.80	1.02	6.73	3.85	5.68
SGR Std dev	1.50	1.81	0.53	0.58	0.85	0.51
Yield (gDW.m-2.day-1)	2.56	4.25	0.63	11.04	3.78	7.58
Yield Std dev	2.13	2.98	0.36	2.12	1.33	1.46
Average temp	30.78	30.78	32.63	32.63	32.58	32.58
Period of experiment	06-Aug-18 to 03-Sept-18		13-Oct-18 to 12-Nov-18		13-Oct-18 to 12-Nov-18	
Bottom or hanging trays comparison						
Site	**Parigi Laikang 9-Nov to 23-Nov**		**Ratte Puntondo 8-Dec to 22-Dec**			
	Bottom	***Hanging***	***Bottom***	***Hanging***		
SGR (%)	4.50	3.63	2.66	2.70		
SGR Std dev	1.88	1.50	2.60	1.62		

Yield (gDW.m-2.day-1)	1.67	1.16	0.97	0.89	
Yield Std dev	0.82	0.51	0.99	0.65	
Average temp	30.93	30.93	30.96	30.96	
Period of experiment	9-Nov to 23-Nov		8-Dec to 22-Dec		



The composition of the two species was also compared using standard methods for biochemical composition of dried material for crude fiber (AOAC Edition 18, 2005), protein content (SNI 01-2354.3-2006), lipid content (SNI 01-2354.2-2006), and ash [mineral] content (SNI 01-2354.1-2006), and moisture content [water] (SNI 01-2354.4-2006). *Caulerpa* across both species and ponds had high ash content (~50% of dry weight), with protein 12-15% and crude fiber 8-6%, and very low levels of lipids (<0.4%) consistent with other *Caulerpa* analyses (Paul et al. 2014). The work on the production of the Caulerpa was complemented by post-harvest experiments led by Mr Imran Lapong exploring potential preservation techniques (Lapong et al. 2019a, 2019b). Efforts were made to characterise the commercial sea grapes (*Caulerpa lentillifera*) from Vietnamese company's products as this is the same species farmed in Makassar. The preservation methods were then evaluated with relatively simple ingredients (as available in South Sulawesi) to create a brine mix and evaluated the product quality over time.

Site	**Lakkang pond 2**		**Lakkang pond 3**	
Composition (% dry weight)	***C. lentillifera***	***C. racemosa***	***C. lentillifera***	***C. racemosa***
Crude fiber	10.09	15.62	10.19	8.4
Protein	13.83	11.85	12.13	14.73
Lipid	0.3	0.37	0.31	0.23
Ash	51.06	51.64	43.33	54.39
Water	6.36	7.39	10.16	9.91

In summary, the key points from the work done in Objective 2 and discussion at the project review related to the production research included that:

- Technical development of the new (at time of project initiation) seaweed research centre (Loka Gorontalo) was prioritised throughout the project. The two major experiments and analyses led by Mbak Pustika Ratnawati (common garden trials of *Kappaphycus* seed stock sourced from around the country) and by Mbak Nova Simatupang (comparison of production in different regions in the country) were significant undertakings, that resulted in publications and many “firsts” for seaweed in Indonesia. Research of this scale, comparing many different sources of seaweed, had never been reported before anywhere in the world;
- The molecular taxonomic work was a significant component of the project, that crossed multiple partners and worked on many species providing important clarification around identification of species which could only be done with genetic analyses. The results are of great benefit to the industry, including researchers and traders and the publication of “A Beginner’s Guide to Molecular Identification of Seaweed” will be an enduring resource of great value to seaweed science and farming in Indonesia;
- Common garden, reciprocal transplant and strain-related research trials on production of *Kappaphycus* and *Gracilaria* yielded important results. This work was effectively the first comprehensive look at interactions between farming methods and seed stocks. While more technical research will result in identification of both improved methods and stocks for farming seaweeds in Indonesia, especially for *Kappaphycus*. Results are highly informative for the future of seaweed farming in Indonesia, for which one pathway is to concentrate on using the natural variation of seed stock rather than (or in addition to) attempting complex selection programs of any sort. It was noted that effort will also be needed to engage farmers in acceptance and thereafter practice of improved farming methods once these have been established, although there was already a good model for uptake from the Seaweed Estate work in Pangkep; and,
- The *Caulerpa* component of the work was comparatively minor but productive area of research. While farming methods are not yet established in many places in Indonesia (which rely on wild harvest) there is considerable interest in farming, most likely because of its visibility as a product which is consumed domestically (unlike *Kappaphycus* and *Gracilaria*, which are largely sold as dried product for extraction of carrageenan and agar). Considerable work remains to be done to identify best practice for farming *Caulerpa* in the coastal ponds (tambak), and the appropriate environmental conditions for healthy production and healthy food, including preservation methods. This can draw on some of the value chain and farming related work ongoing in the Pacific Islands (Morris et al. 2014 and FIS/2010/098).

Key results and discussion relating to Objective 3 – Products

The work program around the creation and evaluation of innovative products from seaweeds and their processed waste streams was the most diverse and ultimately most productive of the three objectives with respect to publications and patents (Table, Section 10.2). Most of the results from the publications are in English language journals (See 10.2), so a summary of the key findings and discussions are presented. Two main types of product innovations were evaluated by Biotek P3DPSB Jakarta. The first comprises alternative methods for processing the seaweed for the carrageenan gels, by initially partitioning a high value component – a seaweed “sap” containing a unique salt profile and red pigments, prior to processing into carrageenan (Wibowo et al. 2020, image right). The second covers the development of a strategy to process the seaweed sustainably, starting with a comprehensive understanding of the quantity and quality of waste streams from carrageenan and agar processing, and exploring other uses including as fertiliser.

Process flow diagrams highlight the pre-carrageenan processing steps for raw material seaweed "sap" into biosalt and biofertilizer, then drying prior to existing steps for carrageenan refining, including ATC (alkali-treated carrageenan). An alternative product is being investigated, after pre-processing step, called OPC (Fateha et al. 2019), organic powdered cottonii (cottonii is the common name for *Kappaphycus alvarezii*). This is made from the sap-free seaweed, i.e. a seaweed of which liquid has been extracted from the thallus. The sap could be used for biosalt and the OPC was then also used for making jellies (Images, right).

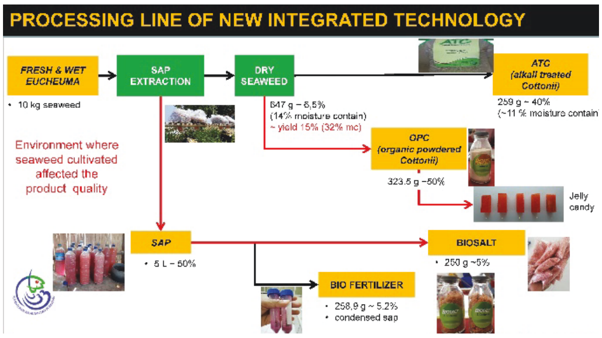
In terms of managing processing waste streams from seaweed, the capacity of 30 processors (18 carrageenan processors and 12 agar processors across) in Indonesia was surveyed and the potential volumes of both liquid and solid wastes from the facilities estimated. The total installed capacity was 24,000 tonnes of carrageenan and 8,000 tonnes of agar, respectively These data highlighted >4,000 ML of liquid waste per annum and >30,000 tonnes of solid waste per annum. Mr Jamal Basmal and his team also provided the data on dried seaweed requirements for the processing industry of 136,575 MT as of 2019 (ASTRULI group = 67,155 MT and non-ASTRULI = 69,420 MT), with estimates of solid waste: refined carrageenan with yield of 20% created 8.5 tonnes per tonne of refined carrageenan, whereas agar with yield of 12% created 8.3 tonnes per tonne of refined agar. The project team has, for example, identified that for 3,500 tonnes of agar (*Gracilaria*) produced, the amount of solid waste is 26,000 tonnes. While these numbers are significant the waste has a range of uses including soil fertiliser and particle boards or even bricks (image, right). The wastes can be characterised (Basmal et al. 2020) and then utilised in different applications like biofertiliser, sometimes with other seaweed ingredients (Basmal et al. 2021).

New liquid and solid fertilisers products were evaluated with different crops (Kusumawati et al. 2019, image right). Some of the methods used boiling to form a seaweed paste which acts as a binder in solid organic fertiliser, and other methods explored blending other active agents (like *Trichoderma* fungus) with seaweed-based fertiliser produced from *Sargassum* (Kusumawati et al. 2021). There were also interesting insights around the composition of the seaweeds being processed, and product innovations that stemmed from these. Agusman and Wibowo (2021) used a scanning electron microscope to conduct energy dispersive spectroscopic analysis and evaluate the surface concentration of salt elements on *Kappaphycus* and *Gracilaria*.

The last efforts in this section were to evaluate food and health applications for seaweeds, specifically focused on recipe innovations and nutritional composition of the cottage industry food products produced by the women's groups. This information is captured in the Makassar Seaweed Recipe Book (Swanepoel et al. 2024). In addition to this Biotek also continue to explore bioactives for their functionality in foods and health "-ceuticals" applications, including nutraceuticals and cosmeceuticals.

In summary, the key points from the work done in Objective 3 and discussion at the project review related to the product innovations included that:

- An alternative processing line for *Kappaphycus* that integrated new technologies like seaweed-sap extractions and biosalt applications is a relatively low technology approach that can be done by farmers and aggregators of fresh seaweed. Importantly the carrageenan product can still be recovered as normal ATC (alkali treated carrageenan) or potentially through an organic labelled process for producing 'organic powdered cottonii' (OPC, image right);



- The major finding of this research on waste-related products brings attention to the massive volumes of solid waste >30,000 tonnes accumulating each year. Importantly, 50% of the solid waste is silica. The products which have been developed (particle boards, light weight bricks) and the raw materials for ceramics have promise in materials and construction. The challenges remain for the liquid waste which will need to be dealt with by processors prior to discharge or through expensive trade waste;
- Solid waste of agar extraction contains macro & micronutrient, growth hormones, and silica, and each can be important functional ingredients in fertilisers and soil conditioning. The use of seaweed and its processing wastes in biofertiliser represented a significant body of work, with 4 publications including a patent (see Section 10.2). Of interest was to determine the 'maximum' levels of seaweed solid waste that could be used in products, as this will enable the potential volumes to be calculated in the future. For example, the solid waste from agar extraction can be included in biofertiliser up to a level of 36%; and,
- The recipe book highlighted the work of the women's groups, giving them exposure and providing an avenue for conveying the potential health benefits of seaweeds, and more generally brings positive attention to the seaweed industry in Indonesia. The recipe book has associated videos that will be beneficial in spreading these messages.

8 Impacts

Seaweed farming is often done in remote coastal areas with few alternative livelihood opportunities. Despite the smallholder engagement and economic importance of the industry, donor support for seaweed R&D had been negligible prior to the inception of this project in 2015. The project strategically engaged most key groups that had requirements for knowledge and skills in seaweed research, development, business and socio-economic empowerment. The direct involvement of seaweed farmers and processors in the project has enriched the research around growing, harvesting, and processing. It is worth considering that the project aligned with 8 of the 10 key targets as outlined in the Australian Government's 'making performance count' development policy: promoting prosperity; engaging the private sector; reducing poverty; empowering women and girls (seaweed farmers in Indonesia are typically smallholder family units, meaning that industry growth will empower women, and the project worked with local women's groups to extend the use of their skills with new product development through village-based processing of seaweeds); focusing on the Indo-Pacific region; delivering on commitments (the project objectives align strongly with the Indonesian President's priorities for development of the seaweed industry, with commitment to these goals across the private sector, relevant ministries and government R&D agencies); working with the most effective partners; and, ensuring value-for-money.

8.1 Scientific impacts – now and in 5 years

One of the main scientific impacts from the project was improved farm production. The productivity of seaweed farms is influenced by the farm location, seasonal conditions, culture methods, and the genetic component of the seaweed stock used. By partitioning these various factors the project provided a better understanding of the major factors influencing seaweed productivity on-farm. The research evaluated production and product quality in *Kappaphycus* cultivated concurrently at more than 15 locations in Indonesia using identical farming methods, leaving local environmental factors and genetics as the two remaining influential factors, and found a 600% difference in production and 300% difference in carrageenan content between locations. Further partitioning of the genetic component of this variability will provide important information for possible improvement in farm production by using seaweed cultivars chosen for improved performance.

Better knowledge of the factors driving seaweed productivity and product quality are essential to mitigate the likely effects of climate change on seaweed farming in the years to come. Some effects can be mitigated by identifying seaweed cultivars that are more resistant to higher water temperatures, and developing new cultivation techniques where water temperatures may be lower. For such culture methods, the trade-off in potential productivity from reduced light availability will need to be balanced against the increased disease risk for shallow lines in the water column. A long-term decline in carrageenan content is reported for both *Kappaphycus* and *Eucheuma* (Rimmer et al. 2021). Future research and development of better-performing seaweed cultivars and policy support for such research, as well as distribution of better-performing cultivars, is essential to halt this trend.

The Objective 1 study of seaweed mariculture in Sumenep Regency, East Java, identified a number of supply-side problems and noted that most could be resolved using relatively simple interventions. However, resolving these constraints through the provision of effective training and support to seaweed farmers is challenging given the widespread distribution and remote locations of many seaweed farms. Research into the provision effective extension and technical support services utilising new approaches, such as social media, could be used to communicate effectively with seaweed farmers in remote communities throughout the archipelago. The Objective 2 evaluation of the optimal environmental conditions for seaweed growth/quality improves our knowledge of the different isolates cultured in the main production areas and their propagation, and the confirmation of the taxonomy of cultured seaweeds using molecular tools has allowed more meaningful comparisons of different seaweed strains.

Overall, the scientific publications and technical reports on new opportunities along the entire value chain in Indonesia will enable end-users to develop new market opportunities for seaweeds, enhance the quality of farmed seaweeds, facilitate the development of emerging species of seaweed, create low-tech and high-tech opportunities, and also to promote socio-economic benefits for women and community-scale processing. These publications contain accessible regional maps capturing the production and flow of seaweed. The project rejuvenated old strains of *Kappaphycus*, essentially creating new strains for improved production. The diverse technical R&D into new products, waste utilisation and recipe describing the food and nutritional profiles of seaweed products can be utilised by many people in Indonesia and beyond. This knowledge will enable the relevant government agencies (for example, the Directorate for Non-consumption Product Development within MMAF) to better target specific sections of the value chain to improve the performance of the Indonesian seaweed industry. For example, the improved knowledge of the socio-economic aspects of seaweed farming, including the role of women in this sector, will allow better targeting of interventions to develop and support women's groups. It will also allow for new intellectual property to be developed (in addition to the patent registered from work during the project: "Formula of liquid and solid bio-fertilizer based on seaweed *Gracilaria* sp and *Sargassum*", especially with current awards (image, right) for innovation and the importance this recognition tends to have in driving new business development.

8.2 Capacity impacts – now and in 5 years

The project activities in engaging seaweed stakeholders at institutional level have successfully brought together group of scientists, governments, and community members. Researchers from government (Ministry of Marine Affair and Fisheries) and university (especially UNHAS) gained significant knowledge through sharing information and collaborative research. Indonesian staff associated with the project have enthusiastically taken on aspects of field and laboratory research, including experimental planning and subsequent reporting. More than 40 people attended the project review in October 2019 and the project reviewers here noted that the "spirit of collegiality and common endeavour within the project was obvious and is a credit to all involved".

Specific capacity related activities included:

Workshops on DNA barcoding – Prof Joe Zuccarello provided two workshops (Jakarta and Makassar). This workshop enabled staff working on live seaweed across the four partner organisations to identify the strains of *Kappaphycus* currently cultured, as well as the nomenclature for *Gracilaria* (*G. changii*). This is an important accomplishment as it provides a standardised nomenclature for commercially produced seaweed and identifies the genetic diversity throughout Indonesia. After these

Biotek P3DSPB Jakarta used their own laboratory facilities to analyse seaweed samples, while Loka Gorontalo was able to use the facilities at the Research Institute for Coastal Aquaculture Maros, near Makassar in South Sulawesi. The adoption of these techniques by both institutions will allow for the accurate identification of seaweed species and strains used for future work, and will support publication of the results in the scientific literature. This component had associated capacity building in genetic techniques – with some of the initial trainees (Mbak Pustika Ratnawati and Mbak Nova Simatupang) now delivering training in molecular biology to others. The project reviewers commended the team for producing the genetics training report, especially considering it is not the usual research output on which scientists are generally appraised.

Writing workshops – Dr Mike Rimmer provided a scientific writing workshop series with the key staff in Loka Gorontalo working on seaweed production.

Culture methods: BPBAP Takalar staff have developed capacity in the aquaculture techniques for *Caulerpa* and *Gracilaria*. For *Caulerpa* (top panels) the team assessed cultivation using three different type of culture methods. Those are #1). polyethylene pipe with the small size of the net (1x1x0.2m), #2). modified bucket (“bottle” bucket), and #3). modified tray using 1 cm size of plastic mesh. An initial trial for the trays deployed in the development centre pond at Takalar and also in one pond in Lantebung, Makassar. The results showed that the best growth of *Caulerpa* was in the type no. 3 (modified tray using plastic mesh). This finding led to an expanded trial that uses the practical design created by the project scientists, that we anticipate will able to be adopted by farmers through the training by the project staff members.

For *Gracilaria*, (images, panels below), the project provided capacity to think outside the box and evaluate through a reciprocal transplant the different strains that are cultured close by to each other (Appendix 5) but have not been tested in standardised conditions. This work was seminal for showing that they are in fact the same species of *Gracilaria* (*G. changii*) but different phenotypes depending on whether they were grown in the sea or in ponds (using a standardised design with culture lines [image below, left]; previously pond biomass was spread on-bottom).

The common garden trials and work done in comparison of *Kappaphycus* strains was built upon the physical infrastructure capacity established by Loka Gorontalo at the Seaweed Estate at Pangkep, South Sulawesi (images below). This experiment proved that the diversity of asexually propagated strains across Indonesia is a national seedbank that can be utilised to manage biodiversity of the cultivated strains and maximise production. Establishing the common garden experiments has allowed Loka to develop the capacity to scientifically evaluate a range of seaweed strains, which will allow it to function as the national centre for seaweed seedstock evaluation and distribution. Seaweed strains were shared with farmers in the Pangkep region during the project, and they were able to utilise these immediately rather than after project completion (see 8.3.1 Economic Impacts).

The ACIAR "Seaweed Gazebo" field station at Pangkep village.

Sign describing "common garden" experimental site with lines of seaweed

While there are numerous regions in Indonesia where seaweed farming is being undertaken which were not within the geographic scope of this project, the wide geographic range of the industry presents a challenge for the Government of Indonesia, researchers, extension officers and traders in maximising the outcomes of the research. The two major experiments and analyses led by Mbak Pustika Ratnawati (common garden trials of *Kappaphycus* seed stock sourced from around the country) and by Mbak Nova Simatupang (comparison of production in different regions in the country) were significant undertakings, demonstrating the logistics and planning capacities developed. These will serve the seaweed industry well into the future.

8.3 Community impacts – now and in 5 years

Seaweed farming supports a large number of rural households in Indonesia, in many cases contributing enough income to lift households out of poverty. The project demonstrated that income generated from seaweed farming is valued by the participant households: it allows spendings on transport, housing, fulfilment of basic needs, secondary needs, and university education. However, for seaweed farming to continue to support coastal communities in Indonesia, the risks identified earlier need to be directly addressed by research, development and extension, as well as through policy development. Importantly, the economic and social benefits of seaweed farming are recognized by the Indonesian government, which has instituted a range of specific laws and national-level policies government regulations and ministry regulations. Those of direct relevance to seaweed farming are listed below with explanatory notes, which should be considered in the context of the the Indonesian government's roadmap for seaweed development (Government Regulation No 33/2019).

A range of community impacts were realised during the project, however, there is significant scope of broadening benefits to rural areas in Indonesia. The Ministry of Marine Affairs and Fisheries (MMAF) regards mariculture in Indonesia as only 2.3% exploited, with a potential area of more than 12 million hectares still available for seaweed development (KKP 2017). The less-developed regions pose significant opportunities for developing, including the Java Sea, the Sulawesi Sea, Lesser Sundas (including East Nusa Tenggara), Banda Sea, Halmahera and Papua, but most other regions still had expansion potential as well. If all areas were developed, at least a three-fold increase in Indonesian seaweed production could probably be accomplished (Neish 2013). Many of these areas are amongst the provinces with the highest levels of relative rural poverty in Indonesia: East Nusa Tenggara, Gorontalo, Maluku, West Papua and Papua (Rimmer et al. 2021). For the immediate future (2021 – 2024) MMAF has nominated seaweed as one of its top three priority commodities for aquaculture development in Indonesia (along with shrimp and lobster) and plans expansion of seaweed farming in eastern Indonesia, including in South Sulawesi, East Nusa Tenggara, Maluku, North Maluku and Papua provinces (Soebjakto 2021).

Indonesian laws and regulations directly relevant to seaweed farming and empowerment of seaweed farmers and local communities.

Legislation/Regulations	Description
PERPRES (Peraturan Presiden, Presidential Regulation) No. 33/2019 Road map of seaweed industry	Several aspects related to community empowerment including: • Provision of quality seeds of seaweed from the results of tissue culture and non-tissue culture nurseries/seaweed garden (kebun bibit) • Facilitating the labour/manpower in the implementation of cultivation and post-harvest in the seaweed development area • Support for the provision of facilities and infrastructure for cultivation and post-harvest seaweed in the cultivation development area. • Guidance and quality improvement through post-harvest and processing technical guidance for seaweed cultivators, processors and traders in the main cultivation development areas. • Implementation of extension and assistance to cultivators for the best practices of cultivation and post-harvest methods in the seaweed cultivation development areas.

	• Improving the institutional status of seaweed cultivators and processors to become a legal entity. • Facilitating groups / cooperatives in access to capital for micro and small-scale cultivation businesses and seaweed processing industries. • Facilitating partnerships between industry and cultivators to strengthen the supply of seaweed raw materials. • Grow/establish new entrepreneurial and the development of small medium scale enterprises of seaweed processing in seaweed cultivation areas.
Law No. 7/2016 Protection and empowerment of fishermen, fish farmers and salt farmers	This law is an umbrella of the law / legal guarantee to protect and to empower small-scale fishery communities (0.5 ha - 5 ha) to overcome problems including from threats of disease, contamination, broodstock, seeds, feed and fertilizers, conflicts of coastal land use / land status (land tenure), climate change and also problems of facilities and infrastructure, marketing of products and access to finance
PP (Peraturan Pemerintah) No. 50/2015 The empowerment of smallholder fishermen and small aquaculture	(The implementation of Fishery Law No. 45/2009 & 31/2004) Based on this regulation, the Government (National & Regional level) with their authority are obligated to facilitate finance/capital to the smallholder fishermen and fish farmers
Law No. 1/2014 Management of coastal areas and small islands (Amendment to law No. 27/2007)	This law guarantees the State's authority and responsibility for the management of the coastal zone and small islands in the form of control over other parties (individual or private) through a licensing mechanism. Granting permission to other parties does not reduce the State's authority to make policies (beleid), make arrangements (regelendaad), carry out administration (bestuursdaad), carry out management (beheersdaad), and carry out supervision (toezichthoudensdaad). Provides rights to communities including customary law community units as well as traditional rights in the principle of the unitary state of the Republic of Indonesia.
Law No. 23/2014 Local government	One of the aspects regulated in this law is the authority of the provincial government to manage marine natural resources except oil and natural gas. Administratively, the Province has the authority to manage the sea to 12 nautical mile limit. However, the limitation of 12 nautical miles does not apply for small-scale fishermen to fishing activities.
Law No. 45/2009 Fishery (Amendment to law No. 31/2004)	The scope of this law includes: Financing and capital. The national / local government is obliged to facilitate capital assistance or credit schemes for business or operations with a simple method and with a low interest of the loan and by considering the abilities of smallholder fishermen and aquaculture farmers. The sources of financing and capital can come from the APBN / APBD (national/local government budget) or from financing institutions appointed / assigned by the state. Education, training and extension are organized by the central and local governments to improve the skills of fishermen and aquaculture farmers. The government may cooperate with educational institutions that are certified and appointed by the Minister and also with business operators or the community. Developing groups (fishermen and/or aquaculture farmers) by facilitating the formation of joint business groups (KUB), aquaculture farmer groups (FGs)/ (Pokdakan) or fishery cooperatives, and empowering women. In this activity the government provides assistance and provides capital or provides technical and managerial assistance. Empowerment of women is carried out by enhancing the income of the family / conducting fishery and non-fishery businesses,

	technical and managerial guidance, and increasing the roles of women in planning, implementation, decision-making, monitoring and evaluation. Implementation of activities by smallholders. Small-scale fishermen and aquaculture farmers can carry out their activities in all Indonesian fisheries management areas and get priority to do their activities in conservation areas in sustainable fisheries zones by following the applicable regulations. Partnership. The Government is obliged to facilitate partnerships between fishermen and small-scale fish farmers with processors and traders, fishery cooperatives, financial / banking institutions, state / regional and private enterprises

8.3.1 Economic impacts

One of the clear areas for economic impacts stemming from this project will be through diversifying market chains. The main farmed seaweeds in Indonesia, *Kappaphycus*, *Eucheuma* and *Gracilaria*, are produced for global commodity markets supplying raw materials for food and pharmaceutical products. Consequently, farm-gate prices are subject to the vagaries of supply and demand, both locally and globally. Increase of in-country industrial processing capacity, supported by both industry and the government, will be an important development for future stability.

Diversification of market chains other than carrageenan and agar would also assist in reducing the price fluctuation that is characteristic of the carrageenan and agar supply chains. An alternative market chain that the project actively researched is the use of seaweed biomass for fertiliser for agriculture and horticulture. Furthermore, the liquid component of *Kappaphycus* ('sap') offers potential for health related "biosalt" and the solid waste component of processed *Gracilaria* shows potential as biofertiliser. Estimates of the biosalt value could be up to US$8 per 100 g (Wibowo, pers. Comm.) which would provide significant motivation for farmers and aggregators of fresh biomass.

More specific examples of economic benefit in the project included direct impacts on those seaweed farmers affiliated to the work. *Kappaphycus* farmers in Pangkep, South Sulawesi, have benefitted directly from the outcomes of the evaluation of 15 strains of *Kappaphycus* seaweed undertaken by Loka Gorontalo. Local adoption of the fast-growing and environmentally robust 'Mamuju' strain (sourced from another province) means that local farmers are able to grow their crop 12 months of the year, compared with <9 months for the established (Pangkep) strain. The farmers were the next users in the trial and benefited immediately after the research was completed, and at the time of an ACIAR team visit had already scaled up their lines. The farmers and the villagers were enthusiastic to capture a "hand over" moment from the ACIAR project team of the new strain (image, right).

Balai Takalar and Mr Imran Lapong introduced sea grape culture to new farmers in the Jeneponto district, Takalar district and at Lantebung Makassar. The project team conducted a mass planting of seed of *Caulerpa* in three ponds, working with farmers to manage the stock and conducting environmental monitoring. This relatively large-scale scientific trial provided immediate economic impact. For example, in Lantebung, 250 kg was sold to the local market towards the end of 2017. Culture of the edible seaweed *Caulerpa* in coastal ponds in South Sulawesi could generate up to IDR 33 million (US$2,357) per hectare per annum, which is higher than that expected from ‘traditional’ shrimp culture (see Rimmer et al. 2021 for more details).

Ultimately, increased proportion of seaweed processing in Indonesia (at time of project initiation, only 20%) will provide national economic benefits through local employment and retaining a larger share of the total value of the seaweed. These initiatives would provide impetus for greater differentiation of material produced at the farm-scale, because of a shorter value chain, which in turn creates the motivation for farmers to produce higher quality products with higher gel quality by adopting the recommended agronomy practices including potential new strains.

8.3.2 Social impacts

The project sought to engage with diverse seaweed stakeholders at the institutional level and successfully brought together groups of scientists, government officials, and community members. One of fundamental changes that the project has contributed to was improvement of the quality and quantity for collaboration and communication among these stakeholders, who are separated geographically but also within different departments of government. The project also sought to work directly with large seaweed processing companies, with cottage scale seaweed processes, and with farmers at the location where seedstock were collected and ultimately at the locations where experimental trials were conducted with all the different varieties of seaweed. The value chain team led by Dr Heri Purnomo was lucky enough, over the course of the project, to see an emerging wild harvest industry with the women making a cottage industry of food and other products in places on Java that this had not been done before.

Overall, the gender equity and empowerment activities in the project for women were highly successful and appropriately resourced from project conception. The project contributed to strengthen existing woman groups for seaweed processing and also develop new woman groups. The work done by Dr Mardiana Fachry, Dr Silva Larson and Dr Libby Swanepoel and the team built upon the early analysis of gender equality gaps, which were then framed as opportunities and substantially informed the project direction. This included adopting direct feedback from the women’s groups, for example, their requests to profile the group’s stories at the same time as promoting the products in the Makassar Recipe Book. Representatives also attended project meetings and discussions. As a result of the project, all of the partners are increasingly considering gender equality as a priority through their own policies and processes. No doubt more opportunities to enhance the role of women more generally in seaweed production, marketing, and product development will follow.

A crucial element for any future social impacts from seaweed is government policy. The Ministry of Marine Affairs and Fisheries (Kementrian Kelautan dan Perikanan) regulations Permen (Peraturan Menteri) and Kepmen (Keputusan Menteri) relevant to seaweed farming and farmer and community empowerment include:

- MMAF-Permen No. 3/201: Community participation in implementing the protection and empowerment of fishermen, fish farmers, and salt farmers (The implementation of Law No. 7/2016);
- MMAF-Permen No.10 /2014: Guidelines for implementing the national program for independently community empowerment for marine and fisheries;
- MMAF-Permen No. 40/2014: Community participation and empowerment in the management of coastal areas and small islands;

- MMAF-Permen No. 31/2014: Guidelines for empowerment of private fisheries extension and community / self-supporting (swadaya) fisheries extension; and,
- MMAF-Kepmen No. 31/2006: Establishment of a community empowerment team for fishermen, fish farmers and business actors in the marine and fisheries sector.

These regulations can be leveraged for social impact, in addition to those regulations covered earlier in the section.

8.3.3 Environmental impacts

The project was more at the whim of the environment rather than having a direct impact on the environment itself. In 2018, there were considerable setbacks in the large-scale production trials of two of the seaweed species (*Caulerpa* and *Gracilaria*) in Makassar, South Sulawesi during the months of December-January. Here uncharacteristically violent weather caused significant infrastructure loss from the sea and severe dips in salinity across production areas. This impacted both the trials and the flow on benefits that would have resulted for the farmers associated with the trials. For example, at one field site in Makassar, an estimate of 2.6 tonnes that had grown in the pond since stocking in July then died in December. New trials have since started mid-year with plans to avoid stock loss the following December by harvesting earlier.

One of the challenges in addressing the perceived environmental benefits of seaweed is that “seaweed” is seen as a silver bullet but is of course a polyphyletic group. This means that one type of seaweed with significant interest for climate mitigation (e.g. *Asparagopsis* for methane reduction) has very different properties and different states of technical development to another seaweed for gel extraction (*Kappaphycus* or *Gracilaria*) or those used fresh for food (e.g. *Caulerpa* sea grapes). Where there are specific bioactives or functional components inside the seaweed that are sought after, these are likely going to be different across the >10,000 species currently described (i.e. “seaweed” is not an effective antimethanogenic feed additive, one specific seaweed is). When there are more general positive environmental outcomes sought from seaweed or being used to justify increasing production – for example, carbon sequestration – it does also pay to understand that carbon concentrations are based on dried seaweed (typically about 25% of dry weight), and that the current in country demand for dried seaweed as of 2019 was 140,000 tonnes (or 35,000 tonnes of carbon). And if these seaweeds are then utilised for traditional products (where carrageenan and agar are consumed and ultimately broken down), then that carbon will inevitably end up back in the environment. Life cycle analyses from cradle to grave for different seaweed systems are important for all carbon offsets and related products.

Increased demand for seaweeds for carbon and nutrient mitigation is also likely to lead to more seaweed farming. A positive environmental impact is that seaweeds utilise dissolved nutrients for growth that enter the sea through coastal runoff and would otherwise contribute to eutrophication of nearshore environments. This will need to be balanced with environmental sustainability from the utilisation of solid and liquid waste streams from seaweed processing to reduce the environmental impacts associated with disposal.

8.4 Communication and dissemination activities

The primary outlets for dissemination of the research results were the 20+ scientific publications, mostly led by Indonesian researchers. The feedback from the Indonesian scientists relating to the joint research was positive, as reported during the project review. The reviewers also noted that the “project missions and outputs were well understood by most key stakeholders both at individual and institutional levels”.

In addition to publications, individual researchers and institutions conducted a significant number of communication activities, including presentations and workshops for knowledge sharing and capacity building for both internal and external audiences. This started with the inception meeting, which was the main opportunity for evaluative learning in the first year of operations. The meeting was held in Makassar, South Sulawesi in March 2017. The meeting was attended by more than 30 participants across three days, with representatives from Research Institute for Marine and Fisheries Product Competitiveness and Biotechnology (BBRP2BKP – Biotek, Jakarta), Centre for Seaweed Research (LRBRL – Loka, Gorontalo), Hasanuddin University (Makassar), Balai Budidaya Takalar (Makassar) and Balai Budidaya Ujung Batee (Aceh). Representatives from the three Indonesian seaweed associations were also present: Indonesian Seaweed Industry Association (ASTRULI), Indonesian Seaweed Farmers and Processors Association (ASPPERLI), and, Indonesian Seaweed Association (ARLI). Guest speakers included Mr Sulkaf Latief, head of Marine and Fishery Agency of South Sulawesi, and Ms Violet Rish, Vice Consul, Australian Consulate-General, Makassar.

A round table format brought together diverse stakeholders (researchers, processors, government officials) for discussions about industry and research priorities, as well as the strengths and weaknesses of the industry as a whole. Following is a word map summary of the presentations from the working groups from each of the three objectives at the project level. The top 5 key words (outside of seaweed) were product, quality, waste, market and processing. The range of other words and concepts discussed was broad, highlighting the need but also the complexities of working across the seaweed value chain in Indonesia. The project inception meeting received good local media coverage with a communication strategy involving media releases and invitations. A snapshot of some of the legacy media coverage from the project is still accessible:

- http://makassar.tribunnews.com/2017/03/11/aciar-gelar-workshop-rumput-laut
- http://makassar.tribunnews.com/2017/03/15/kelompok-peneliti-australia-bahas-potensi-rumput-laut-indonesia-di-makassar

Project meetings and workshops throughout the project were important for engagement. The first DNA barcoding workshop was conducted in Jakarta in March 2018 led by Prof. Joe Zuccarello from VUW. The training workshop combined hands-on laboratory protocols and software analyses of the results of sequencing for the purpose of taxonomic identification and creating phylogenies. This workshop was deemed so successful that a second DNA barcoding workshop was requested and delivered in Makassar in March 2019. The Standard Operating Procedures for sampling of seaweed for DNA barcoding were translated into Bahasa and disseminated for researchers in the project. A paper was subsequently published (Zuccarello and Paul, 2020) as a ‘beginner’s guide’ to molecular barcoding, based upon the training activities.

The annual project meeting was held in Australia at UniSC in May 2018, where key staff from all institutions visited seaweed production and processing facilities on the Sunshine Coast. The project review was held in October 2019 in Makassar, prior to COVID-19. This was the last face-to-face event for the project, with online activities thereafter. Some of these are captured in the table below.

Conferences and presentations were key strategies for communications. Project researchers presented in many international and national events. This included some face-to-face conferences pre-COVID (e.g. the Gender in Aquaculture & Fisheries meeting in Thailand, October 2018) as well as numerous online presentations subsequent. A number of these conference presentations are collated here:

Conference	Title	Presenter	Date	Link
Tropical Phyconomy Coalition Development Workshop Series "Tropical Seaweed Cultivation (Phyconomy)-The Eucheumatoids"	Evaluation of growth and product quality of Kappaphycus from across Indonesia	Pong-Masak, P. R.	7/07/2021	https://youtu.be/kLJoq_gGqJc
	Innovations and impacts of seaweed production and processing in Indonesia	Paul, N.A.	7/07/2021	https://youtu.be/kZJD0cQ3nro
Product Processing Webinar #1	Sea Grapes: Opportunities for Its Utilization	Irianto, H.E and Utomo, B.	2/07/2021	https://www.youtube.com/watch?v=Q380xZTBtok&t=337s https://bit.ly/2VUeAgv
Accelerating the Management of Marine and Fishery Resources to Achieve SDGs amid the Covid-19 Pandemic, 4th International Symposium on Marine Science and Fisheries, Hasanuddin University	Seaweed innovations for sustainable development in Australia and Indonesia	Paul, N.A.	6/06/2021	https://unhas.ac.id/v2/en/article/title/seven-foreign-speakers-attend-symposium-on-marine-and-fisheries-universitas-hasanuddin/
Management and Utilization of High Protein Seaweed as Implementation of SDGs, Webinar Kajian P2RL Hasanuddin University	Seaweed as a sustainable food for the future	Swanepoel, L.	25/02/2021	https://unhas.ac.id/v2/en/article/title/universitas-hasanuddin-conducted-a-webinar-on-seaweed-management-as-sdgs-implementaion/
	Seaweed as a potential source of protein for the future	Paul, N.A.	25/02/2021	
Seeds of Change Conference, University of Canberra, the Australian Centre for International Agricultural Research (ACIAR) and CGIAR Collaborative Platform for Gender Research	Using wellbeing concept to measure economic and social impacts: A case study of the seaweed processing women's groups in Indonesian villages	Larson, S.	2/04/2019	https://www.slideshare.net/CGIAR/using-wellbeing-concept-to-measure-economic-and-social-impacts-a-case-study-of-the-seaweed-processing-womens-groups-in-indonesian-villages
12th Asian Fisheries and Aquaculture Forum	Improving Margins of The Indonesian Seaweed Supply Chain Upstream Players: The Application of The Kaizen Approach	Purnomo, H.	10/04/2019	
Gender in Aquaculture and Fisheries (GAF7): Expanding the Horizons	Chips, sticks and bakso: A case study of the stories of seaweed women's groups in Indonesian villages	Fachri, M.	18/10/2018	https://www.genderaquafish.org/wp-content/uploads/2019/08/GAF7_Long-Report.pdf
	Profit or social capital? A case study of the motivations behind seaweed women's groups in Indonesian villages	Larson, S.	18/10/2018	
Seaweed for Food Security Enhancement, 1st International Symposium of	Diversification of seaweed products and applications: from research to	Paul, N.A.	25/10/2016	https://indoseaweedconsortium.or.id/the-1st-international-symposium-of-indonesian-

Indonesian Seaweed Consortium	development of food and feed			seaweed-consortium/

In country communications were managed by the project communications officer Mr Nur Syamsul (Lukman) in the ACIAR Field Office – Makassar. This included creation and curation of a project specific website, noting that this site (https://rumputlaut.info/wp/) only provided information during the project and was discontinued at completion, and also the production of video and image assets for the project. A snapshot from the project website highlighted research locations for project participants through an interactive map, which provided immediate insight on the breadth of operations or all in the project team. The website also reproduced local level data on the price of seaweed for sale, which is now reported in Appendix 1. The talented Ibu Suliyanti Hakim was a pillar of communications within the project, coordinating activities, travel logistics, budgets, acquittals, government relations and all-round project management, from the banner at the project initiation meeting in 2016 (banner, above) through to COVID-enforced final online meeting and project close.

9 Conclusions and recommendations

9.1 Conclusions

Seaweed farming is an important and growing form of aquaculture in Indonesia, characterised by significant engagement of smallholders over a wide geographical area. It is of particular relevance to rural coastal communities with limited alternative livelihoods options. Seaweed farming is not technically, financially or labour demanding, and the production cycles are short, providing regular income to the farmers. The benefits obtained are not only financial, but personal and social benefits also accrue to seaweed farming households and communities. There is potential for expansion of seaweed farming to the remote coastal and island communities throughout the Indonesian archipelago. Given these characteristics of the industry, it is viewed as a viable option for future betterment of even more coastal communities, and the Indonesian government has implemented a range of laws and regulations to support the industry and its continued development.

The project set out to provide technical support to improve production and processing opportunities for seaweed in Indonesia. With more than 30 formal publications and presentations, over 35 individual collaborators on these research outputs, the project was productive and delivered new knowledge from all activities within its objectives. One of the more pleasing outcomes was the recognition from the formal project reviewers that this solid body of work was achieved with the various challenges faced. They recognised that the project and its partners had delivered an excellent foundation on seaweed taxonomy, a better understanding seaweed production and product quality variability, and new insights into the socio-economics of seaweed farming communities. The significant capacity building of Indonesian researchers was acknowledged as were some fundamental changes that the project facilitated in communication and collaboration between the diverse stakeholders. Given the Indonesian government has committed to support and facilitate the improvement of seaweed-related business, both at national and provincial levels, it was very pleasing to hear that this project remains relevant and will likely do so into the future, especially with the strong collaboration and networks. The project delivered timely and important work to help contribute to the government's goal to see more processing undertaken domestically.

Despite the relatively short time and limited funding, the project has contributed significantly to the ongoing efforts of seaweed development in Indonesia. It was telling that there was a report from the project reviewers that 'the project has been perceived by stakeholders as one of Australia's most significant contributions to Indonesian people'. This feedback was prior to the final year of the project which was defined by the COVID-19 pandemic. COVID-19 did impact the seaweed industry in Indonesia, although this was not a unilateral impact as some areas of the seaweed enterprise benefited (e.g. export of processed seaweed products) whereas other areas were negatively impacted, including exports related to shipping whole/dried seaweed and also declines in farmer wholesale prices (KKP 2021). The original goals of the Government of Indonesia to increase the processing and value adding of the seaweed industry still ring true. It will be interesting to observe whether seaweed production and value adding can renew its upward trajectory after the pandemic, specifically the focus on high value extracts for cosmetics, nutrition and health. This may well include opportunities to work with Australian capacity for innovation into new uses and markets for seaweed can benefit Indonesia and smallholders.

9.2 Recommendations

For seaweed farming to continue to support coastal communities in Indonesia, the identified risks to production, value chains and markets still need to be addressed through research, development and extension, as well as through policy development. The project was able to provide foundational data and new insights and perspectives from its technical research and development, however, the factors affecting farm productivity and product quality still need to be better understood. This will be crucial to improve the reliability of production and reverse the long-term decline in product quality identified for both *Kappaphycus* and *Eucheuma*. Because this is likely to involve the development of high performing seaweed cultivars, we note that the equitable distribution of improved cultivars is also necessary to consider, coupled with extension and technical support. Given the widely distributed nature of seaweed farming in Indonesia, and the remoteness of many farms, innovative forms of extension will need to be developed. This can include facilitating networking with international experts in specific domains with effective communication channels and social media even. Additionally, the impacts of climate change need to be incorporated into any new technical developments.

The Indonesian seaweed value chain would benefit greatly from market diversification. The current model, with production focused on the carrageenan and agar processing industries, leaves producers open to the vagaries of global commodity markets, which causes dramatic fluctuations in seaweed farm-gate prices and impact the farmers most of all, as highlighted in the current project (Purnomo et al. 2021). Increased in-country industrial processing capacity, supported by both industry and the government, would improve future price stability and allow additional economic benefits to flow to Indonesia, broadening the socio-economic impacts of seaweed farming. This is no easy task and requires multiple, coordinated and likely interdisciplinary investments. Such a scope fits squarely with the potential for a CGIAR-like centre relevant to tropical seaweed, and Indonesia would be well placed to host such an initiative. There is significant and increasing interest across the tropics, but seaweed (or aquatic plants) remains the single largest commodity volume in aquaculture and fisheries, with no coordinated effort to support them. ACIAR has the opportunity to leverage the good will and the technical capacity of both existing and new stakeholders in Indonesia into a new program of work. There would be many government, academic and business partners interested from across the Indo-Pacific.

The Indonesian government, project team and industry partners are best placed to determine the priorities for any R&D requirements of a future project that aims to follow this one. It is important to recognise that the success of the current project was because of the relationships and the engagement with most of the key stakeholders in seaweed in Indonesia, including growers, traders, and industries, as well as the government and universities. Long distance project management of the partners might not be the major hurdle that it was once deemed, due to cheap and easy technology in communicating and file sharing that was deployed by the project. The Australian project partners wrote about this during the early COVID-19 experience, reporting positives as well as the negatives from the absence of face-to-face contact, with the caveat that these successes typically leveraged long-term relationships (Swanepoel et al. 2020). Future work should also leverage Indonesian investments, including research student training opportunities. There is also potential to include business in a more direct role working with government and university scientists on shared goals and activities.

Finally, there may be further inspiration for diversification of markets using species of seaweed that are not presently under cultivation in Indonesia but are under development in Australia. For example, it may be possible to integrate seaweed with livestock production in agriculture and aquaculture across the archipelago. This includes the use of seaweed feed additives to reduce methane in cattle, to boost the immune system of fish and to enhance the growth and other productivity traits of crustaceans, including reproductive output and stress tolerance. All of this is work presently being done at

UniSC, from technical R&D through to IP development and commercialisation. These applications in agriculture and aquaculture would generate new short supply chains with national processing and sales of products, whether this be for Indonesian cattle production or shrimp aquaculture.

10 References

10.1 References cited in report

Following are those references cited in addition to project outputs captured in 10.2

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FIS/2010/098 Diversification of Seaweed Industries in Pacific Island Countries. Project Leader: Nicholas Paul. https://www.aciar.gov.au/project/fis-2010-098

SMAR/2008/025 Improved seaweed culture and postharvest waste utilisation in South-East Asia. Project Leader: Symon Dworjanyn. https://www.aciar.gov.au/project/smar-2008-025

FIS/2007/124 Diversification of smallholder coastal aquaculture in Indonesia. Project Leader: Mike Rimmer.

10.2 List of publications produced by project

A total of 24 publications were generated during this project, see Appendix 1 (Publication Summary). There were 20 journal articles published in English (15 with Indonesian first authors/17 with Indonesian collaborators as co-authors, and 15 published as open access, URLs in Appendix 1). Numerous internal reports were produced for internal reporting and in Bahasa for dissemination within the government, including 2 formal publications in the Proceedings of the Annual National Seminar on Fisheries and Marine Products. A single patent was registered based on the work towards Objective 3 (). Other international presentations were made (see Communications). The "Makassar Seaweed Recipe Book" (ACIAR Monograph No. 215) is *in press* for 2024. Publications were relatively evenly spread across the three Objectives (Obj. 3 > Obj. 1 > Obj. 2) and were mostly in the final years of the project (2021 – 8; 2020 – 8; 2019 – 7).

Objectives		# of Publications	% of total
Objective 1: To analyse value chains to identify constraints and knowledge gaps for seaweed production in Indonesia	**Sub-total**	**8**	**33%**
	1.1	*4*	*50%*
	1.2	*-*	*0%*
	1.3	*4*	*50%*
Objective 2: Improve the quality of seaweeds produced at the farm level in Indonesia	**Sub-total**	**6**	**25%**
	2.1	*1*	*17%*
	2.2	*-*	*0%*
	2.3	*3*	*50%*
	2.4	*-*	*0%*
	2.5	*2*	*33%*
Objective 3: To create innovative products from seaweeds and their processed waste streams	**Sub-total**	**9**	**42%**
	3.1	*3*	*30%*
	3.2	*3*	*30%*
	3.3	*4*	*40%*
	Project Total	**23**	**100%**

Key Project Publications (alphabetical order)

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10. Larson, S., Stoeckl, N., Fachry, M. E., Mustafa, M. D., Lapong, I., Purnomo, A. H., & Paul, N. A. (2021). Women's well-being and household benefits from seaweed farming in Indonesia. Aquaculture, 530, 735711 https://doi.org/10.1016/j.aquaculture.2020.735711
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11 Appendixes

11.1 Appendix 1: Publication List

Full Publication List attached in ACIAR format.

Note Pong-Masak, P. R., Ratnawati, P., Simatupang, N. F., Paul, N. A., & Rimmer, M. A. (*In prep*). Evaluation of growth and product quality of seaweed *Kappaphycus alvarezii* cultivars from throughout Indonesia using a common garden approach. Submitted to Indonesian Aquaculture Journal.

Note publication of the patent no. P00202006803: "Formula of liquid and solid bio-fertilizer based on seaweed *Gracilaria* sp and *Sargassum*" DGIP.go.id, *p. 36.*

(20) RI Permohonan Paten

(19) ID **(11) No Pengumuman : 2022/02120** **(13) A**

(51) I.P.C : A 01N 63/00,C 05F 11/08,C 05G 5/20,C 05G 5/10,C 05G 3/00

(21) No. Permohonan Paten : P00202006803

(22) Tanggal Penerimaan Permohonan Paten :
17 September 2020

(30) Data Prioritas :
(31) Nomor (32) Tanggal (33) Negara

(43) Tanggal Pengumuman Paten :
26 April 2022

(71) Nama dan Alamat yang Mengajukan Permohonan Paten :
Sentra Kekayaan Intelektual Kementerian Kelautan dan Perikanan
Gedung Mina Bahari III, Lantai 6-7, Jalan Medan Merdeka Timur Nomor 16, Gambir Indonesia

(72) Nama Inventor :
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Yusma Yenni,ID
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(74) Nama dan Alamat Konsultan Paten :
Sentra Kekayaan Intelektual Kementerian Kelautan dan Perikanan
Gedung Mina Bahari III, Lantai 6-7, Jalan Medan Merdeka Timur Nomor 16, Gambir

(54) Judul Invensi : FORMULA PUPUK HAYATI CAIR DAN PADAT BERBASIS RUMPUT LAUT Gracilaria sp DAN Sargassum sp

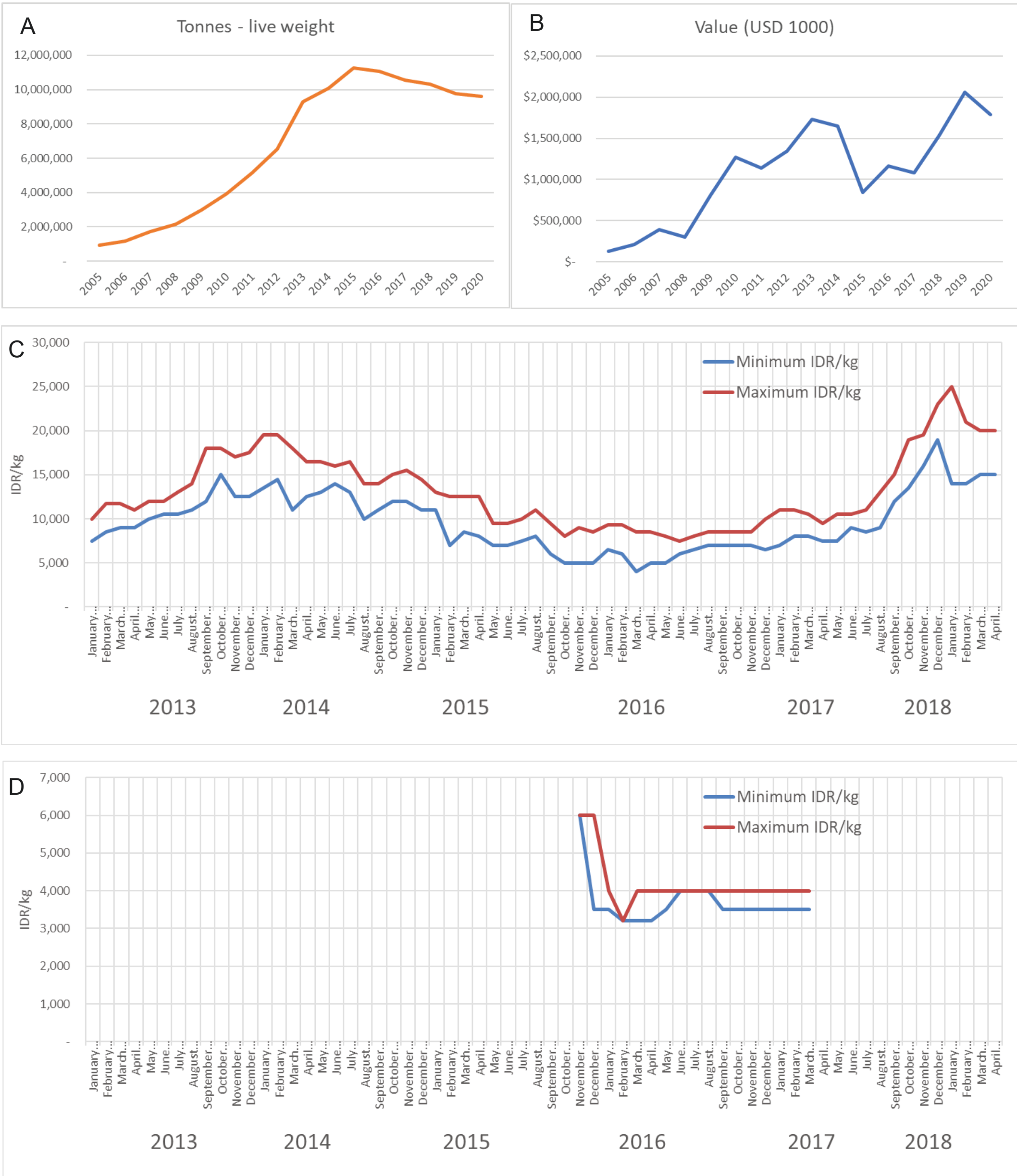
(57) Abstrak :
Invensi ini berkenaan dengan formula pupuk hayati cair dan padat berbasis rumput laut Gracilaria sp. dan Sargassum sp. yang mengandung fitohormon seperti auksin, giberelin, sitokinin-kinetin dan sitokinin-zeatin, mikro dan makro nutrisi berupa boron, tembaga, besi, magnesium, mangan; nitrogen, pospat, dan kalium, asam humat, dan C-organik yang dapat digunakan untuk pemupukan tanaman holtikultura, tanaman tahunan, dan tanaman musiman maupun tambak ikan. Formula pupuk hayati cair terdiri dari: ekstrak cair rumput laut gracilaria 30-50%; ekstrak cair rumput laut sargassum 30-50%; Tepung ikan 1-3%; tetes tebu 1-3%: dan konsorsium mikroorganisme Bacillus subtilus, Serratia marcescens, Pseudomonas flouroscens, Azotobacter, Lactobacillus casei dan kapang Aspergillus niger, Trichoderma, Saccaromyces cereviceae, Penicillium citrinum. Sedangkan formula pupuk hayati padat yang terdiri dari: rumput laut atau limbah padat ekstraksi agar 10–40%; tepung sargassum 10-25%; KoHe atau kotoran sapi yang telah difermentasi 40-55%; tetes tebu 1-3%; tepung ikan 1-4%; dolomit 5-10%; dan pupuk hayati cair 5 - 15%. Pupuk hayati cair dan padat merupakan pupuk yang ramah lingkungan, pembenah tanah, dan dapat memperkaya tanah dengan mikroorganisme pelarut fosfat, pelarut K, fiksasi N, mikroba ligninolitik, mikroba selulolitik untuk melawan mikroba pathogen, serta dapat mensubstitusi pupuk anorganik minimal 25%.

Abstract: This invention relates to liquid and solid biofertilizer formulas based on Gracilaria sp. and Sargassum sp. which contains phytohormones such as auxins, gibberellins, cytokinins-kinetins and cytokinins-zeatins, micro and macro nutrients in the form of boron, copper, iron, magnesium, manganese; nitrogen, phosphate, and potassium, humic acid, and C-organic which can be used for fertilizing horticultural crops, annual crops, and seasonal crops as well as fish ponds. Liquid biological fertilizer formula consists of: liquid extract of gracilaria seaweed 30-50%; sargassum seaweed liquid extract 30-50%; fish meal 1-3%; molasses 1-3%: and a consortium of microorganisms *Bacillus subtilus, Serratia marcescens, Pseudomonas flouroscens, Azotobacter, Lactobacillus casei* and *Aspergillus niger, Trichoderma, Saccaromyces cereviceae, Penicillium citrinum*. Whereas solid biological fertilizer formula consisting of: seaweed or solid waste extraction agar 10–40%; sargassum flour 10-25%; KOH or fermented cow dung 40-55%; molasses 1-3%; fish meal 1-4%; dolomite 5-10%; and biological fertilizers liquid 5 - 15%. Liquid and solid biological fertilizers are environmentally friendly fertilizers, soil enhancers, and can enrich soil with phosphate solubilizing microorganisms, K solubilizing, N fixing, ligninolytic microbes, cellulolytic microbes to fight microbes pathogens, and can substitute for inorganic fertilizers at least 25%.

11.2 Appendix 2: Seaweed trade volume and value

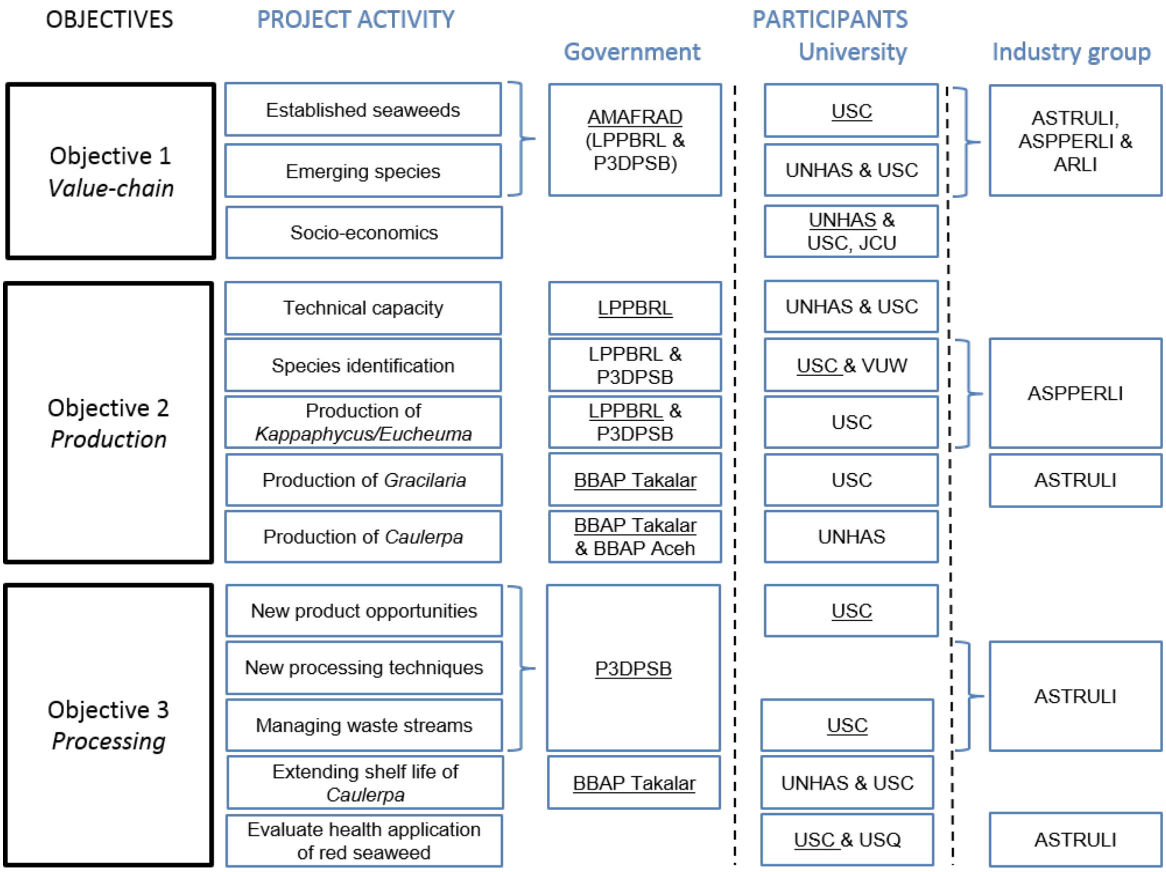
Annual seaweed production quantity (A; tonnes, live weight) and value (B; USD 1000, related to A) for Indonesia from 2005 through to project completion in 2020. Data source: https://www.fao.org/fishery/statistics-query/en/aquaculture/aquaculture_value. Aquaculture quantity and value statistics (“Indonesia”, “Aquatic plants”, FAO Statistical Query).

Monthly variation in the maximum and minimum value of dried *Kappaphycus* (dry weight kilogram) in Makassar, South Sulawesi. Values traded as IDR (Indonesian Rupiah, US$1 = ~10,000 IDR). Data source: Makassar wholesale market data. Monthly variation in the maximum and minimum value of *Kappaphycus* (C) and *Gracilaria* (D) in Makassar, South Sulawesi. Values traded as IDR (Indonesian Rupiah, US$1 = ~10,000 IDR). Data source: Makassar wholesale market data.



11.3 Appendix 3: Project Partners

The role of government, universities and industry in FIS/2015/038 project activities, with Government of Indonesia partner names as per the start of the project (these did change over the project duration). Lead participant underlined where multiple entities are involved in activity, including University of the Sunshine Coast (USC, now UniSC!)



Participants – Government

AMAFRHR – Agency for Marine and Fisheries Research & Development

LPPBRL – Centre for Seaweed Culture Research and Development, Gorontalo (AMAFRHR)

P3DPSB - Research & Development Centre for Marine & Fisheries Product Processing & Biotechnology, Jakarta (AMAFRHR)

BBAP Takalar – Brackishwater Aquaculture Development Centre Takalar, South Sulawesi (*Contracted expenditure*)

BBAP Aceh – Brackishwater Aquaculture Development Centre Ujung Batee, Aceh (*Contracted expenditure*)

Participants – University

UNHAS – Hasanuddin University, Makassar, South Sulawesi

VUW – Victoria University Wellington, New Zealand (*Contracted expenditure*)

Participants – Industry Group

ASTRULI – Indonesian Seaweed Industry Association

ASPPERLI – Indonesian Seaweed Farmers and Processors Association

ARLI – Indonesian Seaweed Association

11.4 Appendix 4: Molecular Barcoding

Scientific Database of Commercial and Emerging Indonesian Seaweeds

Project Team: Bagus SB Utomo, Ekowati Chasanah, M Darmawan, Asri Pratitis, Sihono

Objective: Identify existing and emerging Indonesian species of seaweed using molecular barcoding techniques

Species:Location (Molecular barcoding, GenBank Accession numbers)

1. *Gracilaria*: Makassar (local names *G. chilensis* laut and *G. gigas* laut), Brebes (local name *G. verrucosa*)
2. *Eucheuma*: Makassar (local names *E. cottonii*, *E. spinosum*)
3. *Caulerpa*: Makassar (Lipan), Bintan, Jepara (Kebo, Telon), Lampung (Latoh), Seram, Binuangeun (Pedesan, Latuh)
4. *Halymenia*: Binuangeun

LOCATION	SPECIES (DNA IDENTIFICATION)
Gracilaria	
▪ Makassar	*Gracilaria changii*
▪ Brebes	*Gracilaria heteroclada, Gracilaria blodgettii*
Eucheuma	
▪ Makassar	*Kappaphycus* sp, *Kappaphycus alvarezii, Kappaphycus striatum* *Kappaphycus striatus, Euchema dentilacum*
Caulerpa	
▪ Jepara	*Caulerpa racemosa, Caulerpa racemosa var cylindracea*
▪ Lampung	*Caulerpa racemosa, Caulerpa taxifolia*
▪ Molluca	*Caulerpa microphysa, Caulerpa racemosa*
▪ Takalar	*Caulerpa racemosa, Caulerpa cylindracea, Caulerpa sertularoides*
▪ Binuangeun	*Caulerpa racemosa f macrophysa, Caulerpa chemnitzia, Caulerpa sertularoides*
▪ Bintan	*Caulerpa racemosa, Caulerpa serrulata, Caulerpa cupressoides*
Halymenia	
▪ Binuangeun	*Halymenia floresii*

11.5 Appendix 5: Gracilaria

Locations of key areas relating to production trials with *Gracilaria* (Objective 2.4 reciprocal transplant) in Sanrabone (south of Makassar), South Sulawesi.