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Spiny lobster aquaculture development in Indonesia, Vietnam and Australia

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Spiny lobster aquaculture development in Indonesia, Vietnam and Australia

Proceedings of the International Lobster Aquaculture Symposium held in Lombok, Indonesia, 22–25 April 2014

Editor: Clive M. Jones

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Cover: Farmed juvenile lobster (*Panulirus homarus*) ready for stocking to grow out cages. (Photo: Dr Hoang Do Huu)

Foreword

In April 2014, the Australian Centre for International Agricultural Research (ACIAR) co-sponsored, with the Indonesian Ministry of Marine Affairs and Fisheries, a Symposium in Lombok Indonesia, as a forum to present findings from the project SMAR/2008/021, to discuss constraints and opportunities for the developing Indonesian lobster aquaculture industry and to identify key issues that further research might help to resolve.

At the time of the Symposium, lobster aquaculture in Indonesia was experiencing unexpected constraints in the face of great opportunity. Catch of seed had rapidly increased over the preceding 12 months to an extent that the catch then exceeded that of Vietnam where a large and successful industry was already established. However, the volume of marketable lobsters produced in Indonesia from that seed had shrunk from an already low base, as the small-holders involved chose to catch and sell seed, and to avoid grow out of lobsters. The reasons why were not clear, but what was clear is that Indonesia had opportunity to establish successful grow out, adapting and adopting technology from Vietnam, and expanding production to match or exceed that of Vietnam where in excess of 1,500 tonnes are produced with a farm-gate value of around US$100 million.

ACIAR's project SMAR/2008/021 involving collaboration between James Cook University, Queensland Department of Agriculture, Fisheries and Forestry, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Directorate General Aquaculture Indonesia (DGA), and Vietnam agencies; Institute of Oceanography and Nha Trang University, was commissioned to assist the establishment of a viable lobster aquaculture industry in Indonesia. Success was achieved across all aspects of the research and development activities, with the exception of increased production of marketable lobsters. In this instance, economic and social factors are playing as important a role as those of a biological nature. Further research and development will be necessary to understand and address these factors and to provide basis for efficient and viable lobster growout.

In order to rapidly and widely disseminate the research findings arising from the ACIAR lobster project, the International Lobster Aquaculture Symposium was held from April 22 to 25 in Lombok and provided opportunity to present all the research findings from the ACIAR project SMAR/2008/021. Two days of oral papers were delivered, a field trip was conducted to inspect lobster farming in Lombok, and an industry development workshop was held 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. There were 91 registered participants representing Indonesia, Vietnam, Australia, New Caledonia and USA, including the current and 2 past Directors General Aquaculture.

Nick Austin
Chief Executive Officer
ACIAR

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Note: the appendicies for this report are available separately for download at: http://aciar.gov.au/publication/pr145

Acknowledgments

I am grateful to the Australian Centre for International Agriculture Research (ACIAR) for their support of the research project and encouragement to organise and host the symposium to present the project's outcomes. Eleven agencies in three countries were involved in the SMAR/2008/021 research project, and in particular I would like to acknowledge: in Australia, the Queensland Government Department of Agriculture, Fisheries and Forestry (DAFF and formerly DEEDI and DPI) (the commissioned agency), Commonwealth Scientific and Industrial Research Organisation (CSIRO), Pacific Reef Fisheries (PRF) and Advanced Choice Economics (ACE); in Indonesia, the Indonesian Ministry of Marine Affairs and Fisheries' (MMAF) Directorate General Aquaculture (DGA); Marine Aquaculture Development Centre, Lombok (MADC); Brackishwater Aquaculture Development Centre, Ujung Batee Aceh (BBAP Ujung Batee) and Brackishwater Aquaculture Development Centre, Takalar, South Sulawesi (BBAP Takalar); in Vietnam, the Institute of Oceanography Nha Trang, Vietnam (IO); and Nha Trang University, Nha Trang, Vietnam (NTU). I also gratefully acknowledge James Cook University to whom the project administration was transferred for the final year.

The following people are acknowledged for their particular contribution to the project which ensured its meeting of objectives and delivery of outcomes, to enable this symposium to proceed:

At DAFF: Scott Shanks as the project's fulltime technician for his enthusiasm and commitment to research in Australia and Lombok, also to Nik Sachlikidis, Larnie Linton all of the DAFF Tropical Rock Lobster Aquaculture team for their contributions. I also thank Warwick Nash and the DAFF management team for their support.

At CSIRO: Special thanks to the late Kevin Williams (leader of the previous ACIAR lobster project FIS/2001/058) for his mentorship and support, along with David Smith and Simon Irvin who collectively provided specialist support for nutrition research.

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At NTU: Drs Le Anh Tuan and Lai Van Hung, and the NTU aquaculture staff and students who assisted with the lobster research.

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Special thanks to Kate Langford for technical editing of the papers and Peter Nolan for the graphic design and layout.

Finally, the project and symposium would not have been possible without the support, enthusiasm and commitment of ACIAR's previous Fisheries Program Manager, Barney Smith, the SMAR Program Leader, David Shearer, and most recently the new Fisheries RPM, Chris Barlow; thank you all.

Clive Jones
Editor

1. Introduction

Clive Jones[1]

Development of spiny lobster aquaculture is of increasing interest around the world, as demand increases and capture fisheries supply decreases. There have been two primary sectors of research and development activity: firstly utilizing natural settlement of lobster seed, and secondly developing hatchery technology. Ultimately the two sectors will merge when hatchery technology is fully commercialized and the price of hatchery-produced seed is equivalent to that of the natural supply.

This report provides a summary of information presented at a lobster aquaculture symposium held in Lombok, Indonesia, from 22–25 April 2014. The symposium represented the findings of the ACIAR project SMAR/2008/021: 'Spiny lobster aquaculture development in Indonesia, Vietnam and Australia', and identified knowledge gaps that require further research and development. The project had an industry development focus, and the Symposium provided an opportunity for input from research scientists, extension staff, government policy makers and managers, and lobster fishers and farmers to discuss industry development and identify key issues that further research could address to progress the lobster aquaculture industry's expansion and improved productivity and viability.

To maximise the opportunity, the Symposium was structured to include formal oral presentations (presented in English), a field trip to a lobster seed fishing and farming village, an industry development workshop (presented in Indonesian) and social events to encourage the most comprehensive exchange of information and ideas possible.

Oral papers concerning project research and activities were presented by project collaborators from Indonesia, Australia and Vietnam. Additional oral papers were presented to provide regional and global perspectives on lobster aquaculture from associates from New Caledonia and the USA. The papers were scheduled within five sessions encompassing lobster seed (puerulus) fishing, nursery culture, grow-out, industry development and other perspectives. A synopsis of significant findings, key issues and knowledge gaps was prepared for each session. This publication presents synopses of each of the oral presentations in summarised form.

The Indonesian lobster farming industry began in the early 2000s on the south-east of the island of Lombok as a secondary activity to seaweed and grouper farming. Small lobsters were frequently seen by the seaweed and grouper farmers, settling on the seaweed or cages, and farmers began retaining them for culture in separate cages. By 2005, there were several farmers solely growing lobsters and devoting more time and effort to catching the seed. By 2009, when the ACIAR project began, there was a small but discrete lobster farming industry with targeted fishing for the seed (puerulus stage) lobsters and dedicated grow-out farms. The total production and productivity levels of lobster farming in Indonesia were low relative to the well-established lobster farming industry of Vietnam. ACIAR sought to increase production and improve productivity through the research project summarised in this document.

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2. Seed Supply

2.1 Census of the lobster seed fishery of Lombok

Samsul Bahrawi[1], Bayu Priyambodo[1] and Clive Jones[2]

Introduction

Lobster aquaculture first began in Indonesia in the south-east of the island of Lombok, in West Nusa Tenggara Province (Figure 1). Here, lobster seed were first found and targeted fishing of them developed.

The objective of this research was to establish baseline lobster seed catch data for those areas around Lombok Island where seed were being routinely caught. The research intended to examine and collate data on total catch, localised catch, species composition, seed price and seasonality. The census was designed to be on-going to enable collation of long-term data to examine sector growth, inter-annual variability and trends that might assist in effective management of the resource.

In Lombok, lobster seed are typically fished by placing materials in the water column suspended from floating frames that provide an attractive shelter for the pueruli. The shelter materials used varies, but most commonly it is either rice bag material cut into strips and tied in bundles or cement bag paper which is folded to create multiple crevices.

Methods

For each of the main villages close to where lobster seed are caught (Figure 2), a seed census officer (1 person per location) was recruited and trained in the data collection method. The census officer recorded data once a week from interviews with the lobster seed fishers in their location. Data was recorded on a standardised form, and once these forms were completed, they were photographed and the images sent to the census coordinator.

Figure 1. Map of Indonesia showing the location of Lombok

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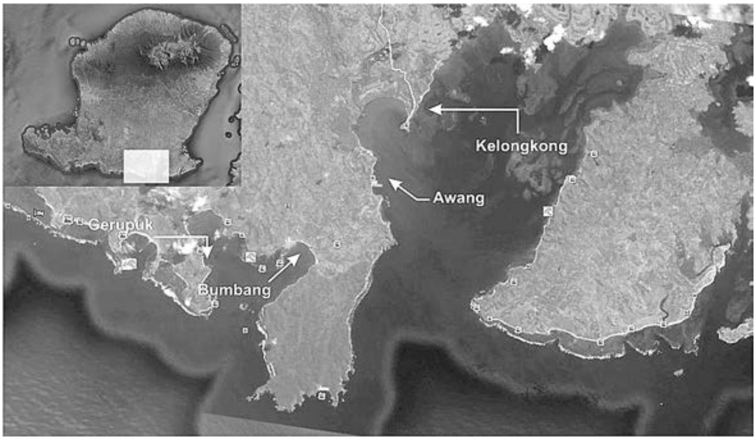

Figure 2. Locations in south-east Lombok for the seed census data collection. Gerupuk: 98 respondents, fishing began in 2004; Bumbang: 233 respondents, fishing began in 2003; Awang: 141 respondents, fishing began in 2000; Kelongkong: 47 respondents, fishing began in 2008

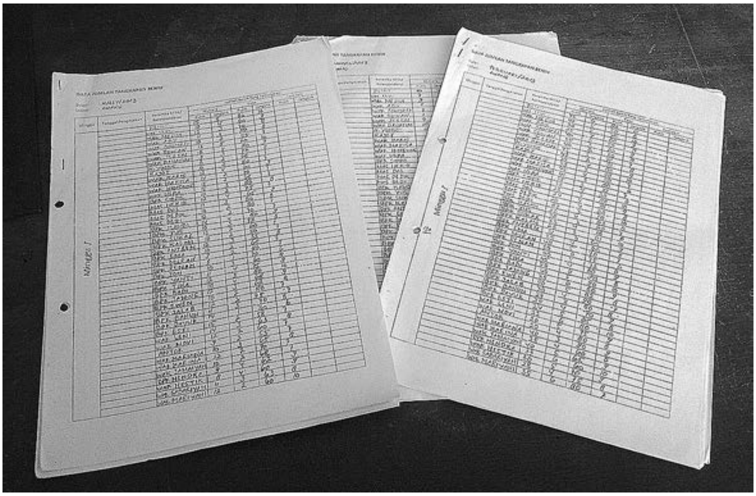

Figure 3. Examples of the census forms used by the census officers

Results and discussion

Seed census data has been collected since 2007. The number of lobster seed fishers contacted to gather the data and the total number of seed fishers operating is shown in Table 1. Over the period 2007 to 2014, data has been gathered from a minimum of 78% of fishers and up to 96% in any given year; thus providing a good representation of actual catch.

Census data confirmed that there are six species of lobsters represented in the seed catch comprising *Panulirus homarus, P. ornatus, P. versicolour, P. longipes, P. penicillatus and P. polyphagus*.

Total catch of all seed, based on census data, is presented for each year from 2009 in Figure 4.

Between 2009 and 2012 the annual number of seeds was relatively stable at 600,000 per year, however in 2013 the number of seed caught increased dramatically. This is attributed to: improved fishing techniques, including the use of lights to attract swimming pueruli; improved deployment of shelter materials; and improved positioning of catching frames within the bay. Increase in catch is also attributable to increased effort, with many more fishers engaged in lobster seed fishing since early 2013. The total seed catch for 2013 was in excess of three million pieces.

Figure 5 suggests a distinct peak in seed catch in the period May to July, with a possible secondary, but much weaker peak in November. By examining the catch data for 2009 to 2012 on a different scale (as shown in Figure 6) the same peaks are evident, although there is considerable inter-annual variability. We suggest that the peak in puerulus abundance in May to July corresponds with early summer reproduction and release of newly hatched phyllosoma larvae in mid-summer, around November to January in the southern hemisphere. This accounts for the five to six month larval duration for the tropical species caught. The secondary peak of puerulus abundance around November and December may relate to reproduction occurring in northern hemisphere stock, where breeding and release of newly hatched phyllosomas would occur around May to July. This contrasts with a distinct single peak in puerulus abundance in Vietnam from November to March.

Table 1. Number of seed fishers interviewed and total number of seed fishers operating each year from 2007 to 2014

Period	Number of contacted seed fishers / total number of seed fishers	Percentage contacted
07/08	245/269	91.1
08/09	287/305	94.1
09/10	309/332	93.1
10/11	315/357	88.3
11/12	387/402	96.3
12/13	408/526	77.56
13/14	484/556	87

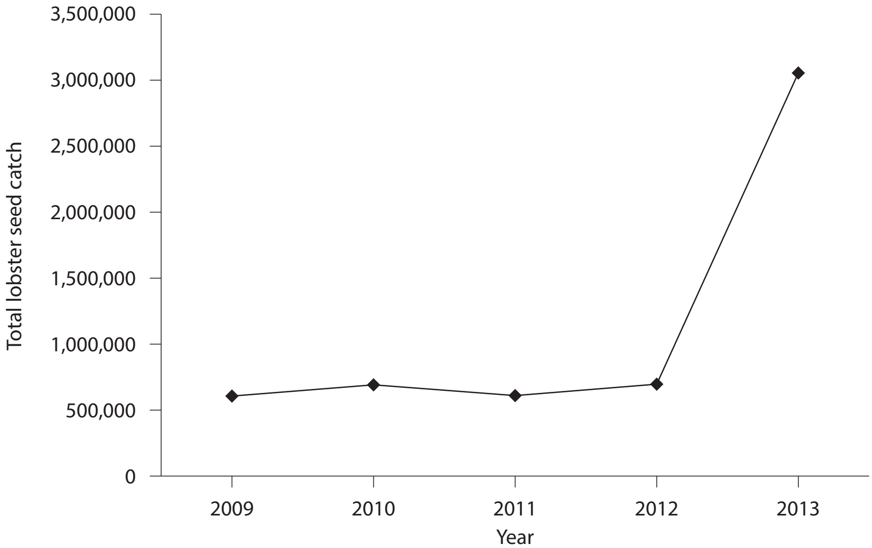

Figure 4. Annual total catch of lobster seed in Lombok 2009 to 2013

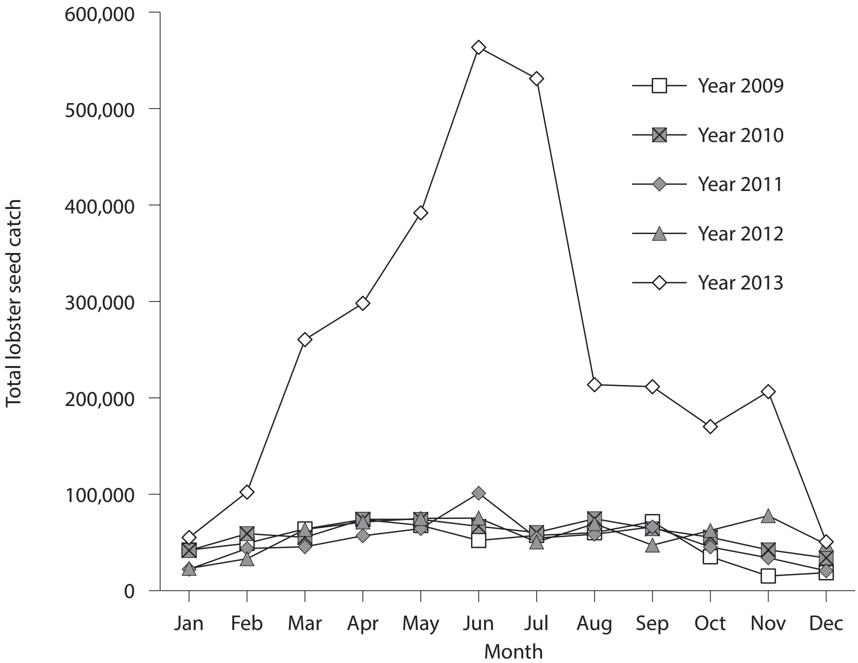

Figure 5. Total lobster seed catch by month for each year 2009 to 2013

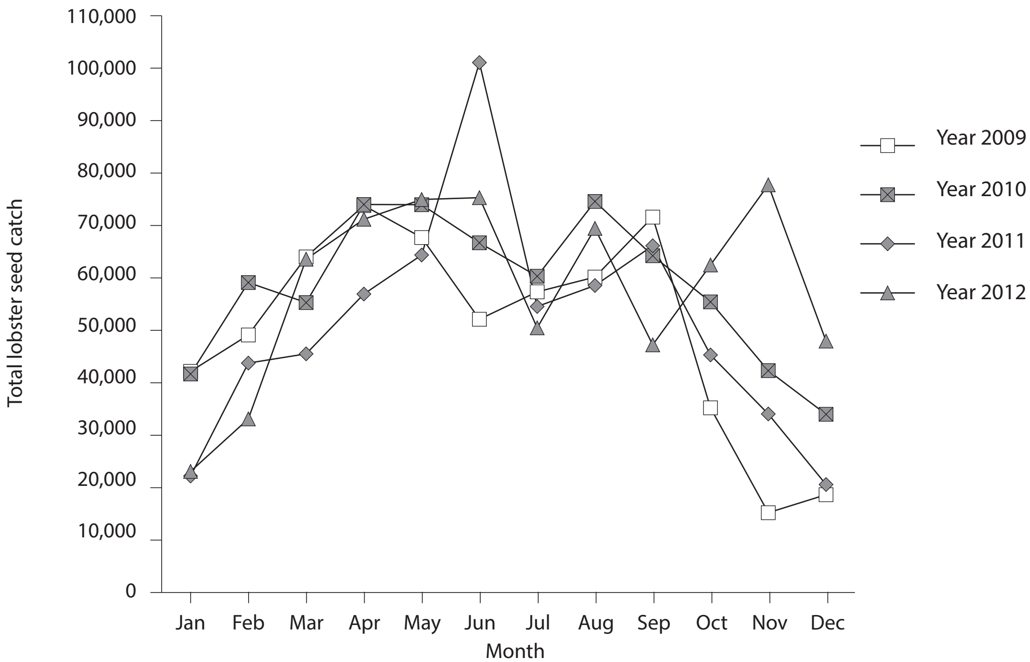

Figure 6. Total lobster seed catch by month for each year, 2009 to 2012 on a finer scale than in Figure 5

Within the lobster seed catch, there are two dominant species: *Panulirus homarus* and *P. ornatus* which account for more than 99% of seed caught. The species composition appears to fluctuate between years, and in 2012, 63.27% of seed were *P. homarus* and 36.73% *P. ornatus*, while in 2013 *P. homarus* represented 86.65%, and *P. ornatus* 13.35%.

Although lobster seed of both *P. homarus* and *P. ornatus* were caught throughout the year, the data for 2012 indicated two peaks, from April to June and October to November (Figure 7). In 2013, when catch rates were much higher, there was a more distinct peak in catch of *P. homarus* from May to July, and no discernable peak for *P. ornatus* (Figure 8).

Individual price for *P. homarus* seed in Lombok is illustrated in Figure 9 for each month of each year from January 2009 through to April 2014. The graph shows that the price from 2009 to 2012 was quite stable from IDR 2,500 to 5,500 (equivalent to US$0.21 to $0.50 each). In April to May 2013 the price decreased dramatically from IDR 5,500 to 2,000 due to the increasing supply of seed. However,

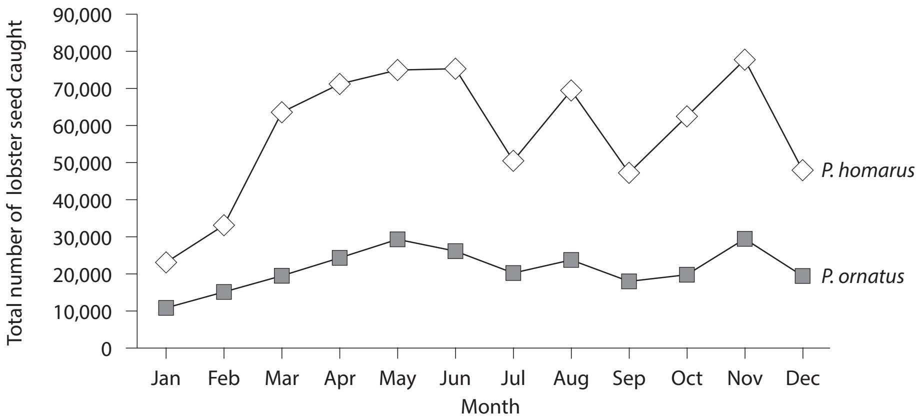

Figure 7. Lobster seed catch by month for *P. homarus* and *P. ornatus* in 2012

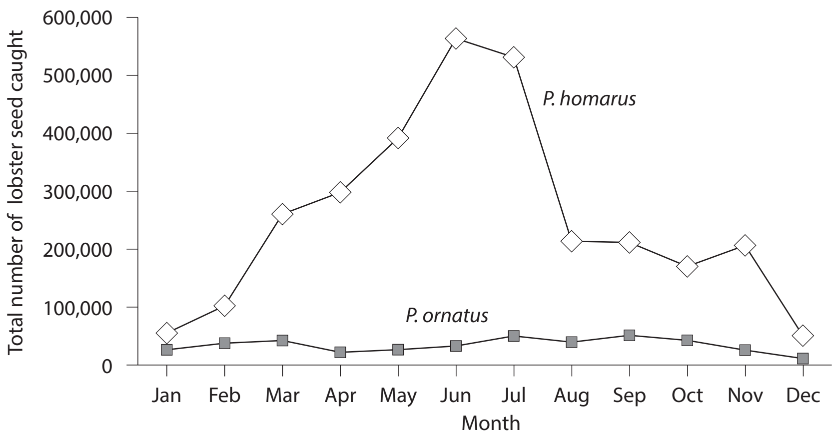

Figure 8. Lobster seed catch by month for *P. homarus* and *P. ornatus* in 2013

from June 2013 to April 2014, the price progressively increased to IDR 16,000 each (US$1.34) as demand also increased. Similarly, the price for *P. ornatus* seed was quite stable from 2010 through to early 2013 (Figure 10) at IDR 4,000 to 8,000 each, but has trended upwards since, to IDR 18,000 in April 2014. Although *P. ornatus* represents a relatively small proportion of the seed caught, and after grow-out is seldom distinguished from *P. homarus*, it fetches a small premium on *P. homarus* because it is perceived to be a more valuable species. Total revenue from both species in 2012 and 2013 is shown in Table 2.

In Vietnam, the relative price of seed for each species is much higher, and the price discrepancy

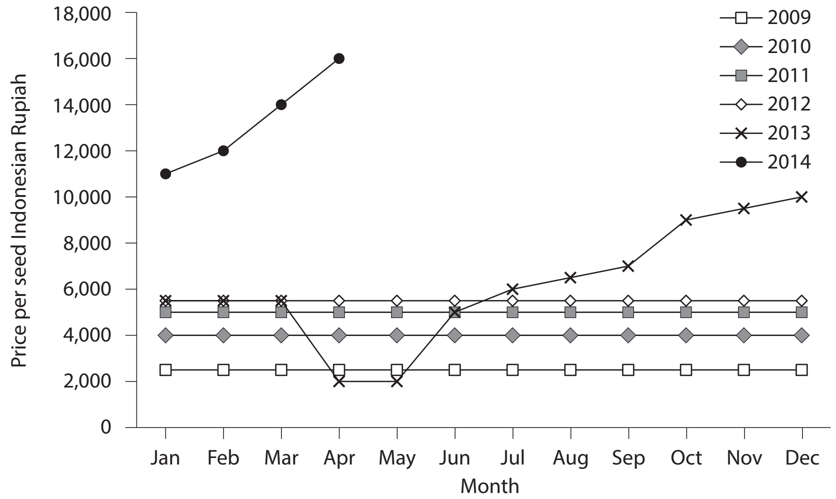

Figure 9. Monthly price for lobster seed for 2009 to 2014 for *P. homarus*

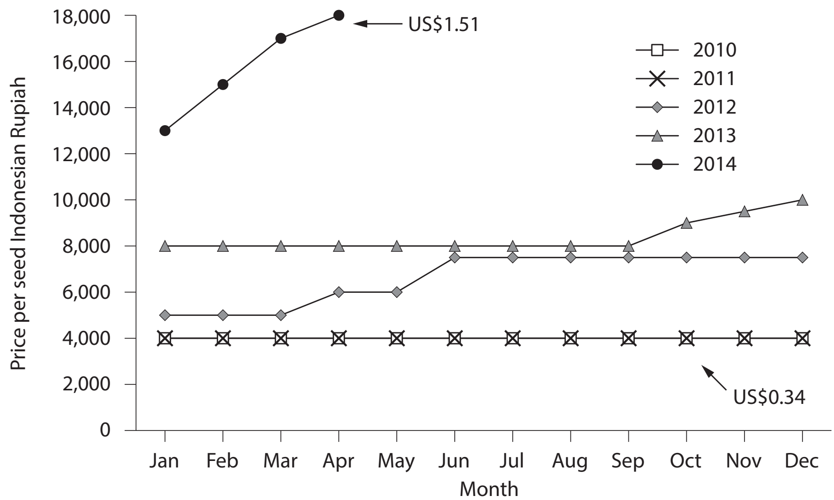

Figure 10. Monthly price for lobster seed for 2010 to 2014 for *P. ornatus*

between the two species is much greater, due to the more developed nature of the lobster farming industry in Vietnam and greater demand (see Chapter 2.2).

By the end of 2013 there were four new locations in south-east Lombok being fished for lobster seed; Batu Nampar, Saung, Ujung and Ekas, all within Ekas Bay where the pre-existing seed fishing areas of Awang and Kelongkong are located. Since late 2013, all these fishing areas use lights as part of their seed fishing method.

Conclusions and recommendations

Through conducting a monthly census of seed catch in Lombok, valuable data is being collected on the development of the fishery since 2009 which will be useful in determining a management plan for sustainable exploitation of the resource. The census should continue indefinitely, and include other locations as lobster seed resources are confirmed there. Long-term monitoring of the seed resource will help

Table 2. Total revenue from lobster seed trade in Lombok for 2012 and 2013

Species	Year	Total seed caught	Price (IDR)	Total Revenue (IDR)
P. homarus	2012	440,684	5,500	2,423,762,000
	2013	2,646,886	2,000 to 10,000	14,049,720,000
P. ornatus	2012	255,861	5,000 to 7,500	1,724,842,000
	2013	407,783	2,000 to 10,000	3,365,768,000

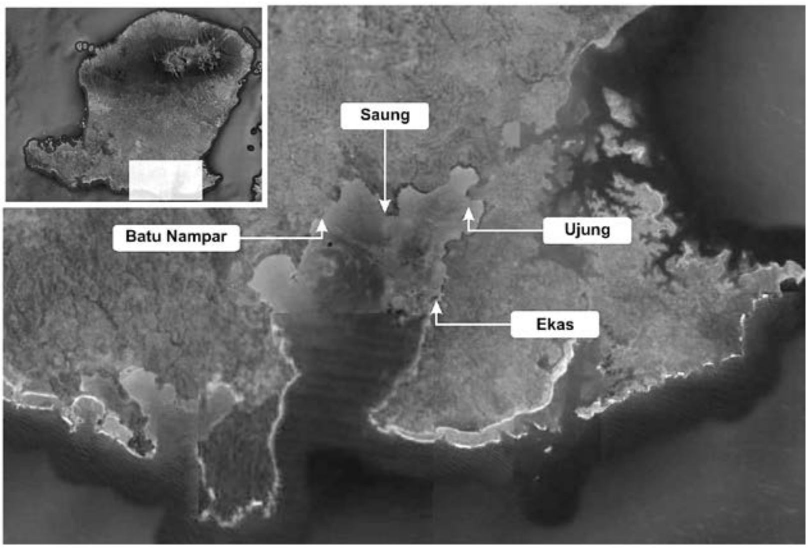

Figure 11. New areas of Lombok being fished in 2013. Batu Nampur: 80 fishers; Saung: 50 fishers; Ujung: 10 fishers; and Ekas: 80 fishers

to identify inter-annual variability and trends in catch per unit effort, and may be correlated with large-scale data on climate, oceanography and breeding stocks.

Further improvements in the accuracy and precision of data collected should be sought by identifying all seed dealers and ensuring their cooperation.

Further research is warranted to investigate and clarify the effects of light, depth and catching equipment on seed fishing in order to maximise catch.

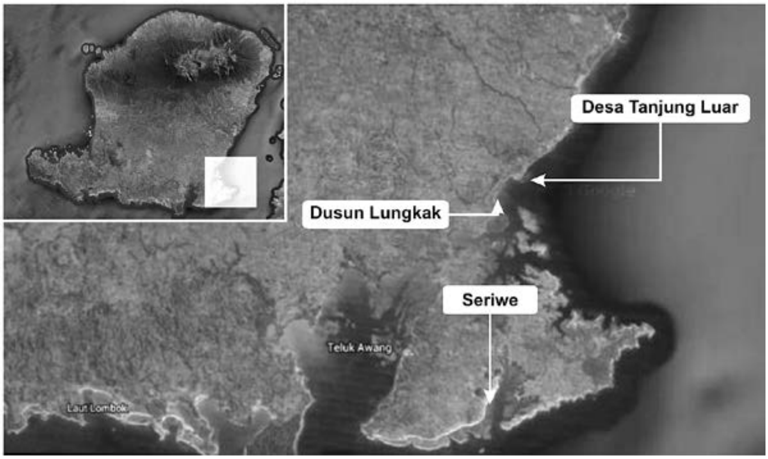

Figure 12. New areas of East Lombok being fished in 2014

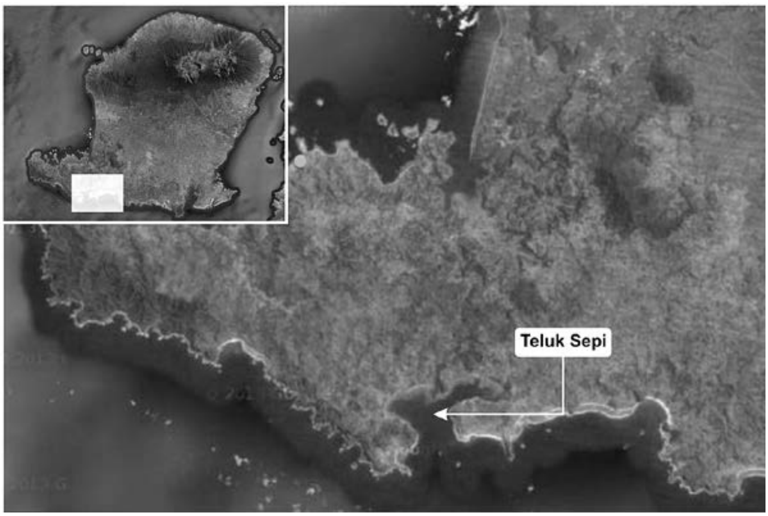

Figure 13. New areas of West Lombok being fished in 2014

2.2 Census of the lobster seed fishery of Vietnam

Hoc Tan Dao[1,2] and Clive Jones[3]

Introduction

Spiny lobsters are the world's most valuable crustaceans. Many countries have an interest in spiny lobster aquaculture but only a few have produced any farmed lobsters for the market due to difficulties in securing a supply of seed. The difficulty arises from challenges in culturing spiny lobster larvae from the eggs through to the puerulus, due to the protracted larval duration (from four months to more than one year) and technical difficulties in nurturing and sustaining them. At present, there is no commercial hatchery production of lobsters anywhere in the world.

Nevertheless, there is a significant lobster aquaculture industry in Vietnam, producing more than 1,500 tonnes of cage-raised lobsters annually. There is also a rapidly developing spiny lobster farming industry in Indonesia. Aquaculture in these countries is based on collection of naturally settling pueruli and juveniles.

Until a hatchery supply of seed can be established, the supply of naturally settling seed is very important for sustaining aquaculture production. Little is known about this supply, including the source and the impact of fishing. A first step in understanding the resource is to conduct a census to collect the catch data, with a view to establishing some form of fisheries management to ensure long-term sustainability.

This paper presents data from an annual census of lobster seed catch in Vietnam from 2005 to 2014.

Methods

As lobster seed are most abundant in the period from October through to April, two surveys were performed each lobster seed fishing season, the first in November and the second in April. These direct surveys were conducted each year from 2005/06 to 2010/11, after which data were collated by phone surveys with significant dealers.

Direct surveys involved a structured interview with dealers, i.e. operators who buy lobster seed from multiple fishers and on-sell it to lobster farmers. The interviews comprised examination of the dealers' logbooks. Photos were taken of the logbook pages and the data was later transcribed to a spreadsheet for collation and analysis. A typical logbook page is shown in Figure 1. The surveys also provided an opportunity to make qualitative assessments of the methods and equipment used by dealers for handling, storage and transport of lobster seed.

Results and discussion

Seven species of *Panulirus* were recorded among the seed catch in Vietnam, including two that were the most abundant, and for which detailed catch data were available: *P. ornatus* and *P. homarus,* and five less-common species: *P. versicolor, P. longipes, P. penicillatus, P. polyphagus and P. stimpsoni*.

Lobster seed were caught in seven central to south coast provinces from Da Nang to Binh Thuan (Figure 2). The catch season extended over six to eight months, from September/October to the following March/April. The provinces from which most seed are captured comprise Binh Dinh, Phu Yen and Khanh Hoa (Figure 2).

Techniques used to catch the seed were primarily aimed at catching swimming pueruli, and secondly at catching settled juveniles. For the pueruli, the methods comprised: i)set seine nets, positioned to intercept the swimming pueruli; ii) netting supported by floating frames, on which pueruli would settle; and iii) various habitat traps made from a variety

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Figure 1. Photo image of typical lobster seed dealers' logbook from Vietnam, showing date, price (for *P. ornatus* / *P. homarus*), boat / fisher and number of *P. ornatus* and *P. homarus* bought

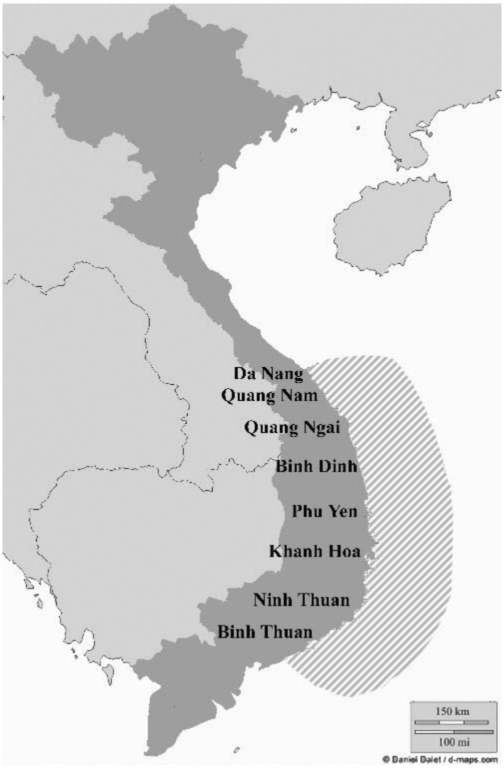

Figure 2. Seven coastal provinces of Vietnam where lobster seed are caught

of materials suspended in the water from floating frames. The majority of pueruli in 2014 were captured using the seine net method.

For the juveniles (i.e. post-puerulus stage, with pigmented body and functional mouthparts), the catching method comprised various habitat traps, designed to provide an attractive habitat for the juvenile lobsters to occupy. The three most common were: i) timber posts with small holes drilled in them; ii) coral rocks with holes drilled in them; and iii) netting bundles with multiple folds, edges and crevices within which the juveniles conceal themselves.

The surveys indicated that more than 95% of seed purchased by dealers were pueruli, and the remaining 5% were small (< 1 g) pigmented juveniles.

For the pueruli, the fishers would hold newly captured lobster seeds in small bottles filled with seawater but with no aeration. These pueruli were then sold to middlemen (dealers) each day, normally in the morning after fishing through the night. The dealers would gather the purchased seed together, storing them for periods of <1 to 3 days in tanks or larger storage containers (buckets, plastic bins) typically at the dealer's house before selling them to farmers. In most instances, the dealers provided no aeration or water quality management (filtration, additives) to the storage containers. Nevertheless, survival of pueruli through this phase appeared to be consistently high.

Analysis of the catch data over successive years showed large variation in total catch of lobster seed, especially for *P. ornatus* (Figure 3). The highest monthly catch was from November to February (Figures 4 and 5).

The price of *P. ornatus* seed between 2005/06 and 2010/11 ranged from US$3.00 to $9.00 each (Figure 6). The price per seed has continued to increase in more recent years with increasing demand, and in 2013/14 the price was US$12.00 to $14.00. The reduced catch of seed in 2006/07 and 2009/10 stimulated a higher price, and in 2007/08 a milky disease outbreak posed increased risk for farmers, coinciding with a large catch that year, which prompted a collapse in price.

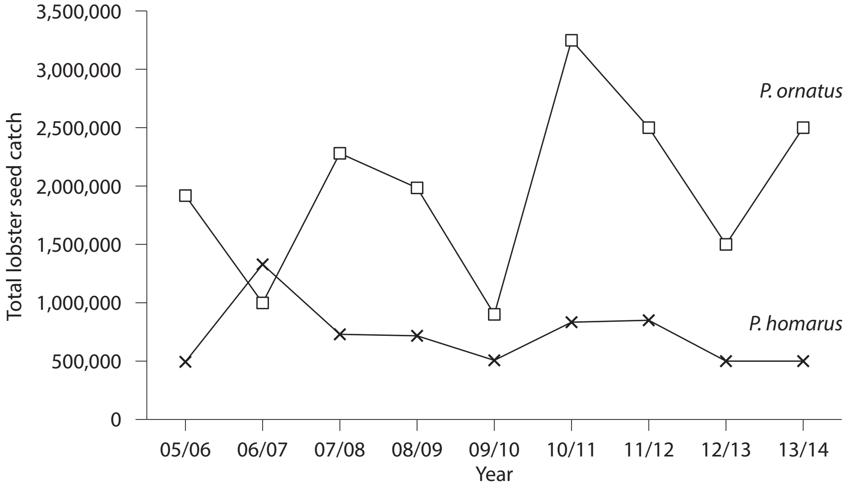

Figure 3. Annual catch of lobster seed in Vietnam 2005/06 to 2013/14

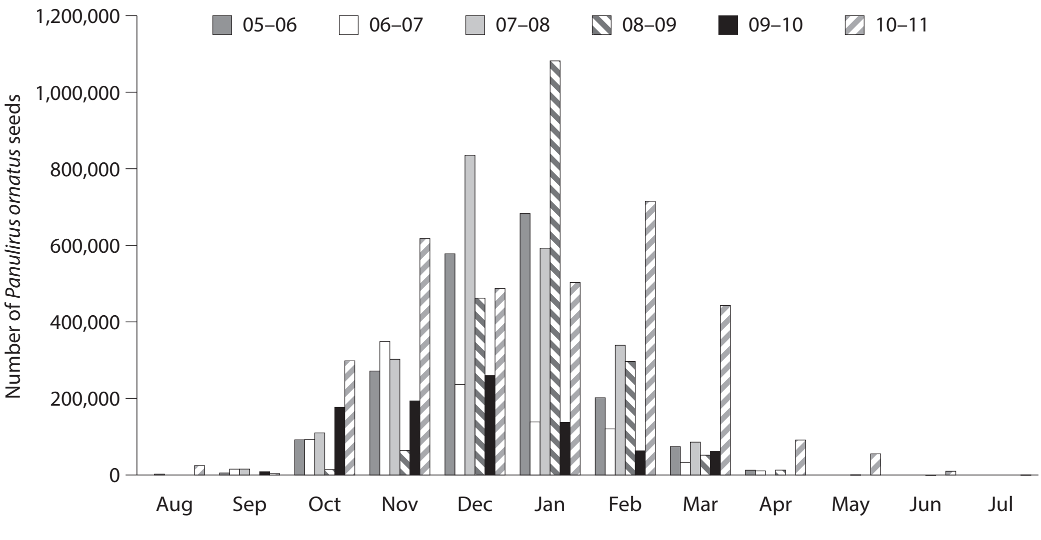

Figure 4. Monthly catch of lobster seed of *P. ornatus* in Vietnam 2005/06 to 2010/11

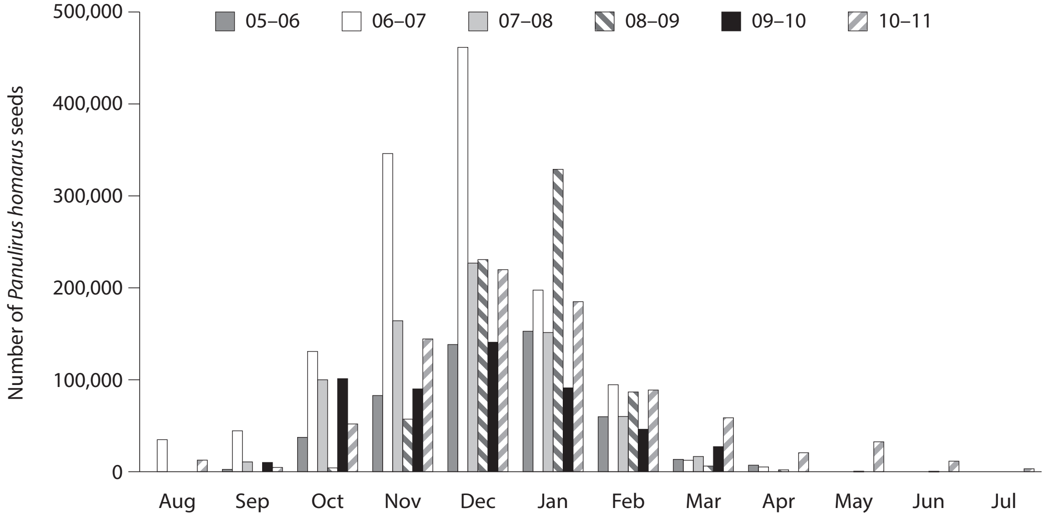

Figure 5. Monthly catch of lobster seed of *P. homarus* in Vietnam 2005/06 to 2010/11

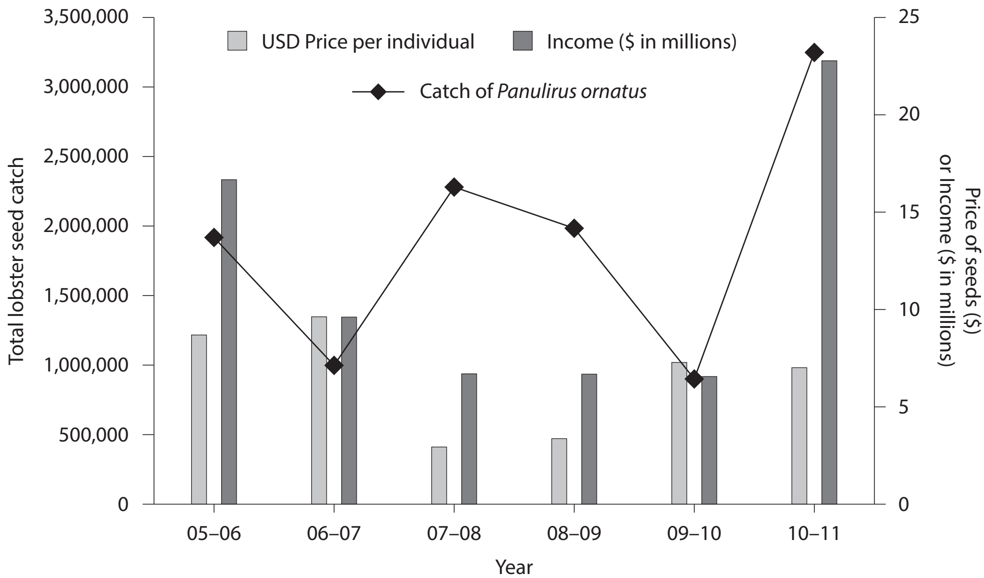

Figure 6. Total catch, revenue and price per seed of *P. ornatus* from 2005/06 to 2010/11

For *P. homarus* seed, the price between 2005/06 and 2010/11 ranged from US$0.60 to $2.40 each (Figure 7). After the 2007/08 milky disease outbreak, the price of *P. homarus* seeds increased steadily as farmers reasoned *P. homarus* lobsters were more robust than *P. ornatus* and less susceptible to milky disease. Although the basis for this assumption has not yet been proven, a higher number of farmers now actively seek to farm *P. homarus*, as the market in China has increasingly accepted this species as a suitable substitute for *P. ornatus*, reflecting an increasing market price for 800 g+ lobsters. Further, *P. homarus* is thought to grow faster than *P. ornatus*, reaching a marketable size in less time.

Table 1. Proportion of dealers interviewed to gather seed catch data

Period	Number of contacted dealers / total number of dealers	Percentage
05–06	71/81	87.7
06–07	94/97	96.9
07–08	97/97	100
08–09	99/99	100
09–10	101/102	99
10–11	114/114	100

Conclusions and recommendations

The fishery for lobster seed in Vietnam to support lobster farming is now well established. Although catches vary from year to year, there is no indication that the exploitation of the resource is unsustainable. As the economics involved are very attractive to poor coastal villagers, i.e. low risk to high return, the sector is likely to be fully developed with no more capacity. Annual catch of *P. ornatus* seed appears to be steady at between one and three million pieces per year, while that for *P. homarus* is steady at between 0.5 and 1 million pieces per year.

The increasing trend in price per seed has applied to both primary species, although the increase has been sharper for *P. homarus* in recent years. The price reflects ongoing increase in demand for on-grown lobsters by the Chinese market. Wholesale price for 1 kg+ *P. ornatus* was up to US$120 per kg in 2014 (see Chapter 5.9) and for *P. homarus* above 700 g, $80.00 per kg. These high prices for consumption-size lobsters have driven demand for the seed, with corresponding increases in seed price. Recent significant increases in supply of seed, particularly for *P. homarus* caught in Indonesia (see Chapter 2.1) and exported to Vietnam and elsewhere, may impact on seed price in Vietnam.

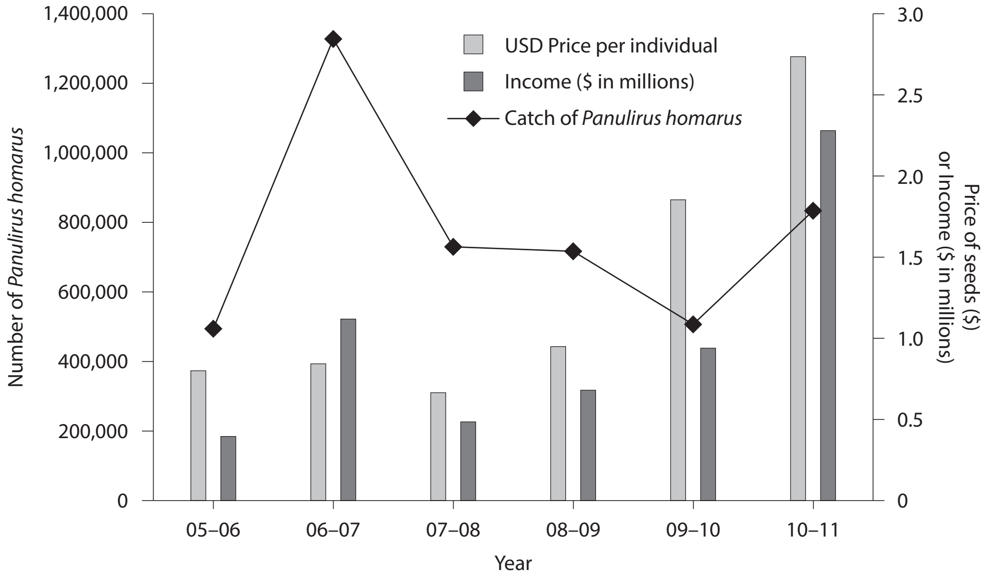

Figure 7. Total catch, revenue and price per seed of *P. homarus* from 2005/06 to 2010/11

Local fishers and dealers in Vietnam suggested there was a relationship between the variations in lobster seed catch and the pattern of seasonal winds, a proposition that is supported by the analysis of lobster seed catch and wind data from 2005 to 2011 (Dao et al. unpub. data). During this period, the number of lobster seeds of *P. ornatus* reaching Vietnam increased with increasing wind stress (Figure 9; $r^2 = 0.885$). *P. ornatus* larvae are found mainly within the well-mixed surface layer, i.e. the layer above the thermocline, which in the tropics is typically about 100m deep (Phillips 2013; Pitcher et al. 2005). Winds blowing over the ocean surface exert a stress on the ocean's surface that drives the surface layer (Fischer 1979; Marschall and Plumb, 2008) which is carrying the lobster larvae. As a consequence, the pattern of seasonal winds has a strong effect on the lobster seed catch in Vietnam. The correlation between recruitment of lobster species and seasonal winds has been documented for other lobster species. Westerly winds positively correlated with the recruitment of *P. cygnus* in Western Australia (Caputi and Brown 1993; Caputi et al. 2003; Caputi et al. 2001; Griffin et al. 2001). Similarly, seasonal onshore winds were shown to be important in the local retention of recruits of *P. homarus* and *P. penicillatus* in Java, Indonesia (Milton et al. 2014).

Further research is warranted on factors affecting puerulus settlement both at regional level (oceanic and weather patterns) and at fine level (coastal hydrodynamics and hydrographic variables).

Middleman with lobster seed

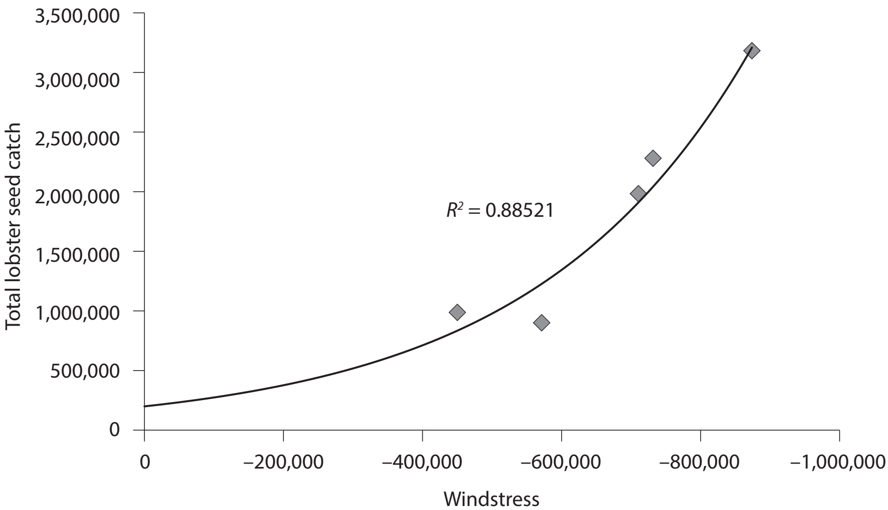

Figure 9. Variation of total wind stress and total seed catch of *Panulirus ornatus* during six fishing seasons in Vietnam from 2005 to 2011

Lobster farmer purchasing seed

Middleman facility for holding lobster seed

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2.3 Assessment and development of the lobster seed fishery of Indonesia

Samsul Bahrawi[1], Bayu Priyambodo[1] and Clive Jones[2]

Introduction

In addition to investigations into the already established fishery of the lobster seed resource in Lombok Indonesia, research was conducted to assess the availability of lobster seed in other parts of Lombok and other Indonesian provinces. The objective was to provide a quantified assessment of lobster seed resources at a range of sites through the application of a standardised seed-collecting device that would enable:

- assessment of the presence of lobster puerulus settlement at each location
- identification of the species available
- estimation of the magnitude of the puerulus resource in each area
- continuous monitoring of the lobster settlement each year to detect seasonal patterns and annual variations.

The ultimate aim of the research was to identify localised lobster seed fisheries that could be developed to supply seed for lobster farming. This paper introduces the lobster seed assessment and development activities across all of Indonesia, but should be read in conjunction with Chapters 5.11 and 5.12 that provide additional details of associated activities in Southern Sulawesi and Aceh.

Methods

From 2010 to 2013 an assessment of lobster seed availability was made at: Aceh Province (Simeulue Island and Breuh / Aceh Island); West Sumatra Province; West Nusa Tenggara Province; East Nusa Tenggara Province; South Sulawesi Province; Southeast Sulawesi Province; North Sulawesi Province and Maluku (Figure 1).

Sites were chosen based on the known presence / abundance of adult lobsters nearby (i.e. an established fishery) and in these areas, in bays where tripods would not be susceptible to strong wind and waves.

The method involved the use of a standardised collector, which was designed based on similar structures used in Vietnam. It is constructed from bamboo bound together with rope to form a rectangular frame with a tripod structure on top. The collector was designed as a sampling tool only and not for maximum catch or commercial purposes. This differs from the typical commercial lobster seed fishing equipment used in Lombok, which is described in Chapter 2.1.

The tripod design facilitated the attachment of a light (powered by either battery, kerosene or electricity) hung from the apex to aid in attracting pueruli. The design is illustrated in Figures 2 and 3. Styrofoam floats were bound to the base of the frame to provide flotation. Tripods were anchored in position using rope tied to an anchor of either concrete, rock or rice bags filled with sand. Each tripod was 2 m long and 1.5 m wide.

At each of the four corners of the frame, shelter traps were suspended on rope lines. On each line, there were two bundles of trap material, the first at 2 m depth and the second at 4 m. For two of the lines, rice bag traps were used, and on the other two lines, bundles of cage netting material. A unit of shelter consisted of two rice bags, with two units of rice bag and two units of waring (cage mesh) per tripod. Therefore 16 rice bags and 16 units of waring (cage mesh) were used per tripod. Four tripod collectors were deployed at each location with spacing of at least 25 m between each tripod in any direction.

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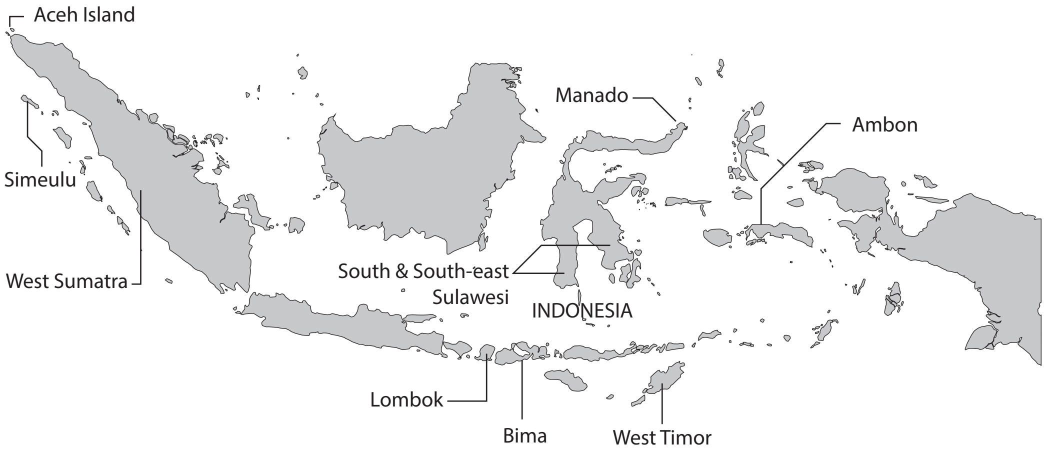

Figure 1. Map of Indonesia showing locations where lobster seed assessment activities were undertaken

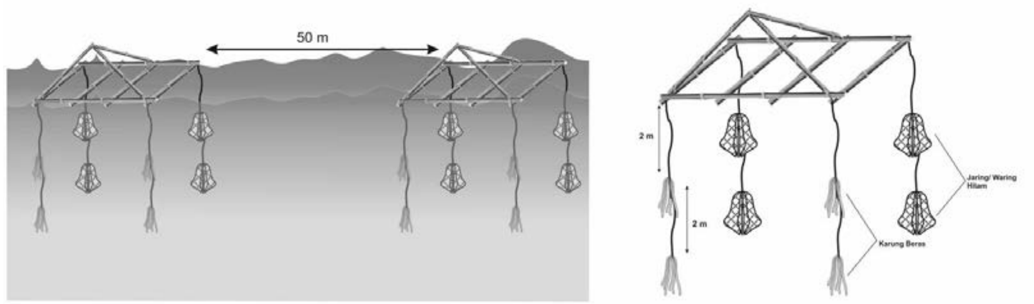

Figure 2. Illustration of the tripod collector for assessing puerulus availability

Once installed, the collectors were left for two weeks for conditioning before collection commenced. Seed collectors were then checked once every three days, and the number and species collected were recorded on a data sheet.

Tripods were left in place and monitored for a minimum of 12 months to account for any seasonal factors in settlement of pueruli.

Results and discussion

The total catch of lobster seeds by the standardised tripod collectors at the various locations is summarized in Table 1. At West Sumatra Province, Ampenan NTB, Bima NTB and North Sulawesi, no lobster seeds were found over at least a 12 month period.

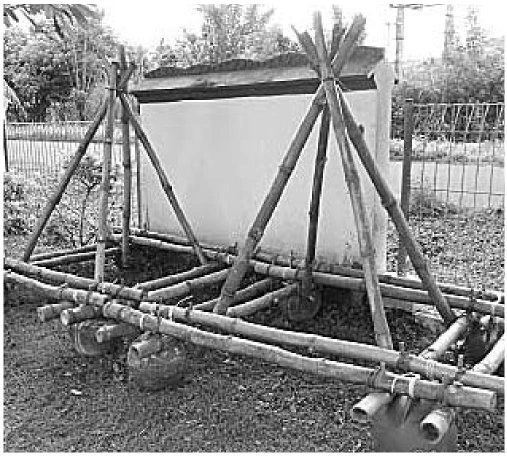

Figure 3. Photo of typical tripod collectors

On the island of Simeulue in Aceh Province, lobster seed assessment activity started in 2010, and although 19 tripods were deployed in three different bays (Teluk Dalam, Teluk Busung dan Teluk Sinabang, see Chapter 5.12), very few lobster seeds were found over two years. The area around Simeulue has well-established lobster fishing, with substantial catch of *P. penicillatus* and *P. versicolor* in particular. As in other locations, the presence of adult lobsters does not necessarily ensure presence of settling pueruli. Furthermore, the tripod collector used which has been confirmed as suitable for catching *P. ornatus* and *P. homarus* may not be suitable for the pueruli of these other species due to behavioural differences and different habitat requirements. It was noted that the three bays sampled were characterised by clear water with live coral at the bottom. This contrasts with conditions at Ekas Bay in Lombok where seed catch is very high, which is turbid with a sandy mud bottom.

Table 1. Total number of lobster seed collected with tripod collectors at locations throughout Indonesia; listed from west to east

Location	No. of Tripods	Year	Lobster seeds	Species *Panulirus*
Aceh Province				
Breuh / Aceh Island 5°41'51.5"N 95°04'10.2"E	6	2012	536	*P. homarus* and *P. ornatus*
Breuh / Aceh Island	6	2013	396	
Simeulue Island 2°38'26.5"N 96°01'24.1"E				
Dalam Bay	5	2010	No seeds	–
Busung Bay	5			
Sinabang Bay	4			
Desa Latak Ayah	8	2011	4	*P. homarus* and *P. ornatus*
West Sumatra Province				
West Sumatra Kampung Sungai Nipah Kanagarian Painan Selatan, Kecamatan IV Jurai, Kabupaten Pesisir Selatan	12	2012	No seeds	-
West Nusa Tenggara Province				
Ampenan Lombok 8°34'26.3"S 116°04'16.7"E	16	2012	No seeds	–
Sekotong Lombok 8°44'07.0"S 115°58'39.3"E	8	2010	No seeds	–
Bima				
Sape Bay 8°26'34.4"S 118°42'13.2"E	16	2010–2011	No seeds	–
Waworada Bay 8°43'09.2"S 118°53'08.2"E	8	2010		
Sanggar Bay 8°21'25.7"S 118°16'50.8"E	8	2011		
South Sulawesi Province				
Laikang Bay 5°34'14.7"S 119°29'24.9"E	28	2010–2012	45	*P. homarus* *P. versicolor*
Bone Bay	16	2011–2012	23	*P. versicolor* *P. ornatus*
Polewali Mandar	8	2012–2014	35	*P. versicolor*
South-east Sulawesi Province				
Labengki Island	–	–	–	–
North Sulawesi				
Desa Tumbak	8	2012	No seeds	–
East Nusa Tenggara Province				
Timor Island	24	2010	No seeds	–
Tablolong		2011	22	*P. ornatus*
Kupang 10°15'13.4"S123°28'28.8"E	12	2012	0	–
Maluku Province				
SeramTimur 2°48'23.9"S 130°23'17.3"E	12	2012	No seeds	–

Conclusions and recommendations

This program was ambitious in its expectation of establishing lobster seed collectors in numerous locations across the country, and being checked every few days over at least a year. The arrangements made with local Dinas staff or other collaborators dissipated over time, leading to inconsistent data collection. In particular, when catch rates initially were low or zero, there was decreased enthusiasm. In hindsight, it is recommended to have paid staff to maintain and monitor such sampling equipment.

The seed assessment activities also highlighted that different methods and equipment may be required for different species. The method applied is suitable for *P. homarus* and *P. ornatus* but may be ineffective for other species. Further, the habitat preference of seed lobsters may also differ between species, such that different habitat types may need to be explored to identify those that attract settlement. Further research is required to explore these knowledge gaps.

Despite some weaknesses in the program, seed resources that may be worth commercial exploitation were identified in Aceh and South-east Sulawesi. At the time of the Symposium, substantial exploitation of seed resources in both these locations had not occurred.

Overall, the seed availability in Lombok currently dwarves that from all other locations in Indonesia, and may in itself be sufficient to support a significant grow-out industry in the country. Further assessment of seed resources is of lower priority now, and emphasis must be placed on extracting maximum value from the confirmed and large seed resource at Lombok.

Figure 4. Photos of lobster seed collectors

2.4 Lobster seed fishing, handling and transport in Vietnam

Tuan Le Anh[1] and Clive Jones[2]

Introduction

In Vietnam, the lobster farming industry comprises distinct sectors, the first of which is the seed supply sector which includes the fishery for the seed and the subsequent handling, storage and transport of the seed to lobster farmers.

This paper describes the methods and equipment applied to the fishing and catching of lobster seed in Vietnam. Lobster seed fishing in Vietnam is primarily focused on the puerulus stage, which is a free-swimming stage, with equipment and methods developed to intercept them as they swim towards suitable habitat for settlement. Secondly, there are fishers who fish for small, juvenile lobsters that have already settled, and are therefore fished using different methods. Handling and transport of the seed is also described in this paper.

Lobster seed fishing

Seine nets in combination with electric light

The most common method for fishing of swimming pueruli involves the use of seine nets, typically 100 to 150 m in length with a depth of 4 to 6 m, and a mesh size of 5 mm. The nets are set from boats in a V-shaped deployment with an opening of around 25 m. The opening faces the direction from which pueruli are expected to swim (Figure 1). The direction of swimming has been determined by trial and error, and is typically in a southerly direction against a north-flowing current which eddies from the predominant southern flow of the Vietnam coastal current. Exceptions to this occur in some locations, and deployment of the seine is thus specific to each location. Common factors correlating with the abundance and catch of pueruli appear to be geography that facilitates a narrowing of the sea within a bay or between mainland and islands, and turbid waters as influenced by river flows in the area.

The boat used in the setting of the net is equipped with strong fluorescent lights with an intensity of 1,000 to 2,000 W. The boat is positioned at the apex of the V-net setting, with lights directed along the set net towards the opening, on the premise that the swimming pueruli are attracted towards the light. This premise is supported by catch rates that are much higher during the dark phases of the moon.

The seine net is usually set at about 8pm, and the first retrieval is made at around 12pm to 1am. At this time, the net is pulled up into the boat to retrieve the lobster pueruli which become caught in the mesh. Shortly afterwards, the net is set again and at around 4am it is pulled in for the second and last time. The nets are not set during daylight hours as catches then are very low, in accordance with the nocturnal swimming activity of the puerulus stage. The collected lobster seeds are consistent in appearance with a transparent body, carapace length of 7 to 8 mm and a weight of 0.25 to 0.35 g.

As per the seed census information presented in Chapter 2.2, the great bulk of lobster seed in excess of 95% are captured as pueruli using this method. Smaller numbers of juvenile lobsters are caught using the methods described below.

Traps made from netting material

A net trap consists of a bundle of netting material made by tying several lengths of fine 5 mm mesh size

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net into a rosette with a diameter of approximately 40 cm.

These traps are submerged in depths of 4 to 5 m around December every year.

The fishers retrieve the net traps at intervals of three to five days, usually in the morning, removing the lobster juveniles by shaking the trap into a scoop net. Lobster seed caught with this trap type are typically pigmented juveniles that have moved past the puerulus stage and settled to a benthic existence. They have a carapace length of around 7.5 to 10 mm, and a weight of 0.3 to 1.0 g.

The season for this seed fishing method extends from December through to the end of June, after which the traps are collected and stored ashore in a cool place for next season.

Traps made of perforated coral or timber

These traps are made from coral rocks and timber poles, into which holes are drilled to create habitat for juvenile lobsters. There is considerable variation in specifications, but typically the coral rock has a weight of between 2 and 5 kg and a diameter of 25 cm. Holes are drilled into the rock at 10 to 15 cm intervals, each hole is 5 to 10 cm in depth with a diameter of 1.0 to 2.5 cm. Timber pole traps are created in an equivalent manner. The poles are usually 2 to 3 m in length with a diameter of 10 to 15 cm.

The coral rocks are placed on the sea floor and the timber poles are embedded vertically into the sediment in 3 to 5 m of water, as per the netting traps described above. Juvenile lobsters are retrieved by diving and manually removing them from the holes. In some instances, these traps are suspended from a fixed floating raft or from a long-line supported between floating tripod frames. The tripods facilitate use of electric lights which enhance catch rates. This method catches settled juveniles of the same size as the net traps.

Diving and catching

This method is based on retrieval of juvenile lobsters from natural habitat, including coral and rocky reefs along the coastline. It typically results in the catching of somewhat larger juveniles compared with the methods described above. These juveniles normally have a carapace length of 12 to 15 mm and a weight of 7 to 9 g. The number of juveniles collected using this method is very limited, with approximately 100 to 150 animals caught by a crew of five people in a 10 day trip during the main seasonal months.

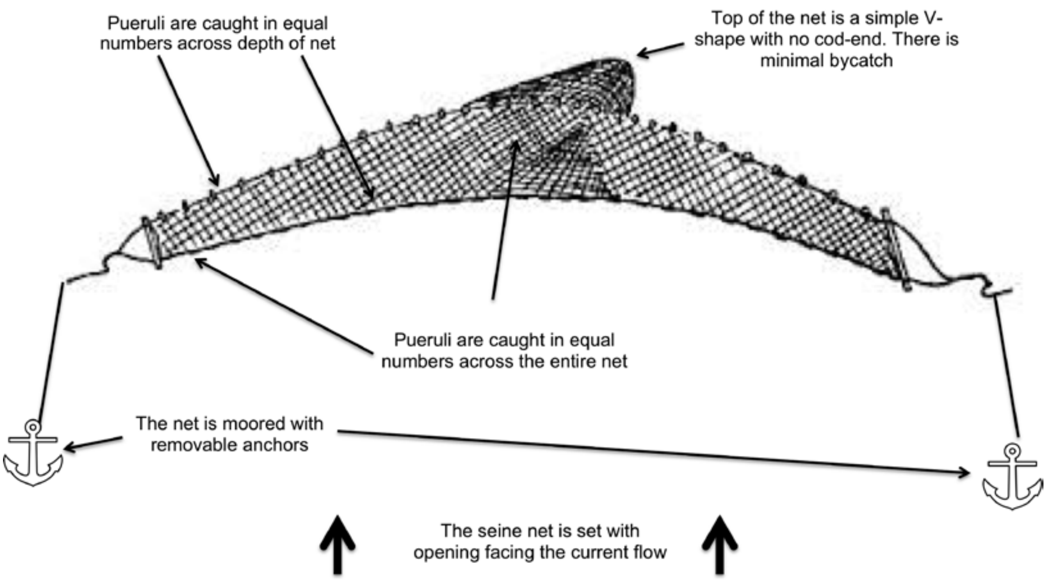

Figure 1. Illustration of seine net as used for capture of lobster pueruli in Vietnam

Lobster seed handling and storage

Pueruli fished by seine net are immediately placed in plastic bottles with a capacity of 4 L. Approximately 100 to 150 lobster seeds are held in each bottle, which is aerated by a battery-operated aerator. Typically the time spent in these bottles is between 5 and 12 hours, after which the pueruli are purchased by the lobster seed dealer and removed for storage or packed for transportation.

The juveniles captured with the trap methods and diving are also normally stored in plastic bottles or small containers, often without aeration, for brief periods until sold to dealers.

Dealers are motivated to hold lobster seed for the minimum time possible to minimise mortality. The period between purchase from the fishers and sale to the farmer is normally one to two days. Consequently, most dealers have some form of holding tank system, usually at their home. In most instances, these systems are primitive with little or no biological filtration, minimal water replacement and only basic aeration. Nevertheless, the survival of pueruli and juveniles in these holding tanks appears to be very high, and thus there has been little incentive for the dealers to provide more sophisticated systems.

Once a sale of seed to a farmer has been secured, usually through mobile phone communication, the lobsters are packed into small Styrofoam boxes for transport. The environment for the holding and packing of lobsters should be well away from direct sunlight. First, the seed lobsters should be separated from any other organic materials and waste, and seed should be of an equivalent size for packing. The lobster seed are placed into a plastic bag which is filled to one third of its volume with clean seawater, and the remaining two thirds with oxygen. Some pieces of fine-mesh net, which have been cleaned and soaked in sea-water for a few days, should be placed in the bag for the lobsters to cling to. The bag is then tied tightly and placed in the Styrofoam box. If ice is to be used, it is made with seawater in a plastic drink bottle, filled 90% then frozen. The frozen bottle is placed on top of the plastic bag in the box. The box is then sealed tightly, ready for transport.

In some instances, oxygen is not used, and in this case an aeration tube is supplied into the bag, connected to a portable, battery operated aerator.

Seed are normally transported by motorbike to the farmer.

Evidence from recent years suggests the mortality of newly purchased seed is consistently greater than 30% within the first several weeks after purchase. This may be attributed to latent physiological stress from the environment provided during holding and transportation. Consequently, there has been a shift to keeping lobster seed in sea cages, rather than tanks, until the day of shipment. Although this adds considerable cost, it is offset by improved condition of the seed, as evidenced by better survival in subsequent weeks.

Common industry practice is for *P. homarus* lobsters to be kept unfed for the day before transportation, while *P. ornatus* lobsters are fed prior to transportation. First stage juvenile lobsters are usually fed on *Acetes* shrimp, small/chopped *Penaeid* shrimp or finely chopped trash fish.

Conclusions and recommendations

The fishing of lobster seed in Vietnam is performed using four techniques: seine nets, net traps, coral/timber traps and diving. The seine net method captures swimming pueruli and accounts for more than 95% of seed captured. Seed are held by the fishers in plastic bottles of up to 4 L.

Lobster seed are purchased from the fishers within a few hours of capture, and then held in basic tank systems prior to being transported to farmers. Seed are transported in bags of seawater with oxygen or aeration, held in small Styrofoam boxes.

It is evident that mortality of lobster seed is low during the first few days after capture, but more than 30% die in the subsequent several weeks. To counter this, there is an increasing trend of holding seed in sea cages where the environment is more stable and conducive to better condition of the lobsters. Further research into lobster seed condition under various holding conditions is warranted to determine the optimal procedure.

Figure 2. Photos of lobster seed capture, handling and transport in Vietnam as described above (continued)

Figure 2 (cont'd). Photos of lobster seed capture, handling and transport in Vietnam as described above

2.5 Lobster seed fishing, handling and transport in Indonesia

Samsul Bahrawi[1], Bayu Priyambodo[1] and Clive Jones[2]

Introduction

The capture of lobster seed for the purposes of aquaculture has developed in Indonesia since the early 2000s, particularly since 2004 after the tsunami. The most well-developed area in Indonesia for lobster seed fishing is in the south-east of Lombok, particularly the villages of Teluk Awang, Kelongkong, Teluk Bumbang and Teluk Gerupuk where seed abundance is highest. These villages are characterised by fishing as the main enterprise, but are quite impoverished. The people, although poor, are innovative and have developed a wide variety of methods and equipment to catch the lobster seed.

This paper describes the equipment and procedures used by lobster seed fishers in Lombok for the capture, handling and transportation of the seed.

Lobster seed fishing

In general, the fishers manufacture their equipment themselves, using bamboo to make rectangular frames that are then equipped with Styrofoam floats. These frames are then positioned at a depth of 5 to 20 m and typically located 100 to 500 m directly out from the beach adjacent to the village. From the frames, habitat traps are suspended, such that they provide a refuge for swimming pueruli. Each morning, the traps are retrieved from the water and lobster pueruli found hiding in the habitat are removed.

Typical frame size ranges from 2.5 × 2.5 m to 12 × 12 m, with around 20 to 30 trap lines suspended from each frame. The habitat material used for the trap was initially (2005 to 2010) rice bags that had been cut into strips and bundled to create a rosette that contained multiple edges and crevices (Figure 1). These rice bag bundles are tied to a rope line at 1 m intervals, such that each line may have five to 20 bundles per line, depending on the depth. Thus, a typical frame may have 200 to 300 traps attached. The trap lines were typically set so that the terminal trap was 1 m above the sea bottom.

Since 2010, fishers have increasingly used recycled cement bag material to fashion habitat traps. Both rice bags and cement bags are very inexpensive, a necessary factor for the fishers involved, but the cement bags appear to support a better catch rate. In addition to a change of material, cement bags have been used to create a different style of trap. The bag, which consists of dual layers of plastic and paper, is folded concertina style and then tied across the middle to create a 'bow tie' like unit with multiple crevices. In this respect, the traps closely resemble the crevice collectors used in Australia and New Zealand for lobster stock assessment research (Booth and Tarring, 1986). The bow ties are attached to a rectangular piece of netting held taught by a timber frame, creating a wall of traps (Figure 2), that is then suspended from the floating frames.

Handling

The fishers usually check the traps every day, or for some who have other jobs, every two to three days, typically in the morning between 7 and 10am. Pueruli retrieved are placed into a plastic bucket or bowl with seawater, sometimes with seaweed or netting material to provide shade and a substrate to cling to. Puerulus are aggregated in these containers until all traps have been checked. They are then returned to shore for

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Figure 1. Photos of typical rice bag bundle traps used for capture of lobster pueruli in Lombok

Figure 2. Photo of cement bag bow tie style habitat traps as used for capture of lobster pueruli in Lombok

selling, or in some cases transferred to a nursery cage if the fisher also farms lobster.

Transportation

Prior to 2010, lobster seed were usually mixed with wet sand and then placed in a cardboard or Styrofoam box for transport. This dry method proved to be a poor approach that resulted in substantial mortality. In recent years, the typical practice has been to place the seed in a plastic drinking bottle or plastic bag that is then aerated with a battery-powered aquarium aerator, or into which oxygen gas is placed (Figure 3).

Figure 3. Photo of plastic bottle with battery aerator used for transport of lobster seed in Lombok

Transport to local grow-out farms in Lombok is typically very simple as the time required is relatively small. Increasing sales of lobster seed to dealers, who then export them to other countries, has seen the development of more sophisticated transport packing and handling methods, involving aeration or the use of compressed oxygen.

Conclusions and recommendations

The catching methods for puerulus in Lombok vary and continue to develop. Most lobster seed are caught using habitat traps that are made from rice bag or cement bag material fashioned into traps that provide multiple crevices. Lights are increasingly used (as in Vietnam) to attract the swimming pueruli to the trap frames. Catch of lobster seed appears to be greatest in the traps deployed close to the sea floor.

It is considered better to transport puerulus rather than small juveniles, as the pueruli appear to be more robust. Portable aeration is recommended when transporting the seed and dry transportation (in sand) is no longer practiced.

There is increasing competition among fishers, resulting in the deployment of frames further away from the village towards to opening of the bay, where seed are likely to be swimming from.

Further research is needed into the effect of trap type and depth on the catch rate of puerulus collectors to improve catch efficiency. Research is also required to improve transport for long distances to maximise survival upon arrival.

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3. Lobster Nursery Culture

3.1 Tropical spiny lobster feed development: 2009–2013

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Introduction

The development of pellet feeds is a priority for the long-term sustainability and advancement of the spiny lobster (*Panulirus ornatus and Panulirus homarus)* aquaculture industry. This paper outlines research performed over several years in the testing and development of moist and dry pellet feeds for juvenile (<8 g) spiny lobsters. A goal of the project was to promote pellet feed use through establishing demonstration farms in Indonesia where formulated feeds were the sole source of nutrition. In a previous ACIAR project (FIS/2001/058) (Williams 2009) formulated feeds were developed which promoted growth and survival rates comparable to those achieved with fresh feed items and trash fish. Although feed development with sub-adult lobsters progressed rapidly, feed development with juvenile lobsters (<5 g) posed more of a challenge, with routine incidences of high mortality within experiments coupled with a requirement for fresh ingredients and high moisture content. Nevertheless, a moist formulated feed was developed that promoted high survival and growth of lobsters, and was superior to feeding a mixed diet of green-lipped mussel and fish (whiting) flesh. At the conclusion of the project, a commercial feed company specialising in extruded shrimp feed had a produced a feed for spiny lobster grow-out. Preliminary studies suggested this feed may be suitable for production of juvenile and sub-adult lobster. Assessment of this feed in replicated trials and on demonstration farms was the starting point for feed development work in the project research reported here.

Throughout Asian-Pacific aquaculture, trash fish (low value fishery product) is still the major source of nutrition for large marine crustaceans. This feeding practice typically originates in the infancy of an industry and becomes entrenched as the industry is established. The development of spiny lobster (*Panulirus spp.)* farming in Vietnam and more recently in Indonesia are prime examples of this reliance on trash fish (Figure 1). While trash fish is effective and economical in establishing an aquaculture industry, it is unsustainable. The nutritional profile of trash fish is variable and suboptimal. Its use as the feed source is likely to result in poor food conversion ratios and negative environmental impacts. High seasonal variability in the availability of trash fish reduces the ability to effectively vary feed rates and frequency. These are important factors in optimising growth and minimising waste. The progression from trash fish to dry feeds is a complex process, starting with the incorporation of trash fish with dry ingredients to produce a moist feed, and ultimately the total removal of fresh items to produce a dry feed. Dry feeds have many advantages, such as the ease and cost effectiveness of storage and conversion to marketable flesh, flexibility with feeding strategies and critically, better environmental sustainability.

In this project we focused on feed development with juvenile spiny lobster via the assessment of dry commercial feed and refinement of lab-produced moist formulated feeds. The culmination of this project was the development and testing of a practical farm feed using locally available ingredients and technology at the village level in Indonesia.

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Figure 1. Photo of typical trash fish used for lobster farming feed

Methods

A total of 11 research trials and experiments were performed, referred to below as Experiments 1 through 11. Due to various constraints affecting the first four, they are summarised very briefly. The subsequent seven experiments are presented in full.

Experimental animals, systems and duration

For all experiments, recently settled juvenile lobsters of either *P. ornatus* or *P. homarus* (0.5–8 g) were sourced from Awang Village, Lombok, Indonesia. Experimental tanks and cages were provided with individual air-stones and supplied with ambient (25 ± 4.0ºC) flow-through (60 Lh^{-1}) seawater (33–35 ‰) and sufficient mesh hides for all lobsters. Unless otherwise stated, the growth and survival data is reported for a trial duration of 42 days.

Diet manufacture

The diets were made at the CSIRO Marine Research Laboratory at Bribie Island, Australia or at the Marine Aquaculture Development Centre (MADC), Lombok under the supervision of ACIAR staff (Figure 2).

Moist feeds

Fresh ingredients, such as mussel, fish flesh and squid were placed at −20°C until semi-frozen then extruded through a 3 mm die plate of a semi-commercial meat grinder to form a homogenous mince. The dry ingredients were finely ground (< 710 µm) using a mortar and pestle for small constituents or by hammer mill (Mikro Pulverizer, Metals Disintegration Coy, Summit, NJ, USA) for bulk ingredients. The fresh ingredients and Pearl E™ binder were thoroughly mixed together using a domestic electric hand mixer before the oil and remaining dry ingredients were added, followed by a further 10 minutes of mixing to form a dough of approximately 40–50% moisture content. The dough was extruded through a 3 mm die plate of the meat grinder to form spaghetti-like strands. The strands were placed in an airtight bag and set overnight in a refrigerator at 4°C. The strands were stored at −20°C until required for feeding.

Figure 2. Photo of pellet feed production at MADC, Lombok

Experiment 1: Commercial diet evaluation—three lobster sizes

The first experiment compared the growth and survival response of juvenile lobsters fed either a commercial lobster feed (Lucky Star, Taiwan Hung Kuo Industrial Co., Ltd) or trash fish. In Lombok, Indonesia, trash fish consists primarily of a single species of sardine captured by seine net in the vicinity of the lobster farming areas. Three size classes of lobster were assessed: 0.5 g, 4 g and 8 g. The objective was to determine the size at which pellet feed promoted superior growth and survival performance over lobsters fed trash fish. At every examined size class, the growth of lobsters fed trash fish was superior to that of lobsters fed the commercial pellet diet. However, an inverse survival relationship was observed, with superior performance achieved by lobsters fed the commercial pellet.

Experiment 2: Commercial diet evaluation—mixed diet

The second experiment compared the growth and survival response of juvenile lobsters fed either a commercial lobster feed (Lucky Star, Taiwan Hung Kuo Industrial Co., Ltd), trash fish or a 1:1 (commercial pellet: trash fish) mixed diet. The hypothesis was that lobsters fed a combined diet 1:1 would achieve superior growth and survival over lobsters fed a diet consisting of only the commercial diet or trash fish. The hypothesis proved accurate. Lobsters fed the mixed diet exhibited superior growth and survival performance over lobsters fed only the commercial diet or only trash fish. As in the first experiment, the growth of lobsters fed trash fish was superior to that of lobsters fed the commercial pellet diet and an inverse relationship was observed in relation to lobster survival.

Experiment 3: Mixed diet evaluation—demonstration farm

At the demonstration farm at Awang Bay, lobsters were fed a mixed diet (1:1) of Lucky star and trash fish. Over a six month period it was reported by the farmer (Pak Pamit) that the lobster consumed little or none of the commercial pellet. The use of pellets in any form is a positive for the industry, however without rapid success, the uptake by the industry is likely to be nil, particularly due to the high availability and low comparative cost of the trash fish diet.

Experiment 4: Commercial diet and ACIAR moist diet evaluation

The fourth experiment compared the growth and survival response of juvenile lobster *(P. homarus* and *P. ornatus)* fed either a commercial lobster feed (Lucky Star) or a moist pellet (ACIAR basal, Table 1). The hypothesis was that lobsters fed the moist pellet would achieve superior growth and survival over lobsters fed the commercial diet. The hypothesis proved accurate in both species. Lobsters fed the moist pellet exhibited superior growth and survival performance over lobsters fed the commercial diet. The improved growth and survival performance was in part hypothesised to be due to increased feed intake of the moist pellet due to the increased palatability and attractiveness provided by the presence of fresh ingredients and high moisture content. *P. homarus* exhibited significantly higher growth and survival rates compared with *P. ornatus.*

These results suggest that fresh ingredients, and/or moisture content, are important components of feeds for juvenile lobsters, and that optimal dietary requirement may vary between lobster species. As protein is the major nutrient and incurs the greatest cost in lobster feed, an inter-species protein requirement study was undertaken.

Table 1. Diet formulations for experiment 4

	ACIAR
Fishmeal	40.00
Krillmeal	10.00
Wheat flour	5.00
Fish (fresh)	17.20
Mussel (fresh)	19.80
Squid (fresh)	1.00
Fish oil	2.00
Astaxanthin	0.80
Cholesterol	0.30
Lecithin	1.25
Mineral premix	0.50
Vitamin premix	0.80
Stay C	0.30
Binder	1.00
Total	100.00
DM (%)	65.9
CP (%)	40.6
Lipid (%)	8.1

Experiment 5: Evaluation of the growth and survival of two spiny lobster species fed formulated feeds containing varying levels of protein

Introduction

Spiny lobsters are opportunistic carnivores, typically consuming high protein invertebrates, such as molluscs, crustaceans and polychaetes (Williams 2007). A study by Smith et al. (2005) confirmed that dry feeds formulated for juvenile spiny lobster (*P. ornatus*) should contain high dietary protein, >60%. One of the challenges of formulating feeds for very small juvenile lobsters is to balance the requirement for high protein with the hypothesised necessity for fresh ingredients and/or high moisture inclusion. As the level of fresh ingredient and moisture increases, the level of protein on an as-used basis decreases. This is important to consider, as although fresh ingredients and high moisture may increase feed intake, total meal size (dry matter basis) already constrained by the presence of a small foregut may be restricted. In this experiment, response to dietary protein was assessed by comparing the growth and survival performance of spiny lobsters (*P. homarus* and *P. ornatus*) fed a moist reference diet or one of three dry feeds formulated to incrementally vary in protein from 33 to 54%.

Methods

Feed and animal preparation

The four experimental feeds were produced by Indonesian University students and MADC staff under the supervision of ACIAR staff at MADC, Lombok (Figure 2.) The feeds were formulated to incrementally vary in protein from 33 to 54% and standard 10% fishery ingredient inclusion. The reference diet contained a protein level of 40% and 38% fishery ingredient inclusion (Table 2). At Awang Bay, 1,500 small juvenile (~1 g) spiny lobsters were transported from a nursery cage to the experimental system located at the MADC's research station at Sekotong. Prior to initiation of the experiment, 40 lobsters were weighed to define the mean ± SD weight. Ten lobsters were then allocated to each cage based on all allocated individuals being within the mean 1.01 g ± 0.23 SD (Figure 3). Lobsters were weighed to minimum of 0.01 g accuracy. Forty cages were used in the experiment, with each treatment replicated five times (Figure 4). The duration of the trial was 42 days. The experimental system was maintained by >100% daily water exchange with the intent of maintaining optimal water production conditions, monitored daily for temperature. The lobsters were fed to satiety twice daily, seven days a week, for the duration of the experiment. The lobsters' survival, final weights and weight gains were analysed as single ANOVA (Table 3).

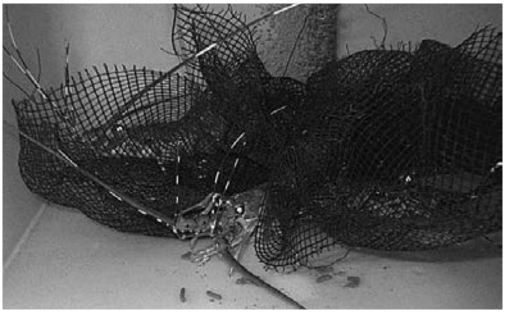

Figure 3. Photo of small spiny lobsters housed in experimental unit

Figure 4. Photo of replicate cages in raceway system

Table 2. Diet formulations

	A/E	B/F	C/G	D/H
Fishmeal	40.00	60.00	44.50	30.00
Krillmeal		10.00	10.00	10.00
Wheat flour	7.50	10.00	10.00	10.00
Casein	7.50	0.00	0.00	0.00
Fish (fresh)	17.20	10.00	10.00	10.00
Mussel (fresh)	19.80	0.00	0.00	0.00
Squid (fresh)	1.00	0.00	0.00	0.00
Fish oil	2.00	0.00	2.00	3.00
Astaxanthin	0.80	0.80	0.80	0.80
Cholesterol	0.30	0.30	0.30	0.30
Lecithin	1.25	1.25	1.25	1.25
Mineral premix	0.50	0.50	0.50	0.50
Vitamin premix	0.80	0.80	0.80	0.80
Stay C	0.30	0.30	0.30	0.30
Binder	1.00	1.00	1.00	1.00
Total	100.00	100.00	100.00	100.00
DM (%)	65.9	84.3	84.3	84.3
CP (%)	40.6	53.9	43.40	33.40
Lipid (%)	8.1	8.9	9.5	9.20

Results and discussion

The average survival, final weight and weight gain of lobsters from each treatment is presented in Figures 5 and 6. The average weight gain and survival rate of Mutiara (*Panulirus ornatus*) lobster was 128% and 66% and for Pasir (*Panulirus homarus*) lobster, 214% and 77%. In both species, lobsters fed the basal diet (A) had significantly higher weight gain and survival rates than those fed the low-, medium- and high- protein diet. There was no significant difference in the weight gain or survival of lobsters fed the protein test diets in either species. As in the previous study, with all feeds it was observed that Pasir lobster have significantly higher growth and survival than Mutiara lobster. The two key differences between the reference diet and protein diets were the fresh ingredient level and moisture content. In the reference feed, these characteristics are interrelated, as it is the inclusion of fresh ingredients which dictates the moisture content. It is unclear whether it is fresh ingredient, moisture content or a combination of both which promotes a positive growth response in small lobsters. At this small size (1 g) it appears that the inclusion level of fresh ingredient and high moisture inclusion outweighs the benefit of high protein inclusion. Future studies should assess the essentiality of fresh ingredients and moisture content, and assess the benefits of bioactive ingredients and protein concentrates in moist feeds.

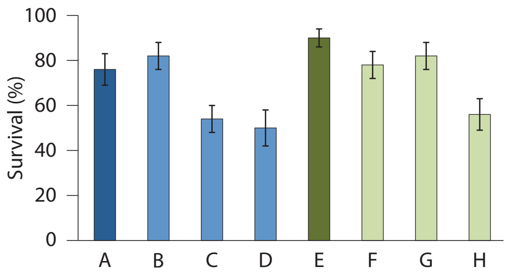

Figure 5. Experiment 5: Survival of *P. ornatus* and *P. homarus* lobster fed different diets

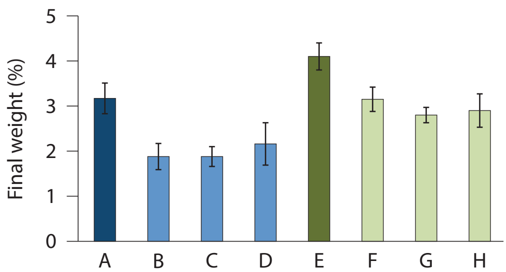

Figure 6. Experiment 5: Growth of *P. ornatus* and *P. homarus* lobster fed different diets

Table 3. Performance attributes of lobsters fed the experimental diets

Lobster	A	B	C	D	E	F	G	H
	P. ornatus				*P. homarus*			
Initial weight (g)	1.00	0.98	0.99	1.00	1.03	1.03	1.03	1.03
Final weight (g)	3.17	1.88	1.88	2.16	4.10	3.15	2.80	2.90
Weight gain (%)	217[a]	91[b]	89[b]	116[b]	298[a]	205[b]	172[b]	181[b]
Final survival (%)	76[a]	82[a]	54[b]	50 [b]	90[a]	78[b]	82[b]	56[b]

a,b,c: column mean without a common letter differ (P<0.05)

Experiment 6: Evaluation of the growth and survival of spiny lobsters fed formulated feeds containing potentially bioactive ingredients

Introduction

Tropical spiny lobsters have a relatively long larval duration exceeding four months. At the completion of the larval phase, the swimming, pigmented post-puerulus settles in shallow, near-shore habitats. These habitats typically consist of seagrass and algae. The microflora and microfauna populations living in this habitat are diverse, consisting of algae, bacteria, fungi and invertebrates. Similar communities of post-puerulus populate near-shore on artificial structures, such as fish cages and pylons. The puerulus utilise these habitats for shelter and nutrition (Williams 2007). It is hypothesised that the addition of these types of flora and fauna to practical lobster feeds may improve lobster growth and survival. Ingredients such as krill and Novacq™ have been shown to promote high growth rates when added at 10% inclusion level in practical diets fed to shrimp. It is hypothesised that a similar result may be achieved when known or potential bioactive ingredients are included in practical diets and fed to very small juvenile lobsters. In this experiment, we evaluated the bioactivity of a range of ingredients (Table 4) by comparing the growth and survival performance of spiny lobster fed a single ingredient substituted basal diet.

Methods

Feed and animal preparation

The seven experimental feeds were produced by Indonesian University students and MADC staff under the supervision of ACIAR staff at MADC, Lombok (Figure 2). The feeds were formulated to contain a 40% crude protein and 38% fishery ingredient inclusion (Table 5).

The commercial control (fresh fish—label H) was sourced locally in Lombok. From Awang Bay, 1,500 small juvenile (~1 g) spiny lobsters were transported from a nursery cage to the experimental system located at the MADC's research station at Sekotong. Prior to initiation of the experiment, 40 lobsters were weighed to define the mean ± SD weight. Twelve lobsters were then allocated to each cage based on all allocated individuals being within the mean 1.37 g ± 0.4 SD. Lobsters were weighed to a minimum of 0.01 g accuracy. Forty cages were used in the experiment, with each treatment replicated five times. The duration of the trial was 70 days. The experimental system was maintained by >100% daily water exchange with the intent of maintaining optimal water production conditions, monitored daily for temperature. For the duration of the experiment, the lobsters were fed to satiety twice daily, seven days a week. The lobsters' survival, final weights and weight gains were analysed as single ANOVA (Table 6).

Results and discussion

The average survival and weight gain of lobsters from each treatment is presented in Figures 7 and 8.

Table 4. Ingredients selected for testing

Ingredient	Description
Krill meal	A high protein and high value ingredient produced from small temperate crustaceans which feed on phytoplankton. It is commonly used as a feed additive at low inclusion levels in crustacean feeds.
Liquid algae	Mixed micro-algal species in liquid form, sourced in Indonesia.
Spirulina	Cyanobacteria, comprising two species: Arthrospira platensis and A. maxima, commonly used as a feed supplement in the aquaculture industry.
Novacq™	Shrimp growth factor developed by CSIRO.
Algamac™	New AlgaMac-ARA (arachidonic acid) is a spray-dried aquaculture nutrition additive. It is produced from cells of *Mortierella alpina* algae, source of phospholipid and Arachidonic acid.
Mixed ingredient	20% inclusion of the above ingredients.

The average final weight and survival rate of lobster was 3.6 g and 57% respectively. Lobsters fed the commercial equivalent of trash fish (H) had significantly lower survival than the average for lobsters fed formulated feeds; 27% and 61% respectively. Lobsters fed the basal diet (A), krill (B) liquid algae (C) and Novacq™ (D) diets had superior survival (>65%) over lobsters fed the mixed (E) spirulina (F) and Algamac™ (G) diets (<55%).

Lobsters fed the basal diet (A), liquid algae (C), spirulina (F) and fresh fishery control diet (H) had significantly higher growth rates than lobsters fed all other diets. The largest weight gain was achieved with lobsters fed the basal diet (A) and fresh fishery control diet (H); 252% and 285%, respectively. None of the ingredients tested produced a growth response typical of known crustacean bioactives. In fact, in all treatments a reduced growth performance was

Table 5. Diet formulations

	A	B	C	D	E	F	G
Fishmeal	40.75	40.75	40.75	40.75	40.75	40.75	40.75
Krillmeal		10.00			2.00		
Liquid algae			10.00		2.00		
Novacq™				10.00	2.00		
Spirulina					2.00	10.00	
Algamac™					2.00		10.00
Wheat flour	7.50	4.00	4.00			2.50	2.50
Casein	7.50	1.00	1.00	5.00	5.00	2.50	2.50
Fish (fresh)	17.20	17.20	17.20	17.20	17.20	17.20	17.20
Mussel (fresh)	19.80	19.80	19.80	19.80	19.80	19.80	19.80
Squid (fresh)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fish oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Astaxanthin	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cholesterol	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Lecithin	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Mineral premix	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Stay C	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Binder	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
DM (%)	65.00	65.00	65.00	65.00	65.00	65.00	65.00
CP (%)	40.50	40.50	40.50	40.50	40.50	40.50	40.50
Lipid (%)	9.00	9.00	9.00	9.00	9.00	9.00	9.00

Table 6. Performance attributes of Lobsters fed the experimental diets

	A	B	C	D	E	F	G	H
Initial weight (g)	1.34	1.39	1.37	1.37	1.42	1.35	1.33	1.38
Final weight (g)	4.57	3.82	4.37	2.57	2.28	4.08	2.30	5.25
Weight gain (%)	251	141	219	86	71	192	75	285
Final Survival (%)	65	68	73	68	56	50	51	27

a,b,c: column mean without a common letter differ (P<0.05) observed compared to the basal diet, with the level of reduction ranging from negligible to highly significant. The addition of liquid algae (C) and spirulina (F) had the least effect, with a 13% and 23% reduction in final weight observed. The inclusion of krill resulted in a growth reduction of 44%. The presence of Algamac™, Novacq™ or ingredient blend resulted in a dramatic reduction in growth rate, between 60% and 70% lower than achieved by lobsters fed the basal diet.

The high performing basal diet supported the best combination of growth and survival. The trash fish diet supported similar growth rates to the basal diet but lobsters fed this diet had very low survival (27%). This suggests that the trash fish diet lacks a critical nutrient affecting survival. The high growth rates of lobsters fed the trash fish diet could be partly attributed to cannibalism and density effects. The best performing test ingredient was the liquid algae treatment, which promoted a slightly higher survival rate than the basal diet, but a lower growth rate.

The addition of krill had an adverse effect on lobster growth. This is a surprising repeat result as growth experiments with larger lobsters have shown krill and krill hydroylsate to be a growth promoter.

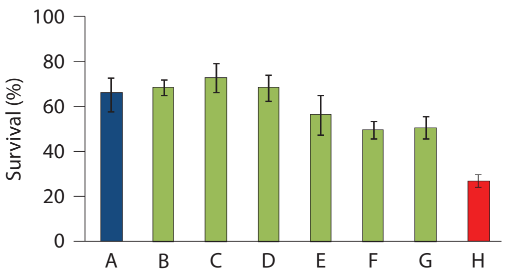

Figure 7. Experiment 6: Survival of *P. homarus* lobster fed different diets

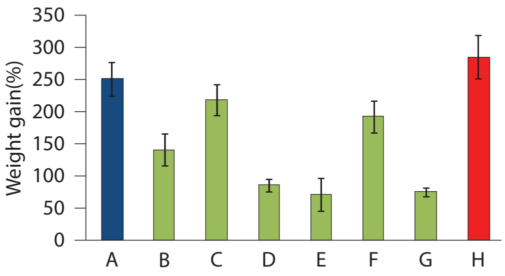

Figure 8. Experiment 6: Growth of *P. homarus* lobster fed different diets

Experiment 7: Evaluation of the growth and survival of spiny lobsters fed formulated feeds containing varying levels of astaxanthin

Introduction

Astaxanthin is an expensive micronutrient known to be critical for lobster growth and health. Although astaxanthin requirement has not been evaluated for *P. homarus*, it has been assessed for the similar species *P. ornatus*. The study found that for juvenile lobsters (18 g) astaxanthin inclusion had no effect on growth or survival, and an inclusion of 50 mg/kg total carotenoid was recommended (Barclay et al. 2006). Preliminary studies suggested that with very small (<3 g) juvenile *P. homarus* lobsters, astaxanthin does have a significant effect on growth and survival. In this pilot study, we directly compared two feeds which only varied in carophyll pink (astaxanthin) level, low 100 mg/kg or high 800 mg/kg.

Methods

Feed and animal preparation

The two experimental feeds were produced by CSIRO at the Aquaculture Feed Technology Laboratory on Bribie Island (Table 7). The feeds were formulated to contain 39% crude protein and two levels of carophyll pink, 100 mg/kg or 800 mg/kg. From Awang Bay, 1,500 small juvenile (~2 g) spiny lobsters were transported from a nursery cage to the experimental system located at the MADC's research station at Sekotong. Prior to the initiation of the experiment, 40 lobsters were weighed to define the mean ± SD weight. Ten lobsters were then allocated to each cage based on all allocated individuals being within the mean 2.30 g ± 0.76 SD. Individual lobsters were weighed to a minimum of 0.01 g accuracy. Twenty cages were used in the experiment, with each treatment replicated five times. The duration of the trial was 42 days. The experimental system was maintained by >100% daily water exchange with the intent of maintaining optimal water production conditions, monitored daily for temperature. For the duration of the experiment, the lobsters were fed to satiety twice daily, seven days a week. The lobsters' survival, final weights and weight gains were analysed as single ANOVA (Table 8).

Table 7. Diet formulations

	A	B
Fishmeal	48.20	40.00
Soy concentrate	0.00	0.00
Casein	0.00	7.50
Wheat flour	7.50	7.50
Fish (fresh)	17.20	17.20
Mussel (fresh)	19.80	19.80
Squid (fresh)	1.00	1.00
Fish oil	2.00	2.00
Astaxanthin	0.10	0.80
Cholesterol	0.30	0.30
Lecithin	1.30	1.30
Mineral premix	0.50	0.50
Vitamin premix	0.90	0.90
Stay C	0.30	0.30
Binder	1.00	1.00
Total	100.00	100.00
DM (%)	65.00	65.00
CP (%)	39.70	39.70
Lipid (%)	8.80	8.80

Table 8. Performance attributes of Lobsters fed the experimental diets

	A	B
Initial weight (g)	2.24	2.20
Final weight (g)	5.91	7.78
Weight gain (%)	163[a]	253[b]
Final Survival (%)	72[a]	76[a]

a,b,c: column mean without a common letter differ (P<0.05)

Results and discussion

The average weight gain and survival of lobsters from each treatment is presented in Figures 9 and 10. The average weight gain and survival of lobsters was 208% and 74% respectively. Lobsters fed the high astaxanthin feed (B) had significantly higher growth rates than lobsters fed the low astaxanthin diet (A). Survival was high, 72–76%, and not significantly different between treatments. A clear growth benefit was achieved with the addition of astaxanthin from 100 mg/kg to 800 mg/kg. Lobsters fed the high astaxanthin diet grew 55% faster than lobsters fed on the low astaxanthin diet. It is clear that very small *P. homarus* have a higher requirement for astaxanthin than juvenile *P. ornatus*. From these results, it is recommended that feeds for juvenile lobsters contain > 800 mg/kg caropyhll pink and that a dose response evaluating the requirement of very small lobster *P. homarus* for astaxanthin should be an essential component of any future project.

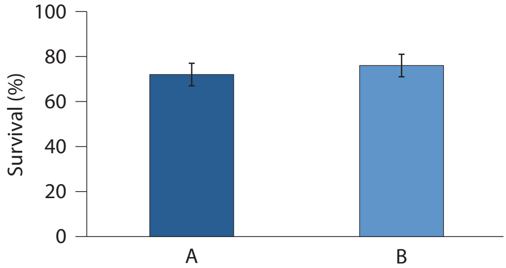

Figure 9. Experiment 7: Survival of *P. homarus* lobster fed different diets

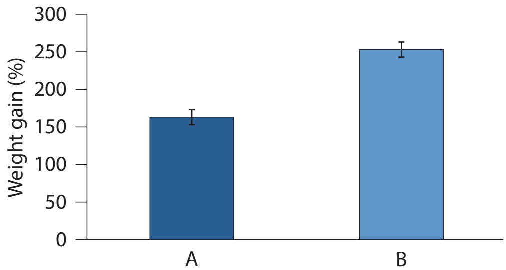

Figure 10. Experiment 7: Growth of *P. homarus* lobster fed different diets

Experiment 8: Evaluation of the growth and survival of spiny lobsters fed formulated feeds containing varying inclusions of fresh ingredients

Introduction

Cage culture of tropical spiny lobster, *P. homarus* is a developing industry in Lombok, Indonesia. Wild harvested seed lobsters are fed solely on trash fish (fishery product) until reaching a market size of 150–250 g. The availability of trash fish varies seasonally, from highly abundant to none, and consists primarily of a single species of sardine. During the period of no availability, lobsters may be fed an alternative diet of freshwater snails, vegetables or nothing. It is during such times that farmers become interested in using a pellet feed. However, when trash fish are abundant there is an opportunity to produce a basic solar-dried feed containing a mixture of minced trash fish and locally available shrimp feed. Little is understood about how essential fresh ingredients (such as fish) are in formulated feeds for survival and growth in juvenile spiny lobsters (<5 g). A study by Irvin and Williams (2009) reported that sub-adult lobsters (>600 g) had no requirement for fresh ingredients in formulated lobster feeds. However, results from preliminary studies suggest that juvenile lobsters do have a requirement for fresh ingredients. It is hypothesised that the presence of fresh ingredients in lobster feeds is beneficial for lobster survival and growth as it increases feed intake. This hypothesis is based on the theory that fresh ingredients contain chemo-attractants which promote a feeding response in crustaceans, and that these diets are texturally softer, which may suit the underdeveloped mouthparts of juvenile lobsters. However, the inclusion of fresh ingredients in feeds leads to an increase in complexity and cost with regard to pre and post storage and the production of the feed. In this study, we compare the growth and survival of juvenile spiny lobsters fed a series of moist feeds which vary only in fresh ingredient inclusion.

Methods

Feed and animal preparation

The four experimental feeds were produced by CSIRO at the Aquaculture Feed Technology Laboratory on Bribie Island. The feeds were formulated to contain 39% crude protein and four levels of fishery ingredient inclusion, incrementally ranging from 38 to 0% (Table 9).

At Awang Bay, 1,500 small juvenile (~2 g) spiny lobsters were transported from a nursery cage to the experimental system located at the MADC's research station at Sekotong. Prior to initiation of the experiment, 40 lobsters were weighed to define the mean ± SD weight. Ten lobsters were then allocated to each cage based on all allocated individuals being within the mean 2.30 g ± 0.76 SD. Individual lobsters were weighed to a minimum of 0.01 g accuracy. Twenty cages were used in the experiment, with each treatment replicated five times. The duration of the trial was 42 days. The experimental system was maintained by >100% daily water exchange with the intent of maintaining optimal water production conditions, monitored daily for temperature. For the duration of the experiment, the lobsters were fed to satiety twice daily, seven days a week. The lobsters' survival, final weights and weight gains were analysed as single ANOVA (Table 10).

Table 9. Diet formulations

	A	B	C	D
Fishmeal	48.20	51.10	53.70	54.50
Wheat flour	7.50	7.90	8.40	9.70
Fish (fresh)	17.20	12.20	6.50	0.00
Mussel (fresh)	19.80	14.00	7.40	0.00
Squid (fresh)	1.00	0.70	0.40	0.00
Fish oil	2.00	2.10	2.20	2.60
Astaxanthin	0.10	0.10	0.10	0.10
Cholesterol	0.30	0.30	0.30	0.40
Lecithin	1.30	1.30	1.40	1.60
Mineral premix	0.50	0.50	0.50	0.50
Vitamin premix	0.90	0.90	0.90	0.90
Stay C	0.30	0.30	0.30	0.40
Binder	1.00	1.00	1.10	1.30
Water	0.00	7.40	16.70	27.50
Total	100.00	100.00	100.00	100.00
DM (%)	65.00	65.00	65.00	65.00
CP (%)	39.70	39.90	39.80	38.40
Lipid (%)	8.80	8.80	8.80	9.00

Table 10. Performance attributes of Lobsters fed the experimental diets

	A	B	C	D
Initial weight (g)	2.24	2.18	2.21	2.23
Final weight (g)	5.91 ^{a}	5.71 ^{a}	5.51 ^{ab}	4.36 ^{b}
Weight gain (%)	163^{a}	162^{a}	149^{ab}	97^{b}
Final Survival (%)	72	80	70	76

a,b,c: column mean without a common letter differ (P<0.05)

Results and discussion

The average survival and weight gain of lobsters from each treatment is presented in Figures 11 and 12. The average weight gain and survival rate of lobster was 143% and 75% respectively. Survival was typical of lobsters of this starting size and not significantly different between treatments. There was no significant difference in the growth rate of lobsters fed diets which had a fresh ingredient inclusion ranging from 38 to 14%. However, lobsters fed a diet containing no fresh ingredients exhibited growth rates significantly lower than all other treatments. This suggests that the inclusion of fresh ingredients does promote improved growth in juvenile spiny lobsters. This is hypothesised to be due to the fresh ingredients containing high levels of chemo-attractants which promote a feeding response in crustaceans, and that these diets are texturally softer which may suit the underdeveloped mouthparts of juvenile lobsters. From these results, it is recommended that feeds for juvenile lobsters contain 15 to 20% inclusion of fresh ingredients. In this study, water was added incrementally to each treatment so that each feed had the same dry matter content. What is equally important is to determine the optimal dry matter content of the feed. Feeds with a dry matter content of <85% have a short shelf life and require freezer storage or frequent production (every two days).

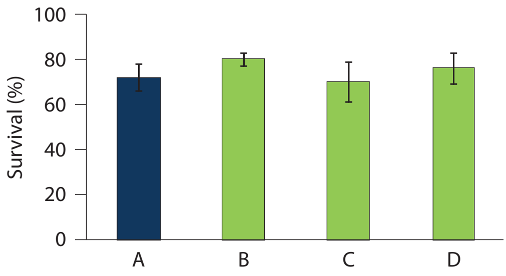

Figure 11. Experiment 8: Survival of *P. homarus* lobster fed different diets

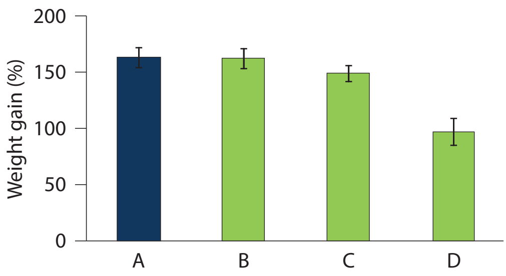

Figure 12. Experiment 8: Growth of *P. homarus* lobster fed different diets

Experiment 9: Evaluation of the growth and survival of spiny lobsters fed formulated feeds containing varying levels of moisture content

Introduction

Feeds with a dry matter content of <85% have a short shelf life and they require either freezer storage or frequent production (every two days). Post-production storage issues can be resolved by oven or solar drying (>90% DM) the feed. However, it is hypothesised that the high moisture content (<85% DM) in lobster feeds is beneficial for lobster survival and growth by increasing feed intake. This is based on the theory that texturally softer feeds promote a feeding response in crustaceans and they may suit the underdeveloped mouthparts of juvenile lobsters. In this study, we compare the growth and survival of juvenile spiny lobsters fed a series of feeds which vary only in moisture content.

Methods

Feed and animal preparation

The four experimental feeds were produced by CSIRO at the Aquaculture Feed Technology Laboratory on Bribie Island. The feeds were formulated to contain 39% crude protein and 38% fishery ingredient inclusion at four levels of feed dry matter, incrementally ranging from 65 to 90% (Table 11). From Awang Bay, 1,500 small juvenile (~2 g) spiny lobsters were transported from a nursery cage to the experimental system located at the MADC's research station at Sekotong. Prior to initiation of the experiment, 40 lobsters were weighed to define the mean ± SD weight. Ten lobsters were then allocated to each cage based on all allocated individuals being within the mean 2.30 g ± 0.76 SD. Individual lobsters were weighed to minimum of 0.01 g accuracy. Twenty cages were used in the experiment, with each treatment replicated five times. The duration of the trial was 42 days. The experimental system was maintained by >100% daily water exchange with the intent of maintaining optimal water production conditions, monitored daily for temperature. For the duration of the experiment, the lobsters were fed to satiety twice daily, seven days a week. The lobsters' survival, final weights and weight gains were analysed as single ANOVA (Table 12).

Table 11. Diet formulations

	A	B	C	D
Fishmeal	48.20	48.20	48.20	48.20
Wheat flour	7.50	7.50	7.50	7.50
Fish (fresh)	17.20	17.20	17.20	17.20
Mussel (fresh)	19.80	19.80	19.80	19.80
Squid (fresh)	1.00	1.00	1.00	1.00
Fish oil	2.00	2.00	2.00	2.00
Astaxanthin	0.10	0.10	0.10	0.10
Cholesterol	0.30	0.30	0.30	0.30
Lecithin	1.30	1.30	1.30	1.30
Mineral premix	0.50	0.50	0.50	0.50
Vitamin premix	0.90	0.90	0.90	0.90
Stay C	0.30	0.30	0.30	0.30
Binder	1.00	1.00	1.00	1.00
Oven time (hrs)	0.00	1.15	2.00	24.00
Total	100.00	100.00	100.00	100.00
DM (%)	65.00	74.00	82.00	90.00
CP (%)	39.70	39.90	39.80	38.40
Lipid (%)	8.80	8.80	8.80	9.00

Table 12. Performance attributes of Lobsters fed the experimental diets

	A	B	C	D
Initial weight (g)	2.24	2.19	2.30	2.24
Final weight (g)	5.91	5.78	6.13	5.47
Weight gain (%)	163	164	166	144
Final Survival (%)	72	76	70	72

a,b,c: column mean without a common letter differ (P<0.05)

Results and discussion

The average survival and weight gain of lobsters from each treatment is presented in Figures 13 and 14. The average weight gain and survival rate of lobster was 160% and 73% respectively. Survival was typical of lobsters of this starting size and not significantly different between treatments. There was no significant difference in the growth rate of lobsters fed diets which had a dry matter content ranging from 65 to 82%. However, lobsters fed a dry diet (<90% DM), exhibited growth rates significantly lower than all other treatments. This suggests that the presence of moisture in feeds does promote improved growth in juvenile spiny lobsters. This is hypothesised to be due to moist feeds being texturally softer which may suit the underdeveloped mouthparts of juvenile lobsters and improve feed intake. From these results, it is recommended that feeds for juvenile lobsters contain >85% DM content. Feeds which contain a dry matter content of <85% have a short shelf life and they require freezer storage or frequent production (every two days).

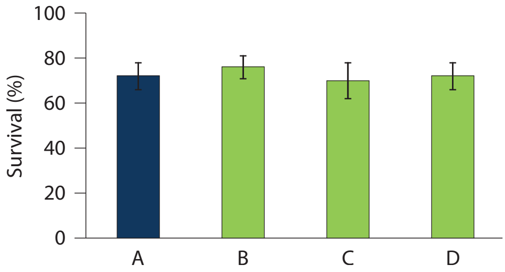

Figure 13. Experiment 9: Survival of *P. homarus* lobster fed different diets.

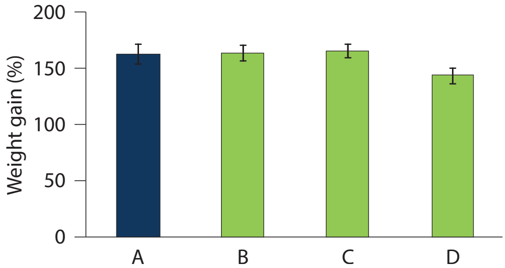

Figure 14. Experiment 9: Growth of *P. homarus* lobster fed different diets.

Experiment 10: Growth and survival of spiny lobsters fed a practical moist diet containing a known high quality fishmeal or local fishmeal of unknown quality

Introduction

The development of a high-performing, pelleted lobster feed is a high priority for long-term sustainability of lobster farming in Indonesia. Fishmeal is the major protein source used in lobster feed, contributing up to 50% of the diet. It is well understood that feed can only be as good as its ingredients

(Glencross et al. 2007). The quality of the fishmeal will greatly impact the palatability and feed intake of the diet, and the growth and survival rate of the lobster. Fishmeal quality and protein level varies due to the species, origin, processing and storage. Feeds tested in previous lobster growth studies in this ACIAR project were reliant on the use of imported (high quality) ingredients, with the exception of fresh fishery products. In this experiment, fishmeal type was assessed by comparing the growth and survival performance of spiny lobster (*P. homarus*) fed a basal diet containing either local or imported fish meal.

Methods

Feed and animal preparation

The two experimental feeds were produced by Indonesian University students and MADC staff under the supervision of ACIAR at MADC, Lombok. The feeds were formulated to contain a crude protein of 44% and fishery ingredient inclusion of 39% (Table 13).

From Awang Bay, 1,500 juvenile (~1 g) spiny lobsters were transported from a nursery cage to the experimental system located at the MADC's research station at Sekotong. Prior to initiation of the experiment, 40 lobsters were weighed to define the mean ± SD weight. Twelve lobsters were then allocated to each cage based on all allocated individuals being within the selected range, mean 1.3 ± 0.3 SD weight. Lobsters were weighed to minimum of 0.01 g accuracy. Ten cages were used in the experiment, with each treatment replicated five times. The duration of the trial was 42 days. The experimental system was maintained by >100% daily water exchange with the intent of maintaining optimal water production conditions, monitored daily for temperature. For the duration of the experiment, the lobsters were fed to satiety twice daily, seven days a week. The lobsters' survival, final weights and weight gains were analysed as single ANOVA (Table 14).

Results and discussion

The average survival, final weight and weight gain of lobsters from each treatment is presented in Figures 15 and 16. The final weight and survival of lobster was 2.68 g and 68% respectively. Lobsters fed the diet containing imported fishmeal had significantly higher weight gain and survival than those fed the diet containing the locally sourced fishmeal. This finding supports the fact that feed ingredient types can vary in quality and are therefore likely to promote variable performance with regard to lobster growth and survival. It is clear that the development of effective formulated feeds for lobsters must be coupled with rigorous evaluation of local and imported ingredients.

Table 13. Diet formulations

	A	B
Fishmeal (Peru)	40.0	0.00
Fishmeal (Indo)	0.00	40.0
Casein	7.50	7.50
Wheat flour	7.50	7.50
Fish (fresh)	17.20	17.20
Mussel (fresh)	19.80	19.80
Squid (fresh)	1.00	1.00
Fish oil	2.00	2.00
Astaxanthin	0.80	0.80
Cholesterol	0.30	0.30
Lecithin	1.30	1.30
Mineral premix	0.40	0.40
Vitamin premix	0.90	0.90
Stay C	0.30	0.30
Binder	1.00	1.00
Total	100.00	100.00
DM (%)	66.00	66.00
CP (%)	41.00	41.00
Lipid (%)	8.00	8.00

Table 14. Performance attributes of Lobsters fed the experimental diets

	A	B
Initial weight (g)	1.31	1.29
Final weight (g)	2.97[a]	2.39[b]
Weight gain (%)	126[a]	85[b]
Final Survival (%)	75	60

a,b: column mean without a common letter differ (P<0.05)

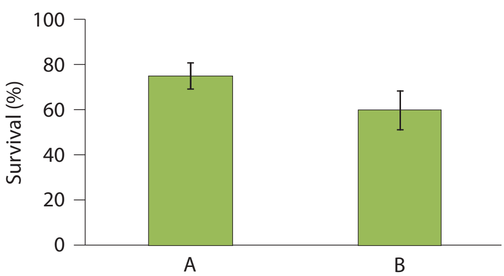

Figure 15. Experiment 10: Survival of *P. homarus* lobster fed different diets

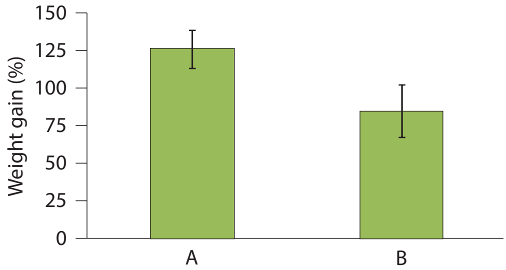

Figure 16. Experiment 10: Growth of *P. homarus* lobster fed different diets

Experiment 11: Evaluation of practical farm feed using locally available ingredients and technology at the village level in Indonesia

Introduction

An important objective of the project was to promote the use of pellet feeds by the lobster industry in Indonesia. Our first study involved co-feeding a commercial (Lucky Star, Taiwan Hung Kuo Industrial Co., Ltd) and trash fish diet. Experimental studies suggest that the feeding of a mixed diet would promote growth and survival superior to the feeding of trash fish alone. However, observations from farmers suggest that lobsters were not consuming pellets in the farm cage environment. The major difference between experimental cages and farm cages is the increased culture depth and water current in the farm environment. The reason for lobster not consuming pellets in farm cages could be partly explained by pellets rapidly losing attractiveness in the farm cage environment. These observations led to a series of studies refining a moist feed, and ultimately led to the development of a feed ready for on-farm testing.

Methods

Feed preparation

The feed was produced by an Indonesian lobster farmer (Pak Werry) under the supervision of ACIAR staff in Lombok. As the quality of locally available ingredients is yet to be adequately assessed, a locally sourced high-quality shrimp feed was used as the base ingredient and major dry source of protein (Table 15).

Table 15. Diet formulations

	A
Shrimp mash	40.0
Fish (fresh)	17.20
Mussel (fresh)	19.80
Squid (fresh)	1.00
Fish oil	2.00
Mineral premix	0.40
Vitamin premix	0.90
Binder	1.00
Total	100.00
DM (%)	66.00
CP (%)	41.00
Lipid (%)	8.00

Results and discussion

Observations from the farmer suggest that lobsters were not consuming pellets in the sea cage environment (Figure 17). However, the same batch of feed was readily consumed by lobsters stocked in land-based tanks. The major reported difference between land-based tanks and the sea cages was the increased culture depth and water current in the sea cage environment. In all environments, the pellets were found intact with high water stability after a 12 hour period. It is possible that lobsters in sea cages do not consume the pellet due to the pellets rapidly losing attractiveness. In the short term, the reason why the pellets are not being consumed should be evaluated. If it is due to a lack of attractiveness, then options which promote and prolong pellet attractiveness should be considered. Increasing the quantity of fresh ingredient and marine protein concentrates, and pre-dipping the pellet in squid mince are a few options which could be investigated. In the medium to long term, it is critical that the lobster feed base is replaced with ingredients of known origin and quality. This will require the assessment of a broad range of locally available ingredients and is more likely to involve a successful collaboration with a locally based feed company.

Conclusions and recommendations

In this project, we focused on feed development with juvenile spiny lobster via the assessment of dry commercial feed and the refinement of moist formulated feeds. The culmination of this project has been the development and testing of a practical farm feed using locally available ingredients and technology at the village level in Indonesia. The key opportunity for lobster farmers is to adopt the technology and produce and store a practical feed when trash fish is abundant, of high quality and low value.

Inclusion of astaxanthin (>0.75%) provided the largest growth benefit to small *P. homarus* lobster. The optimal dietary requirement is unknown and should be investigated. The developed practical farm feed requires refinement to gain acceptance by the lobster (and farmer). In the short term, reasons why pellets are not being consumed should be evaluated. If it is due to a lack of attractiveness to the lobster, then options which promote and prolong pellet attractiveness should be considered. Increasing the quantity of fresh ingredient and marine protein concentrates, and pre-dipping the pellet in squid mince are a few options which could be investigated. In the medium to long term, it is critical that the shrimp feed base is replaced with ingredients of known origin and quality. This will require the assessment of a broad range of locally available ingredients and collaboration with a locally based feed company.

Figure 17. Photo of pellets produced on farm in Lombok Indonesia

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3.2 Transport and husbandry of post-puerulus tropical spiny lobsters

Scott Shanks[1], Samsul Bahrawi[2], Bayu Priyambodo[2] and Clive Jones[3]

Introduction

This paper provides an overview of research conducted, and current industry practices, for the handling, packing and transport of lobster seed, and their initial nursery culture in Indonesia.

Aspects of nursery practices for tropical spiny lobsters are discussed, comprising standard operating procedures, knowledge gaps and research required to improve survival and growth of lobsters through the nursery phase.

For the Indonesian lobster farming industry, accurate statistics on survival of lobsters from point of capture as a puerulus to advanced juvenile of around 10 to 30 g, are not available. Anecdotal evidence suggests survival through this nursery phase may be as low as 20%. This compares poorly with Vietnam, where survival through the nursery phase is greater than 70%.

Experimentation

A series of four experiments were performed to examine aspects of husbandry in the nursery culture of *Panulirus homarus*. These are referred to below as experiments one to four, and cover assessment of density in sea cages, density in tank culture, provision of shelter in tanks and tank colour.

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Experiment 1: Growth and survival of spiny lobsters cultured at three densities in sea cages

Introduction

This experiment set out to assess the effect of density on the growth and survival of *P. homarus* cultured under sea-cage conditions, and was performed in April 2010.

Methods

Traditionally lobster farmers in Vietnam and Indonesia use small fresh fish as lobster feed however this feed type is highly polluting and is unlikely to meet the lobsters' nutritional requirements. To maximise the likelihood of adequate nutrition, a combination of trash fish and a commercial lobster pellet (Lucky Star) was used in a 1:1 mix to feed the lobsters in this experiment.

Each cage was 75 cm wide × 75 cm long × 75 cm high, providing a floor area of 0.56 m^2. Cages were suspended from a floating frame located approximately 200 m offshore of the MADC research facilities at Sekotong, Lombok (Figure 1).

From the village of Awang in south-east Lombok, 1,200 juvenile (<4 g) spiny lobsters (*P. homarus*) were transported from a nursery cage to the experimental system at the MADC's research station at Sekotong. Prior to initiation of the experiment, 40 lobsters were weighed to define the mean ± SD weight. All lobsters were then graded into 3 sizes: small (<0.8 g), medium (0.8–2.0 g) and large (>2.0 g). The medium size grade had the highest number of lobsters so these were used for the experiment. A total of 11, 28 or 45 lobsters lobster were then allocated to each of three cages to achieve stocking densities of 20, 50 and 80 lobsters per square metre. There were four replicates of each of the three treatments.

The duration of the trial was 84 days. Weight samples were taken every two weeks, and during this process all cages were thoroughly cleaned and reinstalled. For the duration of the experiment, the lobsters were fed to satiety three times daily, seven days a week. The lobsters' survival, final weights and weight gains were analysed as single ANOVA.

Results and discussion

The average survival, final weight and weight gain of lobsters from each treatment is presented in Figures 2 and 3. There were significant differences ($p < 0.05$) in both survival and growth between treatments.

Lobsters cultured at the lowest density had significantly higher survival rates (100%) than those in the medium (71.4%) and high density (60%) treatments.

Lobsters cultured at the lowest density had a significantly higher growth rate than those in the medium and high density treatments, with 1.62 g/week, 1.28 g/week and 1.23 g/week respectively.

Figure 1. Experimental sea cages for nursery experiments at MADC Sekotong, Lombok

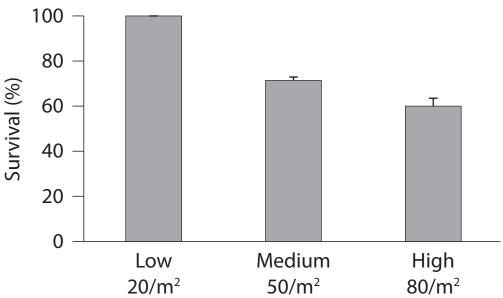

Figure 2. Survival of juvenile *P. homarus* grown at three densities in sea cages for 84 days

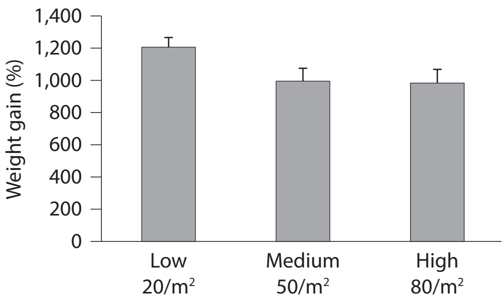

Figure 3. Percentage weight gain of juvenile *P. homarus* grown at three densities in sea cages for 84 days

Experiment 2: Growth and survival of spiny lobsters cultured at three densities in tanks

Introduction

After the MADC sea cage research facility was destroyed by a storm in June 2010, subsequent experiments were performed in a tank system onshore. The experiment summarised here set out to further assess the effect of density on the growth and survival of *P. homarus*.

Methods

Forty small open-top cages (30 cm × 60 cm × 50 cm deep) with a floor surface area of 0.18 m^2 were fabricated from netting attached to a frame, and placed into large concrete tanks as depicted in Figure 4. Five density treatments were applied, comprising: 30, 60, 90, 120 and 150 m^{-2} with eight replicates of each. The experiment was maintained for eight weeks, and was terminated on 4 October 2010.

The mean weight of lobsters stocked was 0.24 g. Feeding was performed twice each day with 35% of the daily ration fed in the morning and 65% in the evening. Lobsters were fed at a rate of 20% of biomass on a dry weight basis.

Results and discussion

At the completion of the experiment after eight weeks, survival was quite low, with the mean for each density ranging from around 30 to 45% (Figure 5). There was no significant difference (P. 0.05) in survival, although a negative correlation between density and survival was apparent.

The mean size at harvest ranged from around 0.9 to 2.2 grams (Figure 6) but there was no significant difference between densities.

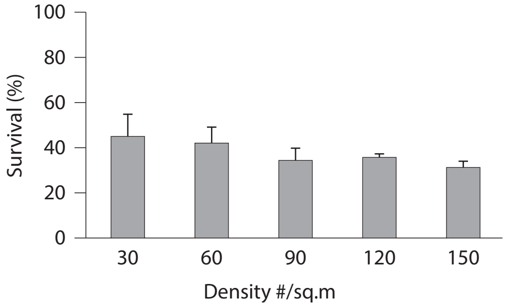

Figure 5. Survival of juvenile *P. homarus* cultured over 56 days at five densities in tanks

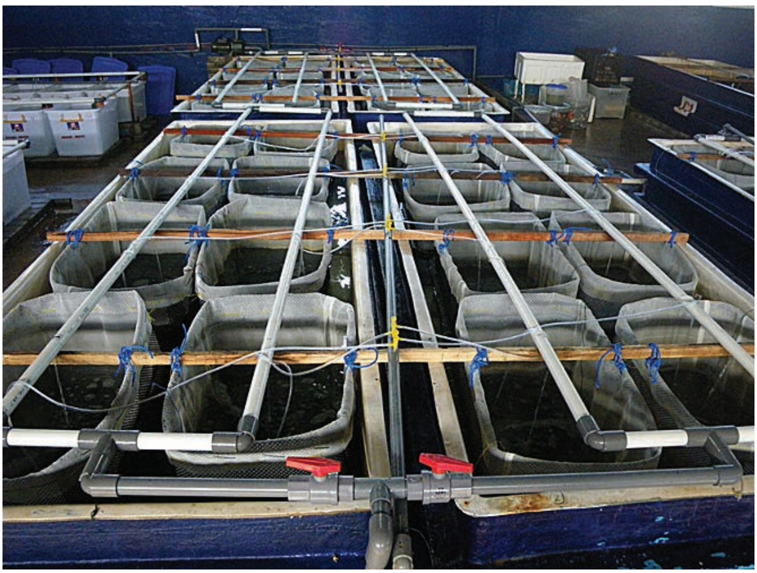

Figure 4. Experiment cages within tanks at MADC Sekotong as used for husbandry and nutrition experiments 2010 to 2012

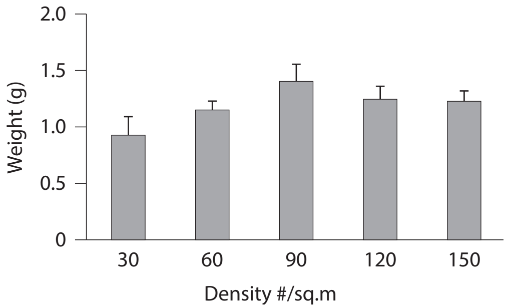

Figure 6. Size of juvenile *P. homarus* cultured over 56 days at five densities in tanks

Survival at 14 days was high, above 95% for nearly all cages, but fell dramatically by day 28 when it was consistently less than 60%, falling further, although more slowly, to the experiment's conclusion at day 56. There was no apparent critical event or factor that the high mortality could be attributed to. Nevertheless, the poor survival is likely to have masked the effect of the density treatments, and no conclusion can be made about the density effect.

It is however possible that the diet provided was inadequate, leading to the poor survival by day 28 as a consequence of high cannibalism.

Experiment 3: Growth and survival of spiny lobsters cultured with different shelters in tanks

Introduction

Previous research has indicated that providing shelter to lobsters cultured in tank-based conditions has a positive impact on survival. This experiment assessed the effect of four different forms of shelter.

Methods

The experiment system used was the same as that described above for Experiment 2, although with four treatments and six replicates. The experiment was initiated on 10 October 2011.

The four shelter treatments comprised: i) seaweed, using small bunches of fresh Gracilaria; ii) mesh bundle, made from a bundle of mono-filament netting; iii) hard shelter consisting of a series of PVC pipes bound together; and iv) no shelter control.

Twelve lobsters were stocked to each cage at a nominal density of 67 m^{-2}. Mean size at stocking was 0.33 g. Lobsters were fed a commercial lobster pellet (Lucky Star) in 1.5 mm noodle form. Feeding was performed twice each day with 35% of the daily ration fed in the morning and 65% in the evening. Lobsters were fed at a rate of 20% of biomass on a dry weight basis.

Results and discussion

Over the duration of the eight week experiment, survival was very low, with the mean for each shelter type ranging from around 20 to 35% (Figure 7). There was no significant difference (P. 0.05) for survival, although the pipe and mesh shelters had the highest survival.

The mean size at harvest ranged from around 0.9 to 1.1 grams (Figure 8), but there was no significant difference between shelter types.

In this experiment, survival fell sharply from the outset, such that less than 50% of lobsters persisted to day 28. As for the previous experiment, there was no apparent critical event or factor that the high mortality could be attributed to. Again, the poor survival is likely to have masked the effect of the shelter treatments, so that no conclusion can be made about the shelter effect.

It is however likely that the diet provided was inadequate, leading to poor survival.

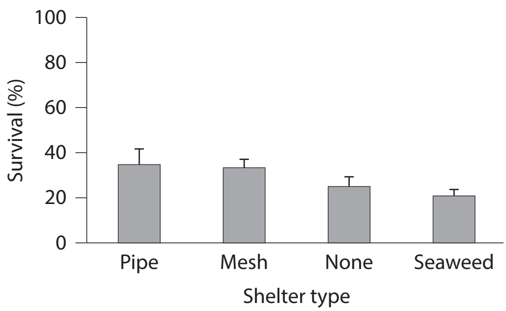

Figure 7. Survival of juvenile *P. homarus* provided with different shelter types and cultured over 56 days

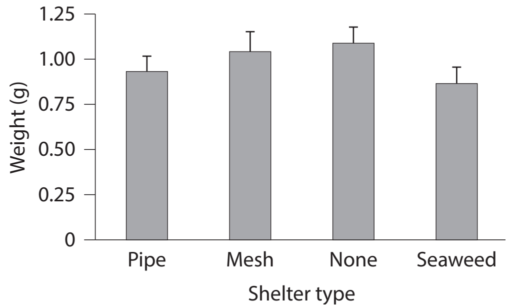

Figure 8. Size of juvenile *P. homarus* provided with different shelter types and cultured over 56 days

Experiment 4: Growth and survival of spiny lobsters cultured in tanks of different wall colour and translucency

Introduction

Tank colour and light levels have both been proven to affect survival in a number of aquaculture species, including but not limited to *Scylla serrata* and *Perca fluviatilis*. Our interest in this factor was aroused by the contrasting results of similar lobster research between two laboratories where tanks of different colour and translucency were used. In Australia, experiments carried out in dark coloured tanks on tropical spiny lobsters resulted in very high survival, while equivalent experiments in Indonesia using white translucent tanks resulted in very poor survival. There could be a variety of reasons for the low survival in the Indonesian experiments, including stock health and water quality, but the differing characteristics of the tank colour and light penetration were also a factor. This experiment was conceived to assess the affect of tank colour / light penetration on survival and growth of juvenile *P. homarus*.

Methods

The experiment system used consisted of rectangular polyethylene tanks equipped with intake and outlet pipes to enable through-flow of seawater. Twenty tanks were set up in a block that was two tanks wide and 10 tanks long to provide for two treatments and 10 replicates. The experiment started on 21 April 2012 and ran for eight weeks.

Fifteen lobsters were stocked to each tank at a nominal density of 83 m^{-2}. Mean size at stocking was 0.33 g. Lobsters were fed a laboratory-made semi-moist lobster pellet, the formulation for which had previously been used with success in similar experiments. Feeding was performed twice each day with 35% of the daily ration fed in the morning and 65% in the evening. Lobsters were fed at a rate of 20% of biomass on a dry weight basis.

Shelter was provided in the form of 2 m^2 of 5 cm cage mesh bundled and weighted, then placed in each replicate cage to reduce stress and cannibalism. Unfiltered seawater was passed through each cage/tank at the rate of 160 Ls per hour or approximately two exchanges per hour.

The two treatments comprised: i) translucent, white-walled, polyethylene tanks; and ii) opaque, black-walled, polyethylene tanks.

Results and discussion

As for previous experiments in this series performed at the MADC research centre at Sekotong in Lombok, the survival of lobsters through the period of the experiment was very poor (Figure 9), with significant mortality occurring consistently from the outset to the completion. By day 56, survival was less than 20%.

As diet in this experiment was considered to be a proven effective diet, and all other known factors were optimal, the high mortality was attributed to an unspecified water quality issue that may have similarly impacted the previous experiments. The poor survival again masked the treatment effect, such that no conclusion could be made about the efficacy of tank colour and translucency.

Conclusions and recommendations

Handling and transport

A variety of techniques have been used for transferring juvenile lobsters from one location to another over the years, with varying levels of success. These include:

- dry in Styrofoam box
- rolled in moist sand and packed in cardboard or Styrofoam box
- seawater-filled soft drink bottle with 5–10 puerulus (puerulus fishermen to middlemen)
- bag filled with seawater in Styrofoam box with/without battery aerator
- bag or bags partially filled with chilled seawater then filled and sealed with pure oxygen.

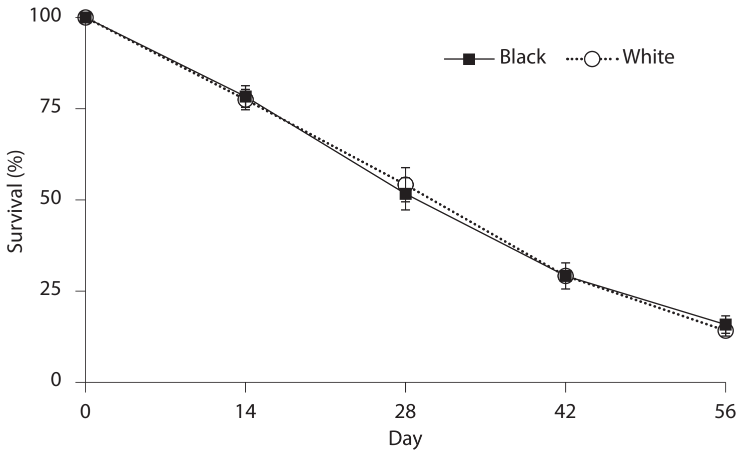

Figure 9. Survival of juvenile *P. homarus* cultured in opaque black and translucent white tanks for 84 days

Some of these techniques are suitable while others can lead to reduced survival during and post transport.

Current best practice for handling and transport comprises:

- juvenile lobsters are not fed for at least 12 hours prior to transport (this requirement is not necessary for translucent puerulus as they are non-feeding)
- lobsters are chilled to 22–25 °C for 30 minutes prior to packing, and graded by size
- 1 L of chilled water is poured into a 10 L plastic bag then 50 juvenile lobsters are added
- each bag is completely filled with pure oxygen before being tied at the top with rubber bands
- 10 of these bags are neatly placed into a 20 kg Styrofoam box then freighted to local and international buyers
- upon arrival at their new destination, the lobsters should be slowly acclimated by exchanging 10% of the bag water volume every 10 minutes until water quality parameters are the same in and out of the transportation bag.

Nursery husbandry

Early cage-based results were excellent, even when suboptimal feeds were provided. This result may indicate substantial nutritional benefits can be derived from a sea-cage environment for *P. homarus*.

All tank-based husbandry experiments were compromised by poor nutrition, highlighting necessity of an effective formulated diet.

By mid-2010, the project's research focus switched to nutrition and led to the discovery of the ACIAR basal diet in September 2011. This diet has consistently supported survival rates of 65–85%, a vast increase from 20–45% previously experienced.

Future research questions

- What is the optimum size to transport juvenile lobsters? Recent experience suggests that puerulus tolerate transport better than advanced juveniles.
- After feeding, how long does it take juvenile (and market size) lobsters to be fully purged?
- What is the lowest temperature at which tropical lobsters can be stored and freighted without adversely affecting survival? Over what time period should this cooling down occur?
- What is the maximum freight time allowed before survival and growth are negatively impacted?
- What is the optimum density for juvenile production in sea cages (20–50/m^2)?
- What is the optimum density for grow-out production?
- At what density is maximum profitability achieved?

It is recommended that the density experiments be revisited using the ACIAR basal diet for varying sized lobsters in sea cages with a strong focus on survival, growth and profitability.

3.3 Preliminary assessment of dietary mannan oligosaccharides on juvenile *Panulirus homarus* lobsters

Hoang Do Huu[1] and Clive Jones[2]

Introduction

This paper presents information on an experiment performed to assess the effects of dietary supplementation with mannan oligosaccharide on post-puerulus *Panulirus homarus*. This research was subsequently published (Do Huu and Jones 2014) and the following account is a summary only, as presented at the Symposium.

The lobster, *P. homarus* is a high-value species from fishery production throughout South-East Asia, and more recently also from aquaculture (Jones 2010). Together with *Panulirus ornatus*, aquaculture of *P. homarus* creates employment and provides an important source of income for communities in the central provinces of Vietnam, including Khanh Hoa, Phu Yen and Binh Dinh (Petersen and Phuong 2010). However, as a consequence of rapid expansion, a number of problems have arisen, including the spread of disease and significant mortality in late 2007 and again in 2012 caused by rickettsia-*like* bacteria (milky disease). In order to help the lobster culture industry develop sustainably, it is essential to better manage lobster health without the use of chemicals and antibiotics.

Prebiotics can improve growth performance and feed utilisation, boost health and enhance the disease resistance of aquaculture species (Delzenne 2003; Li and Gatlin 2004; Staykov et al. 2005; Staykov et al. 2007). Mannan oligosaccharide (MOS) is a prebiotic that has reputedly helped to remove pathogens from the intestine and stimulated the immune system of animals to which it was fed (Delzenne 2003).

Although there are many studies supporting the health benefits of MOS on aquatic species, none have involved the lobster, *P. homarus*. The aim of the present study was to evaluate the effect of dietary mannan oligosaccharide (MOS) on growth performance and gastro-intestinal health of *P. homarus.*

Methods

Three hundred puerulus of the lobster, *P. homarus* (0.16 g ± 0.02SE) were collected from buyers, transported to a sea-cage facility and acclimated for five days before the experiment. After acclimation, 10 puerulus were randomly stocked to each of 30 30 cm × 50 cm diameter tall cylindrical cages. Water temperature was 27–28.5°C, dissolved oxygen 6.5 ± 0.2 mg/l and pH 8.0–8.3 during the experiment.

There were six diet treatments (with five replicates each) including: a control basal diet with no MOS; basal diet with four levels of MOS supplementation; and trash-fish used as reference diet.

To prepare the diets, a basal formulation was prepared, as recommended by previous research that was minced and extruded twice to generate 2 mm diameter noodles. Four levels (0.2, 0.4, 0.6 and 0.8%) of mannan oligosaccharide (Bio-MOS®) were added to the control basal diet. Lobsters were fed slightly over satiation twice daily (25% at 07:00 and the remaining 75% at 17:00).

All lobsters in each cage were weighed and their carapace length was measured at the beginning of the experiment and at two-week intervals. At day 56 (end), five lobsters were randomly chosen for

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haemolymph sampling, proximate analysis and intestinal morphology examination. MOS level requirement was predicted using a compartmental model $y = a \times e^{-bx}(1 - e^{-c(x-d)})$ (SAS 1990; Vedenov and Pesti 2008) in which MOS concentration was the independent variable, and daily growth coefficient (DGC) was the dependent variable. ANOVA was applied to compare means among treatments using SPSS 18.

Results and discussion

The mean weight of lobsters among the treatments deviated significantly from day 28. Over the experimental period, lobsters fed with the various levels of MOS-supplemented diets significantly out-performed those fed on the basal diet. The greatest increase in weight was in the group of lobsters fed 0.4% MOS, at 31.51 times, followed by lobsters fed 0.6% MOS (31.43 times). The lowest weight increment was in the group of lobsters fed the basal diet (24.62 times). The weight of lobsters fed on by-catch increased by 26.20 times (Figure 1).

At the end of the experiment (day 56), survival rates of lobsters ranged from 68 to 78%. The higher survival rates were in lobsters fed diets D3, D2 and D6 which were 78%, 76% and 76% respectively, while the lower survival rates were for lobsters fed D1, D4 and D5 (Figure 1).

The intestinal surface area of lobsters fed with D2, D3 and D4 was significantly higher than that of lobsters fed on D1, D5 and D6 ($P \leq 0.021$) (Figure 2). Protein content in the muscle of lobster ranged from 21.73% in the group of lobsters fed the control to 22.68% in the group fed 0.4% MOS (D3). Lipid content ranged from 2.08 to 2.31%. There was no significant difference in protein, lipid or ash content in lobsters fed the different diets ($P > 0.05$).

The total *Vibrio* count in the gut of lobsters fed any MOS diet was significantly lower than that of lobsters fed the control ($P < 0.021$). There was no significant difference in *Vibrio* counts between lobsters fed control diets (D1) and those fed by-catch ($P = 0.256$). Also, there was no significant different between *Vibrio* counts for lobsters fed any MOS diet ($P = 1.743$) (Figure 3).

Granulocytes, including both granular and semigranular cells, contributed between 20.67% and 31.38%, while hyaline cells were the most dominant haemocytes in the haemolymph of lobsters, ranging from 68.62 to 79.33%. There was no significant difference in either hyaline or granulocytes in lobsters fed different diets ($P = 0.495$) (Figure 4).

Predicted optimal levels of MOS in the diet for maximal growth reduced over time as the weight of lobsters increased. The optimal MOS requirement for maximal growth of lobsters is 0.69%, 0.55%, 0.48% and 0.47% at days 14, 28, 42 and 56, respectively (Figure 5).

Conclusions and recommendations

This report confirms that the inclusion of MOS in the diet improves growth, survival rate, intestinal flora and gut surface area of the lobster, *P. homarus*. The optimal level of dietary MOS inclusion for maximal

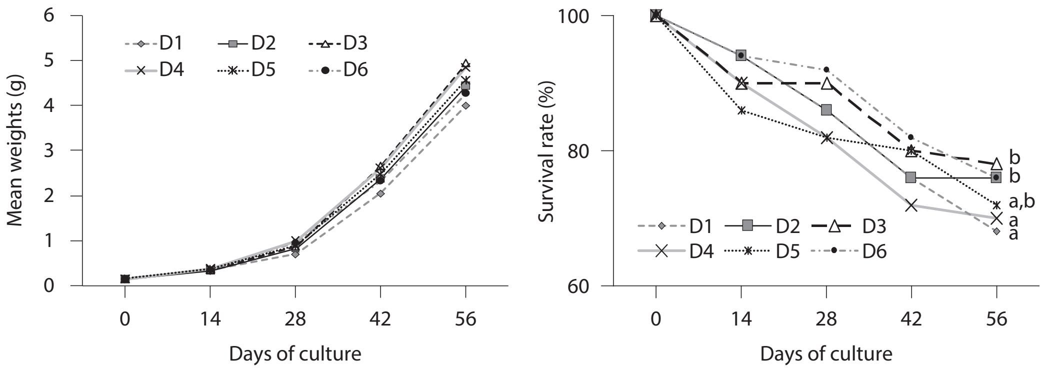

Figure 1. Average weight (left) and survival (right) of lobster fed different concentrations of MOS and by-catch. D1: control, D2: 0.2% MOS, D3: 0.4% MOS, D4: 0.6% MOS, D5: 0.8% MOS, D6: by-catch. Data are presented as mean ± S.E

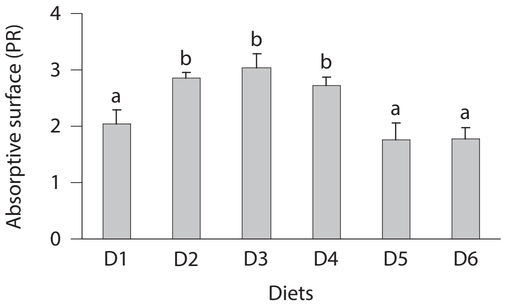

Figure 2. Intestinal absorptive area (PR = internal perimeter/external perimeter), arbitrary units of lobster *P. homarus* fed on different levels of MOS supplemented diets and by-catch at day 56. D1: control, D2: 0.2% MOS, D3: 0.4% MOS, D4: 0.6% MOS, D5: 0.8% MOS, D6: by-catch. Data are presented as mean ± S.E

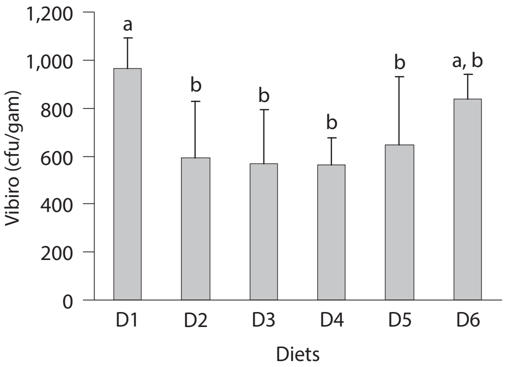

Figure 3. Total *Vibrio* spp. (cfu/gram) in the gut of lobsters at day 56 (n = 5). D1: control, D2: 0.2% MOS, D3: 0.4% MOS, D4: 0.6% MOS, D5: 0.8% MOS, D6: by-catch. Data are presented as mean ± S.E

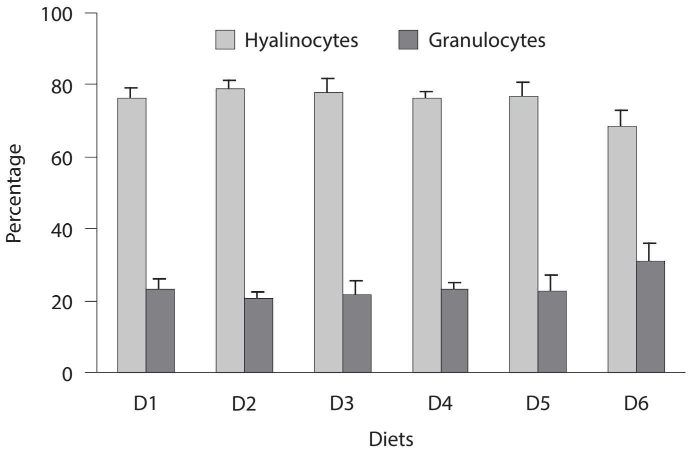

Figure 4. Percentage of haemocyte count of lobsters fed different concentrations of MOS. D1: control, D2: 0.2% MOS, D3: 0.4% MOS, D4: 0.6% MOS, D5: 0.8% MOS, D6: by-catch. Data are presented as mean ± S.E

growth of lobster was also determined, indicating that MOS at 4–6 g kg^{-1} be recommended. However, there are other potential positive benefits of MOS supplementation that are worthy of enquiry, such as increased resilience to environmental stress or pathogens, that should be investigated experimentally. It is also recommended that the effects of dietary MOS on different life stages beyond those in this study be examined.

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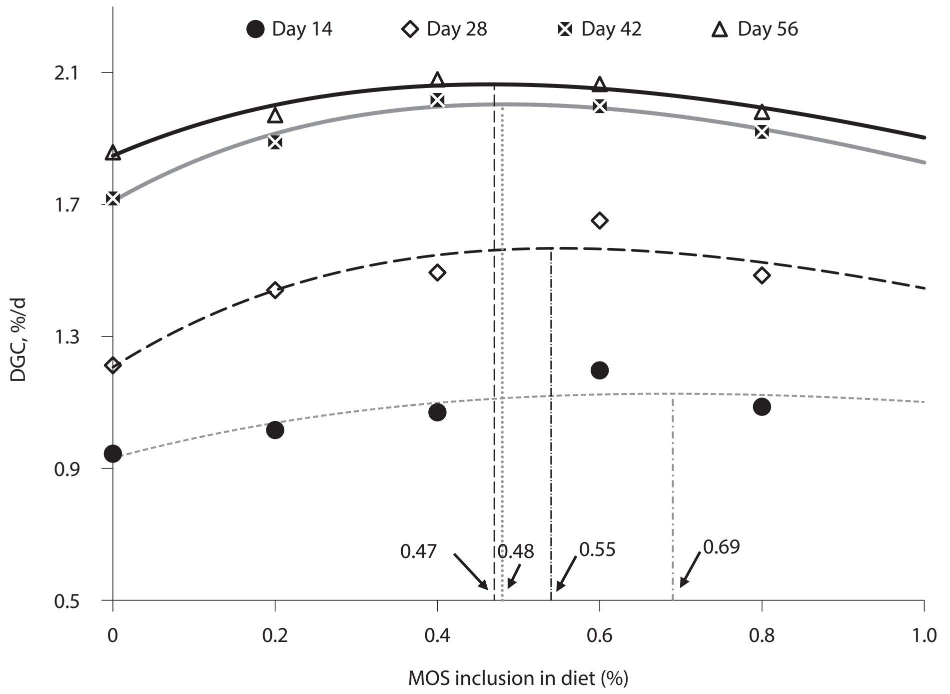

Figure 5. Predicted optimal MOS concentration in the lobster diet for maximal growth (DCG, %/day) at different days of culture of lobster, *P. homarus*

Puerulus lobster, *P. homarus* at the beginning of the experiment (left) and at 8 weeks (right)

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4. Lobster Growout

4.1 Comparative assessment of manufactured pellet feed and traditional trash fish feed on production of tropical rock lobster (*Panulirus ornatus*) and environmental effects in sea-cage culture in Vietnam

Le Lan Huong [1], Vinh Le Thi[1], Tuyen Hua Thai[1], Clive Jones[2], Huynh Minh Sang[1], Nguyen Trung Kien[1], Nguyen Thi Kim Bich[1], Hong Phan Thi Kim[1], Khang Nguyen An[1], Du Hoang Trung[1], Tam Pham Huu[1] and Hoc Dao Tan[1]

Introduction

The impact of disease on spiny lobster production in Vietnam has been significant over recent years, with production diminished in some years by more than 50%. Thuy et al. (2010) reported production in 2009 was approximately 700 tonnes while in previous years, production exceeded 1,500 tonnes. It is believed that disease has flourished due to environmental stress from localised pollution, largely caused by the traditional feeding practice of using trash fish which is often of poor quality and necessitates high feeding rates because of low food conversion ratio (FCR). Manufactured diet formulations provided in pellet form have been defined for tropical lobsters which support good growth under experimental conditions. These pellet diets are likely to have a much lower environmental impact and may help to reduce the stress that is leading to disease.

This notion prompted the design of a field-based comparison of traditional trash fish feeding with pellet feeding to confirm the efficacy of the pellet diet under normal commercial conditions, and to measure the relative environmental impact of the two feeding approaches. To best gauge the difference, the experiment included production of lobsters at two locations representing high and low farming intensity. The low farming intensity or 'pristine' site provided an opportunity to measure the difference in environmental impact exclusive of any background environmental degradation. The high intensity or 'degraded' site was a site of existing lobster farming, where the immediate environmental benefit of pellet feeding could be measured.

The experiment provides both an assessment of the manufactured diet under practical, commercial conditions, and analyses the comparative benefit it provides environmentally. The experiment was administered by the Institute of Oceanography in Vietnam which has proven capacity in this area. The following report provides a summary of the experiment as presented in the following three papers at the Symposium.

- Sea cages experiment using manufactured pellet for production of spiny lobster *(Panulirus ornatus)* Nha Trang, Vietnam—Le Lan Huong, Huynh Minh Sang, Clive Jones, Nguyen Trung Kien and Nguyen Thi Kim Bich
- Environmental effects of sea-cage grow-out—Le Thi Vinh, Le Lan Huong, Tam Pham Huu and Du Hoang Trung

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- Benthic fauna at Dam Bay Lagoon—Hua Thai Tuyen, Phan Thi Kim Hong, Nguyen An Khang and Dao Tan Hoc

Methods

Four replicate cages of 3.5 × 3.5 × 6 m deep were positioned within a floating frame in a 2 × 2 arrangement at each of four sites within Dam Bay Lagoon on Tre Island to the east of Nha Trang in south-central Vietnam (12°11'41.0"N 109°17'35.8"E). Two sites were within an existing lobster farming area and were nominated as 'degraded' sites, and two were located approximately 250 m away from the nearest commercial lobster farm, nominated as 'pristine' sites. Within these two locations, the two sets of four cages were positioned more than 10 0m apart to avoid interactive effects (Figure 1).

Juvenile lobsters of mean weight 47.5 g were stocked to each cage at a density of 4.5/m² (i.e. 55 lobsters per cage) and on-grown for 12 months from September 2010 to October 2011.

At each of the pristine and degraded sites, one set of four cages was fed with traditional trash fish and the other with a commercial lobster pellet (Lucky Star, Taiwan Hung Kuo Industrial Co., Ltd). Feed ration was as per a feeding schedule that was based on 3% (dry weight) of biomass, adjusted daily by visual inspection to detect uneaten food. Food was delivered into each cage within a feeding tray consisting of a circular 100 cm diameter frame covered in shade cloth with 10 cm high sides.

The metrics for lobster production included size, growth rate, survival and food conversion ratio based on samples taken at stocking, day 95, day 200, day 271 and at final harvest on day 379. Two-way ANOVA was performed (location, diet) on final weight and survival data.

For water quality assessment, pH, salinity and temperature were measured once at each cage site every two months with a Horiba U-10 water quality meter. For analytical purposes, four samples of water were taken at each of the four locations, two at the surface from opposing corners of the cage frame and two from near the sea floor at the same position. Sampling occurred seven times at two month intervals from October 2010 to October 2011. The following 11 variables were measured from those samples: DO, BOD5, TSS, nutrients $NH_{3,4}$, PO_4, chlorophyll-a, particulate organic phosphorus (POP), particulate organic nitrogen (PON), particulate organic carbon (POC), *E. coli* and fungi.

Four sediment samples were taken from each cage site at the four corners of the floating frame,

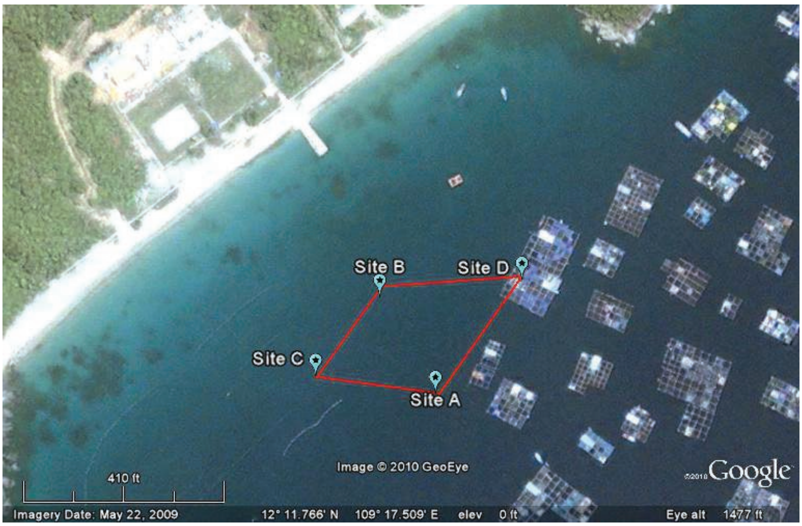

Figure 1. Locations for the experiment within Dam Bay Lagoon. Site A: degraded with pellet feed; site B: pristine with pellet feed; site C: pristine with trash fish feed; and site D: degraded with trash fish feed

with a van Veen grab at four month intervals (i.e. four measurements). Variables measured were: *E. coli,* fungi, chlorophyll-a, organic C, N and P, and relative fractions of mud (<0.063 mm), sand (0.063 to 2.0 mm) and gravel (> 2.0 mm). Both water and sediment samples were preserved and analysed following standard procedures (APHA 2005; Austin 1988; FAO 1975; Parsons et al. 1984).

In addition to the environmental sampling at and below the experiment cages, water and sediment samples were also taken from four other sites within Dam Bay Lagoon on two occasions (August and October 2011) for comparative purposes. The location of these additional sampling sites is shown in Figure 2.

All analyses were conducted using SPSS (Version 21). Student t-tests were applied for pair-wise testing between subgroups of the water quality data. A three-way multivariate analysis of variance (MANOVA) in which all factors (date, location and diet) were considered to be fixed, was applied to the water quality data.

A faunal study of the sediment beneath the cages was also performed, by examining the fauna within the sediment samples taken, as described above. Sediment was sieved with a 0.5 mm nylon mesh sieve. Echinoderms were preserved in 70% alcohol and all other specimens were fixed in 10% buffered formalin. All sieved material was maintained in this condition until sorted in the laboratory, where specimens were identified using taxonomic keys. Raw data were stored and analysed in Excel spreadsheets. Bray-Curtis similarity index was used for analysis of structure of species composition between months. Simper analysis was used to determine the contribution to similarity within a group.

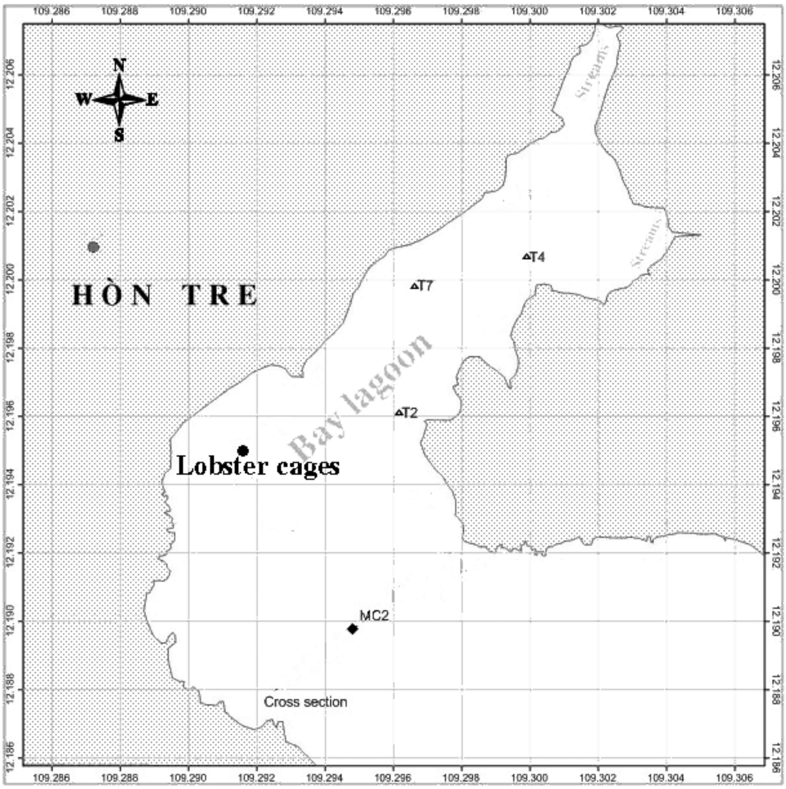

Figure 2. Locations within Dam Bay Lagoon where additional water and sediment samples were taken for comparison with lobster cage location

Results and discussion

Lobster production

The mean weight of lobsters for each treatment at each of five sampling events, including stocking and harvest, are presented in Table 1 and Figure 3. Final (harvest) weight is presented in Figure 5. Survival at harvest is presented in Figure 4. Growth data and FCR values for each treatment are presented in Table 2.

A two-way ANOVA was conducted that examined the effect of diet and site on survival. There was a statistically significant interaction between the effects of diet and site on survival $F_{(1, 12)}$=6.037, p=0.03, although no significant simple main effect for either diet or site. The combination of trash fish diet at the pristine site resulted in the highest survival with a mean of 65.5%.

Similarly, a two-way ANOVA was conducted that examined the effect of diet and site on mean harvest weight. There was no statistically significant

Table 1. Mean weight (g ± SE) of lobsters through the duration of the experiment at the four sites

	Day 0	Day 95	Day 200	Day 271	Day 379
Site A Pellet feed Degraded area	47.0 ± 10.9	151.2 ± 23.6	276.0 ± 44.5	355.3 ± 66.3	547.4 ± 112.8
Site B Pellet feed Pristine area	47.3 ± 10.0	132.5 ± 26.0	261.0 ± 48.3	367.0 ± 64.1	511.2 ± 106.1
Site C Trash fish feed Pristine area	47.1 ± 10.4	175.5 ± 32.2	317.5 ± 51.0	423.3 ± 53.4	554.3 ± 85.1
Site D Trash fish feed Degraded area	48.4 ± 9.8	169.5 ± 30.8	322.7 ± 63.6	424.4 ± 93.1	618.7 ± 121.9

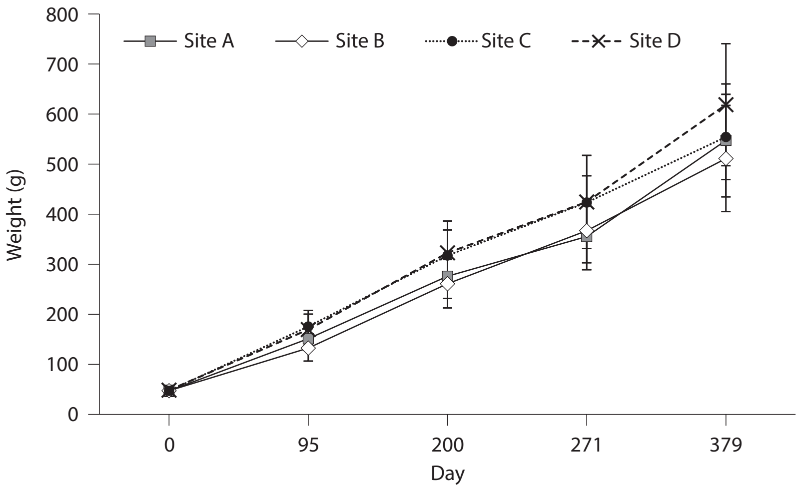

Figure 3. Mean weight g(SE) through 12 months of the experiment at four sites. Site A: degraded with pellet feed; site B: pristine with pellet feed; site C: pristine with trash fish feed; and site D: degraded with trash fish feed

interaction between the effects of diet and site on weight. The main effects analysis showed that both diet (p=0.010) and site (p=0.013) had a significant effect on weight. For diet, trash fish generated a larger harvest weight than pellets, and for site, degraded generated a greater weight than pellets. The combination of the trash fish diet at the degraded site resulted in the greatest weight (mean 619.1 g ± 20.1).

A number of environmental and health issues arose over the duration of the experiment which are likely to have impacted negatively on the survival and growth of lobsters both in the commercial farms and in the experiment. An outbreak of milky haemolymph disease occurred in the Dam Bay Lagoon starting in September 2010, causing about 10% loss in the commercial farms. Introduction of Babylon snail farming from January 2011 was believed to pollute the environment, causing lobster losses in the commercial farms. A fish kill event occurred starting in September 2011 affecting wild fish in the lagoon, caused by an unidentified environmental issue that may have been linked to heavy rainfall and runoff from the island.

Growth of lobsters in the experiment was equivalent to standard industry levels, although survival was somewhat lower, possibly attributable to the negative environmental and health impacts described.

Environmental assessments

Water quality

Temperature, salinity and pH values over the course of the experiment are presented in Table 3. There were no substantial differences in these variables among the experiment cage locations. Temperature ranged from 25.5 to 29.6°C, salinity from 32.1 to 34.5ppt and pH from 8.12 to 8.18.

Mean values for each of the seven bi-monthly measurements for the 11 water quality variables at the four treatment sites are presented in Figure 6.

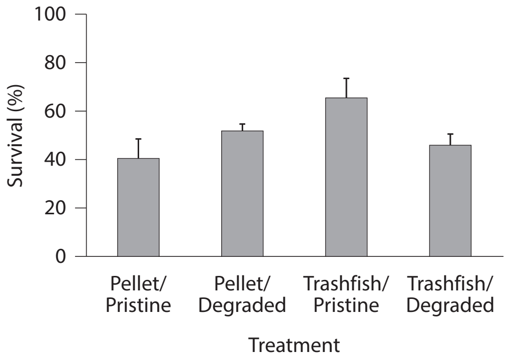

Figure 4. Survival (% ± SE) of lobsters after 12 months culture at four sites representing feeding with pellets or trash fish and at pristine or degraded locations

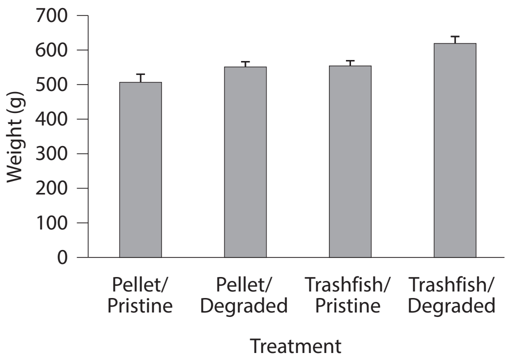

Figure 5. Final mean weight of lobsters (g ± SE) after 379 days of culture subjected to the four treatments

Table 2. Growth statistics and FCR for *P. ornatus* lobsters grown over 379 days at four sites

	Site A Pellet feed Degraded area	Site B Pellet feed Pristine area	Site C Trash fish feed Pristine area	Site D Trash fish feed Degraded area
Initial weight (g)	47.0 ± 10.9	47.3 ± 10.0	47.1 ± 10.4	48.4 ± 9.8
Final weight (g)	547.41 ± 13.40	511.22 ± 20.70	554.13 ± 15.16	619.06 ± 20.11
SGR (%/day)	0.68 ± 0.01	0.65 ± 0.01	0.68 ± 0.01	0.71 ± 0.01
AWG (g/week)	9.73 ± 0.27	9.02 ± 0.40	9.85 ± 0.28	11.09 ± 0.36
FCR	7.93 ± 0.41	8.74 ± 0.59	47.29 ± 7.71	63.28 ± 10.51

Data for the four other locations in Dam Bay Lagoon are presented in Figure 7, alongside pooled data (mean) for the lobster cage site. Analysis of variance was performed for each of the variables.

ANOVA of all water quality variables with depth as the fixed factor revealed no significant difference, and the data for surface and bottom measurements were then pooled. This suggests there was no stratification within the water column.

Using two-way ANOVA (location x feed type) there were no significant differences for any of the variables, with the only exceptions being a significant interaction for BOD5 ($F_{(1,107)}$=3.87, p=0.05) for which mean values were highest for degraded location with trash fish (6.88 and 6.92 respectively), and for particulate organic phosphorus a significant effect for diet ($F_{(1,107)}$=8.97, p=0.045), where trash fish had a mean POP value of 3.15µg/L and for pellet, the mean was 2.58µg/L.

The analyses indicate strong seasonal differences, most likely influenced by wet season rainfall and runoff from the adjacent land. Water quality variables were generally higher in October (both 2010 and 2011) when the wet season starts. At the time of each sampling, there were no significant differences in water quality between the locations or diets. This lack of difference may have been influenced by the prevailing current which is likely to have created sufficient mixing to minimise any differences.

Overall, there was no clear treatment effect and trash fish and pellets had an equivalent impact on water quality. Where higher readings of variables were recorded, it can be attributed to seasonal factors, particularly the influence of wet season and associated terrestrial runoff.

Comparison of water quality from the lobster cage area with that of the other four locations in Dam Bay Lagoon (Figure 7) suggests water quality was equivalent or better than the other locations.

Sediment quality

Mean values for all sediment variables are presented in Figures 8 and 9. For sediment variables, there were significant differences between dates, with some indication of higher values for the February and June readings particularly for organic Phosphorus, Nitrogen and Carbon, and proportion of mud. The higher values of *E. coli* and fungi in the sediment at the October readings can be attributed to seasonal factors, as October coincides with the onset of the wet season with increased terrestrial runoff.

Examining the data at each date for variance between location and diet indicated several significant differences, although none that could be interpreted as a clear treatment effect. It was apparent that sediment quality beneath the cages was not differentially affected by the different diets or by the localised farming activity (i.e. pristine versus degraded).

This conclusion was further supported by the comparison of sediment quality at the four other sites within Dam Bay Lagoon (Figure 9) which shows that sediment at the lobster cage area was equivalent or of better quality (i.e. lower values) than the other sites.

Benthic fauna

A total of 14,654 macro-invertebrate individuals were isolated from 94 sediment samples over the duration of the experiment. These individual specimens were assigned to 363 taxa, most to genus or species, from 136 families of four phyla of animals, as follows:

- Annelida—182 taxa (Polychaetes only)
- Mollusca—82 taxa
- Arthropoda—78 taxa
- Echinodermata—28 taxa.

The number of invertebrate species at the lobster sea-cage locations was significantly higher than the surrounding areas in Dam Bay Lagoon. Similarly, the species composition at the lobster cage sites area was significantly different from the surrounding areas in the lagoon. The benthic fauna results also showed the species composition similarity changed over the course of the experiment. The faunal differences between the lobster cage sites and the surrounding bay sites were almost entirely attributed to changes in density and species composition of polychaetes.

Table 3. Water quality for the duration of sea-cage experiment

	Oct 2010	Dec 2010	Feb 2011	Apr 2011	Jun 2011	Oct 2011
Temperature °C	29.6	26.0	25.8	25.5	28.3	27.4
Salinity ppt	33.3	33.5	33.5	34.1	34.5	32.1
pH	8.18	8.18	8.14	8.13	8.12	8.13

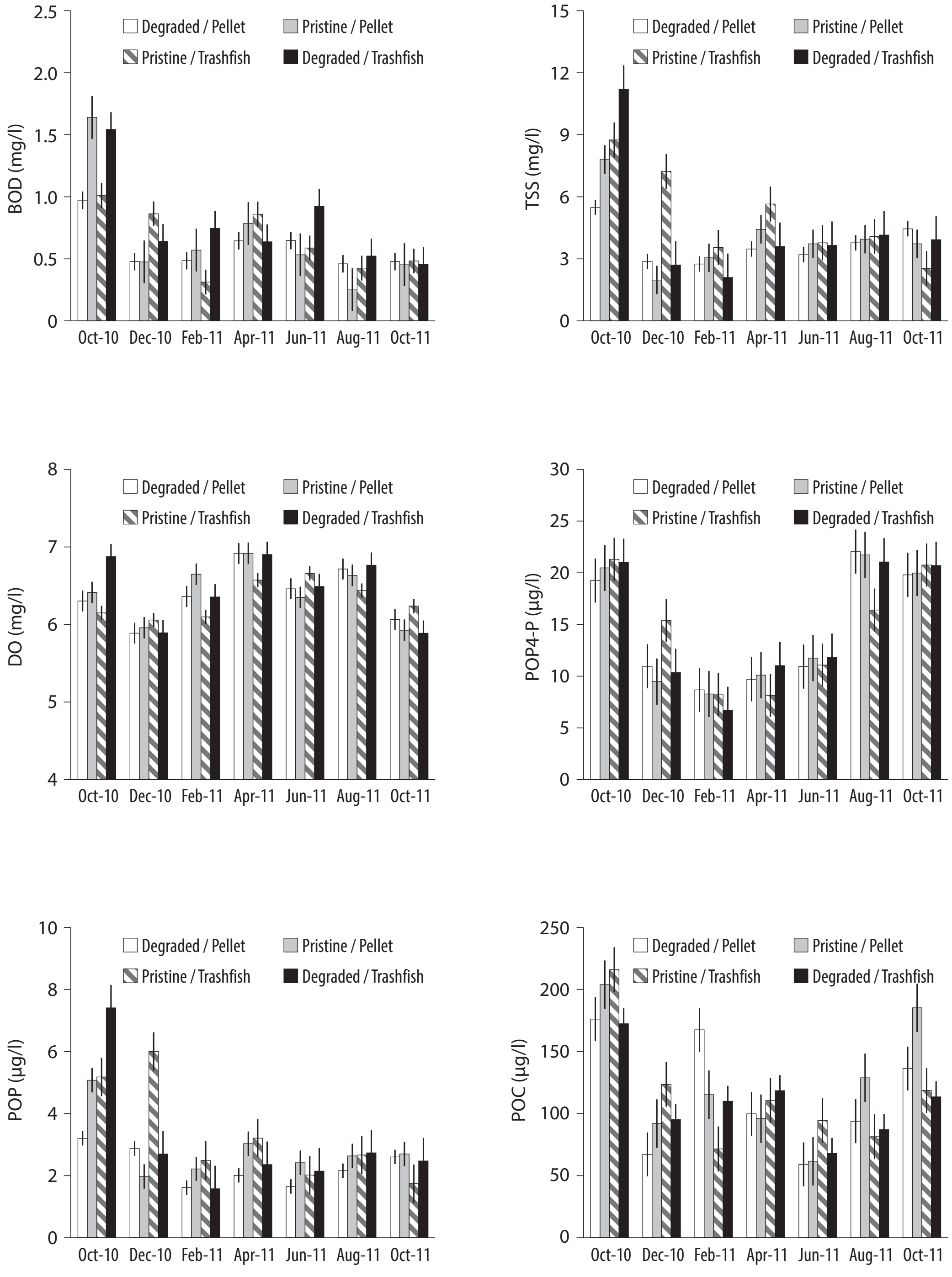

Figure 6. Water quality data (mean + SD) at each of the four treatment locations for the duration of the experiment (surface and bottom readings combined) (continued)

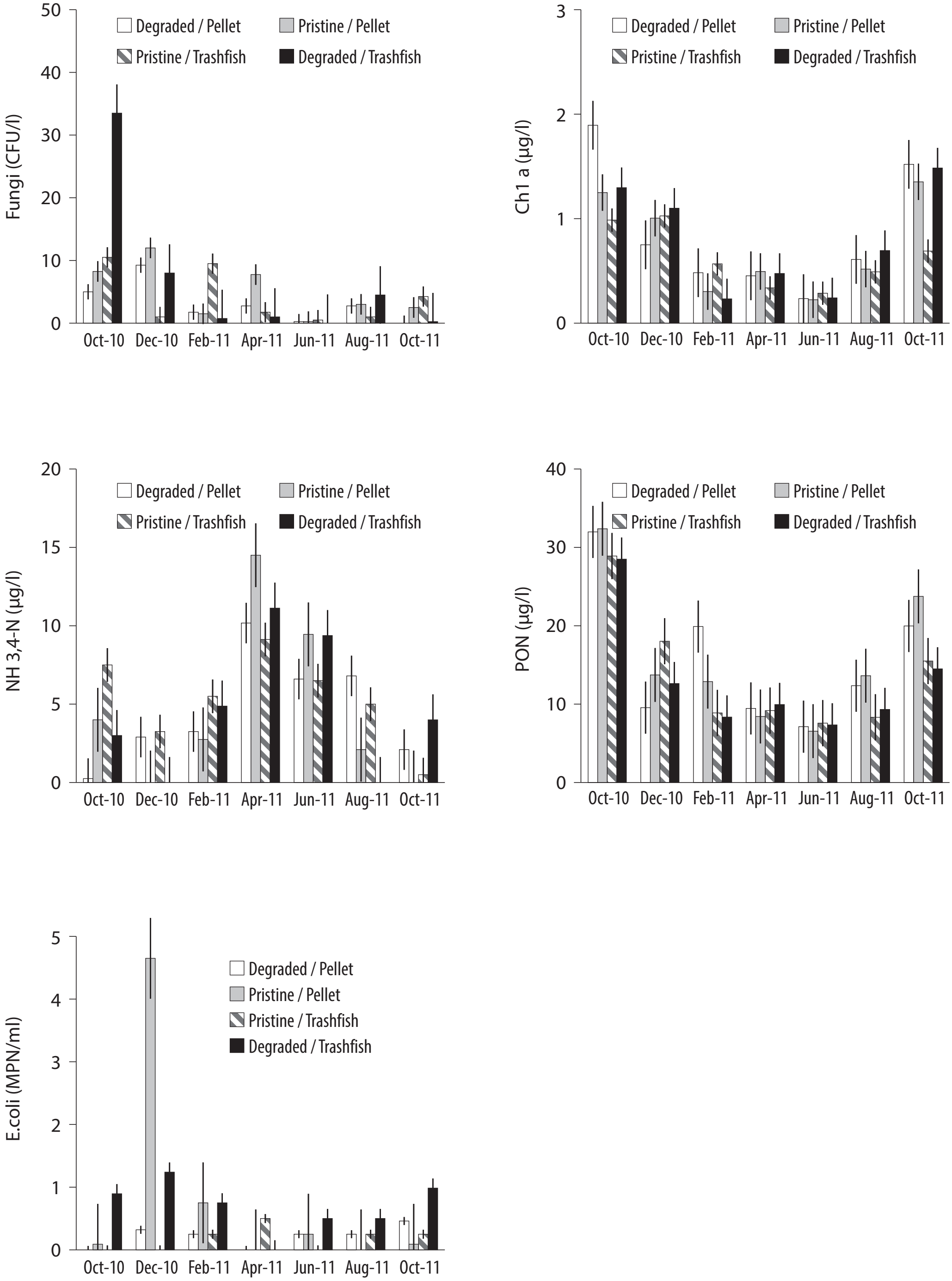

Figure 6. (cont'd) Water quality data (mean + SD) at each of the four treatment locations for the duration of the experiment (surface and bottom readings combined)

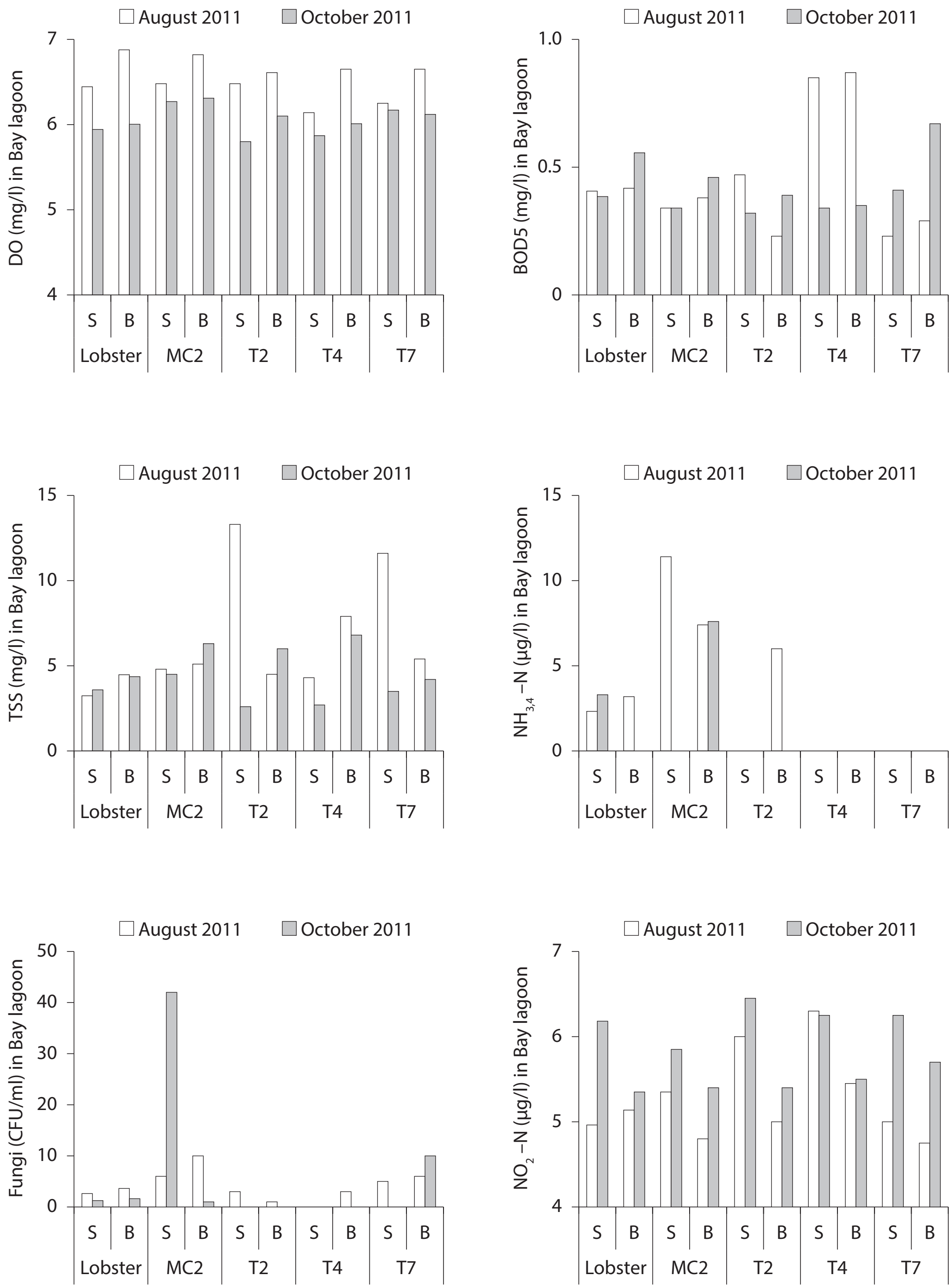

Figure 7. Water quality data (mean + SD) at four locations in Dam Bay Lagoon and at lobster cages in August and October 2011. S = surface reading; B = bottom reading (continued)

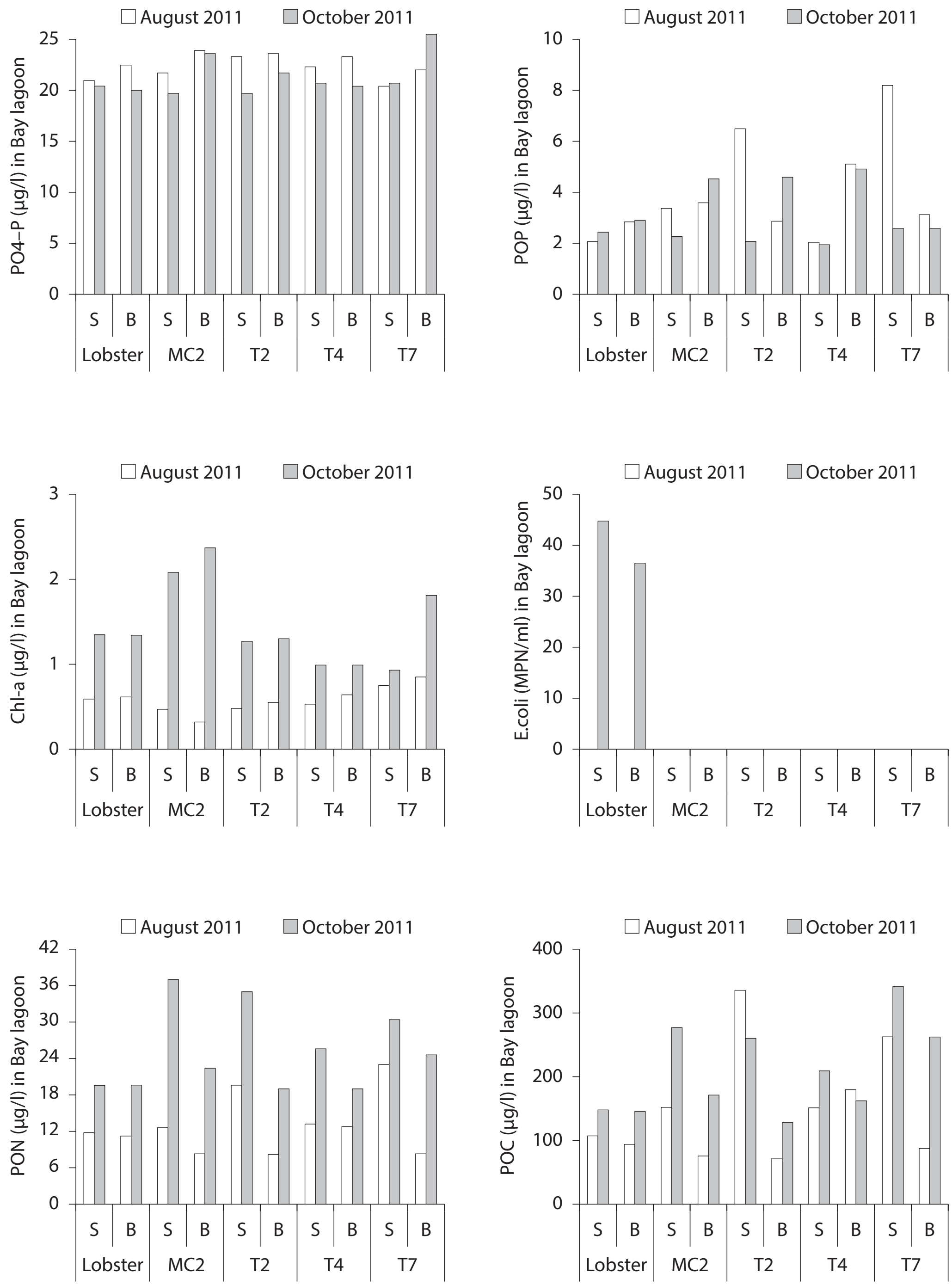

Figure 7. (cont'd) Water quality data (mean + SD) at four locations in Dam Bay Lagoon and at lobster cages in August and October 2011. S = surface reading; B = bottom reading

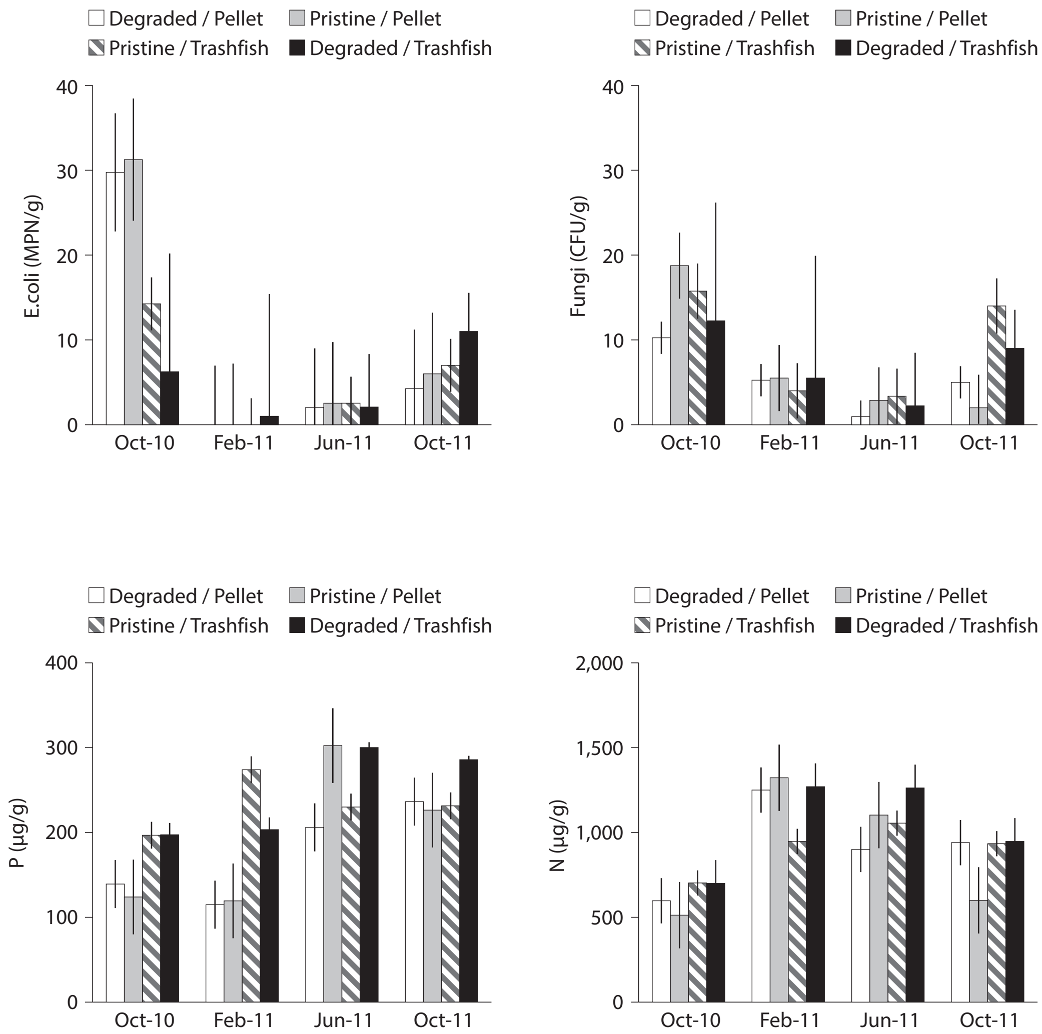

Figure 8. Sediment quality data (mean + SD) at each of the four treatment locations for the duration of the experiment (continued)

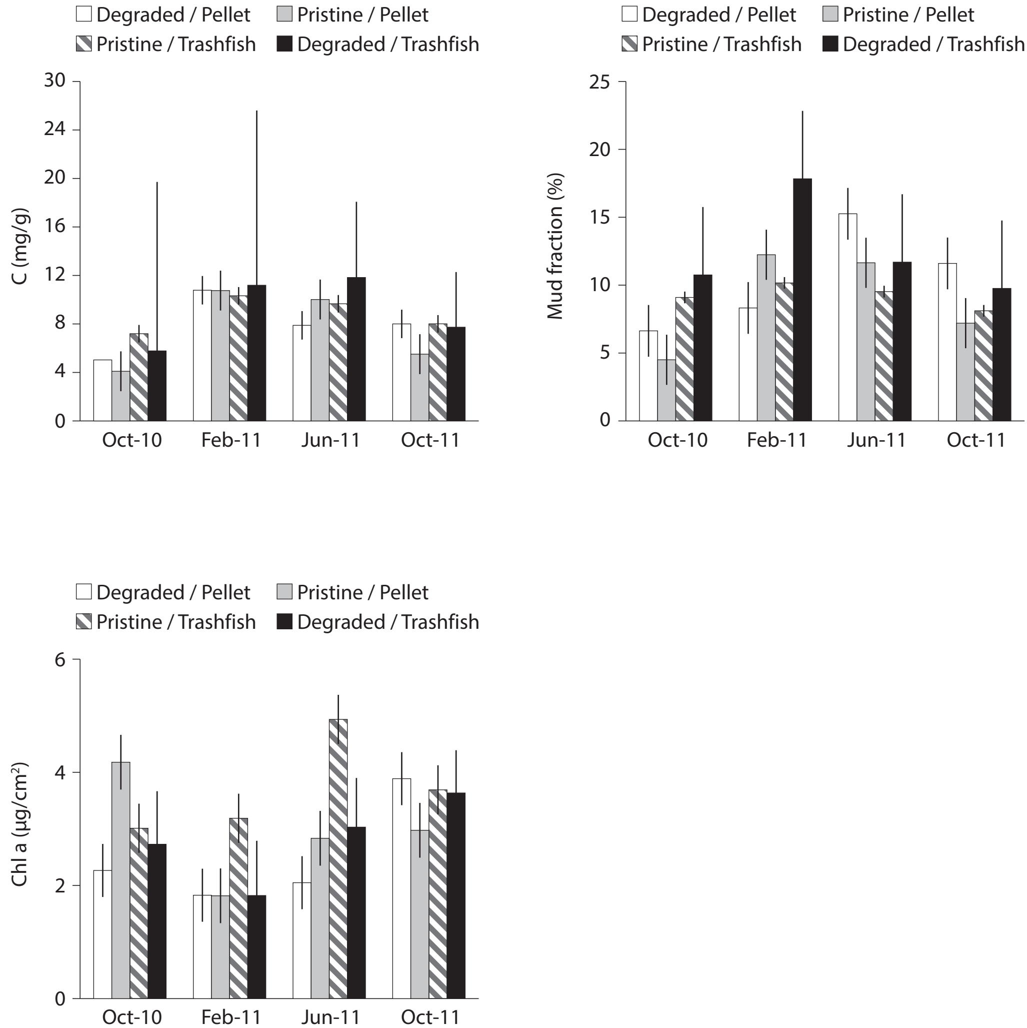

Figure 8. (cont'd) Sediment quality data (mean + SD) at each of the four treatment locations for the duration of the experiment

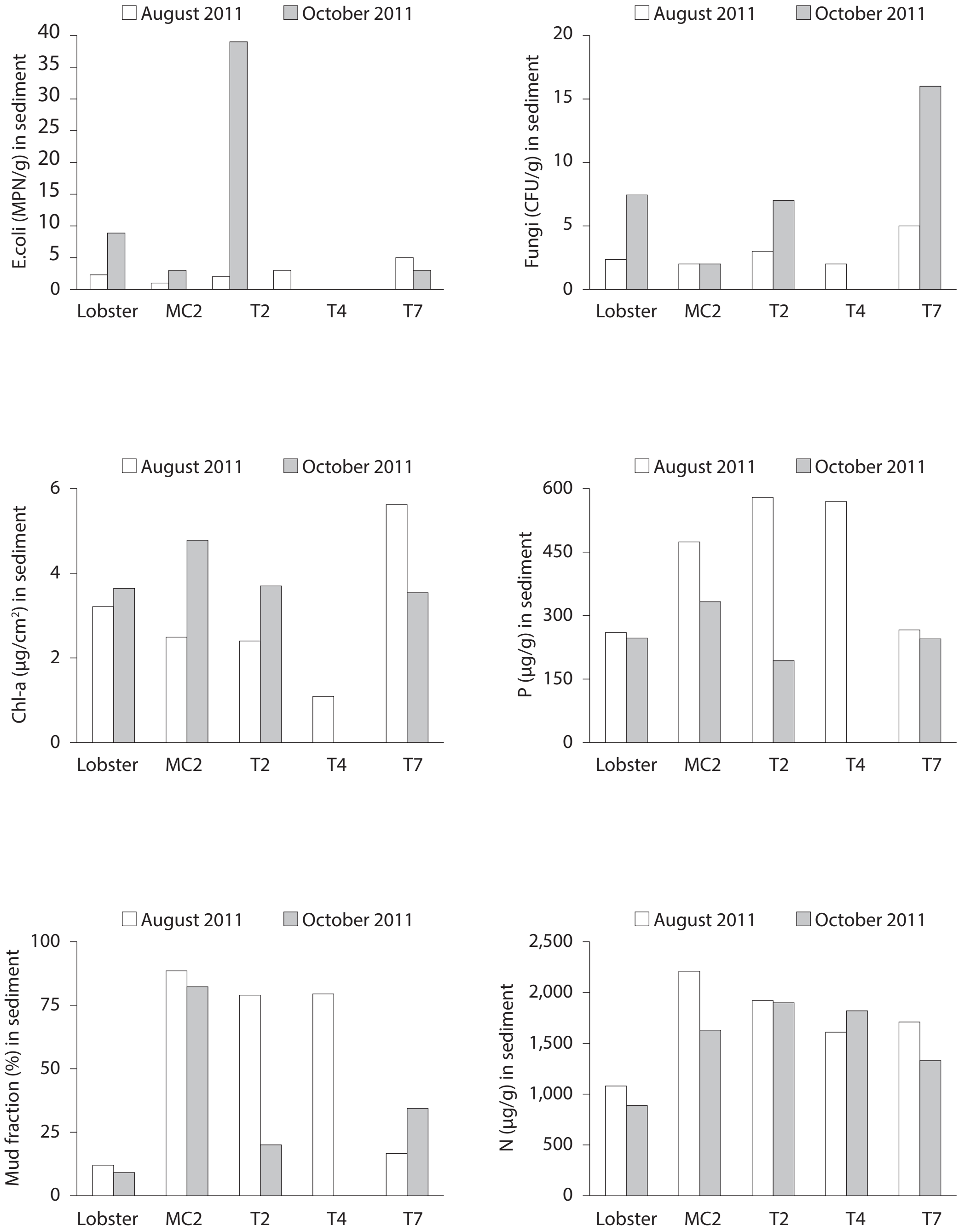

Figure 9. Sediment quality data (mean + SD) at four locations in Dam Bay Lagoon and at lobster cages in August and October 2011 (continued)

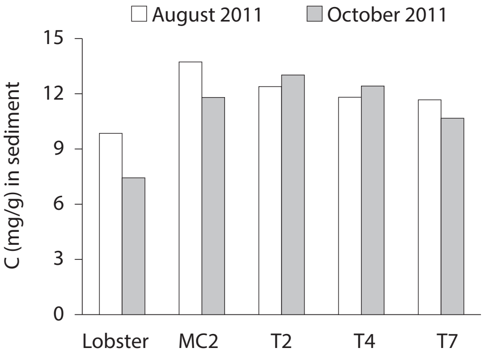

Figure 9. (cont'd) Sediment quality data (mean + SD) at four locations in Dam Bay Lagoon and at lobster cages in August and October 2011

Conclusions and recommendations

Although trash fish generated slightly better growth, its effect on survival was equivalent to that of pellets. It can therefore be concluded that a pellet diet can be used as a successful alternative food source to trash fish in culture of *P. ornatus* at commercial scale. The pellet food used (Lucky Star lobster diet) is developmental, and further improvements to its nutritional adequacy and attractiveness are likely.

The FCR's experienced in this experiment (Table 2) suggest considerable wastage of feed. Clearly, an FCR for a high specification 'total diet' pellet should be less than three, and in this experiment it averaged 8.3. In laboratory, tank-based experiments on the same species using the same diet, FCR's under three have been achieved. It is highly likely that a considerable proportion of the pellets used in the experiment were lost from the cages due to wave and current action. Improving the design and application of feeding trays to best retain the pellets may mitigate such loss. The FCR for trash fish in the experiment averaged 55.3 which is somewhat higher than that which is typical for the Vietnam lobster farming industry. Anecdotal data suggest the typical FCR for the industry is in the range of 35 to 40. Nevertheless, based on the FCR's recorded for the experiment and the growth rates and survival achieved, the pellet diet at a cost of A$5.00 per kg provides a cheaper overall feed cost ($41.50/kg) than trash fish ($55.30/kg) which is typically around A$1.00 per kg. Under improved feeding management, FCR for pellets should be reduced to less than three, which equates to an overall feeding cost of $15/kg, far cheaper than the industry average of $35 to $40/kg using trash fish.

The differences between water quality data from surface and bottom sample layers were negligible, suggesting good exchange of water and no stratification.

The variation of most of the water quality variables appeared to correlate with seasonal factors rather than factors relating to lobster production. Trash fish and pellets appeared to have an equivalent impact on the surrounding water quality, and that impact appeared to be negligible when compared to general background water quality in the surrounding bay. Nevertheless, once improved feeding husbandry for pellets is achieved (i.e better FCR and therefore reduced feed quantity) pellet feeding is likely to result in less wastage of organic materials into surrounding waters due to the more stable nature of pellets and the significantly lower feed biomass applied.

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4.2 Status report of Vietnam lobster grow-out

Tuan Le Anh[1] and Clive Jones[2]

Introduction

This paper presents information on the status of lobster farming in Vietnam including:

- status
  - history
  - production systems
  - scale and geographical location
- constraints
  - disease
  - mortality of wild caught puerulus
  - trash fish feeding issues
  - availability of sea-cage sites
- opportunities
  - land-based production systems
  - use of pellet feed
  - expansion from *Panulirus ornatus* to *Panulirus homarus*
  - impact of hatchery supply of juveniles.

Status

The history of lobster farming in Vietnam is summarized in Table 1.

Production systems initially comprised fixed cages with an outer frame made of salt-resistant wood, 10–15 cm diameter and 4–5 m length, which were embedded every 2 m to create a rectangular or square shape. Each cage normally has a cover, and the cage may be resting on or suspended above the sea floor. Cages placed on the sea bed had a layer of sand across the floor, while those fixed off the bottom had a gap of about 0.5 m from the sea bed. The fixed cages were the earliest form of lobster farming systems (Figure 1).

Table 1. Key events in the history of lobster farming development in Vietnam

Period	Main events
1975–1985	Annual catch < 100 t; *P. ornatus*—moderate part of the supply, only modest local demand
1986–1991	Chinese demand for lobsters grew rapidly, especially for *P. ornatus* >1 kg
1992–1995	Fishers started fattening lobsters; fixed cages; production < 100 t
1996–1999	Fishers started collecting swimming pueruli; production < 300 t
2000–2006	Mainly floating cages; production 500–2000 t; signs of overload
2007–2009	Disease problems; production ~ 860 t (2008/2009); government-led industry planning implemented
2010–2014	The industry recovered; production for 2010 to 2014 about 1,500 t per annum

Submerged cages are also commonly used, particularly for nursery culture of smaller lobsters, although in some instances for grow-out to market size. The frame work is made of iron with a diameter of 15–16 mm. The bottom shape is rectangular or square, with an area normally between one and 16 square metres. The height is 1.0–1.5 m and the cage has a cover and a feeding pipe (Figure 2).

Floating cages are currently the most common production system for lobster grow-out in Vietnam. The cages are either square or rectangular with sides of 2.8–4.0 m with 4.0 x 4.0 m being the most common dimensions. The frame supporting the cages is made from timber planks with length of 3.5–5.0 m, width of 8–15 cm and thickness of 6–10 cm. The floats supporting the frame structure are re-used plastic drums of about 200 L or smaller plastic cans of 20 L capacity (Figure 3).

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Production of lobsters in lined earthen shrimp pond systems, as an alternative to sea-cage farming, was assessed in 2011. Due to high variability in salinity (20–35‰) and temperature (20–34°C) which caused growth inhibition, and at the extremes, significant mortality, earthen ponds are considered unsuitable for lobster production.

The geographical extent of lobster farming in Vietnam is depicted in Figure 4. Vietnam lobster production statistics, in terms of volume, value, productivity and number of sea cages, are presented in Figure 5.

Figure 1. Photo of typical fixed lobster farming cage in Vietnam

Figure 2. Photo of submerged cage for lobster farming in Vietnam

Figure 3. Photo of typical floating cages used for lobster farming in Vietnam

Figure 4. Map showing areas of lobster seed catch and sea-cage grow-out in Vietnam

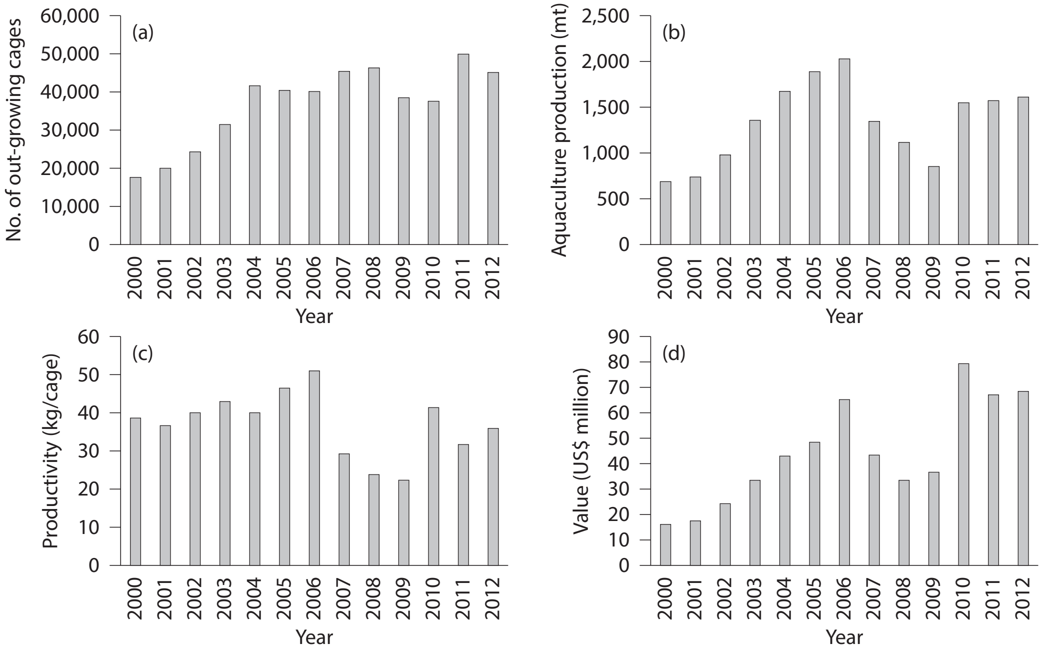

Figure 5. Production statistics for Vietnam lobster aquaculture, including volume, value, productivity and number of cages

Constraints

Several health and disease issues impact lobster farming and constrain production. The most common are: red-body disease, milky disease, black gill disease, big head syndrome and separate head syndrome. More detailed information on these is presented in Chapter 5.4.

The proportion of lobster farms impacted by milky disease in 2007 in the farming areas of Ninh Thuan, Binh Thuan, Phu Yen and Khanh Hoa provinces was 61%, 71%, 36% and 31% respectively. Approximately 50% of total production was lost due to milky disease from 2007 to 2009; equating to approximately US$50 million lost and affecting more than 5,000 households.

Before 2002, the typical survival rate through the grow-out phase was 70%, but during the milky disease outbreak of 2007 to 2009 it dropped to around 50% with approximately US$30 million lost annually.

The mortality of the captured lobster seed prior to stocking for grow-out is between 40 and 60%. This mortality can be attributed to a variety of factors, including capture technique, handling, transport, and during the nursery phase to nutrition, husbandry issues. If lobster losses during the capture through nursery phase could be reduced to only 10%, Vietnam's total annual lobster production could be doubled without any increase in catch.

Vietnam's lobster production is currently constrained by suboptimal nutrition, resulting from reliance on a fresh diet of low-value marine species, collectively referred to as trash fish. Trash fish, as used by lobster farmers, is made up of a variety of species including molluscs (~10%) crustaceans (~17%) and fish (~73%). The molluscs comprise squid, cuttlefish and some shellfish. Crustaceans include shrimps, crabs and stomatopods. Fish include lizard fish (Siganidae), big-eye fish (Nemipteridae), pony fish (Leiognathidae) and others. Although an appropriate mix of these trash fish species can provide a reasonable diet, the condition of the fish when applied to the lobster cages is often poor, and over time this diet is deficient in essential nutrients. The food conversion ratio (FCR) of trash fish ranges from 17 to 30 on a fresh weight basis. It is estimated that the excess nitrogen introduced into the sea from uneaten particles and leaching of the trash fish is between 150 and 410 g/kg lobster produced. Given average annual production of 1,500 tonnes, this equates to ~225 to 615 tonnes of nitrogen released into the environment each year. It is likely that such pollution is contributing to the lobster health issues referred to above.

Further compounding the unsuitability of trash fish as lobster feed is the increasing price of trash fish, which has quadrupled in the past 10 years from an average of US$0.25 to more than US$1.00 per kg. A formulated manufactured diet (i.e. a pellet diet) will be necessary to provide optimal and sustained nutrition.

Lobster farming in Vietnam is also constrained by availability of suitable sea-cage sites. Due to competing demands on marine areas, particularly for increasing tourism, many established lobster sea-cage sites have been closed to farming, forcing farmers to relocate or stop farming. Table 2 provides data illustrating this point for the two primary lobster farming provinces of Phu Yen and Khanh Hoa.

Opportunities

Much of the early research on aspects of husbandry and feed development was conducted in tanks, and growth and survival in such systems was generally good. This suggests that commercial lobster production may be possible in tanks, although the cost of this approach is likely to be relatively high. In Vietnam, there is considerable interest in assessing underutilized shrimp/clam hatchery tank production systems as an alternative for lobster production, which in turn may enable disease issues to be better managed.

As the use of trash fish as a food source would be inappropriate for tank systems, where stocking density may be quite high, pellet feeds will be essential. Such a diet can provide good nutrition and minimal waste; both of which are necessary for a land-based approach.

There is an opportunity in Vietnam to increase lobster production through expansion beyond the target species, *Panulirus ornatus*. Although this species is likely to remain the major cultured species in Vietnam, the availability of seed of *Panulirus homarus* presents an opportunity to produce a secondary species. Although *P. homarus* fetches a lower market price, it is believed to be more disease resistant and more tolerant to environmental variation. Its growth rate is as fast, if not faster, than *P. ornatus*, at least to a size of 300–500 g.

Having established a successful lobster farming industry, based on natural supply of seed, Vietnam lobster farming could expand significantly if a hatchery supply of reared pueruli could be established. At present, this appears to be some years away, but if it is successful, Vietnam is in a strong position to capitalize.

Summary and conclusions

The Vietnamese spiny lobster aquaculture industry has developed for nearly 20 years with annual production now consistently about 1,500 t, with a value of more than US$100 million.

The major constraints to the industry include:

- disease
- mortality of wild caught puerulus
- trash fish feeding issues
- availability of sea-cage sites.

The major opportunities are:

- land-based production systems
- use of pellet feed
- expansion from *P. ornatus* to *P. homarus*
- industry expansion when hatchery supply of juveniles is available.

Table 2. Data on sea cages and available sites for lobster farming in Phu Yen and Khanh Hoa provinces of Vietnam

Trait	Phu Yen province	Khanh Hoa province
Maximum number of lobster cages (2008)	19,414	27,000
Current number of lobster cages (2013)	17,100	20,300
Planned number of lobster cages (2015)	18,100	20,000 to 16,000
Current number of farming areas (2010)	3 (Song Cau, Tuy An, Dong Hoa)	4 (Van Ninh, Ninh Hoa, Nha Trang, Cam Ranh)
Planned number of farming areas (2015)	1 (Song Cau) ~320 ha	3 (Van Ninh, Nha Trang, Cam Ranh) ~800 ha

4.3 Preliminary assessment of tank-based grow-out of tropical spiny lobsters (*Panulirus ornatus*) in Vietnam

Tuan Le Anh[1] and Clive Jones[2]

Introduction

Following an assessment of growing tropical rock lobsters in earthen shrimp ponds (both in Australia and Vietnam) which demonstrated that this environment was unsuitable, focus shifted to tank systems, where better control of water quality (particularly temperature and salinity) could be achieved.

ACIAR provided additional funding for this research through a small research activity project: FIS/2011/008 to supplement the assessment of land-based production systems which was the objective of the primary project: SMAR/2008/021. The research undertaken in Vietnam examined the use of typical Vietnamese shrimp hatchery tanks as an alternative to sea-cage farming. The research sought to examine density and shelter in regard to production of lobsters in tanks, and establish baseline production statistics for survival and growth.

Methods

Three successive experiments were performed over durations of: 60 days (Experiment #1), 120 days (Experiment # 2) and 180 days (Experiment #3), using the same pool of lobsters. Two treatments were applied for stocking density and shelter setting with 4 replicates. Initial mean weight of lobsters in the experiments was 25 ± 9.5 g, 34 ± 12.6 g and 84 ± 38.1 g. Three densities were applied in each successive experiment as follows: Experiment 1: 6, 8, 9.5; Experiment 2: 5, 6.5, 8; and Experiment 3: 4, 5.5, 7 lobsters per m^2. For each density, there was one of two shelter settings: table shelter or pipe shelter. The table shelter consisted of a PVC rectangle 25 × 90 cm supported off the tank floor by 10 cm legs on each corner. The pipe shelter consisted of a 25 cm length of 5 cm diameter PVC pipe placed on the tank floor. Experiment tanks were of concrete construction, 2m × 2m by 1m deep. For table shelter treatments, one shelter was provided per tank. For the pipe shelter treatments, 5 pipes were provided in each tank.

Lobsters were fed a laboratory-manufactured diet, as per Table 1, which had been used successfully in earlier tank experiments.

Table 1. Composition of manufactured diet used in the tank experiments

Ingredient	Percentage
Fresh fish	40
Fish meal	50
Shrimp powder	5
Fish oil	1
Others	4
TOTAL	100

Results and discussion

Throughout all experiments, water quality remained quite stable, as shown in Table 2. Survival and growth data for the experiments is presented in Table 3. Two-way analysis of variance indicated no significant interaction between treatment main effects ($P > 0.05$) in any of the three experiments. The only significant treatment effect was for density in Experiment #3,

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where survival was significantly less at the highest density than in the lower two densities.

There was no significant difference in the growth of lobsters between shelter settings ($P > 0.05$) (Table 4). Table shelter setting resulted in a significant improvement ($P < 0.05$) in survival.

Conclusions and recommendations

Tank systems appeared to provide a suitable environment for culture of *P. ornatus* with survival and growth rate equivalent or better to that achieved in sea cages. Growth was unaffected by densities of between four and nine lobsters per m^2. Survival was affected by density, but only for larger lobsters greater than around 80g. This highlights the weakness of using numerical density alone as a measure of quantity of lobsters that may be supported by the system. More effective may be a combination of density and size; the biomass. In Experiment 3 the highest density of 7 per m^2 with lobsters at stocking of 84 g provided a biomass of 588 g/m^2, and at this biomass, survival was significantly less than at the next biomass of 462 g/m^2. This does not necessarily suggest biomass should be no more than 462 g/m^2, but that other factors may need to be adjusted to ensure higher survival at higher biomass. For example, shelter can have a significant impact on survival as demonstrated in all three experiments. Of the two shelter types used, table shelters supported higher survival. By optimizing shelter type and availability, biomass in excess of 462 g/m^2 may be supported without impact on survival.

Overall, the experiments support the technical feasibility of tank culture of *P. ornatus*, although further research will be necessary to maximize productivity. Commercial viability of tank culture will necessitate economic assessment that accounts for the specific capital and operating costs of tank culture as compared with sea-cage systems.

Table 2. Water quality statistics over the duration of three successive experiments

Variable	Level
Water temperature	26 ± 2.1 °C
Salinity	28 to 34 ppt
pH	7.3 to 8.5
Dissolved Oxygen	4 to 6 mg/L
Nitrite	<0.3 mg/L
Ammonia	<0.03 mg/L

Table 3. Mean growth (expressed as specific growth rate) and survival of lobsters in relation to density

	Experiment #1 density			Experiment #2 density			Experiment #3 density		
	6.0	8.0	9.5	5.0	6.5	8.0	4.0	5.5	7.0
SGR %/d	0.47^a	0.45^a	0.50^a	0.72^a	0.70^a	0.74^a	0.78^a	0.69^a	0.68^a
Survival %	77^a	81^a	87^a	84^a	83^a	77^a	86^a	82^a	75^b

Table 4. Mean growth (expressed as specific growth rate) and survival of lobsters in relation to shelter

	Experiment #1		Experiment #2		Experiment #3	
	Table	Pipe	Table	Pipe	Table	Pipe
SGR %/d	0.483^a	0.466^a	0.74^a	0.70^a	0.713^a	0.723^a
Survival %	86^a	77^b	84^a	78^b	84^a	78^b

4.4 Effects of pellet shape and size on production of spiny lobster (*Panulirus ornatus*)

Hoang Do Huu[1] and Huong Le Lan[1]

Introduction

Tropical spiny lobster, *Panulirus ornatus,* is a high-value commercial species now farmed in Vietnam. Aquaculture of this species started in the early 1990s, mostly in Khanh Hoa, Phu Yen, Binh Dinh, Ninh Thuan and Binh Thuan provinces of south-central Vietnam. Lobster farming is reliant on the collection of seeds from nature that are then reared in sea cages and fed fishery by-catch or trash fish. The industry has great potential for expansion but is faced with several problems, including over fishing of the trash fish required as food, environmental degradation and disease. These problems all involve, or stem from, the use of by-catch fishery product as food, the cost of which is about 60% of total production.

It is essential therefore to reduce the reliance on trash fish as the food source for lobster farming, and this can be achieved through the adoption of pellet feeds. Pellet feeds are likely to reduce the overall cost of feed, reduce environmental degradation, reduce incidences of disease and improve farmers' profitability.

Baseline nutrition information for *P. ornatus* has been gathered through earlier research (Barclay et al. 2006; Hung et al. 2010; Irvin and Williams, 2009; Williams 2007; Williams 2009) which provides robust data on protein, lipid, cholesterol, fatty acid, vitamin, carotenoid and mineral requirements. From this data, laboratory manufactured diets have been formulated. In testing these developmental diets, issues have arisen in relation to losses due to sea-cage design, wave action and currents. Further, there have been problems with pellet water stability, hardness, size and shape; also contributing to losses.

An experiment was designed to examine the effect of pellet shape and size on growth, mortality and body composition of lobster. To achieve this, a commercial lobster pellet formulation which was available in different shapes and sizes was used.

Methods

Five pellet types were used: a noodle shape in 1.5 mm and 3 mm diameter size; and a disk shape in 3 mm, 5 mm and 7 mm diameters. These five pellet diets were applied to juvenile lobsters in small sea cages alongside a control of typical by-catch fishery food.

Thirty-six cylindrical cages of 1,200 mm in diameter and 800 mm in height were used, made from 2 mm nylon mesh netting stretched over a frame consisting of two circles of 10 mm steel rod held apart with four timber supports. Six replicates of the five pellet types plus one control diet were applied. Juvenile lobsters that had previously been fed trash fish were purchased for the experiment. Mean size at stocking was 60 g, with 20 lobsters stocked to each cage (i.e. 20/m^2). Lobsters were fed to satiation twice per day. Carapace length and weight of all individuals was measured at stocking, after one month and at two months, when the experiment was terminated. Two lobsters from each treatment were sacrificed at harvest to measure body composition (protein and lipid).

Results and discussion

Growth expressed as mean weight over the duration of the experiment is presented in Figure 1 and survival in Figure 2. There was a significant difference

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in mean weight at harvest, with lobsters fed the trash fish diet around 100% heavier (mean 137 g) than those fed the commercial diet (73 to 83 g). A significant difference in survival was also measured, with lobsters fed 1.5 mm noodle and trash fish having a higher survival (mean 90%) than lobsters fed the other diets (mean 69%).

Observation of the lobsters at harvest revealed those fed trash fish were not only bigger on average, but had clean shells as compared with lobsters fed the pellet diet. The latter tended to have shells fouled with barnacles and coralline algae, suggesting suboptimal moult rate.

Proximate composition of body tissue revealed significant variation for total protein and lipid, although no clear correlation between diet and level. That is, the trash fish diet did not generate body composition consistently different to the pellet diet. The variation measured was therefore attributed to high variability between individuals, which may relate to moult stage, and also to the low sample size.

Conclusions and recommendations

Overall, the pellet diet appeared to be nutritionally deficient, supporting poor growth and relatively poor survival compared with trash fish. This deficiency is likely to have masked any affect that the pellet form and size may have had. Of the five pellet types, the 1.5 mm noodle supported better survival than the other forms. This compares positively with observations of feeding behavior that suggest lobster feed ingestion is most effective with a small diameter noodle form diet. Nevertheless, the diet formulation of the pellet will need to be improved to make a more authoritative assessment of the effect of pellet form.

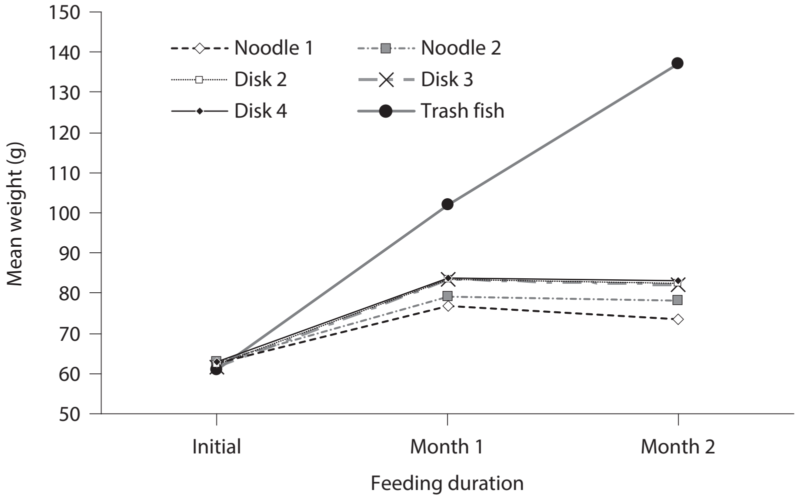

Figure 1. Mean weight of lobsters fed one of six diets over two months

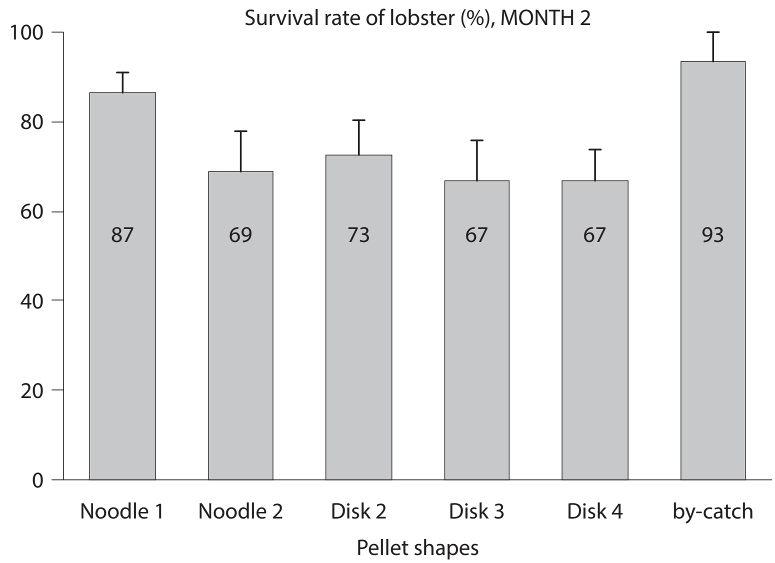

Figure 2. Survival of lobsters fed one of six diets over two months

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4.5 Bio-economics of spiny lobster farming in Indonesia

Liz Petersen[1], Clive Jones[2] and Bayu Priyambodo[3]

Introduction

This paper presents information on the bio-economics of lobster farming in Indonesia based on a farmer survey conducted in 2011, the results of which were subsequently published (Petersen et al. 2013). The purpose of the survey was to conduct preliminary bio-economic analysis of lobster grow-out in Indonesia to determine the sensitive factors of economic feasibility and the implications for the industry's growth.

Lobster is a highly-prized product, with most production from capture fisheries. In recent years, culture of lobster commenced in Vietnam, and by 2011 production of farmed lobster had grown to 1,600 tonnes with a value of US$80 million. Expansion of production in Vietnam and elsewhere is constrained by availability of wild-caught puerulus and feed. Demand exceeds supply, resulting in relatively high price for lobster seed.

As efforts are made to establish lobster farming in Indonesia, using the Vietnam approach, it is prudent to assess the bio-economics of production in Indonesia. The small lobster farming communities of south-east Lombok provide such an opportunity. Lobster farming began here in the early 2000s, and when the survey was performed in 2011, grow-out production was estimated to be 60 tonnes with a value of US$2 million. The primary species farmed was *Panulirus homarus*, the scalloped or sand lobster. The typical grow-out period was eight to 10 months, during which they grow from an average of 13 to 120 g. The survival rate over the grow-out period was estimated to be 70%, and the price given to farmers was US$35 to $40 per kg.

Methods

Face-to-face interviews of 11 lobster farmers were performed with five farmers at Telong Elong/Gili Belik and six at Ekas Bay, using a questionnaire with 42 questions. Bio-economic modeling involved inter-relating a biological model of lobster growth with an economic model of costs and returns.

Results and discussion

Lobster seed (puerulus) are captured via traps which consist of cement bag bow-ties fastened to nets hung from cages or frames. These nets are raised twice a day and the pueruli are placed in nursery cages. Lobster fishers or collectors sell a portion (~65%) and retain the balance for their own nursing and/or grow-out. Price per seed in 2011 was US$0.52/piece.

The nursery culture involved feeding low-value fish (sardines) for approximately 3 months to produce juveniles of 2 to 4 g individual weight which were then on-sold for US$1/piece or retained for further grow-out. As demand for pueruli has increased, price has also increased, and by late 2014 it reached US$2 per piece for pueruli and higher still for juveniles. This price increase has had a dramatic negative affect on local grow-out as farmers can no longer afford to buy the seed Consequently they have focussed their attention on catching and selling seed to middlemen who are exporting the seed to other countries such as Vietnam, where they are then on-grown to market size.

Statistics on seed price, stocking density and total number stocked for grow-out at the two Lombok locations in 2011 are provided in Table 1 along with

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comparative figures for Vietnam. The relatively high price of seed in Vietnam is driving the demand for export from Indonesia, which in turn is constraining local grow-out. The much lower stocking density and total numbers stocked in Lombok compared with Vietnam is similarly a result of availability and the increasing price which is a further constraint to the viability of their farms.

Lobster grow-out farmers in Lombok use low-value finfish as feed for the lobsters, with 13–40% of farmers purchasing the fish from others, and the remainder catching their own. This finfish is bought at a price US$0.46–58/kg, but the quantity used was not accurately known by the farmers of Telong Elong / Gili Belik as no measurements or records were made. The Ekas Bay farmers estimated that lobsters under 13g received around 1g of food per lobster per day, and lobsters over 13 g received 7 g per lobster per day. This relates to a food conversion ratio (FCR) of approximately 11.5 which seems quite low. It is therefore likely that greater feed quantities than those estimated are being used.

Lobster farmers were asked about their perceptions of pellet feeds for lobster. They were uniformly positive about adapting to pelleted diets. Most farmers did not know the relative prices of pellets versus low-value finfish. Farmers from Telong Elong / Gili Bilik expected pellets to lead to faster growth rates while Ekas Bay farmers did not know. Pellets are not currently available but farmers are willing to try them.

Discussion about lobster feeding indicated that nutritional deficiencies are evident in current feeding practices. The use of molluscs and crustaceans to supplement the fish is needed to improve nutrition. Pellets have the potential to improve lobster quality and provide a number of other benefits, including a reduction in local pollution and water quality degradation, longer shelf life, and potentially more stable supply.

The cost structure of Lombok lobster farms is presented in Table 2 and economic statistics presented in Table 3.

A sensitivity analysis was performed using the Ekas Bay farmers, whose bio-economic data revealed

Table 1. Statistics for seed price and stocking in Lombok in 2011 with comparative values for Vietnam

	Ekas Bay	Telong Elong/ Gili Belik	Vietnam
Average price of seed (US$/seed)	0.43	0.95	13.00
Average stocking density (lobsters/m^3)	24	7	93
Average number of seed stocked	1,500	520	2,000

Table 2. Cost structure of lobster nursing and grow-out in Lombok (% of total costs unless otherwise stated)

	Puerulus nursing	Grow-out	
	Ekas Bay	Telong Elong/ Gili Belik	Ekas Bay
% of total cost	100	100	100
Seed	0	22	24
Feed	0	5	3
Cage	10	4	2
Other capital items	24	25	23
Other variable items	61	17	17
Interest	0	22	25
Contingency	5	5	5
Total cost (US$/crop)	2,000	2,300	2,700
Cost/kg production (US$/crop)	47	44	22

a cost benefit ratio of 1.7 (Figure 1). The model was particularly sensitive on the downside to harvest price and mortality. Harvest price is not expected to diminish given the strong demand for lobsters but mortality during grow-out must be kept to a minimum to maximise profitability. There was considerable upside opportunity revealed in the analysis, particularly for harvest size, demonstrating there are strong opportunities for greater profitability.

Conclusions and recommendations

Lobster grow-out is a viable alternative for Indonesian coastal smallholders. Returns to investment are modest and dependent on seed price and availability as well as access to credit. There is some economic risk, in particular, susceptibility to disease epidemics.

Table 3. Economic statistics for lobster farming in Lombok

Annual statistics	Puerulus nursing	Grow-out	
	Ekas Bay	Telong Elong / Gili Belik	Ekas Bay
Total revenue (US$/crop)	14,000	2,100	4,400
Net revenue (US$/crop)	12,000	–190	1,800
Benefit cost ratio	6.8	0.92	1.70

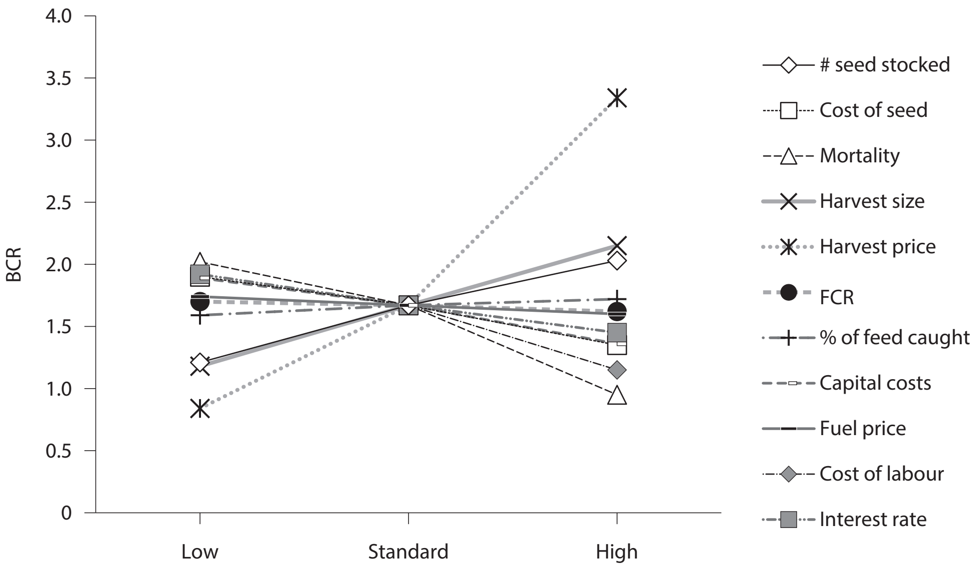

Figure 1. Sensitivity analysis of the bio-economic modelling of tropical rock lobster farming in Lombok, Indonesia

The economic potential suggests significant benefits would be realized for delaying harvest (currently 100 g) until lobsters are larger (approximately 300 g) and shifting from low-value finfish to practical and functional pelleted diets. It is encouraging that farmers are willing to try pellets as these have the added benefit of reducing environmental impact.

Further research is required, including a continuation of regular farmer household surveys to capture the changing bio-economic statistics as the industry develops and expands. Identification of policy and institutional constraints should be added to assessments to assist in creating the best environment for industry growth, which in particular needs to address improving access to inexpensive credit.

Research is also required to better understand, minimise and manage risk, and the impacts of hatchery-produced seed availability should the technology be commercialized. Lastly, it would be instructive to gather accurate annual lobster production statistics to monitor the growth of this new and exciting industry.

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5. Industry Development

5.1 Assessment of spiny lobster farming in New Caledonia

Manuel Ducrocq[1]

Introduction

New Caledonia is a French overseas territory with local autonomous government, located in the South Pacific (21°S 165°E) with a geographic area of 19,000 km^2, a population of 256,000 and a GDP of US$ 9.9 billion.

New Caledonia has one of the world's three most extensive reef systems, with low human and fishing pressure, very high diversity and endemism. UNESCO listed New Caledonia barrier reef on the world heritage list in July 2008, and a project to create a marine protected area that includes the entire exclusive economic zone (EEZ)of New Caledonia is currently being developed.

Currently, New Caledonia has a fishery production of 3,575 tonnes per annum and an aquaculture production of 1,562 tonnes, primarily from shrimp. Aquaculture provides a significant opportunity for the country, and its expansion is widely supported. Diversification of aquaculture is a key to success, and there is existing production of microalgae, sea cucumber, clam, oyster, lobster and finfish (snapper, grouper, and rabbitfish).

This paper summarises recent activity in support of developing lobster aquaculture in New Caledonia.

Methods

To assess and encourage lobster aquaculture, a pilot project was established based on collection of naturally settling lobster seed, and their grow-out in sea-cage systems. The aim of the project was to: identify potential seed capture sites; implement trials with fresh feed and dry pellets to compare growth and mortality; identify market response to farmed product; and quantify threshold profitability of spiny lobster farming in New Caledonia.

Seed collecting activity included identification of different locations (Figure 1) to collect seed and determine seasonality of their availability. Ten sites were assessed around New Caledonia within seven different bays, using two collecting traps at each location (net bundles and timber poles with holes—see Figure 2). There were 30 collectors per line, and the study extended over two years. Collectors were checked every two weeks to retrieve and count the lobster seed.

A series of grow-out trials were performed in a sea-cage system as depicted in Figure 3. Large cages had a volume of 27 m^3, and smaller cages were 0.5 m^3. Trial setup data is summarised in Table 1. Captured seed lobsters were stocked to the cages and fed either fresh feed (tuna by-products) or a combination of shrimp and finfish pellets.

Results and discussion

In 2011, 2,037 lobster seed were captured, and in 2012, 1,025; 95% of which were captured at one site, Ouano Bay (Figure 1) from eight lines with 120 of each habitat trap type. All pueruli captured were *Panulirus ornatus*. There was distinct seasonality in the catch, with most puerulus caught between April and August, the winter period (Figure 4).

Table 2 presents results of an initial grow-out trial using sub-adults of around 170 g, fed with a shrimp brood stock diet. Although survival was reasonable, growth was very low and food conversion ratio (FCR) very high. Density appeared to have a significant effect on survival. The results did not support profitable production.

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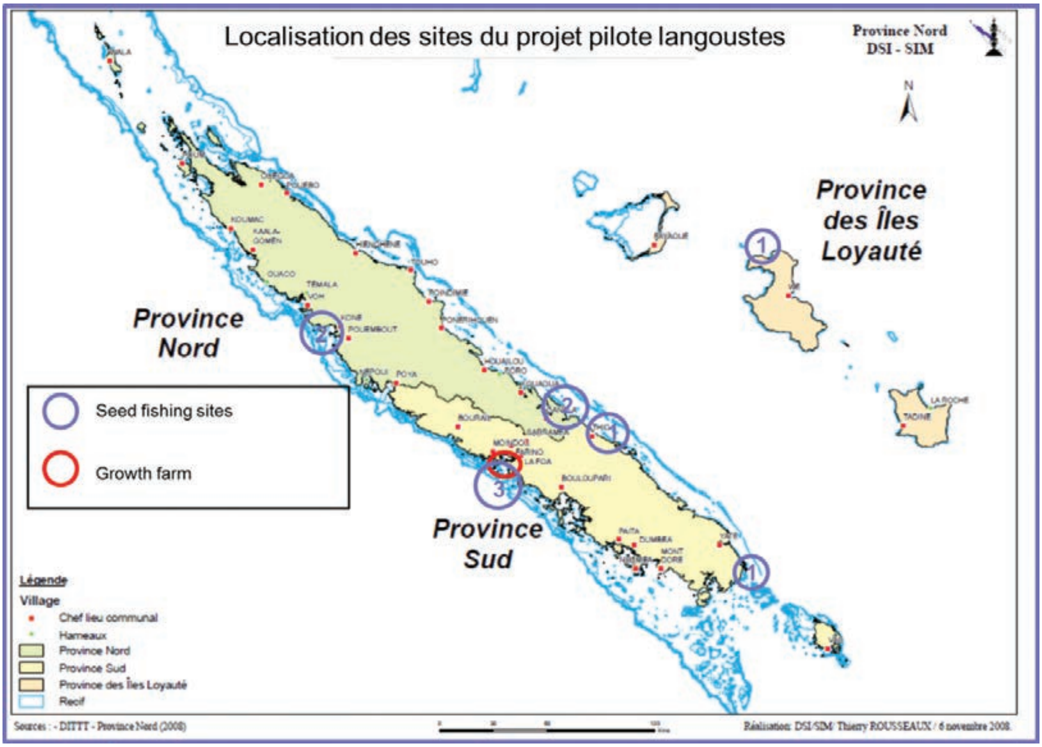

Figure 1. Map of New Caledonia showing sites for lobster seed catch assessment, and grow-out site at Oanao Bay

Figure 2. Two habitat trap types used to catch lobster seed

Grow-out trials using captured pueruli in year one examined production using different diets (fresh tuna by-product and finfish pellets). Survival was around 50%. Growth results from the first experiment are illustrated in Figure 5. Growth over four months was very low and the production was considered to be unviable.

In year two, a puerulus grow-out trial used diets of tuna by-product and a laboratory formulated pellet. Results are depicted in Figure 6. Although survival was higher than in the year one trial, growth was lower. Results again did not support viable production.

Figure 3. Photo of sea-cage system used for grow-out trials

Table 1. Summary of the set-up for grow-out trials

Trial	System	Density	Diet	Lobster weight	Duration
1	Large cage 27 m^3	1.1/m^2	Tuna by-product	280 g	4 months
			Shrimp pellet	306 g	
2	Large cage 27 m^3	2.6/m^2	Shrimp pellet	mean weight 170 g	9 months
		1.1/m^2			
3	Small cage 0.5 m^3	30/cage	Tuna by-products	mean weight 2 g	4 months
			Finfish pellet		
4	Small cage 0.5 m^3	30/cage	Laboratory made pellet	7 g	5 months
				14 g	
			Tuna by-products	7 g	
				14 g	

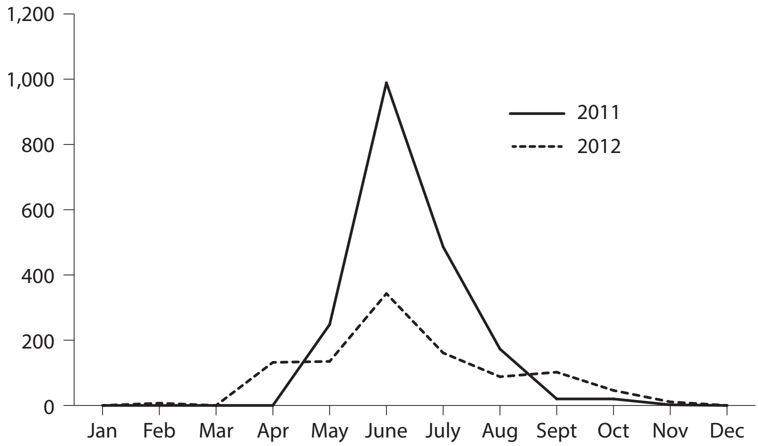

Figure 4. Seasonality of lobster seed catch in New Caledonia

Table 2. Results from feeding lobsters with shrimp brood stock diet

Number of lobsters stocked	117	51	52
Density (m2)	2.6	1.1	1.1
Initial Biomass (g)	23,100	6,250	8,500
Final Biomass (g)	24,200	11,966	10,400
Growth (g/day)	0.77	1.02	0.68
Gain biomass (kg)	1.04	1.9	1.22
Mortality	32%	12%	27%
FCR	37	20	26

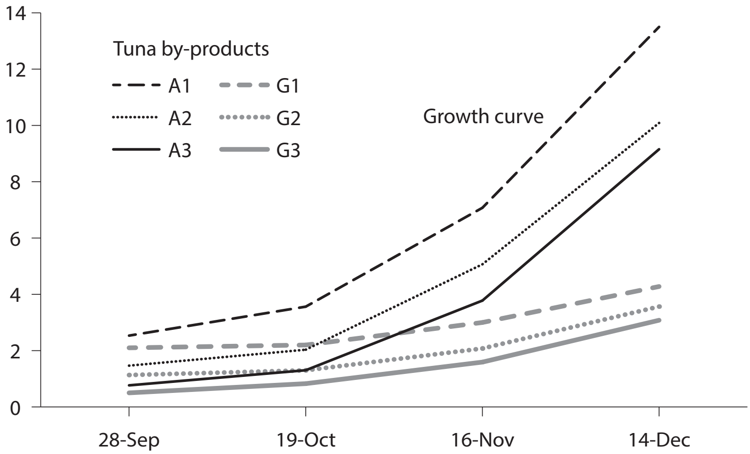

Figure 5. Growth of *P. ornatus* pueruli fed either tuna by-product or finfish pellets

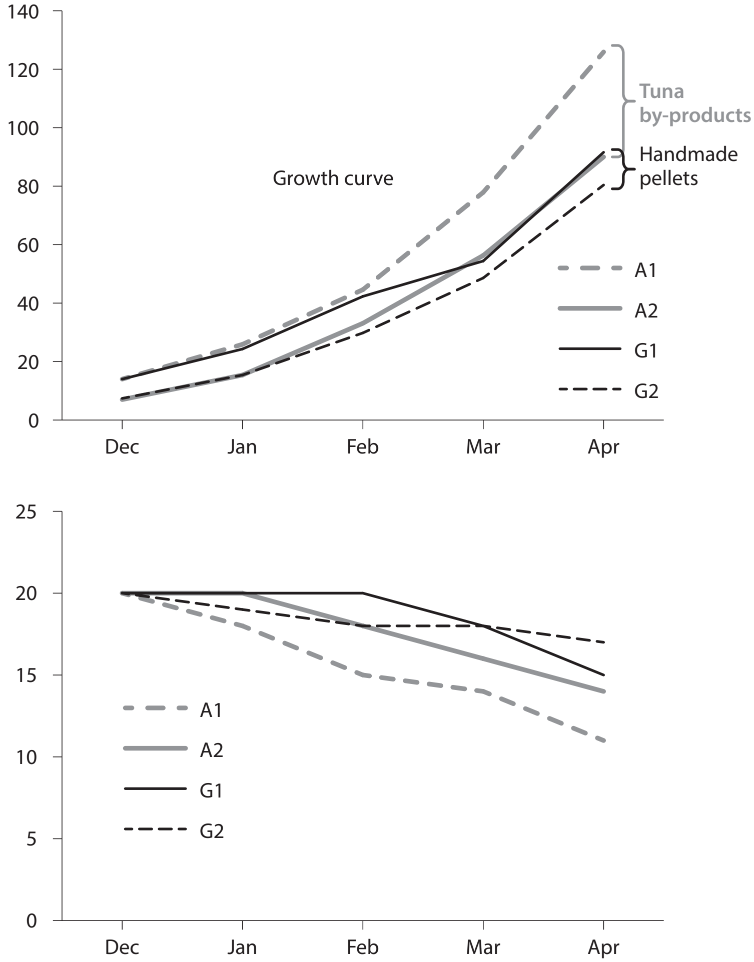

Figure 6. Growth (top) and survival (bottom) of *P. ornatus* lobsters fed either tuna by-product or pellet diet in sea cages

Conclusions and recommendations

Although a small seed resource of *P. ornatus* was identified, much higher numbers will be required to support a grow-out industry. Growth trials were significantly impacted by high mortality and low growth, resulting in productivity that cannot be considered commercially viable. It is possible nevertheless, that improving the diet will improve both survival and growth rate.

Further research should focus on optimization of seed collection, particularly identifying the most productive sites, and on reducing mortality, increasing growth and reducing feed cost.

Training of prospective seed fishers and lobster farmers will be necessary, and the first exercise to meet this requirement was performed when a group of New Caledonia operators participated in a training program at the Marine Aquaculture Development Centre in Lombok, Indonesia in April 2013.

Postscript

In 2013, some 1,300 lobster seeds were captured and used for a grow-out trial, but a storm delivering heavy rainfall caused a significant drop in salinity at the grow-out site, causing 95% mortality. This highlights the importance of site selection where terrestrial run-off such as this cannot occur.

5.2 Tropical lobster aquaculture: Bridging the gaps and forging new frontiers

Jason S. Goldstein[1,2]

Introduction

Based on information covered in a previous conference, the key topics for this paper are:

- sustainable lobster aquaculture
- improving nursery culture
- lobster grow-out systems
- lobster grow-out feeds and practices.

The most important knowledge gaps to be addressed through research and development are:

- phyllosoma culture
- ways to better enhance puerulus culture and grow-out
- environmental variables (e.g. temperature, light) of importance.

The new frontiers where breakthroughs will be critical include:

- feed and wild diets
- hatchery conditioning
- novel tank designs.

The information presented in this generalized summary is drawn from a wide variety of previous and ongoing research activities. This includes work with North American clawed lobsters (*Homarus americanus)* in New England (and an associated *H. americanus* research hatchery) and with tropical lobster projects in Mexico, Brazil, New Zealand and in the Florida Keys. Of particular relevance are the pilot-scale research activities in Japan with Dr Hirokazu Matsuda.

There is broad acceptance that lobsters are both ecologically and economically important. Of the more than ~150 known species (spiny, slipper, clawed) there are few species that are of significant commercial value (Holthuis 1991; FAO 2014). In general, lobsters have complex life cycles that may include a protracted larval or egg stage (Phillips and McWilliam 1986). Lobsters are large, abundant and play a significant ecological role as predators within the communities they inhabit. Lobsters further support the livelihoods of many coastal regions through fishing and to a lesser extent through endeavors in aquaculture.

Despite the strong interest in further developing lobster aquaculture, at present, the volume of production is negligible (Figure 1). This is, however likely to change within the next few decades. One of the most influential reasons is the current status of wild fisheries for lobsters throughout the world. With only a few exceptions, most quantitative indicators (e.g. CPUE, catch, recruitment) suggest that lobster stocks are in decline, as measured by total landings and biomass of spawning stocks (Chavez 2009). These shortcomings provide the impetus for the improvement of current projects and the design and development of future lobster aquaculture efforts.

Lobster aquaculture

Tropical spiny (palinurids) lobster species have garnered the most interest as candidates for commercial aquaculture over the past three decades (see reviews in Booth and Kittaka 2000; Jeffs 2010) for two primary reasons: 1) these species demand consistent and strong interest among international seafood markets; and 2) empirical data along with various pilot studies have created a wealth of biological data (e.g. growth, larval duration, feeds etc.) that contribute to, and advance further development (Jeffs and Davis 2003;

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Jeffs 2010). Of the various life-history stages within the spiny lobster life cycle, the two that are of most interest in the expansion of lobster aquaculture are the pelagic phyllosoma (larval stage) and the transitionary post-larva (puerulus) stage. Understanding the biology and the rearing requirements of the phyllosoma stage are pivotal to unlocking the commercial potential for large-scale, fully sustainable commercial lobster hatchery production from egg through grow-out.

The phyllosoma ('leaf-like') stage in spiny lobsters represents the larval phase and aptly describes the very delicate, dorso-ventrally flattened and transparent body. Across all spiny lobsters, phyllosomas spend between four and 12 months in the plankton (depending on species) and can undergo dozens of molts, instars, and intermediate stages (Phillips et al. 2006). It is this life-history phase that represents the greatest bottleneck to establishing fully-fledged lobster aquaculture. Current obstacles to successful large-scale phyllosoma production include: improvements to water quality; the development of nutritionally complete and cost-effective feeds; control of disease vectors; and the design of flow-efficient mass culture tanks (Matsuda and Takenouchi 2005; 2007; Jeffs 2010; Goldstein and Nelson 2011). More recent efforts have been aimed at understanding how other environmental factors (e.g. light, biofilms, flow rates) should be considered in the future development of phyllosomal culture (e.g. Bourne et al. 2006). Studying phyllosomas *in-situ* is difficult, and it is only recently that accurate data have been gathered on larval duration for a few commercially important species through laboratory-based studies (Figure 2).

As a case in point, in 2005 adult Caribbean spiny lobster (*Panulirus argus)* were transported from Florida USA to Japan in a comprehensive effort to study reproduction and phyllosomal rearing in the laboratory. The fishery for *P. argus* is the largest in the world for any spiny lobster species, and development of successful aquaculture operations would be of great value. The research was successful, for the first time, in rearing phyllosomas of *P. argus* through all the stages through to metamorphosis to the puerulus stage, and then to on-grown lobsters (Goldstein et al. 2008). This experience highlighted the necessity of an integrated approach to establishing technology for mass rearing, which must involve an understanding of the biology, nutrition and physiology of these phyllosomas. These findings will help to ensure the engineering of beneficial tank designs and a healthy, suitable aquatic environment.

Our work in Japan has provided baseline information for the larval duration of *P. argus* and size-at-age for the 10 successive phyllosomal stages. The total time from egg hatch to final phyllosomal metamorphosis ranged from 140–198 days with a mean of 174 days. Further experiments examined the behavioral changes in phyllosomas in relation to light. We found that early-stage phyllosomas demonstrated a very strong positive phototaxis (i.e. phyllosomas actively swam towards a light source (Goldstein et al. 2008)).

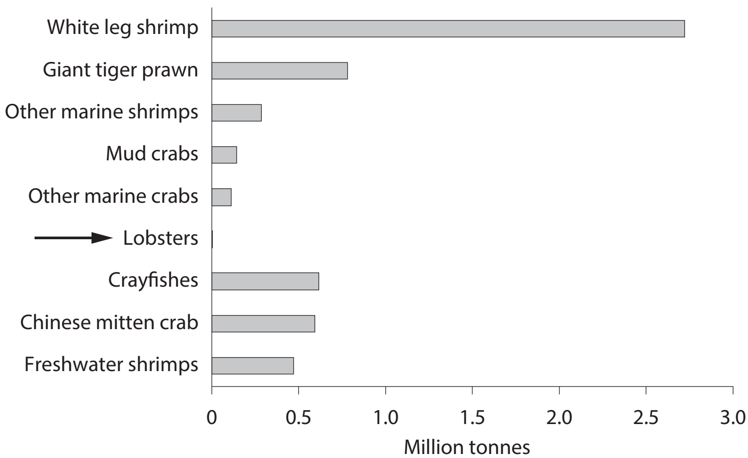

Figure 1. Production of major species from aquaculture in 2010. Source: FAO 2012

This behavior persisted until ~ 100 days of age, at which point there was a profound switch to negative phototaxis, whereby phyllosomas swam away from a light source (Butler et al. 2011). These findings not only emphasize the importance and integration of environmental variables in phyllosoma cultures, but also provide correlates for our understanding of *in situ* larval dispersal which continues to be an active area of research (Butler et al. 2011).

An assessment of the dietary needs for *P. argus* phyllosomas were also investigated in this work. The traditional laboratory diet for lobster phyllosomas, mussel gonad and *Artemia spp*, although successful, are not necessarily the most suitable for mass culture, nor do they provide optimal nutrition for growth and metamorphosis. In an effort to provide better guidance for more suitable diets for phyllosomas, studies have been carried out to investigate the natural diets of phyllosomas in the plankton using sophisticated molecular tools to identify prey items, the proportion of those items and their specific nutrient profiles (Saunders et al. 2012; O'Rorke 2013). Complementing this nutritional research are ongoing studies of the feeding morphology of phyllosomas, including examination of the appendages, mouthparts and digestive tracts, to better understand their capabilities and the form of diet best suited to this morphology (Johnston et al. 2004; Johnston et al. 2008).

In addition, there has been recent research of digestive physiology in regard to enzymes that might also elucidate the make-up of an optimal phyllosomal diet (O'Rorke 2013). Based on the information gathered to date, it may be concluded that manufactured phyllosomal feeds will need to be high in protein and energy (lipids and carbohydrates) easy to grasp and fleshy, inexpensive to produce and non-fouling of water quality (Jeffs 2010).

Nutritional research in other lobster species, such as clawed American lobsters (*Homarus americanus*) may provide useful information for spiny lobster nutrition. Simple dietary manipulations in *H. americanus* have been shown to alter lobster shell color, and may be an economically beneficial tool in lobster aquaculture to meet specific market demands (Tlusty et al. 2005a,b). Seeking out other species for answers to homologous challenges is an important exercise to continue undertaking.

Challenges with pueruli

The puerulus stage is a critical stage both in the natural life cycle and for aquaculture. The puerulus is highly mobile, persists for between two and four weeks, has strong swimming ability and is a non-feeding stage reliant on lipid reserves. Pueruli display specific habitat preferences as they seek out a suitable settlement environment, and their abundance varies with both season and lunar periodicity. They tend to

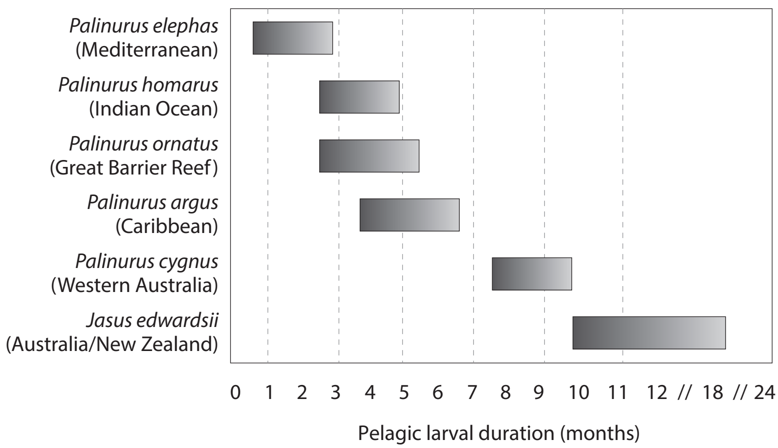

Figure 2. Estimated duration of the larval phase of commercially important spiny lobsters

be most active at night and around the new moon (Phillips and McWilliam 1986; 2008).

With respect to this life stage, there are a number of ecological questions that may be examined, leading to better aquaculture practices. For example, how are pueruli locating suitable coastal habitat for settlement; what distance from the coast; using what specific cues or stimuli? (Jeffs et al. 2005; Fitzgibbon et al. 2013). There is now some evidence that pueruli of *P. argus* are able to cue to chemical signals in the water to direct their swimming. Furthermore, these chemical signatures may modulate a trigger for the transition from a swimming puerulus to a settled, benthic juvenile (Goldstein and Butler 2009; Kough et al. 2014). In attempting to answer these questions, simple choice experiments were performed, giving wild caught pueruli the option to move in one of two directions toward water that has been conditioned with different chemical scents. For example, when water conditioned with the red coralline alga (*Laurencia spp.*) was offered with an alternative of plain sea water (control), pueruli moved towards the alga-scented water, presumably as this represented suitable habitat for settlement. A similar result was achieved when oceanic water was offered with seawater from in Florida Bay, with a significant preference for bay water, as reported by Goldstein and Butler (2009).

As an extension to this research, an assay was performed where pueruli were placed in a variety of water baths representing the same chemical scents (e.g. secondary metabolities) as in the choice experiment, and the time to pigmentation (i.e. metamorphosis to the benthic juvenile stage) was measured. The change from the transparent, swimming puerulus stage to the pigmented, settled stage is considered to represent a significant transition that indicates the lobster has reached suitable habitat for its ensuing benthic life phase. Again, a clear result showed the time taken to transition to the pigmented 'juvenile' stage was significantly faster with water from the bay (or infused with *Laurencia* algal scent (Goldstein and Butler 2009)).

Taken together, these studies have important implications for aquaculture, as the duration of the puerulus stage may be minimized by introducing an appropriate chemical cue. The resulting juveniles with an accelerated transition are likely to be stronger, as they have moved through the non-feeding puerulus stage more quickly, and are therefore less likely to have exhausted their energy reserves (Jeffs et al. 2005; Fitzgibbon et al. 2013).

This research is the first for any palinurid lobster to demonstrate enhancement of puerulus behavior to stimulate the transition from the swimming to the settled stage, which in turn may improve our ability to utilize conditioning techniques for aquaculture.

Environmental effects on development

Environmental (abiotic) factors (e.g. light, temperature, current, substrate etc.) can be crucial for the settlement and survival of marine larvae. Research with clawed lobsters (*H. americanus*) has demonstrated that in captivity, the development of the claws is influenced by the substrate on which the lobsters are reared. The asymmetry between the two claws (in nature, lobsters typically have distinct crusher and cutter claws) is far less on a cobble stone substrate than when reared on a crushed shell substrate (Goldstein and Tlusty 2003). Temperature and photoperiod are both significant factors in the timing of metamorphosis of several species of phyllosomas, both in the lab and field (Kittaka 1997; Matsuda et al. 2003) and chemical cues (described above) have been implicated as settlement cues in a variety of marine organisms, including lobsters (reviewed in Grasso 2001). The influence of environmental variables on development suggests that the inclusion of environmental manipulation in aquaculture operations may be used to affect desired developmental outcomes for lobsters, including for spiny lobsters. These factors should be integrated as part of a large-scale design and production operation.

Phyllosoma rearing tank design

Many tank designs have been applied to the rearing and culturing of phyllosomas, from older designs used for the larval rearing of other species to new designs customised specifically for phyllosomas (Illingworth et al. 1997; Matsuda and Takenouchi 2005; 2007, Goldstein and Nelson 2011). Tanks typically used for rearing and displaying jellyfish (i.e. gelatinous plankton kriesels) have been successfully used to culture phyllosomas (Raskcoff et al. 2003; Goldstein and Nelson 2011).

Not only do these tank designs provide a suitable environment for rearing phyllosomas, but the integration of jellyfish and phyllosomas in the same tank has demonstrated a strong association between these species (already documented in the wild). Phyllosomas may benefit from this association in many ways. For example, phyllosomas may obtain nutrients by feeding on jellyfish and/or use jellyfish for transportation and thus energy conservation (Wakabayashi et al. 2012; O'Rorke et al. 2015). Continued development in this area of polyculture may become a viable alternative to the mass production of phyllosomas alone, however more studies are needed to determine the efficiency and compatibility of species.

Alternative tropical spiny lobster species

Beyond the well-documented tropical species currently being cultured or under consideration for aquaculture potential, there are other species (e.g. *Panulirus laevicauda* and *Panulirus guttatus*) that are poorly understood, but show promise as aquaculture candidates. Studies directed at a more comprehensive look at similar species and their life cycles may provide insight for potential development.

Conclusions and recommendations

Given the continued trend in unreliable wild-caught fisheries, the prospects for aquaculture production that will help meet the global demand for lobster products is a real one. The ability to solidify the technology and develop proven and reliable methods for lobster aquaculture should focus on tropical spiny lobsters worldwide. Creating and sustaining viable lobster aquaculture involves the sharing of new ideas and fostering more studies aimed at addressing and resolving important biological roadblocks (e.g. diet, disease etc.) that still exist. Successes then need to be scaled up to meet the demands of commercial production that includes quality control and consistent, environmental conditioning as well as maintaining a healthy supply of animals. The integration of land-based (larval culture systems) with sea-cage culture (grow-out) may also be a strategy to support full aquaculture potential.

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5.3 Student involvement in spiny lobster aquaculture research in Indonesia

Ihsan Muhsinul[1]

As a student of the University of Mataram, West Nusa Tenggara, Indonesia with an interest in lobster physiology, I was able to assist the ACIAR lobster aquaculture project in 2010 and continued my association through to 2013. During this time I participated in annual project meetings, and in 2012 I attended the lobster aquaculture industry development workshop. Through these experiences, I became familiar with the many students who participated in various activities with the ACIAR lobster aquaculture project.

Due to the significant amount of research required to answer many questions about lobster farming technology, staff from MADC Lombok approached the University of Mataram to request the assistance of Biology Department students to support research activities. The first instance of student involvement was in 2010 when 7 UNRAM students (including myself) spent 10 weeks at MADC Lombok assisting with lobster research.

Over the next three years, students continued to be involved, representing seven different Universities: Mataram University, Diponegoro University, Gadjah Mada University, Padjajaran University, Bogor Agriculture University, Hasanudin University and Fisheries University of Jakarta.

The students' participation included conducting research, collecting and processing data, and introducing the Lombok culture to project staff. There were four advantages for students who joined the ACIAR lobster project: i) helping to complete our University study; ii) increasing our scientific knowledge; iii) exploring our potential; and iv) enabling us to develop a new business.

Conclusions and recommendations

The opportunity for students to participate in the ACIAR lobster aquaculture research provided several advantages and no disadvantages. Such collaboration should be continued in future.

Personally, the involvement has led me to consider applying for an Australian Awards Scholarship to continue lobster research and to develop a lobster feed business.

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5.4 Summary of disease status affecting tropical spiny lobster aquaculture in Vietnam and Indonesia

Clive Jones[1]

Introduction

Information presented here is primarily gathered from a lobster disease information audit conducted under the ACIAR project (ACIAR SMAR/2008/021) in Vietnam in 2009, and subsequent qualitative assessments based on discussion with industry participants and researchers. The audit was performed by Drs Richard Callinan and Flavio Corsin, as a contracted activity of the ACIAR project. Their unpublished report (Callinan, et al., 2010) is presented as Appendix 3.

Subsequent to completion of the audit, the Vietnam Ministry of Agriculture and Rural Development convened a workshop in November 2009 to generate a national response to disease within the lobster farming industry. The industry suffered particularly high levels of disease-related mortality in 2007 and 2008.

The following summary provides information on the five recognised diseases and health related syndromes, their symptoms, possible causes, treatment and prevention. Some farm management considerations are presented that may assist in minimising disease issues. Although there has been no formal assessment of lobster disease status in Indonesia, some qualitative assessment is presented.

Red-body disease

Red-body disease has been observed in four species in Vietnam: *P. ornatus, P. homarus, P. longipes* and *P. polyphagus*, in both juvenile and adult stages. The symptoms include a distinctly red coloration initially to the carapace and/or abdomen, which ultimately affects the whole body. Internal examination reveals necrotic (dead and blackened) tissue in the hepatopancreas. The pathogen implicated is *Vibrio alginolyticus*, although other viral pathogens and factors of stress may be involved. Mortality rate is high (estimated >90%) for lobsters affected. Prevention is via integrated preventive measures discussed below.

Black gill disease

Black gill disease has been recorded for *P. ornatus, P. longipes* and *P. penicillatus* in sub-adults and adults. Symptoms are a gradual darkening in colour of the gill filaments from brown to black, followed by progressive tissue breakdown and shedding of the gills. The disease is typically not fatal but does impact negatively on growth and marketing quality of affected lobsters. The primary pathogen involved is the fungus *Fusarium*, although other pathogens have been implicated. Prevention is via integrated preventive measures discussed below.

Milky disease

Milky haemolymph disease, most commonly referred to as milky disease, affects *P. ornatus, P. homarus, P. stimpsoni* and *P. polyphagus* at all life stages, from small juveniles to adults. Infection is apparent when abdominal tissue color turns from translucent to opaque white, as the cells become engorged with the pathogen, a Rickettsia-like bacterium. Mortality of infected lobsters is 70–100%. The disease can be treated effectively with properly administered antibiotics (oxytetracycline), although industry practice of mixing antibiotics with food is not particularly

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effective. Incidence of milky disease can be managed through integrated preventive measures.

Big head syndrome

Big head syndrome is a health issue rather than a disease, and has been observed in *P. ornatus, P. homarus, P. longipes, P. penicillatus* and *P. versicolor*, primarily in adults. It is characterised by an abnormally big carapace relative to the abdomen, and affected lobsters appear to have their growth retarded, and experience difficulty in moulting. The syndrome results in poor marketing quality but is typically not lethal. The cause is believed to be nutrient deficiency, and thus can be treated with provision of improved feed quality through supplementation or preferably through use of a suitable manufactured pellet diet.

Separate head syndrome

Separate head syndrome can affect all cultured species at any life stage. The symptoms involve a separation of the carapace from the abdomen, caused by excess body fluid which appears under the epidermis at the junction of the head and tail. Although typically not lethal, it impacts negatively on marketing quality and is thought to be caused by exposure to low salinity (<25 ppt). Treatment is to relocate lobsters to areas with higher and stable salinity (>25 ppt), and preferably at normal seawater salinity of 35 ppt.

Causes

The causes of these diseases and health issues are in most cases attributable to farm and sea-cage design and management, and to feed quality and feeding management. The current industry practice of using trash fish as lobster food is likely to have nutritional deficiencies that will render lobsters more susceptible to disease. Further, the application of trash fish is wasteful, and a significant proportion of the food is lost from the cage either as fine particulate or dissolved organic material that has an immediate and on-going nutrient impact on the water and sea floor adjacent to the farm. The water quality that lobsters are exposed to is therefore suboptimal and causes physiological stress that increases disease risk.

Similarly, the location of farms, density and spacing between cages, and cage mesh size may all contribute to the degree of flushing of cages, which in turn will influence water quality within the cage.

Although no analytical assessment has been made of the relative condition of lobster seed as supplied to farmers, there may be a link between poor condition of seed and disease susceptibility . Although all seed appear to be the same, there is a strong likelihood that their condition varies as a result of differeces in duration since their metamorphosis from the phyllosoma stage. As the puerulus is a non-feeding stage, those individuals that have spent longer in the plankton will have expended more of their energy reserves and will be in a weaker condition. Such individuals may suffer health and disease problems more readily than others.

There is also a regulatory aspect to lobster disease with regard to: provincial planning (location and number of cages permitted within a given location); institutional capacity within each province to respond to disease problems; training in disease prevention and treatment; and communication of disease outbreaks.

Lobster disease impact

The diseases and health issues detailed above have collectively cause substantial losses to lobster production each year. Significant additional loss occurred specifically from milky disease in 2007 and into 2008 in Vietnam when production losses of 31–71% were experienced across all provinces. The average across the entire industry was a 50% reduction in production due to milky disease in 2007–2008, valued at US$50 million lost and more than 5,000 households affected. Prior to 2002, survival rate through the grow-out phase was 70%, and by 2008 this was less than 50% due to disease. By 2011, overall survival was back to 70% as a result of disease prevention measures. However, in 2012 a further milky disease outbreak had occurred, although with a much lower impact than 2007–2008.

Lobster disease in the Indonesian lobster farming industry has been a significant issue even though overall production is very small; less than 50 tonnes. Milky disease was confirmed in lobsters in the village of Telong Elong in eastern Lombok in 2012, with the same Ricketssia-like bacteria involved. This suggests that the milky disease agent, the Ricketssia-like bacteria, are endemic, and that milky disease is an ongoing threat to lobsters in compromised condition due to poor nutrition and environmental stress. Although milky disease infected lobsters respond positively to antibiotic treatments, prevention is key to the long term sustainability of the industry.

Preventative measures

There are a number of preventative measures that can be taken to reduce disease susceptibility, and when integrated, are likely to reduce the risk of losses from disease and health issues to a negligible level. Firstly, site selection is important, with a recommended depth of greater than 2.5 m from cage bottom to sea floor and a location with good water movement from tide and currents that enables constant flushing of the cages with clean water. Density of farming (i.e. the distance between farms and spacing of cages within each farm) is important to minimise the ratio of lobster biomass to volume of water. Cage design and mesh size are important to maximise the flow of water through the cage.

It is likely that the use of trash fish as lobster food is a major contributing factor to poor condition of lobsters and increased susceptibility to disease. Pelleted feeds will provide a much cleaner and nutritionally complete diet, and increase disease resistance. Where such pelleted feeds are unavailable, fresh flesh diets should be comprised of clean, fresh (less than 24 hours since capture) seafood materials and the use of crabs avoided.

Use of high quality seed is also likely to lead to less disease and health issues, therefore choosing the strongest looking seed is worthwhile. Using larger juveniles rather than puerulus may provide an advantage in this regard, although the higher price would need to be accounted for.

Regular grading of stock within grow-out systems is also a useful disease mitigation technique with regard to minimising aggression between lobsters.

Effective maintenance of cages is beneficial to health management, including daily cleaning of waste and uneaten food from the cages, and periodic exchange of cage nets, including sun drying.

Farm workers should be well trained in disease symptom awareness and observation, with corresponding skills on how best to respond.

Conclusions and recommendations

Fortunately, the diseases of tropical lobsters as outlined here are primarily the result of opportunistic infection and physiological degradation rather than from primary pathogens. They are all preventable, and with best practice husbandry and nutrition, can be avoided. As such, every effort should be made to provide an environment which maintains lobsters in optimal condition such that their susceptibility is as low as possible. Above all, optimal nutrition will likely mitigate infection with milky disease.

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5.5 Development of the lobster farming industry in Indonesia

Bayu Priyambodo[1]

Introduction

To assist in the introduction of lobster farming and facilitation of its development throughout Indonesia, demonstration grow-out farms were established at six sites in three provinces. This paper provides a summary of the demonstration farm program, its objectives, program of activities, outcomes and recommendations.

A number of other industry development activities were also performed as part of the program, and these are summarised below.

Current Indonesian lobster production is mainly from capture fisheries, with *Panulirus homarus* and *P. penicillatus* the major species. On average, the total aquaculture production from 2005 to 2011 contributed only 2.7% of the total national lobster production (aquaculture and fishery) as shown in Table 1.

Lobster aquaculture, including fattening of small sub-adults and full grow-out of puerulus, is developing at a very slow pace. ACIAR and the Indonesian Directorate General of Aquaculture (DGA) are collaborating to improve lobster aquaculture methods to provide alternative livelihoods for rural coastal communities. A common and effective extension method employed in Indonesia for a variety of farming options is the establishment of demonstration farms, and therefore the lobster grow-out demonstration farms discussed here were established.

Demonstration grow-out farms

Initially, interest in lobster grow-out was focused on Lombok, where the naturally settling pueruli have been found since the early 2000s. From 2000 to 2012 the lobster grow-out industry was able to produce 20 to 30 tonnes of marketable size lobster (up to 100 g each) per annum with a value of IDR 20 Billion or around US$1.5 million (Petersen et Al. 2013). Lobster grow-out was seen as a new type of aquaculture that could alleviate poverty and provide many job opportunities for communities living in the rural coastal zone (Tuan and Jones 2014), and therefore demonstration farms were introduced to stimulate industry growth and facilitate extension of best-practice farming methods. Choosing the right sites and collaborators was done with support from the local fishery agencies in Bima, Sape, South Sulawesi, Takalar and Ujung Batee.

Table 1. Indonesian spiny lobster production from capture fisheries and aquaculture (MMAF, 2014)

Source	Production (tonnes)							Average
	2005	2006	2007	2008	2009	2010	2011	
Aquaculture	61	558	371	292	339	312	225	308
Fisheries	6,648	5,254	4,705	9,896	5,893	7,651	10.541	7,227
Total	6,709	5,812	5,076	10,188	6,232	7,963	10,766	7,535
Aquaculture %	1	1.1	1.6	3	6	4	2	2.67

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Objectives

The aim was to establish six demonstration grow-out farms over the three years of the ACIAR project (two per year) at sites chosen for their proximity to likely puerulus supply and suitability for sea-cage farms. The intention was that smallholders from areas nearby the selected sites, who might be interested in trying lobster farming, could follow the example of the demonstration farm and adopt the cage construction and farming techniques being used. It was therefore hoped that through the demonstration grow-out farms, other farmers would engage in lobster farming to establish a viable and productive local industry.

Project activities

Each demonstration farm consisted of a framed unit comprising six floating sea cages. The frames for the sea cages were made from locally available materials. Bamboo was chosen as the most suitable material because it is strong and has a relatively long lifespan. The cages were made from polyethylene netting with dimensions of 3 × 3 × 3 m. The diameter of the net was 25 mm. The floating frame supporting the cages was equipped with a small guard house (Figure 1).

One thousand to 1,200 lobster seeds of *P. homarus* were provided to each farm, for a stocking density of around 200 pieces per cage. Trash fish and a commercial lobster pellet (Lucky Star Brand) were used to feed the lobster. Other support provided by the ACIAR project staff and local fisheries agency included work equipment, extension, technical assistance and daily protocol.

Collaborators

In Lombok, there were two demonstration farms established with local fishermen: Mr Pamit in Awang, Central Lombok and Mr Murdi in Telong Elong, East Lombok. In Sumbawa, there was a demonstration farm established in Teluk Sanggar in collaboration with the Bima Fisheries local district. In East Nusa Tenggara, a demonstration farm was established under management and support from the Tablolong Marine Aquaculture Centre, a technical implementation unit of Ministry of Marine Affairs and Fisheries. In South-east Sulawesi, Takalar Brackishwater Aquaculture Development Centre ran the demonstration farm in Laikang. The sixth demonstration farm was established at Pulo Aceh Nanggroe Aceh Darussalam, with Mr Muazzi as

Figure 1. Lobster grow-out demonstration farm, comprising six cages suspended from a floating frame, and small guard house for the operator

the person in charge. This demonstration farm was also supervised and monitored by Ujung Batee Brackishwater Aquaculture Development Centre. Details of the grow-out demonstration farms from 2010–2013 are summarised in Table 2.

Demonstration farm results

The following key elements were identified as factors representing success in the new grow-out farms.

1. *Exposure of contracted farmers/collaborators to the activity*. Farmers who have previous experience in marine aquaculture tended to have much more motivation to be successful, particularly those in Awang, Telong Elong, Aceh and Laikang.
2. *Farmers' attitude, application and practice*. Attitude is an important element in aquaculture which requires relatively long production duration. Daily protocol will only be effective if farmers have a positive attitude to applying and practicing it.
3. *Farmers' knowledge and skills*. The knowledge and skills of contracted farmers can be improved through technology transfer and supervision by researchers from DGA centres and local fishery agencies, and through farmer meetings, publications etc.

Some possible reasons for failure experienced in the activity are as follows:

1. lobster disease outbreaks
2. farmers' lack of skill in nursery techniques using very small and fragile puerulus
3. transportation issues
4. lack of sufficient local seed available
5. technical issues, such as a high rate of cannibalism among farmed lobsters.

Impact of demonstration farms

In Awang, Lombok between 2010 and 2012, there were 17 new grow-out farmers who started growing lobsters in the vicinity of the demonstration farms. However, from early 2013, due to a dramatic increase in puerulus catch, new grow-out farmers displayed an increasing preference to catch and sell pueruli rather than grow-out, as this involves lower risk and quicker cash flow compared with farming. In light of this, growing out lobster is much less attractive for them.

At Laikang Bay in South Sulawesi, there were 11 new cages established to cultivate lobster after the demonstration farm had been operating for three years (Table 3).

Table 2. Collaborators in the grow-out demonstration farms from 2010–2013

No	Locations	Collaborators	Year of activity	Unit	Crop cycle
1	Awang, NTB	A farmer group led by Pak Pamit	2010–2013	2	3
2	Telong Elong NTB	A farmer group led by Pak Murdi	2012–2013	1	2
3	Sanggar Bay	Local Farmers and DKP Kabupaten Bima	2012	1	1
4	Tablolong, NTT	Brackish water aquaculture center of Tablolong	2010–2011	1	1
5	Teluk Laikang, Sulsel	Brackishwater aquaculture center of Takalar	2011–2012	1	1
6	Pulo Aceh	A farmer group led by Pak Muazi	2010–2012	1	1

Table 3. The impact of grow-out demonstration farms in Laikang Bay, South Sulawesi

Years	Number of cages	Type of cages	Farmers involvement/status
2010	2 units	Holding	Individuals
2011	2 units	Grow-out	Individuals
2012	5 units	Grow-out	Individuals
2013	11 units	Grow-out	9 cages: Individuals 2 cages: Farmer groups

Other industry development activities

During the project, pamphlets, brochures, a brief production manual and short movies on lobster aquaculture techniques were produced, including on seed collection methods, nursery and grow-out husbandry, disease management, and transportation techniques for seed and market size lobster (Figure 2).

An informal health monitoring and disease prevalence survey was performed within the Lombok lobster grow-out community in collaboration with the Lombok MADC laboratory of fish disease and provincial Dinas environmental group. The gathering of disease information and associated communication helped farmers to better understand disease issues and methods for prevention and treatment.

Figure 2. Lobster aquaculture brochure to provide practical information to farmers

The involvement of university students in lobster production experiments from 2010 to 2013 (see Chapter 5.3) has had an unexpected positive impact, with many of the students returning to their home towns and villages and communicating the opportunity for lobster farming. The students came from Mataram University (UNRAM), Gadjah Mada University (UGM), Diponegoro University (UNDIP), Bogor Agriculture Institute (IPB) and Brawijaya University of Malang (UNIBRAW).

A specific on-farm feed manufacture trial was performed in 2013 with Mr Werry at his farm in Telong Elong, East Lombok to examine the practicality of making lobster pellets on-farm to supplement the commonly used fresh fish diet. This exercise was very effective, and good quality pellets were made using simple and readily available ingredients and equipment. Although the particular formulation needs further improvement, the concept was proven. The need for such pellet manufacture will depend on interest among commercial aquafeed companies in providing a cost-effective diet.

During the course of the project, an industry development workshop was delivered once a year in Lombok. The workshops were attended by farmers, middlemen, exporters and other stakeholders, and provided an opportunity to communicate project research results and discuss industry issues. They provided a valuable information exchange to improve the performance of the industry.

Conclusions and recommendations

Regular and effective contact with farmers to communicate best practice farming methods is key to the development of lobster grow-out farms in Indonesia. The farmers' attitude, capacity and skill level will be critical factors in the success of lobster farming. Consequently, social and economic considerations will be just as important as biological and technical support. Farmers' knowledge and skills will be improved through the supervision and monitoring by researchers and extension staff from the DGA centres and local DKP.

At the national level, the identification and promotion of the most suitable farming locations is required. Lobster grow-out has tended to occur in close proximity to the source of lobster seed in locations that are not necessarily the most suitable for sea-cage production.

Constraints to industry development include access to lobster seed and to suitable pelleted diets. There appear to be sufficient seed available in Lombok for a large grow-out industry that may comprise multiple locations throughout Indonesia. Developing effective transportation techniques will be a factor in achieving such development.

Access to effective pelleted diets is a difficult issue for a small, developing industry like lobster farming. The small volumes of feed required makes manufacture unattractive to aquafeed companies, but industry expansion and increased demand will only occur when such a diet is available. Research support and on-farm pellet production may help to bridge the gap.

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5.6 Opportunity for developing tropical spiny lobster aquaculture in Australia

Clive Jones[1]

Introduction

Aquaculture in Australia is relatively small scale, although it exhibits examples of strong commercial success (e.g. Salmonid farming in Tasmania) and many examples of failure. As a developed nation, operating costs for industry are comparatively high in Australia, particularly in regard to labour and regulatory compliance. This makes it difficult for Australia to compete with other nations farming the same or similar aquatic species. The opportunity to develop lobster farming must therefore be assessed in the context of Australia's competitiveness. Rock lobsters present a sound proposition for aquaculture development from a market price perspective, as they are one of the highest value seafoods and therefore have the capacity to absorb high production costs. However, the technical requirements for farming lobster are still developmental, and a guaranteed supply of seed lobsters does not exist.

Development of hatchery technology for lobsters will provide the necessary foundation for lobster farming, and to this end, Australia has invested heavily in research and development in this area (see Chapter 5.13). Nevertheless, at the time of the symposium, hatchery technology was still not available and not likely within five years.

Following the example of Vietnam, collection of pueruli for the purposes of aquaculture is a technically feasible option for Australia, although not a popular one due to perceived conflict with fisheries management. Although the value proposition of lobster aquaculture, based on collection of naturally settling seed has been considered in Australia (Gardner et al. 2006), it seems unlikely that it would be permitted.

An alternative proposition to enable lobster farming development in Australia is to grow-out subpremium sized lobsters that are above minimum legal fishery size, but smaller than that which fetches the greatest price per kilogram. In the case of *Panulirus ornatus*, this represents lobsters of around 700g which could be on-grown to the premium size of 1 kg.

Such 'fattening' production of *P. ornatus* was considered a potential opportunity for existing shrimp/fish pond farms in tropical parts of Australia as a diversification, and for coastal Indigenous communities as an enterprise that complements their cultural connection to the sea. If such production could be successfully established, it would provide a foundation of experience and technology adaptation that could be applied to a broader scale and possibly more intensive lobster farming when a hatchery supply of seed becomes available.

Use of sea cages for lobster grow-out in Australia is likely to be the most cost effective option as the technology is well established in Vietnam and could easily be adapted to Australia. However, at present sea-cage aquaculture is not permitted along the east coast of Australia within the bounds of the Great Barrier Reef Marine Park, and the coastal areas outside the park are either climatically unsuitable or very remote. Consequently, only land-based systems were considered in the assessments reported here.

Tank-based experiments of lobster growth through the early 2000s demonstrated good production credentials for *P. ornatus* (Jones et al. 2001). These data provided the starting point for the assessment of pond-based production of lobsters using existing shrimp farm infrastructure, and an assessment of the opportunity to establish lobster grow-out at an Indigenous community.

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Indigenous lobster farming

A scoping study to establish pilot grow-out facilities in Australian Indigenous communities was conducted. Grow-out 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. Using a SWOT analysis approach, the Yarrabah community was identified for the initial development with the intention of expanding to other communities as the project progressed.

The scoping study was completed in November 2010 and 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 grow-out enterprise. Facilitated through engagement with Jaragun Pty Ltd, broad community consultation was achieved, including support from Council and the traditional owners. A young traditional owner who had completed TAFE Certificate 1 aquaculture training was chosen as the candidate for training to be the initial pilot grow-out operator, and who would subsequently train others from the Yarrabah community.

The scoping study generated a detailed report (Owen and Ahkee 2010)(Chapter 6.4 Appendix 4) outlining the opportunity and necessary steps to progress to a business plan.

The business plan was subsequently prepared (Owen and Ahkee 2012)(Chapter 6.5 Appendix 5), providing a detailed analysis of the necessary permits that would be required to enable a pilot lobster grow-out facility to be established. Unfortunately, the regulatory requirements were so onerous and expensive as to render the project unviable. Some relaxation of these requirements or identification of alternative locations where permission would be easier to achieve will be required to make further progress.

Pond-based production

Field trials were conducted in Australia at two shrimp farms, firstly at Seafarm's farm near Port Douglas (16°30'16.1"S 145°27'04.4"E) north of Cairns, and subsequently at Pacific Reef Fisheries' prawn farm (19°29'53.9"S 147°26'27.8"E) north of Ayr.

At Seafarm, cages (2.5 × 2.5 × 1.5 m deep) were constructed to house lobsters, and were placed in pond inlet channels where water quality was equivalent to the adjacent shrimp ponds. Legal sized, live *P. ornatus* lobsters were purchased from a Cairns-based wholesaler for the trial and stocked at 20 lobsters per cage. They were fed a 7 mm moist pelleted diet manufactured in the laboratory and maintained in the cages for 126 days. Results were positive with survival overall of 78%, a specific growth rate of 0.14% per day and harvest size of around 900 g (Figure 1). Water quality during the trial was typical of prawn farms in north Queensland, with high turbidity and substantial variation in temperature and salinity. Although growth rate was not as great as experienced in tank experiments, and lobsters at harvest had moderately dirty shells due to bio-fouling, the results were sufficiently positive to justify further assessment (Jones and Shanks 2008).

Subsequent trials at Pacific Reef Fisheries' farm were conducted in four shallow, plastic lined raceways supplied with intake water as applied to adjacent prawn ponds. An experiment was performed in which each raceway was separated by a mesh barrier into two halves, one of which was furnished with table-type shelters and the other with no shelter. Lobsters were fed with a commercial lobster pellet (Lucky Star brand). Water quality during the trial is summarised in Table 1.

As can be seen from the water quality in the raceways (Table 1), conditions were far from optimal for a marine species accustomed to relative stability. Temperatures above 30°C and below 20°C can be considered extreme for *P. ornatus*. Similarly, salinity above 35 ppt and below 30 ppt will be stressful to this species (Jones 2009). As water quality varied outside of the preferred levels for *P. ornatus*, feed intake dropped and mortality increased, and as a result, the experiment was terminated.

Although *P. ornatus* appears to be an adaptable species that copes well with variations in its environment and is tolerant to average shrimp pond conditions, the extremes experienced in this case were beyond its tolerances. Such extremes in shrimp pond environments are common, even if they are of short duration. Consequently, it was concluded that this environment is not suitable for lobster production. This summation was similarly reached in Vietnam where pond-based trials were also underway (Jones and Anh 2013).

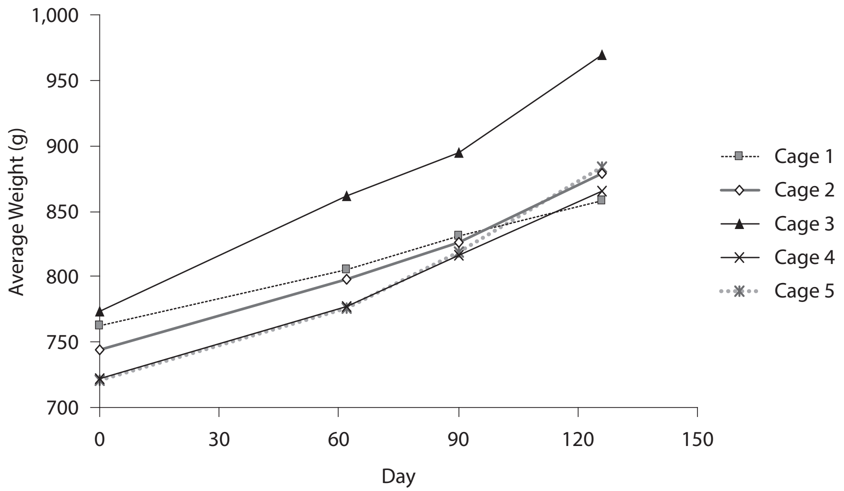

Figure 1. Growth of lobsters in cages in Seafarm pond water

Table 1. Water quality in raceways at Pacific Reef Fisheries during lobster production trial

Variable	Minimum	Maximum
Temperature °C	17.9	36.0
Salinity ppt	20.8	37.5
pH	7.68	9.3
Dissolved oxygen mg/L	2.7	15.1

Subsequent research efforts were directed towards tank-based production of lobsters on the basis that tank systems would confer greater control of water quality (see Chapter 4.3).

Conclusions and recommendations

The opportunity for establishing lobster aquaculture in Australia remains uncertain. Hatchery technology will provide the necessary seed supply and independence from natural stocks to form a foundation for an Australian industry, but such technology is still developing and is some years from being commercially viable. In the meantime, fattening of subpremium size lobsters may be viable. Production trials in shrimp farm water clearly showed that this environment was not suitable due to extremes in salinity and temperature. However, tank-based production would provide the necessary control of water quality to enable viable production.

Some preliminary economic analysis of tank-based production in Australia suggested that high capital and labour costs would necessitate an intensive approach, with a requirement to stock lobsters at very high densities. Given the social nature of lobsters, and advances in recirculation technology, it is technically feasible that super-intensive tank-based production might work. Specific research and development would be necessary to test this hypothesis, with a focus on maintaining lobsters throughout the full water column within production tanks.

Such economic constraints highlight that sea-cage production would be more cost effective and more immediately successful, if permits to enable this were forthcoming. This still appears unlikely in Queensland, at least on the east coast, but may be possible in the Northern Territory where there are fewer impediments to establishing sea-cage systems.

For Indigenous lobster aquaculture, a tank-based system was considered technically feasible but was precluded by a negative regulatory environment. The preferred option is for sea-cage based grow-out production. Constraints on achieving this include identification of sites where sea cages will be permitted, and effective training of Indigenous participants.

More broadly, the development of lobster aquaculture involving full grow-out from puerulus to market size in Australia will necessarily involve intensive tank systems, whose productivity may compensate the high labour, capital and compliance costs. Research and development of such intensive systems is a priority for future research.

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5.7 Genetics and recruitment of spiny lobsters *Panulirus ornatus* and *P. homarus* in the Indo-West Pacific

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Introduction

Lobsters from the genus *Panulirus* are commercially important species, occurring throughout the tropical eastern Indian Ocean, South-East Asia, Australia and the West Pacific. Spiny lobster puerulus (postlarval stage) are under heavy exploitation as seed stock for aquaculture, particularly in Vietnam and Indonesia. Of concern to managers of this fishery is the fact that large fluctuations in juvenile recruitment have been experienced in recent years, suggesting that the fishery may be subject to collapse in heavily exploited regions like Vietnam. In Vietnam, for example, total catch of *Panulirus ornatus* from eight provinces in the seasons 2006–2007 and 2009–2010 was only approximately 1 million puerulus, about half of that in other seasons. Whether the annual removal of 1 to 2 million puerulus by fishers is a factor in the absence of any recovery to adult stocks is unknown (Joneset al. 2010; Long and Hoc 2009). Recovery of fisheries in these exploited populations will be particularly problematic if recruitment is localized. An investigation into the genetic structure of spiny lobster species will therefore provide valuable data on the resilience and potential of populations to recover from heavy exploitation, as well as providing important information on sources and sinks for settling seed stock.

P. ornatus and *P. homarus* have lifehistories that provide the opportunity for long-distance dispersal, and consequently high rates of gene flow between populations. Firstly, adults are very adaptable in where they can live. They are denizens of a diversity of habitats from shallow (1–8 m depth) to deep waters (>50 m) sandy or muddy substrates, rocky bottom, or even turbid coastal waters, often near the mouths of rivers. They also inhabit coral reefs (Holthuis 1991). Moreover, some spiny lobster adults are known to migrate hundreds of kilometers to form large spawning aggregations at locations that benefit larval pelagic dispersal through strong water flow. Tagged adult *P. ornatus* in northern Torres Strait, for example, were detected to migrate about 511 km to the Gulf of Papua to spawn (Booth and Phillips 1994; Moore and MacFarlane 1984; MacFarlane and More 1986). Secondly, larvae from spawning events have a long planktonic phase lasting from four to eight months before they settle as puerulus (Booth and Phillips 1994; Phillips and Matsuda 2011). This provides the opportunity for larvae to be transported long distances by ocean currents before they become resident on reefs or other preferred habitats. Considering these characteristics, and the potential for long-distance dispersal, it is hypothesized that these species may exhibit low levels of genetic structuring across their distribution. This study investigated the genetic structure of spiny lobster *P. ornatus* and *P. homarus* throughout the species' distribution; essential in enabling resource managers to effectively regulate this fishery. Apotential dispersal pathway of *P. ornatus* was also inferred, based on a synthesis of data on regional oceanography and the lobsters' known biology, to explain the observed patterns of genetic structure.

Methods

To determine the genetic structure among *P. ornatus* and *P. homarus* populations across a broad part of the

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species' geographical distribution, a total of 216 *P. ornatus* individuals from two sites in Vietnam, three in Indonesia, and one in Australia were collected, while 229 *P. homarus* samples were collected from one population in the west Indian Ocean (Masirah, Oman) and six populations in the South-East Asian archipelago (Taiwan; Da Nang and Binh Thuan in Vietnam, along with West Sumatra, Lombok, and West Timor in Indonesia) (Figure 1). Specimens from Vietnam were all pueruli, while those from Indonesia and Australia were juveniles. Samples from Taiwan and Oman were adults collected from local fishing markets. All samples (pleopods from adults or abdominal muscle tissue from juvenile lobsters) were preserved immediately in a DMSO-salt preservative solution (Dawsonet al. 1998). Genomic DNA (gDNA) from all lobster samples was extracted from 4 mm^2 pleopod clips, or from the abdominal muscle tissue of juveniles using a modified CTAB protocol (Adamkewicz andHarasewych 1996).

Mitochondrial DNA (mtDNA) control region

DNA extracted from samples was diluted to 10–40 ng/µl for use in a polymerase chain reaction (PCR). The control region was amplified in 20 µl reaction volumes. PCR was performed on a BioRadC1000 Thermal Cycler. PCR products were then run on a 1.5% agarose gel for quantity and quality verification. A repeat region in the start of the reverse primed sequence resulted in deterioration of sequence. Consequently, only DNA sequence from the forward primer was used. To verify nucleotide base cells, each sample was sequenced at least twice at the Australian Genome Research Facility (AGRF) in Brisbane, Australia. PCR primers previously designed for *P. ornatus* mtCR (PO_F2 5' - ATAAAGGTAATAGCAAGAATC and PO_R1 5' - CAAACCTTTTGTCAGGCATC) were used for the amplification of 800 bp of the control region.

Sequence data were trimmed and aligned using Geneious ver. 6.1 with default alignment parameters and checked manually for misalignments. The statistical packages MEGA6 (Tamura et al. 2013) DNAsp 5.1 (Rozaset al. 2003) and ARLEQUIN ver. 3.5 (Excoffieret al. 2005) were used to perform partitioning of genetic structure Φ_{ST} (using genetic distance). For calculation of the statistical significance of the Φ_{ST} values obtained, a significance test with 10,000 permutations was carried out with ARLEQUIN ver. 3.5 (Excoffieret al. 2005). Φ_{ST} and pairwise Φ_{ST} comparisons between populations were estimated using the T92 model (Tamura 1992) with a gamma correction (α = 0.633) as determined by Model Selection in MEGA6. The median-joining network (Bandeltet al. 1999) for the haplotypes generated was constructed using NETWORK v. 4.6.1.0 (http://www.fluxus-engineering.com).

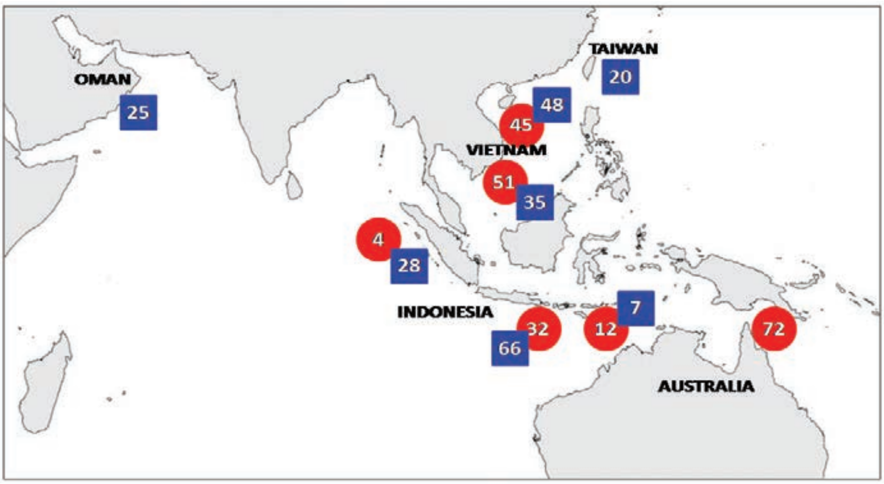

Figure1. Sampling sites and numbers of *Panulirusornatus* (red circles) and *Panulirus homarus* (blue squares) specimens collected from across species distribution

Microsatellite markers

Ten and six highly polymorphic microsatellite markers developed for *P. ornatus* and *P. homarus*, respectively (Daoet al. 2013) were used for population genetic analyses based on the nuclear genome of all specimens belonging to different localities.

DNA was diluted to 10–40 ng/µl for use as template in a polymerase chain reaction (PCR). Microsatellites were individually amplified in 10 µl reaction volumes. PCR was performed on a BioRadC1000 Thermal Cycler. The PCR products were then checked for consistent amplification and pooled and purified using Sephadex G-50 resin before loading on a Megabace 1000 Capillary Sequencer for size separation of alleles (Amersham Biosciences). Alleles were scored on the basis of fragment size using the Fragment Profiler 1.2 package (Amersham Biosciences).

The level of genetic structure of *P. ornatus* and *P. homarus* based on microsatellite markers was analysed using an Analysis of Molecular Variance (AMOVA) with 10,000 permutations as well as by calculating pairwise F_{ST} comparisons between populations, both of which were carried out with ARLEQUIN version 3.5 (Excoffieret al. 2005). Further to these analyses, the Bayesian clustering algorithm implemented in STRUCTURE 2.2.3 (Pritchardet al. 2000) was used to determine spatial genetic discontinuities by inferring the highest probable number of genetic clusters present within the dataset with prior knowledge of the individual's origin. The package Structure Harvester (http://taylor0.biology.ucla.edu/structureHarvester/) was used to determine the optimum number of clusters used in the analysis and CLUMPP (http://www.stanford.edu/group/rosenberglab/clumpp.html) was also used to create averages across the replicate runs, after which the outputs were put through DISTRUCT (http://www.stanford.edu/group/rosenberglab/distruct.html) to graph average q values.

Larval dispersal pathway map of *P. ornatus*

Physical and biological data were integrated to develop a larval dispersal pathway map of *P. ornatus.* This analysis could not include *P. homarus* due to a lack of knowledge about spawning grounds of this species. A literature review was undertaken, and expert opinion from relevant fisheries scientists in Australia, Vietnam and Indonesia was sought, to identify data on spawning grounds and pueruli settling locations within the archipelago (Daoet al. 2015). Biological data was then merged with oceanographic data to construct a map of the mean surface water circulation in the South-East Asian Archipelago, focusing on different months for different areas based on the known age of lobster larvae found during those months in those areas (Daoet al. 2015).

Results

Genetic variation of the mtDNA control region

No significant population subdivision was detected among the populations of *Panulirusornatus* sampled, with a non-significant fixation index evident (F_{ST}= –0.008; P = 0.922 ± 0.003). All of the genetic variation measured with mtDNA occurred within populations with no detectable among- population variance (Table 1). In addition, no evidence of genetic structure was detected across the wide geographical range sampled from the Torres Strait of Australia to Vietnam and Indonesia, with negligible and non-significant pairwise F_{ST} values between populations being very low (from –0.076 to 0.004, P>0.05) (Table 2). As further evidence for widespread gene flow and lack of genetic structure the network tree showed no clustering of haplotypes into geographical regions or location based groups, with the majority of haplotypes being single or unique units (Figure 2).

Table 1. Summary table of analysis of molecular variance (AMOVA) describing the partitioning of genetic variation for six *Panulirus ornatus* populations based on both mtDNA control region sequences and 10 microsatellite loci

	Source of variation (%)		Φ_{ST}/F_{ST}	P ± SD
	Among population	Within population		
mtDNA-control region	–0.80	100.80	–0.008	0.922 ± 0.003
Microsatellites	0.26	99.74	0.003	0.195 ± 0.004

Therefore, mtDNA based on the control region provided no evidence for genetic population structure in *P. ornatus* across the geographical range sampled.

In terms of *Panulirus homarus*, no population structure was revealed in AMOVA test using Tamura 1992distance performed on the mtDNA control region sequence data set (Φ_{ST} = 0.004; P >0.05; Table 3). No significant population subdivision was detected among sampling sites. At the initial analysis, the pairwise Φ_{ST} among populations shows a significant difference between samples collected in Taiwan and BinhThuan (Φ_{ST} = 0.029) Taiwan and Sumatra (Φ_{ST} = 0.023) Taiwan and Oman (Φ_{ST} = 0.034) or Taiwan and West Timor (Φ_{ST} = 0.077) but were not significant after correction using False Discovery Rate (FDR) (Table 4). As further evidence for a lack of genetic structure, the haplotype network tree showed no clustering of haplotypes into geographical regions, or location based groups, with the majority of haplotypes being single or unique units (Figure 3). Therefore, analysis based on data of the mtDNA control region failed to detect genetic population structure in *P. homarus* across the geographical range sampled.

Table 2. Genetic differentiation between *Panulirus ornatus* from collection locations using pairwise Φ_{ST} for mtDNA-control region (upper value) and for microsatellite loci (lower value). No significant F_{ST} value was found after correction using FDR

Localities	Torres Strait	West Timor	South Lombok	Binh Thuan	Da Nang
Torres Strait		–0.011	0.002	0.000	0.004
West Timor	0.006		–0.038	–0.018	–0.004
Lombok	–0.003	0.008		–0.015	–0.002
BinhThuan	0.001	0.002	0.004		–0.007
Da Nang	0.000	0.009	0.001	0.002	

Table 3. Summary table of analysis of molecular variance (AMOVA) describing the partitioning of genetic variation for six *Panulirus ornatus* populations based on both mtDNA control region sequences and 10 microsatellite loci

	Source of variation (%)		Φ_{ST}/F_{ST}	P ± SD
	Among population	Within population		
mtDNA-control region	0.35	99.65	0.004	0.227 ± 0.004
Microsatellites	6.02	93.97	0.060	0.000 ± 0.000

Table 4. Genetic differentiation between *Panulirus homarus* from collection locations using pairwise Φ_{ST} for mtDNA-control region (upper value) and pairwise F_{ST} for microsatellite loci (lower value)

Locality	Masirah	Binh Thuan	Da Nang	Taiwan	West Sumatra	Lombok	West Timor
Masirah		–0.001	–0.009	0.034	–0.001	0.015	–0.069
BinhThuan	**0.198**		–0.010	0.029	–0.012	0.007	–0.012
Da Nang	**0.175**	0.010		0.017	–0.006	0.003	–0.019
Taiwan	**0.181**	0.001	0.005		0.029	0.006	0.077
West Sumatra	**0.075**	**0.058**	**0.041**	**0.051**		0.006	0.023
Lombok	**0.085**	**0.052**	**0.044**	**0.043**	–0.001		0.010
West Timor							

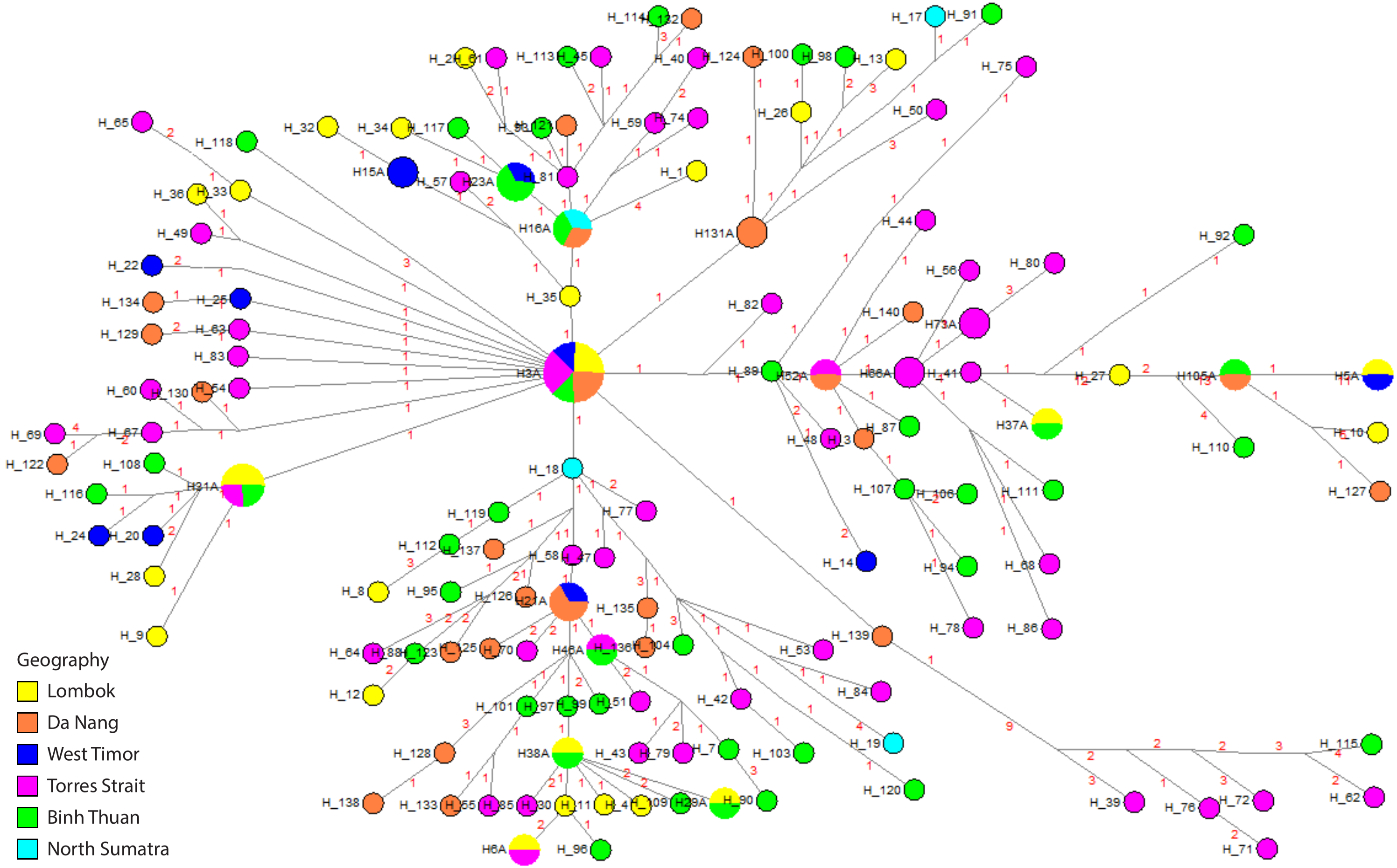

Figure 2. Network of *Panulirusornatus* control region sequences from six collection locations from the South-East Asian archipelago. Each circle represents a haplotype, whose diameter is proportional to the number of individuals with that haplotype. The numbers on the connecting lines are the number of mutations between haplotypes

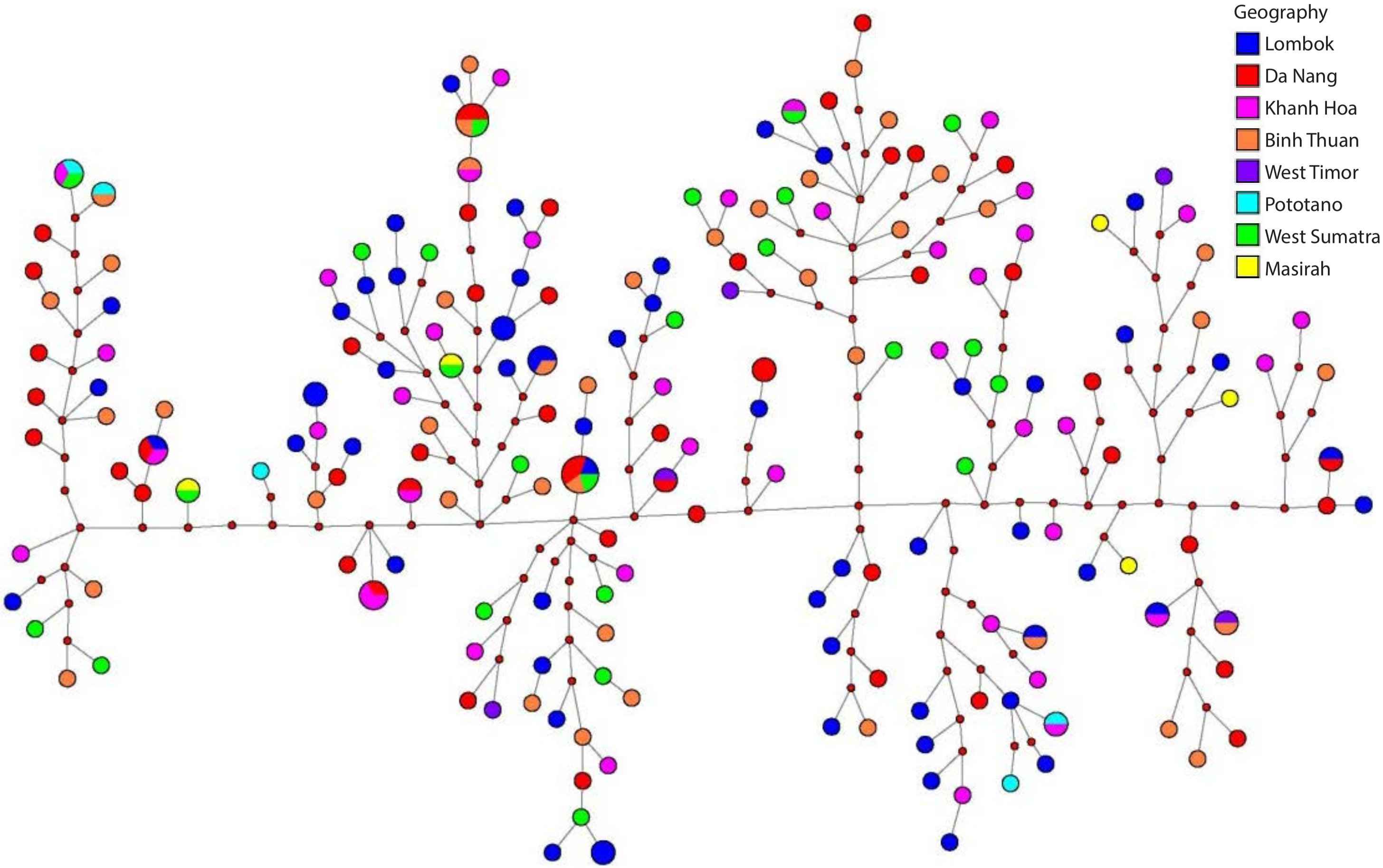

Figure 3. Haplotype network of *Panulirus homarus* control region sequences from six collection locations from the South-East Asian archipelago and one site from Arabian Sea. Each circle represents a haplotype, whose diameter is proportional to the number of individuals within that haplotype. The numbers on the connecting lines are the number of mutations between haplotypes. Small red dots are missing haploptypes.

Genetic variation of microsatellite markers

Ten polymorphic microsatellite markers were successfully amplified (Daoet al. 2013) and PCR products of all 216 samples of *P. ornatus* were genotyped for subsequent population genetics analyses.

As for the mtDNA control region, no significant population genetic structure was evident between the six sites when genotyped with the 10 microsatellite loci. F_{ST} estimates of population structure were again negligible and non-significant (AMOVA, $F_{ST} = 0.003$; $P = 0.195 \pm 0.004$) (Table 2).The microsatellite data indicated that less than 1% of genetic variation was present among populations. A similar lack of population genetic structure was evident in population pairwise comparisons across the Indo-West Pacific region (F_{ST} ranged from –0.003 to 0.031; Table 3). The pairwise F_{ST} comparison between North Sumatra and other sampling sites were the highest observed (from 0.017 to 0.034) but were all insignificant after FDR correction (P> 0.05). Due to the small sample size collected from Sumatra, these higher sample F_{ST} values are likely a result of sample size effects.

Individual based Bayesian assignment tests supported the lack of population genetic structure seen in pairwise F_{ST} estimates. Although Structure Harvester suggests K = 2 from multiple simulations run at values of K from one to 10, visual examination of individual bar plots for K = 2 indicates an inability of the STRUCTURE algorithm to reliably assign any of the individuals to a distinct cluster, with assignment probabilities for each of the two populations of 50% for all individuals sampled (Figure 4). The inability to assign individuals using post-hoc plots if the true K < 2 has been discussed in Evannoet al. (2005). Therefore, Bayesian analysis using STRUCTURE also suggests panmixia or lack of genetic structure among the six populations examined despite the widely spaced regional sampling employed here.

Six highly polymorphic microsatellite markers were successfully amplified in PCR and PCR products of 229 samples of *P. homarus* genotyped for the population genetics analysis. Significant genetic structure was detected among the seven sampling sites of *P. homarus* using F_{ST} estimates of population structure (AMOVA, $F_{ST} = 0.060$, $P = 0.0000 \pm 0.0000$). Due to the small sample size collected from West Timor (seven samples) the higher sample F_{ST} values involving this population are likely a result of random sampling effects and small sample

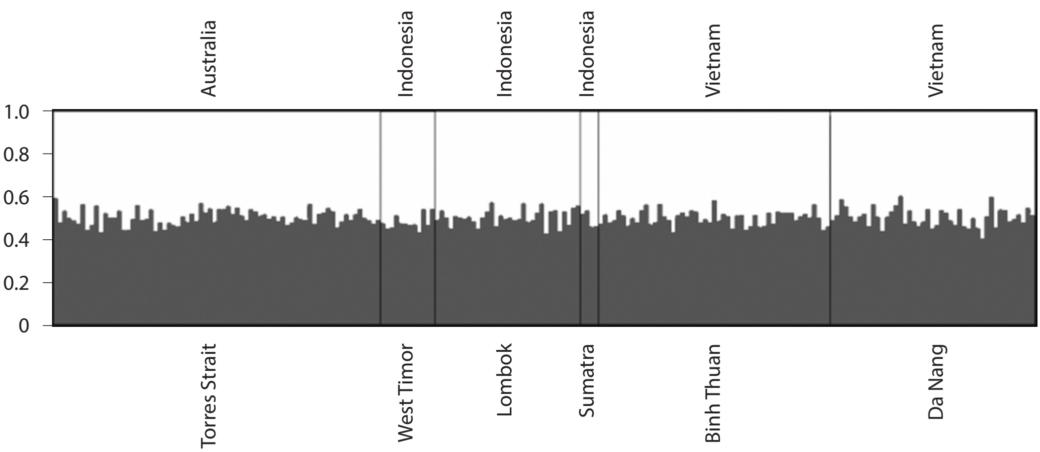

Figure 4. Bayesian individual assignment analysis for K = 2 for *Panulirus ornatus* genotyped at 10 microsatellites across six Indo-Pacific sampling sites. Colours (grey or white) represent probability (y-axis) of individuals being assigned to each genetic cluster, whilst numbers (x-axis) represents population individuals sampled from 1 = Torres Strait, 2 = West Timor, 3 = Lombok, 4 = North Sumatra, 5 = BinhThuan (Vietnam) 6 = Da Nang (Vietnam). Sampling locations were used as priors

size. About 6.2% of the observed genetic variation occurred among localities (Table 4). Pairwise F_{ST} revealed significant genetic structure between three groups of sampling site. The first group includes only Oman samples (Masirah). The second were Vietnam (BinhThuan and Da Nang) and Taiwan sampling sites, and Indonesia sampling sites from Sumatra and Lombok were in the third group. About 17.5–19.8% genetic differentiation were detected between samples from Oman and the second group, while less different rates (from 0.075 to 0.085) were found among Oman and Indonesia samples (Table 4).

The population genetic structure differentiation seen in pairwise F_{ST} estimates were consistent with the results obtained using Bayesian assignment tests. Results applied to Structure Harvester (http://taylor0.biology.ucla.edu/structureHarvester/) suggests K = 2 (Figure 5). Based on the pattern observed in the genetic clustering, we found regional structuring between Arabian Sea and Indo-West Pacific populations and within Indo-West Pacific populations of *P. homarus*, which explain the genetic variation (6.2%) between the regions. All samples from Oman were assigned to blue genetic cluster (more than 70% of blue colour) while most of samples collected in Vietnam and Taiwan were with more than 70% red proportion. Indonesian samples were a mixture of patterns from Oman and Vietnam-Taiwan samples.

Larval dispersal pathway map of *Panulirus ornatus* throughout the South-East Asian archipelago

The above genetic studies using both mtDNA control region and microsatellites reveal a single genetic population of *P. ornatus* within the South-East Asian archipelago, implying high population connectivity of *P. ornatus* throughout this region. To explain how this connectivity may eventuate, the distribution of currents in the surface well-mixed layer in the South-East Asian archipelago is shown in Figure 6. The suggested connectivity network is shown in Figure 7 and further elaborated on in the discussion. Accordingly, the apparent lack of genetic structure in this tropical lobster species across the South-East Asian archipelago is explained by current-mediated larval transport that connects lobsters among spawning populations. This connectivity requires at least three generations (Daoet al. 2015).

Conclusions and discussion

Both mitochondrial DNA (mtDNA) and microsatellites have been widely used for studies of genetic population in the spiny lobster genus, *Panulirus*. Genetic studies on Japanese spiny lobster, *P. japonicus,* failed to reveal any stock heterogeneity

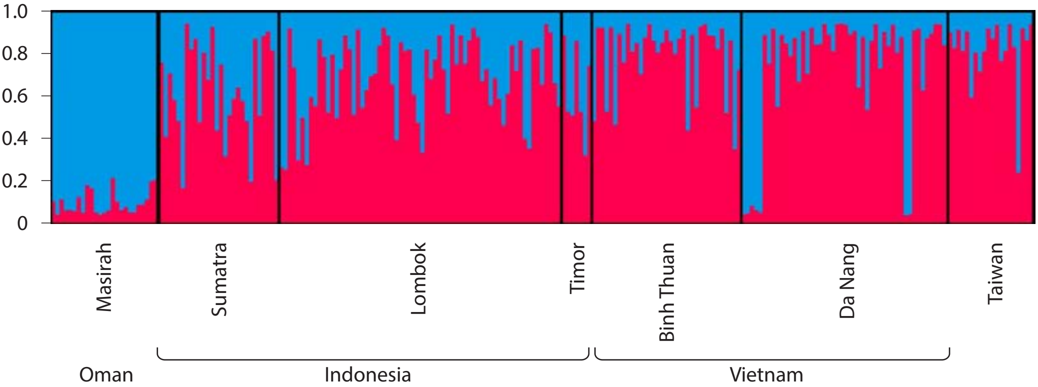

Figure 5. Bayesian individual assignment analysis for K = 2 for *Panulirus homarus* genotyped at six microsatellites across seven sampling sites. Colours (grey or white) represent probability (y-axis) of individuals being assigned to each genetic cluster, whilst numbers (x-axis) represents population individuals sampled from Oman (Masirah) Indonesia (West Sumatra, Lombok, West Timor) Vietnam (BinhThuan and Da Nang) and Taiwan. Sampling locations were used as priors

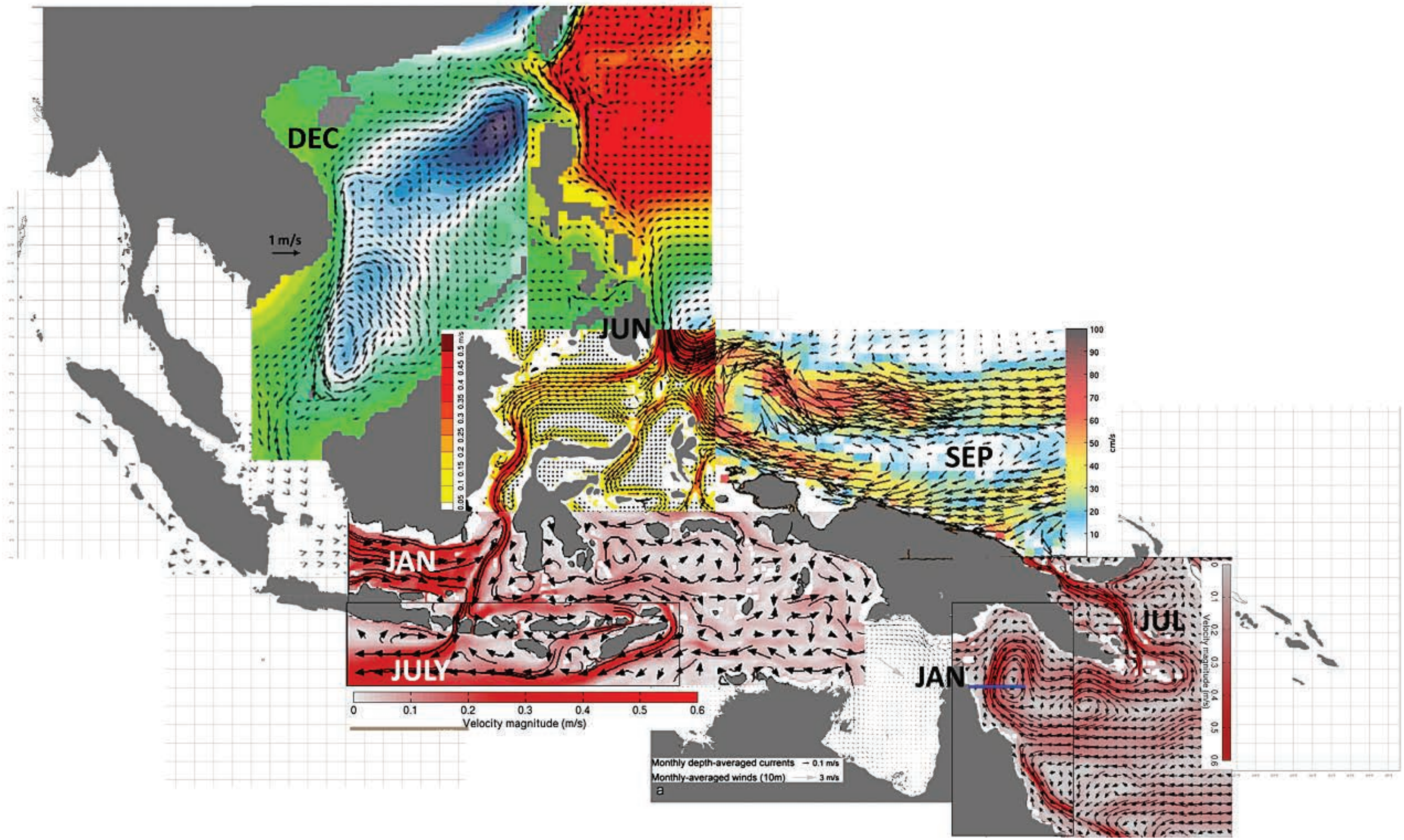

Figure 6. Seasonal surface ocean currents in the surface well-mixed layer in the South-East Asian archipelago at the times when *Panulirus ornatus* larvae are travelling between the various sites shown in Figure 7. To explain how this connectivity may eventuate, this figure shows the distribution of currents in the surface well-mixed layer in the South-East Asian archipelago during the periods of larval transport

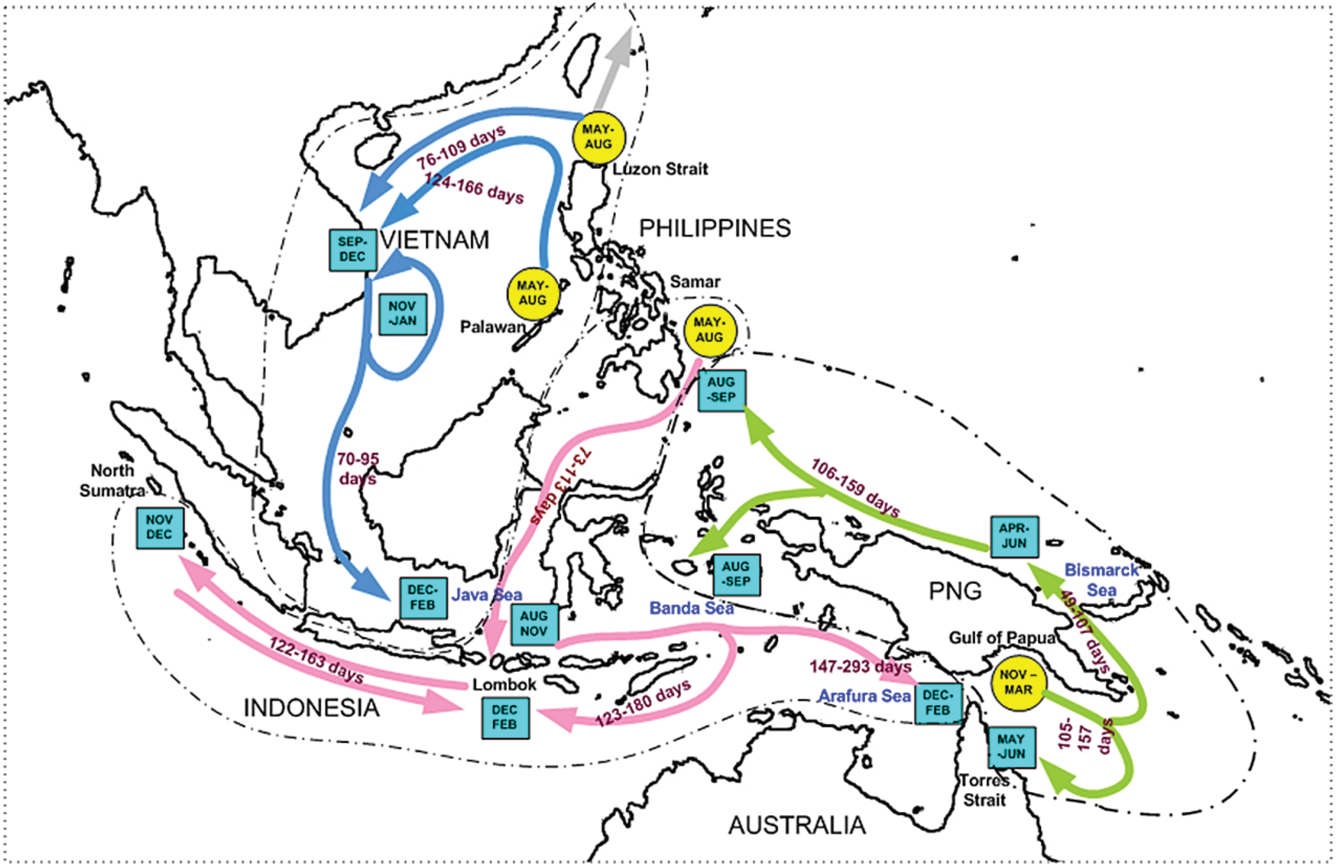

Figure 7. Suggested larval dispersal pathways based on the surface water oceanography and the location of spawning grounds, dispersion patterns and connectivity for *Panulirus ornatus* larvae throughout the South-East Asian archipelago. Round circles indicate spawning grounds where the larvae are released. Square boxes are estimated time that the larvae reach different locations as suggested by the oceanography and confirmed by field data. Of these, only two points have no field data, namely arrival times of larvae from Lombok in Torres Strait and the time of transit of the larvae along the north coast of Papua New Guinea. The different colours represent the different putative larval dispersal pathways, in order to distinguish separate flows

within the Japan Sea (Inoueet al. 2007) while low population divergence was observed for *P. gilchristi* in the deep shelf waters along the southern coast of South Africa. In addition, *P. cygnus* along the coast of Western Australia and *P. inflatus* in the Pacific coast of Mexico lack genetic structuring (Garcia-Rodriguez and Perez-Enriquez 2008; Thompson et al. 1996).

They also suggested that the panmixia is related to oceanographic flows in the area, coupled with a long larval period (Garcia-Rodriguez and Perez-Enriquez 2008; Inoueet al. 2007). However, panmixia is not always the situation. In *P. argus,* for example, genetic differentiation is present among Bermuda and Florida populations within the Caribbean Sea, as well as those sampled from Venezuela and Brazil (Sarveret al. 1998). Likewise, South African *P. delagoae* and *P. elephas* populations in the Atlantic Ocean and Mediterranean Sea exhibit shallow, but significant, levels of genetic structuring (Gopalet al. 2006; Paleroet al. 2008). Recently, Chowet al. (2011) and Abdullahet al. (2013) found no genetic structure of pronghorn spiny lobster *P. penicillatus* within Western/Central Pacific populations, but high genetic variability was observed between Eastern and Western/Central Pacific localities.

In the present study, a combination of mitochondrial DNA control region and microsatellite DNA data suggest a single, genetically homogeneous stock of *Panulirus ornatus* across a broad region of the South-East Asian archipelago. Genetic differences were not detected between samples of *P. ornatus* from Vietnam, Indonesia and Australia-PNG, supporting the hypothesis by Williams (2004) of low genetic structuring of this species across the region due to its long oceanic larval development phase and wide larval transport capability. Neither population genetic (F_{ST}, Φ_{ST}, Bayesian) or phylogeographic network analyses indicated any evidence for restrictions on gene flow across the region, and integration of biological and oceanographic data show that genes can potentially circulate unimpeded throughout the entire region in only a few generations. Our oceanographic informed dispersal modelling suggests the potential for complete connectivity of *P. ornatus* populations within the South-East Asian archipelago within three generations of breeding (Figure 7).

For *Panulirus homarus*, the mtDNA control region failed to detect genetic differentiation among localities ($\Phi_{ST} = 0.004$; $P > 0.05$) which might be the consequences of small sampling size. In contrast to this limitation in our mtDNA control region data, however, six polymorphic microsatellites revealed significant genetic structure (overall $F_{ST} = 0.060$, $P = 0.0000 \pm 0.0000$) among populations of *P. homarus*, with a strong differentiation between Indo-West Pacific and Arabian Sea (7.5–19.8%) and a shallower genetic variation within Indo-West Pacific (5.2–5.8%). Significant genetic divergence between Arabian Sea and Indo-West Pacific might be due to the ocean movement patterns which restrict the gene flow among these localities (Berry 1974; Pollock 1993).

The Bayesian individual assignment analysis (Figure 5) in our present study shows different genetic patterns among Oman populations and others. All samples from Oman were more homogeneous with the blue genetic cluster than most samples from other populations in Indonesia, Vietnam and Taiwan. However, some of individuals collected from West Sumatra, Lombok and Da Nang also had similar genetic patterns to Oman samples, which suggests a one-way dispersal pathway of *P. homarus* larvae from the Oman population to other localities.

Implications for management

The existence of a single genetic population of *P. ornatus* characterised by drift connectivity (Lowe and Allendorf 2010) might have important implications for the sustainable management of this lobster, in that the species within the region need to be managed as one genetic stock. However, more work is required on the demographic connectivity of these populations so that the combined genetic and demographic connectivity datasets can inform management of this species as either one unit, or on the basis of individual spawning grounds (Ovenden 2013). Consequently, a multi-governmental fishery policy should be developed by Australia, Papua New Guinea, the Philippines, Vietnam and Indonesia, to ensure sustainability.

Our study findings provide genetic evidence to suggest genetic structuring *P. homarus* among populations across geographic distribution, as the species has a high dispersal potential throughout its life history, including adults spawning migration and long pelagic larvae duration. There are still knowledge gaps about the sources and sinks of recruited lobsters landing on the coastline of many countries. It is suggested that further studies be carried out on ecology, especially on the breeding grounds and spawning time of the species, and that these be applied to a bio-physical model to understand the oceanographic dispersal pathway of *P. homarus* larvae in their large distribution. This may have major implications for fisheries managers.

While the sinks of *P. ornatus* larvae are known, the knowledge of larval sources for both species is still rudimentary, with only a few spawning sites confirmed to-date. The present study suggests that an additional spawning ground may be present in Indonesia, and its location needs to be identified and protected. More detailed studies on population connectivity are necessary to ensure the sustainability of lobsters in the South-East Asia archipelago. Genetic connectivity should be conserved as a priority.

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5.8 Study tour of Indonesian farmers to Vietnam lobster aquaculture industry in 2013

Bayu Priyambodo[1]

Introduction

To assist in the transfer of lobster farming technology and stimulate expansion of lobster farming in Indonesia, a study tour was undertaken to Vietnam in March 2013. This paper provides a summary of the tour, its objectives, the participants' credentials, the program of activities, outcomes and recommendations.

Farming techniques in Indonesia are at an early developmental stage in contrast with Vietnam, where the lobster industry is highly developed. Over the past decade, ACIAR has supported the sustainable development of rock lobster farming in Vietnam and Indonesia. Given the success of the industry in Vietnam, it was deemed prudent to use a study tour as one method to transfer technology. By exposing Indonesian aquaculture farmers and government officials tasked with supporting aquaculture development directly to Vietnamese industry practices, effective technology transfer was facilitated.

To aid in the process and minimize communication difficulties, a translator fluent in both Indonesian and Vietnamese languages was employed to enable direct translation between Vietnam industry personnel and study tour participants.

Study tour participants and program

The study tour took place over nine days in March 2013 in and around the city of Nha Trang, where lobster farming is well developed and represents one of the most successful aquaculture industries in Vietnam. It was surmised that the lobster farming technology in Vietnam could potentially be adapted to Indonesia.

The objectives of the tour were to broaden the participants' knowledge of lobster aquaculture, to give them an idea of the scale in which an Indonesian industry might reach, and to stimulate participants to become agents of change in their farming areas.

The backgrounds of the tour participants are provided in Table 1. In addition to the core participants, the tour group also comprised a tour supervisor from ACIAR, a translator and a tour leader from Nha Trang University who managed all logistics and coordinated industry visits.

The program of activities is summarized in Table 2. The program was designed to expose the participants to all aspects of lobster farming from capture of lobster seed through to grow-out.

To assist in measuring the effectiveness of the tour, an interview-based survey of participants was performed, including pre and immediate post-tour interviews, with plans for a follow-up interview six months after the tour. The outcomes of the survey will form part of a PhD thesis by the author.

Outcomes

The tour was performed without incident, and all participants were fully engaged and stimulated by the experience. A summary of industry statistics was prepared from the data gathered, presented in Table 3.

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Table 1. Background information on study tour participants

Profession	Experience with lobster (years)	Based at
Researcher	0	RICA Maros
Aquaculture engineering	2	Lombok MADC
Aquaculture extension	15	Lombok MADC
Aquaculture extension	3	Takalar BADC
Postgraduate student	7	UNSW Australia
Aquaculture extension	0	DKP NTB
Lobster farmer	15	Awang Lombok
Lobster farmer	6	Pulo Aceh
Aquaculture technician	1	Takalar
Aquaculture manager	15	Lombok

Table 2. Program of activities for study tour

Date	Activity	Place
1-Mar-13	Travel	Jakarta to Ho Chi Minh City to Nha Trang
2-Mar-13	Recovery and briefing Pre-tour participant survey / interview	Nha Trang city
3-Mar-13	Seed collection Interview seed fishers Q&A Lunch + discussion	Nha Trang city Bai Tien village catching area 1
4-Mar-13	Nursery farms Travel (boat) Inspect nursery farm Interview farmer Q&A Lunch + discussion	Nha Trang city to the nursing farms Bai Tien
5-Mar-13	Grow-out farms Inspect grow-out farms Interview farmers Q&A Lunch + discussion	Nha Trang city to Cu Lao landing port, to farm 1 Bich Dam (*P. ornatus*), to farm 2 Hon Mieu (*P. homarus*)
6-Mar-13	Field trip Meeting with local fishers/farmers Travel (boat) Q&A Lunch + discussion with locals Visit to the catching area 2 Visit to the tank facilities	Van Ninh Distrit to Xuan Tu village, to the farming area Xuan Tu, back to Xuan Tu village. Ran Trao MPA's to the catching area 2 Luong Son, to the tank facilities Bai Tien
7-Mar-13	Lecture on lobster health and disease Travel Lecture + Q&A Lunch + discussion	Nha Trang University R&D Centre
8-Mar-13	Visit to fish landing port Visit to the museum Post-tour participants survey/interviews	Nha Trang city to the landing port Cau Da port Vien Dong hotel to the ION's museum
9-Mar-13	Travel, return to Indonesia	Nha Trang to Ho Chi Minh City to Jakarta

Table 3. Lobster farming industry statistics for Vietnam and Indonesia

Metric	Vietnam	Lombok
Annual puerulus supply	2–5 million	600,000 (2008–2012)
Annual production of live lobster	> 1,000 tons	20–25 tons (before 2012)
Number of sea cages	35–50,000 cages	2–3,000 cages
Puerulus price[1] (each)		
Panulirus homarus	\$2.00 to \$2.40	\$0.20 to \$0.60
Panulirus ornatus	\$5.00 to \$7.50	\$0.40 to \$0.70
Market price per kg		
Panulirus homarus	\$50 to \$60 (400 to 500g)	\$35 to \$40 (100 to 200g)
Panulirus ornatus	\$80 to \$120 (1kg)	Not applicable[2]
Lobster food price per kg		
Acetes shrimp	\$1.50	\$2.50
Baby crabs	\$0.95	Not available
Trash fish	\$0.70 to \$1.00	\$0.10 to \$1.50
Grow-out duration (months)		
Panulirus homarus	12 to 15	8 to 10
Panulirus ornatus	18 to 20	Not applicable[2]
Survival rate		
Panulirus homarus	80 to 90%	20 to 50%
Panulirus ornatus	70 to 80%	Not applicable[2]
Food Conversion Ratio		
Panulirus homarus	15	15
Panulirus ornatus	15 to 25	Not applicable[2]

1 Prices in US dollars
2 Lobster species in Indonesia are not distinguished for marketing or production

Conclusions and recommendations

The study tour appeared to be very effective in improving the knowledge of participants, particularly in regard to detailed technical information on seed collection, nursery, grow-out (sea cages, submerged cages and tanks) and disease.

Qualitative assessment of farming practices since returning to Indonesia suggest there has been distinct improvement in grow-out management techniques, particularly management of cage depth and routine cleaning of cages, nutrition and lobster health.

The most dramatic impact of the study tour was the significant increase in lobster seed catch attributed to improved techniques, modified equipment and application of light to attract seed to the fishing equipment. In Lombok, more than 60% of farmers modified their seed traps to improve the catch, particularly with the inclusion of lights.

The puerulus fishing grounds throughout Indonesia have expanded from three bays (Awang, Bumbang and Gerupuk Bays) in Lombok to the entire south coast area of Lombok, and also Dompu, Bima and several parts on the south coast of East Java. Based on the knowledge gained from the study tour, two new seed catching areas were identified in Aceh.

As reported in these proceedings (Chapter 2.1), seed catch in Lombok increased dramatically within one month of completion of the study tour, resulting in the subsequent annual catch for 2013 exceeding five million lobster seeds compared with 600,000 per annum previously. The lobster seed census for 2014 recorded five million lobster seeds caught in 2014.

The number of the puerulus fishers has also increased significantly from around 300 in the previous period (2008–2012) to 3,000 in 2014. This activity has generated very good income for the coastal communities involved.

Knowledge gained on diseases also assisted in the application of more effective preventive and curative measures, decreasing prevalence.

Suggestions for future study tours include: greater focus on grow-out techniques, longer periods of interaction with farmers, and bringing Vietnamese lobster farmers to Indonesia.

Acknowledgements

The financial support of ACIAR is gratefully acknowledged and special thanks given to Dr Clive Jones for supervising the study tour. The leadership and guidance of Dr Le Anh Tuan from Nha Trang University is greatly appreciated. Thanks to Ms Hoa Dang Hoang for translation service. Many thanks to the Vietnamese farmers who shared their knowledge, and to the study tour participants for their enthusiastic attendance.

Figure 1. Study tour group assembled at Nha Trang, Vietnam.

Figure 2. Tour group uniform

Figure 3. On board lobster seed fishing vessel

Figure 4. Indonesian farmer discussing nursery culture techniques

Figure 5. Tour group on transport vessel to grow-out farms

Figure 6. High quality farmed lobster *P. homarus* (left) and *P. ornatus* (right)

5.9 Market perspective on farmed tropical spiny lobster

Clive Jones[1]

Introduction

This paper provides a synopsis of market information for lobsters gathered by the project team through their experiences and project travel during the course of the ACIAR project SMAR/2008/021: Spiny lobster aquaculture development in Indonesia, Vietnam and Australia. The audience is advised to also read a market assessment report for tropical lobster prepared as part of a previous ACIAR project (Hart 2009).

The information provided covers primary markets for farmed lobsters, general observations, wholesale prices, import tariffs, seed supply and regional developments.

General observations

Marine spiny lobsters are a premium seafood product representing esteem, wealth and fine dining. Farming of lobsters is not for production of protein to feed hungry people, it is rather to supply prestige to a specific market motivated to boast and impress for social eminence.

Much of the farmed lobster from Vietnam is supplied to Hong Kong live seafood markets, from where it is trans-shipped to other mainland Chinese cities. Insights from MG Kailis Australia Pty Ltd (Brett Arlidge pers. comm.) indicate that *P. ornatus* supplied from the north-eastern Australian fishery is considered the premium in the Chinese market, and that farmed product from Vietnam is now of equal value. In contrast, the farmed lobster coming from Indonesian farmers (primarily *P. homarus*) is considered to be of relatively low quality relative to fishery product of the same species. Farmed product is generally in a weak condition, with poor colour. To increase their profitability, Indonesian farmers need to work towards price equivalency for their farmed product.

Primary markets

The primary market for farmed tropical lobster is China, with Taiwan a valuable secondary market. Farmed *P. ornatus* and *P. homarus* from Vietnam are nearly all sold to these markets as live lobster. This supply joins wild fishery product of the same species from Australia, India, the Philippines and other South-East Asian countries. Farmed product from Indonesia is currently too small in volume to register on any formal databases. It is understood that nearly all Indonesian farmed lobster is supplied to domestic markets, primarily in Bali. As farmed production from Indonesia increases it should look towards China to achieve premium price.

In regard to tropical lobster species, the Chinese market displays a clear preference for *P. ornatus* at 1kg size and alive. Nevertheless, there is increasing acceptance of other species and price is trending upwards for all species. *P. homarus* is increasingly accepted as a substitute for *P. ornatus*. Wholesale price in China fluctuates around cultural events, when lobsters are traditionally sought or avoided, e.g. Chinese New Year (lantern festival) vs Tomb-sweeping Day. The increasing size of the Chinese upper class with a taste for fine dining continues to drive demand.

Although the China market is the primary market for farmed lobsters and offers the highest price, driven by strong demand that exceeds supply, there is some risk in complete reliance on this market. Decrees from the Chinese central government to reduce or avoid celebratory corporate events and

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dining can have a dramatic effect on demand for some products. In the past, this has significantly affected abalone and grouper sales, as these products were specifically mentioned in the government pronouncements. Some diversification in marketing of farmed lobster is prudent to mitigate such risk.

Wholesale prices

At the time this report was prepared, Australian fishery sourced *P. ornatus* was fetching a wholesale price of $90/kg in Australia, which equates to A$130/kg in Hong Kong, which applies a 40% tariff. Vietnamese farmed product of *P. ornatus* and *P. homarus* are now generally transported directly to China overland by truck via Hanoi to avoid payment of import duties through Hong Kong. Under this arrangement, they achieve a wholesale price of A$130/kg for *P. ornatus* and A$80/kg for *P. homarus*. Indonesian farmed *P. homarus* is generally of low quality and small size (<300g) and fetches a wholesale price of A$40/kg.

Wholesale price for all species of lobster have continued to increase over the past decade as demand increases and supply remains steady. This price trend is well illustrated for farmed *P. ornatus* prices as per Figure 1.

Import tariffs

Both Vietnam and Indonesia are advantaged by having free trade agreements with China by virtue of their ASEAN (Association of South East Asian Nations) membership that precludes any import tariffs. Nevertheless, importation via Hong Kong still attracts significant costs in other taxes and duties which has prompted Vietnam to bypass Hong Kong for the importation of live lobster by using road transport overland via Hanoi.

Australia does not have a free trade agreement with China, and consequently attracts a 40% import tariff on imported live lobster coming from the fishery in north Queensland and the Torres Strait. This is to the advantage of Vietnam and Indonesia as they do not have such a tariff added to the cost of their lobster product.

Attempts by importers in Hong Kong to evade tariffs by clandestine trans-shipping of product to mainland China cities, thus avoiding customs inspection, have sometimes backfired, when Chinese authorities have issued temporary bans on all lobster imports from Australia.

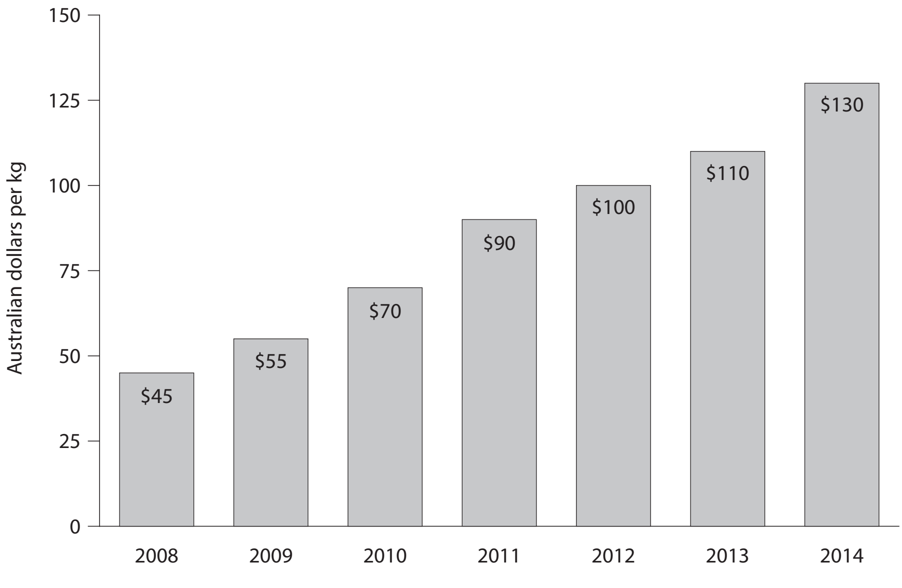

Figure 1. Price trend for farmed *P. ornatus* from 2008 to 2014 based on Vietnamese production

Seed supply

Farm production of lobster is currently limited by the natural seed supply. In Vietnam, the seed catch has been consistently two to four million pieces per year, from which farmers generate around 1,500 tonnes of marketable lobsters. Opportunities to increase production to meet demand can come from increasing the survival rate of lobsters along the production chain through improved husbandry and nutrition, and from increased seed supply. It seems unlikely that any more seed can be captured in Vietnam as the fishery appears to be fully developed, however importing seed from other countries could be further developed.

Indonesia has increased its seed supply through improved seed fishing technology (see Chapter 5.8), and much of the increased catch has been exported to other countries, including Vietnam, for on-growing. The marketing of lobster seed is a relatively simple and low risk business that appeals to smallholders in Indonesia, but their potential returns would be far greater if they grew the seed lobsters to consumption market size. At present, Indonesia produces less than 50 tonnes of farmed, consumption-size lobsters from the seed they capture. Applying best practice production technology from Vietnam, and on-growing lobsters to larger sizes could generate more than 1,500 tonnes.

Hatchery technology for the production of lobster seed would enable even greater production of farmed lobster to meet market demand. However, given difficulties in commercialising the technology (see Chapter 5.13) it seems that such supply is many years away.

Regional developments

Vietnam is the only country in the region supporting a viable and commercial-scale lobster farming industry. Production from Vietnam is steady at around 1,500 tonnes of farmed lobster per year. Indonesia is the next best positioned country to develop lobster farming, based on an established puerulus fishery in Lombok now producing in excess of five million lobster seed each year. The challenge for Indonesia is to convert the seed into marketable lobsters to exploit available market opportunities.

In Malaysia, the establishment of an integrated lobster aquaculture park in Sabah was recently announced. The project is a joint venture between the United States-based Darden Corporation (owner of the Red Lobster restaurant chain) and Malaysian partners to establish both grow-out farms and a hatchery. However, to date, there has been no commercial output from this enterprise.

Anecdotal reports suggest there is some farmed lobster production in the Philippines, Thailand and India, although no confirmed statistics are available. It appears that such production is low in volume, irregular and likely represents simple fattening of smaller lobsters.

Australia has expressed considerable interest in developing lobster farming to bolster its successful fishery production, and to take advantage of market opportunities. However, to date, no farmed lobster production has been established for any Australian species.

Conclusions

High market demand for lobster from China and Taiwan presents a significant opportunity for farmed product, and Vietnam has begun to seize this opportunity. Farming of lobster provides the additional opportunity of customizing product to meet specific market requirements in regard to size, vigor and possibly colour, such that farmed product could attract a premium over wild caught fishery lobster. Although the highest price is paid for *P. ornatus*, there is great demand and good price available for other tropical species, including *P. homarus*.

Indonesia has an opportunity to be a major producer of farmed lobster.

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5.10 Building Indonesia's lobster farming industry

Bayu Priyambodo[1] and Clive Jones[2]

Introduction

This paper provides a broad perspective on the prospects for developing lobster farming in Indonesia, including a discussion of government support and a SWOT analysis. Barriers to development are identified, as well as recommendations for research and development activities that might enable lobster farming in Indonesia to reach its full potential.

Vision

A sustainable lobster farming sector engaging coastal communities throughout Indonesia producing high quality lobsters for the market.

The goal is to establish Indonesia's most valuable aquaculture industry. This will be accomplished by researching, developing and extending best practice technology to coastal communities to provide them with the knowledge, capacity and confidence to engage in lobster farming.

The lobster farming industry is small but well established in Lombok. Strong potential exists for this nascent industry to flourish throughout Indonesia, benefiting impoverished coastal communities. Continued ACIAR support at this critical time will ensure development problems are addressed and benefits are maximised.

Based on puerulus availability of five million pieces, lobster production could reach more than 2,500 tonnes and a value of over $130 million.

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Prospects

Indonesia has a coastline spanning some 54,716 km from a combined total of 17,508 islands. Consequently, there are many suitable sites to develop marine aquaculture in Indonesia, including lobster farming. Straddling the equator, the climate is a relatively benign tropical one that provides great opportunity for sea-cage culture of tropical lobsters.

Strong market demand from China and Taiwan for live lobsters provides a strong foundation, and the Vietnam experience suggests farmed lobsters can achieve the same high price as wild caught product. An enormous lobster seed supply has been established in Lombok that can support a significant industry, with strong prospects. This could be expanded from additional seed supply in Southern Sumbawa, Southern Sulawesi, South-east Sulawesi, Aceh and other parts of Indonesia.

Government support

The Indonesian Directorate General Aquaculture (DGA) has developed a mid-term plan of Aquaculture Development 2015–2019. Although lobster is not specified as one of the main commodities for aquaculture development, it is included in the 'Other Commodities' category that is also well supported by central government.

Lobster is specifically included in the DGA program for the industrialisation of mariculture. Other species in this program include silver pompano, groupers, sea-bass, tuna, cobia, ornamental fish, crustaceans, sea cucumbers, sea horse and seaweeds. DGA is developing a draft of a National Standard of Indonesia for lobster aquaculture. The location of government-supported pilot lobster sea-cage operations in Indonesia are shown in Figure 1.

A SWOT analysis of lobster aquaculture in Indonesia is provided in Table 2. This will be useful in directing research and further government support.

Constraints

Lobster farming in Indonesia is a small and fragmented industry that would be well served by communication between operators. There are no established lobster associations as yet, and this confers a relatively weak negotiating position for farmers, particularly in regard to middlemen who purchase lobsters from the farmers and who tend to make the biggest profit.

In general, coastal communities rely too much on government support. The people living in the coastal zone prefer to sell puerulus rather than grow lobsters out to marketable size (aquaculture), as sale of seed provides quicker cash flow and has relatively low risk.

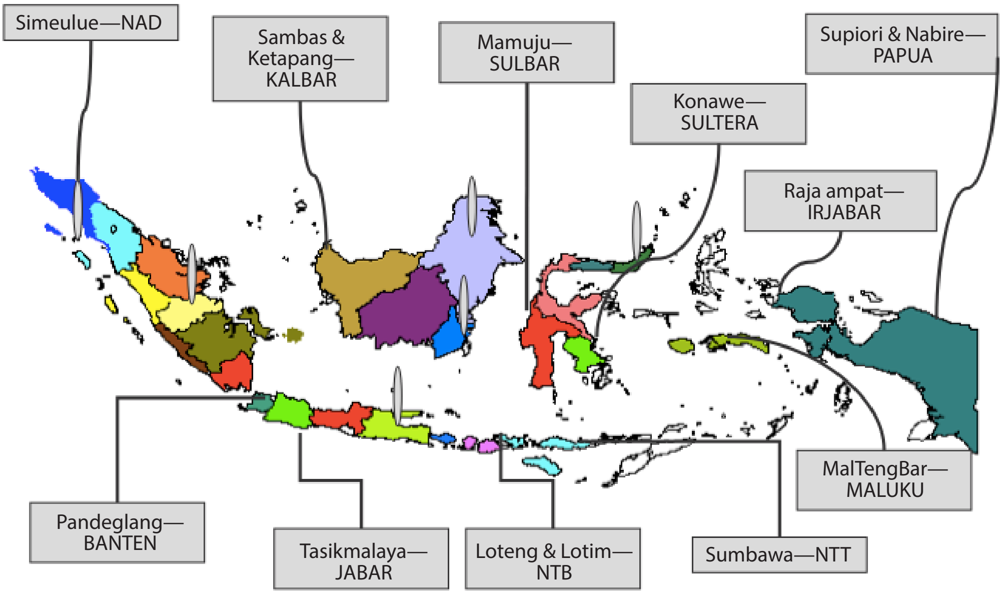

Figure 1. The location of government-supported pilot lobster sea-cage operations in Indonesia

Table 1. SWOT analysis of lobster aquaculture in Indonesia

No	Strengths	Weaknesses	Threats	Opportunities
1	Existing seed resource identified and exploited	Industry small with limited recognition	Climate change Seed availability	ACIAR support to grow
2	Grow-out established	Poor access to capital	Export of seed	Expansion of seed resource
3	Farmed lobsters being marketed	Poor decisions driven by cash flow constraints (harvest size)	Diseases	Significant number of suitable grow-out locations
4	Knowledge and capacity within Lombok	Lobster farming only known in Lombok	Poverty	Corporate investment
5	ACIAR support	Limited extension capability	Education/knowledge of farmers	Growing demand
6	High-value species	Limited farmer capability	Ignorance of opportunity	Improve product quality
7	Site availability and potential for development	Limited technology	Increasing cost of production	

A further constraint for poor coastal smallholders is their access to credit. There are some credit programs provided by the Ministry of Marine Affairs and Fisheries for coastal communities, but most smallholders are unfamiliar with how to access them. Most lobster farmers prefer to borrow money from their neighbours, private financiers and relatives, who charge very high levels of interest.

Industrial support for lobster farming is also limited or difficult for farmers to access. The government can provide manufactured cage systems for groups of farmers, but lobster farmers are yet to access this option. National aquafeed companies have not expressed interest in producing a pelleted feed for lobster, as the sector is too small and dispersed.

Conclusions and recommendations

Goals

- Increase puerulus catch to >five million pieces per year from multiple locations. This means that lobster production could reach more than 2,500 tonnes and a value of over $130 million.
- Grow-out established in more than five provinces.
- Puerulus export abandoned in favour of local grow-out.
- Coastal communities advised, educated and engaged in lobster farming.
- Export of farmed lobsters to premium markets exceeds 1,000 tonnes.
- Average harvest size >500 g per lobster.
- Average farm gate price >$50 per kg.

Recommendations for industry development

	Duration	Description
1	Short term	Developing a supply of wild puerulus Establishment of grow-out techniques Regulation for controlling export of lobster seed Improvements in nutrition and feed supply Marketing system for export of farmed lobster Access to capital Extension and dissemination program
2	Mid term	National plan for lobster farming development Industrial support (feed manufacture and cage construction)
3	Long term	Hatchery supply

Research required

Project	Disciplines	Objectives	Priority
A	Biology Nutrition Husbandry Fisheries (puerulus)	Improve production survival and growth Increase productivity Increase production	1
B	Economics Social Science Technology adoption	Robust economic models as collateral for finance Understanding of social factors in engaging more people	2
C	Policy Planning	National plan for lobster farming development Identified grow-out locations with support	3
D	Disease	Identify key health and disease issues Develop mitigation strategies Develop treatments	2
E	Training Education	Knowledge and capacity development at the community level	1
F	Marketing Product development	Improve market access Increase farm gate price New products to meet market	3
G	Biology Recirculation Technology	Intensive lobster production systems Land-based production	2

5.11 Assessment of tropical spiny lobster aquaculture development in South Sulawesi, Indonesia

Muhammad Idris[1] and Samsul Bahrawi[2]

Aquaculture development in South Sulawesi is strongly supported by the Ministry of Marine Affairs and Fisheries through the Brackishwater Aquaculture Development Centre (BBAP) at Takalar. During 2010–2014, BBAP Takalar staff conducted a range of activities to assess the potential of lobster farming and support its development. These activities were applied in the locations shown in Figure 1 and complement support for other aquaculture species, including swimming crab, abalone, grouper, sea bass, seaweeds (*Eucheuma cottoni* and *Gracillaria gigas*) and rabbit fish. Prior to 2011, there was no lobster farming activity at all in South Sulawesi but now there are around nine lobster farmers.

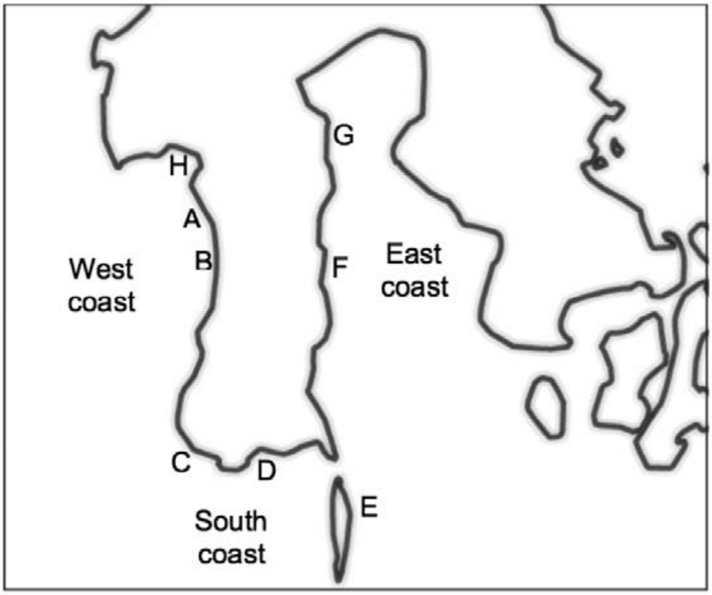

Figure 1. Map of South Sulawesi showing locations of lobster farming activity, including puerulus fishing and/or lobster grow-out: A—Barru; B—Pangkep; C—Takalar; D—Bantaeng; E—Selayar; F—Bone; G—Luwu; and H—Polman

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The species of lobster recorded from fishing in South Sulawesi include *Panulirus ornatus, P. homarus, P. versicolor and P. longipes*. Standardised 'tripod' collectors (see Chapter 2.3) for assessing puerulus availability have been deployed at these locations. Records collected are summarised in Table 1.

The catch of puerulus was seasonal, with all seed caught between October and March. A demonstration grow-out farm was established in Laikang Bay near Takalar in 2011. Due to the small number of puerulus caught locally, seed from Lombok were transported there for a grow-out trial. The seed supplied were on average 5 g in weight at stocking and on-grown for 13 months, with a survival of 62% and average growth rate of 0.5 g per day, to achieve an average harvest size of 205g. Following the example of the demonstration farm, by 2013 there were 11 lobster grow-out cages established in Laikang Bay, two in Barru, one in Luwu and one in Polman.

Although the catch of lobster seed from the tripod collectors has been relatively low, the presence of the seed is a positive indication that with improved technique and fishing equipment, the catch may be much higher, and sufficient to support a lobster farming industry.

Opportunities and constraints

There is a need to continue seed collection, including expanding into other areas that have potential lobster seed resources. Where seed are found, commercial fishing techniques should be applied, comparable to those already established in Lombok.

Table 1. Summary of information and data collected from lobster puerulus assessment activities in South Sulawesi from 2010 to 2014

Location	Activity	Comment
West coast—Makassar Bay (Polman, Barru, Pangkep)	8 tripods deployed	35 post-puerulus collected November 2012 to February 2014 100% *P. versicolor*
South coast—Flores Sea (Takalar, Bantaeng, Selayar)	16 tripods deployed	45 post-puerulus collected 2010 to 2012 60% *P. ornatus*, 20% *P. homarus* and 20% *P. versicolor*
East coast—Bone Bay (Bone, Luwu)	28 tripods deployed	190 post-puerulus collected 2011 to 2012 80% *P. versicolor* and 20% *P. ornatus*

5.12 Assessment of tropical spiny lobster aquaculture development in Aceh, Indonesia

Syafrizal[1], Hasanuddin[1] and Samsul Bahrawi[2]

Introduction

In connection with ACIAR project FIS/2007/124: 'Diversification of smallholder coastal aquaculture in Indonesia', a lobster seed resource assessment was conducted in Aceh Province in north-west Sumatra. Lobster fisheries in parts of Aceh are well developed, and so there was confidence that puerulus resources may be available that could form the basis of a local lobster farming industry.

Initially, seed assessment activities were focused on three regencies in Aceh: Pulau Simeulue, Pulo Aceh, and Aceh Jaya.

Pulau Simeulue

The island of Simeulue (2°35'27.7"N 96°18'37.9"E) lies in the Indian Ocean, off the west coast of northern Sumatra, and supports productive lobster fisheries, primarily for *Panulirus penicillatus* and *P. versicolor*. Simeulue is serviced by ferries mainly from the Port of Meulaboh (Aceh Barat) around 200 km to the north, and by light plane from Medan.

Tripod lobster seed collectors, as described in Chapter 2.3, were deployed at three locations, as shown in Figure 1.

Figure 1. Simeulue Island on the west coast of Sumatra (Aceh Province), showing locations of lobster seed assessment

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The first results of the seed assessment at Simeulue were gathered for the period June to October 2011. At Teluk Dalam, four tripods remained operational and three were damaged by wave action. No puerulus were caught. At Teluk Sinabang, there were no puerulus recorded, and this was attributed to low current, depth and high suspended solids. For Teluk Busung, no puerulus were found, and the reason for this is thought to be because the current was too strong and there was high turbidity.

In December 2011, four pueruli were collected from the tripods, both *P. ornatus* and *P. homarus*. Neither of these species is very abundant as adults in this area. Subsequently, small numbers of settled juvenile lobsters were found on the west coast of Simeulue, although not sufficient for farming purposes. The prevailing wind and waves along this exposed coast are not suitable for tripod-type collectors.

Seed collecting activities in Simeulue progressively declined due to the low catch and no further development has occurred.

Pulo Aceh

Local knowledge in Pulo Aceh Regency suggested that lobster seed were present at Ulee Payaa Village, Pulau Aceh and Pulau Breueh. A brief survey in December 2011 confirmed this, and tripod collectors were subsequently deployed.

A local fisher from Pulau Breueh, Pak Muazzi became enthusiastic about developing lobster farming, and assisted with the seed assessment activities. He also established some sea cages for holding and growing lobsters.

In this location, 12 tripods were used for collecting the lobster seed, equipped with bundles of marlin net, rice bag or cement bag materials. In addition to the tripods, Mr Muazzi also used his sea cages to deploy more collectors, as shown in Figure 3.

The collectors were checked every three days by manually retrieving the traps and removing the pueruli. Captured pueruli were transferred to sea cages that were stocked with seaweed, as a form of shelter and to minimise cannibalism.

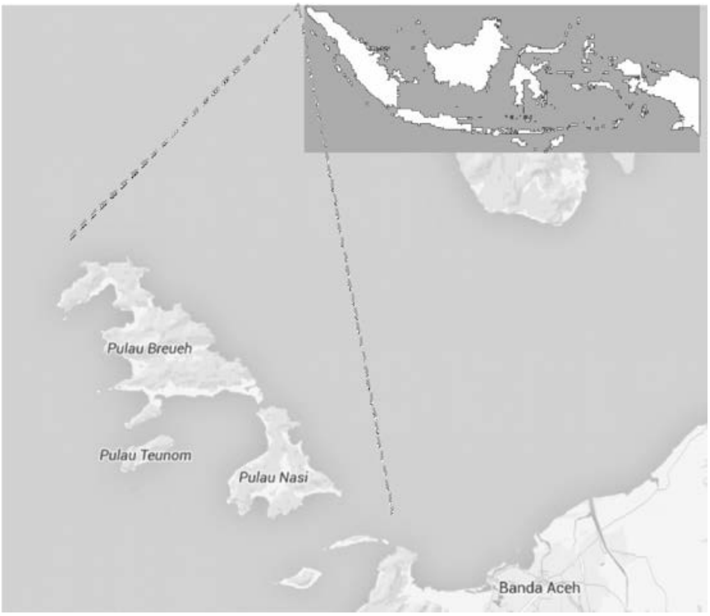

Figure 2. Pulo Aceh off the north-west tip of Sumatra

Results of the puerulus collection are presented in Table 1 for 2012 and Table 2 for 2013.

Subsequent grow-out of the captured pueruli from 2012 resulted in a harvest of 65 kg of 200 g+ lobsters in January 2014. The sea cages in this location are exposed to seasonal strong wind (wet season) and waves, causing damage to the puerulus collecting traps and grow-out cages. Heavy rain also caused high turbidity at times. Mr Muazzi has remained the only local person engaged in lobster seed collection and grow-out in Pulo Aceh.

Aceh Jaya

Following an annual meeting of ACIAR Project FIS/2007/124 in Banda Aceh in 2013, a decision was made to examine the availability of lobster pueruli in Aceh Jaya. A survey on 6–7 November 2013 revealed three options as summarised in Table 3.

From the survey, Ujung Seudeun was chosen as a site to establish puerulus assessment. Arrangements were made for Mr Huzaimah to travel to Pulo Aceh to learn from Mr Muazzi about how to collect

Table 1. Puerulus catch data from tripods in 2012 using three different materials for habitat collectors

	Marlin net	Rice bag	Cement bag	Total
April	0	0	0	0
May	0	0	3	3
June	0	0	3	3
July	0	0	0	0
August	5	1	8	14
September	50	49	68	167
October	14	24	43	81
November	0	0	0	0
December	0	0	0	0

Table 2. Puerulus catch data from tripods in 2013

Month	Amount of Puerulus
January	8
February	10
March	7
April	36
May	25
June	36
July	9
August	60
September	34
October	42
November	64
December	65

Figure 3. Pak Muazzi inspects the collectors suspended from the sea cages

Table 3. Opportunities for puerulus assessment in Aceh Jaya

No	Location	Advantages	Disadvantages
1	Batee Rutong Desa Panton Makmur	Near to the bay and water source	No sea cages at this location
2	Rigah	In the bay, far from freshwater source	No sea cages at this location No interest
3	Ujung Seudeun	Close to fresh water source Sea cages present, facilitating setting of tripod collectors Strong enthusiasm for puerulus	No culture yet

puerulus, how to make tripods and traps, and how to culture puerulus. Following the field excursion, Mr Huzaimah went on to make six tripods, from which puerulus have been collected.

Conclusions and recommendations

From January 2012 to December 2013, 664 pueruli were collected at Pulo Aceh. With increased fishing equipment deployed, increased catches are likely. At Ujung Seudeun in Aceh Jaya, more than 162 pueruli were caught from six tripods from January to March 2014. This location has good potential for further development.

There is enough evidence of puerulus availability in parts of Aceh to expand the puerulus assessment activity to new locations, and to further develop the exploitation of seed resources in Pulo Aceh and Ujung Seuden. Further extension is required to advise coastal communities on the economic potential of this activity. Collaboration with the University in Aceh will be helpful for lobster aquaculture development.

Future research and development activities should include the application of commercial techniques for puerulus collection, as applied in Lombok, support for sea-cage grow-out of lobsters and application of formulated feeds.

Acknowledgments

We would like to express our gratitude to ACIAR for the financial support, to Dr Mike Rimmer, Dr Clive Jones and Abidin Nur for their great assistance; to Samsul Bahrawi and Bayu Priyambodo, our colleagues from BBL Lombok; and to Pak Muazzi and Pak Huzaimah who cooperated on this project.

5.13 Status of lobster hatchery technology development

Scott Shanks[1] and Clive Jones[2]

Introduction

This paper presents an overview of tropical rock lobster hatchery research in Australia that has focussed on the tropical species *Panulirus ornatus*. Information is presented on the life cycle and technical challenges of rearing lobster larvae, the history of achievements across the research hatcheries, the status of the technology and plans for future development.

Research on hatchery technology of *P. ornatus* has been performed at four research hatcheries in Australia: that of the Queensland Department of Agriculture, Fisheries and Forestry at the Northern Fisheries Centre in Cairns; at the Australian Institute of Marine Science in Townsville, at Lobster Harvest Pty Ltd in Exmouth, Western Australia; and at the University of Tasmania in Hobart in collaboration with Darden Corporation (USA). At the time of the Symposium in April 2014, only the Hobart research hatchery was still in operation, with Darden committing significant funding to the program.

Technical challenge

Lobster larvae (phyllosoma) are small, delicate creatures that moult frequently and are prone to *Vibrio sp.* infection. For *P. ornatus*, the duration of the larval phase in the hatchery environment is 100 to 150 days. This is relatively long when compared with most established aquaculture species that have hatchery (larval) durations of less than 30 days. However, the tropical species have a distinct advantage over temperate spiny lobster species, whose larval duration is more than 300 days. Common to all aquaculture species, the key to success in hatchery production of lobsters is water quality and nutrition.

The life cycle of *P. ornatus* is depicted in Figure 1, showing the 11 successive stages of phyllosoma, which develop over 100 to 150 days in the hatchery, and possibly over longer periods in the wild.

History

Research into the aquaculture of *P. ornatus* by the Queensland Government at the Northern Fisheries Centre in Cairns began in 1999, and the first attempt to rear larvae resulted in 100% mortality within 30 days. Progressive improvements in survival and growth were achieved with each batch as the bottlenecks were overcome one by one. After 10 years, survival of up to 80% to 100 days was consistently achieved. At 100 days old, phyllosoma are approaching their final stage, which precedes metamorphosis to the puerulus. Further research is required to resolve the final bottlenecks prior to metamorphosis so that commercially viable technology can be ensured.

Puerulus of *P. ornatus* were first produced in captivity in 2006 at the Lobster Harvest facility in Exmouth, Western Australia and at the Northern Fisheries Centre in Cairns, in 2009. Although many batches of larvae were subsequently reared, pueruli were produced on only three occasions. Nevertheless, progress on resolving obstacles and scaling up production was achieved through focusing research on the primary issues of nutrition and metamorphosis. By 2013, the only ongoing research in this area was being conducted in Hobart, and these researchers were confident that commercial technology would be developed within three to five years. Business analysis had clearly confirmed that a tropical rock lobster hatchery could be a viable business, based on

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existing and potential demand from grow-out industries in Vietnam and other parts of South-East Asia.

The Darden Corporation has indicated they will invest $700 million in a lobster farming precinct in Malaysia that will produce one million pueruli and 1,000 tonnes of market-size lobster each year.

Experimental approach

To develop robust larval rearing technology that can be scaled to commercial production levels requires a science-based approach, based on rigorous experiments with replication. Figure 2 shows the setup for small-scale larval rearing experiments at the Northern Fisheries Centre, Cairns.

The first requirement for running larval rearing experiments is to have a supply of egg-bearing female lobsters to achieve regular hatching. Figure 3 shows aspects of the lobster breeding systems, including multiple breeding populations of five females with two males in 2,000 L tanks, whose reproductive phase was controlled by a specific temperature and photoperiod regime to simulate summer breeding conditions. In this way, breeding could be achieved in every month of the year, and newly hatched phyllosoma were available on a weekly basis.

To support the newly hatched larvae, a continuous supply of suitable food is required. This typically consists of enriched and on-grown Artemia. Enrichments typically consist of live micro-algae and proprietary larval crustacean nutritional supplements. Although Artemia is not the ideal diet, it represents the only viable option at present until a suitable manufactured diet is developed. Figure 4 shows a

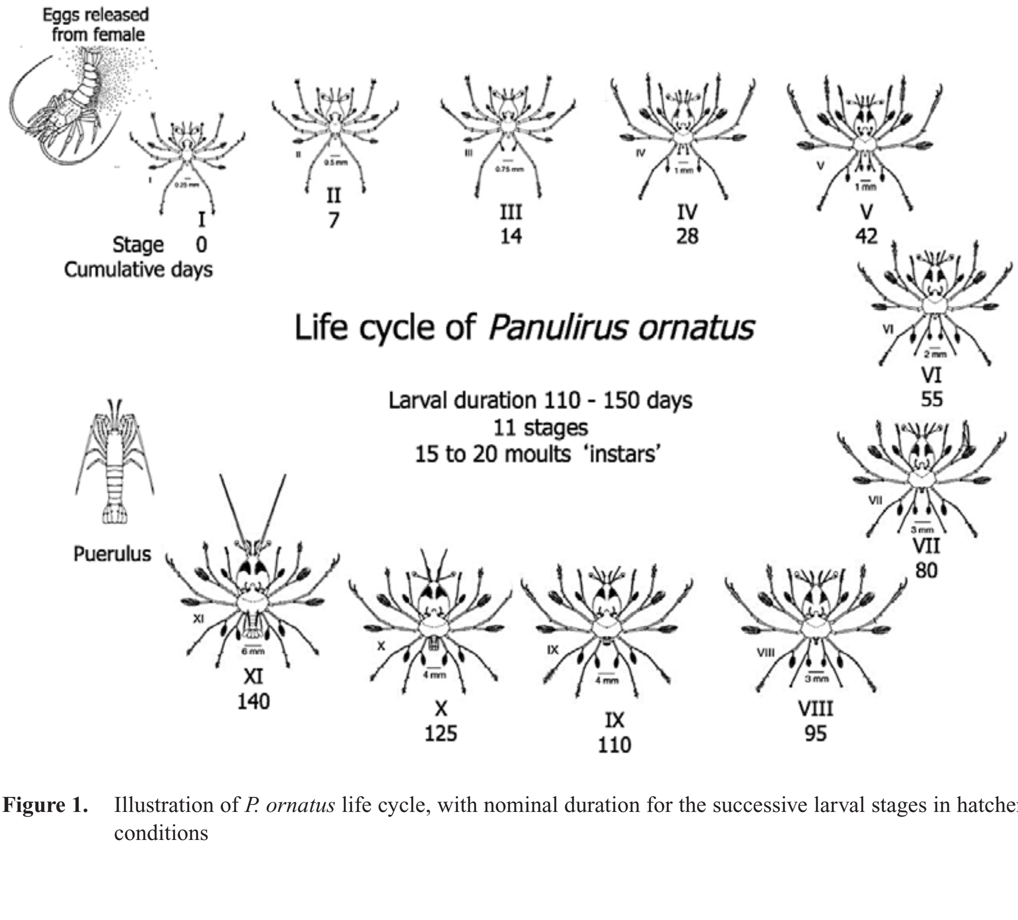

Figure 1. Illustration of *P. ornatus* life cycle, with nominal duration for the successive larval stages in hatchery conditions

late stage phyllosoma and newly metamorphosed puerulus produced in the Northern Fisheries Centre hatchery.

Summary and conclusions

Hatchery technology for the tropical rock lobster *P. ornatus* reached proof of concept in 2006 when the first puerulus were produced in a hatchery setting. Despite ongoing research efforts at four laboratories in Australia, commercial technology has not yet been achieved. Currently there is only one research hatchery operating in Hobart Tasmania, in collaboration with Darden Corporation (USA) which has invested significantly in establishing commercial hatchery production and grow-out in Malaysia.

Figure 2. Photos of larval rearing systems using 3L water jugs and 5L tubs for small-scale, replicated experiments

Figure 3. Brood stock system for year-round breeding of *P. ornatus*, comprising multiple populations (5F:2M) under controlled temperature and photoperiod

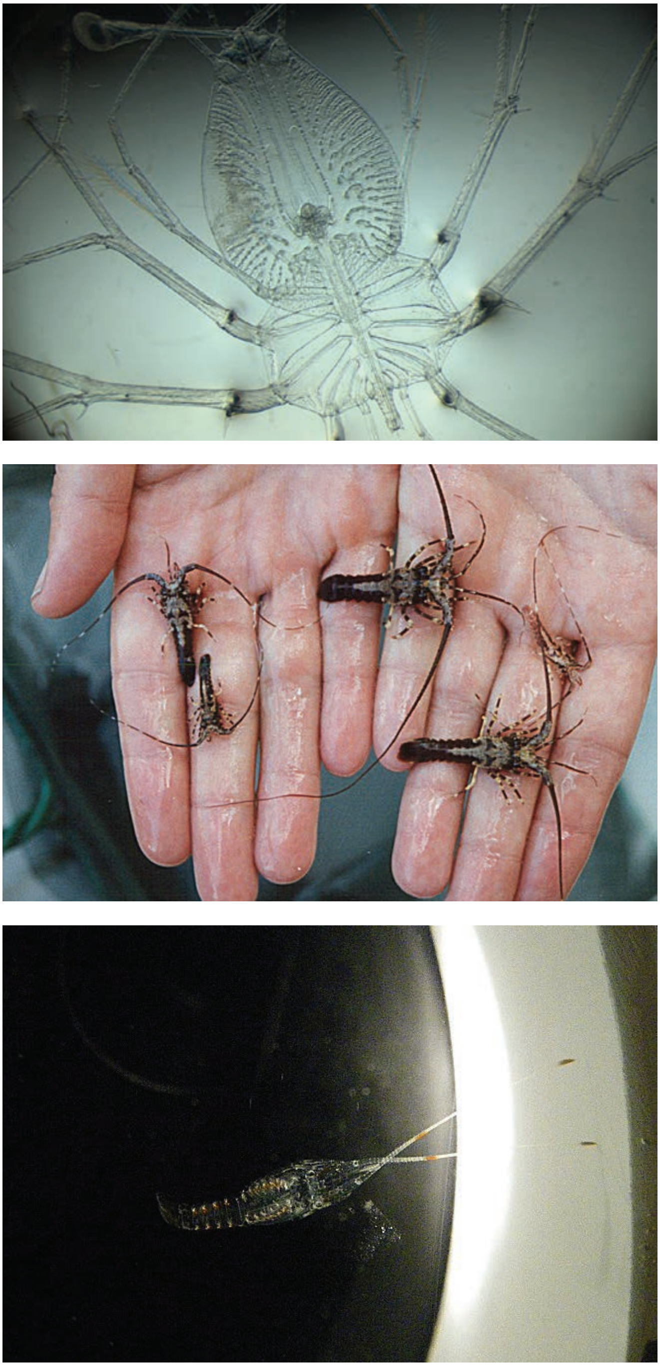

Figure 4. Photos depicting late stage phyllosoma, newly metamorphosed puerulus and 7 to 28 day old juveniles of *P. ornatus* produced in the Northern Fisheries Centre hatchery

5.14 Executive summary of Industry Development Workshop discussion

Prepared by staff of Directorate General Aquaculture, Indonesia[1]

The Lobster Aquaculture Industry Development Workshop of 2014 was conducted at The Santosa Hotel, Villas and Resort, Lombok, Indonesia on 25 April, 2014 and involved 70 participants. The objective of the workshop was to generate a reference of industry issues to inform policy implementation for the development of lobster aquaculture in Indonesia.

The workshop was opened by the Director of Production, Directorate General of Aquaculture and attended by Head of Dinas Kelautan dan Perikanan Province NTB (Provincial fisheries authority of NTB) , a representative from the bureau of planning and regional development of NTB (Bappeda NTB), a representative from Echelon-1 Directorate General of Aquaculture, Marine Fisheries Aquaculture Development Centre of Lombok, a representative from Australian Centre for International Agricultural Research (ACIAR), private sector representatives, puerulus fishers and grow-out farmers.

Topics presented were as follows.

a. Policy in development of lobster aquaculture in NTB, delivered by Head of Dinas Kelautan dan Perikanan Provinsi NTB.
b. Spatial planning and zonation for lobster aquaculture, delivered by Bappeda Prop. NTB.
c. Policy in development of lobster aquaculture, delivered by the Director of Production, DGA.
d. Data on lobster seed exporting and destination, distributed by Fish Quarantine Province NTB.
e. Status of lobster aquaculture in NTB, distributed by MADC of Lombok.

Based on the material delivered by presenters, and also from the results of discussion during the workshop, the following conclusions were reached.

General condition

- Lobster is a very significant commodity in terms of business, public welfare, poverty reduction and transformation of mindset.
- Lobster aquaculture is growing through community initiatives.
- Seed collection is growing through community initiatives, and has been transformed with the opening of an international market.
- The number of grow-out cages in 2010 was 2,000 units.
- Dominant species is *Panulirus homarus* (90%).
- The number of puerulus fishers is currently increasing dramatically. On the other hand, the number of grow-out farmers has decreased significantly since early 2013.

Table 1. Potential area of lobster farming in Lombok

No	Districts	Potential area (ha)
1.	Central Lombok	628,50
2.	East Lombok	526,68
Total		1,155,18

Problems and constraints

Problems

1. There is tremendous fear that the exploitation of wild puerulus will disturb the natural balance of lobster populations.
2. Supply and variation of trash fish as a food source are very limited in central Lombok.

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3. Mastering of lobster farming skills and techniques is at a low level.
4. Grow-out farmers' knowledge is still very low.
5. Feed supply for the grow-out sector tends to be inconsistent in terms of quality and quantity.
6. Most grow-out farmers face challenges when buying lobster seeds, because the price is increasing; now reaching IDR 12,000 (US$0.90). Grow-out farmers prefer to buy seeds for approximately IDR 5,000–7,000 (US$0.38–0.52). The majority of grow-out farmers can only achieve a survival rate of less than 50% per unit crop as they have not mastered the required farming techniques.
7. There is large income gap between puerulus fishers and grow-out farmers.

Constraints

1. Sustainability of the industry.
2. Legal protection/regulation.
3. Improvement of technical capabilities.
4. Improvement of business skill capabilities which comprise more than just selling raw material products.
5. Commitment.
6. Fostering empathy (i.e. concern to other groups in society).
7. Increasing lobster production rate 3.95% per year.
8. Importer countries can buy puerulus at a highly competitive price because they can produce market-size lobster with relatively high survival rate (> 60%).

Recommendations and solutions

Regulations

1. Urgent need to control the selling of lobster seed overseas.
2. Need to unite all stakeholders with a common vision for lobster aquaculture development.
3. Need zoning certainty for marine aquaculture.
4. Need to regulate the utilization of lobster seed.
5. Acceleration of Plan Zoning Bylaw on Coastal Areas and Small Islands.
6. Compilation of the NTB governor rule/regulation on the size limit and number of seed lobsters that may be caught and shipped out of NTB.
7. Encourage each region to have PERDA (district regulation) especially for fisheries.
8. Need to control the increasing number of cages in a given area, based on scientific studies (carrying capacity).
9. Determination of areas to be used by smallholders and by corporate investors.

Technical

1. Provision of hatchery and nursery technology.
2. Improvements to lobster grow-out techniques to provide better survival rate (recommended for MMAF's technical implementation units).
3. Establish demonstration grow-out farms in the marine aquaculture central areas.
4. Develop pelleted feed for lobster.
5. Provision of information about seed handling.
6. Research to determine environmental conditions in the bay areas.
7. Stock population studies of lobster in Bumbang and Ekas Bays.

Human resources

1. Technology dissemination for lobster aquaculture.
2. Improvement of business capability for grow-out farmers.
3. Improvement of capacity building of puerulus fishers and grow-out farmers.
4. Provide information about market demands in both quality and quantity.

Non-technical recommendations

1. Build a partnership and integrated farming system.
2. Capital support to improve lobster farming.
3. Supporting infrastructure to develop lobster farming.

Action plan

1. Establish a lobster farmers' association consisting of puerulus fishers, grow-out farmers, middlemen and exporters.
2. Further technical meetings on lobster will be conducted by provincial fisheries authority 'Dinas Kelautan dan Perikanan NTB Province', with core agenda as follows:
   a. dealing agreement between puerulus middlemen and grow-out farmers
   b. arrangement of rules/regulations on selling seed, both to domestic and overseas markets

- c. licensing (fisheries business license ‘SIUP’) and registration of fish farming for small-scale farmers
- d. monitoring
- e. district incomes (taxes).

3. Dissemination of spatial regulations and related zoning of lobster aquaculture development in NTB by the regional planning and development agency of NTB or ‘Bappeda NTB’.
4. Technical training for puerulus fishers and grow-out farmers conducted by local and central government.
5. Further research needed on stock assessment and carrying capacity in the targeted areas of lobster farming throughout Indonesia, to be carried out by the Agency of Marine Affairs and Fisheries Research and Development or ‘Balitbang KKP’.
6. National or international research agencies conduct research on stock assessment.
7. MMAF’s Technical Implementation Units conduct study on nursery techniques and feed.
8. Dissemination of lobster aquaculture technology throughout Indonesia.

6. Appendicies

Note: the appendicies for this report are available separately for download at:
http://aciar.gov.au/publication/pr145

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