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Final report

project

Spiny lobster aquaculture development in eastern Indonesia, Vietnam and Australia

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2 Executive summary

The project was successful across all objectives, making demonstrable progress in support of establishing tropical lobster farming in Indonesia. The industry remains most active in Lombok where lobster seed resources are most abundant, and impact has been greatest there. Nevertheless, project activities have established activity and interest in lobster farming in other provinces and particularly Aceh and, South and Southeast Sulawesi. The project met all of its 23 milestones with the exception of publishing a production manual, which has been held over until 2017. For several milestone activities, further research will be required to build on the outcomes generated and reach practical commercial outputs.

The research was instigated to address the opportunity to establish a significant small-holder based industry in Indonesia that could alleviate poverty in coastal communities. The premise was that such an industry – lobster farming, had been established in Vietnam, with ACIAR involvement, and it could be replicated in Indonesia where the availability of necessary basic requirements had been confirmed through a previous ACIAR project focussed in Vietnam (FIS/2001/058). The broad aim was to assess, develop and expand the resources of naturally settling lobster seed (puerulus), and develop grow out of those seed to meet export market demand. This was to be achieved by adapting and transferring to Indonesia technology from Vietnam, where lobster farming had become a successful industry producing 1,500 tonnes of export quality lobsters valued at $A100 million.

Project activities were primarily Indonesia based, with a modest commitment of resources to Vietnam and Australia. The Vietnam lobster farming industry had reached a level of some stability, but was clearly in need of improved sustainability. Research there was focussed on sustainability issues, which would have important impact in Vietnam with flow-on benefit to Indonesia to avoid the pitfalls experienced.

In Australia, project activities were directed to assessing the potential to establish lobster grow out in this country to maximise benefit from expected hatchery supply of seed. Lobster grow out was seen as a potential diversification for existing aquaculture operators and for Indigenous communities.

In Indonesia, the lobster seed resources in Lombok were closely examined and defined in regard to spatial and seasonal distribution, species composition, market price and fishing methods. From 2008 to 2012, catch was consistent with stable fishing effort, at around 600,000 seeds per year. In 2013, catch per month increased with improved techniques and increasing effort (more fishers) and had reached an annual total of over 5 million seeds by mid 2014. Around 75% of the seed captured were *Panulirus homarus*, the sand lobster, and the remaining 25% primarily *Panulirus ornatus*, the pearl or ornate lobster. At the beginning of the project, seed price was around IDR2,000 each ($A0.20), and by June 2014 was exceeding IDR18,000 each ($1.80). Thus, value of the seed resource had increased from $A120,000 to $A9 million. The most significant influence on this increase was a study tour arranged through the project that took a group of 10 Indonesians to Vietnam to learn first hand the techniques of lobster seed fishing and grow out. Abundant seed resources were also identified in Aceh and Southeast Sulawesi.

In contrast to the increased seed catch from 2008 to 2014, lobster grow out in Indonesia decreased as grow out farmers focussed their attention on seed fishing only. As seed catch grew in Lombok, demand from export markets (primarily Vietnam) also grew, with concomitant increase in price. The seed were destined for markets where lobster grow out was well established and the Indonesian seed were of good quality and significantly lower price than locally sourced seed (seed price in Vietnam was over $5.00 for *P. homarus* and more than $A12.00 for *P. ornatus*). Lombok fisher/farmers who had been less effective at grow out than those of Vietnam, as their knowledge and capacity were only developing,

chose to avoid the risk of grow out and cash-in on sale of seed. This unexpected consequence of the increased seed catch is unfortunate, as it precludes the Indonesians gaining the most value from their lobster resources.

In parallel to the research activities assessing and expanding seed catch, were activities to improve the survival and growth rate of lobsters from point of capture through nursing and to grow out to market size. This comprised knowledge gains in lobster nutrition, husbandry and health management. Although significant gains in knowledge of these disciplines had been made in Vietnam through FIS/2001/058, they had focussed on *P. ornatus*, the most common species in Vietnam, while in Indonesia, the focus was on *P. homarus*, which exhibited differences in its requirements.

Much of the Indonesian research was performed by the Marine Aquaculture Development Centre in Lombok, and over the course of the project, the capacity of the centre and the staff was significantly increased for experiment-based research of lobster aquaculture. This flowed on to improved technology extension, as the MADC staff, who have a strong extension responsibility, were better equipped to advise farmers.

The primary impact has been the improved livelihoods of village communities throughout southeast Lombok. At the outset of the project some 3 villages and around 200 households were involved in lobster farming activities (catching of seed and grow out). By project's end, there were 2,000 households involved directly including men, women and children. Economic impact included increased family incomes and improved community infrastructure. Social impact included engagement of several family members – particularly women and older children, an expansion beyond just men who had been the initial participants.

While the project achieved a substantial positive impact in assisting the establishment of lobster farming in Indonesia, more research and development is required to realise the full potential. The unexpected decrease in lobster grow out can and must be reversed, to enable the full benefit of the Indonesian lobster seed resources to be gained. This will require definitive lobster production technology appropriate to the lobster species available and to the smallholders who will be involved. To this end, a new ACIAR project (FIS/2014/059) has been approved.

Core activities will include the adaptation of existing nutrition information to an effective commercial pellet diet, available and attractive to Indonesian lobster farmers. Improvements in survival of lobster seed, particularly during the catching / transport phase and subsequent nursery phase are required. These improvements will come from improved nutrition, husbandry and health management.

Most importantly the technologies generated by the research must be effectively extended to the farmers, and achieving that will necessitate a strong focus on socio-economic factors. It is now clear from the research completed that development of lobster farming in Indonesia should have a broader approach to harness existing aquaculture capacity beyond Lombok, Aceh and southern Sulawesi, to stimulate diversification by existing farmers and attract greater investment to the industry.

3 Background

Farming of lobsters has long been sought to meet increasing demand for these premium crustaceans that fisheries production increasingly fails to meet. Lobster fisheries throughout the world have static or decreasing production because of poor management or due to broad scale factors linked with climate dynamics and possibly climate change (Caputi*, et al.*, 2013; Pecl*, et al.*, 2009). While the proposition of lobster aquaculture is attractive, its realisation is problematic because of biological impediments. For spiny or rock lobsters (family Palinuridae) the most significant biological constraint is the prolonged larval life and the delicate nature of the larvae. This constraint however has been circumvented to some extent by the capture of naturally settling baby lobsters (lobster seed or pueruli), and their subsequent rearing to marketable size. This form of lobster aquaculture is, to this point in time, the only one with commercial success, and it is most well developed in Vietnam. Research is continuing in a number of countries to generate larval rearing technology (Jones, 2009; Phillips, 2013), and while proof of concept for such hatchery technology has been achieved for several commercially important species, large-scale hatchery production appears to be some years away.

ACIAR has supported the expansion and sustainable development of lobster farming based on wild lobster seed supply in Vietnam, primarily through project FIS/2001/058, which in its final year (2007) included a variation to assess the potential for establishing an equivalent lobster aquaculture industry in Indonesia. That assessment led to the development of the SMAR/2008/021 project reported here.

Unlike Vietnam, where the lobster seed fishery was well established and catching one to three million lobster seeds per year for farming purposes, Indonesia had only just identified a small resource of catchable lobster seed on the island of Lombok. The SMAR/2008/021 project was tasked with examining that seed resource with a view to its expansion and to assessing availability of lobster seed elsewhere in Indonesia. Secondly, the project sought to transfer growout technology from Vietnam to Indonesia to generate marketable lobsters from the seed available.

While the project was firmly focussed on Indonesia and establishment of lobster aquaculture there, it also included research activities in Vietnam and Australia. For Vietnam the goal was to improve sustainability of the industry through better understanding and potential management of the seed fishery and through improved survival and growth for the growout of lobsters with emphasis on nutrition and disease management. In Australia, where lobster farming is non-existent, the project sought to assess potential for land-based growout and potential for Indigenous communities to engage in lobster farming.

It is important to note that the Vietnam lobster farming industry is based primarily on the ornate or pearl lobster *Panulirus ornatus* which is the highest value tropical rock lobster in the primary market of China. More than 70% of the captured seed in Vietnam are this species. The China market is currently paying a wholesale price of >$US100 per kilogram for live 1kg plus lobsters of this species. In Vietnam the second most abundant species captured as seed is *Panulirus homarus*, which is accepted into the China market at smaller sizes (300g +) and at lower price per kilogram of $50 to $80/kg. In Indonesia, the seed captured are around 75% *P. homarus* and 25% *P. ornatus*.

The broad goal of the project was alleviation of poverty, and in this respect lobster farming is a particularly attractive opportunity for Indonesia because capture of seed lobsters and their growout involves simple technology, minimal capital and is ideally suited to village based enterprises.

The project was initiated on 1st January 2010. Three variations were approved during the course of the project, which included extensions of time that resulted in an end date of 30 June 2014, and total project duration of 4 ½ years. The project culminated in an

international lobster aquaculture symposium held in Lombok from April 22 to 25, 2014 in Lombok Indonesia. Two days of oral papers were delivered, a field trip was conducted to a lobster farming village, followed by an industry development workshop on the final day. Thirty-one oral papers were delivered representing all research conducted through the life of the project, and perspectives on industry development constraints and opportunities. A symposium Proceedings has been prepared and published as an ACIAR monograph (Jones, 2015) with summaries of all papers, representing the outcomes of the project, key results and discussion. As such, those details are not presented in this project final report, and both this report and that Proceedings document should be read in conjunction to obtain the full extent of project results.

There was a change in the commissioned agency for the project during its tenure. As part of Queensland Government Public Service reductions announced in September 2012, the original commissioned agency, the Department of Agriculture, Fisheries and Forestry (DAFF), made a decision to close its Tropical Rock Lobster (TRL) Aquaculture Program after attempts to attract external investment failed to secure a suitable partner. This process included termination of employment of all associated research staff and disinvestment from all associated projects including this ACIAR project. The closure of the program was completed on 19 April 2013 including retrenchment of the project leader Dr Clive Jones. Dr Jones negotiated re-employment by James Cook University including transfer of the ACIAR project from DAFF to JCU. The novation of the project from DAFF to JCU was amenable to both parties and the process completed on April 22, 2013.

The change of commissioned agency and employer of the project leader caused some disruption to milestone achievement, particularly because of the loss of the projects primary technician officer Scott Shanks. Nevertheless, the project was completed successfully.

4 Objectives

The aim of this project was to develop sustainable production of tropical spiny lobster in Indonesia; to assist in consolidating production in Vietnam, and to facilitate commercial growout production in Australia. The project comprised three major objectives and their respective activities as outlined below:

Objective 1: Improve the sustainability of lobster seed collection in Indonesia and Vietnam

1.1 Continue compilation and analysis of annual lobster seed catch data throughout Indonesia and southern Vietnam

1.2 Identify sustainable lobster seed collecting areas throughout eastern Indonesia

1.3 Develop improved puerulus collecting methods and handling to increase survival rates

1.4 Investigate genetic stock structure to identify sources and sinks for the settling seed as far as this proves possible

Objective 2: Development of sustainable growout production systems

2.1 Optimise holding, transport and nursery conditions for newly caught post-pueruli and juveniles.

2.2 Define environmental impact of lobster sea cage farming and the comparative contribution of pelleted feeds and trash fish

2.3 Establish 'best management practice' demonstration lobster grow-out facilities in strategic sites throughout eastern Indonesia and pond-based alternatives in Vietnam

- 2.3.1 Lobster growout demonstration farms
- 2.3.2 Comparative assessment of pond-based growout
- 2.3.3 Lobster growout field trials
- 2.3.4 Practical diet formulation and feeding strategies
- 2.3.5 Scoping lobster growout opportunities in indigenous communities

2.4 Develop economic models of farmed lobster in Indonesia, Vietnam and Australia

2.5 Review current status of lobster disease threats and related ongoing investigations in Vietnam with a view to developing an appropriate project response that complements active National and industry supported programs

Objective 3: Improve capacity to assess sustainable industry development practices and improve adaptive research process

3.1 Develop understanding of sustainability indicators that affect the successful development of the lobster industry in eastern Indonesia and Vietnam

3.2 Deliver community-based training courses/workshops to assist communities to establish lobster grow-out and adapt best management practices

3.3 Develop science-based training in experimentation at Balai Budidiya Laut Lombok (BBLL) with BBLL staff and students from University of Mataram (UNRAM) that develop their skills and address knowledge gaps in lobster feeding and husbandry

3.4 Develop and trial innovative extension and technology transfer practices that assist communities to consider lobster grow-out as a new enterprise.

5 Methodology

The project sought to adapt existing lobster farming technology from Vietnam, to apply to Indonesia where lobster seed resources had been confirmed and assist in its further expansion throughout Indonesia. Negative environmental impacts experienced in Vietnam were to be avoided by facilitating uptake of pelleted diet feeding which is likely to be both more cost-effective and much cleaner, and by effective planning for growout development that meets carrying capacity benchmarks defined from research in Vietnam.

A substantial lobster seed resource (> 600,000 per annum) had already been identified in Lombok (through project FIS/2001/058) and a small growout industry was established. As exploitable seed resources were likely to exist elsewhere in the archipelago, upon which a significant lobster farming industry could be developed, a primary goal of the project was to assess availability and relative abundance of seed in multiple locations.

In sites where seed availability was confirmed, 'best management practice' demonstration grow-out farms were established to extend the technology to local communities and to stimulate farming activity. The Indonesian Directorate General for Aquaculture had a core role responsibility for lobster farming development planning, to ensure carrying capacity of proposed farm areas was not exceeded and local environments were sustained. The Marine Aquaculture Development Centre in Lombok had the primary role of seed assessment, establishment of demonstration farms and technology extension, and in providing research support for lobster nursery husbandry and feeds development.

The Vietnam component of project was focussed on lobster farming industry issues and problems identified from FIS/2001/058, primarily environmental and disease related. Having project-based research in Vietnam provided a significant benefit to the Indonesian activities by facilitating on-going adaptation of Vietnam lobster farming technologies for Indonesia. The Vietnam-based work comprised environmental assessments (with Institute of Oceanography) to gauge the impact of lobster sea cage farming and specifically the relative contribution from traditional 'trash-fish' feeding practices as compared with use of manufactured pelleted feeds. Secondly, in Vietnam there was an assessment of land-based farming systems for lobsters performed by Nha Trang University as a possible alternative to sea-cage systems.

The Australian component of the project assessed commercial-scale, land-based growout systems to prepare the Australian aquaculture sector for the possible availability of hatchery-reared lobster seed. Hatchery technology was being commercialised by Queensland Government at the outset of this ACIAR project, although that program was subsequently closed and commercial hatchery technology is not yet established.

The project also sought to develop lobster farming for Indigenous communities by establishing a pilot growout system in an Indigenous community (Yarrabah).

Details of methods applied within each of the three project objectives are summarised below. Specific methods and materials for all research activities and experiments are provided in the Proceedings of the International Lobster Aquaculture Seminar 2014.

5.1 Objective 1: Sustainability of lobster seed collection in Indonesia and Vietnam

5.1.1 Compile annual lobster seed catch data

Reliable data on the number, locality, seasonality and species composition of lobster seed were collected for each year of the project in both Indonesia and Vietnam. Data collection was by means of a structured questionnaire administered by local project staff. In Vietnam

this involved two surveys during the seed catching season, the first in December and the second in March. In Indonesia (Lombok), data was collected monthly. Data was collected from the middlemen and/or fishers who facilitate the distribution of collected seed to grow-out sites.

At the completion of the project, a synopsis of seed resource data across Vietnam and Indonesia was documented, summarising the data and describing inter-annual variability in the various resource statistics. This data is available to resource management agencies to be considered for planning purposes.

5.1.2 Identify suitable lobster seed collecting areas throughout Indonesia

This work was specifically aimed at identification of localities throughout Indonesia, where settlement of lobster seed was considered likely to be prevalent, and which might support commercial exploitation. The tripod frame developed in Vietnam and now used in Lombok provided a simple tool that could be cheaply and easily made at each chosen location. This standardised tool enabled data to be collected that was directly comparable from site to site. Servicing of the collectors to retrieve the settling lobsters was negotiated with the village leaders, and they were trained in the correct methods for maintaining the collectors and recording the information. This work was coordinated by MADC Lombok and involved collaboration with other identified agencies in Nusa Tengara Barat, Nusa Tengara Timur, South Sulawesi and Aceh Provinces.

Data collected was in the form of weekly counts of settled puerulus per tripod including species identification. These were collated by the local agency responsible and transmitted by email to MADC Lombok.

5.1.3 Develop improved puerulus collecting methods and handling

Fishing for swimming puerulus represents the most productive method for capturing seed lobsters, and in Vietnam represents over 90% of seed caught. However, the mortality of puerulus within 24 hours of capture is excessive, and much higher than that of juveniles. Mortality of the puerulus remains a critical control point in the supply chain, and one for which improvements are a high priority. An assessment of all current seed collecting methods in Vietnam and Indonesia was made, and experiments performed to address critical control points. The experiments were performed by MADC in Lombok at research facilities at Sekotong and Gerupuk.

Experiments were designed and implemented which assessed the efficacy of the puerulus capture methods and post-capture handling against subsequent performance of the post-puerulus. Capture methods (from Vietnam and Indonesian experience) and post-capture handling techniques were used to define treatments that were applied under controlled conditions. Post-puerulus lobsters were reared under uniform conditions within floating cages and their performance measured over time in terms of survival, growth and moult frequency.

5.1.4 Identify the genetic stock structure of *P. ornatus*

Sustainable management of the lobster seed stocks relies on knowing if recruits come from a common pool, are they self-recruiting, what impact will harvesting have on replenishment, and is there evidence of local adaptation that may be useful to future breeding. Microsatellite and mitochondrial DNA based assignment tests were performed from samples of local adult and puerulus populations, with the goal of assigning seed lobsters to their source. This research was performed by Dao Tan Hoc from Institute of Oceanography Vietnam as part of his PhD research at James Cook University.

The genetic results allow us to visualise for the first time how geographical populations of *P. ornatus* within the South China Sea, Indonesian archipelago and northern Australia are genetically interconnected and whether the harvested recruits can be identified as originating from a common pool, or from local recruitment.

Genetic comparisons were conducted to obtain the information needed to address the question of where recruits are coming from. These are: a) the genetic composition of adult crayfish sampled from geographically dispersed populations which were compared to each other to identify spatial differences in gene frequencies; b) settled pueruli were sampled from multiple locations and the genetic composition of these recruits compared with those of adults from the same location. This analysis provides data on recruitment origin.

5.2 Objective 2: Development of sustainable grow-out production systems

5.2.1 Optimise holding, transport and nursery conditions for newly caught post-pueruli and juveniles.

This objective is sequential to work defined above for puerulus capture. Knowledge gaps remain concerning optimal methods for the supply of robust juveniles to the growout sector. A series of experiments was performed which addressed the knowledge gaps that exist in regard to post-capture holding systems and methods, transportation arrangements and husbandry of juveniles through to the target size of 5g+, suitable for stocking to growout cages.

An experimental approach was applied using the floating cage systems and land-based tank systems available at MADC at Sekotong. Treatments were defined in regard to physical, environmental and feeding aspects of holding, transport and nursery husbandry and tested under uniform conditions with replication.

5.2.2 Define the environmental impact of lobster sea cage farming and the comparative contribution of pelleted feeds and trash fish.

An experiment was established at an existing lobster farming area where experiment lobster cages could be located within the lobster farming area, representing a ‘degraded’ site and at some distance away from the commercial lobster farm cages, representing a ‘pristine’ site. Within these locations, the relative environmental affect of diet (trash fish feeding vs manufactured pellet) was assessed. The experiment provided both an assessment of the manufactured diet under practical, commercial conditions, and the comparative benefit it provides environmentally. The experiment was performed by Institute of Oceanography.

5.2.3 Establish demonstration lobster growout facilities in strategic sites throughout eastern Indonesia and Aceh.

Best Management Practice demonstration lobster farming systems were established at six locations to model the cage system and its operation. Each demonstration farm consisted of 4 cages each 3m x 3m x 3m on a floating frame.

Suitable sites and personnel to manage the demonstration farms were identified through the project development mission.

5.2.4 Assess the suitability and comparative advantages of pond-based growout of lobsters in Vietnam as an alternative to sea-cages.

Disease has caused a decline in productivity and production in the Vietnam lobster farming industry. While it is hoped that improvements in environmental management, particularly in feeding practices, will alleviate the disease issues, it is prudent to assess alternative production systems that are not subjected to the same environmental problems. An assessment of lobster growout in typical shrimp-pond conditions in the vicinity of Cam Ranh, at the NTU experimental shrimp farm was performed.

A replicated experimental approach was taken involving the design of successive experiments applying treatments including provision of shelter, lobster density and feeding method.

Subsequently, assessment of tank systems for growout of lobsters was made in a purpose built system established and operated by NTU staff.

5.2.5 Provide a comparative assessment of lobster growout production systems in Australia.

Project FIS/2001/058 provided a comprehensive database of growout requirements for *P. ornatus* including environmental tolerances and preferences, stock husbandry, feeding strategies and system requirements. Based on that data, the recommended practices were applied at semi-commercial level, on-farm to fully assess efficiency, productivity and cost-effectiveness of lobster production in earthen ponds and tank systems. The research was performed at the Pacific Reef Fisheries Pty Ltd prawn farm in north Queensland.

While it is recognised that the growout of tropical spiny lobsters has been successfully developed in Vietnam using sea-cages, a development of this kind in Australia is unlikely due to the strict environment regulations that exist in waters surrounding the Great Barrier Reef. Therefore other methods of grow out need to be identified and tested to confirm viability of a lobster farming industry in Australia. The most likely method of development in Queensland will involve current prawn farming infrastructure for lobster grow out. The ability of lobsters to not just survive but prosper under these conditions needs to be examined. A replicated experimental approach was taken involving successive experiments applying treatments including provision of pond cover, shelter, lobster density and feeding method.

5.2.6 Define optimal feeding practices that maximize growth and survival of lobsters

Lobster diet formulations were developed through project FIS/2001/58 and assessed at experimental, tank level. The current lobster project assessed the most successful of the previously developed diet formulations in the field. Part of the assessment included adaptation to locally available ingredients and diet preparation at village level (Indonesia) and with a view to least-cost formulations.

Assessments included field-based experiments at MADC Lombok where experimental sea cage facilities were used, and in the farm-based trial site in Australia. In addition to different diet formulations, feeding strategies, ration and frequency of feeding were tested. These were assessed through structured, replicated experiments.

5.2.7 Scoping study to establish pilot growout facilities in Australian indigenous communities

Growout of tropical rock lobsters in Australia will be best suited to locations north of Bowen through to the Torres Strait Islands, where climate and seawater access are most amenable to good growth and production. On this basis, there is strong opportunity for Indigenous community involvement. The concept considered was that legal sized (i.e >600g) but sub-premium (i.e < 1kg) lobsters will be purchased through existing wholesale channels for stocking to a production system. These will be on-grown to >1kg and re-sold to the wholesaler. The process would necessarily include training in production system establishment and operation, husbandry, feeding and handling. Once a successful operation was established, expansion to other communities in Queensland and possibly elsewhere in northern Australia could be pursued.

A two-stage scoping analysis was performed. The first stage scoped which of four locations / communities (Yarrabah, Cooktown, Lockhart River and Torres Strait) would

best serve for establishing a pilot lobster growout operation, and the second scoped specific locations within the preferred community of Yarrabah.

The scoping study recommended that a business case be developed to identify the resources necessary and processes required to establish the pilot operation.

5.2.8 Develop economic models of lobster farming businesses in Vietnam, Indonesia and Australia

This research analysed the economic feasibility of lobster growout aquaculture in Indonesia, Vietnam and Australia. This comprised development of discounted cash-flow models for lobster growout aquaculture in each of the three project countries. The Indonesian model was developed using previously developed and well-tested models as a template, and informed by data collected through a survey of existing lobster farmers in Lombok.

For Vietnam, lobster growout aquaculture is relatively more advanced, and development of the bio-economic model, and associated data collection, was completed through a parallel ACIAR project led by Advanced Choice Economics Pty Ltd ('Policy, Institutional and Economic Constraints to Aquaculture Research Adoption in Vietnam', PLIA/2007/050).

For Australia, where collection of naturally settling seed is unlikely to be viable, growout must rely on a supply of hatchery-produced seed. As hatchery technology is not yet commercial, bio-economic modelling was based on hypothetical production metrics.

The research was performed by Dr Liz Petersen and linked directly with project PLIA/2007/050, for which she was project leader. For each of the three models, the economic feasibility of the aquaculture operations was assessed, and sensitivity analysis were conducted on key model variables (such as interest rate, capital costs, seed and feed costs, labour costs, mortality rate, and harvest price) to assess those factors which have the greatest impact.

In addition to the economic modelling, insights into market supply chains for farmed lobsters were made by project team members during project related travel. This topic was discussed at the various project meetings and workshops and the information collated to generate a market synopsis.

5.2.9 Review current status of lobster disease threats and related ongoing investigations in Vietnam with a view to developing an appropriate project response which complements active National and industry supported programs

Discussion of the various lobster health and disease issues through the conduct of FIS/2001/058 indicated that several investigations of lobster diseases by Vietnam agencies have been made previously. Because the extent of these investigations and the data gathered were unknown, the project facilitated a lobster disease information audit to gather and collate these data through meetings with key stakeholders including lobster researchers, lobster farmers and marketers and provincial government representatives. Appropriate fish / aquaculture disease specialists were engaged to conduct the audit.

Following the information audit, a project-sponsored lobster disease workshop was to be convened in Vietnam to present the information gathered by the audit and enable discussion of the Vietnam response to the disease issue to date. This proposed workshop became redundant when the Vietnam Ministry for Agriculture and Rural Development convened its own lobster disease workshop in November 2009.

5.3 Objective 3: Improve capacity to assess sustainable industry development practices and improve adaptive research process

The project will develop an understanding of sustainability indicators in both Indonesia and Vietnam. These indicators will involve biophysical and economic assessments that will influence the long-term profitability of the lobster industry. These indicators will be refined during the project and discussed with regional planning agencies to influence development. These include but are not limited to; resource management data for seed lobsters including relative spatial abundance, seasonality, species composition and inter-annual variability; improved lobster seed catch, handling and transport methods that result in reduced mortality to juvenile stage; clearly defined cost:benefit data for pellet feeds for growout; sensitivity analyses of production economics to identify critical control points and defined carrying capacity metrics for appropriate industry development planning and management.

The project will use a number of platforms to disseminate project findings to ensure the information is widely distributed and effectively communicated. The first such platform is face-to-face communication between project participants and industry and government personnel. Such communication is facilitated by the extent of field-based activities within the project including the field seacage experiment in Vietnam (IO), pond production assessment in Vietnam (NTU), seed collection and growout demonstration activities throughout Indonesia, and field based growout development in Australia.

Secondly, there are planned and budgeted annual technical workshops in Lombok including representatives from research, local, provincial and national government and the lobster industry. These are planned to extend over 2 days, and will include experimental results, field assessment results from all involved regions (i.e. NTB, NTT, Sulsel and Aceh), industry perspectives from the regions, information of relevant products and technologies (e.g. commercial feeds, feed production equipment) and government perspectives on industry development and planning. The workshop will also include a field component to demonstrate equipment (e.g. for seed collection, growout cages) and practices.

In Vietnam, budgeted workshops have not been included, however, equivalent meetings at provincial level will be encouraged via the collaborating agencies (IO and NTU) who have a proven record of arranging such meetings to extend information.

The third platform will be the annual project workshops to be held sequentially in Indonesia, Vietnam and Australia. They provide opportunity for key, senior project participants to meet together, exchange project results, discuss issues and plan on-going activities.

Fourthly, it is proposed to develop posters and manuals in the appropriate languages that are aimed at industry participants. These will cover specific components of lobster production including seed catching, nursery production, growout husbandry, feed production and feeding practices, harvesting and transport.

In Australia, the project enables the establishment of pilot-scale lobster grow-out facilities on an existing commercial prawn farm, to demonstrate the feasibility of tropical spiny lobster grow-out in Australia. Results from this activity will be communicated to the broader aquaculture industry through presentation at the Australian Prawn Farmers Association and Australian Barramundi Farmers Association annual workshops. The project also proposes to invite expressions of interests in lobster grow-out development from indigenous communities, and to establish pilot growout operations at one site. This will be used to demonstrate lobster production practices to the broader indigenous community with a view to expanding production facilities to multiple communities in northern Queensland.

Lastly, scientific results will be published where appropriate through international conferences and peer-reviewed journals. The project will provide support to the Vietnamese and Indonesian participants to have a direct role in such scientific publication. For example, the project provides support for Bayu Priyambodo from Indonesia and Le Lan Huong from Vietnam to present project findings at an international lobster conference in Norway (2011), which will include peer-reviewed conference proceedings publication.

Increased travel of Australian project staff to Indonesia will occur for more effective engagement, training and capacity building, particularly at Balai Budidiya Laut Lombok (BBLL). The increased travel will enable a greater focus on structured training on experimental design, data recording and handling, experiment set-up and operation, data analysis and reporting. It will increase the capacity within BBLL and University of Mataram (UNRAM) in conducting rigorous science-based experiments and field research. Through the inception period of the project it has become abundantly clear that BBLL staff have limited knowledge of experimentation nor of scientific rigour in the design and operation of field-based research activities. This was offset to some extent by the engagement with UNRAM, who in turn gained valuable practical experience currently unavailable within the university. The training will be delivered within the context of lobster husbandry outcomes that were sought within the original project document.

6 Achievements against activities and outputs/milestones

Objective 1: To facilitate sustainable lobster seed collection in Indonesia and Vietnam

No.	Activity	Outputs/ milestones	Completion date	Comments
1.1.1	Lobster seed census IND, VN	Annual lobster seed catch data compiled for Indonesia and Lombok and published in the public domain.	June 30, 2012	In Indonesia during the first 3 years of the project the seed census was conducted in Lombok, reporting detailed data on the seed catch and indicating a consistent year-on-year catch of around 600,000 lobster seeds. In the last 12 months the catch increased dramatically to more than 5 million seeds, more than an 800% increase over previous years. This increase is attributed to improved catch techniques arising from the study tour to Vietnam in March 2013, and subsequently a sharp rise in the number of fishers from the various villages throughout south-east Lombok. An unexpected and negative consequence of the increased seed catch in Lombok has been the almost wholesale abandonment of lobster growout in favour of seed fishing and direct sale of seed to dealers. The seed from Lombok are now in high demand from Vietnam and other South-east Asian countries, with price now exceeding $A2.00 per seed. In Vietnam, seed census proceeded as normal from the 2009/10 season to 2011/12 season. The 2009/10 season was relatively poor with around 1 million seed caught, but the 2010/11 catch reached an historical high of over 3 million seeds caught. In 2011/12 the catch was just over 2 million pieces. For Vietnam, project funding for the seed census was fully expended by the 2011/12 season, and no census was performed for the 2012/13 season. A recommendation was made through IO for the seed census to be continued under VAST funding, but this has not yet happened. Anecdotal information suggests catch in Vietnam for the 2013/14 year was relatively high and price has continued to increase now exceeding $A13.00 per puerulus for P. ornatus and $5.00 for P. homarus.

1.1.2	Lobster seed census IND, VN	Synopsis of seed catch data to be published in the public domain.	Feb. 28 2013	IO staff member and JCU PhD student Dao Tan Hoc prepared a synopsis of the annual seed census for Vietnam for 2005 through 2014 which was presented at the International Lobster Aquaculture Symposium in April 2014. The data is presented in detail in the Proceedings of the Symposium and will be published in a scientific journal during 2015. MADC staff member Samsul Bahrawi prepared a synopsis of the annual seed census for Lombok for 2007 through 2014 which was presented at the Symposium. The data is presented in detail in the Proceedings of the Symposium.
1.2	Lobster seed resource assessment IND	Suitable lobster seed collecting areas throughout Indonesia identified	June 30, 2012	Over 200 standardised tripod seed collectors were deployed at more than 20 locations over 8 Provinces in Indonesia during the 4 ½ years of the project. Information about possible seed resources was received regularly from multiple locations throughout Indonesia, but was well beyond the scope of the project to pursue. DGA indicated they would provide resources to expand the seed assessment program, including extension activities to train villagers in commercial seed catching methods, although this has not yet happened. Reliable data was by and large, not forthcoming at locations where trained DKP or Provincial Fisheries staff were not involved. As the project progressed, the focus of the seed assessment was only in areas with such trained staff available. Overall, substantial numbers of pueruli were caught at sites in Aceh and South Sulawesi that appeared sufficient to support a local growout industry, but at the time of reporting such growout development had not occurred. It is conceivable that seed fishing may provide a viable commercial activity in its own right, with seed captured sold and transported to other locations for growout. At the time of reporting demand and price for seed were both high, although for export to other countries. The challenge is to ensure the seed are retained by Indonesia for growout to market size, and then exported as premium, high value product to achieve the greatest return.

1.3	Puerulus capture and handling IND	Improved puerulus collecting methods and handling defined and published in the scientific literature	June 30, 2012	Building of capacity and knowledge in handling puerulus and juveniles has occurred via the nursery experiment program at MADC that involves handling of small lobsters for experiments. Extension to industry in Lombok has then occurred through MADC staff as they interact with farmers. A field experiment examining the effect of light on puerulus catch was performed, with the result that light appeared to not have any affect on catch, which is counter to the experience in Vietnam. Further experiments were planned but not performed due to on-going difficulty with capacity to establish an run effective experiments, as evidenced in the nursery experiment program. Although building of capacity and knowledge in handling puerulus and juveniles has occurred via the nursery experiment program at MADC, this aspect of lobster farming remains a key constraint for Industry. Mortality of puerulus from time of capture to stocking to growout is higher than 50%.
1.4.1	Population genetics study of P. ornatus IND, VN, A	Microsatellites developed for identifying genetic stock structure of P. ornatus	June 30, 2010	Tissue samples from P. ornatus and P. homarus pueruli and adults were collected from several sites in Vietnam, Indonesia, Australia, Taiwan and Oman and were analysed in Australia by Dao Tan Hoc, PhD student at JCU. Microsatellite and mitochondrial DNA markers were developed and applied, with analyses demonstrating no discernable population structure, throughout this range. Populations of these two species appear to be homogeneous, reflecting likely widespread movement and mixing of larvae during the extended oceanic larval phase subject to strong current movement. Two scientific journal papers have now been published on this research with another two in preparation.
1.4.2	Population genetics study of P. ornatus IND, VN, A	Microsatellite and mtDNA population genetic screening completed and results published in the scientific literature	June 30, 2011	Tissue samples from 216 P. ornatus and 209 P. homarus lobsters were collected from Vietnam, Indonesia, Australia, Taiwan and Oman. Microsatellite and mitochondrial DNA markers were successfully developed. Results published in scientific journals.

IND = Indonesia, VN = Vietnam, A = Australia

Objective 2: To develop sustainable lobster grow-out production systems

No.	Activity	Outputs/ milestones	Completion date	Comments
2.1	Development of lobster nursery technology IND	Optimal holding, transport and nursery conditions for newly caught post-pueruli and juveniles defined and published in the scientific literature.	June 30, 2012	Sea cage and tank based experiments were designed to examine aspects of nursery culture in relation to nutrition and husbandry. The initial several experiments did not generate meaningful results due to high mortality, storm damage to the sea cage facility and lack of capacity of the MADC staff in experimentation. It was apparent that the complexity of the protocols and lack of communication contributed to the limited success of the initial experiments. Subsequently, experimental protocols were simplified, experiments were confined to land based tank experiments rather then the logistically difficult and weather dependent sea cages a communication plan was applied. It became clear that the experiment program would serve two purposes, firstly to address specific questions about improved nursery culture of lobsters and secondly to build capacity in the staff managing the experiments. As existing experimental capacity was very low, the first purpose had been compromised by the second. To that extent, results from the first 2 years experiments were mixed and generally of insufficient rigour to draw conclusions. Nevertheless, capacity was improved and subsequent experiments generated more useful results. A significant development in both improvement of experiment rigour and capacity building was the engagement of University of Mataram students in the experiment program (see 3.3). The nursery research conducted over the life of the project was presented at the symposium in 2014. Mortality through the Nursery phase remains the greatest problem for industry and further research and extension are critical.

2.2	Environmental impact of lobster sea cage farming VN	Experiment established and environmental metrics confirmed. Preliminary data available for application to CADS	June 2010	A seacage experiment in Vietnam was established by Institute of Oceanography in June 2010 and started in October with 900 lobsters at 47.5g average weight. Sixteen cages were deployed under two levels of treatments, location (pristine vs degraded water) and diet (trash fish vs pellet feed). The experiment suffered some problems associated with monsoon-induced salinity drops and subsequent disease, but these were not critical and the experiment was successfully completed in December 2011. Although growth appeared to be higher on trash fish than pellet, this is likely to have been influenced by density factors as survival was higher with pellets. Overall the use of pellet feed is supported providing the formulation and form are improved. The farmer managing the experiment declared he would prefer to use pellets, which provides important endorsement. The relative impact of pellet feeding on the environment compared with trash fish was not discernable from the experiment. Further development of pellet diets and promotion of their adoption by farmers is critical.
2.3.1	Lobster growout demonstration farms IND	Lobster growout demonstration farms established, 2 per year in eastern Indonesia and Aceh	June 30, 2012	Six demonstration growout farms were established over the life of the project, in Awang (Lombok), Telong Elong (Lombok), Tablolong (West Timor NTT), Sanggar (Sumbawa NTT), Laikang (South Sulawesi) and Pulau Aceh (Aceh). Insufficient seed lobsters, storm damage and lack of local support impacted those in West Timor and Sumbawa, and both were subsequently abandoned. Outcomes of the demonstration farm program varied from ineffective to strongly effective. Further demonstration of best practice via this approach is warranted although with greater control over the operations, which may involve project employees running the farms rather than volunteers supported by the project, who will often apply their own management protocols rather than following the prescribed 'best practice' protocol provided.

2.3.2	Comparative assessment of pond-based growout in Vietnam VN, A	Suitability and comparative advantages of pond-based growout of lobsters assessed as an alternative to sea-cages, and information published in the scientific literature	June 30, 2012	Shrimp pond based trials performed by Nha Trang University in Vietnam had started well, and then suffered the same issue as in Australia (see 2.3.3), with exceptional monsoon rains and reduced salinity. Although several experiments were performed which generated useful results, it was concluded that pond-based production of lobsters was not a viable proposition and the focus of subsequent research was re-directed to assessing lobster production in tanks. An SRA (FIS/2011/008) was approved to support the change to assessing tank based lobster production. In Vietnam a tank-based facility was established at Nha Trang University including a pilot commercial system and experiment system. The results were positive and confirmed that tank systems are a viable alternative for lobster production in Vietnam. Further research is required to define appropriate recirculation technology and production protocols.
2.3.3	Lobster growout field trials in Australia A	Lobster growout production systems in Australia developed and results published in the scientific literature	June 30, 2012	Lobster production in synthetic-lined raceways at Pacific Reef Fisheries shrimp farm in north Queensland was good until early wet-season rain caused salinity to drop significantly, and the trials were terminated. Given the lack of control of salinity in such environments, risk of losses is too high to support this type of system for lobster production. The field trial agreement with PRF was terminated, and the activity was re-directed to tank-based production at Northern Fisheries Centre, Cairns. The tank work focussed on improving pellet diets which will be essential to tank production. A desktop economic analysis of tank production was made, which indicated that production would need to be highly intensive to achieve profitability. R&D of intensive tank production of lobster is required.

2.3.4	Practical diet formulation and feeding strategies IND, A	Optimal feeding practices that maximize growth and survival of lobsters defined and published	June 30, 2012	The principal objective was to develop an effective pellet diet and encourage widespread adoption of pellet feeds rather than fresh fish in the fledgling Indonesian lobster industry. Despite early encouraging results with commercial spiny lobster feed from Luckystar for larger lobsters, field trials and tank experiments across Vietnam, Indonesia and Australia on both P. ornatus and P. homarus confirmed the diet was deficient. A revised formulation was generated which Luckystar agreed to make. Subsequent experiments confirmed the revised commercial Luckystar diet was still deficient, and that laboratory diets were more effective. The experiments also showed that P. ornatus and P. homarus have different nutritional requirements. The lab diets formulated were most effective for P. homarus. It was clear that to achieve uptake, pellet diets would need to be made locally and be costed to meet the market. Further discussions with feed manufacturers in Vietnam and Indonesia were held to promote lobster pellet manufacture, but the response was negative on grounds the industry was too small and volumes required unprofitable. A field trial making pellet on farm was performed in Lombok in August 2013, proving high quality semi-moist pellets can be made easily and cheaply with locally sourced equipment and ingredients. The diet however appeared to leach and was not effective in sea-cages. Further fine tuning of farm diets will be necessary, and are unlikely to be a longterm solution. Collaboration with feed manufacturers in Vietnam and Indonesia must occur to promote lobster pellet manufacture.

2.3.5	Scoping study for growout operations in indigenous communities A	Assess opportunities at various communities and provide recommendations of how to engage	June 2010	Assessment of a number of possible Indigenous communities for engagement to establish a pilot lobster growout operation revealed that Yarrabah would be the best, due to its proximity to Cairns and the project base. Within Yarrabah a number of potential sites were available which were assessed via a scoping study performed by Jaragun Pty Ltd. A Project variation was approved in early 2011 to enable a business case to be developed including full costings of the proposed pilot. A trainee from Yarrabah was employed at DEEDI to develop his skills to establish and operate the pilot. The trainee's employment persisted for just 4 months and by mutual agreement was terminated. A number of cultural issues arose that precluded effective training which suggest that training within the community is likely to be more effective. The business case developed indicated Queensland State Government approvals for the proposed aquaculture operation are too onerous and costly to permit any further progress of this initiative.
2.4.1	Economic modelling of lobster farming IND, VN, A	Economic models of lobster farming businesses in Vietnam, Indonesia and Australia developed and published.	June 30, 2011	Dr Liz Petersen conducted a survey-based assessment of the bio-economics of lobster farming in Lombok and then generated a spread-sheet based model. This complements an equivalent model she produced for the Vietnam industry. She subsequently generated a model for tank-based lobster production in Australia, which suggests the high labour and capital costs in Australia will necessitate a more intensive production approach. Bioeconomics of lobster farming in Vietnam indicate strong viability and attractive business proposition for small holders. In Indonesia the economics are different due to the small harvest size of lobsters and the very high cost of credit. Given dramatic changes and developments in the lobster farming industry in Lombok in past 12 months, bio-economics must be re-surveyed and analysed. The bio-economic modelling for both Vietnam and Indonesia are published in the scientific literature.

2.4.2	Market supply chain insights IND	Synopsis of information gathered by project team through project travel on marketing issues and opportunities	June 30, 2012	The primary market for farmed lobster is China via Hong Kong. The price for P. ornatus has increased from around $A50 per kg at the beginning of the project to over $A130 per kg currently. Farmed product from Vietnam generally achieves same price as premium wild caught product from Australia. Price for P. homarus is lower (currently $A50 to $A80/kg), although this species is increasingly being accepted as a substitute for P. ornatus. Several initiatives in the region suggest substantial increase in farming of lobsters and supplies to market. Thailand announced an incentivised program to develop sea cage culture of lobsters on the Andaman coast. Darden Corporation announced development of an integrated lobster aquaculture park in Sabah Malaysia. Opportunity for aquacultured lobster remains very strong.
2.5	Lobster disease information audit and workshop VN	Status of lobster disease threats reviewed. Workshop convened to discuss issue and make recommendations for a response. Results of workshop documented.	June 30, 2010	The Vietnam lobster disease information audit was completed in 2009, generating a report (see Symposium Proceedings (Jones, 2015)). There was no further activity for this milestone. It is worthy of note that in early 2012, milky disease appeared to increase in prevalence in Vietnam causing a substantial decline in production over subsequent months, although not to the extent seen in 2008/09 when production was halved. Milky disease is already prevalent in Lombok, and farmers are responding with application of anti-biotics. Milky disease continues to be a significant problem in both Vietnam and Indonesia.

IND = Indonesia, VN = Vietnam, A = Australia

Objective 3: To improve capacity to assess sustainable industry development practices and improve adaptive research process

No.	Activity	Outputs/ milestones	Completion date	Comments
3.1	Improving lobster industry development sustainability IND, VN	Sustainability indicators developed for Indonesia and Vietnam	June 30, 2012	Sustainability indicators for seed capture are not forthcoming. The population genetics study indicates no population structure and therefore source of seed is effectively unknown and possibly unknowable. Given that adult lobsters are particularly rare in the primary puerulus catching areas of Vietnam and Lombok, there is a strong likelihood that these seed resources represent sink populations, whose exploitation may be of minimal consequence. Promotion of pellet feeds for more sustainable growout is not yet possible given disinterest by feed companies due to the small scale of the industry. Suitable feed formulations are now available, so the challenge is to engage the feed companies. Good economic data are now available which may assist sustainability of growout farming in Vietnam and Indonesia. In Vietnam, strong profitability has been demonstrated and provides collateral for seeking credit. In Indonesia profitability is more marginal but suggests farmers should seek a more profitable harvest size. Access to reasonable credit terms is also key.

3.2	Establish lobster grow-out and adapt best management practices IND	Community-based training courses/workshops delivered	June 30, 2012	To facilitate industry coordination and communication, and provide an effective forum for extension of project results, an industry development workshop was convened in Lombok in January 2011 for existing and prospective farmers. In addition to small-holders, the Directorate General Aquaculture was well represented at the workshop and were actively involved. DGA subsequently committed to support the running of future industry development workshops. A second workshop was held in April 2012. A third industry development workshop was held in Lombok in April 2014 as part of the symposium. Revised and more comprehensive written extension materials are required in both Vietnam and Indonesia. This led to the addition of a project objective to produce a production manual (see 3.7), which although not complete, is well advanced. A proposed study tour of Indonesian small holders and provincial government persons to see first hand scale and methods of Vietnam industry was realised in March 2013 (see 3.6), with significant positive impact.
3.3	Develop science-based training in experimentation at BBLL with staff and UNRAM students	Experimentation skills enhanced and knowledge gaps addressed in lobster feeding and husbandry	June 30, 2012	Intensive experiment programs comprising multiple experiments at MADC were held on six occasions involving MADC staff, University students and project associates from Australia. Thirty one students from 4 Universities participated and developed significant capacity in experiment design and lobster biology. Two students continued to Masters studies. Although application of MADC staff to experiments was less than expected due to conflicting work commitments, those involved developed their skills and there was progressive and compounding improvement.

3.4	Develop innovative extension and technology transfer practices	Communities assisted to consider lobster grow-out as a new enterprise.	June 30, 2012	Three Industry development workshops in 2011, 2012 and 2014 were well attended and effective. Engagement of DGA to coordinate these workshops in future is a significant outcome. Two project staff undertook study in Australia to improve their skills and benefits to their respective countries. Bayu Priyambodo on a JAF will complete a PhD at UNSW on lobster farming technology adaptation and extension. Dao Tan Hoc studying for a PhD on lobster genetics at JCU has now submitted his thesis. Extension materials were developed in Indonesia, although they need revision. A rough draft production manual was produced that can be revised and extended to specify current best practice methods for lobster farming and published in Vietnamese, Bahasa and English (see 3.7). Engagement of University students in the experiment program at MADC provided opportunity to extend lobster farming technology across Indonesia. Students gained considerable knowledge about lobster farming methods and opportunity that they can transfer to their respective home villages. The study tour to Vietnam has had the most effect of any project activity in assisting industry development. The impact has been seen most noticeably in Lombok in the lobster villages where there has been a marked increase in community participation. Smaller scale but significant effects have occurred in Aceh and South Sulawesi.
3.5	International lobster aquaculture symposium	Organise a symposium involving project staff and other stakeholders from the region. Publish Proceedings	28 February 2014	Symposium was successfully held on April 22/23 2014, with associated field day to lobster farms on 24th and an industry workshop on the 25th. Thirty-one oral papers were delivered representing all research conducted through the life of the project, and perspectives on industry development constraints and opportunities. There were 91 registered participants representing Indonesia, Vietnam, Australia, New Caledonia and USA, including the current and 2 past Directors General Aquaculture. A Proceedings of the Symposium was prepared and published by ACIAR (Jones, 2015) that provides comprehensive and detailed presentation of the results and outcomes of the project.

3.6	Study tour of Indonesian farmers to Vietnam	Appropriate Indonesian farmers receive practical information to expedite lobster aquaculture development in Indonesia	28 February 2014	A Study tour was successfully completed in March 2013, with 4 farmers, 5 DGA research / extension staff plus PhD student Bayu Priyambodo. Expectations that the study tour would have significant impact were met with an increase in seed catch directly attributable to improved techniques arising from the study tour. See Symposium Proceedings for detailed description.
3.7	Prepare a lobster aquaculture production manual	Practical manual prepared for farmers in Indonesian, Vietnamese and English	28 February 2014	A rough draft of the manual in English has been prepared but was not completed due to delays in obtaining critical input from international associates. Those associates remain committed to the task, and progress is being made. In the interests of producing a high quality manual, this task has been held over into a new project FIS/2014/059.
3.8	International lobster aquaculture symposium	Deliver a symposium involving project staff and other stakeholders from the region. Publish Proceedings	30 June 2014	See 3.5 above
3.9	Publish a lobster aquaculture production manual	Practical manual prepared for farmers in Indonesian, Vietnamese and English	30 June 2014	See 3.7 above

IND = Indonesia, VN = Vietnam, A = Australia

7 Key results and discussion

All aspects of the project were presented at the International Lobster Aquaculture Symposium held in Lombok from April 22-25, 2014. This Symposium represented an end of project workshop, and provided detailed results and discussion on all project objectives and broader industry development issues. A Proceedings publication from the Symposium has been prepared which presents the detailed results and discussion, and information presented below is therefore brief and of a summary nature.

7.1 Compilation and analysis of annual lobster seed catch data throughout Indonesia and southern Vietnam

A census of lobster seed captured in Indonesia and Vietnam during each year of the project was successfully completed. Comprehensive data were collated concerning total number of seed captured, species composition, seasonal and spatial variability and price. In Vietnam, it is clear that the seed fishery is likely to be fully exploited with a consistent catch of between 1 and 3 million seeds each season over the past several years. In Indonesia, the seed census was performed only in Lombok where a dedicated seed fishery exists. The total catch from 2008 through to 2013 was consistently around 600,000 seeds per year, however, it increased dramatically from April 2013 and was in excess of 5 million seeds over the past 12 months (to July 2014). In Vietnam, the majority (>75%) of seed are *P. ornatus*, with *P. homarus* making up the bulk of the remainder. In Indonesia, most of the seed captured are *P. homarus*, with *P. ornatus* the dominant component of the balance.

7.2 Identify sustainable lobster seed collecting areas throughout eastern Indonesia

Assessment and expansion of seed fishing in Indonesia was a successful activity that resulted in commercial seed resources being identified in South-east Sulawesi and Aceh, and the significant increase in seed captured in Lombok.

The initial concept was that where seed were available, a local growout industry might be established, but this has since been revised in accepting that locations where seed are abundant do not necessarily represent suitable growout locations. Even in Lombok, where seed availability now exceeds 5 million pieces per year, there is a growing acceptance that growout in the same villages where seed are captured is not viable. Translocation of the seed to sites in Indonesia where seacage aquaculture is well established may be a more successful model.

7.3 Develop improved puerulus collecting methods and handling to increase survival rates

The intention of the project at its outset was to conduct a series of field experiments to define best practice seed fishing methods applicable to Indonesia. Although one experiment was completed (examining the effect of light on catch), the capacity of the MADC staff to manage such experiments became a limiting factor. Nevertheless, project activities did lead to a significant increase in seed catch, primarily the effect of technology transfer from Vietnam to Lombok facilitated by the study tour conducted in March 2013. The challenge remaining is to improve the survival of those seed captured to ensure the maximum number persist through the first several weeks after capture to be suitable for on-growing. This will involve fine-tuning of capture methods and the handling procedures particularly at the point of capture and in the following 1-2 days.

7.4 Investigate genetic stock structure to identify sources and sinks for the settling seed as far as this proves possible

The population genetics component of the research was performed as part of a PhD research program of Dao Tan Hoc from Institute of Oceanography Vietnam, who conducted his PhD at James Cook University. Hoc was also responsible for the seed census in Vietnam, although this was transferred to other colleagues when Hoc moved to Australia.

The population genetics research revealed there was no structure to the populations of either *P. ornatus* or *P. homarus* within the Vietnam, Indonesia and Australian distribution, and that regular mixing of the stocks was apparent, facilitated by the widespread movement of larvae via ocean currents. For effective management of these stocks, this presents a significant constraint as they cross several independent international jurisdictions.

7.5 Optimise holding, transport and nursery conditions for newly caught post-pueruli and juveniles.

This objective was focussed on the nursery phase of lobster aquaculture. A series of experiments in Indonesia and Australia generated strong results enabling definitive recommendations for nursery management. However, there were difficulties in the conduct of some experiments in Indonesia that reflect the limited capacity the MADC staff had in managing such experiments. Those difficulties were countered to a degree by engaging University students in the experiments to provide additional skilled labour and experimental rigour. In the process, the capacity of MADC staff was also improved. Nevertheless, the body of research planned was not fully completed and knowledge gaps remain about aspects of nursery culture, particularly concerning diet and feeding strategy, and importance of shelter and grading.

7.6 Define environmental impact of lobster sea cage farming and the comparative contribution of pelleted feeds and trash fish

This objective was addressed through a large scale field experiment performed in Vietnam by the Institute of Oceanography. The experiment examined the relative impact of traditional trash-fish feeding compared with pellet feeding on production of lobsters and the environment surrounding the cages. The experiment ran for 15 months and generated robust data that confirmed the efficacy of pellet diets both for lobster production and reduced environmental impact. The challenges remaining are to refine the pellet formulation, stimulate the commercial feed companies to manufacturer pellet diets, to refine feed management practices and to encourage adoption of pellet use by farmers.

7.7 Lobster growout demonstration farms

Six demonstration farms were established during the project across four provinces in Indonesia. Those in Kupang and Sumbawa proved to be ineffective due to a lack of supply of lobster seed, and in hindsight had been established too soon, before seed availability was confirmed. The other four were operated effectively for a reasonable period, although the operators engaged did not strictly follow the best practice management procedures conveyed to them. Consequently, none persisted to the end of the project. The concept of the demonstration farm approach to extend best practice lobster farming management is sound, but must involve operators who consistently follow the recommended practices. For future demonstration farms it's advisable to staff them with salaried operators who are incentivised to comply with the recommended methods.

7.8 Comparative assessment of pond-based growout in Vietnam

Assessment of earthen shrimp ponds as production systems for lobster growout was made in Vietnam. Early indications were positive, revealing the robustness of tropical lobsters and their amenability to the environment. However, wet season rainfall that was much greater than anticipated, led to salinity reductions that were lethal. Salinity of between 35 and 25ppt is tolerated by *P. ornatus*, although with reduced feeding and therefore growth, and salinity below 25ppt for any extended period is lethal. Given the lack of control of salinity in earthen pond systems exposed to wet season rainfall, and the necessity to grow lobsters for more than 12 months (i.e. through at least one wet season) to reach acceptable market size, such systems are not suitable for lobster production.

Project resources assigned to this objective were subsequently redirected to assessment of lobster production in tank systems, where greater control of the environment including salinity was possible. These resources were bolstered with additional funds through FIS/2011/008, and the results of the tank assessments presented in the final report for that project.

7.9 Lobster growout field trials in Australia

This research complemented that reported above for Vietnam, in examining lobster growout in commercial prawn farm conditions in Australia. Using existing ponds at Pacific Reef Fisheries near Ayr in north Queensland, *P. ornatus* lobsters were subjected to a series of growout experiments. As per the Vietnam experience, preliminary results were encouraging, but wet season rain that was much greater than expected over a brief period, caused a significant salinity drop that proved lethal.

Although there was some consideration given to pond covers and other methods to ameliorate salinity fluctuations, on balance it was concluded that such pond systems are not a viable option for lobsters.

In Australia where lobster farming is currently non-existent, the production systems recommended are sea cages or tank systems.

7.10 Practical diet formulation and feeding strategies

This research comprised tank-based experiments in Australia and Indonesia primarily with post-puerulus lobsters to define a diet formulation that could be made with local ingredients and that supported acceptable growth and survival. The research also examined aspects of feeding strategy including feeding frequency and ration.

Significant progress was made in defining effective formulations but there were limitations. In Australia the main limitation was the low availability of small lobsters to use in experiments, which constrained the number of experiments performed. In Indonesia, the main constraint was the quality of experiments, impacted by lack of experience and capacity of the project associates involved. By the end of the project, suitable formulations had been defined for both *P. ornatus* and *P. homarus*. It was concluded that for the nursery phase, such diets be of a semi-moist consistency in noodle pellet form with 2mm diameter, and they be fed in two portions daily, representing 70% of the ration fed in late afternoon and 30% fed in the morning.

The next step in perfecting pellet diets is to collaborate with commercial Aquafeed companies to adapt the lab-based formulations to commercial manufacture.

7.11 Scoping lobster growout opportunities in indigenous communities

The project completed a scoping study in November 2010 that confirmed the potential for Indigenous Australian communities to grow lobsters in a land-based system. Specific sites within the Yarrabah community were identified as suitable for the establishment of a pilot lobster growout enterprise. Facilitated through engagement with Jaragun Pty Ltd, broad community consultation was completed, including support from Council and the traditional owners. A young traditional owner was chosen for training, to become the operator of the proposed pilot lobster production system. Due to unforseen cultural issues, the traineeship was not successful and the trainee returned to the community without the required capacity. Further, business analysis revealed the permitting requirements (both State and Federal) to establish the proposed pilot system were too onerous and expensive to justify any further action. For such a project to proceed, issuing of necessary permits would need to be simplified and made much cheaper, and training should be performed with a group within the community.

7.12 Develop economic models of farmed lobster in Indonesia, Vietnam and Australia

Bio-economic models for lobster aquaculture in Vietnam and Indonesia were generated and published (Petersen, Phuong, 2010; Petersen*, et al.*, 2013). For Vietnam, lobster farming was revealed to be a viable business with manageable risk, relatively low capital cost and moderate operating costs, and strong upside potential due to increasing demand and market price. For Indonesia, modelling revealed lobster farming to be only marginally viable due to the high cost of credit, small harvest size and poor productivity. A hypothetical model for lobster production in Australia in a land-based tank system was generated, indicating that the high labour and capital costs in Australia would need to be offset by much more intensive production than has previously been achieved.

7.13 Review current status of lobster disease threats and related ongoing investigations in Vietnam with a view to developing an appropriate project response which complements active National and industry supported programs

A lobster disease information audit was completed in Vietnam by appropriate aquaculture health specialists (see the associated Symposium Proceedings (Jones, 2015)). This audit provides a comprehensive summary of the diseases and health issues facing lobster farming. A national response to lobster disease in Vietnam was made via a workshop held in November 2009, and since then lobster disease has been of less concern. In Indonesia, milky disease is prevalent, although its importance has been overshadowed by the significant reduction in lobster growout.

7.14 Develop understanding of sustainability indicators that affect the successful development of the lobster industry in eastern Indonesia and Vietnam

The sustainability indicators for lobster farming were defined in regard to seed capture, nursery production and growout. These indicators include bio-physical, economic and social factors.

For seed capture, sustainability is difficult to ensure, based as it is on natural factors. Key data collected include the census data for both Vietnam and Indonesia (Lombok only) which now comprises 7 consecutive years in Vietnam and 5 for Lombok including total

catch, species composition, seasonality, location and price. For Vietnam the data suggest some stability with catch consistently between 1 and 3 million seeds per year for the past 5 years. It appears that the resource is fully exploited and no further expansion is likely. In Lombok, the catch had been steady at 600,000 seeds per year until mid 2013, when it increased dramatically to more than 5 million. The increase is attributed to improved catch technique facilitated by the study tour to Vietnam, and to increased effort. Further expansion of catch is possible including new areas in Lombok, and in other Provinces.

Sustaining the seed catch through conservation of the source breeding populations is unlikely to be achievable as the population genetics research revealed that the lobsters (both *P. ornatus* and *P. homarus*) in Vietnam, Indonesia and Australia are from one homogeneous population, and the location of the broodstock producing the seed captured is unknown. It is clear that the source broodstock for both Vietnam and Lombok seed resources is unlikely to be local, as in both instances the populations of adults are very small. Modelling of the dispersal of the larvae, given the protracted development time (4-6 months) and oceanic distribution, suggests settling seed may come from breeding up to several thousand kilometres away.

Improving the sustainability of lobster production involves achieving greater survival and growth rate of the seed available, through to harvest. Primary variables in such achievement are nutrition, improved through the development of formulated pellet diets, husbandry – particularly handling of seed, provision of shelter and regular grading, and lastly health management. Data on each of these factors were generated to provide clear recommendations for best practice, although there are still knowledge gaps that future research will need to address.

Baseline data on the nutrient footprint of typical lobster farming in Vietnam were collected from the pellet vs trash-fish field experiment that will provide a foundation to determine carrying capacity for future industry planning purposes.

Sustainability of lobster production was also examined through bio-economic assessments. In Vietnam, where lobster farming is mature, the economics are attractive involving moderate capital and operating costs, and strong profitability. Analysis suggests that introducing pellet diets will provide even greater profits. In Indonesia where lobster growout is very new and capacity of farmers under-developed, the economics are marginal at best due to very high cost of credit and poor productivity.

7.15 Deliver community-based training courses/workshops to assist communities to establish lobster grow-out and adapt best management practices

Peer-to-peer transfer of knowledge and skills can be a powerful process and particularly effective in a village-based industry like that of lobster farming in Lombok, and especially when the practices are new and developing. In order to facilitate the meeting and mixing of lobster farmers in Indonesia, an industry development workshop was conceived to bring together the project associates with lobster farmers and government officials to enable presentation of project results and open communication among farmers. The first of these, held in Lombok in 2011, was well attended, providing an effective forum for farmer interaction and generated great enthusiasm to repeat these annually. The Ministry of Marine Affairs and Fisheries which was represented by the Director General Aquaculture at the initial workshop, committed to providing budget support to coordinate future workshops and support participation from stakeholders from other provinces. A second workshop was held in 2012 and a third in 2014 in association with the international lobster aquaculture symposium. These workshops are likely to become an annual event with the agenda largely driven by industry.

7.16 Develop science-based training in experimentation at Balai Budidiya Laut Lombok (BBLL) with BBLL staff and students from University of Mataram (UNRAM) that develop their skills and address knowledge gaps in lobster feeding and husbandry

During the first 12 months of the project, experiments examining aspects of nutrition and husbandry were performed at MADC facilities at Sekotong in Lombok. The results of these experiments were compromised by several factors including limited capacity of the staff involved and conflicting duties. A potential solution was conceived which proposed that students from University of Mataram might bolster the experiment program at MADC while providing mutual benefit to them in the form of real-world experience and training. Top ranking, third year Science students from UNRAM were given the opportunity to participate in the experiments to ensure the experiments were performed with rigor, and they in turn had access to data that the used to prepare a scientific report. To maximise the value of the students limited time (i.e. in blocks of 10 weeks), intensive experiment programs were developed where several experiments were performed in parallel. Australian project associates Scott Shanks (DAFF), Simon Irvin (CSIRO) and Nik Sachlikidis (DAFF) were involved in the lead up and start of experiments and in the final harvest and data collation. In this way, they provided training in experiment design, establishment and management, nutrition and husbandry of lobsters, data collection, collation and analysis and report writing. This training applied to both the University students and to MADC staff.

Such intensive experiment programs comprising multiple experiments at MADC were held on six occasions involving MADC staff, University students and the project associates from Australia. By project end, thirty one students from 4 Universities had participated and developed significant capacity in experiment design and lobster biology. Two students continued to Masters studies. Although application of MADC staff to experiments was less than expected due to conflicting work commitments, those involved developed their skills and there was progressive and compounding improvement.

7.17 Develop and trial innovative extension and technology transfer practices that assist communities to consider lobster grow-out as a new enterprise.

Establishment of an annual industry development workshop for the primary benefit of farmers was a product of the project. The three industry development workshops held in 2011, 2012 and 2014 were well attended and effective. Engagement of DGA to continue to coordinate these workshops in future is a significant outcome.

During the course of the project two project associates undertook study in Australia to improve their skills and expertise. Bayu Priyambodo was awarded a JAF to undertake a PhD at UNSW on lobster farming technology adaptation and extension. He has made good progress and will complete in 2016. Dao Tan Hoc from Institute of Oceanography in Vietnam was awarded an Australia Awards Scholarship to study for a PhD on lobster genetics at JCU. He has now submitted his thesis.

Extension materials concerning lobster aquaculture were developed in Indonesia, although they need revision in line with developing and changing best practices.

The engagement of University students in the experiment program at MADC provided opportunity to extend lobster farming technology across Indonesia. Students gained considerable knowledge about lobster farming methods and opportunity that they can transfer to their respective home villages.

The study tour to Vietnam (see 7.19) had the most effect of any project activity in assisting industry development. The impact has been seen most noticeably in Lombok in the lobster villages where there has been a marked increase in community participation. Smaller scale but significant effects have occurred in Aceh and South Sulawesi.

7.18 International lobster aquaculture symposium

This symposium was conceived to provide an end-of-project meeting and workshop that would enable all key project participants to come together to present results from all project activities. It was held on April 22/23 2014, along with a field trip to lobster farms on April 24th and an industry development workshop on the 25th. Thirty-one oral papers were delivered representing all research conducted through the life of the project, and perspectives on industry development constraints and opportunities. There were 91 registered participants representing Indonesia, Vietnam, Australia, New Caledonia and USA, including the current and two past Directors General Aquaculture. A Proceedings of the Symposium was prepared to be published by ACIAR that provides comprehensive and detailed presentation of the results and outcomes of the project.

7.19 Study tour of Indonesian farmers to Vietnam

A study tour of Indonesians to the Vietnam lobster farming industry was made in March 2013. Four lobster farmers from Lombok, South Sulawesi and Aceh participated, along with 5 government staff representing provincial fisheries agencies from Lombok, South Sulawesi, Aceh and from DGA Jakarta. In addition, Bayu Priyambodo (BBLL staff) a current JAF PhD student studying at UNSW attended as part of his PhD research. Project leader Dr Clive Jones led the tour and Dr Le Anh Tuan from Nha Trang University was the host. A Vietnamese – Bahasa Indonesian translator also participated to provide direct translations. A comprehensive program was delivered over 7 days comprising morning visits to the various sectors including seed fishing, nursery culture, growout, various farming communities and markets. Participants appeared to gain significant, detailed knowledge and all were enthusiastic to return to Indonesia to apply their new knowledge.

Expectations that the study tour would have significant impact were met with an increase in seed catch directly attributable to improved techniques arising from the study tour. Seed catch in Lombok increased dramatically within 1 month of the study tour being completed, and within 12 months, the annual catch was up by more than 800%.

7.20 Prepare a lobster aquaculture production manual

The lobster farming production manual planned to be delivered within the project was to be based on a revision and combination of two documents, one in Vietnamese prepared in 2009 by Nha Trang University and the second in Bahasa Indonesian prepared in 2011 by Marine Aquaculture Development Centre Lombok Indonesia, both of which provided a synopsis of farming practices in the respective countries. Neither were formal publications, but internal reports. Despite best efforts it was not possible to have them fully translated to English (by the authors) to form the foundation for the manual. The dates for publication proposed – initially April then December 2014 were based on premise that an English version of the two earlier documents would be available to facilitate a reasonably straightforward task of revision. It became apparent that the authors of the earlier documents were dissatisfied with the quality of those documents and they had insufficient time to translate them. Discussion of the manual at the Symposium in Lombok in April 2014 suggested the best approach would be to write the manual from scratch. It is now proposed to continue this task within a new follow-on project.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Lobster farming has long been sought throughout the world, because of the high value of the product, whose development has been curtailed by the complex nature of the biology and technical demands of producing the seed lobsters. The collection of naturally settling seed for on-growing has also long been considered, with no significant development because of sustainability concerns. Less than 20 years ago, Vietnam established the world's first substantial lobster farming industry based on wild caught seed, which quickly grew to a significant level. Improving sustainability of this industry in terms of the wild seed collection and the production practices was a core plank of the project. Comprehensive data were collected on the seed resources in both Vietnam and Indonesia, which have been in demand from other countries interested in emulating the success. Although there is now clear descriptive and quantitative data concerning the seed catch, fishing methods, species composition, seasonality and economics, generated by the research of the project, such data is not sufficient to enable resource management recommendations.

Population genetics research was also completed to understand the source and delivery of the seed supply to Vietnam and Indonesia. This research successfully demonstrated that the populations of *P. ornatus* and *P. homarus* (through identification of microsatellites and isolation of mtDNA genes) lobsters throughout the Southeast Asian region were of a homogeneous genetic makeup and mixing of the localised populations within each country occurs readily, facilitated by the long-lived larval stage being transported long distances by ocean currents. It appears likely that larvae spawned on the east coast of northern Australia can be deposited as far north as the Philippines, and larvae from there can be delivered to Vietnam and to Lombok in Indonesia. Thus, within the space of just 2 generations, the lobster populations of this broad region are mixed. These results have important value to the understanding of population structure and dispersal mechanisms for all other Palinurid lobsters worldwide.

The combination of seed resource data and population genetics, while informative and valuable to others contemplating the possibility of wild seed-based lobster aquaculture, does not enable effective, specific resource management recommendations to be made. The existing seed resource of Vietnam appears to be stable, albeit with substantial inter-annual variation in total catch between 1 and 3 million seed. In Indonesia, where the industry is new and growing, seed catch has been increasing significantly, particularly over the past 2 years. On-going collection of accurate annual statistics of seed catch will be essential to understand longer term trends and such information will be applied by others in the management of various lobster species throughout the world.

Most of the jurisdictions encompassing the populations of lobsters within the region of the projects' activities provide ineffective resource management programs for lobster fisheries. Catch, size and spatial restrictions are available and in some instances legislated, but there is no effective enforcement. Unless they can all agree and implement uniform management with enforcement, any effort to manage the lobster seed resource may be futile. This same dilemma is acknowledged for other lobster species, and there is strong interest in the findings of the project research, to apply it to the management of these other species.

Another sustainability measure examined by the project was that of environmental impact. Data generated by the sea cage growout experiment involving a comparison of pellet versus traditional trash fish feeding, revealed that pellet feeds can be equally effective for lobster production and will likely have a lesser environmental impact. This information will be of value to others seeking to establish lobster farming. Effective diet formulations were

developed which will provide useful scientific knowledge on lobster nutrition for the species studied and for others.

Scientific value was also gained from the development of a standardised lobster seed assessment technique, the 'tripod collector' that will continue to have benefit across Indonesia, Vietnam and potentially beyond as a simple tool that can be used to determine the availability and relative abundance of settling lobster seed for use in farming.

8.2 Capacity impacts – now and in 5 years

The most significant capacity impact was that generated by training and hands-on experience in the conduct of experiments performed at MADC Lombok. Both MADC staff and University students were engaged in these activities, which were primarily aimed at answering questions concerning the nursery culture of lobsters, and that had the additional benefit of building capacity of the people involved. It became evident early in the project that the MADC staff were not well equipped to conduct the type of experiments necessary to address questions about nutrition and husbandry of small lobsters. Their skills and duties as per the intended purpose of MADC, were more developed for technology extension and industry development. It became apparent that most staff had no knowledge of or experience with small-scale, replicated and carefully managed experiments. To build such knowledge and experience for the benefit of the research required by the project, and for more broad application in future, a series of intensive experiment programs were performed led by various Australian project associates, and involving theoretical background in regard to lobster biology, experimental design and planning, and then execution of experiments, collecting and collating data, basic data analyses and reporting. To bolster these activities and ensure on-going support over periods of 10 to 15 weeks, students from the Mataram University in Lombok were invited to participate. These students were 3rd year Bachelor of Science students, nominally the best performing students selected by the Head of Department, and who were individually very motivated by the opportunity and who would gain benefit by using the experience to prepare a report necessary as a component of their 3rd year assessment. Thus there was mutual benefit to MADC and the University students. Four such intensive programs were performed over the duration of the project, involving some 10 MADC staff and 31 students from 4 different universities. Two students subsequently progressed to study for their Masters.

During the course of conducting the experiments at MADC as described above, the research facilities for such experiments were greatly improved. A sea cage system of small cages was established, although damaged by storms, and a tank-based system of small cages was also established, which will have on-going benefit for future research.

Capacity impacts for lobster farmers were also significant as findings from the project research were extended to them through the normal extension practices of the MADC Lombok. To focus and optimise extension of research findings, the project also facilitated the establishment of an industry development workshop, aimed at farmers. The first was conducted in 2011, and subsequently 2 more have been held, with increasing involvement of the DGA and the farmers themselves in the planning and delivery. These workshops have proved effective in gathering farmers together, who might otherwise have no interaction, in a forum where practical information is presented and common issues are discussed.

Significant lobster farmer capacity improvement was also evident from the conduct of the study tour to Vietnam in March 2013. The dramatic increase in lobster seed catch which began in April 2013, is attributed to the knowledge gained by the farmers on the study tour. Other benefits in knowledge and capacity of the farmers involved are likely and are the subject of specific assessment by JAF Fellow Bayu Priyambodo who is examining this as part of his PhD studies.

In regard to specific academic impacts, two project associates enrolled in post-graduate courses. Firstly, Dao Tan Hoc, a staff member of the Institute of Oceanography in Vietnam, enrolled at JCU for a MSc to study the population genetics of lobsters. He subsequently upgraded to a PhD, completed his research and submitted his thesis in October 2014. He has two papers now published from the research with another 2 in preparation. Secondly, Bayu Priyambodo from MADC Lombok was successful in being awarded a JAF, and is currently conducting his research at UNSW. He is due to complete in 2016.

The project also provided capacity impact through support of the post-JAF research of Dr Hoang Do Huu from IO Vietnam, who conducted an experiment examining effect of pre-biotics to the diet of small lobsters. This research was very effective and led to a publication (Do Huu and Jones, 2014).

The project sought to establish a pilot lobster growout operation at an Australian Indigenous community that would include building operational and physical capacity at the Yarrabah community near Cairns. Although an Indigenous trainee was engaged for training purposes, the exercise was unsuccessful due to cultural issues. Nevertheless, the learning from the experience was that lobster growout could be a viable business at an Indigenous community and that training would be best performed within the community, and involving a group of trainees.

Capacity in lobster biology, farming technology and associated research was built within the post-graduate students at Nha Trang University who were involved in the project activities. Their knowledge and skills will have on-going benefit as they apply them to further studies and to professional duties in Vietnam. Associated with the NTU research was the establishment of new research facilities for tank-based production of lobsters. These facilities represent a substantial increase in capacity to conduct such tank-based aquaculture research.

Similarly, the project associates at IO Vietnam who were involved in the sea cage field experiment appeared to gain new knowledge and skills in the design and conduct of such experimentation. This will have flow-on benefits to their professional activities.

8.3 Community impacts – now and in 5 years

At the outset of the project, lobster farming had only been established in the southeast of Lombok adjacent to 3 villages – Awang, Gerupuk and Telong Elong. There were around 200 households involved. By 2014, 17 villages were involved, comprising more than 500 households. Nearly all activity in these communities is now restricted to lobster seed fishing, with lobster growout negligible. Nevertheless, men women and children all play a part in aspects of the industry.

Beyond Lombok, lobster seed fishing and limited growout was also established in Aceh, South Sulawesi, Sumbawa, East Java and Southeast Sulawesi. There are more than 1,500 households involved in various communities in these provinces.

As demand and price for seed lobsters continues to grow, it is anticipated that growth in the number of households involved will continue at 10% per annum or more.

In Vietnam, the number of coastal communities involved in lobster farming has been static through the period of the project. Nevertheless, the sustainability of the industry has been improved through project outcomes in regard to advocating for pelleted diets to supplement and ultimately replace trash fish feeding, which in turn reduces disease prevalence, improves environmental impact and increases profitability. In this respect, the communities have benefited, and this benefit will flow forward and likely be more significant in five years time, and beyond.

The assessment of tank-based aquaculture of lobsters in Vietnam revealed positive prospects for this alternative production system. With limited opportunity for increased sea

cage culture due to availability of suitable sites, competing demands particularly from tourism and increasing government restrictions, land-based culture of lobsters in tanks represents opportunity to expand the industry. Although very few commercial tank farms exist at this time, the knowledge generated by the project will likely benefit communities in the future as tank farming of lobsters becomes established.

8.3.1 Economic impacts

Economic impact was most significant for the lobster fisher / farmers of southeast Lombok. As an outcome of the project, seed capture was increased from an annual total catch of around 600,000 seeds to more than 5 million. The increased volume also stimulated increased opportunity for export to other countries where lobster seed were in demand for established lobster farming operations – particularly Vietnam. This increased demand was reflected in an increased price per seed, rising from IDR 2,000 per piece ($A0.20) to IDR 18,000 per piece ($A1.80) between 2012 and 2014. The economic value of seed fishing therefore increased from $120,000 to $9 million per annum.

In parallel to the increased lobster seed fishing effort and catch, there was a decrease in grow out of lobsters, as the participants focussed all their attention to seed sales. The growout industry had reached a total production of around 50 tonnes in late 2012, worth approximately $1.5 million. This has diminished to less than 25 tonnes with a value of around $1 million. Market price for farmed lobsters from Lombok has increased from $30 to $40 per kg.

Although household incomes were not specifically assessed by the project, it is clear from the interactions with several individual farmers, that disposable income has increased significantly, and many more households have become involved in the lobster industry over time.

The reduction in lobster growout was an unexpected negative consequence of developments over the duration of the project. Although the smallholders catching and selling seed, and avoiding growout are well justified in their actions which reduce risk and ensure a steady income, at a broader level the community is missing out on potentially much greater income from the much higher value of consumption size lobsters. Concern over this development was highlighted at the 2014 Symposium in Lombok where government representatives raised the prospect of a ban on lobster seed export to ensure the full value of the resource was retained for the benefit of Indonesia. There is clearly a role for ACIAR in this, to support the smallholders to on-grow the lobster seed captured, and maximise economic impact. Such support will comprise defining appropriate production technology and ensuring its adoption by the farmers.

8.3.2 Social impacts

Social impact has occurred in Lombok and to a lesser extent in Aceh, South and Southeast Sulawesi, where lobster farming activities have established and expanded. Over the course of the project, more communities have become engaged, and households that previously gained their income from fishing or other activities now gain the bulk of their income from lobster seed fishing and/or growout.

Lobster seed fishing has become a lucrative livelihood, and to maximise income, households have engaged all family members in the various activities involved. Women and older children are routinely involved in the fabrication and repair of the seed capture materials, the sorting of the seed on land in preparation for sale, and in the fishing activity directly.

The village of Awang in southeast Lombok provides a good example of the community social impact. This village was one of the first to establish lobster seed fishing and farming, from around 2004. Over time an increasing number of households substituted their existing livelihoods for lobster farming, and the whole village is now primarily a

lobster farming community. A similar impact is occurring in other villages in Lombok and is likely to occur in other provinces as the seed resources there are identified and exploited.

8.3.3 Environmental impacts

The capture of large numbers of newly settled lobster seed (pueruli) for purposes of farming raises immediate concern that such fishing will negatively impact the adult populations, that is, the practice is unsustainable. Project data however counters this in respect of the sustained catch of seed in Vietnam, now extending over some 20 years with no apparent decline, and the population genetics information generated which reveals the lobster populations (for the species studied – *P. ornatus* and *P. homarus*), are homogeneous across the entire regional distribution (Dao*, et al.*, 2013).

The long duration of the larval stage and its oceanic planktonic mode, confers a very large dispersal capacity. The prevailing ocean currents enable larvae spawned in Australia to be deposited in the Philippines, and from the Philippines to Vietnam or Lombok. Indeed it is likely that spawning by adult lobsters in any part of the regional distribution – from Taiwan in the north to Australia in the south, and from West Sumatra in the west to the Solomon Islands to the east, may result in pueruli being deposited several thousand kilometres away. Dao Tan Hoc (Dao*, et al.*, 2015), through studies within the project, suggests that there are primary pathways for larval dispersal corresponding with main oceanic currents within the region. However, these are just primary pathways, and there may be many other subsidiary pathways available through the many eddies and sub-currents known to exist. Thus Lombok or Vietnam or indeed any other settlement site in the region, may receive seed spawned from several widely disparate adult populations.

The impact of seed fishing must be considered on a regional basis, and unless agreement can be reached across all the jurisdictions, and a universal suite of resource management regulations implemented, managing the resource is fraught. Given that adult populations of *P. ornatus* in Vietnam and of *P. homarus* in Lombok are in relatively low abundance, it appears likely the local adult populations are not directly linked to the seed settlement. Identifying the spawning populations that deliver the seed to Vietnam and Lombok may be impossible to determine. Regardless, the seed resources are not likely to contribute significantly to those spawning populations, and the low natural abundance of adults in the vicinity of the seed populations suggests natural survival to adulthood is low. Thus, the capture of the seed for managed growout represents a negligible impact on the environment and a net gain to the volume of large lobsters available to the market.

The direct physical impact of lobster seed catching devices and of growout farms (floating sea cages), appears to be negligible other than from an aesthetic perspective. The floating frames used for both seed fishing and lobster growout are fabricated from natural materials (primarily bamboo) with some use of styrofoam floats. The frames are anchored to the sea floor with steel anchors or concrete moorings, the impact of which does not extend beyond the immediate location where the anchor or mooring is embedded.

Feeding of lobsters for the growout phase is potentially of significant negative environmental impact, as excess nutrients are released from uneaten food. Estimates by Le Anh, Jones (2014) suggest that in Vietnam the nitrogen released from lobster farms is between 150 and 410 g/kg of lobster produced, generating a total input of nitrogen of between 225 and 615 tonnes per year. The sea cage experiment conducted by IO indicates that pellet feeds can substitute for trashfish and will reduce the wastage and environmental impact significantly.

In Indonesia, where lobster growout production is small, the environmental impact is correspondingly small. To minimise such impact now and for the future, there has been a strong emphasis through the project's extension activities to promote use of pelleted feeds.

8.4 Communication and dissemination activities

During the course of the project 47 oral papers were presented concerning project data and activities at 6 international conferences. They are listed in the List of Publications 10.2 below.

The project also generated 6 published papers in peer reviewed scientific journals and a further 10 magazine papers and reports. These are detailed in 10.2.

Three annual workshops were held comprising all key project participants, with 2 of these convened in Indonesia (2011, 2013) and one in Vietnam (2012).

An Indonesia Lobster Aquaculture Industry Development Workshop was arranged in Lombok in 2012 with express purpose of involving and informing lobster farmers. A further two such workshops were then held in Lombok in 2013 and 2014.

An International Lobster Aquaculture Symposium was convened, taking place in April 2014 in Lombok and representing an end of project meeting. A Proceedings of that symposium was published by ACIAR (Jones, 2015).

9 Conclusions and recommendations

9.1 Conclusions

The opportunity to establish a significant and sustainable lobster farming industry in Indonesia is strong, but several obstacles must be overcome for it to be realised. Significant lobster seed resources have been confirmed, particularly in Lombok, where more than 5 million seed were captured in 2014. This is between 20 and 50% higher than the entire Vietnam industry, which generates 1,500 tonnes of on grown lobsters for export markets, valued at more than $A100 million and engaging more than 4,000 smallholder households. It is therefore realistic to project that Indonesia could produce this level of production or more, and provide livelihoods to thousands of people in coastal communities throughout Indonesia.

Currently, the bulk of the lobster seed captured in Indonesia are exported providing a positive benefit to the communities involved, but a far lower benefit than would be conferred if those seed were on grown to consumption size suitable to premium seafood markets. It was concluded that the Indonesian small holders involved in lobster seed fishing are averse to the on-growing due to perceived risks and lack of necessary knowledge. Definitive production technology appropriate to these farmers must be generated and extended to them. This must involve better understanding of social and economic factors concerning the farmers to better customise the technology and its transfer.

Sustainability of the Vietnam lobster farming industry will be improved through the adoption of pelleted feeds. While appropriate nutrition information and pellet formulation data was generated by the project to achieve this goal, uptake by commercial aquafeed companies has not occurred, ostensibly because of the relatively small volumes involved. Further communication to aquafeed companies will be necessary to stimulate their involvement.

Establishment of lobster farming in Australia is not imminent, neither as a diversification for existing aquaculture businesses, nor for Indigenous communities. Sea cage production is likely to be the most cost-effective system for production of lobsters in Australia, but remains unacceptable to the authorities responsible for providing permission. Pond-based production of lobsters is not viable, but tank-based production may be a viable alternative to sea cage production. Further research and development will be necessary to generate tank production technology. As Australia is unlikely to support capture of naturally settled seed, hatchery technology must be commercialised to establish the necessary seed supply. The availability of commercial hatchery technology appears to be 5 to 10 years away.

9.2 Recommendations

To address the obstacles to the further development and expansion of lobster farming in Indonesia, a new project is recommended, with emphasis on technology transfer and improved understanding of socio-economic drivers and roadblocks. Such a project proposal was presented to ACIAR during the preparation of this final report and has since been approved.

Indonesia should prohibit or regulate the export of lobster seed to other countries to help facilitate greater grow-out production within the country for export of premium market lobsters.

Further research and development is necessary to gain greater return for each lobster seed captured, including improved capture methods, handling and transport to maximise

quality and rigour of the seed, and enhanced culture practices to maximise survival and growth through the nursery phase.

Lobster farming industry development activities should be broadened beyond the localities where lobster seed are captured. This may include; engagement with existing sea cage aquaculture operations throughout Indonesia to encourage their involvement in lobster farming, identification of optimal lobster growout locations across the entire archipelago, and marketing the business credentials of lobster aquaculture to attract corporate investment.

Vietnam should actively promote the production of pelleted feeds and encourage adoption by farmers to reduce environmental impact, improve production and profitability and to ensure greater sustainability.

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