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Final report

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Abbreviations

AMAFRAD	Agency for Marine Affairs and Fisheries Research and Development, within Ministry of Marine Affairs and Fisheries, Indonesia
AMAFRHRD	Revised name of AMAFRAD, to Agency for Marine Affairs and Fisheries Research and Human Resources Development
BRSDM	Bahasa Indonesian name for AMAFRAD
BBAP	Brackishwater Aquaculture Development Centre, Ujung Batee, Aceh
DGA	Directorate General of Aquaculture, within Ministry of Marine Affairs and Fisheries, Indonesia
IMRAD	Institute for Mariculture Research and Development, Gondol. Administered by AMAFRAD, Indonesia
IPB	Bogor Agricultural University, Indonesia
JCU	James Cook University, Queensland
MADC	Marine Aquaculture Development Centre, Lombok. Administered by DGA, Indonesia Indonesian name: Balai Perikanan Budidaya Laut Lombok

1 Acknowledgments

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2 Executive summary

Lobster aquaculture in Indonesia is likely to develop significantly in the next several years, bolstered in part by the outputs from this project. Significant outcomes and outputs were achieved, despite substantial challenges of a political nature that necessitated suspension of several planned research activities during the course of the project. It was fortunate that the project made a fast and robust start, subsequent to and as a result of the project inception meeting held in October 2015. Significant progress was made across all four original objectives and milestones through 2016 and up to the projects first annual workshop on 7 March 2017. Immediately following that workshop, political sensitivity surrounding the wild harvest of lobster puerulus (early juvenile growth stage transitioning from planktonic to benthic adult) resulted in a project variation. Once banned, lobster cage-based farming by coastal communities was deemed illegal as it relied on the wild harvest of puerulus. While the fishing and farming of lobsters in Indonesia remained a politically sensitive issue, the new regulation specifically allowed for research on lobsters to continue, including for aquaculture. BRSDM requested the variation to reduce the footprint of the project by removing the activities at DGA Centres in Lombok and Aceh. While the variation was being considered by the Indonesian authority, all research activities were suspended, which continued to February 2018. The variation was revised further to remove Objective 1 (lobster seed fishery assessments) and all industry development activities. The project subsequently focussed on diet development using 200g+ wild lobsters (as collection of smaller sized animals was illegal by then).

Research into lobster seed (common term for lobster puerulus) supply included field and tank experiments and assessments conducted by project associates at MADC Lombok and BBAP Ujung Batee Aceh. A field survey was completed to quantify the geographic extent and catch statistics for seed from west Java to east Sumbawa, that confirmed high abundance of settling puerulus throughout that range and an estimated annual catch of 100 million seed. Experiments were completed for seed catch technique, seed condition, transport methods, weaning to manufactured diets and feeding frequency. These data contribute significantly to a standard operating protocol for seed capture and handling. Nevertheless, post-capture seed mortality remains high and further development of effective technology to achieve acceptable survival (>70%) and high quality (robustness in cage rearing systems) is necessary for commercial operations (Jones *et al.*, 2019).

Research on diet development for nursery production conducted at IMRAD Gondol, Bali included several experiments to refine the formulation of pelleted feed. These experiments confirmed that diets made with locally available ingredients are as effective as others with ingredients sourced from outside Indonesia, and that dry pellets are as effective as semi-moist for juvenile lobsters greater than 3g. The research has highlighted the need for more research and development on the initial nursery phase, from puerulus to 3g. Mortality of juveniles through this nursery phase was consistently high and unacceptable for commercial success. Further research is required to develop husbandry management methods to achieve the target survival of more than 70% from stocking with juveniles to harvest of market-sized animals at 500g to 1kg.

A diet formulation was defined from a series of experiments using 200g+ lobsters. This formulation is suitable for commercial manufacture. However, the growth and survival of lobsters is superior when a fresh seafood diet is used, and further research. Further developments are required to address issues of formulated diet attractiveness to achieve maximum ingestion. Unlike most aquacultured fish species, marine rock lobsters are fussy feeders and will require food variety and diets that are highly attractive.

Socio-economic research was performed with community surveys in Lombok and Sumbawa. In Lombok, where lobster growout had been established in the past, but is currently abandoned, a survey was conducted to explore the opportunity for coastal villages to re-engage with lobster farming. In Sumbawa, where lobster farming has never before been contemplated, a comprehensive socio-economic survey was performed to

explore the opportunity for coastal villages to engage in lobster farming in future. The data indicate the individuals and families of these coastal communities are risk averse and will require interventions to increase their knowledge and confidence to engage in lobster aquaculture. Community discussion (focus groups), demonstration farms and government extension programmes will be required to increase participation.

Market-chain assessment research was completed with information gathered on the existing fishery lobster products in Indonesia and on premium markets in China. The market opportunity for Indonesian farmed lobsters is strong, but must be met with a focus on meeting market requirements and quality of product. Farmed lobster from Vietnam is perceived by China markets as inferior, attracting a sub-premium price. Indonesia has an opportunity to avoid this, focussing on product that is equivalent to premium wild caught.

Indonesia is poised for rapid and significant expansion of lobster aquaculture. At the time this report was prepared, Indonesian Government policy had been revised to once again support lobster seed fishing and lobster farming, and likely allow a small export sector to develop. The fundamental requirements for a large scale, sustainable lobster aquaculture industry are in place, and with further government and R&D support, Indonesian lobster aquaculture can grow quickly and employ thousands of people in coastal communities in viable and sustainable livelihoods.

3 Background

The project was activated on 1 July 2015 as a four year project, to be completed by 30 June 2019. Subsequent to an end of project review completed in November 2018 the end date was extended to 31 December 2019. James Cook University (JCU) was commissioned for the project, with Dr Clive Jones as project leader. The project co-operated with Indonesia's Agency for Marine Affairs, Fisheries Research and Human Resources Development (AMAFRAHRD) (BRSDM), with Dr Toni Ruchimat as the project coordinator.

The project followed earlier investments by ACIAR in tropical rock lobster aquaculture development, that were first focussed on Vietnam and subsequently on Indonesia. This project was the first to focus exclusively on Indonesia with the aim to develop effective production technology for on-growing wild seed lobsters to minimal legal size lobsters, with a priority on developing a suitable formulated diet and improving production husbandry techniques.

The premise of the project was the significant, unmet demand for marine rock lobsters that can be supplied with farmed product using relatively simple technology and providing economic benefits to impoverished coastal communities in Indonesia.

It had been established in previous ACIAR projects that, during periods of high puerulus fishery productivity, growout of lobsters in Indonesia diminished as farmers switched to the lucrative business of harvesting and exporting of puerulus seed to Vietnam. Coastal communities focussed on harvesting and selling the seed, an approach that is lucrative and low risk, but diminishes the more significant economic benefit of on-growing lobsters, to those communities. There is sufficient seed to support sea cage production of more than 5,000 tonnes of market size lobsters, and to provide several thousand jobs to women and men of coastal communities throughout Indonesia. The projects purpose was to see increased engagement in lobster growout, through further technical advances (primarily formulated feed development) and socio-economic assessments to develop strategies for increasing participation. It is a significant challenge to provide a framework of knowledge and support to encourage small-holders to revert from seed fishing to lobster farming.

4 Objectives

The overall aim of this project was to expand production of tropical spiny lobster in Indonesia through research that defined best husbandry and feeding practice and ensured its adoption by farmers. The project comprised four objectives which addressed seed supply, growout production, and capacity and impact.

An ACIAR-sponsored international lobster aquaculture symposium held in Lombok in April 2014 defined knowledge gaps and key issues. The research questions were based on the key recommendations from this event, and are focused around lobster farming methods and their adoption by coastal communities:

- Can the catch of lobster seed be increased and expanded to other parts of Indonesia?
- How can the lobster farming industry gain greater returns from the lobster seed that are captured?
- Can farmers achieve greater survival and growth of lobsters through the nursery and grow-out phases?
- Are best-practice lobster-farming methods understood and adopted by fishers/farmers?
- What are the socio-economic benefits of lobster farming for industry participants and communities?

To answer these questions, the following objectives were defined.

Objective 1: *Develop and expand a sustainable lobster seed catch sector in Indonesia*

- Compile, analyse and report annual lobster seed catch data
- Identify lobster seed resources in multiple locations and develop their sustainable exploitation
- Optimise catching, handling and transport of puerulus lobsters for the transition from catch to nursery

Objective 2: *Define optimal lobster growout production technology*

- Increase nursery production through improved nutrition and disease management
- In collaboration with private sector feed companies, finalise development of practical diet formulations and feeding strategies that promote use of pelleted feeds on farm and account for differences between species
- Review current status of lobster disease threats in Indonesia
- Assess feed supplementation, including use of pre- and pro-biotics to minimise disease in farmed lobsters
- Scope lobster grow-out opportunities for Indigenous communities in northern Australia

Objective 3: *Build capacity in lobster aquaculture research and production*

- Provide training in laboratory-based experimentation, particularly for nutrition research
- Prepare and publish a farmer-level lobster-farming manual

- Perform a market-chain analysis for Indonesian lobster
- Develop opportunities for lobster grow-out beyond Lombok
- Improve extension of technology to industry

Objective 4: *Evaluate the socioeconomic impacts and maximize the benefits of the project's activities*

- Develop robust economic models of lobster farming in Indonesia that enable comparative assessment of pellet diets, production systems and other critical factors
- Assess and monitor the socioeconomic costs and benefits of lobster farming in the communities involved
- Identify the socioeconomic factors that influence the adoption of lobster-farming technology and explore strategies for scaling out production.
- Develop strategies for maximising the benefits of project activities in the communities.

After Variation #1, Objective 1 was removed, and all subsequent research focussed on the remaining objectives.

5 Methodology

Objective 1: Develop and expand a sustainable lobster seed catch sector in Indonesia

Although Objective 1 was removed from the project in March 2017, considerable research was completed up to that time.

Lobster seed catch data were collected from a series of coastal villages where seed fishing was known to occur. Structured interviews were conducted at three villages in Java and Sumbawa to collect quantitative data. Semi-quantitative data was collected from many more villages through phone interviews with seed dealers. Data collected comprised monthly catch, species composition and price, and analyses were made concerning catch per unit effort, seasonality, inter-annual variability, markets, price trends and economic indicators.

From locations in Lombok, Java and Sumbawa where detailed data were collected, a definition was generated of the physical characteristics associated with puerulus abundance. Using Google Earth, a detailed examination of the southern coasts of Java and Sumbawa identified additional locations with these characteristics occur, as a basis for estimating the entire puerulus resource. Full details of methods are presented in Appendix 1.

Improved catch rate and survival of seed was investigated through a series of controlled experiments performed in both tank and sea-cage systems at MADC Lombok and BBAP Ujung Batee, Aceh. Experiments examined aspects of catch methods, handling and transport of pueruli to maximise catch rates and improve survival and condition from point of capture to farms.

Objective 2: Define optimal lobster growout production technology

Improved survival and growth of juvenile and adult-sized lobsters was investigated through a series of carefully designed experiments performed in both tanks (to maximise control of variables) and sea-cage systems (to best represent typical industry conditions). These experiments investigated the nursery and growout stages as distinct processes. For nursery, the treatments within experiments included aspects of diet, husbandry and disease management to improve survival.

Growout experiments were conducted to inform diet formulations and practical pellet feeding strategies at farm level. Past research provided nutritional information on tropical lobsters to formulate effective pellet diets. The research conducted will support the transition from laboratory made pellet diets to commercial production. The industrial manufacturing processes are likely to constrain some aspects of what might be ideal formulation and form of the diet in terms of lobster nutritional needs. Adjustments to both formulation and form may be required for practical pellet diets that are effective on farm, at least cost.

Given limitations for commercial feed manufacturers to produce small ‘research’ quantities of diet formulations, it was not possible to engage them in the project and make diets for the experiments performed. However, IMRAD Gondol has both the necessary equipment (small extruder and pellet press) and expertise to make small batches. Trial feeds were manufactured successfully under the guidance of the CSIRO partners.

Periodic disease issues have been a significant problem in the Vietnam lobster farming industry, primarily attributed to the milky haemolymph disease. Because lobster growout in Indonesia is currently negligible, the impact of disease is difficult to gauge. Nevertheless, as the project was strongly focussed on increasing lobster growout, consideration of disease was important. A survey of lobster disease issues and the relative impact of disease on growout success was conducted. In designing the survey,

aquatic animal health knowledge was sourced through the Jakarta Fisheries University, and results on disease status were documented. See Appendix 10.

The efficacy of probiotics to manage bacterial infect on farms was tested using intestinal bacteria extracted from wild *P. homarus* lobsters collected from coastal waters off the Jembrana District of Bali, Indonesia. Intestinal bacteria were isolated and identified, followed by enzymatic hydrolysis tests to select candidates of bacteria that could be used as probiotics in lobster culture. The research found four bacteria with probiotic characteristics that were subsequently assessed in tank-based growout trials. The efficacy of the probiotic - mannan oligosaccharide - was tested in tank based growout trials.

In Australia, a scoping study enabled further consideration of opportunities for lobster farming for Indigenous communities in northern Australia. This built on outcomes and constraints identified towards this goal in an earlier project SMAR/2008/021.

Objective 3: Build capacity in lobster aquaculture research and production

Capacity building of partner research personnel in nutrition research was achieved through specific training exercises and workshops. A specific training course over 3 weeks in nutrition research was delivered in Australia at Bribie Island Research Centre led by CSIRO. This training was delivered to a participant from each of the partner organisations - MADC, IMRAD and BBAP Ujung Batee.

A lobster farming manual was prepared, which aimed to provide practical husbandry and feeding information for lobster farmers. The manual was written in both English and Bahasa. The manual was not distributed to farmers due to the ban on farming, but can be quickly published and distributed under the now revised regulations.

A review of the lobster market-chain and marketing opportunities for farmed Indonesian lobster was performed by seafood-marketing specialist Nick Ruello, based on terms of reference prepared by the project leader. This review was conducted through both market interviews in Bali and Jakarta, and desk-based enquiry. Due to the ban on lobster farming, the market review report was not published nor distributed at the time. It remains current and can now be distributed to relevant stakeholders.

Project participant Samsul Bahrawi from MADC Lombok was identified as a suitable candidate for a JAF, and was successful in being awarded the scholarship. He undertook an MSc in aquaculture nutrition at JCU.

Capacity building of partner research personnel at IPB in socio-economic research occurred through the collaboration and mentoring of Amy Diedrich and Liz Petersen. Several students studied for MSc and PhD as part of the socio-economic research conducted for the project.

Objective 4. Evaluate the socio-economic impacts and maximize the benefits of the project's activities

Dr Liz Petersen and counterpart Indonesian economists from Bogor Agriculture University performed a review of the bio-economics of lobster farming in Indonesia, based on previously published models produced in 2010, to enable comparative assessment of adoption by farmers of pellet diets, production systems and other critical drivers and barriers. The review encompassed household surveys of those previously involved in lobster farming activities, using standard interview and survey techniques to gather quantitative data.

Dr Amy Diedrich performed assessments in collaboration with counterpart social scientists from Bogor Agriculture University examining and monitoring socioeconomic impacts of lobster-farming technology, which also explored strategies for scaling out production. This comprised household surveys, focus groups, and key informant interviews in villages in Lombok and Sumbawa where lobster-farming had previously occurred or was an available option. The social research focussed on gender roles in lobster farming, identifying the potential for increased opportunities for the role of women.

6 Achievements against activities and outputs/milestones

Note the following achievements against milestones are based on the objectives and research activities as specified in the original project document. Subsequent to the Variation #1 in 2017, original Objective 1 was removed (as outlined in section 7.1). Objectives 2, 3 and 4 (and all their respective research activities) were re-numbered as 1, 2 and 3, in annual reports and other reporting from 2017 to 2019. For full disclosure of results, this final report has reverted to the original 4 objectives and their numbering.

Objective 1. Develop and expand a sustainable lobster seed catch sector in Indonesia

no.	Activity	Outputs/ milestones	Completion date	What has been achieved / Comments
1.1	Compile and analyse annual lobster seed catch data	Data on catch, species composition, seasonality and variability	March 2017	Field surveys were performed that collected data on puerulus catch, species composition, seasonality, lunar periodicity and capture methods in areas of Indonesia where puerulus abundance appeared to be relatively high based on anecdotal fishery information. The study also made an estimate of the entire resource by mapping of suitable settlement locations and extrapolation from data from quantified populations. Lastly, the data compiled enabled estimates of the scale of lobster farming that Indonesia might have. Policy recommendations to achieve this are provided. The outcomes of this research are presented in Chapter 4 of the PhD thesis of Bayu Priyambodo, and have been prepared for scientific journal publication (Priyambodo, *et al.*, 2020).
1.2	Identify lobster seed resources in multiple locations and develop sustainable exploitation of them	New seed resources identified in new locations	December 2018	In addition to the more thorough investigations into the existing fishery of the lobster puerulus resource already established in Lombok, assessment was made of the availability of lobster puerulus in other parts of Indonesia. It was clear from these assessments that the primary and most abundant resource of lobster seed is located along the southern coastline of Java, Lombok and Sumbawa, likely resulting from the delivery of very high numbers of late stage phyllosoma larvae, by the Indonesia Throughflow current running southwards through the Bali / Lombok Strait and then eddying west to Java and east to Lombok and Sumbawa. Further analysis, using existing information, may help better define the way forward for sustainable exploitation of what are very substantial seed resources in Indonesia.
1.3	Optimise catching, handling and transport of puerulus lobsters for the transition from	Standard operating procedures for puerulus catch, handling and transport	March 2017	A series of experiments was performed to address this objective, resulting in several publications, listed below. This aspect of the project's research was identified as an on-going priority at March 2017, and a program of focussed research at the collaborating Centres in Lombok, Aceh and Gondol was planned. This was in response to the significantly high

no.	Activity	Outputs/ milestones	Completion date	What has been achieved / Comments
	catch to nursery through laboratory and field experiments			mortality of puerulus lobsters after delivery to the various research facilities. Unfortunately, this work was discontinued as of March 2017 due to the removal of the DGA Centres from the project and the requirement to cease all research on seed capture and nursery, and restrict on-going research to experiments with 200g+ lobsters. Nevertheless, the project achieved a significant body of work for this objective as evidenced by the following publications. (Fachry, *et al*., 2018 (Appendix 2); Jones, 2017; Jones and Muhammad, 2018; Priyambodo and Jones, 2018; Priyambodo, *et al*., 2015; Priyambodo, *et al*., 2017; Priyambodo, *et al*., 2016; Rusdi, *et al*., 2017; Sahidhir, *et al*., 2017; Selamet, *et al*., 2017; Syafrizal, *et al*., 2017; Syafrizal, *et al*., 2018). Six experiments completed: MADC Lombok – 3 experiments completed (seed fishing and seed condition), BBAP Ujung Batee Aceh – 3 experiments completed (seed transport, weaning and feeding frequency) Although a formal 'standard operating procedure' document for lobster seed catch, handling and transport, has not been prepared, the elements for such are available as outputs from the project. To prepare such a document for provision to industry, would require further research to confirm efficacy of practices, and policy support to permit commercial seed capture and nursing.

Objective 2: Define improved lobster nursery production technology

no.	Activity	Outputs/ milestones	Completion date	What has been achieved / Comments
2.1	Increase nursery production through improved nutrition and disease management	6 experiments are completed Data on nutrition, husbandry and disease	March 2017	Prior to March 2017, when the project variation was initiated, experiments on post-puerulus and sub-100g lobsters were performed at MADC Lombok, BBAP Ujung Batee Ache and IMRAFE Gondol. Post March 2017 and due to the requirement of AMFRHR to cease all project activities at DGA Centres and only work with >200g lobsters (to comply with current fisheries regulation), 'nursery production' then transitioned to 200g+ lobsters of species *Panulirus homarus*. No nursery experiments were performed after March 2017. In general, the project activities aimed at enhancing production through improved nutrition for the culture from seed (post puerulus), sub-100g and more than 200g were successful. However, the survival rates (SR) achieved during trials were generally poor (15% to 35 %),

no.	Activity	Outputs/ milestones	Completion date	What has been achieved / Comments
				when the target for commercial purposes demands a SR exceeding 50-70%. For the first time, base line data for nursery production of *P. homarus* is now available for Indonesia. Further effort is required to improve SR in experiments.
2.2	In collaboration with commercial feed companies, finalise development of practical diet formulations and feeding strategies that promote use of pelleted feeds on farm and account for differences between species	Commercial pellet formulations are tested Pellet diet formulations that are effective and can be commercially produced	December 2019	At the project outset, contact was made between IMRAFE Gondol staff (through Dr Adiasmara Giri) and JAPFA Comfeed subsidiary Suri Tani Pemuka (STP), Indonesia's largest aquafeed company and PT. Cargill Indonesia, who produce aquafeed for mariculture, especially for grouper. They expressed interest in working with the project to trial commercial production of diet formulations generated by the project, for testing with lobster farmers. This was anticipated to occur in the second half of the project, when diet formulations tested under experimental conditions, would be available for such 'commercial' assessment. Due to the project's suspension and subsequent requirement to not engage with industry, it was not possible to pursue any collaborative work with STP nor Cargill. Further the ban on lobster farming, precluded any lobster farmer involvement and STP advised they would have no interest in working with lobster feed if farming was not permitted. Similarly, with Lucky Star, the Taiwan based aquafeed company. We worked with them in 2015/16 to assist in them gaining approval to import their proprietary lobster food for testing against our project formulated diets. We also shared with them our most effective (at that time) formulations to incorporate in their manufacture. Lucky star diets were used in experiments at MADC Lombok through 2016 but proved to be ineffective. No further collaboration has occurred since. Nevertheless, our relationship with them has remained strong and there is occasional contact. They remain the only known commercial producer of a lobster diet and are well placed to benefit from the diet formulations generated by the project. Despite the necessary absence of commercial feed companies from the project, the development of effective, practical and commercially relevant diet formulations continued, such that the most effective formulations now defined are available for commercial feed companies to consider in future. Interest has recently been expressed from Tateh Aquafeeds (subsidiary of Santeh Feeds Corporation) in the Philippines. The most effective 'basal' lobster diet formulation was shared with Tateh, and Clive Jones assisted in performing a lobster diet development experiment at BFAR facilities in East Visayas in the Philippines. The experiment demonstrated that the ACIAR basal formulation was effective when prepared as a moist dough diet mixed with 30% fresh seafood. It is significant outcome, as Santeh is a regional aquafeed company that exports feeds throughout Asia.

no.	Activity	Outputs/ milestones	Completion date	What has been achieved / Comments
				The project has successfully produced and tested commercially relevant diet formulations which were trialled at laboratory scale. Base line information has been achieved but will require further effort to scale up to an industrial/commercial level.
2.3	Review current status of lobster disease threats in Indonesia through an industry survey	Knowledge of diseases and their prevalence Recommendations on further action required	March 2017	At the time of project initiation in early 2015, the project leader was advised by Dr Ketut Sugama that a lobster disease survey – incorporating wild and farmed populations, was to be performed by a Masters student at Jakarta Fisheries University - Miss Niluh Anggra Lasmika. Rather than duplicate the research, which was current and well performed, Dr Sugama agreed we should use this lobster disease survey in response to the ACIAR project objective 2.3. In return, Clive Jones committed to working with Dr Sugama and Miss Anggra to prepare the research for publication. A manuscript has been prepared for Journal of Fish Diseases. (Lasmika*, et al*., 2018) The original disease report has been revised by project leader Clive Jones and is included in the project final report. Appendix 10. The current status of lobster disease threats in Indonesia is now documented, revealing milky haemolymph disease to be the greatest threat, as it is for Vietnam. Recommendations for addressing the threats are primarily in regard to best practice husbandry, and the inclusion of pre and pro biotics as dietary supplements to boost immune response. Through the project, Indonesian Lobster disease status was documented for the first time providing valuable base line information. Among many disease problems caused by bacteria, parasites and fungus, milky tail disease which is caused by Rickettsia-like bacteria is particularly lethal for lobster. No effective cure is known at present once symptoms are expressed by the infected lobster. Milky tail disease appears widely dispersed, with lobster from various sites found to be infected. Guidelines for the management and mitigation of milky tail disease may be useful for farmers and the production of a simple manual to this end should be prepared.
2.4	Assess feed supplementation including use of pre- and pro-biotics to minimise disease in farmed lobsters	Data on efficacy of pre- and pro-biotics	December 2018	Dr Haryanti of IMRAFE Gondol is an aquatic health specialist with experience in identification, isolation and production of native probiotics. As part of the ACIAR project, she has isolated 4 probiotics specific to lobsters at the IMRAFE Gondol system, and with demonstrable health benefits. These were tested in isolation and in combination through dietary supplementation with positive results. Data on the probiotiocs was presented at the end-of-project workshop and has been prepared for publication – Appendix 11.

no.	Activity	Outputs/ milestones	Completion date	What has been achieved / Comments
				The primary benefit of the probiotics is in minimising the incidence of milky haemolymph disease – the most common and destructive health issue for cultured lobsters. The well know prebiotic mannan oligosaccharide was assessed as a dietary supplement for juvenile lobsters *Panulirus ornatus* in Vietnam as part of the previous ACIAR lobster project SMAR/2008/021. Its efficacy was demonstrated. It has subsequently been assessed in this project with *P. homarus* with positive result and has become a baseline ingredient in the diet formulations used. IMRAFE Gondol has the capacity to investigate the potential use of native probiotics for feed supplementation. The project was able to isolate 4 strains of potential bacteria candidates for probiotics - *photobacterium damsela n-5, Bacillus subtilis C-1*, *Bacillus oceanisediminis*–H-3, *Bacillus, amyloliquefaciens I-5* which were shown to increase survival and growth rates by enhancing the immunity of lobster (post puerulus and baby lobster). Translating the findings to the routine use of probiotics by lobster farmers should be pursued.
2.5	Scope lobster grow-out opportunities for Indigenous communities in northern Australia	Opportunity to establish Australian Indigenous lobster farming defined	December 2018	This activity was approached through further discussion with Jaragun Pty Ltd (Dennis Ahkee and Liz Owen) who are business development consultants specialising in Indigenous enterprises. They performed the scoping study and business planning for proposed lobster farming in an Australian Indigenous community for the previous ACIAR lobster project SMAR/2008/021. Their advice was consistent with the earlier reports that current regulatory compliance requirements in Queensland were incompatible with lobster aquaculture, and that there is greater scope for such an initiative in the Northern Territory. Subsequently, an opportunity arose to submit a concept for lobster farming on Groote Eylandt. This pre-proposal is currently under consideration by the Anindilyakwa Land Council. It includes assessment of naturally settling lobster seed in the Groote Archipelago area, and nursery and grow out operations. These represent 3 distinct components that could operate effectively as independent enterprises or in combination. The regulatory framework of the NT is conducive for such enterprises, and the proposed Groote project could serve as a model for other areas in the NT and WA. In addition, project associate Simon Irvin (CSIRO) has performed an assessment of the potential for lobster aquaculture in the Torres Strait. While technically feasible, lobster farming in the Torres Strait is constrained by high operational and logistics costs and local capacity in lobster aquaculture techniques. Several lobster grow-out opportunities for indigenous communities in northern Australian were identified and examined. While limited in scope, this suggests the establishment of Indigenous lobster farming may have limited potential at this point in time.

Objective 3: Build capacity in lobster production research

no.	Activity	Outputs/ milestones	Date completed	What has been achieved / Comments
3.1	Provide training in laboratory-based experimentation, particularly for nutrition research	Officers from collaborating agencies trained and capacity increased	March 2017	The training was successfully performed in March 2017, over an 18 day period, involving 3 young scientists representing MADC Lombok (Mr Hidayat Muhammad), IMRAFE Gondol (Mr Wawan Andriyanto) and BBAP Ujung Batee Aceh (Mr Ibnu Sahidhir). The training was coordinated and delivered by CSIRO Nutrition Scientist Mr Simon Irvin at the Bribie Island Aquaculture Research Centre. The training had two objectives, firstly to provide theoretical basis and practical demonstration of tank and cage based experimentation as applied to developing aquaculture technology. The second objective was to build the capacity of the Indonesian ACIAR team, to promote consistent and high quality experiment management. Training was provided in a relaxed and informal format, conducive to open discussion. The training program involved theoretical and practical exposure on a range of topics. This knowledge was directly applied in the design, set up and conducting of a short feed study In addition to general familiarisation with all aspects of a high functioning aquaculture research facility, the participants also set-up and ran their own tank-based experiment on prawn nutrition. Post training assessment both by the participants and the coordinators suggest the training was very effective and worthwhile, with likely on-going benefits by virtue of the increased capacity. In addition to the increased knowledge specific to aquaculture nutrition experimentation, the improved capacity of the three young scientists will benefit them and the organisations they work for, in regard to scientific rigor, accuracy and precision in measurement, forward and contingency planning, and risk assessment and management. Capacity building throughout all laboratory based experimental work was strongly emphasised and delivered to the young scientists during the life span of the project. Informal discussions with 3 of the young scientists involved in the capacity building process at Bribie Island was very positive indicating improved overall capacity and more confidence related to nutrition research for spiny lobster aquaculture.
3.2	Prepare and publish a farmer-level lobster farming manual	Lobster farming manual in Bahasa Indonesian and English	December 2019	This manual has been prepared in both English and Bahasa, and represents a current revision of earlier manuals produced in Vietnam and in Indonesia. With the current Indonesian regulations prohibiting lobster aquaculture, and AMAFRHRD policy precluding engagement with industry, the manual has not been formally published.

no.	Activity	Outputs/ milestones	Date completed	What has been achieved / Comments
				Nevertheless, if the policy is revised to enable lobster farming in future, the manual can be published quickly.
3.3	Perform a market-chain analysis for Indonesian lobster	Data on lobster market characteristics and opportunities in region	June 2017	A comprehensive market chain analysis was performed by seafood marketing specialist Mr Nick Ruello. This revealed some local idiosyncrasies to the market, not evident in Vietnam. Nevertheless, the market opportunity for Indonesian farmed lobsters is strong, and Indonesia could support farmed lobster production of several thousands of tonnes with high market price exceeding $A35 per kg for *Panulirus homarus*, and higher for *P. ornatus*. The market report has been submitted to ACIAR and is attached as Appendix 14 to the final report
3.4	Develop opportunities for lobster grow-out beyond Lombok	Locations and potential operators identified and informed Commercial production of lobsters at locations beyond Lombok	December 2019	Lombok has been the centre of attention of lobster aquaculture development in Indonesia due to the initial identification of abundant lobster seed (puerulus) resources there, from 2004 onwards. Although the seed resources there have been developed further and a small grow out industry became established through to 2015/16, it became clear that Lombok provided limited opportunity for lobster grow out in regard to high quality sites for marine sea cages. As the project progressed, opportunity to make qualitative assessments of other areas in Indonesia for sea cage grow out were made. These assessments were constrained post-March 2017 when the project was required to focus only on research and not industry development activities. Nevertheless, informal discussions with private investors, with interest in establishing lobster aquaculture, occurred. Notwithstanding there are likely to be many more suitable sea cage sites, those that were identified include Sumbawa (particularly Teluk Saleh), parts of South and Southeast Sulawesi, and southern coast of Lampung. These areas already support sea cage culture of fish species and have characteristics conducive to sea cage culture of lobsters, including high quality oceanic water, protection from strong wind and waves and proximity to necessary services. Planning for lobster aquaculture development is a responsibility of the Directorate General Aquaculture. The removal of DGA from the project and government policy precluding lobster farming stopped any such planning. It is clear that there is ample opportunity in regard to suitable sites, for lobster aquaculture development in Indonesia.
3.5	Forum group discussions on improved technology of lobster farming (rescinded Mar. 17)		January 2019	Despite planning for forum group discussions to connect the research project with extension officers and fishers and farmers, no such forums took place due to the suspension of such activities from project variation #1. A road map for a future lobster farming industry in Indonesia was prepared. This Industry Road Map is an important output of the project. If the regulation is modified, it would be

no.	Activity	Outputs/ milestones	Date completed	What has been achieved / Comments
	Prepare road map for future lobster farming industry	A standalone summary of technical results and detailed recommendations for policies to enable lobster farming to be permitted		valuable to revisit this document to update and encourage broader ownership within Government and industry. Further specific recommendations on fisheries policy have been formulated in regard to sustainable a lobster seed fishery, that could form the foundation for a substantial lobster farming industry. These policy recommendations have been published in journal papers (Jones, 2018; Priyambodo, *et al*., 2020) and a PhD thesis (from JAF Fellow Bayu Priyambodo) (Priyambodo, 2018).

Objective 4: Evaluate the socioeconomic impacts and maximise the benefits of the project's activities

no.	Activity	Outputs/ milestones	Date completed	What has been achieved / Comments
4.1	Develop robust economic models of for coastal livelihoods including lobster farming	Bioeconomic model that assesses relative merits of lobster farming Model updated with commercial production data	December 2017	The bio-economic model for Indonesian lobster aquaculture has been prepared and published (Petersen, *et al*., 2020; Petersen, *et al*., 2013; Petersen, *et al*., 2015). In addition, bio-economic input has been provided to the other activities for this project objective. It was not possible to update the bio-economic model with commercial production data due to the absence of commercial lobster farming in Indonesia.
4.2	Assess and monitor the socioeconomic costs and benefits of livelihood options in the communities involved	Socioeconomic data collected, analysed and reported	December 2017	Comprehensive socio-economic assessment was made concerning lobster aquaculture in both Lombok – where commercial lobster farming had been established prior to the 2015 regulation, and in Sumbawa – where a proposed, lobster farming enterprise was being planned. These assessments and associated research were comprehensive in their scope and resulted in a series of high quality publications listed below.
4.3	Identify the socioeconomic factors that influence the adoption of aquaculture and fishing technology and explore strategies for scaling out production	Data on uptake of new technologies and industry expansion including socioeconomic drivers, analysed and reported	December 2017	Socio-economic factors influencing the adoption of lobster aquaculture were thoroughly researched using a model community at Sumbawa Besar adjacent to Teluk Saleh in Sumbawa. This exercise could only be conducted to concept stage, as no actual lobster farming development was possible during the life of the project, due to the fishery regulations. Related documents on the concept of socio-economic factors influencing the adoption of lobster farming were developed. See appendix 17.

no.	Activity	Outputs/ milestones	Date completed	What has been achieved / Comments
		Status of industry development reported identifying key socioeconomic factors		
4.4	Develop strategies for maximising the benefits of project activities in the communities	Clear definition of role of women in industry and opportunities for their role to be increased Recommendations for targeted training and actions to build the capacity of local communities (e.g. leaders, farmers, key stakeholders) to obtain maximum socioeconomic benefits from lobster aquaculture	December 2017	Recommendations for specific strategies to maximise benefits of lobster farming in Indonesia, and particularly for women, were developed during the assessment of both the Lombok and Sumbawa communities with interest and/or experience with lobster farming prior to the prohibition. These are presented in a series of publications – (Diedrich, *et al*., 2019; Fatchiya, *et al*., 2017; Jones, 2017; Kurniawan, *et al*., 2017; Kurniawan, *et al*., 2018; Oktaviani, *et al*., 2017; Puspitawati, *et al*., 2017; Rahmah, *et al*., 2017; Susanti, *et al*., 2018a; b) Such recommendations were not prepared, as this represented industry development work which was prohibited.

7 Key results and discussion

7.1 Impact of Indonesian Government Fisheries Regulation Changes on Project Deliverables

Key Results

- Planned research on puerulus stock assessment, nursery culture, industry development and socio-economic aspects was suspended from March 2017. Nevertheless, substantial progress was achieved in 2016
- Subsequent project research focussed on diet development for 200g+ lobsters, generating an effective diet formulation in terms of growth promotion

Discussion

A mid project variation was finalised in late 2017 to accommodate major and unexpected changes to the lobster fishery management policy framework in Indonesia. The agreed project modifications effectively reduced the institutional footprint of the project in Indonesia and restricted the scope and focus of the research to be undertaken over the final 18 months of work.

Substantial progress was reported across all objectivities/activities at the first Annual Project Meeting in Feb 2017. A project variation was developed and finalised in late 2017 to accommodate policy and regulatory changes in Indonesia that occurred after the original project approval. The approving agency for the project AMFRHR, requested the project variation align activities with the fisheries regulation NOMOR 56/PERMEN-KP/2016 that prohibits the taking of lobsters less than 200g, the capture of berried females, and the commercial farming of lobsters. In spite of the regulation, significant illegal catch of seed lobsters continued throughout Indonesia, with subsequent smuggling to other countries (Priyambodo *et al.*, 2020). While the fishing and farming of lobsters in Indonesia remained a politically sensitive issue, the new regulation specifically allowed for research on lobsters to continue, including for aquaculture. AMFRHR advised that the Ministry of Marine Affairs and Fisheries was open to future approval of lobster aquaculture once appropriate production technology was developed through research.

In view of this ACIAR agreed that the project should continue with the emphasis on the development of commercial lobster aquaculture technology, in a manner that is complementary to the regulation. The research would source legal size lobsters, greater than 200g, for use in experiments, rather than use juvenile or seed lobsters as originally planned. The revision process resulted in an effective 12 month suspension of project activities in Indonesia, with operations restarting in Feb 2018. The research activities that were performed from then on focussed on improving commercially relevant production technology for the on-growing of legal size lobsters >200g. This included the development of an effective diet formulation and husbandry methods, including health management.

The variation primarily impacted the activities planned with the Directorate General Aquaculture (DGA) centres (MADC in Lombok and the BBAP in Ujung Batee, Aceh), which were suspended and so removed DGA from project activities. The other agencies – IMAFE Gondol and IPB - remained, although IPB-led activities were completed by the end of 2017.

7.2 Compile and analyse annual lobster seed catch data and identify lobster seed resources in multiple locations and develop sustainable harvesting strategies

Key Result

- Based on quantitative and qualitative assessments, the annual seed fishery abundance of pueruli in Indonesia was estimated to be around 100 million pueruli, providing an opportunity to support a viable lobster aquaculture sector if sustainably fished.
- The Indonesian lobster seed resource appears to be confined to the southern coastline from west Java to east Sumbawa, over a distance of 1,500km
- The results have been published as Priyambodo*, et al.*, (2020). See Appendix 1.

Discussion

Indonesia has a unique opportunity to establish the world's largest lobster aquaculture industry, based on a significant natural resource of settling puerulus. These seed lobsters can be captured and on-grown to generate high value lobsters for local and international markets. However, current fisheries regulation prohibits fishing of these seed lobsters in Indonesia. Nevertheless, seed fishing continues illegally (Priyambodo *et al.*, 2020) and is smuggled into Vietnam where the greatest commercial benefits are realised. By denying coastal farmers' access to pueruli, these regulations have stopped the capacity of Indonesian lobster farmers to develop a sustainable grow-out industry and improve their livelihoods. Although the new policies were introduced as a management intervention to protect wild adult lobster stocks, past work under ACIAR projects (ACIAR FIS/2001/058 and SMAR/2008/021) have demonstrated no apparent impact of seed fishing on abundance of adult lobsters.

This study collected quantitative data on the annual puerulus catch in Indonesia for 2016, its species composition and seasonality, and fishing methods. The detailed census of seed capture determined that approximately 5.24 million pueruli were fished from two bays in the southeast of Lombok in 2014, representing approximately 65 thousand pueruli per km^2. These data were used to extrapolate to estimate the entire catch across the full geographic extent of lobster seed fishing. The composition of puerulus fished consisted of two species, *Panulirus homarus* and *Panulirus ornatus*. *P. homarus* was most abundant at 63-87%, while *P. ornatus* represented 13-37%. Seasonality of catch was characterised by a peak around April to July and a smaller peak around October to November. Although these semi-quantitative data are considered robust (Priyambodo *et al.*, 2020), further quantitative assessment of the lobster seed resource over multiple years is required to fully define the resource and its variability.

Surveys of puerulus fishers beyond Lombok, where smaller levels of fishing occur, showed high abundance of seed in areas with similar characteristics. Location with substantial puerulus abundance were the southern coast of Java, Bali, Lombok and Sumbawa, covering a total coastline of 1,500km. Puerulus abundance was highest in enclosed bays with distinct currents, relatively high turbidity attributable to terrestrial inflows, and muddy/sandy substrates.

Aerial geographic mapping identified potentially suitable locations for puerulus settlement nationally. The total potential puerulus catch across these locations was estimated to be approximately 103.5 million puerulus per year. If fished at sustainable levels, the magnitude of the puerulus resource of Indonesia is more than 20 times greater than that of Vietnam (Dao and Jones, 2015). If used for aquaculture, the seed available can support an industry generating more than 12,500 tonnes of market size (based on Vietnam farmed lobster productivity (Jones *et al.*, 2019)) lobster and provide social and economic benefit to many thousands of households. Fisheries policies will need to be revised and a regulatory framework established to manage the puerulus fishery and support lobster

farming. With the appropriate settings, Indonesia can have a sustainable lobster aquaculture sector with significant economic, social and environmental benefits.

7.3 Optimise catching, handling and transport of puerulus lobsters for the transition from catch to nursery through laboratory and field experiments

Key Result

- Aspects of lobster seed catching, handling and transport were examined that will contribute to a standard operating protocol for fishers, when further research is possible
- Experiments were significantly reduced in March 2017 due to the new regulations banning puerulus fishing, but work in 2016 and subsequent revised activities resulted in several publications. See Appendices 1-6.

Discussion

Seed catch experiments

A field experiment by JAF Fellow Bayu Priyambodo from MADC Lombok assessed the catch rate of various lobster trap types used by fishers for seed capture. The effect of trap depth on catch rate was also determined. The research demonstrated that 'bow-tie' style traps made from cement bag paper and deployed near the sea floor captured the greatest number of lobster seed (Priyambodo *et al.*, 2015 – Appendix 5).

A follow-on tank-based experiment assessed different materials for the settlement substrate and the optimal angle of the crevice on settlement rates. The most effective substrate material was cement bag paper and the most effective crevice angle was 10 to 20 degrees. To ground truth the tank experiment results, a field experiment was performed assessing the same substrate materials, standard 'bow-tie' arrangement and optimal crevice angle. This experiment confirmed the superiority of these trap characteristics as the most effective for seed capture (Priyambodo *et al.*, 2017 – Appendix 6).

Additional lobster seed catch assessment was performed at Aceh Jaya by the team at BBAP Ujung Batee Aceh. A comparison was made on lobster seed settling rates between a long line system with suspended substrate trap attached versus traditional lift nets (called Bagan). Data are not yet available.

Puerulus condition experiment

At MADC Lombok, the energy reserves of newly settled pueruli was determined for the two primary aquaculture candidate species of lobster, *Panulirus homarus* and *P. ornatus*. The study aimed to assess if variability in pueruli condition during collection and transport may explain variable survival once stocked into aquaculture cages.

A total of 100 pueruli were randomly assigned to each of starved, fed (control) and point of no return (PONR) treatments for each species. All lobsters were maintained in individual experimental units (IEU) housed in indoor tanks supplied with recirculating sea water. Lobsters were maintained individually to enable close monitoring of development (moult interval), to eliminate cannibalism, and to preclude direct interactions between individuals. Daily observations were made throughout the experiment to record the date individual post-puerulus moulted, to allow calculation of the number of days between subsequent moults (moult frequency) and to immediately remove dead animals. Dead pueruli were removed as soon as possible, their total length, weight, coloration (clear, white or full pigmented) and day of death (days since stocking) recorded and then frozen.

To test the effects of extended periods of starvation, post-pueruli were starved from first moult until either they died or were euthanised at specific time intervals for biochemical

analysis (total lipid, lipid class, fatty acid, total protein and total glycogen). Individual survival and progress between consecutive moults was monitored daily, with a number of individuals randomly selected for euthanasia and biochemical analysis every 5 days.

To determine whether post-pueruli can subsequently feed and grow after starvation, 20 random specimens were fed after 10, 20 and 30 days of starvation from day 1. The influence of starvation on survival to the next moult was monitored. Post-pueruli were deemed to have recovered from starvation if further growth (moulting) occurred. Analysis of results for this experiment are on-going, as there was a substantial delay in obtaining the biochemical data to assess condition. The data are now available and are being analysed, with aim to submit a journal manuscript by late 2020.

Transport experiment

A series of lobster seed transport trials was performed using different packing techniques for transport of lobster seed from Aceh Jaya to Ujung Batee over 6 hours. These included provision of oxygen, substrate and cooling within the styrofoam transport box. Results to date have been inconclusive and further trials are planned.

Weaning experiment

The objective of this study was to evaluate growth performance and survival of lobster pueruli which were adapted gradually to formulated diet. The experiment was conducted in a recirculation system with round rearing tanks 56cm in diameter and 46cm high. The lobster pueruli (mean weight 0.31g ± 0.01) were reared for 30 days, fed with one of 5 different strategies i.e. formulated diet only (FD), 10% fresh diet replacement per day (D1), 10% fresh diet replacement every 2 days (D2), 10% fresh diet replacement every 3 days (D3), and fresh diet only (fish, crab and mollusc) (Sahidhir *et al.*, 2017).

Results showed that growth performance was significantly affected by the treatments but not survival (Sahidhir *et al.*, 2017). This study suggested that 10% gradual replacement of fresh diet every three days generates the best growth performance. High mortality and moulting were evident in the first week, in the transition phase between puerulus to post puerulus stage. At the completion of the experiment, the remaining lobster population was dominated by *Panulirus ornatus* and *P. homarus*. Other *Panulirus* species were present at the outset, but died during the experiment, suggesting *P. ornatus* and *P. homarus* are the most robust species for aquaculture.

Feeding frequency experiment

An experiment was performed to assess the effect of feeding frequency on juvenile lobsters (Syafrizal *et al.*, 2018 – Appendix 4). The experiment used a randomized design. Bamboo spiny lobsters (n=352) (*Panulirus versicolor)* with mean weight of 0.48±0.51g were reared for 4 weeks in 16 circular 80L tanks within a closed recirculation system. Four feeding frequencies were applied to 4 replicate tanks. The treatments were: FR1 fed once per day, FR2 two times per day, FR3 three times per day and FR4 four times per day. Initial feed ration was 100% of biomass per day, progressively reduced to 50%, 30% and 25% of biomass by week 4 of the experiment. The diet consisted of a pellet, formulated and manufactured at IMRAD Gondol. Analysis of survival and growth was performed using SPSS version 23.0.

After 4 weeks of culture using 4 different feeding frequencies, there was no significant difference ($p > 0.05$) for weight, carapace length, moult frequency, specific growth rate (SGR), survival or food conversion ratio (FCR). Further research over a longer time period may be necessary to determine optimal feeding frequency for nursery culture.

7.4 Increase nursery production through improved nutrition and disease management

Key Result

- This research activities were confined to the first 18 months of the project due to the new legislation and during that time trials were hampered by poor survival. Suitable nursery practices for Indonesia remain undefined
- See Appendix 7 and 20 for a full report on diet development including some preliminary research on the nursery phase and poor survival of juveniles

Discussion

The poor survival of juveniles in the initial several days after transport has been attributed to the handling and transport processes of the wild caught pueruli. Observations by project associates during the seed assessment research (see section 7.3) indicate that captured pueruli are placed into water bottles until transferred back to shore. The water temperature is likely to be high as the water bottles are left exposed to the sun, there is no aeration and density of seed often high. After landing at shore, the typical conditions to hold and transport the seed is also poor. Even though the seed may be delivered to their intended destination within 24 hours of capture, the poor environmental conditions during transit are likely to compromise health, irrespective of improved conditions once arriving on farm.

The experimental work for this project activity was reliant on puerulus supply, so was only pursued during 2016. However, problems with high mortality rates on arrival at the research facilities hampered trial progress. This experience highlights the priority for understanding optimal seed handling and transport requirements.

Nursing trials at Gondol

The nursery diet experiments at IMRAD Gondol aimed to use 3g lobsters rather than pueruli, as they were assumed to be more rigorous and provide uniformity of initial condition status. To source sufficient numbers of 3g lobsters, a pre-experiment rearing stage to raise puerulus to 3g was required. Four batches of pueruli were purchased from seed middlemen over a 12 month period (2016), transported to Gondol and stocked to tanks. In all cases survival was poor – less than 50% and for some less than 20% over 4 to 6 weeks (Sudewi *et al.*, 2019 – Appendix 20). Although sufficient numbers of 3g juveniles were raised to stock two experiments, this approach in generating stock for experimental work was problematic. An alternative approach was therefore conceived for dedicated first phase nursery culture at MADC Lombok.

Planned first phase nursery work at Lombok

Due to the high mortality of juveniles at Gondol, a dedicated nursery production trial was planned at the MADC Lombok facility to compare the nursery systems used in Vietnam (suspended round cages, which achieved relatively high survival of >70% from puerulus to 3g), and the traditional square surface cage used in Indonesia (pictured below).

Twenty of each cage type were fabricated and deployed from an Aquatec floating frame, situated 100m offshore at Sekotong, MADC Lombok. It was planned that the comparison of commercially used cage types would provide a robust assessment, and the best performing would be used for all future experimental work. Unfortunately, the nursery operation was suspended before the first stocking due to the suspension of nursery work (see Section 7.1). The 40 nursing cages (20 of each type), were then relocated to Gondol. Unfortunately, all nursery operations remained suspended and no further nursery research was performed.

Vietnam style round nursery cage

Traditional Indonesian square nursery cage

7.5 In collaboration with commercial feed companies, finalise development of practical diet formulations and feeding strategies that promote use of pelleted feeds on farm and account for differences between species

Key Result

- A diet formulation was prepared that supports commercially acceptable survival and growth, and is suitable for commercial production
- A criteria-based condition assessment for lobsters using blood sugar level was developed that enables healthy lobsters to be chosen for experimentation
- A photographic method was developed to collect individual growth data through non-invasive identification of individual lobsters
- The diet formulation developed in this project was tested at the lobster aquaculture laboratory at University of Tasmania using juvenile tropical spiny lobster *Panulirus ornatus*. This experiment generated a publication. See Appendix 8.
- The diet formulation was also subject to commercial production by Santeh Feeds in the Philippines and then assessed in a lobster growth experiment, generating the report in Appendix 9.

Discussion

A summary of the results is presented below, and a complete report in Appendix 7. The photographic identification method is described in Appendix 19.

Improvement of the benchmark diet at IMRAFE Gondol was constrained by disease issues. Many of the trials conducted during the project period resembled disease challenge trials rather than feed assessment trials. This was due to the high prevalence of disease in the lobsters available for experimental use. Highlights of the project included the development of criteria to select robust lobsters and methodology to identify individuals. The criteria-based selection process led to significant improvements in the survival and growth performance. For instance, in the first tank trial the average lobster survival was 32% compared to 96% in the final tank trial.

The only guaranteed method to ensure clean stock are used in experiments is to apply disease screening at the individual lobster level, but this is not a practical option due to cost and logistics. The presence of disease was a major issue in this project and is likely to be a major bottleneck for industry expansion. Practical recommendations to reduce the risk of sourcing and selecting diseased stock are provided in the full report (Appendix 9).

The addition of a probiotic to the benchmark diet improved lobster performance, although results were likely compromised due to the prevalence of disease in the lobster used for these trials. The effectiveness of the probiotic is affected at high temperature, such as when dried pellets are manufacture, requiring the feed to be provided in moist form. Use of a dry pellet will be important in the establishment of a large industry, while probiotics may remain a viable option as a functional feed additive in nursery systems.

The potential for conducting short duration lobster feed intake trials was demonstrated, enabling six trials to be completed in the same period as a standard growth trial. The benefits of hydrolysates (protein concentrates) as an additive to feeds for improving feed intake was established. All hydrolysate sources tested improved feed intake; the cheapest fish hydrolysate was amongst the best ingredients tested in terms of improving intake. It is recommended that this area of research be further investigated as improving lobster feed intake is critical for improving nutritional condition. In addition, there may be application in using hydrolysates as a replacement for the fishery-based ingredients in the trial diet developed in this project. The potential for using BRIX to predict nutritional condition showed promise and show be further investigated.

The project confirmed that a high-quality mixed fishery diet promotes the good growth performance and survival in healthy lobsters. Feed intake data determined that lobsters have a preference for consuming mussels. Although the addition of raw crustaceans was found to be nutritionally beneficial, it also comes with significant disease risks and ideally should not be fed to lobsters. The best results were achieved when lobsters were fed a dried pellet and a mixed fishery diet. Lobsters will preferentially consume fishery products over pellets; but careful management of the feeding regime can ensure they consume a mix of pellets and fishery product.

The finding that lobsters can be fed partially with pelleted feeds is very significant for Indonesia, as the supply of affordable fresh seafood is very limited and seasonally variable compared to Vietnam, making a 100% fresh seafood diet unviable. While further diet development research is necessary, lobster farming can be supported with an acceptable manufactured food based on the formulation developed by the project.

The majority of trials were completed with sub-adult lobsters, and future research and commercial grow out will need to focus on seed or juvenile lobsters. Future research should determine what is transferable from sub-adults to seed lobsters in regard to selection criteria for robustness and ability to identify individuals.

7.6 Review current status of lobster disease threats in Indonesia through an industry survey

Key Result

- Indonesian lobster populations are exposed to a number of health and disease threats that are likely to impact a future lobster aquaculture sector
- The most significant threat is milky haemolymph disease which compromised lobsters and lead to high mortality
- Health of farmed lobsters can be maintained with adequate nutrition, husbandry and effective site selection
- A lobster health and disease report is attached as Appendix 10.

Discussion

A health survey was performed of tropical spiny lobster *Panulirus homarus,* from fishery and farmed sources, to assess presence and pathogenicity of parasites, fungi, bacteria and viruses. Milky Haemolymph Disease (MHD) was the most pathogenic of diseases observed.

The spiny lobster samples were collected from Awang Bay, Telong-Elong Bay and Gerupuk Bay in southeast Lombok in Nusa Tenggara Province, Indonesia. The samples were analysed using various techniques including microscope identification of parasites and fungi, and bacteria by chemical and conventional methods. MHD was examined using PCR with specific primer 254 bp, and histological assessment. Gram-Twort staining was used to examine tissue damaged by Rickettsia like bacteria (RLB). The MHD was tested using a molecular DNA technique, and options examined to treat MHD.

No fungi infections were found in either wild or farmed lobsters. Parasites were found in lobsters from both sources, and included *Epistylis sp*, *Octolasmis* sp, and *Amyloodinium* sp. Bacteria confirmed from wild lobster included *Acinetobacter sp, Proteus rettgeri, Vibrio damsella, V. fluvialis, V. mimicus, V. parahaemolyticus, V. alginolyticus, V. cholerae* and *V. carchariae*. Bacteria in cultured lobster included *Acinetobacter sp, Proteus rettgeri, V. damsella, V. fluvialis, V. mimicus, V. parahaemolyticus, V. alginolyticus, V. cholerae, Actinobacillus sp* and *E. aerogenes*. MHD disease was found in farmed lobsters from sea cages located at Teluk Gerupuk. MHD infection was successfully treated with oxytetracycline (OTC).

The observed health issues and diseases of tropical lobsters are primarily the result of opportunistic infection and physiological degradation rather than from primary pathogens. They are all preventable in culture operations, and with best practice husbandry and nutrition can be avoided. In addition, disease and pests are manageable if farming operations are located in optimal marine environments, through effective site selection planning and management. Optimal nutrition will likely mitigate infection of milky disease in lobster growout systems.

7.7 Assess feed supplementation including use of pre- and pro-biotics to minimise disease in farmed lobsters

Key Result

- Four pro-biotic bacteria were identified from the lobster culture systems at Gondol, and then isolated and cultured. In combination, these pro-biotics provided demonstrable benefit to the culture of lobsters when administered as a dietary supplement
- The inclusion of the pre-biotic, mannan-oligosaccharide (MOS), in the diet provided the greatest benefits in the culture of lobsters
- A journal manuscript from this research component is attached as Appendix 11 that presents full methodology, results and discussion.

Discussion

A primary challenge in the culture of *Panulirus homarus* lobsters are diseases such as bacteria-induced red body disease and rickettsia like bacteria-induced Milky Hemolymph Disease (MHD), which result in low survival. An effective option to ameliorate disease may be the application of probiotics in the diet. A study was conducted to identify potential strains of probiotic bacteria in the local marine environment, and test them as a dietary supplement to lobsters to assess effects of survival, growth and health status.

A study was also conducted to evaluate potential bacteria as probiotics from bacteria in the lobster's intestine. Wild *P. homarus* lobsters were collected from coastal waters of Jembrana District of Bali Indonesia. Intestinal bacteria were then isolated, identified, and tested used enzymatic hydrolysis to select candidates for probiotics. Lobsters with average body weight of 76.55 ± 12.03 g were cultured in concrete tanks of 4 m^3 capacity at density of 15 individuals/m^3. Six tanks were used to feed the lobsters with a moist pellet diet supplemented with probiotics (A) or the same moist pellet diet without probiotic (B), and each treatment had two replications. The research found four bacteria that could potentially be used as probiotics i.e., *Photobacteria damsela* N-5*, Bacillus subtilis* C-1*, Bacillus oceanisediminis* H-3*,* and *Bacillus amyloliquefaciens* I-5. These four bacteria

were combined and applied to lobsters as a dietary supplement. Growth of lobsters fed with supplemented probiotic (A) was higher (198.21g) than the control without probiotic (B) (169.76 g), while survival was similar. Immune response of lobster fed the probiotic diet was18 times that without, after challenging with MHD, especially for the target gene ALF-2, while for ProPO, CP, and GPO the increase was 13, 35 and 94 times. Application of this probiotic in the diet could increase growth and immunity for commercial lobster aquaculture in Indonesia.

7.8 Scope lobster grow-out opportunities for Indigenous communities in northern Australia

Key Result

- New opportunities for rock lobster aquaculture engaging Indigenous communities at Groote Eylandt and the Torres Strait are being pursued

Discussion

This activity was developed through discussion with Jaragun Pty Ltd (Dennis Ahkee and Liz Owen) who are business development consultants specialising in Indigenous enterprises. Their advice was consistent with earlier reports that current regulatory compliance requirements in Queensland were incompatible with lobster aquaculture, and that there is greater scope for such an initiative in the Northern Territory.

Subsequently, an opportunity arose to submit a concept for lobster farming on Groote Eylandt. This pre-proposal is currently under consideration by the Anindilyakwa Land Council. It includes assessment of naturally settling lobster seed in the Groote Archipelago area, and nursery and growout operations. These represent 3 distinct components that could operate effectively as independent enterprises or in combination. The regulatory framework of the NT is conducive for such enterprises, and the proposed Groote project could serve as a model for other areas in the NT and WA.

In addition, project associate Simon Irvin (CSIRO) has performed an assessment of the potential for lobster aquaculture in the Torres Strait. While technically feasible, lobster farming in the Torres Strait is constrained by high operational and logistics costs and local capacity in lobster aquaculture techniques.

7.9 Provide training in laboratory-based experimentation, particularly for nutrition research

Key Result

- Training was provided to a research officer from each Indonesian partner research institute in nutrition experimentation at the CSIRO aquaculture nutrition laboratory at Bribie Island, Australia
- Three Indonesian participants gained significant benefits in regard to increased capacity in experimentation that will extend to their roles and their research centres in Indonesia. A report is attached as Appendix 12.

Discussion

Three early career scientists from the three partner research centres - IMRAFE Gondol, DGA MADC Lombok and DGA BBAP Ujung Batee Aceh - were given training in nutrition research experimentation. Project associate Simon Irvin (CSIRO) delivered a 3-week program in March 2016 at Bribie Island Research Centre.

On return, Mr Muhammad Dayat from Lombok from DGA MADC Lombok set up and managed a significant experiment on puerulus condition. His improved skills and knowledge will be of benefit to the MADC across a range of aquaculture species.

Mr Wawan Adrianto from Gondol has managed some smaller aquaculture experiments since returning. His increased confidence appeared to be the greatest benefit from the training.

Mr Ibnu Sahidhir from Aceh had some experience prior to the Bribie training. He now has a more robust understanding of rigor and consistency in experimentation that is being applied at BBAP Ujung Batee in his role as a senior scientist.

7.10 Prepare and publish a farmer-level lobster farming manual

Key Result

- A manual on lobster all aspects of lobster farming was prepared for farmers in English and Bahasa
- Due to the sensitivities of lobster farming in Indonesia during the course of the project, the manual has not yet been formally published. The manual (English version) is attached as Appendix 13.

7.11 Perform a market-chain analysis for Indonesian lobster

Key Result

- The market opportunity for Indonesian farmed lobsters is strong, but must be promoted with a focus on meeting market requirements and quality specifications
- The complete marketing report is attached as Appendix 14.

Discussion

Indonesia's lobster farming industry has a short and unusual history. Grow out activities expanded steadily from 2008 to 2012 and the combined annual production of small *Panulirus homarus* and *Panulirus ornatus* rose to around 50 tonnes by 2013, but then interest in grow out activities quickly came to a halt in favour of the quicker cash flow from the collection and sale of the plentiful puerulus seed caught around Lombok and Bali.

Meanwhile the strong growth in global demand for lobster, particularly from China, has continued. Prices have risen because wild catch landings globally are limited by national fishing controls while aquaculture production volume from Vietnam, the sole producer, has only grown modestly. Consequently, Vietnamese lobster growers have recorded strong prices for their live product in China. The continued interest in lobster grow out in Indonesia indicates that a revival there seems inevitable.

Over the past few years Vietnam has been growing around 1500 tonnes of lobster per year with growers receiving around US$50 per kilogram for lobster, mostly 1kilogram size *P. ornatus*. The smaller of the two species farmed, *P. homarus*, matures at a size as small as 300 grams and fetches lower prices than *P. ornatus*: about US$33/kg versus US$40 for the 500 gram category. Comparison with Indonesia is difficult as there is currently no farming in Indonesia and so no recent price data for comparison with Vietnam. March 2017 data from Indonesia's wild fishery catch show a similar price premium for *P. ornatus* over *P. homarus* and remarkably strong prices of 300,000 Rupiah ($US20) per kilogram for 300-500 gram *P. homarus* (and Rp 400,000/kg ($US27) for *P. ornatus*). Vietnam's farmers' prices quoted above are apparently profitable for Vietnamese growers while the Indonesian fishers' prices are also encouragingly high.

The global outlook for lobster demand and price growth is very encouraging as lobster demand in Indonesia and elsewhere is growing at a faster rate than supply. However, there is increasingly more intense market competitiveness through branding, national promotion for market share, and high prices in China and elsewhere. This will require the Indonesian lobster sector to set in place best practice marketing and supply chain management to ensure they secure top prices.

The Indonesian lobster supply chain is an informal seafood industry distribution chain linking fishers with buyer middlemen and exporters. It has developed from traditional seafood business practices between commercial fishers and wholesalers/exporters; information sharing. Traditionally the relationships between supply chain partners are not strong. There are no evidence of product promotion either domestically or overseas.

It is recommended that growers could work collaboratively with supply chain partners, in adopting more modern marketing practices and investing in product differentiation and national brand promotion. This would require sector support with capacity building for farmers delivered either from government, non-government organisations or business parties.

Such supply chain and market development is not without their challenges. The Indonesia farmed lobster industry will need to differentiate the 200-300 and 300-400 gram animals as farmed lobsters, otherwise consumers may perceive them as illegal and/or unsustainable wild-caught product.

7.12 Develop opportunities for lobster grow-out beyond Lombok

Key Result

- Up to March 2017, lobster industry development activities were conducted only in Sumbawa, Lombok

Discussion

Since 2004 Lombok had been the centre of lobster aquaculture development in Indonesia due to the abundant puerulus resource. Although a small growout industry was established, it became clear that Lombok offered limited optimal sites for marine sea cage culture. The project qualitatively assessed other areas in Indonesia for sea cage growout, including informal discussions with potential private investors. Notwithstanding additional sites may be found suitable, those identified in the project include Sumbawa (particularly Teluk Saleh), parts of South and Southeast Sulawesi, and the southern coast of Lampung. These areas already support fish-based sea cage culture and have characteristics suitable for lobsters, including high quality oceanic water, protection from strong wind and waves, and proximity to services.

Planning for lobster aquaculture development is a responsibility of the Directorate General Aquaculture. The removal of DGA from the project and government policy precluding lobster farming have stopped any further sector planning.

7.13 Provide training to improve extension of technology to industry

Key Result

- It was not possible to provide this training, due to the project variation which led to the suspension of all industry development activities

7.14 Prepare road map for future lobster farming industry

Key Result

- A road map for development of a large, sustainable lobster aquaculture industry for Indonesia was prepared

The industry vision is for a $US250 million, sustainable and export-oriented lobster aquaculture sector employing small-holders and creating economic and social benefits throughout Indonesia. The roadmap document is attached as Appendix 15.

Discussion

Tropical marine rock lobster aquaculture offers a major opportunity for high-value aquaculture production to contribute to the Indonesian economy. It will create thousands of jobs and a new high-value industry benefitting both rural coastal areas and regional centres.

Indonesia has the potential to match the Vietnamese capability for lobster production within 5 years and to be 5 times bigger within 10 years.

Strategic steps to achieve a sustainable lobster aquaculture industry

1. **Identify lobster as a priority aquaculture species**

Government of Indonesia identifies lobster aquaculture as a national priority, with supporting policy to permit capture of lobster seed and lobster farming

2. **Manage lobster seed resources**

Assess and sustainably manage the lobster seed resources

3. **Support research programs**

Build on past research with a focus on identifying commercialisation pathways that support integrated smallholder and private enterprise business models, farmer extension services, and commercial production of manufactured diets.

4. **Demonstration nursery and growout**

Support demonstration nursery and growout operations at selected sites to stimulate uptake of lobster farming technology, by both the smallholder and private sectors.

5. **Corporate investment**

Actively encourage and support corporate investment from Indonesian companies to assist poor communities to become engaged in lobster farming, through contract farming arrangements.

7.15 Develop robust economic models of lobster farming in Indonesia

Key Result

- The project originally aimed to revise and strengthen previous bio-economic modelling using recent industry data, but was discontinued due to the project variation
- Nevertheless, some economic assessment was done in Sumbawa

Discussion

Economic assessments were made as part of the survey of communities in Sumbawa. The draft publication is attached in Appendix 17. A report was also prepared that combined the economic data from previous and the Sumbawa study with the social science assessments. This report is attached as Appendix 16, and includes reference to a series of publications from the project. Results suggest that the time spent on lobster operations (largely household labour) is high. It is recommended that farmers are supported to adopt technologies and improve feeding strategies to optimise economic and labour efficiency.

7.16 Identify the socioeconomic factors that influence the adoption of lobster farming technology and explore strategies for scaling out production

Key Result

- Although lobster farming was banned during the course of this research, interviews with prospective lobster farmers were conducted in the context of future permission being granted. Data gathered are therefore speculative based on perceived behaviour and attitudes.
- A farmer's decision to harvest is determined by a number of factors, including: loyalty of the farmer-client relationship, uncertainty associated with prolonging harvest for maximum economic return (e.g. risk of disease), and work complexity
- A farmer's decision to harvest is not driven by their management philosophy, networking skills, education or training

Discussion

A journal paper was published from this research, see Appendix 18.

The capacity of aquaculture development to deliver economic and social outcomes is not without challenges, particularly for marginalised groups. This is especially true if the introduction of novel technologies is applied with an incomplete understanding of the complexity of the social, economic and bio-physical context into which new innovations are inserted. The project found that net incomes of households in the study area were low relative to the country's average net wage and the net wage of agricultural sector employees. Not surprisingly, most survey respondents indicated they would like to be involved in lobster farming in their village, with varied perceptions on how easy it would be for them to do so.

Multiple linear regression was used with model averaging to test the influence of five capital assets (human, social, natural, physical, and financial) including agency, equity, and household sensitivity on people's perceived ability to adopt lobster aquaculture. Agency and sensitivity, measured as a household's dependence on natural resources, had the greatest influence on the dependent variable. Correlation analysis was then used to develop a heuristic model of potential indirect causal mechanisms affecting people's perceptions of adoption suggesting: (1) more sensitive households tended to have lower agency, making it harder for them to adopt, (2) those who perceived a more equitable community had higher agency, making it easier for them to adopt, and (3) households with higher social capital had higher agency and may also be less sensitive, making it easier for them to adopt. The results point to the existence of a 'sensitivity trap', where more sensitive or marginalized households are less likely to engage in new economic opportunities.

7.17 Develop strategies for maximising the benefits of project activities in the communities

Key Result

- It is important to consider equity and distribution of social capital in communities where alternative livelihood activities are taking place. Equity considerations will identify those households that might find it more challenging to adopt and allow monitoring of the benefit distribution between community groups.

Discussion

A report of socio-economic drivers to adoption is attached as Appendix 16, and includes reference to a series of publications. A journal paper was also published, see Appendix

18. See Appendix 15 for a full report on the recommended strategies to maximise community engagement in lobster aquaculture.

Strategies for adoption must emphasize the value of a range of livelihood options for improving livelihoods, particularly for poorer, more vulnerable households. Failure to consider the specific challenges that vulnerable groups face in accessing new economic opportunities, including the potential for these barriers to maintain them in a state of vulnerability, is likely to jeopardize development goals.

8 Impacts

The project's impacts were compromised due the introduction of the government fisheries regulations that banned the collection of wild lobster puerulus and their growout. Nevertheless, the project contributed significantly to the national debate on the viability of an Indonesian seed and aquaculture sector. The project generating data, both in the field and desk-based, to develop science-based evidence on the sustainability of a well-managed lobster seed fishery, which now serves as foundational science for lobster aquaculture development into the future. Partly due to this scientific contribution, in early 2019 the Indonesian government revised its policy to once again support a sustainable lobster seed fishery and aquaculture sector. The nature of the considerations on the sustainability of the puerulus fishery is summarised in publications by Jones (2018) (Appendix 3); Priyambodo*, et al.* (2020) (Appendix 1).

The project also generated significant new knowledge and technical husbandry methods that will support future industry growth. Work with significant potential to deliver impacts include: new data on additional seed fishing sites, allowing expansion beyond the current sites in Lombok; better understanding of the socio-economic barriers and drivers to farmer adoption, particularly for marginalised groups within communities; and development of a practical diet that promotes reasonable survival and growth, particularly if supplemented with fresh seafood.

8.1 Scientific impacts – now and in 5 years

Lobster aquaculture is of interest throughout the world as many wild-caught stocks are either fully or over-exploited. The project's scientific impacts are therefore of global interest.

To date knowledge of puerulus ecology and recruitment has been gathered to inform wild lobster fisheries management. (Phillips, 2006). This project's and preceeding research is the first to address puerulus ecology from an aquaculture perspective – examining and assessing puerulus populations from a resource extraction management perspective. Data on the behaviour of settling puerulus and their crevice/substrate preferences informed optimal fishing devices. Similarly, publications on puerulus ecology and their abundance in relation to optimal hydrographic conditions (Priyambodo*, et al.*, 2015; Priyambodo*, et al.*, 2017; Priyambodo*, et al.*, 2020) will inform future development plans for the sector.

Diet development studies identified practical formulations of mixed pelleted feeds and fresh fish species were appropriate for transitioning to commercial manufacture and application. This finding is significant as Indonesia lacks sufficient fresh fish volume to support industry growth. Pre- and pro-biotics were effective as dietary supplements to improve disease resistance in young lobster. This is also an important finding as results are potentially applicable to all lobster species and can assist in managing the inherent risk of disease in aquaculture systems.

Knowledge of the socio-cultural and economic aspects of aquaculture in Indonesia revealed new understanding of the aspirations of the people, and the drivers and constraints to engaging in the sector.

8.2 Capacity impacts – now and in 5 years

The project has successfully enhanced technical capacity in partner agencies through targeted training and through cooperation in research activities. Three early career Indonesian researchers were trained in aquaculture experimentation in Australia. Similarly, several Indonesian researchers from IPB were trained in all stages of the socio-economic research through collaboration with Australian researchers, leading to a number

of international conference presentations and publications. The social scientific skills developed at IPB will be of value as farming expands across new locations in Indonesia in coming years.

The completion of a PhD by project associate Dr Bayu Priyambodo through an ACIAR John Allwright Fellowship (JAF), is a particularly significant capacity impact for Indonesia. Dr Priyambodo is now a member of a Ministerial committee established in early 2020 to develop the Indonesian lobster aquaculture. He is drawing on his comprehensive knowledge and research experience of lobster biology and farming technology.

Project associate Mr Samsul Bahrawi from MADC Lombok was awarded a JAF to undertake an MSc at JCU. He has since returned to his workplace with increased confidence and knowledge in aquaculture.

Project associate Mr Syafrizal from BBAP Ujung Batee, Aceh completed an MSc at IPB during the project. As part of the Masters program he completed a nutrition experiment, subsequently published the results (Syafrizal, *et al.*, 2018) and has returned to his workplace with greater confidence and ability to perform aquaculture research and extension.

Indonesian lobster researchers and management staff toured the Vietnam lobster farming industry, providing them with broad insights that will benefit their future professional activities.

Five years on, the extensive capacity built in the above mid-career professionals will ensure their agencies and government are well supported in developing an economically viable and sustainable Indonesian lobster industry.

8.3 Community impacts – now and in 5 years

The primary beneficiaries of the project are the coastal village communities of Lombok, Java, Sumbawa, South Sulawesi and Aceh, where improved access to the lobster seed resources was developed as a direct outcome of the project. Despite the prohibition on seed fishing, the fishers of these communities continued to fish for lobster seed in the face of few alternative livelihoods. Improved seed access provided significant material benefit to fishers, their families and their communities. The involvement of women and men in seed fishing, holding and transport provides equitable benefits. Under effective fishery management arrangement, the seed fishing industry will likely emerge as a significant livelihood opportunity, involving export to Vietnam as well as seed sales to the farming sector.

The project results will contribute directly to the re-establishment and growth of lobster farming in Indonesia. In early 2020, government policy is being revised to once again support lobster seed fishing and aquaculture. Project results can be applied quickly to support poor coastal communities to re-engage in farmed lobster livelihoods and support industry expansion to suitable locations across Indonesia.

8.3.1 Economic impacts

The most significant economic impact of the project is through its direct stimulus to seed fishing which expanded from only Lombok in 2014 and around 40 to 50 households to many hundreds of households along the southern coastline of central Indonesia from Java in the west to Sumbawa in the east, and additional pockets in Aceh Besar and South Sulawesi by 2019. It is estimated that the seed fishery now exceeds 100 million seed captured per year, and with a conservatively estimated average price of $A2.00 each, this represents a $200 million industry. Most seed is traded through dealers for export, primarily to Vietnam. This supply chain represents additional positive economic impact.

Once a domestic lobster growout industry is established, as now seems likely, even a small proportion of the seed directed to supplying farming operations would generate

significant economic impact. For example, if 5 million of the 100 million seed available was retained in Indonesia for on-growing, it could generate 1,500 tonnes of market sized lobsters with a value of more than $A100 million (based on the ratio of seed to production in Vietnam).

As outlined in the industry development roadmap (Section 7.15), a lobster farming industry worth $US250 million is achievable within 5 to 10 years.

8.3.2 Social impacts

Based on the socio-economic assessments performed in this and previous ACIAR projects, it was estimated around 800 households are engaged in lobster seed fishing in Lombok, where it was first established. The project activities indirectly influenced many more households to engage in lobster seed fishing from the west of Java to the east of Sumbawa, with possibly 10,000 households now involved (Fachry, *et al.*, 2018; Priyambodo *et al.*, 2020). The social impact is significant, as seed fishing is technically straightforward, inexpensive and equitable in opportunity for women and men. Seed fishing has become a viable livelihood that is now sustaining many poor coastal communities.

Comparison of industry status with that of Vietnam indicates the potential for further social impact. In Vietnam, there are approximately 4,000 households engaged in the on-growing of lobsters (Jones *et al.*, 2019), utilising 3 to 5 million seed captured each year. In Indonesia there are now in excess of 100 million seed caught per year. Although a substantial proportion, perhaps more than 50% will continue to be exported as seed, the grow out of 50 million seed could readily support another 20,000 households nationally. Within 5 years, there are likely to be more than 2,000 households involved in the farming of lobsters in Indonesia.

8.3.3 Environmental impacts

Lobster fisheries around the world are static or in decline due to overfishing. Similarly, in Indonesia lobster fishery statistics indicate declining production over the past 10 years. It is natural, therefore, to be concerned that the fishing of puerulus may have a negative impact on adult populations. Research conducted by previous ACIAR research concluded the natural mortality of the seed lobsters is likely to be greater than 99%. By sustainably harvesting the swimming pueruli before they perish, a significant aquaculture industry can be supported, with negligible impact on the environment and without the significant challenge and cost associated with attempting to develop national lobster hatchery operations.

Globally, the prospect of lobster farming raises significant concern over the environmental impact of nutrient loading from sea-cages, particularly using trash fish. A significant outcome of the project was the experimental development of an effective formulated diet. Although commercial production has not yet begun, demand from a growing lobster farming sector will likely be sufficient to stimulate commercial investment in a appropriately formulated diet that minimises waste and nutrient leakage.

The project has built capacity and understanding within the Indonesia government to effectively regulated and managed lobster industry development. Such measures will ensure suitable marine zoning for environmental sustainability.

8.4 Communication and dissemination activities

Project communications were negatively impacted by the project variation that resulted in suspension of all planned industry meetings and workshops. Nevertheless, the project delivered a strong publication output, generating some 46 outputs comprising international conference presentations, peer-reviewed journal publications and other reports.

Regular meetings with the Chairman of BRSDM (Professor Widjaya and his predecessors), and BRSDM Director of Research Dr Toni Ruchimat was an important mechanism for disseminating project results to the highest levels of government and building the case for policy revisions that are now (2020) being realised.

8.4.1 List of publications arising from the project

See Appendix 21.

9 Conclusions and recommendations

9.1 Conclusions

The project delivered significant new knowledge on lobster seed fishing and growout farming, despite the Indonesian government banning both industry sectors early in its course. The government's recent reversal of the ban and their prioritisation of lobster industry development is now expertly supported by the many mid-career staff who's capacity was built during the project. The opportunity for lobster aquaculture in Indonesia is significant, based on the magnitude of the wild seed resource identified by the project. It is reasonable to conclude that Indonesia, with an estimated seed catch of 100 million per year, could develop a lobster aquaculture industry 20 times larger than Vietnam, which produces 1,500 tonnes annually from approximately 3 to 5 million seed caught. Realising the potential will require enabling policy and well managed development planning. The road map for Indonesian lobster aquaculture sets out an action plan for establishing a national lobster industry, with associated strategies for its development.

Where puerulus seed naturally occurs off Indonesian coastlines, many thousands of coastal people could potentially benefit from a vibrant lobster industry (Fachry *et al.*, 2018 – Appendix 2). However, Indonesian fishers and farmers are somewhat risk averse and lack the knowledge to adopt lobster fishing and farming. Adoption and scale-out can be facilitated through well-resourced extension activities that are attuned to risk perceptions, demonstration farms to build understanding and confidence, and engagement with the private sector to strengthen supply chains, grow markets and facilitate scale-out.

9.2 Recommendations

The road map for Indonesian lobster aquaculture details future research priorities on policy and planning development and improvements in technological aspects of fishing and farming to support government extension services. Focus should be on improving seed handling and transport, nursery technology, growout diet formulation and commercialisation, and health/disease management.

It is recommended that Indonesia formulates new policies to support industry growth, such as regulations for seed fishing and export, and zoning and planning for seed fishing and sea-cage development.

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11 Appendixes

11.1 Appendix 1. Priyambodo, B., Jones, C.M. and Sammut, J., 2020. Assessment of the lobster puerulus resource of Indonesia and its potential for sustainable harvest for aquaculture. Aquaculture, 528: 1-17.

11.2 Appendix 2. Fachry, M.E., Sugama, K. and Rimmer, M.A., 2018. The role of small-holder seed supply in commercial mariculture in Southeast Asia. Aquaculture, 495: 912-918.

11.3 Appendix 3. Jones, C.M., 2018. Progress and obstacles in establishing rock lobster aquaculture in Indonesia. Bulletin of Marine Science 94: 1223-1233

11.4 Appendix 4. Syafrizal, Jones, C.M., Permana, I.G. and Utomo, N.B.P., 2018. Effect of Feeding Frequency on Survival and Growth of Juvenile Spiny Lobster Panulirus versicolor in Indonesia. AACL Bioflux 11: 1427-1434.

11.5 Appendix 5. Priyambodo, B., Jones, C. and Sammut, J., 2015. The effect of trap type and water depth on puerulus settlement in the spiny lobster aquaculture industry in Indonesia. Aquaculture 442: 132-137.

11.6 Appendix 6. Priyambodo, B., Jones, C.M. and Sammut, J., 2017. Improved collector design for the capture of tropical spiny lobster, *Panulirus homarus* and *P. ornatus* (Decapoda: Palinuridae), pueruli in Lombok, Indonesia. Aquaculture 479: 321-332.

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