The development of spiny lobster aquaculture in Indonesia through the enhancement of puerulus catch and technology transfer

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The development of spiny lobster aquaculture in Indonesia through the enhancement of puerulus catch and technology transfer

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

School of Biological, Earth and Environmental Sciences

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Spiny lobster farming is an emerging industry in Indonesia, reliant on wild puerulus supply, which is constrained by underdeveloped skills of puerulus fishers. The aim of the study was firstly to address the development of spiny lobster aquaculture by understanding barriers to effective puerulus collection through a study tour to Vietnam; second, to assess Indonesia's puerulus resource and potential for sustainable exploitation for aquaculture; and finally, to increase catch rates by assessing collection devices and techniques. The study tour was a very effective method for improving knowledge of participants, particularly detailed technical information on puerulus collection. The impacts of catching pueruli were determined to be minimal with no significant environmental impact due to low natural survival. Growing pueruli to market-size lobsters provides significant benefits for both humans and the environment. A series of tank and field-based experiments revealed significant differences for depth and collector type in catches of *Panulirus homarus* and *P. ornatus*. The greatest catch of *P. homarus* was on the sea floor using a cement bag paper trap. For *P. ornatus*, catch rate was less strongly associated with a specific depth or trap type, although catch was highest at or near the sea floor in cement bag paper collectors. Crevice angles of 10o and 20o were significantly preferred over 30o. Cement bag paper, a locally available material, was the most preferred material in the field, followed by cement bag plastic, insect mesh, weed fabric and PVC rubber. Overall, this study provides a strong basis for the puerulus collection industry to become more cost efficient and profitable, due to improved techniques, modified equipment and application of light to attract pueruli to the fishing equipment. At the time of the study the Indonesian government introduced a new fisheries regulation (in 2015) implementing a minimum legal size for lobsters of 200g. Designed to manage the adult lobster resources, this regulation rendered puerulus fishing illegal. The study provides evidence to justify legalisation of puerulus fishing and lobster farming, and provides policy recommendations to support a viable lobster farming industry for Indonesia.

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Glossary of Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
ANOVA	Analysis of variance
BPS	Badan Pusat Statistik, Indonesian Statistics
CL	Carapace Length
DKP	Dinas Kelautan dan Perikanan, Marine Affairs and Fisheries Office Indonesian; a government institution responsible for marine and fisheries affairs at the provincial and district levels
DM	Dry Matter
FAO	Food and Agriculture Organisation
FCR	Feed conversion ratio
GDP	Gross Domestic Product
HREC	Human Research Ethics Committee
IDR	Indonesian Rupee currency
MADC	Marine Aquaculture Development Centre; a technical implementation unit under management of the Directorate-General of Aquaculture under MMAF
MMAF	Ministry of Marine Affairs and Fisheries, Indonesia
NTB	Nusa Tenggara Barat or West Nusa Tenggara (a province in Indonesia)
PNG	Papua New Guinea
SADI	Smallholder Agribusiness Development Initiative
SMAR	Support for Market-Driven Adaptive Research
USD	United States Dollars currency
VND	Vietnamese Dong currency

Abstract

Spiny lobster farming is an emerging industry in Indonesia. However, its dependence on wild puerulus (an intermediate larval–juvenile phase) supply is critical and the industry has been constrained by the underdeveloped skills of puerulus fishers. The overall aim of this study was, first, to address the development of the spiny lobster aquaculture in Indonesia by understanding barriers to puerulus collection through a study tour involving an Indonesian spiny lobster stakeholder group to Vietnam; second, to address the assessment of the lobster puerulus resource and its potential for sustainable exploitation to support aquaculture; and finally, to identify the most effective collection devices and techniques, and understand puerulus behaviour and ecology.

The study tour appeared a highly effective method for improving the knowledge of participants, particularly in regard to detailed technical information on puerulus collection. The most important outcome of the study tour was the substantial increase in lobster puerulus catch, attributed to improved (adopted) techniques involving modified equipment and application of light to attract pueruli to the fishing equipment. Many new Indonesian puerulus hotspots have been identified, including the entire south coast from Sumbawa to Java. Puerulus exporters have played an important role in the expansion of new puerulus fishing grounds throughout the country by delivering skilled puerulus fishers from Lombok elsewhere around Indonesia to disseminate information about new puerulus catching techniques. However, although the number of caught puerulus has increased dramatically, this has not generated positive effects for development of the grow-out sector because collected pueruli are designated for more lucrative international markets. Additionally, as both grow-out and collection of pueruli became illegal under

Indonesian legislations introduced in 2015 and 2016, a puerulus black market has emerged.

Removal of pueruli for the purpose of aquaculture is unlikely to negatively affect future catches or the breeding stock because of the extremely low wild survival rate of this larval stage. However, growing pueruli on to market-size lobsters provides significant benefits for both humans and the environment. Given that the natural mortality of pueruli in Indonesia is likely to be >99%, combining lobster grow-out of wild-caught pueruli and restocking a certain percentage of farmed lobsters back into the wild provides a win–win solution. Indonesia has a puerulus resource exceeding 100 million individuals, which is 20 times greater than that of Vietnam where a large, stable and sustainable lobster farming industry based on the puerulus resource is established. If 50% of the Indonesian fishable lobster puerulus resource (i.e., 50 million pueruli) was allowed to be fished, this would be sufficient to support production of 12,500 tonnes of market size lobsters—assuming 50% survival from puerulus to a harvest size of 500 g. This could provide a livelihood for more than 50,000 households.

Table of Contents

List of Tables

List of Figures

Chapter 1: General Introduction

1.1 Introduction

Spiny lobster farming is a growing global industry that supplies a lucrative export market with table-size lobsters as well as lobster pueruli (an early life stage) for grow-out in regions where the wild puerulus is insufficient to support the industry. Indonesia, principally the island of Lombok, recently became involved in lobster farming and puerulus collection and export. This thesis addresses some of the key challenges and opportunities currently affecting Indonesian spiny lobster aquaculture with a particular focus on the adoption and adaptation of puerulus collection technologies from Vietnam, where the industry is advanced.

The Australian Centre for International Agricultural Research (ACIAR) supports several spiny lobster aquaculture development projects in both Vietnam and Indonesia. While Vietnam's lobster aquaculture production now contributes significantly to the global lobster supply, Indonesia is still struggling with the development of farming technologies despite good access to wild puerulus. The capture of large numbers of newly settled lobster seed (pueruli) for purposes of farming raises immediate and logical concern that such fishing will negatively impact the adult populations, that is, the practice is unsustainable. However, it is estimated that their survival rate to adult stage in nature is extremely low, it's less than 0.01% (Jones, 2015b). Therfore, the capture of the puerulus/seed for managed grow-out (lobster farming) represents a negligible impact on the environment and a significant net gain to the volume of large lobsters available to the market.

The technology deficit among Indonesian lobster farmers is another critical inhibiting factor (Jones, 2010; Jones et al., 2007; Priyambodo, 2013). Overcoming this will increase Indonesian farmers' ability to produce spiny lobster from aquaculture for an international market, similar to Vietnam.

This chapter first briefly discusses the global spiny lobster aquaculture industry (Section 1.2), and then outlines the Indonesian spiny lobster aquaculture industry in terms of its history and current practices. This is followed by an outline of the technology deficits, production issues and sustainability of lobster puerulus fishing and opportunities (Section 1.3). This leads to the objectives, argument and research questions underpinning this thesis (Section 1.4). Finally, a brief outline of each chapter is presented (Section 1.5).

1.2 The Summary of Life History of Spiny Lobster

The generic term of "lobster" refers to four distinct family groups: The clawed lobsters (Nephopidae), the spiny lobsters (Palinuridae), the slipper lobsters (Scyllaridae) and the coral lobsters (Synaxidae) (Sachlikidis, 2010). The Palinuridae comprises over 47 species (Holthuis, 1991) which are about 33 species support commercial fisheries (Williams, 1988). Spiny lobsters or rock lobsters are among the world's most valuable and commercially-important groups of animals harvested and farmed throughout the world (Lipcius and Eggleston, 2000).

Spiny lobsters inhabit temperate and tropical waters; however, most species and the highest abundances are found in the tropics (Holthuis, 1991). Spiny lobsters have been classified into eight genera inhabiting marine environments from 50 degrees of latitude, depths to 1000 metres and temperatures between 5 - 30^{0}C (George and Main, 1967), as shown in Figure 1.1. Their habitats include the intertidal zone through to the deep sea down to almost 3000m. They shelter within substrates such as surrounding rocky crevices, mud and sand bottoms, and vegetated beds (Lipcius and Eggleston, 2000).

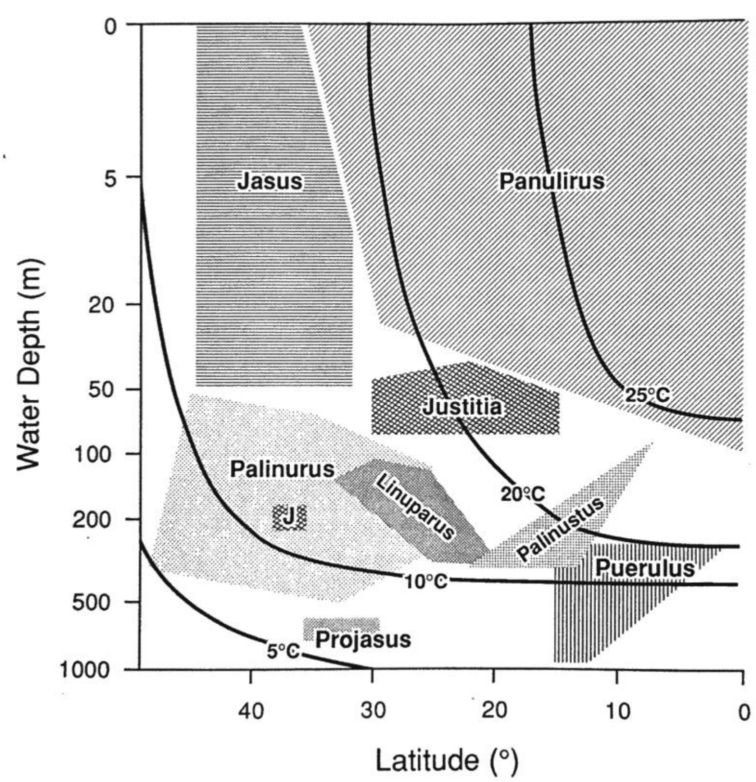

Figure 1.1. The distribution of lobsters of the family Palinuridae by latitude, temperature and depth according to George and Main (1967).

Spiny lobsters exhibit five major stages within the life cycle: adult, egg, phyllosoma (larval stages), puerulus (post-larval stage of spiny lobsters that has metamorphosed from the final stage of phyllosoma; it is transparent) and juvenile (Phillips et al., 1980). The life cycle of *Panulirus* species is complex and includes a long large-scale oceanic dispersal of larval phase, which varies in length between species from few months to more than a year (see the illustration of life history for *P. cygnus* at Figure 1.2).

Larval stage spiny lobsters are unique as they have relatively large clutches, short periods of fertilisation, and long periods of planktonic formation that are widely dispersed across coastal areas, and then becoming oceanic before metamorphosing to the puerulus stage and swimming inshore to settle (Phillips et al., 2006). The duration of the larval phase varies across species; generally tropical water species tend to have a shorter larval duration than temperate water ones (Sekine et al., 2000). For example, *P.ornatus* is one of the shortest known larval phases of any rock lobster species, estimated at approximately 129 days (Payne, 2006). In contrast, the length of the larval phase for Palinurid lobster *Jasus verreauxi* is more than 330 days. During this larval phase, the larvae undergo approximately 17 moults before they metamorphose into the puerulus stage, which incorporates a non-feeding pelagic and a benthic life stage as the animal seeks an appropriate habitat on which to settle (Dennis et al., 2004).

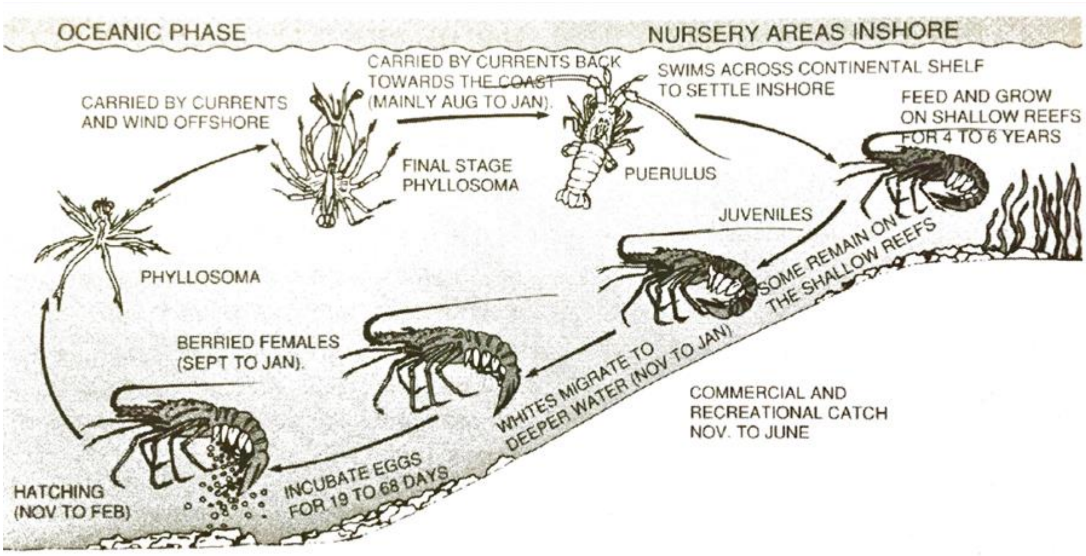

Figure 1.2. The life history of the western spiny lobster, *P. cygnus* (Kaliola et al., 1993).

1.3 Global Spiny Lobster Aquaculture

The high value of live lobster (up to $100/kg for ornate spiny lobster, *P. ornatus*) and strong international market demand has led to high global interest in lobster farming (Radhakrishnan, 2012; Wickins & Lee, 2002). Currently, the only supply of initial (seed) stock for spiny lobster aquaculture is wild caught, as no culturing programmes have been sufficiently successful (Phillips et al., 2001, 2006; Williams, 2009). Thus, the development of this aquaculture is reliant on improving the efficacy of puerulus collection technology (Jeffs, 2010; Kenway et al., 2009). In addition to meeting market demands, lobster farming is considered a viable livelihood for impoverished coastal communities in some developing countries (Cox et al., 2008; Jeffs, 2010; Jones, 2010b; Juinio-Menez and Gotanco, 2004; Petersen et al., 2015; Petersen & Phuong, 2010; Radhakrishnan et al., 2005; Vijayakumaran et al., 2009).

Asian countries such as Vietnam, the Philippines, Indonesia, Malaysia, India and Thailand have the fastest-growing sea-cage aquaculture production of spiny lobster globally (Phillips & Matsuda, 2011). The only significant production of farmed lobster comes from Vietnam; in 2012, production was estimated at 1,600 tonnes (AU$100 million) of *P. ornatus* based on the wild puerulus catch (Jones et al., 2010a; Tuan & Jones, 2015a). With almost three decades of experience, Vietnam has become one of the most advanced lobster-growing countries. The skills and knowledge of Vietnamese lobster farmers is clearly much more developed than that of neighbouring countries such as Indonesia, Malaysia, India and the Philippines (Priyambodo, 2013). Farming techniques used in Vietnamese spiny lobster aquaculture include various types of cages and puerulus collection methods (Hung & Tuan, 2009; Jones et al., 2010b; Tuan & Jones, 2015b). As with any farming, the ability of farmers to understand and incorporate leading technologies and techniques is crucial for development and growth. Thus, with the support of ACIAR lobster projects, there is an opportunity for Indonesia to adopt and adapt Vietnamese technology in puerulus collection to enhance the production of lobster and develop Indonesian lobster aquaculture. This would lead to significant economic returns and help to develop job opportunities for coastal communities.

1.4 Indonesia's Spiny Lobster Aquaculture

1.4.1 History of the Industry

Indonesia has approximately 54,716 km of coastline from a combined total of 17,508 islands. Consequently, the potential for suitable sites to develop marine aquaculture in Indonesia (Ministry of Marine Affairs and Fisheries [MMAF], 2013), including lobster farming, is high. However, the utilisation of those potentially suitable marine aquaculture sites remains highly restricted, involving only 1.4% of 12.5 million hectares in 2012 (Soebjakto, 2014). Lobster farming provides a particularly attractive opportunity for Indonesians because it involves simple technology and minimal capital and is ideally suited to village-based enterprises (Hart, 2009; Jones et al., 2015). Additionally, experience suggests that farmed lobsters can attract the same high price as other fishery products (Jones, 2010b).

Spiny lobster and grouper aquaculture in Indonesia first emerged in Lombok in 1998 as an initiative of the Asian Development Bank (ADB) through its Coastal Community Development and Fisheries Resources Management Project (ADB, 2008). The ADB project in Lombok was mainly focussed on promoting Community-based coastal Fisheries Resource Management and increasing the income and living standards of poor coastal communities through the provision of appropriate opportunities and social infrastructure facilities. Compared with other farmed marine species, such as seaweeds and grouper, ADB (2008) reported that the returns for caged lobster culture enterprises were over 100% higher. Many people in Lombok have become involved in this form of aquaculture and recently, spiny lobster aquaculture has become fragmented into two main activities: puerulus collection and grow-out (Priyambodo & Sarifin, 2009, Priyambodo & Suastika-Jaya, 2009).

In 2007, the ACIAR lobster project began working in Indonesia, promoting adaptive research to improve the sustainability of the spiny lobster aquaculture industry. This project was initially part of an ACIAR SADI (Smallholder Agribusiness Development Initiative) project that aimed to improve rural sector productivity and growth in four eastern provinces: Nusa Tenggara Timur, Nusa Tenggara Barat, South-East Sulawesi and South Sulawesi. Each province had a different product to be developed. The project would improve incomes and productivity for farmers and agribusiness in response to market opportunities, through a process underpinned by improved adaptive research (ACIAR, 2017a). In the years since, several ACIAR lobster projects have been undertaken in Indonesia:

- FIS/2001/058 'Sustainable tropical spiny lobster aquaculture in Vietnam and Australia', Support for Market-Driven Adaptive Research (SMAR) variation to include Nusa Tenggara Barat and Nusa Tenggara Timur Indonesia, 2007–2008
- SMAR/2008/021 'Spiny lobster aquaculture development in Indonesia, Vietnam and Australia', 2008–2012
- FIS/2014/059 'Expanding spiny lobster aquaculture in Indonesia', 2015–2019
  FIS/2015/034 'Research support for lobster restocking in Indonesia', 2015.

Those projects involve several main activities including trials of lobster puerulus collection and grow-out; trials of nursery and juvenile management techniques; formulation of functional and cost-effective artificial diets; assessment of supply and market demands and identification of business models and socio-economic benefit of lobster farming; technology transfer and dissemination; and lobster translocation research (ACIAR, 2017b).

The transfer of puerulus collection technology from Vietnam to Indonesia (through a comprehensive week-long study tour supported by ACIAR lobster project FIS/2014/059) improved the puerulus catch from 600,000 to around 3 million pueruli per annum in 2013 (Bahrawi, 2012; Bahrawi et al., 2015a). The candidate was involved in this study and the data collected are presented and analysed as part of this thesis. With the increase in wild-caught pueruli, the capacity of puerulus fishers has improved and the potential for a larger industry employing entire rural coastal communities has increased (Jones et al., 2015; Jones & Priyambodo, 2014). However, switching to direct puerulus sales rather than growing-out them has led to increased puerulus prices such that the superior, competitive international market prefers to buy pueruli. This unfortunately has reduced the profit margin with respect to market-size lobster because the production cost has substantially increased, and ultimately reductions in the local grow-out industry.

In 2015 there was a substantial change in the Indonesian spiny lobster aquaculture industry because the new Indonesian government released a policy (Decree 1/2015) that imposed the minimum legal size of spiny lobsters that can be caught and traded; to 200 g for all species. In 2016 the government released another policy (Decree 56/2006) that completely banned grow-out activity involving spiny lobster. By removing access to pueruli and grow-out opportunities, these regulations have diminished the capacity of Indonesian lobster farmers to develop a sustainable grow-out industry. Although the new policy was mainly introduced to maintain the abundance of adult lobsters, it has not translated directly into an abundant source of adult lobster larger than the regulated size limit. Further, despite Decree 1/2015, puerulus collection continues illegally and is thought to involve more puerulus fishers and to cover a greater area and number of actors than before the regulations were implemented. The regulations do not apply to scientific research; hence this study was able to utilise wild-caught pueruli and work on lobster farming technology development.

1.4.2 Overview of Farming Practices

1.4.2.1 Puerulus collection techniques

Pueruli were originally collected using a very basic, ‘passive method’ using a set of single collectors. Each collector consisted of a rice bag or piece of canvas bundled up and suspended in the water column from a unit of puerulus sea-rafts. The puerulus sea-rafts were made of bamboo (Priyambodo & Suastika-Jaya, 2009). The collectors were generally inspected every second or third day. A puerulus sea-raft with 25–50 bundles of collectors may capture up to 20 pueruli per night during peak season (Jones et al., 2007). However, with improved knowledge and skills regarding the best depth for collector placement, currents, lunar cycles, puerulus behaviour and the material and design of collectors, the average puerulus catch per retrieval might be improved. This is a central research theme of this thesis and is elaborated on later in this chapter.

In 2013, there was an improvement in the puerulus collection technique involving a 'semi-active method' that combines the use of passive collectors and artificial lighting, which was based in assumption that pueruli are attracted to light (Bahrawi et al., 2015c. This new method, used by Lombok puerulus fishers, was adapted from similar ones used in Vietnam (Jones & Tuan, 2013; Long & Dao, 2009) following the study tour described in Chapter 3.

1.4.2.2 Nursery phase and grow-out

Two lobster species commonly cultivated in Lombok are *P. ornatus* and *P. homarus*. Lobster grow-out generally involved periodic grading into three stages: a puerulus nursery phase (from puerulus to 5-cm total length (TL) juvenile), a juvenile phase (from 5 cm total length to 30–50 g) and a grow-out phase to market size (from 50–100 g each for *P. homarus* and >300 g each for *P. ornatus*) (Jones et al., 2007). The puerulus nursery phase was characterised by short duration (2–4 weeks) and high mortality, with no particular husbandry applied (Priyambodo & Suastika-Jaya, 2010).

Pueruli were placed in small cages (generally 3.5 m^3) stocked at up to 100 individuals per cage (28/m^3) and fed with finely chopped trash fish (Jones et al., 2007). When they reached the juvenile stage they were transferred into a larger cage (up to 9 m^3) at densities of up to 20/m^3 and fed trash fish. Finally, larger juveniles were transferred to larger cages for growth through to market size at densities up to 10/m^3

(Priyambodo & Sarifin, 2009). The average production of market-size lobster per cage was low, around 12–15 kg (Petersen et al., 2015). This was much lower than Vietnam's production, which can reach 35–50 kg/cage (Petersen & Phuong, 2011; Tuan & Jones, 2015b).

1.4.3 Technology Deficits

Puerulus fishers and grow-out farmers in Lombok used very basic techniques leading to inefficient productivity in both sectors compared with Vietnam. The mortality of puerulus within 24 hours of capture was excessive (Jones et al., 2007, 2010b; Priyambodo, 2013). More importantly, the handling of pueruli after immediate capture was a problem in Indonesia (Priyambodo, 2013; Priyambodo & Bahrawi, 2012) as it resulted in a high mortality rate for the puerulus (ABLobster, 2015; Jones et al., 2007). Thus, mortality of puerulus remained a critical control point in the supply chain and one for which improvements were a high priority (Jones et al., 2007; Priyambodo et al., 2012a).

Poor husbandry practices and reliance on wet feed, such as trash fish and golden snail, were further issues in the grow-out sector (Priyambodo, 2013) that resulted in low survival rates, poor condition and pale colour in farmed lobster (Irvin & Williams, 2009; Jones et al., 2007). Trash fish, if not handled properly, such as not being stored in cold containers, will be easily decrease in quality. Most Indonesian lobster farmers are likely not aware of this. Therefore, low quality trash fish could possible disease vector of farmed lobsters. However, it is noted that crustacean disease-causing pathogens are not carried by finfish. Disease is most likely to occur through bacteria in putrid trash fish or snails. The low survival rates may be attributed to low consumption of essential nutrients, but further research is needed to test this hypothesis. Further complications arose in 2011 when Milky Haemolymph Disease syndrome outbreaks spread through the entire Lombok grow-out sector (Priyambodo & Bahrawi, 2012; Priyambodo et al., 2012a, 2012b). This syndrome is well documented in many crustaceans' species (Koesharyani et al., 2017, Srimeetian and Tunkijjanukij, 2016) and is caused by Ricketsia-like bacteria. It is unrelated to PAV1 virus in *P. argus* (Behringer et al., 2012, Briones-Fourzán et al., 2009). Many grow-out farmers were financially affected by this disease outbreak. However, no serious action was taken by the authorities to manage the disease. Overall, because of technical constraints in lobster grow-out practices, grow-out productivity was inefficient (Jones et al., 2007; Petersen et al., 2015). The opportunity cost of this technology deficit is obvious when Indonesia's productivity is compared with that of Vietnam, as discussed in Chapter 2.

1.4.4 Production Issues

Several critical problems hindered the progress of Indonesia's spiny lobster aquaculture industry. A basic challenge was the lack of puerulus collection knowledge and skills. These included an understanding of puerulus behaviour, settlement patterns and seasonality, the locations where settlement occurs, the optimal depth for collection and the effects of lunar phase on settlement rates. There were also practical challenges related to effective puerulus collector designs, collector materials, access to fishing grounds and how to target efforts to maximum settlement periods. Grow-out farmers' knowledge and skills were also underdeveloped (Priyambodo et al., 2015). They also employed poor practices, for example, they did not undertake daily maintenance of cages (Shanks et al., 2015). Ultimately, these problems resulted in an extremely low survival rate of puerulus to juveniles and from juveniles to market size (Jones, 2010b; Jones et al., 2007; Priyambodo, 2013).

Globally, the success of the lobster aquaculture industry currently depends on wild puerulus collection (Booth & Kittaka, 2000; Hart, 2009; Phillips & Melville-

Smith, 2006). It is estimated that <0.01% of wild pueruli survive to the adult stage in nature (Jones, 2015b). Thus, by retaining wild pueruli for managed grow-out, and assuming a 70% survival rate (as achieved in Vietnam), significant lobster production can be achieved. This would benefit thousands of Indonesian spiny lobster farmers and provide spillover benefits for local economies. Therefore, understanding the behaviour and settlement of pueruli in Indonesia will support the development of a sustainable aquaculture industry if puerulus collection is allowed in future. This also has the potential to generate significant job opportunities and livelihoods for many rural coastal communities throughout the country.

1.4.5 The Sustainability of Lobster Puerulus Fishing and Opportunities

1.4.5.1 The sustainability of lobster puerulus fishing

The most important consideration in the management of the lobster resource is the sustainability of puerulus fishing. In Vietnam, there has been no scientific effort to quantify lobster resources and their recruitment. However, available anecdotal data suggest that the annual influx of settling pueruli is disconnected from adult stocks in Vietnam waters, which are at historically low abundance. Dao et al. (2015) have surmised that the source of puerulus settling in Vietnam each year is likely to be far to the north and east; the protracted larval period and oceanic life habit provide the opportunity for larval stages travel significant distances from the point of hatching to the location of settlement.

Depending on the location of puerulus capture, removing them from nature may have no effect on adult populations and the fishery (Phillips et al., 2003a, 2003b). Research on the Caribbean rock lobster *P. argus* showed that in some locations adult abundance is low and post-larval (puerulus) abundance is high (Lipcius et al., 1997). In these locations, the pueruli are concentrated at sites determined by the nature of regional and local oceanic currents. These are termed 'sink' populations because most pueruli will not survive or contribute to adult populations (Briones-Fourzán et al., 2008). The puerulus supply is effectively disconnected or decoupled from adult abundance. The occurrence of these sink populations of lobster pueruli is greatly enhanced by the biology of the species, particularly the long duration (4–6 months for tropical species) of the larval stage (phyllosoma) that is released into oceanic currents and physically transported very long distances from the spawning site (Dao et al., 2013, 2015). Philips et al., (2003a) used detailed data available for the Western Rock Lobster *P. cygnus*, to suggest that removal of 20 million pueruli would have an impact on the adult lobster fishery by reducing catch by just 0.62%, reflecting the extremely high natural mortality of the seed. This is a fishery where the puerulus population is directly connected with adult spawning stocks, that is, the puerulus population is not a sink.

The *P. homarus* and *P. ornatus* puerulus resource along the central southern coast of Vietnam is likely to represent a sink population, as is that of southern central Indonesia along the southern coastline of Java, Bali, Lombok and Sumbawa (Jones, 2015b). In Indonesia, there is a confluence of geographic and oceanographic conditions that would likely lead to a concentration of late-stage phyllosoma larvae, particularly of *P. homarus* and *P. ornatus* in the Java Sea, generated from the pull of the Indonesian Throughflow, a powerful current running south through the strait between Bali and Lombok (Dao et al., 2015). As this current enters the Timor Sea to the south, it slows and eddies west to Java and east to Lombok and Sumbawa; larval lobsters complete their development, transform to puerulus and then settle along the coastline in this region (see Figure 1.3).

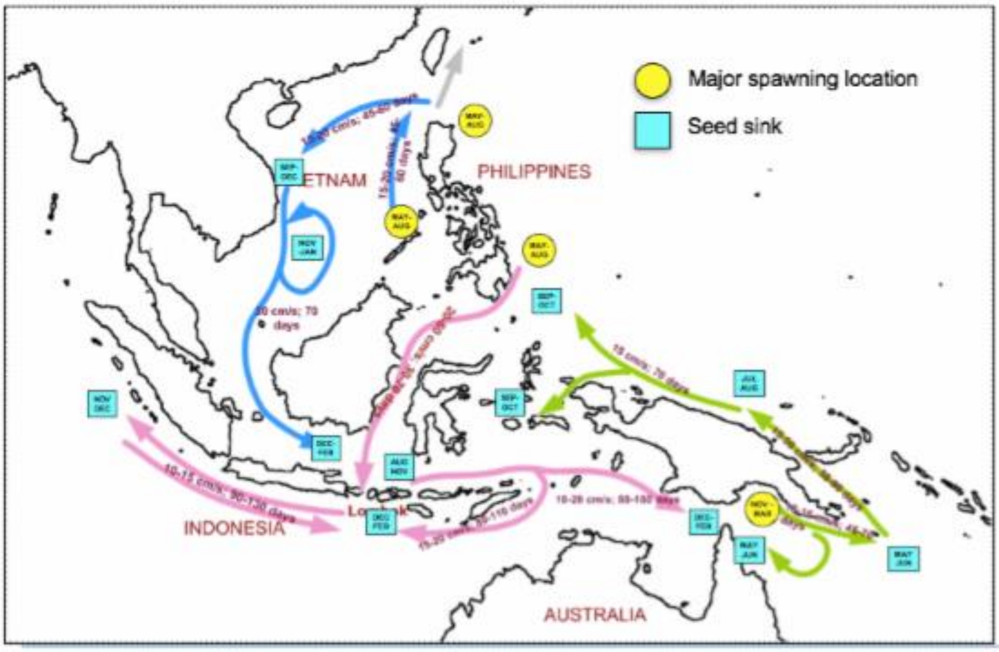

Figure 1.3. The concentration of late-stage phyllosoma, particularly of *P. ornatus* and *P. homarus*, occurs as one homogeneous population throughout the Western Pacific; the puerulus deposited along southern coastline of Java, Lombok and Sumbawa is spawned far to the north. This population of puerulus is a sink (Dao et al., 2015).

Their concentration along this coastline appears to be far higher than elsewhere, based on semi-quantitative surveys of other Indonesian provinces (Bahrawi et al., 2015a). In addition, there is limited suitable natural habitat, such as preferred habitat with coral or rocky reef substrate, low turbidity and full marine salinity in the settlement locations to support juveniles and adults (Milton et al., 2014). The southern coastlines of Java, Bali, Lombok and Sumbawa are characterised by steep topography with a narrow strip of fringing reef adjacent to the coast flanked by an immediate drop off to depths unsuitable for lobster habitation (Milton et al., 2012). The absence of suitable habitat to support further life stages means that the bulk of the lobster seed settling in these locations is likely to die from natural attrition. This lobster seed population might accurately be described as a sink population, as it is disconnected from the reproductive stock from which it arose (Dao et al., 2015). On this basis, the resource can be exploited to supply seed for farming with no significant effect on adult lobster populations. Although Milton et al. (2014) suggested there was a high degree of local recruitment of adult population along the south-central coast of Java, this is not inconsistent with the hypothesis of a sink, as their modelling also suggested that >25% of recruitment to their study location was sourced remotely. It is noteworthy that Milton et al. (2014) recorded very few *P. ornatus* within the commercial catch and yet *P. ornatus* pueruli are a significant component of the puerulus settlement in southern Java (Priyambodo & Bahrawi, 2015, 2016a). This suggests that the *P. ornatus* pueruli originated elsewhere and were transported to this location through the Indonesian Throughflow model as suggested by Dao et al. (2015).

1.4.5.2 Opportunities

Because Vietnam has a long history of success with lobster farming supported by the ACIAR lobster project, there is a high chance of successful technology transfer from Vietnam to Indonesia. In the adoption of aquaculture technology, greater interaction among developers, transfer agencies and farmers themselves are the key factors of success (Dlamini, 2003; Yap-Gnaore et al., 1995). However, funding technology transfer to farmers is a crucial issue. In some cases, the inability of farmers to afford technologies offered to them may force them to abandon their crops and the method of technology adoption can affect its success (Rogers, 2003; United Nations Development Program, 2017). On this basis, the Indonesian lobster stakeholder participants in the study tour described in Chapter 3 were appropriately selected, ensuring that they included puerulus fishers and grow-out farmers, extension officers, aquaculture engineers and researchers. It was hoped that they would become role models on the front line of the development of Indonesian spiny lobster aquaculture.

Principally, there are three primary opportunities in the development of spiny lobster aquaculture in Indonesia which include 1) the abundant resource of wild puerulus; 2) the expansion of suitable grow-out sites; and, 3) the availability of farming technology (Priyambodo, 2015b). An increased puerulus catch to 5 million pueruli per year from multiple locations, for example, could lead to production of >2,500 tonnes of market-size lobster with a value of over US$130 million (Priyambodo, 2015a). Straddling the equator, Indonesia's tropical climate provides an ideal opportunity for sea-cage aquaculture of tropical lobsters in Indonesia. Strong market demand from China and Taiwan for live lobsters provides a strong foundation (Hart, 2009).

1.5 Research Objectives, Research Questions and Approaches

The opportunity to develop spiny lobster aquaculture in Indonesia is clearly apparent, but the means of achieving such development with sustainability and stability requires answers to several critical questions. The research presented here was designed to answer some of these questions by addressing key issues in regard to the Indonesian seed supply and the technology to transform the seed into marketable product. Thus, the overarching research aim of the study was, therefore, to investigate the efficacy and efficiency of lobster pueruli collection technologies to enable sustainable development of the industry. Principally, can adopted or adapted technologies from Vietnam and understanding of local conditions improve puerulus catch, and how can the industry grow sustainably? Five specific objectives were defined as follows.

1.5.1 Research Objectives

Objective 1:

To review the profile of the development of Indonesian spiny lobster aquaculture.

Questions:

1. What is the history of spiny lobster aquaculture?

2. What are the current status and its prospects?
3. In what ways does the industry generate benefits for communities?

Objective 2:

To determine the effects of puerulus collection technology transfer from Vietnam to Indonesia on the development of lobster farming.

Questions:

1. What are the best methods to disseminate information?
2. Why do some farmers adopt, and others do not?
3. How can the adoption of technology by Indonesian lobster puerulus fishers be improved?

Objective 3:

To understand the sustainability of puerulus capture to provide a strong foundation for examining puerulus resource for subsequent on-growing.

Questions:

1. What is the potential number of available pueruli along the entire south coast of Indonesia, from Sumbawa to Java islands?
2. How many pueruli can be sustainably caught for the purpose of aquaculture?
3. What is the potential economic benefit of puerulus fishing?

Objective 4:

To determine the effectiveness of different puerulus collector types and optimal depths for deployment.

Questions:

1. Which collector types are most effective for collecting pueruli?
2. What effect does collector depth have on the puerulus catch rate?

Objective 5

To determine the effectiveness of different materials and crevice angles used in puerulus collectors.

Questions:

1. Which collector materials are locally available and the most effective?
2. Which crevice angles are the most effective?
3. What are the effects of lunar phase on puerulus settlement?

1.5.2 Research Questions

This thesis addresses the development of the spiny lobster industry in Indonesia, by understanding its history and uncovering barriers to technology transfer and dissemination. The research approaches will be based on data collected from surveys and interviews, and factors influencing the development of spiny lobster aquaculture in Indonesia. Underpinning this research was a study tour to Vietnam with Indonesian spiny lobster stakeholders, which also involved multiple social surveys, farmer interviews and discussions.

This thesis also addresses understanding of puerulus behaviour, by developing puerulus collection devices and techniques. Although the study aimed to identify the best collecting methods, it also provides insights into puerulus behaviour through observation and capture measurements. The results of tank and field-based experiments using different collector types, materials, depths and crevice angles for puerulus fishing equipment are used to identify the most effective design of collectors.

Finally, the thesis addresses the assessment of the lobster puerulus resource and its potential sustainable exploitation for the purpose of aquaculture. The series of surveys and interviews and a literature review are used to perform a detailed analysis of captured pueruli, the number of collectors, catch statistics, seasonality, species, and pricing.

1.6 Thesis Structure

Chapters are presented in manuscript form; some chapters have already been published in international journals and/or presented at international conferences. One of the unpublished chapters (Chapter 4) is also planned for publication.

Chapter 2 presents an overview of spiny lobster aquaculture development in Indonesia, explaining its emergence, establishment and current status. The chapter provides the necessary context to understand basic farming operations. The economic benefits, major constraints and opportunities of lobster aquaculture are also presented. Finally, the research and development required for the future sustainability of spiny lobster aquaculture in Indonesia is discussed. The material in this chapter has been presented three times at international conferences: 1) Asia Pacific Aquaculture World Aquaculture Society Conference in Ho Chi Minh City Vietnam (10–13 December 2013); 2) International Lobster Aquaculture Symposium in Lombok, Indonesia (22–25 April 2014); and 3) Asia Pacific Aquaculture World Aquaculture Society Conference in Kuala Lumpur Malaysia (24–27 July 2017). Additionally, some sections of the work have been published in ACIAR Proceedings No. 145 as Priyambodo (2015a), Priyambodo (2015b), Priyambodo (2015c), Priyambodo and Jones (2015), Bahrawi et al. (2015a) and Petersen et al. (2015).

Chapter 3 describes how technology transferred during the Indonesian study tour to Vietnam influenced the development of lobster aquaculture in Indonesia. The data in the chapter were presented at the 10th International Conference and Workshop on Lobster Biology and Management in Mexico (18–23 May 2014) and at the International Lobster Aquaculture Symposium in Lombok, Indonesia (22–25 April 2014). The work outlined here has been published in ACIAR Proceedings No. 145 as Priyambodo (2015c).

Chapter 4 assesses the lobster puerulus resource of Indonesia and its potential for sustainable exploitation for aquaculture. The quantity and distribution of pueruli were used to estimate potential number of households in the country that would receive economic benefits if puerulus fishing is allowed in future. The lobster puerulus census data in Lombok gathered as part of the ACIAR lobster project, combined with more recent puerulus collection data from Java and Sumbawa, were used to propose a puerulus fishery policy. Some sections of the work outlined here have been published in ACIAR Proceedings No. 145 as Bahrawi et al. (2015a), Bahrawi et al. (2015b) and Bahrawi et al. (2015c). Further, results were presented at the International Lobster Aquaculture Symposium in Lombok, Indonesia (22–25 April 2014). The candidate was involved in those studies and collected the data used in this thesis.

Chapters 5 and 6 examine the effect of collector designs, collector materials, crevice angles, water depths and lunar phases on puerulus catch. Finding cheap, accessible and sustainable technology approaches (e.g., recycled and locally available materials) and more effective collector locations will improve puerulus fishers' ability to provide pueruli for the purpose of aquaculture in Indonesia. The data in Chapter 5 were presented at the 10th International Conference and Workshop on Lobster Biology and Management in Mexico (18–23 May 2014). The data in Chapter 6 were presented at the Asia Pacific Aquaculture World Aquaculture Society Conference in Surabaya Indonesia (26–29 April 2016). Both chapters outlined here have been published in the *Journal of Aquaculture* as Priyambodo et al. (2015) and Priyambodo et al. (2017b).

Chapter 7 summarises the thesis and presents recommendations.

1.6.1 Limitations of the Study

Spiny lobster aquaculture comprises two main activities: puerulus collection and grow-out. The research presented in this thesis is focussed on puerulus collection rather than grow-out. A study on both puerulus collection and subsequent grow-out methods would be beyond the scope of a PhD.

Chapter 2: The History of Spiny Lobster Aquaculture in Indonesia

2.1 Introduction

Demand for market-size spiny lobster is increasing and exceeding supply from the wild fishery, which itself is in decline. Consequently, there is significant global interest in the development of spiny lobster aquaculture (Beveridge et al., 1997; Kittaka & Booth, 2000; Radhakrishnan, 2012). Generally, three alternatives are recognised for growing out lobster: 1) closed-cycle farming whereby phyllosoma hatched from captive broodstock are reared to puerulus stage and then on-grown to a marketable size; 2) the capture and subsequent grow-out of wild post-pueruli and juveniles; and 3) the on-growing and value-adding of adult lobsters (fattening) in sea-cages and land-based systems (Phillips & Liddy, 2003). However, the most two feasible options in terms of feasibility and in terms of producing the highest economic return, in the short term, is to collect wild pueruli using specialised collectors and cultivate them in sea-cages or using a land-based system (Jeffs & Hooker, 2000; Johnston et al., 2006). The Indonesian spiny lobster aquaculture industry prefers this option by cultivating the wild pueruli in sea-cages (Priyambodo & Jones, 2015).

The lobster farming industry in Indonesia is still immature compared with Vietnamese lobster farming. Vietnam produces a significant number of market-size *P. ornatus*—1,500 tonnes annually—valued at 80 million USD (Tuan & Jones, 2015b). In contrast, Indonesian spiny lobster production is still dominated by the wild fishery. Although this fishery has been valued at >150 million USD (Anonymous, 2007) it is not considered sustainable as spiny lobsters are overfished (Radhakrishnan et al., 2005; Sharp et al., 2005). However, supply from aquaculture has been minimal (Hart, 2009), accounting for only 2.67% of total production (fishery plus aquaculture) between 2005 and 2014

(MMAF, 2015). The total production from fishery and aquaculture sources is presented in Figure 2.1. Data for aquaculture production between 2009 and 2016 in West Nusa Tenggara (NTB) Province, the major location of spiny lobster aquaculture in Indonesia, are presented in Figure 2.2. The figure shows a sharp decline from 2013 to 2016. The main reasons of the decline were likely both the effect of exported pueruli and new regulations.

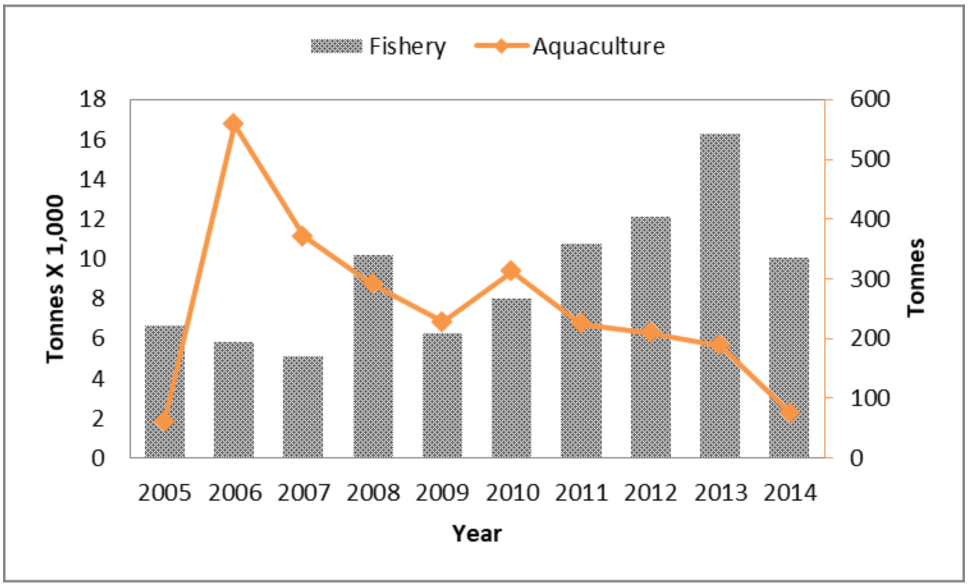

Figure 2.1. Production of Indonesian spiny lobster from fishery and aquaculture 2005–2014

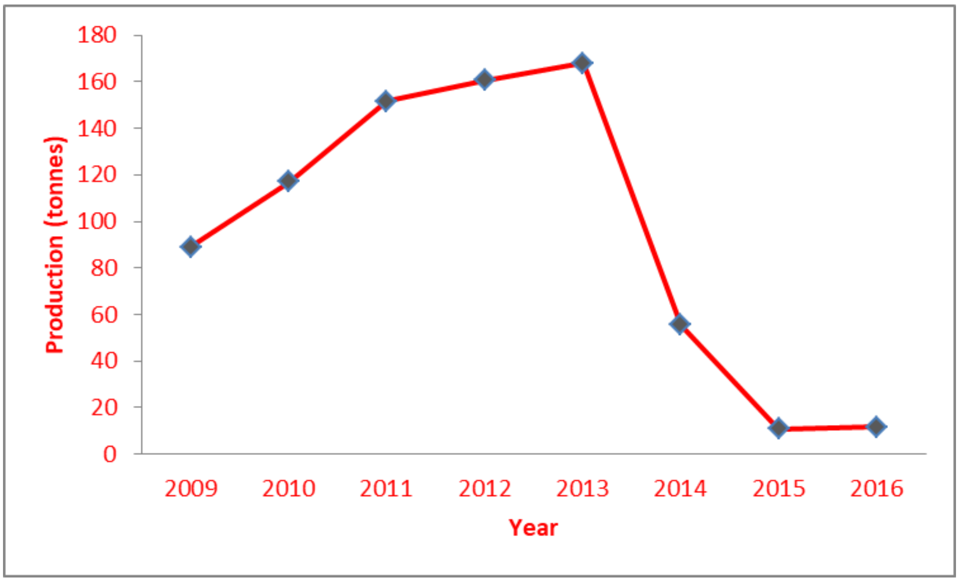

Figure 2.2. Production of spiny lobster aquaculture 2009–2016 in Nusa Tenggara Barat Province (Badan Pusat Statistik [BPS], NTB, 2017)

The lobster fishery relies on up to six species of *Panulirus* (*P. ornatus, P. homarus, P. penicillatus, P. versicolour, P. longipes* and *P. pakistany*) and Scyllarids (*Scyllaroides squamosus*, *Thennus* spp. and *Parribacus antarcticus*), with the most important species varying regionally (Hart, 2009; Milton et al., 2012). The identification of early-stage pueruli between species was based on well-established criteria used in Vietnam developed by Hoc Tan Dao (unpublished paper). The identification of *P. ornatus* and *P. homarus* includes diagnostic characteristics of the antennae and body morphology as discussed in Chapter 5. Southern Java is one of the more productive regions, contributing up to 10% of the national catch (Anonymous, 2007). Most catch is *P. homarus* and *P. penicillatus* (Hart, 2009; Milton et al., 2012).

Farming techniques used in Lombok are still underdeveloped which indicates low survival and growth rates of farmed lobsters (Petersen et al., 2015; Priyambodo, 2013). Lobster grow-out has been attempted by some lobster middle persons in onshore ponds and in sea-cages in several places on the south coast of Java, with mixed success. None has yet achieved a grow-out operation that is sustainable and cost effective

(Milton et al., 2012). However, lobster aquaculture in Indonesia has the potential to be a livelihood alternative for poor coastal rural communities because it involves low capital input, simple technology and high-value species (Jones, 2012). Currently, returns on investment are modest and largely depend on the price and availability of lobster pueruli and credit (Petersen et al., 2015).

In contrast, local investment in lobster farming in Vietnam is high compared with other enterprises in the region, and farms are profitable, with an average benefit-cost ratio of 1.44 and an average net revenue of 262 million VND (~11,550 USD) per farm per year (Petersen & Phuong, 2010). In addition, small-scale lobster culture is particularly suited to poverty alleviation in Vietnam because it does not require land, is flexible in terms of low capital input and employs cheap labour (Hambrey et al., 2001). The positive outcomes of Vietnam's spiny lobster aquaculture have created significant interest in lobster farming among other South-East Asian countries (Jones, 2010; Phillips, 2013).

This chapter reviews the status of Indonesian spiny lobster aquaculture, which includes 1) the common practice of Indonesian spiny lobster aquaculture (prior to 2012); 2) the transition era of lobster farming (2013–2014); 3) the economic benefits of puerulus collection and grow-out; and 4) research and development relating to Indonesian spiny lobster aquaculture.

2.2 Materials and Methods

This chapter uses a multiple methods approach including a descriptive analysis of the data to examine the history of development, production systems, the problems encountered, and policy. The primary data were collected through a series of surveys and farmer interviews. Given the time limits and geographic spread of puerulus fishers and grow-out farmers, a structured survey was considered the most efficient method for gathering data from a wide range of participants. Data from the survey and discussions enabled further analysis to characterise and describe the status of the spiny lobster aquaculture industry in Indonesia. Secondary data were gathered from a literature review and databases from national and local fishery agencies in Indonesia.

The literature review and structured interviews were used to collect data on the history of development. A structured survey was used to gather data on production systems, problems encountered and policy impacts. The social survey was conducted under the approval of the University of New South Wales (UNSW) Human Research Ethics Committee (No: HREC Ref: #HC13346). The surveys were conducted in Lombok, Sumbawa, Trenggalek and Banyuwangi. The number of surveyed participants in each location is presented in Table 2.1.

Table 2.1

The Number of Surveyed Participants

No	**Location**	**Number of participants**		
		Puerulus fishers	Grow-out farmers	Ex-grow-out farmers
1	Lombok			
	Gerupuk (8°54'39.40"S 116°20'37.37"E)	30	-	1
	Bumbang (8°54'12.10"S 8°54'12.10"S)	15	-	2
	Awang (8°52'58.16"S 116°23'36.04"E)	15	-	1
	Telong Elong (8°48'28.70"S 8°48'28.70"S)	-	4	6
	Ekas (8°52'27.52"S 116°27'23.13"E)	30	11	-
2	Sumbawa (8°55'38.33"S 117°46'11.59"E)	8	-	-
3	Banyuwangi (8°35'23.50"S 114°15'4.41"E)	7	-	-
4	Trenggalek (8°15'23.15"S 111°47'50.51"E)	11	-	5
		116	15	16

To facilitate an analysis of the economic benefits of puerulus collection and grow-out, data were gathered from the eight main villages closest to where pueruli are caught as presented in Table 2.1. This study conducted interviews with 116 key/important puerulus fishers, 15 grow-out farmers and 16 ex-grow-out farmers (farmers who ceased operation). The respondents were selected using a random sampling method that provided equal probability for each individual in a population of each background to be a respondent (Bergman, 2008). The sampling method was free of bias, which provides a representation and generalisation of a participant's background (Dattalo, 2010).

The structured questionnaire contained questions on human capital, economic and husbandry information associated with stocking, harvest, equipment requirements, feeding, labour, credit, other household farming operations and other sources of household income; for both puerulus fishers and grow-out farmers (see Appendix A and B, respectively). Questions were also asked about the effects of the regulations (Decree 1/2015). The questionnaire was administered via face-to-face interviews with participants. Data are presented using graphs and tables. Given the small population sample size, data analysis was restricted to descriptive analysis of the economic benefits of both puerulus collection and grow-out activity.

2.3 Results and Discussion

2.3.1 The Common Practice of Indonesian Spiny Lobster Aquaculture (Prior to 2012)

This section discusses the industry before the current research commenced in 2013, to explain why particular technologies are investigated in the present study.

Spiny lobster aquaculture in Indonesia began in the early 1990s as a way for lobster fishers in Telong Elong, East Lombok, to utilise undersized lobsters caught as bycatch, particularly from beach seine netting and diving (Priyambodo, 2015b; Priyambodo & Sarifin, 2009). Typically, individual lobsters of <60 g or ± 22 mm CL were stocked in floating sea-cages and fed with trash fish (Jones et al., 2007; Priyambodo & Suastika-Jaya, 2009). After several months, these grow-out farmers harvested the farmed lobsters at a market size of at least 100 g or 40 mm CL. In the early 2000s, seaweed and grouper grow-out farmers in Gerupuk and Awang bays in Lombok discovered and caught pueruli settling on floats and seaweed rafts (Jones, 2010; Priyambodo & Sarifin, 2009). These were also stocked to sea-cages for grow-out, although with very limited success.

Since then, enterprising farmers began collecting and targeting pueruli of two main species, *P. homarus* and *P. ornatus*, for the purpose of aquaculture with the main farming area being located in Telong Elong (Priyambodo & Suastika-Jaya, 2009). The industry began to develop after some farmers regularly caught pueruli and post-pueruli and grew them to market size (at least 100 g at that time), and a market chain developed (Hart, 2009; Jones et al., 2007). The local spiny lobster aquaculture industry thus developed into two primary activities: 1) puerulus collection, which is situated in Southeast Lombok; and 2) grow-out to market size, located in East Lombok. The location of lobster puerulus fishing and grow-out, and the status of Indonesian lobster farming (prior to 2012) are shown in Figure 2.3 and Table 2.2, respectively.

As described in Chapter 1, ADB and ACIAR SADI have facilitated the development of lobster aquaculture in Indonesia; particularly in Lombok as part of two projects that commenced in 1999 and 2007, respectively. ADB (2008) reported that the profits for lobster and grouper aquaculture enterprises was over 100%, exceeding that for other types of aquaculture such as shrimp and seaweed cultures, and some fish processing enterprises during the ADB project was commenced. However, a feasibility study of lobster aquaculture undertaken as part of the ACIAR SADI project identified that the main constraints for the expansion of the lobster aquaculture industry were the lack of puerulus supply and poor aquaculture practices (Jones et al., 2007). When this PhD study commenced in 2013, the most pressing issues hampering development of the Indonesian lobster farming industry were even more complex: in addition to the existing problems, they included diseases and nutrition, as described in Chapter 1.

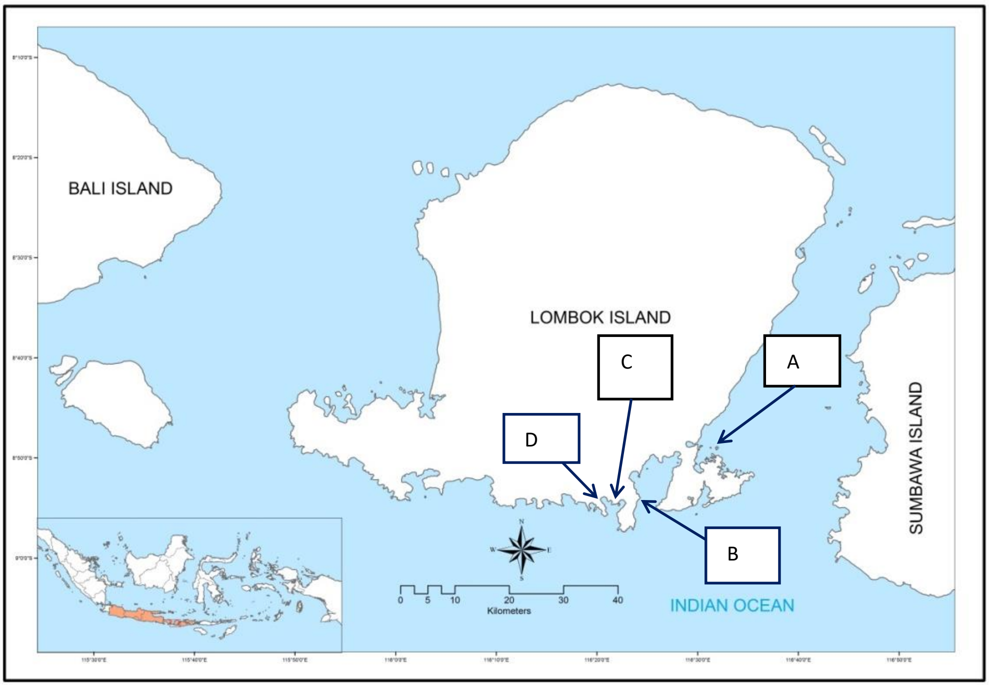

Figure 2.3. Map of Lombok Island, showing the location of lobster farming in Telong Elong (A) and puerulus collection sites in Awang (B), Bumbang (C), and Gerupuk (D) when the industry began (up to 2012)

Table 2.2

The Status of Spiny Lobster Farming in Indonesia (Prior to 2012)

Year	Main events
1990–1997	Fishers started fattening lobsters; a small number of floating cages and fishers involved as their side job in Telong Elong and Ekas villages, Lombok
1998	ADB, through the Co-Fish Project, initiated spiny lobster aquaculture in Telong Elong and Ekas bays; a few lobster farmers collaborated on fattening spiny lobsters
2000	Pueruli found in Gerupuk and Awang bays of Lombok and sold to Telong Elong, East Lombok, to grow
2001–2007	Puerulus fishers (400–500) continued to catch ~250,000 pueruli per annum in the three main puerulus hotspots in Lombok (Gerupuk, Bumbang and Awang bays)
	Lobster grow-out took place in Telong Elong and Ekas bays using floating sea-cages; the number of grow-out farmers was ~500; production was 50–80 tonnes of *P. homarus* per year
	In 2007, ACIAR SADI became involved in the development of spiny lobster aquaculture in Indonesia (FIS/2001/058–SMAR variation)
2008–2012	ACIAR lobster project SMAR/2008/021; the number of pueruli caught increased from 250,000 to 600,000 per year; production of market-size lobster, was 80–160 tonnes per year in 1,000 grow-out sea-cages

2.3.1.1 Puerulus collection

During the early stages of lobster farming in Lombok, the only significant demand for puerulus came from Telong Elong and Ekas villages in East Lombok, with fewer than 500,000 pueruli collected per year. Based on the ACIAR lobster puerulus census, as many as 600,000 pueruli were caught annually between 2008 and 2012 (Bahrawi et al., 2015a; Jones et al., 2010). The domestic/overseas demand for these pueruli from other domestic locations and from overseas was small and ranged between 260 and 132,000 pueruli from 2006 to 2012 (Balai Karantina Ikan dan Pengendalian Mutu [BKIPM], 2015). The bulk of the seed captured in Lombok at this time were used for grow-out in Lombok only.

The price of puerulus was the same for *P. homarus* and *P. ornatus*, at ~3,000 IDR (0.27 USD) per individual for pueruli; 5,000–7,000 IDR (0.46–0.64 USD) per individual for post-pueruli of 25–50 mm; and up to 10,000 IDR (US$ 0.90) per juvenile (5 g +), depending on size (Priyambodo and Sarifin, 2009; Priyambodo & Suastika-Jaya, 2009, 2010). These prices were in contrast to the significant price differential for these species in Vietnam. Photographs of puerulus and post-puerulus individuals of the two species are shown in Figure 2.4 and 2.5. During this period, most grow-out farmers preferred to cultivate *P. homarus* rather than *P. ornatus* because *P. homarus* attract their premium price at only 100 g whereas premium price for *P. ornatus* is only achieved when they exceed 500 g (Jones et al., 2007; Priyambodo & Sarifin, 2009). In contrast, P. ornatus is the much preffered species in Vietnam, farmed to 1 kg+, which fetches a higher price than *P. homarus*.

Figure 2.4. Puerulus of *P. homarus* (top) and *P. ornatus* (bottom), both specimens are approximately 10 mm CL.

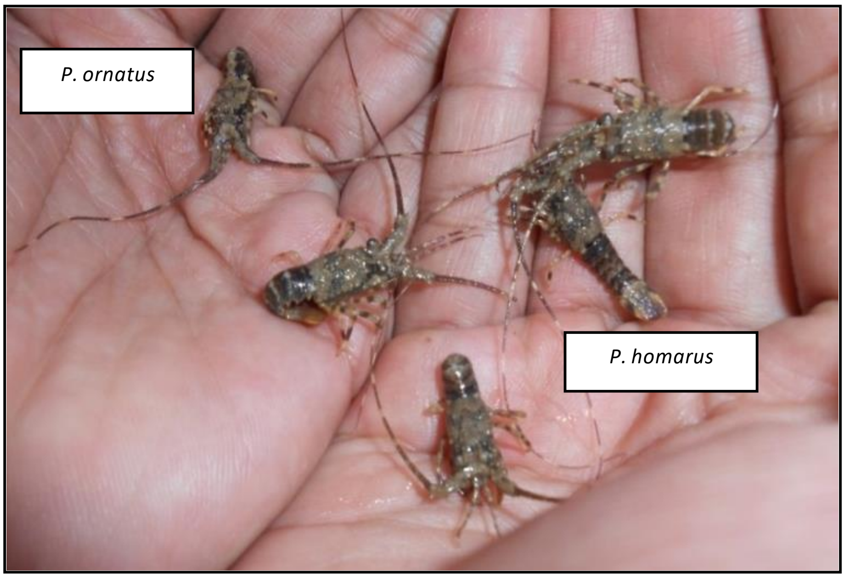

Figure 2.5. Post-puerulus juveniles of *P. ornatus* and *P. homarus*

2.3.1.1.1 Puerulus collection area and puerulus fisher involvement

The entire south coast of Lombok Island is a potential source of puerulus, but the collection of puerulus between 2000 and 2012 occurred only in Gerupuk, Bumbang and Awang bays, as shown in Figure 2.1. Further, only 250–400 puerulus fishers were involved in puerulus collection in these bays (Bahrawi et al., 2015b; Priyambodo & Sarifin, 2009). At this time, there was limited demand for pueruli and therefore limited interest in expanding the puerulus fishery to other locations.

2.3.1.1.2 The puerulus collection method used and its productivity

As mentioned in Chapter 1, Section 1.3.2.1, the puerulus collection methods used until 2012 were simple, traditional methods consisting of a group of single collectors or traps. This is commonly known as the ‘passive method’. It used common collector materials that included rice bags and various kinds of canvas (Figure 2.6) bunched up to form collectors that were hung in the water column from a set of floating frames made of bamboo, varying in size from 64 m^2 to 81 m^2 (Figure 2.7). The pueruli settled into the folds of these materials. These collectors would be inspected every second or third day.

Figure 2.6. Collectors made of bundled rice bags (A) and canvas (B)

Figure 2.7. Traditional puerulus fishing rafts

2.3.1.2 Lobster farming

In Lombok, where lobster pueruli were caught, the grow-out of lobster in sea-cages made a significant contribution to local and export markets (Jones, 2010).

Approximately 1,000 small-scale farm units were established in 2008 (Priyambodo & Suastika-Jaya, 2009). However, because of technical constraints in relation to lobster grow-out practices—such as high stock mortality, reliance on low-nutrition trash fish and diseases (Bahari, 2012; Jones et al., 2007; Priyambodo et al., 2012a)—annual production of market-size lobster from 2007 to 2012 was very low (Dinas Kelautan dan Perikanan [DKP] NTB, 2015) at around 100 tonnes in comparison with Vietnam's figures for the same period: ~1,500 tonnes per annum (Tuan & Jones, 2015b).

The strong market demand for spiny lobster and the success of lobster grow-out farmers will ensure that lobster aquaculture remains a profitable business in Indonesia. This, however, requires the need for the legislation to change. Prior to 2012, lobster aquaculture in Indonesia occurred in combination with other species, primarily *Cromileptes altivelis* (humpback grouper) and the seaweed *Eucheuma cottonii* (Jones, 2010; Priyambodo & Sarifin, 2009). High prices for farmed lobster and cheap transport to exporters in Bali made lobster farming attractive option for aquaculture farmers (Hart, 2009). However, exporters were paying a slightly lower price for farmed than for wild-caught lobster, primarily because the supply volume of farmed lobster was small and inconsistent (Jones et al., 2007).

Additionally, farmed lobsters from Lombok were pale in colour and considered to lack vigour (Jones, 2012), which substantially reduced their live transport suitability for global markets. Nevertheless, market demand for lobster was significant and increasing during that time, and farming lobsters continued (Hart, 2009; Milton et al., 2012).

2.3.1.2.1 Area of lobster farming and grow-out farmer involvement

Based on the interviews and surveys undertaken during this study, prior to 2012, there were two main lobster aquaculture areas, Telong Elong Bay and Ekas Village, located in the south-central and eastern regions of Lombok and involving around 400 farmer households.

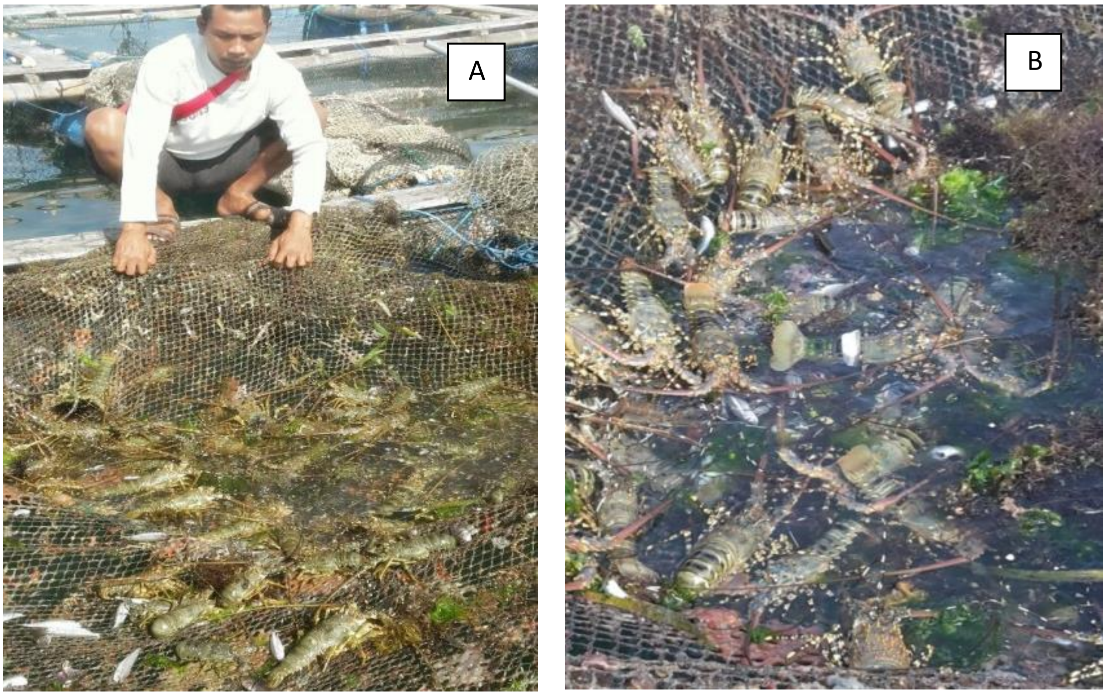

Figure 2.8. Farmed lobster of *P. homarus* (A) and *P. ornat*us (B), using a 3 x 3 x 3 m^3 net cage mesh size 1 inch with the density of 10-15 individual per m^2.

The majority of grow-out farmers preferred to grow only P. homarus (see Figure 2.8A). One of the main reasons for this was related to the growth rate and shorter farming duration to achieve market size: 100 g each for *P. homarus*. Although *P. ornatus* takes longer to reach a marketable size; some grow-out farmer still cultivated *P. ornatus* (see Figure 2.8B).

2.3.1.2.2 Grow-out method

In Vietnam, the three major grow-out methods used are wooden fixed cages, submerged cages and floating cages (Hung & Tuan, 2009). However, the primary grow-out method used in Lombok prior to 2013 was floating cages only, with considerable variation in raft design and cage specifications (Priyambodo & Suastika-Jaya, 2010). All cages were supported by floating rafts anchored 100 m or more off the beach. The materials used varied from less sophisticated structures made from bamboo to better engineered platforms made from milled timber. Floats consisted of plastic or polystyrene foam drums covered in canvas. Rafts varied in size but were typically 64–110 m^2. The common set-up of the floating cages at the time is presented in Figure 2.9.

Sea-cage nets made from nylon fishing net materials were supported within the raft in a rectangular grid pattern of varying specifications. Nets varied from small (8 m^3) to large (27 m^3), depending on the size of stock: for example, smaller cages were used for pueruli and larger cages for grow-out. The larger cages tended to use larger mesh size, although none exceeded 20 mm (Priyambodo & Suastika-Jaya, 2009, 2010).

Figure 2.9. The commonly used unit of floating sea cages, with several cages of 3 × 3 × 3 m. A unit of floating sea frames usually consists of 9 cages (243 m^3 total volume).

2.3.1.2.3 Feed

One of the major constraints to increasing lobster aquaculture production is the development of cost-effective feeds and knowledge of optimal feeding strategies (Edwards et al., 2004). In Lombok, lobsters were fed mainly with small fish (commonly reffered to as trash fish) caught as a byproduct of other fishing activities, particularly from fish traps (*bagan*) and traditional surface trawling. Trash fish were roughly chopped and used as feed each morning. Based on the interviews from this study, the feed conversion ratio (FCR) was very poor—~25–30:1 (i.e., 25–30 kg of trash fish was used for each kg of lobster produced)—which is inefficient and likely to result in environmental degradation (Irvin & Williams, 2009).

There may be an opportunity to supplement trash fish diets with molluscs and crustaceans to ensure essential nutrients are available to the farmed lobsters. In certain seasons where the availability of trash fish is low, the freshwater golden snail (*Pomacea bridgesiii*) retrieved from rice paddies (Figure 2.10) are commonly used as feed for farmed lobsters. Even though golden snails are high in protein (50–54% protein dry weight), digestibility is poorer than expected when used for grouper feed (Rimmer, Faculty of Veterinery Science, University of Sydney). Thus, even though trash fish are deficient in essential nutrients, they are likely to be nutritionally superior to golden snails as a feed source. Mixing snails with fish or alternating between the two is yet to be tested and may improve growth performance in lobster.

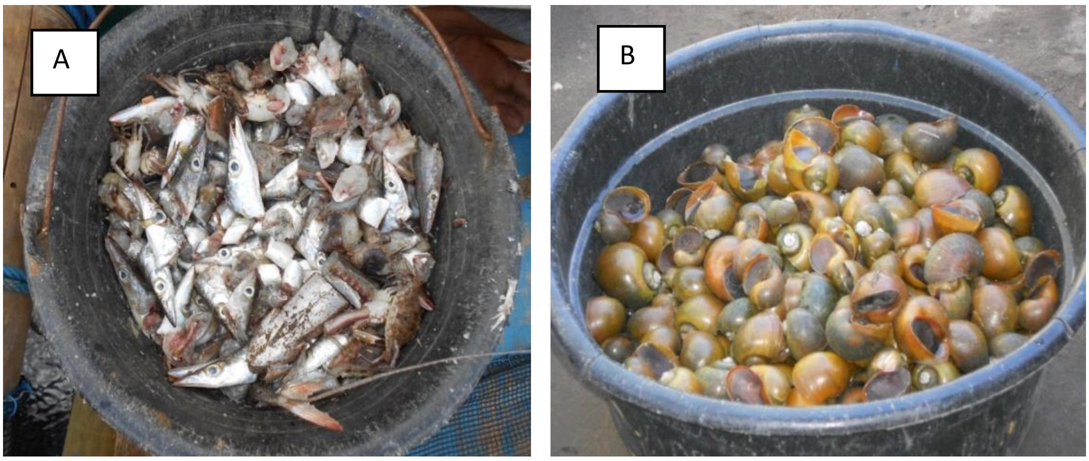

Figure 2.10. Trash fish (A) and freshwater golden snails (B) as the main sources of feed for farmed spiny lobster in Lombok

When developing an artificial feed, knowing what the animal prefers to eat in the wild, what food is attractive to them and whether the feed's physical characteristics (size, shape, texture, etc.) influence the animal's selection preferences is useful information (Williams, 2009). A series of tropical spiny lobster artificial feed formulations was developed as part of the ACIAR lobster project between 2009 and 2013 with variable success (Irvin & Shanks, 2015). The primary objective of the research was to avoid an alternative to the dependence on trash fish. The aim in developing formulated diets was to reduce the FCR and improve the performance of farmed spiny lobster, thereby improving the profitability and quality of the farmed product.

2.3.1.2.4 Productivity

Mortality during the rearing of lobster from the puerulus stage can be very high (50–60%) and this is thought to be primarily attributable to natural cannibalism behaviour (Priyambodo & Sarifin, 2009). The other possible factors that contribute to the cannibalism are lack of husbandry practices, such as not offering sufficient refuge for the intended stocking densities, insufficient feed quality and quantity input, and inappropriate cage designs. Tuan and Jones (2015b) suggested that a round cage could arguably reduce the mortality of reared pueruli because it has no corners where pueruli usually tend to gather and concentrate. The concentration of reared pueruli in one spot, such as the corners of a rectangular-shaped nursery cage, could result in increased chances of injury and death to the pueruli, and thus decrease survival rate. Survival of lobsters through the juvenile phase is often 50% or less (Jones et al., 2007; Priyambodo & Suastika-Jaya, 2009, 2010). Based on the interviews conducted during this study, the grow-out phase in Lombok has associated with relatively high risk. There were varying accounts of survival, with some farmers experiencing very good survival (>70%) and others, very poor (<50%). In contrast, the proven track record of Vietnamese lobster farmers suggests that with good husbandry and nutrition, grow-out survival should consistently be above 80% (Hung & Tuan, 2009, Petersen & Phuong, 2010, 2011).

The overall production or yield per cage unit in Lombok is difficult to calculate a because of variation in puerulus density, survival and growth rates, harvest size and the number of cages employed in the grow-out of lobster (Jones et al., 2007, Priyambodo, 2013). However, a rough estimate can be attempted. On average, it takes 8–10 months for a 5–7 cm juvenile (TL) *P. homarus* to reach a market size of 100 g and 16–18 months of farming period for *P. ornatus* to reach a marketable size of 300 g (Jones & Priyambodo, 2014). Initially, *P. homarus* grows faster than *P. ornatus,* up to 100 g, but thereafter *P. ornatus* grows faster (Tuan & Jones, 2015b; Tuan & Mao, 2009). Therefore, approximately 10–15 kg of marketable *P. homarus* is produced per average cage (27 m^3) per annum (Jones et al., 2007). Based on interviews during this study, the number of cages in which lobster were grown successfully in Lombok before 2012 was estimated at 1,000 sea-cages. Hence the total annual production was likely to be around 12.5 tonnes (12.5 kg/cage × 1,000 cages). The average production per cage of market-size lobster in Vietnam between 2007 and 2012 was more than twice this, at ~25–52 kg (Tuan & Jones, 2015b). It is obvious that the methods used in Vietnam were more effective as they resulted in greater amounts of product than those used in Lombok.

2.3.2 The Transition Era of Lobster Farming (2013–2014)

Prior to 2013, lobster farming techniques in Indonesia were at an early developmental stage compared with those in Vietnam, where the lobster industry was highly developed. ACIAR lobster projects since 2008 have supported the sustainable development of spiny lobster farming in both Vietnam and Indonesia. To support the development of spiny lobster aquaculture in Indonesia, The ACIAR lobster project SMAR/2008/021 recommended that lobster aquaculture technology used with success in Vietnam be transferred to Indonesia (Jones et al., 2015). Given the success of the industry in Vietnam, it was deemed prudent to undertake a study tour involving Indonesian farmers, puerulus fishers, researchers, extension staff and industry representatives visiting Vietnam, as one method of transferring technology. Such a tour was undertaken, facilitated by the ACIAR, in March 2013 (Priyambodo, 2015c).

Based on data gathered during this PhD study, following three months of the study tour to Vietnam, the spiny lobster aquaculture industry in Lombok changed, with increased performance of major activities. Previously, both puerulus fishing and grow-out farming struggled with several constraints (e.g., fishing gear, collector materials and design, feeding issues, diseases, farmer attitudes). However, application of the improved knowledge gained during the study tour was immediately apparent in puerulus collection.

One of the ex-study tour participants from Lombok combined the use of lights (i.e., light traps) with their traditional collectors to catch pueruli. This new technique was then followed by other puerulus fishers in almost all puerulus fishing location in Lombok, resulted in a substantial increase in puerulus catch from around 500,000 to 3.5 million pueruli per year in 2013 in Lombok (Bahrawi et al., 2015b). Based on the surveys undertaken during this PhD study, demand from the domestic grow-out industry for pueruli remained steady before decreasing over time. Simultaneously, the demand from Vietnam for Indonesian pueruli began to increase, which resulted in increased price. Finally, the high international puerulus demand and high puerulus price made lobster farming in Indonesia less profitable, which led to a shift from grow-out to exclusively puerulus collection from mid-2013 onwards (Priyambodo, 2015b; Priyambodo et al., 2017a). By 2015, there were very few lobster grow-out farmers.

The study tour exposed Indonesian participants tasked with supporting aquaculture development directly to Vietnamese industry practices. A detailed discussion of the Indonesian lobster farmers' study tour to Vietnam and its effects on both Indonesia's and Vietnam's spiny lobster aquaculture is presented in Chapter 3.

2.3.2.1 The puerulus collection method used and its productivity

After the study tour, the number of puerulus fishers increased substantially from around 200–400 between 2009 and 2012 (Bahrawi et al., 2015b) to >5,000 from 2013 onwards in Lombok (Anonymous, 2015). Based on surveys and interviews undertaken during this PhD study, the increase in number of puerulus fishers was attributable to two main factors: the high price for pueruli and simplicity of methods used to collect, which were easily adopted. The number of puerulus fishers had reached >25,000 people by 2015 (two years after the study tour) distributed throughout the country, operating along the entire south coasts of Sumbawa and Java (Priyambodo & Bahrawi, 2015, 2016b).

Based on the primary surveys and interviews, puerulus exporters played an important role in the expansion into new puerulus fishing grounds throughout the country by delivering skilled puerulus fishers from Lombok to other parts of Indonesia to teach fishers about the new puerulus catching techniques. Many new puerulus "hotspots" were established, including the entire south coast of Java (Priyambodo & Bahrawi, 2015, 2016a), the entire south coast of Sumbawa (Priyambodo & Bahrawi, 2016b), several sites in South and South-East Sulawesi (Idris & Bahrawi, 2015) and several locations on the west coast of Aceh (Syafrizal et al., 2015).

The total catch of pueruli then increased dramatically in accordance with the expansion of catching areas and the implementation of new techniques of puerulus catching, mostly the use of lights (Bahrawi et al., 2015c). A map indicating the extent of current puerulus fishing locations is presented in Figure 2.11. An assessment of the lobster puerulus resource of Indonesia and its potential for sustainable exploitation for aquaculture is provided in Chapter 4.

Figure 2.11. The current puerulus fishing locations (red line), covering a distance of approximately 1,500 km of coastline

2.3.2.2 The puerulus collection method used and its productivity

Puerulus fishing methods have progressed from passive rice bag collectors to semi-active methods using cement bag paper bowtie collectors attached to a net, in combination with light (Bahrawi et al., 2015c; Priyambodo et al., 2015, 2017a). The collectors are generally suspended from puerulus sea-rafts (Figure 2.12) but can be deployed in a variety of ways, such as hung from traditionally used floating seaweeds rafts, fishing boats and longlines (Bahrawi et al., 2015a; Priyambodo & Bahrawi, 2015, 2016a, 2016b). Both floating puerulus sea-rafts and fishing boat methods are used in combination with lights (Figure 2.13), and in a longline design (Figure 2.14).

Figure 2.12. The new puerulus collector design, called "bowtie collector", with cement bag paper bowties attached in a single layer of s net size of 1.2 x 3-6 m^2, currently employed in Indonesia

Figure 2.13. Current puerulus fishing sea-cages consist of 6-8 unit collectors used in combination with 6-8 electricity lights performed by 750 watts generator set. The generator needs approximately 5 L of fuel to run overnight used in combination with lights

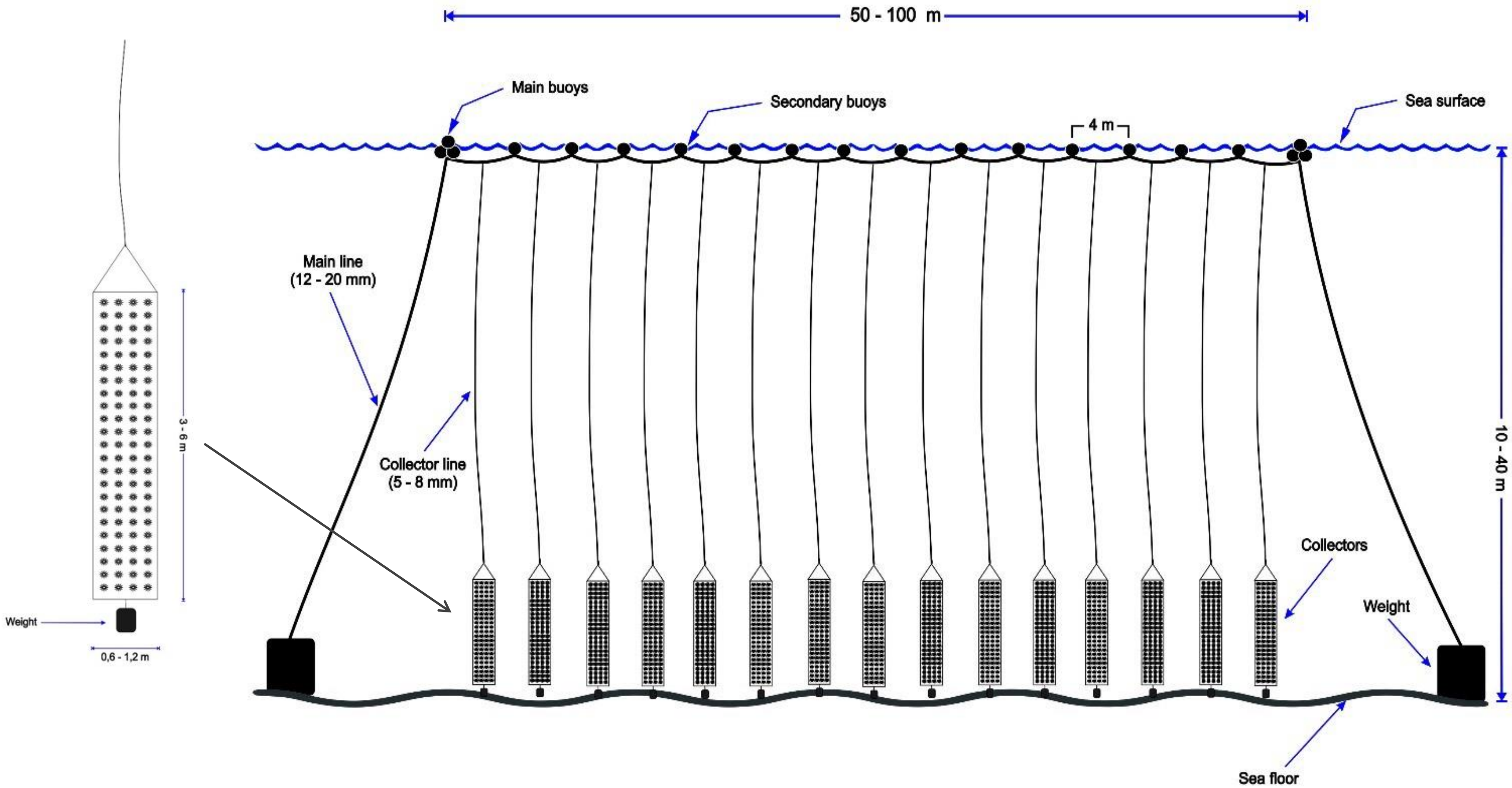

Figure 2.14. Illustration of a longline puerulus collector

Based on the survey and interview results, productivity using this new method has increased in comparison with the previous passive method. Puerulus fishers now catch 7–10 times more pueruli than they did with the earlier methods. The improved puerulus collection due to these collectors is discussed in Chapters 5 and 6.

2.3.2.3 Lobster grow-out

Prior to 2012, spiny lobster aquaculture consisted of the two major activities of pueruli collection and lobster grow-out. However, it has now completely shifted to puerulus collection alone, which provides much faster cash and better returns than grow-out and is low in risk (Priyambodo, 2015b; Priyambodo et al., 2017a). As a consequence, many grow-out sea-cages were abandoned from 2013 onwards as their owners switch to catching pueruli. Sugama (2015) reported that the number of lobster farmers in 2015 had decreased to <5% of that in 2012.

Based on the primary surveys and observations during this PhD study, several grow-out farmers tried to continue operation by using undersized lobster (50 to ±100 g) as an initial 'seed' stock, although this became illegal under the new regulations (Decree 1/2015) in late 2015. An undersized lobster had previously reffered to a 60 g lobster, but the regulation imposed a minimum legal size of 200g. The supply of 60g lobsters, although seasonal and somewhat limited, was far greater than the supply of 200g+ lobsters. Consequently, grow-out of lobsters with a reduced supply of stock became more difficult and the grow-out industry stagnated and effectively collapsed due to the regulation (Decree 1/2015).

2.3.3 Current Status (2015–Present)

2.3.3.1 New government regulations

In each of 2015 and 2016, the newly elected government of Indonesia launched two special ministerial decrees (Decree 1/2015 and Decree 56/2016) through MMAF that banned the capture of spiny lobster of any species <80 mm in carapace length (CL) or weighing <200 g. Therefore, it is prohibited to exploit pueruli of <15 mm CL for commercial purposes.

Additionally, Decree 56/2016 specifically stated that spiny lobster aquaculture is banned. Therefore, spiny lobster aquaculture, regardless of the initial stock size is prohibited. One of the main reasons for imposing these decrees was to conserve adult stocks and to enhance the lobster fishery. The decrees apply to commercial industry but not to educational, training and scientific research purposes. Hence, this PhD research was allowed to continue.

The research carried out here has become more particularly pertinent, as a better understanding of an Indonesian puerulus resource may provide the basis for an economically and environmentally sustainable industry to be developed in future where lobster farming is again allowed in Indonesia. The knowledge generated by this research may enable changes to fishery policy and regulation such that the ministerial decrees might be amended with science underpinning the decision-making process.

After the current decrees came into effect and puerulus collection became illegal, and the grow-out sector completely collapsed. The effects were both direct and indirect. Direct effects included the loss of jobs and associated income; and indirect effects included difficulty paying school fees, increased crime, an increase in the number of backyard loan sharks and middle persons losing money they had invested in crops that are now illegal

(Sugama, 2015). As a consequence, in mid-2017, the central government under the management of the Directorate-General of Aquaculture launched a bailout programme for ex-grow-out farmers and ex-puerulus fishers who were affected by the new lobster regulations.

The total funds provided by the government for the bailout was 3,750,000 USD. In the first stage, the bailout programme covered as many as 2,500 ex-grow-out farmers and puerulus fishers in Lombok alone. Each person was allowed to choose the type of aquaculture they wanted to pursue to provide them with an alternative livelihood (i.e., in general terms, forms of freshwater, brackish water or marine aquaculture). In addition, the bailout provided fish seed, feed, nets, and boats and so on to a total of 1,500 USD per recipient. The government also provided technical farming consultancy, training and monitoring. The bailout recipients had to sign an agreement to cease their puerulus collection and lobster grow-out activities (Priyambodo et al., 2017a). However, observations during this study suggest that the bailout programme has not completely stopped puerulus fishing; in many places in Lombok, collectors are still operating, and a black market has become established.

Based on direct observations, although the ban has made puerulus collection and export illegal, the black market has become lucrative for those willing to participate. Ironically, the number of pueruli caught has increased substantially as a result of illegal fishing and new sources of puerulus became broader, from Lombok to Sumbawa, South-East Sulawesi, Java, and Aceh (Priyambodo & Bahrawi, 2016a). However, the major benefit of the puerulus resource now goes to what locals call the ‘puerulus mafia’. Puerulus fishers receive less benefit than they did before as the price of caught pueruli has plummeted because black market actors control pricing. The authorities continue to catch and arrest puerulus fishers, middle persons, smugglers and the people controlling them, but the black market continues at the time of writing.

2.3.3.2 Re-focus on lobster grow-out development in Indonesia

The reduction in lobster grow-out was an unexpected negative consequence of the improved puerulus fishing techniques introduced from Vietnam. Although puerulus fishers' preference for catching and selling puerulus and avoiding the risks associated with grow-out is understandable, this reduces the potential for the income from higher-valued, market-size lobster to be distributed throughout the community. Concern over this development was highlighted at the International Spiny Lobster Aquaculture Symposium and the Industrial Workshop held in Lombok, Indonesia, 22–25 April 2014, at which both local and national government representatives raised the prospect of banning puerulus export to retain the full value of the resource for Indonesia.

Indonesian spiny lobster aquaculture, particularly the grow-out sector, is currently in rapid decline. However, providing appropriate production technology and facilitating its adoption may lead to farmers being more likely to on-grow the pueruli caught, maximising domestic economic benefits. Additionally, engagement of large-scale investors that participate actively in the development of a grow-out sector and create farming job opportunities is likely to secure the future of Indonesian spiny lobster farming. Investor driven large-scale farms may stimulate industry growth, providing a foundation for further development. To date there have been no large-scale farms involved in the development. Further, policy change is urgently required to allow this to occur; without it, future development of this industry will stall.

2.3.4 Economic Benefits

2.3.4.1 Puerulus collection

As lobster puerulus fishing in Indonesia is a nascent industry, reliable data on the industry's production and value are not yet available. Based on an ACIAR puerulus census reported by Bahrawi et al. (2015b), between 2009 and 2012 the annual number of pueruli caught in Lombok remained relatively stable at 600,000 per year. In 2013, the number of pueruli caught increased dramatically. This was 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. Increased catch is also attributable to increased effort, with many more fishers engaged in lobster puerulus fishing since early 2013. The total puerulus catch in Lombok for 2013 was in excess of 3 million pueruli (Bahrawi et al., 2015b). The increased puerulus catch also presented increased opportunity for export to other countries where lobster pueruli were in demand for established lobster farming operations, particularly Vietnam (ABLobster, 2015).

P. homarus and *P. ornatus* together account for >99% of pueruli caught in Indonesia. The species composition appears to fluctuate between years: for example, in 2012, 63.27% of pueruli were *P. homarus* and 36.73% were *P. ornatus*, whereas in 2013, *P. homarus* represented 86.65% and *P. ornatus* was 13.35% of the catch. In 2014, the proportions of *P. homarus* and *P. ornatus* were 79.26% and 20.74, respectively. This variability is likely caused by the strong correlation between oceanographic conditions and puerulus numbers (Dao et al., 2015).

Prices for individual *P. homarus* pueruli in Lombok are shown in Figure 2.15 for each month of each year from January 2009 to April 2014. The graph shows that the price from 2009 to 2012 was quite stable at 2,500–5,500 IDR (equivalent to 0.21–0.50 USD) each. In April–May 2013, the price decreased dramatically from 5,500 IDR (0.46 USD) to 2,000 IDR (0.21 USD) because of the increased supply of puerulus. However, from June 2013 to April 2014, the price progressively increased to 16,000 IDR (1.34 USD) as export demand increased. Moreover, price and demand in 2015 continued to increase compared with previous years. The peak price reached was 2.18 USD or 29,000 IDR per puerulus in July. The price tends to increase slightly in June – August due to the high pueruli demand from overseas, especially from Vietnam, where the domestic pueruli supply experiences a low season.

Similarly, the price for *P. ornatus* pueruli was quite stable from 2010 to early 2013 (Figure 2.16) at 4,000–8,000 IDR each, but has since trended upwards, to 18,000 IDR in April 2014. Although *P. ornatus* represents a relatively small proportion of captured pueruli compared to *P. homarus*, it fetches a higher premium than does *P. homarus* because it is perceived to be a more valuable species. In Asia, *P. ornatus* has a strong market demand particularly in Chinese and Hong Kong markets. The stronger colour and bigger market size of *P. ornatus* are preferred by Chinese consumers (Hart, 2009). The occasional events, such as Chinese New Year and Lucky Day, require this kind of species for the cultural celebration. The potential revenue gain from this resource based on the available data for Lombok from 2013 to 2015 is shown in Table 2.3. The basic components required to create a unit of puerulus fishing sea-raft are presented in Table 2.4.

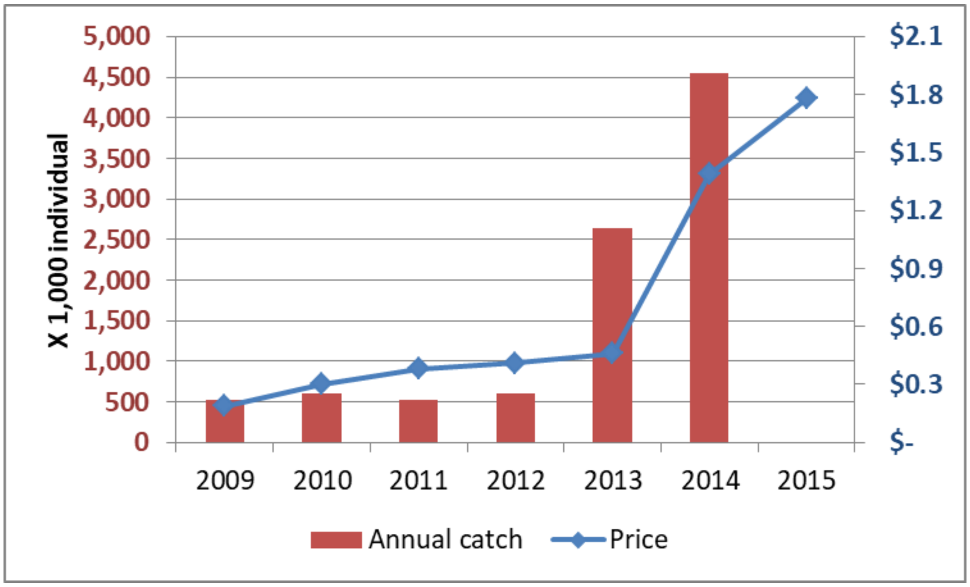

Figure 2.15. Annual price and catch for *P. homarus* lobster pueruli 2009-2015 (no available annual data catch for 2015)

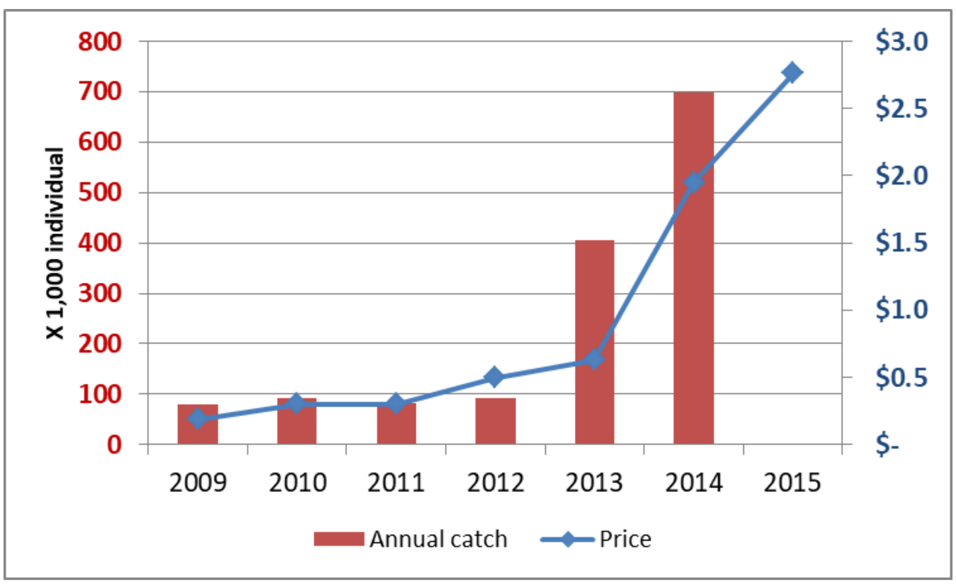

Figure 2.16. Annual price and catch for *P. ornatus* lobster pueruli 2009-2015 (no available annual data catch for 2015).

Table 2.3

Potential Revenue from the Lobster Puerulus Trade in Lombok 2012–2014

Species	**Year**	**Total no. pueruli**	**Price (USD) per puerulus**	**Total revenue (USD)**
P. homarus	2012	440,684	0.4	178,388.88
	2013	2,646,886	0.15–0.74	1,588,132
	2014	4,364,068	0.85–1.8	5,891,491.3
P. ornatus	2012	255,861	0.37–0.55	117,691.1
	2013	407,783	0.15–0.74	244,669.8
	2014	879,819	1.8–3.0	1,891,611.6
Total				9,911,984.68

Table 2.4

Basic Components of a Single Puerulus Fishing Sea-raft with Lights

No	**Description**	**Volume**	**Unit cost (USD)**	**Total cost (USD)**	**Expiry (years)**
1	Sea-cage construction (4 frames of 3 × 3 m)	1	450	450	5
2	Collectors	6	12	72	1
3	Simple boat with engine	1	450	450	5
4	Generator set	1	120	120	2
5	Lights	6	3.75	22.2	0.3
Total				1,114.5	

2.3.4.2 Grow-out

In parallel with the increased lobster puerulus fishing effort and catch, there was a collapse in grow-out of lobsters as the participants focussed all their attention on puerulus catching. Because the grow-out industry has been shut down, lobster farming is no longer creating economic benefits for people in Lombok. However, prior to its closure, a study in which the candidate was involved (see Petersen et. al., 2015) suggested that lobster farming is a reliable alternative livelihood for Indonesian fishers. Results of the analysis of survey and interview data showed that grow-out farming was conducted in earnest for around 7 years. Puerulus collection was demonstrated to be a lucrative industry, with average returns to a collector of around 51 million IDR (5,900 USD) per year and a return on investment of approximately 4.1:1. Grow-out aquaculture of lobster is less lucrative, providing around 16 million IDR (1,780 USD) per year with returns to the investment of around 1.67:1.

Beside the current regulations, the other main constraints to the development of the lobster grow-out industry in Indonesia are price and availability of pueruli/seed and credit. Farmers feed lobster largely on low-value finfish, the majority of which they catch themselves at minimal cost. Although manufactured diets are not yet available to Indonesian grow-out farmers, they generally indicate a willingness to trial them. A scenario analysis of a range of potentially improved diets (see Petersen et.al, 2015) indicated that manufactured diets are likely to significantly improve returns on investment for farmers, possibly increasing the Benefit Cost Ratio (BCR) to 2:1 or even higher if the diets are also functional feeds which can be added new ingredients or more of existing ingredients. It is necessary to promote pelletised lobster feed to grow-out farmers as it offers an ideal feed.

2.3.5 Research for Development

To address obstacles to further development of lobster farming in Indonesia, more research is required so that it can reach its full potential, emphasising technology transfer and understanding of socio-economic drivers and roadblocks. The decreases in lobster grow-out can and must be reversed to effectively capitalise on the rich lobster seed resource in Indonesia. This will require definitive lobster production technology that is both appropriate for the lobster species available and to the smallholders involved.

Indonesia should manage or regulate the export of pueruli to facilitate greater grow-out production within the country for export of premium market-size lobsters (Jones et al., 2015). Further research will lead to improved capture methods, better handling and transport to maximise the quality and rigour of pueruli, and enhanced culture practices to maximise survival and growth through the nursery phase. Ultimately, this should allow a greater return for each puerulus caught.

Activities aimed at developing the lobster farming industry should look beyond puerulus fishing locations and include engagement with existing sea-cage aquaculture operations throughout Indonesia to encourage their involvement in lobster farming; identification of optimal lobster grow-out locations across the entire archipelago; and marketing of the business credentials of lobster aquaculture to attract corporate investment. The disciplines, objectives and priorities for research and development are presented in more detail in Table 2.5.

Table 2.5

Further Research and Development Required for the Establishment of Indonesian Spiny Lobster Aquaculture

No	Disciplines	Objectives	Priority
1	Biology	Improve production, survival and growth	1
	Nutrition	Increase productivity and feed efficiency	
	Husbandry	Increase production in terms of survival and growth rates	
	Fisheries (puerulus collection technology)	Assess across Indonesia	
		Improve collection techniques including collector designs, types, depths, materials, crevice angles, lunar phase and other environmental factors influencing settlement behaviour	
2	Economics	Robust economic models as collateral for finance	2
	Social science	Understand social factors in engaging more people	
	Technology adoption	Provide better extension and dissemination	
3	Policy	National plan for lobster farming development	3
	Planning	Identify grow-out locations with full support	
		Control export of juveniles	
4	Disease	Identify key health and disease issues	2
		Develop mitigation strategies	
		Develop treatments	
5	Training and education	Knowledge and capacity at community level	1
6	Marketing	Improved market access	2
	Product development	Increased farm-gate price	
		New products to meet markets	

2.4 Summary

This chapter presented the status of Indonesian spiny lobster aquaculture development since its inception. It provided an insight into the opportunities for and threats to business segments in spiny lobster farming. Improving the capacity building of spiny lobster grow-out farmers is one of the key factors that will drive the success of Indonesian lobster farming. This can be done via improved education, training and dissemination of information. Government support in regard to policies is necessary to sustain the development of spiny lobster aquaculture. Creating an appropriate business atmosphere for investment in spiny lobster farming will contribute to the realisation of a viable and sustainable industry.

This chapter has highlighted the economic role of spiny lobster farming and its related activities, which need to be sustained and enhanced to support continued development. It also demonstrated the necessity of transferring technology from Vietnam, a global supplier of farmed lobster, to enhance the sustainable development of an Indonesian industry and to provide job opportunities for impoverished rural communities. In addition, the engagement of large-scale farms that participate actively in the development of grow-out sectors and provide job opportunities is likely to play an important role in the success of the development of Indonesian spiny lobster aquaculture.

Unless the current lobster regulations are changed, the country is going to lose the opportunity to gain significant potential economic value from national spiny lobster aquaculture production. Findings discussed in Chapter 4 support this assertion, and there is now anecdotal information that other countries will attempt to fill the supply gap created by the legislation. Scientific studies have shown that Indonesia can successfully supply pueruli without causing any environmental impact (Phillips et al., 2003a, Phillips et al., 2003b, Jones, 2005b).

Chapter 3: The Influence of Puerulus Collection Technology Transfer on Development of Lobster Farming In Indonesia

3.1 Introduction

This chapter reviews the requirements for developing Indonesian lobster farming technology by adopting Vietnamese's puerulus collection practices. This information leads to addressing of the first objective of this thesis: to determine the effects of puerulus collecting technology transfer on the development of lobster farming in Indonesia using Vietnamese practices. Further, this chapter addresses the following research questions: i) how can the adoption of new technology by Indonesian lobster puerulus fishers be improved? and ii) how effective is a study tour as a means to transfer technology?

Information presented in this chapter describes how Vietnamese lobster farming practices (including puerulus collection techniques) and knowledge were transferred through a comprehensive study tour made by a group of Indonesian lobster associates (Section 3.3.1). The participants' perceptions are presented in Section 3.3.2 and the outcomes of the transferred technology for the development of the lobster farming industry in Indonesia are outlined in Section 3.3.3. Finally, the status at the time of writing of the Vietnamese lobster farming industry, using imported Indonesian puerulus, is presented in Section 3.3.4.

Despite the great interest in developing spiny lobster aquaculture throughout the world, there remain very few examples of commercial production. The most significant lobster farming industry is that of Vietnam, which produces around 1,500 tonnes per year (Hung & Tuan, 2009; Jones, 2010; Phillips, 2013). The industry is reliant on a natural supply of settling pueruli, which in Vietnam are abundant and easily caught; some 3–5 million lobster pueruli are caught each year (Dao & Jones, 2015; Long & Dao, 2009). These are primarily *P. ornatus*, at around 75% of the total captured; the remaining 25% are *P. homarus* (Dao & Jones, 2015; Jones et al., 2010). To meet market requirements for export to Hong Kong, where they achieve high prices at wholesale markets, *P. homarus* are grown to around 0.5 kg over a period of 12–18 months, and *P. ornatus* are cultivated to around 1 kg over 20–24 months (Hart, 2009; Jones, 2015a).

Globally, the lobster farming industry comprises puerulus collection, nursery production and grow-out farms. Figures 3.1 and 3.2 depict aspects of the lobster farming industries in Indonesia and Vietnam, respectively. While Vietnamese lobster farmers and puerulus fishers use advanced methods, Indonesian farmers and puerulus fishers use very simple methods, as can be seen in the figures. In Indonesia the infrastructure and technology involved is somewhat more primitive than that in Vietnam, which has much more advanced techniques and infrastructure.

The Indonesian lobster farming industry was primarily focussed on *P. homarus*, which is the most abundant species caught as pueruli, and for which there is strong demand and prices through wholesalers in Bali. The lobster farming industry is village based, involving local farmers only, with no corporate investment. Lobster farming is characterised by relatively low input costs, simple technology and a high-value product (Jones, 2015a; Petersen & Phuong, 2010; Petersen et al., 2007). It provides a real opportunity to alleviate poverty in the poor coastal communities where it has developed (Hambrey et al., 2001), and this may be expanded to other parts of Indonesia. Nevertheless, it remains a very small industry producing <50 tonnes of market-size lobsters, worth <2 million USD per annum (Petersen et al., 2015).

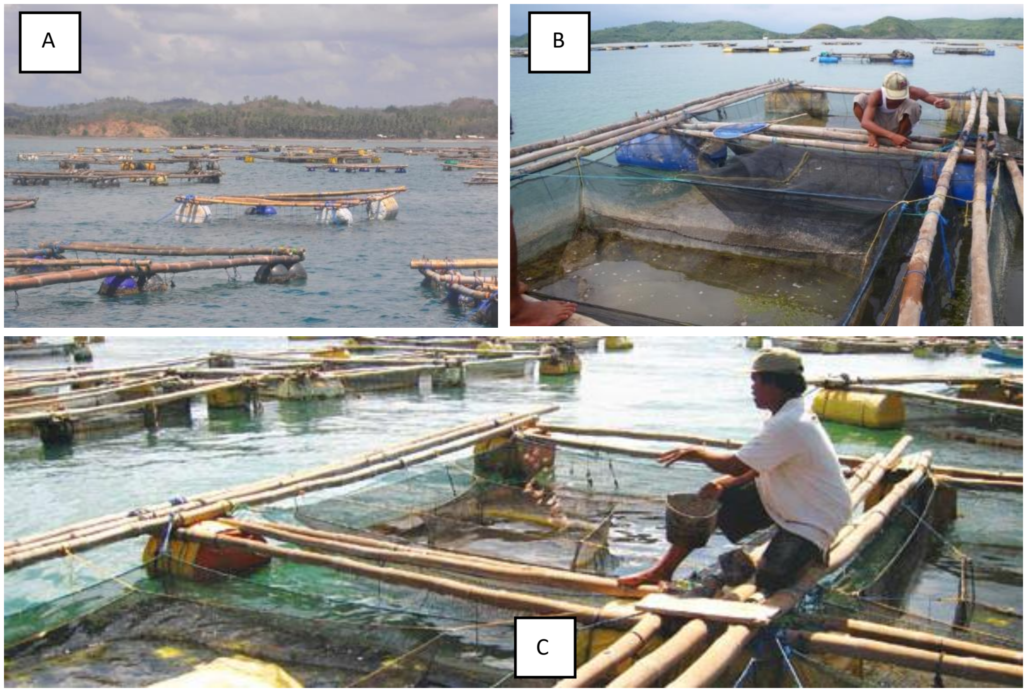

Figure 3.1. Common set-up used for lobster farming in Indonesia: (A) traditional puerulus fishing rafts without lights; (B) nursery cages; and (C) a typical simple grow-out cage with a farmer feeding his crop using trash fish, which is the main feed for farmed lobster

Figure 3.2. Common set-up for a lobster farm in Vietnam: (A) puerulus fishing tripod with electric lights; (B) sophisticated grow-out cages with living quarters for farmers; (C) round

cages used as puerulus nurseries, which has smaller mesh size, approximately 2mm. Therefore, it is an open system of cultivation where seawater can flow through the net.

A comparison of the Vietnamese and Indonesian lobster farming industries identifies some clear differences. Until recently, the catch of puerulus in Vietnam was in the order of 3–5 million (Tuan & Jones, 2015a), compared with 600,000 for Indonesia (Priyambodo & Bahrawi, 2012). Vietnam has more *P. ornatus* available and cultured, while Indonesia was primarily farming *P. homarus* (Petersen & Phuong, 2010, 2011; Petersen et al., 2015). There are many more cages in Vietnam, and the industry has established over a very broad geographic area (Hung & Tuan, 2009). Clearly, some of these differences can be attributed to the long history of the Vietnamese industry relative to that of Indonesia.

With its richer natural resources, and more extensive coastline compared with Vietnam, Indonesia should have a greater opportunity to develop lobster aquaculture (Jones et al., 2010; Priyambodo, 2015a). However, Indonesia has faced several constraints in developing lobster farming from the outset of this study, including dependency on puerulus availability, lack of knowledge of puerulus ecology—particularly where they settle—lack of hatchery supply and low survival rate from puerulus to juvenile through the nursery and husbandry stages. Most significantly, lobster grow-out techniques in Indonesia were underdeveloped and farmer skill levels were, and continue to be, low (Priyambodo, 2013; Priyambodo & Jones, 2015). In light of this, the ACIAR established research and development project SMAR/2008/021 'Spiny lobster aquaculture development in eastern Indonesia, Vietnam, and Australia' to assist with spiny lobster technology transfer to Indonesia through a comprehensive study tour to Vietnam in early 2013, when this study begun. The key to success of development, dissemination and adoption of improved technologies for smallholders depends on more than careful planning of research and the use of appropriate methodologies in extension (Cramb, 2003). The approach of ‘technology transfer’ through training and the visit system method was promoted extensively by the World Bank in the 1970s and 1980s (Antholt, 1998).

Appropriate Indonesian lobster farmers, puerulus fishers and other targeted participants travelled to Vietnam, with support from ACIAR, to gain practical knowledge for expediting lobster aquaculture development in Indonesia. It was projected that the study tour would have a substantial effect in regard to the improvement of puerulus catches and lobster farming practices. Accordingly, this chapter investigates whether the tour did indeed influence farmer perceptions about technologies that could be applied in Indonesia.

3.2 Materials and Methods

3.2.1 Materials

Materials used in this study included structured questionnaires (Appendix C) and recording forms. Also, to aid the process and minimise communication barriers, a translator fluent in both Indonesian and Vietnamese was employed to enable direct translation between Vietnamese industry personnel and study tour participants.

3.2.2 Methods

Study tours used to provide information sharing, knowledge exchange and practical exposure to agriculture and aquaculture development industries have been successfully and widely promoted (Anonymous, 2012; Chang, 2015; Cummins et al., 2011; Davis et al., 2016). For example, study tours were used to assist project participants in addressing a range of technical and socio-economic constraints to development, adaptation and adoption of conservation farming systems across northern Africa (Cummins et al., 2011). A study tour was also organised to a cage culture site in Malta for staff members of the Food and Agriculture Organisation (FAO) Aquaculture Service, the FAO Fishing Operations, and Technology Service to obtain first-hand experience (Anonymous, 2012). The Malta study tour provided technical and practical exposure to capture-based cage mariculture and its complexities, as well as information related to the operation of vessels in support of offshore mariculture activities (Anonymous, 2012).

In the current study, various methods were used to investigate Vietnamese techniques of lobster farming during the study tour. The learning method was designed to be comprehensive, ranging from learning by field visits, practising, class meetings and daily discussions. Participants were expected to experience significant learning during the study tour. Participants were interviewed with a structured questionnaire at the beginning of the study tour and immediately after it finished. The initial questionnaire aimed to gather general information and background of each participant relating to their role and their basic knowledge of lobster farming, including lobster puerulus collection, nursery techniques and the grow-out phase. The end-of-study-tour questionnaire was designed to collect data on participants' perceptions about Vietnamese practices and whether they might adopt and adapt particular techniques they learned.

The selected participants were from two main backgrounds: puerulus fishers and grow-out farmers. The number of surveyed participants was planned to be equal and to include up to 30 people from each background. However, because puerulus fishing had become the main activity and grow-out farming was rare at the time of the study, equal numbers of participants from each background could not be achieved. Observations were conducted for up to 24 months and aimed to monitor how knowledge transfer from the study tour worked and how it influenced the performance of the spiny lobster aquaculture industry in Lombok and other parts of Indonesia. The effects of new techniques employed by study tour participants and other puerulus fishers or farmers were observed for a period that is no longer than 24 months, depending on how the industry was progressing. Observations covered the area of Lombok, Sumbawa and Java, as described in Chapter 4.

3.2.3 Study Tour Participants

Participants were selected from each institution involved in the ACIAR lobster project SMAR/2008/021. Puerulus fishers and grow-out farmers were also involved in the study tour. In addition, a representative from the local marine and fishery affairs agency of Nusa Tenggara Barat Province (DKP Provinsi NTB) was invited to join the study tour because that institution has responsibility for undertaking extension on mariculture, including spiny lobster aquaculture. Their involvement in the study tour was a critical part of capacity building.

In addition to the core participants, the study tour group also comprised a tour supervisor from ACIAR, a translator and a tour leader from Nha Trang University in Vietnam, who managed all logistics and coordinated industry visits. To assist in measuring the effectiveness of the tour, an interview-based survey of participants was undertaken, including pre- and immediate post-tour interviews and a series of follow-up interviews. The learning approach used in this study was similar to that reported by Davis et al. (2016). The backgrounds of the study tour participants are provided in Table 3.1. The origin and number of study tour participants is shown in Figure 3.3. The main location of the study tour in Vietnam is shown in Figure 3.4.

Table 3.1

Background Information on Study Tour Participants

No	Profession	Number of participants	Experience with lobster (years)	Based at
1	Researcher	1	0	Research Institute for Coastal Agriculture, Maros Sulawesi
2	Aquaculture engineering	1	2	Lombok MADC
3	Aquaculture extension	2	15	Lombok MADC
			3	Takalar Brackishwater Aquaculture Development Center (BADC)
4	Aquaculture extension	1	0	DKP NTB
5	Postgraduate student	1	7	UNSW Australia (Lombok MADC)
6	Grow-out farmer and puerulus fisher	1	15	Lombok
7	Grow-out farmer and puerulus fisher	1	6	Pulo Aceh
8	Aquaculture technician	1	1	Takalar
9	Industry representative (Lobster aquaculture manager)	1	15	Lombok
Total		10		

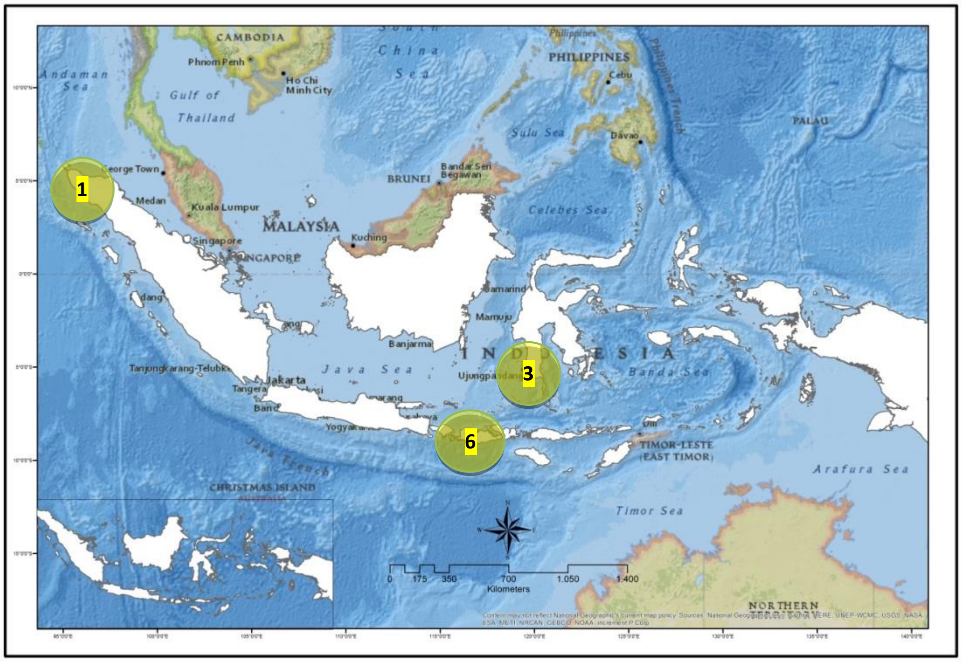

Figure 3.3. The origin and number of study tour participants

Figure 3.4. The main location of the study tour in Vietnam

3.2.4 Study Tour Main Venues and Programmes

To assist with the transfer of lobster farming technology and stimulate the expansion of lobster farming in Indonesia, a study tour was undertaken to Vietnam in March 2013. The programme was designed to expose the participants to all aspects of lobster farming from the capture of lobster puerulus through to grow-out. The programme of activities is summarised in Table 3.2.

Table 3.2

The Study Tour Programme

Date	Activity	Place
1 March 2013	Travel	Jakarta to Ho Chi Minh to Nha Trang
2 March 2013	Recovery and briefing Pre-tour participant survey	Nha Trang city
3 March 2013	Puerulus collection Interview puerulus fishers Q&A Lunch & discussion	Bai Tien village catching area 1
4 March 2013	Nursery farms Travel (boat) Inspect nursery farms Interview farmers Q&A Lunch & discussion	The nursing fams Bai Tien
5 March 2013	Grow-out farms Inspect grow-out farms Interview farmers Q&A Lunch & discussion	Cu Lao landing port; farm 1 Bich Dam (*P. ornatus*); farm 2 Hon Micu (*P. homarus*)
6 March 2013	Field trip Meeting with local fishers/farmers Travel (boat) Q&A Lunch & discussion	Van Ninh district of Xuan Tu village; farming area of Xuan Tu; Ran Trao MPAs; catching area Luong Son; tank facilities Bai Tien
7 March 2013	Lecture on lobster health and disease Travel Lecture & Q&A Lunch & discussion	Nha Trang University R&D Centre
8 March 2013	Visit fish-landing port Visit the Museum of Oceanography Post-tour participant survey/interviews	Cau Da landing port ION museum
9 March 2013	Travel, return to Indonesia	Origin cities of participants

3.2.5 Post-study Tour Impact Assessment

To measure the influence of the study tour (knowledge transfer and sharing), a series of surveys was conducted periodically every 6 months for up to 2 years. These surveys took place mainly in Lombok to observe any changes in the performance of puerulus collection and lobster grow-out. Key people such as puerulus fishers, heads of villages and middle persons were interviewed in the surveys. Surveys were also conducted in other provinces and islands such as Trenggalek and Yogyakarta (Java) and Sumbawa. The results of the surveys are presented in Chapter 4.

The data gathered were analysed using descriptive methods because of the low number of participants. A larger number of participants were not possible because of the high cost of this activity and the logistical challenges involved.

3.3 Results and Discussion

The study tour was performed without incident, and all participants were fully engaged and stimulated by the experience. The study found that the most informative statistic to use for comparing the two countries was the financial return to a farmer for every puerulus caught. In Vietnam, the return was on average 65 USD per puerulus, while in Indonesia it was just 3 USD. The primary reasons for this were a higher survival rate from puerulus through to market size, faster growth rate, larger harvest size and higher value species of *P. ornatus* in Vietnam. The much better return per puerulus in Vietnam was in part due to a much higher puerulus price, which was >7.85 USD per puerulus captured in Vietnam, and <2.36 USD in Indonesia. A summary of spiny lobster industry statistics for Vietnam and Indonesia was prepared from the data gathered and is presented in Table 3.3.

Table 3.3

Lobster Farming Industry Statistics for Vietnam and Indonesia

Parameter[1]	**Vietnam**	**Indonesia (Lombok)**
Annual puerulus supply	2–5 million The peak season is from November to March (it is different in time frame compared to Indonesia's pueruli catch season).	600,000 (2008–2012)
Annual production of live lobster	>1,000 tonnes	20–25 tonnes (before 2012)
Number of sea-cages	35–50,000	2–3,000
Puerulus price (each)		
P. homarus	$2.00–$2.40	$0.20–$0.60
P. ornatus	$5.00–$7.50	$0.40–$0.70
Market price per kg		
P. homarus	$50–$60 (400–500 g)	$35–$40[2] (100–200 g)
P. ornatus	$80–$120 (1 kg)	
Lobster food price per kg		
Acetes shrimp	$1.50	$2.50
Baby crabs	$0.95	Not available
Trash fish	$0.70–$1.00	$0.10–$1.50
Grow-out duration (months)		
P. homarus	12–15	8–10[2]
P. ornatus	18–20	
Survival rate		
P. homarus	80–90%	20–50%[2]
P. ornatus	70–80%	
Food conversion ratio		
P. homarus	15	25–30[2]
P. ornatus	15–25	

[1] All prices are given in USD

[2] Lobster species in Indonesia are not distinguished for marketing or production, so figures are provided for both species combined

3.3.1 Knowledge Transfer During the Study Tour

Based on the observations, field visits, discussions and class tutorials during the study tour, key important aspects of the success of Vietnamese spiny lobster farming techniques were as described below. The methods described in the following sections apply to the both species of *P. ornatus and P. homarus.*

3.3.1.1 Puerulus collection techniques

In Vietnam, the catch of puerulus is primarily achieved with a set of seine nets. More than 90% of local pueruli available are caught with the net. The remaining 10% are caught using collectors. There is some fishing of settled juveniles using collectors, but such juveniles are less valuable because their survival through handling and transport is lower. Study tour participants were introduced to and taught four puerulus fishing methods: 1/ seine nets in combination with electric lights; 2/ collectors made of old nets (used net); 3/ collectors made of perforated coral or timber; and 4/ diving and catching. Each method has specific characteristics and standard operating procedure as follows.

3.3.1.1.1 Seine nets in combination with electric lights

The most common method for fishing of swimming pueruli involves the use of seine nets, typically 100–150 m in length with a depth of 4–6 m and mesh size of 5 mm. The nets are set from boats in a V-shaped deployment with an opening of around 25 m. This method is illustrated in Figure 3.5. The opening of the seine faces the direction in which the pueruli swim. The direction of swimming is determined by observation and knowledge, and is typically in a southerly direction against the north-flowing current that eddies from the predominantly 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. Factors that appear to be associated with greater abundance and catch of pueruli include a narrowing of the sea within a bay or between a mainland and island, and turbid water caused by river flows into an area.

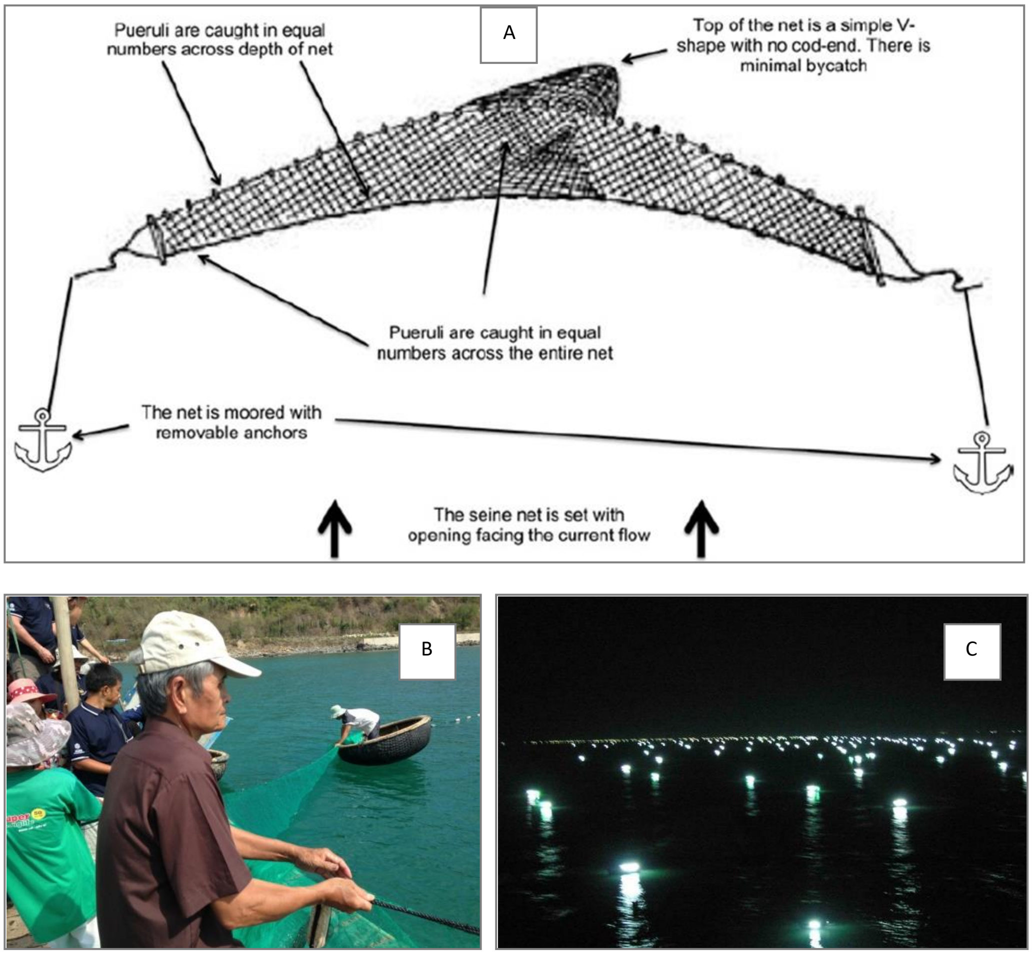

Figure 3.5. Illustration of seine net (A and B) used in combination with electric lights (C) as used for capture of lobster pueruli in Vietnam

The boat used in the setting of the net is equipped with strong fluorescent lights with an intensity of 1,000–2,000 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.

The seine net is usually set at around 8 pm and the first retrieval is made at around 12 pm–1 am. At this time, the net is pulled into the boat to retrieve the lobster pueruli that have become caught in the mesh. Shortly afterwards, the net is re-set and at around 4 am it is pulled in a final time. The nets are not set during daylight hours because catches at that time are very low in accordance with the nocturnal swimming activity of the puerulus stage. The collected lobster pueruli are consistent in appearance with a transparent body, CL of 7–8 mm and a weight of 0.25–0.35 g.

3.3.1.1.2 Collectors made of old nets (used nets)

The net collector used to trap juvenile lobsters consists of a bundle of netting material created by tying several lengths of fine 5-mm-mesh-size net into a rosette with a diameter of approximately 40 cm. These collectors are submerged at depths of 4–5 m. The fishers retrieve the net collectors at intervals of 3–5 days, usually in the morning; removing lobster juveniles by shaking the collector into a scoop net. The lobster stage caught with this collector type is typically pigmented juveniles that have moved past the puerulus stage and settled to a benthic existence. Pueruli have a CL of around 7.5–10 mm and a weight of 0.3–1.0 g. The season for this puerulus fishing method extends from December to the end of June, after which the collectors are removed and stored ashore in a cool place for the next season. A collector made of old net is shown in Figure 3.6.

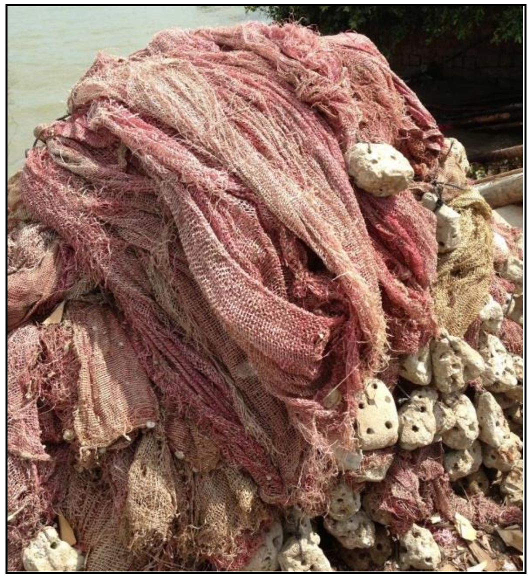

Figure 3.6. A collector made of old nets (used nets)

3.3.1.1.3 Collectors made of perforated coral, timber or rubber

Some collectors 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 used weighs 2–5 kg and has a diameter of 25 cm. Holes are drilled into the rock at 10–15-cm intervals; each hole is 5–10 cm deep with a diameter of 1.0–2.5 cm. Timber pole collectors are created in an equivalent manner. The poles are usually 2–3 m in length with a diameter of 10–15 cm.

Coral rocks are placed on the sea floor and timber poles are embedded vertically into the sediment in 3–5 m of water. Juvenile lobsters are retrieved by diving and manually removing them from the holes. In some instances, these collectors are suspended from a fixed floating raft or from a longline supported between floating tripod frames. The tripods facilitate the use of electric lights, which enhance catch rates. This method catches pueruli of the same size as the net collectors. Examples of collectors made of perforated coral and rubber are shown in Figure 3.7.

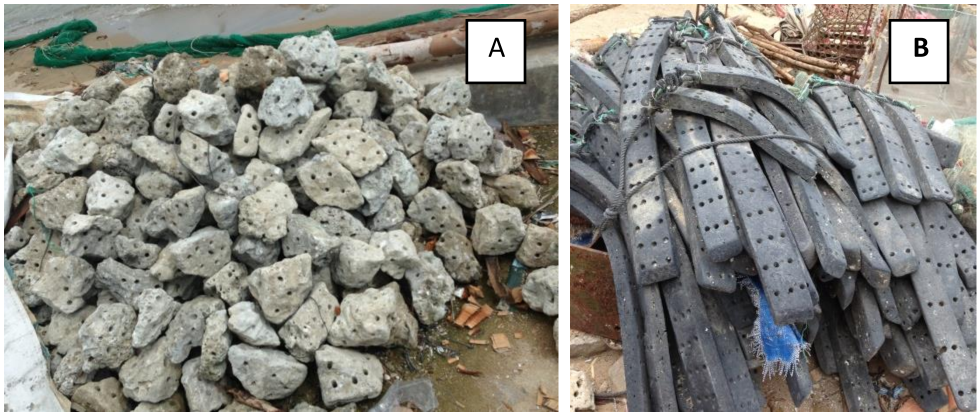

Figure 3.7. Puerulus collectors made of perforated coral (A) and rubber (B)

3.3.1.1.4 Diving and catching

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

3.3.1.2 Nursery farming

There are several key important procedures involved in conducting puerulus nursery farming in Vietnam. These are site selection, cage design, stocking and husbandry as described below.

3.3.1.2.1 Site selection

The nursery site is one of the most important factors to be considered. The ideal location for a nursery farm is one that is unaffected by flooding and discharge from upstream factories, agricultural activities, strong winds and waves; but with relatively strong tides and bottom flows that are reflected in a hard sea-floor. It is also better to choose sites that are close to puerulus where possible, and feed supplies. The water should have salinity of 30–35 parts per thousand, a minimum depth at ebb tide of 1.5 m and a sea floor that is sand or silty sand with or without small corals and mollusc shells. In addition, locations that offer shelter from typhoons and easy access by any means of transports are considered important.

3.3.1.2.2 Cage designs

There are three commonly used cage designs:

- submerged cages ranging in size from 0.7 × 0.8 × 1 m to 3 × 2 × 2 m
- fixed cages of various sizes: 0.7 × 0.8 × 1 m; 1 × 1 × 1.2 m; 1.5 × 1.5 × 1.2 m; 2 × 2 × 1.2 m; 3 × 3 × 2 m and 3 × 2 × 2 m
- floating cages consisting of rectangular cages of various sizes, including 0.7 × 0.8 × 1 m; 1 × 1 × 1.2 m; 1.5 × 1.5 × 1.2 m or 2 × 2 × 1.2 m; 3 × 3 × 2 m; 3 × 2 × 2 m, and round cages with a diameter of 0.8–1 m. The round cages facilitate a higher survival rate as the nursed pueruli are not gathered into a corner but are evenly distributed around the sides of the cage (Figure 3.8).

Figure 3.8. Round puerulus nursery cages (Nha Trang Bay, Vietnam)

3.3.1.2.3 Stocking

Stocking includes the activities of puerulus selection, transportation and adjusting of stock density.

3.3.1.2.4 Puerulus selection

Chosen pueruli have all body parts intact and are of a natural bright colour. A healthy puerulus has strong swimming ability. They should be of similar size; with priority given they should have all their body parts intact.

3.3.1.2.5 Transportation

Pueruli and juveniles are transported in seawater that is continuously aerated and housed in polystyrene foam boxes. For long transport distances requiring more time, more sophisticated handling and packaging is applied. Typically, 100 pueruli are placed into a 1 litre plastic bag filled with 500 ml of oxygenated seawater. Up to 10 plastic bags with 100 pueruli in each are then placed into a Styrofoam box. The temperature in the box is maintained at 25 to 26ºC by placing two frozen, water-filled plastic bottles that are positioned among the plastic bags. The seawater in each bag is isolated from any melted ice, so salinity is not affected. Upon arrival at the culture area, the bags containing the pueruli are typically acclimated to ambient conditions by floating them in the local culture water for 1 hour, before the pueruli are released. During this time, local seawater is mixed with the water in the polystyrene foam box to enable the lobsters to adapt gradually to their new environment.

3.3.1.2.6 Stocking density

First, a random sample of 15–20 lobsters is selected to determine the average weight of the catch. From this, an estimate of the total initial weight of the catch is made. The weight data are used to estimate the daily feeding rate based on the percentage biomass. The lobsters are then released into the nursery cage at a density of 50–60 animals per cubic metre.

3.3.1.2.7 Husbandry or nursery phases

Juvenile lobsters are fed daily on fresh acetes shrimp, chopped shrimp/crab, or clams/oysters and fish. The ration of feed for juvenile lobsters in the first 30 days is 15–20% of the total initial biomass. On the 15th day after stocking, a sample of lobsters is weighed to determine mean weight and survival rate. This is repeated monthly, to adjust the feed amount. For days 30–60, the food intake is increased to 20–25% of the total biomass.

After 60 days of rearing, the density is reduced by using additional cages to 15–20 animals per cubic metre. After 90–100 days of rearing, the density is reduced further to 12–15 animals per cubic metre. After 120 days of rearing, lobsters are of a size suitable for transfer to out-growing cages. Cages are monitored on a daily basis to check the status of lobsters, feed utilisation and the cage itself. Cage maintenance and cleaning is carried out weekly.

3.3.1.3 Grow-out farms

The juveniles generated from nursery production are stocked into small grow-out cages with fine mesh. The first phase of grow-out is in a cage of size 1.5 × 1.5 m, stocked with around 120 pieces. These are on-grown and progressively graded and moved into larger cages with a larger mesh as it provides better water flows and oxygenation. At harvest, a typical cage is 4 × 4 m with a stock of 60–80 lobsters up to 1 kg each in size (maximum biomass of 5 kg/m^2).

Lobster grow-out practices involve standard operation procedures in regard to site selection, cage design, husbandry, feed type and feeding practices, and harvest.

3.3.1.3.1 Site selection

Farming sites are usually selected in bays or straits satisfying the following requirements:

- well away from rivers to avoid the influence of freshwater
- areas minimally affected by storms and big waves
- water not affected by wastewater from residential and industrial activities and agriculture
- a location with high water exchange provided by relatively strong tides and currents, and where the sea floor has low organic matter
- water at least 3–5 m or 6–8 m deep for fixed cages and floating cages, respectively.

3.3.1.3.2 Cage designs

Cages are designed in various ways depending on the characteristics of the culture area and the farmer's financial circumstances. The three common cage designs are as follows.

Submerged cages (Figure 3.9)

The frame is made from iron rod with a diameter of 15–16 mm. The bottom is rectangular or squares with an area normally 1–16 m^2. The most common specifications are between 2 × 3 × 1 m and 3 × 2 × 1.2 m. The cage is fully enclosed with feeding pipe that extends to the sea surface. This kind of cage is also common for nursing juvenile lobsters. The materials for making cages are locally available, such as wood, iron and net.

Figure 3.9. Submerged grow-out cages with the dimension of 2 x 3 x 1.2 m and 3 × 2 × 1.2 m (Nha Trang, Vietnam)

Fixed wooden cages (Figure 3.10)

The frame of these cages is made of salt-resistant wood. Wooden stakes of 10–15 cm in diameter and 4–5 m in length are embedded every 2 m to create a rectangular or square shape. The basal area is normally 20–40 m^2 but may be as large as 200–400 m^2. The cage size also varies between 4 × 4 × 3 m and 6 × 6 × 5 m. Each cage normally has a cover. The cage may be on or off the seabed. A fixed, off-bottom cage is positioned about 0.5 m above the seabed. A fixed, on-bottom cage is lined with a layer of sand. This kind of cage is suitable for sheltered bays and behind islands where there is shelter from big waves and typhoons.

Figure 3.10. Typical wooden fixed grow-out cages set in relatively shallow water compared with floating sea-cages (Nha Trang, Vietnam)

Floating sea-cage (Figure 3.11)

Floating sea-cages comprise a rectangular net, typically supported by a frame with buoys. The common floating cage sizes are between 4 × 4 × 6 m and 4 × 4 × 8 m. Farms employing floating cages are commonly located in deeper water with a depth of 20–30 m. The summary Table Comparing Different Cage Styles Used to Cultivate Spiny Lobster in Vietnam is presented in Table 3.4.

Figure 3.11. Floating grow-out cages made of timber with plastic drums as floaters, complete with temporary shelters for farmers (Vu Ngan Bay, Nha Trang Vietnam)

Table 3.4

Summary Table Comparing Different Cage Styles Used to Cultivate Spiny Lobster in Vietnam

Descriptions	Cage Styles		
	Submerged cages	Fixed wooden cages	Floating cages
Frame materials	Steels	Woods	woods/bamboos
The most common sizes	2 × 3 × 1 m and 3 × 2 × 1.2 m	4 × 4 × 3 m and 6 × 6 × 5 m	4 × 4 × 6 m and 4 × 4 × 8 m
Purposes	nursing juvenile and growing out lobsters	growing out lobsters	nursing juvenile and growing out lobsters
Water depth characteristic requirement	10-15 m	5-6 m	deeper water, 20-30 m
Net mesh size	Nets to cover frame have a mesh size of 3-4 cm	2.5 cm	2.5 – 5 cm

3.3.1.3.3 Husbandry

After around 4 months of grow-out rearing, juvenile lobsters have typically reached a size of 30–50 g. At this stage, they are graded to create uniform size groups and then stocked into out-growing cages at a density of 5–8 animals per cubic metre. Lobsters are fed daily on a variety of fresh seafood including shrimp, crab, fish, clams, oysters and starfish. The food is partially processed to remove parts that cannot be eaten by lobsters, for example the hard shells of molluscs and crustaceans, and then chopped into small pieces. The daily feed ration is ~10–17% of the total biomass, depending on the type of food (hard shelled or not) and stage of development. Generally, the percentage of biomass is progressively reduced over the production cycle. Small lobster (<200 g) are typically fed once or twice a day, while larger lobster (>200 g) are fed only once per day. Feeding is done in the evening when lobsters are most active, as per their habit in the wild.

In the final months of the production cycle, the proportion of shellfish including molluscs and crustaceans in the feed should be increased to around 70%, and that of finfish reduced to around 30%. Daily monitoring of lobster health status and removal of leftover food and molted shells from cages is recommended. Periodic cleaning of cages with a high-pressure hose to remove bio-fouling is recommended to prevent obstruction of water exchange. Lobsters are sampled and weighed every 3 months to provide estimates of the total biomass for adjusting the feed ration. When lobsters reach a weight of 500–600 g, the density is reduced to 3–4 animals per cubic metre. After 20–30 months of farming, lobsters of *P. ornatus* can be harvested. Farmed lobster of *P. homarus* can be harvested earlier after 12-16 month of farming.

3.3.1.3.4 Feed and feeding practices

Feed

The preferred feed for lobsters is lizardfish (*Saurida* spp.), red bigeye fish (*Priacanthus* spp.), swimming crab (*Portunus pelagicus*) and shrimp (*Panaeus* spp.), which have high protein content (Table 3.5). Finfish comprises around 73% of the diet, with the remaining 27% being shellfish. The preferred fish (comprising 46% of fishes in the diet) is lizardfish. However, because of the high price of crustacea and finfish, farmers have tended recently to use more molluscs in the spiny lobster diet.

Table 3.5

Composition of Fishes and Shellfishes Commonly Used for Lobster Farming (Based on Proximate Analysis)

Composition		Moisture	Protein (DM basis)	Lipid (DM basis)	Ash (DM basis)	Carbohydrate (DM basis)
Molluscs	Arc clam (*Arca* spp.)	83.8	54.3	2.5	24.7	18.5
	Clam (*Spisula* spp.)	82.9	76.7	10.7	10.8	0.4
	Squid (*Mastigotheutis* spp.)	80.0	76.9	7.4	9.9	0.1
Crustaceans	Shrimp (*Panaeus* spp.)	75.5	81.2	2.0	7.8	9.0
	Swimming crabs (*Portunus* spp.)	80.0	84.1	6.2	4.6	0.3
Finfish	Lizardfish (*Saurida* spp.)	74.8	68.7	10.3	14.7	6.3
	Red bigeye fish (*Priacanthus* spp.)	74.7	64.0	6.7	21.0	8.3

Table 3.5 (continued)

Composition		Moisture	Protein (DM basis)	Lipid (DM basis)	Ash (DM basis)	Carbohydrate (DM basis)
	Ponyfish (*Leiognathus* spp.)	74.6	51.6	7.9	25.4	15.1
	Anchovy (*Engraulis* spp., *Stolephorus* spp.)	75.7	61.3	6.6	12.9	19.2

3.3.1.3.5 Feeding practice

All types of current feed including molluscs, crustaceans and trash fish are given in mixed form with proportions recorded in Table 3.6 for each size group of spiny lobster. In practice, depending on availability, each kind of feed is given individually provided that the proportions are similar. For example, after 2 days of feeding trash fish, the following day the feed should be crustaceans and/or molluscs, for lobsters of size 30–700 g. The major proportions of lobster feed types used in Vietnam in 1998 and in 2008 are presented in Figure 3.12. The figures show that the feed composition was changed over the time, where crustacean was gradually no longer used.

Table 3.6

Current Feed, Feeding Regime and Ratio by Lobster Size

Lobster size (g)	% Feed ingredients (range)	Feeding regime (times per day)	Ratio (kg/100 pieces/day)
<30	Finfish: 11, chopped Molluscs: 33, chopped Crustacea: 56, chopped	1–2	0.4 (0.1–1)
30–200	Finfish: 67, chopped Molluscs: 16, chopped Crustacea: 17, chopped	1–2	2.5 (1–4)
200–700	Finfish: 67, whole Molluscs: 16, chopped Crustacea: 17, chopped	1	3.5 (2–7)
>700	Finfish: 27, whole Molluscs: 46, chopped Crustacea: 27, chopped	1	4.5 (3–9)

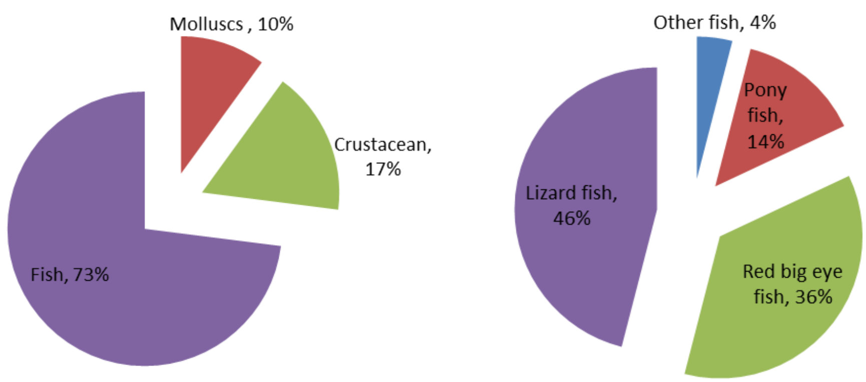

Figure 3.12. Relative proportions of food type for farmed lobsters in Vietnam in 1998 (left) and 2008 (right)

3.3.1.3.6 Harvest

Live-harvested lobster is the main goal of lobster farming as it achieves the highest premium price. Lobsters can be harvested selectively (individually) by a diver, or the whole cage contents may be taken. Selective harvesting is used when the lobsters are of different sizes. Only market size lobsters are harvested, by diving and using a scoop net. Whole harvest is conducted only when the lobsters are of a uniform size and market prices are high or when a storm is coming. Harvested lobsters are placed inside a pipe to immobilise them for weighing (see Figure 3.13).

Figure 3.13. Harvested *P. ornatus* of marketable size up to 1 kg each

3.3.1.3.7 Transport of market-size lobsters

Lobsters harvested from cages are transferred to land during a 15–20-minute boat trip. They are normally transported dry, in open plastic boxes or barrels without seawater.

There are approximately 20–30 lobsters in a barrel. Transport of lobsters from the central provinces to Ho Chi Minh City (~500 km away) or Hanoi (~1,000 km) is performed in open fibreglass tanks with continuously aerated clean seawater. The fibreglass tank is mounted on a truck.

Lobsters may also be transported dry, sealed in cardboard boxes or polystyrene foam boxes with sawdust used as a cushioning material. If this practice is applied appropriately, transported market-size lobsters could survive up to 24 hours with 100% survival rate (Bahari, 2012, Priyambodo, 2012). The wall thickness of the cardboard boxes and polystyrene foam boxes is >7 mm and >20 mm, respectively. Blocks of ice or cooling bags insulated with thick plastic bags (≥70µm) and paper are used to keep the box cool. The box is carefully lined and waterproofed, particularly for air transport. Several holes (≥3 mm) are made in the box lid to provide ventilation. The weight of shipping containers including lobsters, buffer and cooling materials is typically around 10–20 kg when transported by air. Using this practice, lobster can survive up to 24 hours.

3.3.1.4 Lecture on lobster health and disease

A lecture was delivered by Dr Nguyen Huu Dung, the director of the Center for Aquatic Animal Health and Breeding Studies at Nha Trang University. Common diseases in spiny lobsters are red body disease, black gill disease, milky disease, incomplete molting syndrome and separated head syndrome. Lobsters infected with these diseases are shown in Figure 3.14.

Several of these health issues are well known, including their specific causes; however, some are not well understood. For example, vibrio and fungi are known to cause red body and black gill diseases, while Rickettsia-like bacteria such as *Vibrio fluvialis* and *V. alginolyticus* cause milky disease. The abdomen's appearance of spiny lobsters infected by milky disease is cloudy.However, the causes of the incomplete molting and separated head syndromes are not known.

Milky disease is the most common disease issue encountered in Vietnam's spiny lobster aquaculture. The proportion of lobster farms infected with milky disease in 2007 in Vietnam was 31–71% across all farming provinces. This led to a 50% reduction in production in 2007–2008 (50 million USD lost, and more than 5,000 households affected). Prior to 2002, survival rate through grow-out was typically 70%; by 2008 this had reduced to 50% (30 million USD lost annually). By 2011, overall survival had returned to 70% because of disease prevention measures, but in 2012 disease struck again. Nevertheless, treatment of diagnosed milky disease lobster is possible using effective antibiotics such as fluoroquinolones, oxytetracycline, tetracycline, doxycycline, thiamphenicol and rifampin.

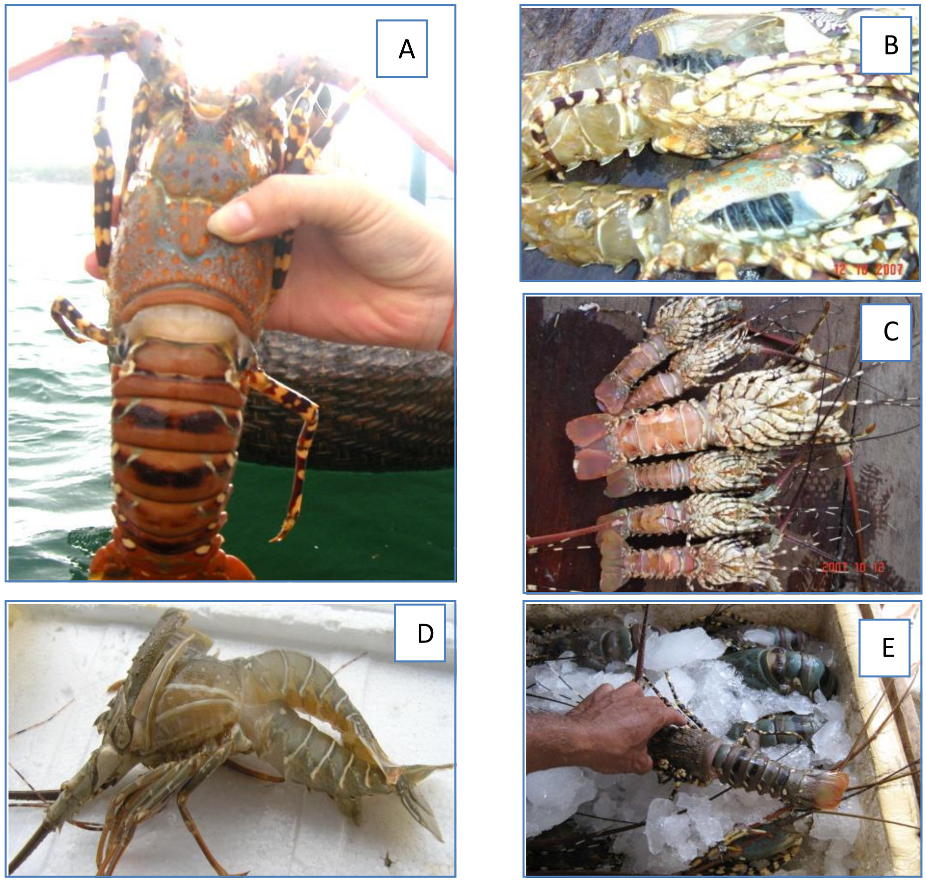

Figure 3.14. Common diseases in spiny lobster aquaculture: (A) red body disease; (B) black gill disease; (C) milky disease; (D) incomplete molting syndrome; and (E) separated head syndrome (Dung, 2013)

Integrated preventive measures to prevent diseases include 1/ site selection to ensure the depth is >2.5 m under cages with good water movement from tides and currents; 2/ managing the density of cages in farming areas, feed wastage, low water exchange and upstream pollution; 3/ attention to cage and farm design (spacing between cages and mesh size allowing flushing); 4/ attention to feed (clean and fresh, pellets are best); 5/ attention to nursed puerulus (high-quality, strong juveniles rather than puerulus, regular grading); and 6/ diagnostic support (fish health and environment laboratory).

Knowledge and skills gained from this lecture were implemented by participants from the Lombok MADC following completion of the study tour. The centre regularly provides diagnosis and treatment of lobsters infected by milky disease in farming locations in Lombok and elsewhere.

3.3.2 Participants' Perceptions

Of the study tour participants, based on their experience and exposure to the industry, two were seen as key people who would play an important role directly in their community when they returned from the programme. They were projected as agents of change in communities where the adopted new technology was disseminated. These two participants were both from Lombok: a lobster farmer (PLF_1) and a grow-out industry representative (PIR_1). With many years of experience dealing with lobster fisheries and grow-out in Lombok, PIR_1 said that he was not surprised by the grow-out methods used in Vietnam, but he was surprised by the feed used. He had used several similar farming methods as those employed by Vietnamese farmers, such as fixed cages, submerged cages and floating cages of varying size. However, despite applying these practices he had not achieved similar success. The variation in natural feed that was locally available and fed to the farmed lobster impressed him. He felt that the wide variety of feeds was a significant factor in making the Vietnamese industry sustainable and successful.

Another impression he related was about the feeding of crustaceans to lobsters. From the knowledge he trusted, spiny lobsters would not be healthy if they were fed other crustaceans, because these can be disease vectors. However, what he saw in Vietnam altered his belief. Nevertheless, finding the same species or closely related species of small crabs/crustaceans used in Vietnamese to feed his lobster in Lombok was almost impossible.

Therefore, he had decided to cultivate Vanamei shrimp (*Litopenaeus vannamei*) in his floating cages as an alternative source of feed for his lobster crops.

For PLF_1 the most important learning from the study tour was a new method of puerulus fishing. He was impressed with the way puerulus fishers in Vietnam use light to attract puerulus. Once he returned to Lombok, he planned to combine use of his passive puerulus collector with lights. His reasons for adopting this new technique related to its feasibility, profitability, cost and level of difficulty.

Other participants, such as lobster farmers from Aceh and Sulawesi, extension staff, and aquaculture engineering staff admitted that their involvement in lobster farming should be categorised as a beginner. Therefore, they used this study tour as an opportunity to improve their knowledge in all aspects of lobster farming. Overall, the respondents' perceptions of the benefits of the study tour were favourable, as shown in Table 3.7.

Table 3.7

Participant Responses Regarding the Benefits of Participating in the Vietnam Spiny Lobster Aquaculture Study Tour (n =10)

	'Yes' response	
Question	**Number**	**Percentage**
Has your confidence in various new technologies in the spiny lobster industry increased?	10/10	100
Did the tour provide you with new knowledge about skills and the needs of the spiny lobster aquaculture industry?	10/10	100
Did the tour expand your understanding of the spiny lobster aquaculture industry?	10/10	100

3.3.3 Outcomes of Technology Transfer on the Development of Lobster Farming in Indonesia

Based on observations made during the study, the immediate outcomes of the study tour were positive and profound. These included an improved knowledge of the participants in all aspects of effective lobster farming with a strong focus on practical information and covering all sectors: puerulus fishing, nursery culture, grow-out husbandry and disease management. This knowledge has broadened the participants' horizons and given them greater confidence.

The lobster farming study tour to Vietnam has had a major effect on ACIAR lobster project activity with respect to assisting industry development in Indonesia. The effect has been seen most noticeably in the lobster villages in Lombok where there has been a marked increase in community participation. Smaller scale but substantial effects have also been seen in Aceh and South Sulawesi. More substantial effects have been noted along most of the south coast of Java Island where many new puerulus fishing sites have been established from East to West Java (Priyambodo & Bahrawi, 2016a) as described in Chapters 2 and 4.

3.3.3.1 Effects on puerulus collection in Indonesia

The most obvious effect was the improved techniques of puerulus collection across all Lombok puerulus fishing villages. This resulted in a dramatic increase in pueruli captured within 1 month of the study tour being completed; within 12 months, the annual catch had increased by >800% (Bahrawi et al., 2015a). A number of puerulus fishers in Awang gradually introduced puerulus collection using lights. Improvements were not only made by implementing the use of lights but in other aspects of set-up relating to depth, currents, collector design and sea-bottom preference; and methods of collection such as use of longlines, boats, puerulus sea-cages and modified puerulus sea-cages for use under strong wave and current conditions. The methods for keeping and transporting pueruli were also improved from the very basic method using unaerated water in buckets to the more sophisticated use of appropriate containers with a battery-powered aquarium aerator. Another method uses plastic bags with pure oxygen being pumped into the bags (this practice is used by middle persons to transport pueruli to upper-level middle persons in Lombok).

Broader effects include the substantially increased area of puerulus collection and number of people involved. The area of collection has expanded from Lombok to other islands and provinces. These mainly include the southern coasts of Sumbawa and Java, South Sulawesi, South-East Sulawesi and Aceh (Idris & Bahrawi, 2015; Priyambodo & Bahrawi, 2015, 2016a, 2016b; Syafrizal et al., 2015).

Although it is clear there has been an expansion in puerulus fishing, it is difficult to calculate precisely the numbers of pueruli caught and people involved. Based on interviews with Indonesian puerulus exporters during this study, 20 is a reasonable estimate of the total number of Indonesian puerulus exporters between 2015 and 2016. Further, the number of pueruli captured was estimated to be 100 million pueruli per year in 2016, as each exporter can collect as many as 5 million pueruli per season, which extends for 8–9 months annually. In comparison with Vietnam, where the average annual catch of naturally settling pueruli is 3–5 million, this Indonesian estimate seems large and unexpected. However, considering that the length of coastline fished is around 1,500 km and thousands of puerulus fishers are involved, the estimated total catch is not unrealistic. A broader discussion of this issue is presented in Chapter 4.

3.3.3.2 Effects on grow-out

It is unfortunate that the effect of the study tour on the Indonesian grow-out sector was less than for the puerulus collection sector. In fact, as the number of pueruli caught in Indonesia has increased, the number of grow-out farmers has decreased. The spiny lobster aquaculture industry has completely changed from two main activities in the past (puerulus collection and grow-out farming) to almost exclusively puerulus collection for the main purpose of meeting international market demand, as described in Chapter 2.

Although the number of caught pueruli has increased dramatically, positive effects have not yet been seen in the development of the grow-out sector. It appears likely that almost all puerulus caught in Indonesia are exported to Vietnam. This is highly regrettable as another country is enjoying the added value benefit of these lobsters. The enormous puerulus supply in Indonesia should support a significant farming industry involving multiplier effects (Priyambodo & Jones, 2015).

It is clear that the effects of the study tour were positive given the increase in puerulus collection, but this is not so for grow-out. By 2014, this had led to the number of grow-out farmers in Indonesia dropping to only around 5% of those in 2012 (Priyambodo, 2015b; Sugama, 2015). This was because farming lobster was no longer profitable compared with previous years when pueruli were affordable. The export market for pueruli has driven the price up from <1 USD in 2012 to >4 USD per puerlus in recent times (Bahrawi et al., 2015a). There was an imbalance in the cost and return of lobster farming. Therefore, grow-out farmers abandoned their lobster cages, and new players in other villages such as Ekas, Awang and Bumbang are only catching puerulus, not growing them on.

In addition, the new lobster fishery regulations as described in Chapter 2, have contributed to the diminished grow-out sector. Instead of supporting grow-out, the regulations have retarded lobster farming. By implementing a new minimum legal size of lobsters that can be caught and traded, the regulation (Decree 1/2015) has undermined the grow-out activity as it is not economically feasible to start growing out lobsters at this size and they are rare in the wild. At 200 g they are already close to the optimal market size and there is no profitable outcome through any attempt to collect them at this size and grow them further. Finally, in the revised current regulation (Decree 56/2016), farming lobster is now completely prohibited.

3.3.4 The Current Status of Vietnam's Lobster Farming After 3-4 Years of 'Using' Imported Puerulus From Indonesia

3.3.4.1 Puerulus supply

This study found that the availability of imported puerulus from Indonesia has affected local Vietnam puerulus fishing. The large supply from Indonesia has negatively affected price, and the local fishing effort has consequently reduced. Most (90%) puerulus imported from Indonesia are *P. homarus*, so the effect on price has been greatest for this species. Importation is currently (2016) in the order of around 50 million pueruli per year, a substantial increase from the preceding 2 years, when imports were of 10–20 million pueruli only.

The catch of puerulus in Vietnam has been affected by both a reduction in the availability of local settling pueruli and the increased importation of puerulus from Indonesia. In the puerulus seasons of 2014/15 and 2015/16 Vietnam had far fewer pueruli available. There has been some suggestion this was associated with low winds and few storms (Dao et al., 2015). The puerulus season of 2016/17 has just begun and the winds and storms are stronger and more frequent (six typhoons already), so there is some expectation that local puerulus settlement will be greater.

In Vietnam, locally caught *P. ornatus* puerulus currently (2016) fetch a price of 360,000–400,000 VND (18–20 USD) per piece. Imported *P. ornatus* puerulus fetch of 300,000–350,000 VND (15–17.50 USD) each. Locally caught *P. homarus* puerulus typically cost 45,000 VND (2.25 USD) each, while imported *P. homarus* puerulus are 35,000 VND (1.75 USD). These prices are for the point of sale in Vietnam for viable puerulus. The price fluctuates quite widely according to supply and demand. As in October–November 2016, *P. homarus* imported from Indonesia cost only 15,000 VND (0.75 USD) each. This may reflect local availability increasing as the season has begun and supply is therefore up. Pigmented juveniles attract a lower price as they are considered less viable (i.e., their mortality will be higher during handling and transport). For example, a *P. ornatus* pigmented juvenile will fetch only 200,000 VND (10 USD).

Unlike in Indonesia, there is no provincial or central government control or management of the puerulus fishery in Vietnam. The Vietnamese and Indonesian governments have held discussions and are cooperating at the ministerial level on the import of seed from Indonesia, including entering into an agreement to curtail supply. Some local prosecution of importing middle persons has occurred with fines and jail sentences being applied. However, based on observations during this PhD study, the impact of the agreement appears to be minimal as pueruli are still collected, which means trading puerulus continues and smuggling prosecutions increase over time in Indonesia. Overseas demand for Indonesian pueruli remains high. For example, ABLobster (2015) reported that from June to December 2015 as many as 3,792,230 pueruli (540,463 *P. ornatus* and 3,251,767 *P. homarus*) valued of 8,352,849.75 USD were imported from one Indonesian puerulus dealer over 127 shipments. The figure was reportedly 75% higher than that in the previous year.

Survival of pueruli from landing (during fishing) to delivery (for nurseries) is typically 95–99% for locally caught puerulus, whereas that of imported pueruli is <50% because of the longer distances and duration of transport involved. The Vietnamese government has generated a Master Plan for lobster aquaculture development that sets goals and controls around lobster production across 14 central Vietnam provinces.

3.3.4.2 Grow-out

In 2016, around 53,000 cages are allocated to lobster grow-out in Vietnam. The number of sea-cages allowed in the traditional lobster farming provinces has remained static and the Master Plan does not allow for any increases there. New growing areas have been identified in some northern provinces, and more sea-cages may be added there. For example, 7 of the 14 provinces where lobster farming is undertaken have allocated land-based farming as well.

Grow-out production for 2016 was 1,600–2,000 tonnes, similar to the previous year when Vietnam did not import an enormous amount of puerulus from Indonesia. This suggests there may be issues with the survival rate of imported seed, resulting in static grow-out production. As there are no official production statistics for Vietnam and there is an apparently considerable black-market operation to avoid taxes/duties, the actual grow-out production in Vietnam may be much higher. Land-based tank farming of lobsters remains in the developmental stage only and there is no commercial production in tanks as yet.

The typical production period is 18–20 months for *P. ornatus* grown to 1 kg and 12–15 months for *P. homarus* grown to 500 g+. At harvest, because of variable growth, *P. ornatus* lobsters are graded as follows:

- Grade #1: 1 kg+ 1,250,000 VND (62.5 USD) per kg
- Grade #2: 0.8–1 kg 1,125,000 VND (56.25 USD) per kg
- Grade #3: 0.7–0.8 kg 1,000,000VND (50 USD) per kg
- Grade #4: 05–0.7 kg 900,000 VND (45 USD) per kg.

P. homarus lobsters fetch around 600,000 VND (30 USD) per kg. Grow-out of *P. ornatus* requires very clear/clean water to achieve acceptable growth rates, while *P. homarus* can be grown in slightly turbid conditions. At harvest, lobsters are packed into bins without water during brief transport to land, where they are graded and packed into bins with aerated water and chilled to 20°C in refrigerated trucks for transport to the Chinese border via Hanoi. Delivery into China is complete within 24 hours.

3.4 Conclusion

The study tour appeared to be very effective in improving the knowledge of participants, particularly in regard to detailed technical information on puerulus collection, nursery, grow-out (sea-cages, submerged cages, tanks) and disease. The most dramatic effect of the study tour was the substantial increase in lobster puerulus catch attributed to improved techniques, modified equipment and application of light to attract pueruli to the fishing equipment. In Lombok, almost all of the puerulus fishers in all puerulus fishing ground (hot spots) have modified their collectors to improve their catch, particularly by modifying their puerulus collectors with lights and changing their collectors from single rice bag collectors to cement bag paper bowtie collectors. It is also apparent that puerulus fishing no longer uses puerulus fishing sea-cages, and has converted to longlines, which are much more effective, inexpensive and technically friendly.

The puerulus puerulus hotspots throughout Indonesia have expanded from the three original Lombok bays (Awang, Bumbang and Gerupuk) to now include the entire south coasts of Lombok, Sumbawa, Bali, Java and several parts of the coast in South-East Sulawesi and Sumatera (Aceh). Puerulus catch in Lombok increased dramatically within 1 month of completion of the study tour, resulting in a subsequent annual catch for 2013 in excess of 3.5 million pueruli compared with 600,000 pueruli per annum in previous years.

However, the effects on the grow-out industry were observed to be negative. This is because as the price of pueruli increased as a consequence of the overseas demand has substantially increased, most pueruli were sold to international markets, primarily Vietnam. There was no more puerulus supply for local grow-out as farmers could no longer afford to buy pueruli. The new regulations as described in Chapter 2 have further retarded the grow-out sector. Instead of supporting grow-out, the regulations have successfully diminished lobster farming. In contrast, puerulus collection continues illegally and now supports a black market. Therefore, in future, the Indonesian government should take charge of managing this resource to provide prosperity for the people of Indonesia.

Chapter 4: Assessment of the Lobster Puerulus Resource of Indonesia and its Potential for Sustainable Exploitation for Aquaculture

4.1 Introduction

Aquaculture of marine spiny lobsters in Indonesia was confined to the on-growing of wild-sourced pueruli captured in shallow coastal waters where natural settlement occurs, and their abundance is sufficient to justify the effort to fish for them (Jones et al., 2010). In Vietnam, the practice is well developed; a stable lobster farming industry is established and produces around 1,500 tonnes of marketable (1 kg+) lobsters each year (Jones, 2010; Tuan & Jones, 2015b).

Methods for the fishing of lobster pueruli were first developed in Vietnam in the mid-1990s (Jones et al., 2010). Entrepreneurial Vietnamese fishers recognised that small lobsters could be fattened to a more valuable product, as the Chinese demand and price per kilogram was greatest for lobsters larger than 1 kg (Tuan & Jones, 2015b). In the early years of the Vietnamese industry, methods were developed for catching small juveniles, typically by creating habitat in which juvenile lobsters would settle. Small holes were drilled into coral rocks and timber posts, and these materials were placed in shallow waters along the coastline. Puerulus fishers would periodically dive in these habitats and manually remove settled juveniles (Long & Dao, 2009). This method was progressively replaced by fishing for the puerulus stage using various nets to capture the swimming pueruli as they actively moved through inshore waters seeking suitable habitat.

Puerulus fishing quickly proved to be more effective than juvenile fishing, as the abundance of pueruli was much higher. Methods evolved and catch rates increased as canny fishers came to understand the oceanographic conditions associated with the highest abundance. These conditions were characterised by inshore areas protected from larger swells, inside embayments often with fringing islands, moderate currents against which the puerulus would swim, and often in proximity to river mouths where turbidity was elevated. Nets set across the current would effectively intercept pueruli as they swam through the hours of darkness (Jones et al., 2010). Today, the most common and effective method for fishing of pueruli in Vietnam is a set seine, deployed in a V-shape with its opening facing the prevailing current, and using lights positioned near the net apex to attract the pueruli (Tuan & Jones, 2015a). These nets are set in the hours around dusk and retrieved twice each night, around midnight and again at dawn, with pueruli manually collected from the net as it is hauled aboard.

Interest in farming lobsters in Indonesia began in the mid-2000s on the island of Lombok (Chapter 2). Although the Vietnam rock lobster aquaculture industry was well established by this time, the coastal communities of Lombok were unaware of the methods employed by Vietnamese fishers. Consequently, the Indonesians developed their own unique methods for catching lobster seed and on-growing them. It was only in 2013, following a study tour of Vietnam by a group of Indonesian farmers (Chapter 3), that some cross-fertilisation of methods occurred, leading to the more effective puerulus fishing methods now employed. The Indonesian method shares with Vietnam the practice of intercepting pueruli as they swim; however, rather than using a seine net, artificial habitats into which pueruli settle are deployed throughout the water column.

The development of the Indonesian methods has been well described by Bahrawi et al. (2015a) and Bahrawi et al. (2015c), and the effectiveness of various habitat materials and their positioning to maximise catch are detailed in Chapters 5 and 6. At present, the most common and effective method employed in Indonesia consists of an array of small fabricated habitats that are suspended in the water column from a floating frame. The frame is typically rectangular, ranging in size from 2.5 × 2.5 m to 12 × 12 m, constructed from bamboo and supported by polystyrene foam floats. The frame is moored semi-permanently in locations known to have a high abundance of pueruli lobsters. These locations have the same characteristics as described for Vietnam: protected bays with distinct currents and elevated turbidity from terrestrial outflows.

The array of habitats is attached to a rectangular panel of netting approximately 1.5 m across and 2 m in depth, its top edge held rigid by a timber frame and its bottom edge weighted. Across the panel, up to 25 individual habitats are attached, each consisting of a folded piece of plastic lined paper or rice bag material. The paper is sourced from used cement bags that have been cut open to form a rectangle; similarly, the rice bag material (woven polyurethane) is sourced from disused rice bags. The material is folded across its width in a concertina fashion to create a series of folds and the folded material is then tied at its centre, so the resulting item resembles a bowtie. Such fabrication results in a series of sharply creased crevices that are attractive to pueruli as a suitable habitat in which to settle. These bowtie habitats have much in common with the crevice traps widely used for resource management assessment of commercial lobster fisheries settlement throughout the world (Booth & Tarring, 1986; Phillips & Booth, 1994), but in Indonesia are used for fishing rather than management.

Research (Priyambodo et al., 2015) and commercial trial and error have determined that catch is greatest near the sea floor, and consequently, the bowtie habitat arrays are positioned just off the sea floor. Priyambodo et al., (2015, 2017b) have also determined that cement bag paper is superior to other materials (including rice bag), as it is quite robust through immersion and supports an optimal amount of bio-fouling that appears to contribute to its attractiveness to pueruli. The combination of dual plastic and paper layers provides dual benefits. Finally, cement bag paper is ideal for Indonesian farmers as it is in ready supply and inexpensive.

Unlike Vietnam, where nets are actively deployed and removed each day, the puerulus fishing frames in Indonesia are moored in place and only shifted or removed if rough conditions develop. One of the most important methods borrowed from the Vietnamese was the application of lights to puerulus fishing devices, first applied in 2013 (Priyambodo, 2015b). A single fluorescent or incandescent light mounted above the frame results in significantly increased catch rates, presumably because of positive phototaxis of the swimming pueruli. Indonesian puerulus fishers visit their fishing frames early each morning to lift each panel of habitats and manually remove the settled seed hiding in the habitat crevices.

In both Vietnam and Indonesia, captured pueruli are immediately placed into containers with fresh seawater, sometimes aerated. These containers are returned to shore and the pueruli are sold to puerulus dealers (middle persons) who move the seed to holding facilities where they can be packed for transport to farmers. Holding facilities are typically tanks at the dealers' household, with rudimentary filtration. Pueruli are most often graded by species and quality, and housed in plastic colanders floating in the tank. Once sold, they are counted and placed into plastic bags of around 4–5-L capacity, nearly always with aeration and sometimes with oxygen injected. The plastic bags are then placed in polystyrene foam boxes for transport by road to their destination. In Vietnam, transport distances may be up to 1,000 km from the more northerly seed fishing grounds to the central and southern coast where the bulk of farming occurs. In Indonesia, pueruli may be transported a short distance to adjacent farms or, more commonly, to an airport for export to Vietnam. Details of pueruli handling and transport are provided in the reports of Jones et al. (2010), Bahrawi et al. (2015c) and Tuan and Jones (2015a).

The on-growing of wild-caught pueruli is an established practice in Vietnam (Jones, 2015b; Williams, 2009), but is only in its developmental stage in Indonesia (Priyambodo, 2013). Indonesian lobster farmers lack the skills to generate sufficient productivity to justify their commitment, and most who try lobster farming soon abandon it in favour of simply fishing for pueruli that are then sold to middle persons who market them to other countries for grow-out there (Chapter 2). A key obstacle for the Indonesian lobster farmer is the high mortality of pueruli immediately or soon after stocking to the grow-out system (floating sea-cage) (Jones et al., 2007; Priyambodo & Sarifin, 2009). Although there appears to be little if any variation in the quality of captured pueruli on the basis of their size and morphology, there is a likelihood that they do vary in regard to their condition. Extensive research (Jeffs, 2000; Jeffs et al.,1999, 2001a, 2001b, 2002; Phillips et al., 2006a, 2006b; Wilkin & Jeffs, 2011) on puerulus condition for *Jasus edwardsii* and other species in the context of understanding and managing recruitment to lobster fisheries provides a strong foundation for examining puerulus condition in the context of their quality for subsequent on-growing.

Although there have been extensive studies on recruitment of palinurid lobsters as part of broader population research for resource management purposes, the cues that determine when and where pueruli settle are not well understood (Butler & Herrnkind, 1991). For the tropical species *P. ornatus* and *P. homarus*, the developing puerulus fisheries in Vietnam and Indonesia indicate that abundance is highest in areas of the coastline where there is some protection from prevailing wind and wave action and often proximity to terrestrial outflows from creeks and rivers. These areas are often characterised by high turbidity, salinity <33 ppt and with currents of either tidal or oceanic origin. Such physico-chemical characteristics may therefore be used as a predictor of puerulus settlement in areas where late-stage phyllosoma are delivered by prevailing currents (Hinojosa et al., 2015; Jeffs et al., 2005; Próo et al., 1996).

In Indonesia, the opportunity exists to establish a lobster farming industry like that of Vietnam, as a significant resource of pueruli has been identified (Bahrawi et al., 2015b; Priyambodo et al., 2015). While the extent of the puerulus resource in Vietnam appears to be fully developed, as evidenced by relatively stable annual catch, Indonesia's resources are only partially defined. Catch data for puerulus were collected from 2007 to 2012, but were restricted to the island of Lombok (Bahrawi et al., 2015a). By late 2012, anecdotal data suggested pueruli were available in high concentrations (i.e., fishable abundance) over a much larger coastal spectrum beyond Lombok, potentially representing a resource far larger than that of Vietnam. To evaluate the puerulus fishery resource of Indonesia more thoroughly, surveys were performed to gather data from coastal villages where pueruli were fished.

This study sought to collect data on puerulus catch, species composition, seasonality, lunar periodicity and capture methods in areas of Indonesia where puerulus abundance appeared to be relatively high based on anecdotal fishery information. In addition to more thorough investigations into the fishery of the lobster puerulus resource already established in Lombok, research was performed to assess the availability of lobster puerulus in other parts of Lombok and other Indonesian provinces. The study also sought to estimate the entire resource by mapping suitable settlement locations and extrapolating from data from quantified populations. Finally, the data compiled enables estimates of the potential scale of future lobster farming in Indonesia. Policy recommendations to achieve this are provided.

4.2 Materials and Methods

4.2.1 Puerulus Census of Lombok

To record fishery catch data for lobster pueruli with accuracy and precision, a logbook was prepared that enabled recording of catch data from each fisher.

Data were recorded once a week from interviews with the lobster seed fishers in four locations in Lombok, as shown in Figure 4.1, onto a standardised form recording the places, puerulus fishers' name, capture dates, name of species captured and its numbers. Data were subsequently transcribed to Excel spread sheets to enable collation and analyses.

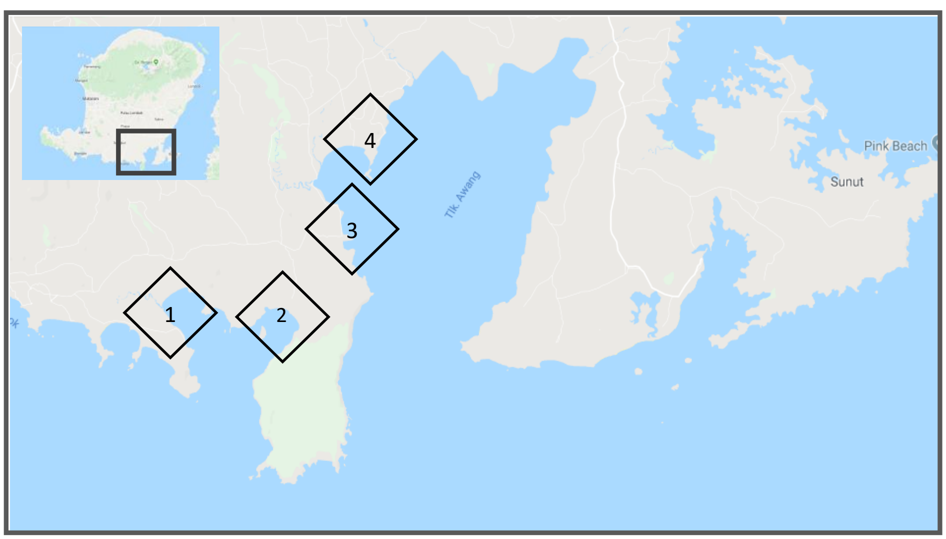

Figure 4.1. Puerulus fishing locations in Lombok where the lobster puerulus/seed census was performed in 2007–2013: 1. Gerupuk; 2. Bumbang; 3. Awang; 4. Kelongkong

For the period 2007–2013 the candidate managed the census, covering four villages in Lombok and 245–484 puerulus fishers in the two main puerulus fishing bays. For each main village a puerulus census officer was recruited and trained in the data collection method. Data were recorded on a standardised form, which when completed, was photographed and the images transmitted to the candidate.

In 2014, the number of puerulus fishers increased substantially compared with previous years and it was impossible to collect data from every puerulus fisher, as their number exceeded 4,000. Therefore, data were collected only from the top six puerulus dealers in Lombok. The number of puerulus fishers or dealers interviewed, and the total number of fishers or dealers operating each year from 2007 to 2014 is presented in Table 4.1. However, data on the puerulus catch for 2015 could not be gathered because puerulus middle persons became more sceptical about sharing their data with researchers as a consequence of the new fisheries regulations introduced, which banned the collection of lobsters weighing <200 g (see Chapter 2).

Table 4.1

The Number of Puerulus Fishers or Dealers Interviewed and Total Number of Fishers or Dealers Operating Each Year 2007–2014

Puerulus fishing season	**Number of contacted puerulus fishers or dealers/total number**	**Percentage**
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	77.6
13/14	484/556	87
14/15	6/6*	100

* top dealers of Lombok

4.2.2 Field Survey of Puerulus Fishing

By the beginning of the 2013/14 puerulus season, puerulus fishing in Lombok had become a lucrative business involving both domestic demand to supply the emerging lobster grow-out sector (primarily in Lombok), and export demand from Vietnam to supply their well-established lobster farming industry. Consequently, fishers in other areas beyond Lombok began fishing for pueruli and anecdotal information at that time suggested fisheries were establishing with catch rates equivalent to those of Lombok. A field survey was therefore performed, comprising collection of quantitative and qualitative data on the puerulus fisheries in three villages: two on the south-east coast of Java and one on the south coast of Sumbawa. A structured questionnaire (see Appendix D) was used to gather information on the number of pueruli caught, species composition, lunar periodicity, seasonality, fishing methods, capture equipment and materials and general environmental characteristics of locations in which pueruli were fished. Ten puerulus fishers were interviewed at each location.

The surveys were performed in 2015 and 2016 in villages near Banyuwangi (8°36'8.50"S 114°13'29.75"E) and Trenggalek (8°17'11.60"S 111°43'42.02"E) in Java and near Labangka Sumbawa (8^{o}53'19.3527"S 117^{o}47'55.6889"E) in Sumbawa. To provide verification of the data collected, interviews were performed with several main lobster puerulus dealers who had detailed knowledge of the number of fishers in their location, the number of other dealers in their region and the volumes of puerulus being marketed. Based on these data, an estimate of the total puerulus fishery catch was made.

4.2.3 Identification of Puerulus Fishing Location Using Google Earth

Based on the data collected from the census in Lombok, and the field surveys in Java and Sumbawa, a definition was generated of the broad physical characteristics associated with puerulus abundance. These characteristics included bays with some protection from strong wave action, in proximity to coastal currents and with terrestrial inflows likely to elevate turbidity and nutrients. Using Google Earth, a detailed examination of the southern coasts of Java and Sumbawa was made to identify locations with these characteristics. Additional verification of the location as suitable for puerulus fishing was the visible on satellite photos on Google Earth, with the presence of puerulus fishing frames.

Google Earth was used to estimate the area of puerulus fishing within each bay via its ‘polygon measurement’. The fishing area was defined by the outer limits of the floating frames or, in bays where frames were not present, the area between 100 and 500 m from the coastline within the bay.

Based on the recorded number of pueruli captured in Lombok from previous puerulus censuses undertaken in 2014, an estimate of the typical number of puerulus caught per square kilometre per year was made. From this figure, an estimate of the pueruli that may be available at each of the locations was generated. In turn, this allowed estimation of the overall number of fishable pueruli available in Indonesia. Data gathered were analysed using Microsoft Excel and are presented using graphs and tables.

4.3 Results

4.3.1 Puerulus Census of Lombok

Data gathered from the puerulus censuses from 2009 to 2014 are presented in Figure 4.2. The figures for 2013 and 2014 show a substantial increase in the total puerulus caught per annum compared with previous years. The increase in catch was large, from around 600,000 pueruli per year between 2009 and 2012, to 3 million in 2013 and 5 million in 2014. The total catch of lobster puerulus by month from 2009 to 2014 is presented in Figure 4.3. Total lobster puerulus catch by month for each year, 2009–2012 on a finer scale is presented in Figure 4.4. Data and analysis of lunar periodicity are presented in Chapters 5 and 6.

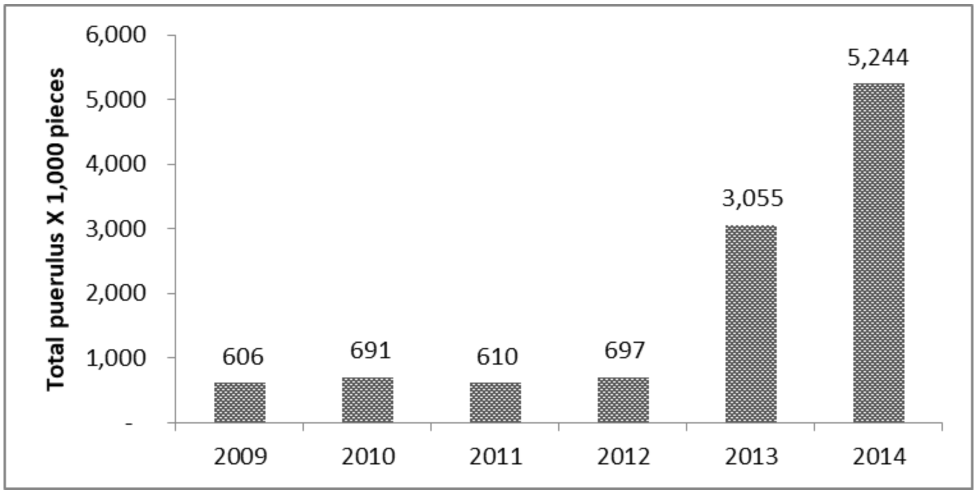

Figure 4.2. Annual total catch of pueruli 2009 – 2014 in Lombok (data were collected from 2,441 out of 2,747 puerulus fishers from 2009 to 2013 and from 6 puerulus dealers in 2014)

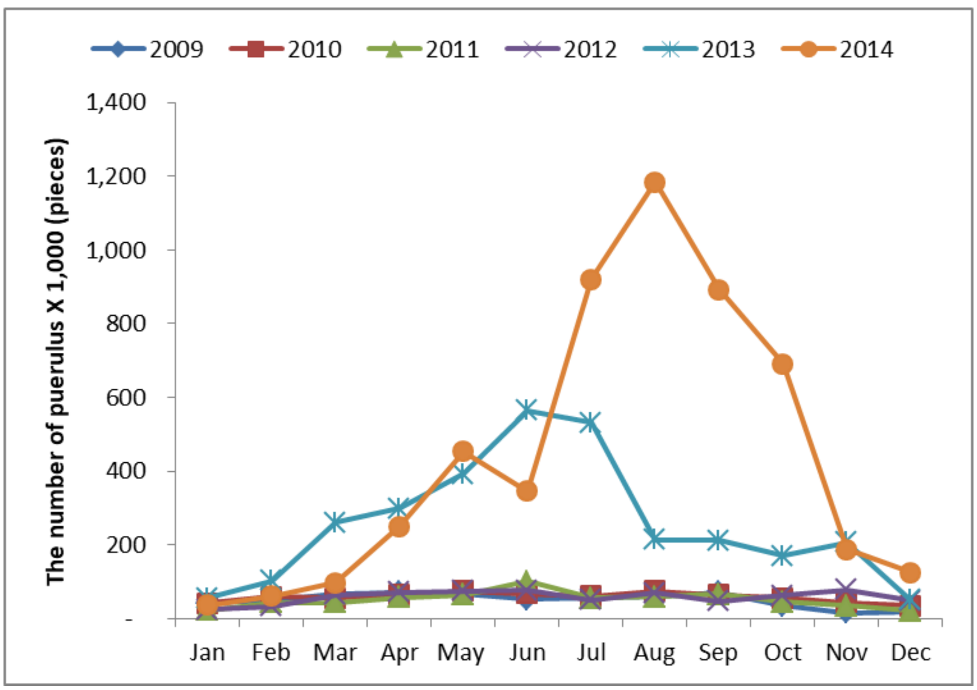

Figure 4.3. Total catch of lobster pueruli by month 2009–2014

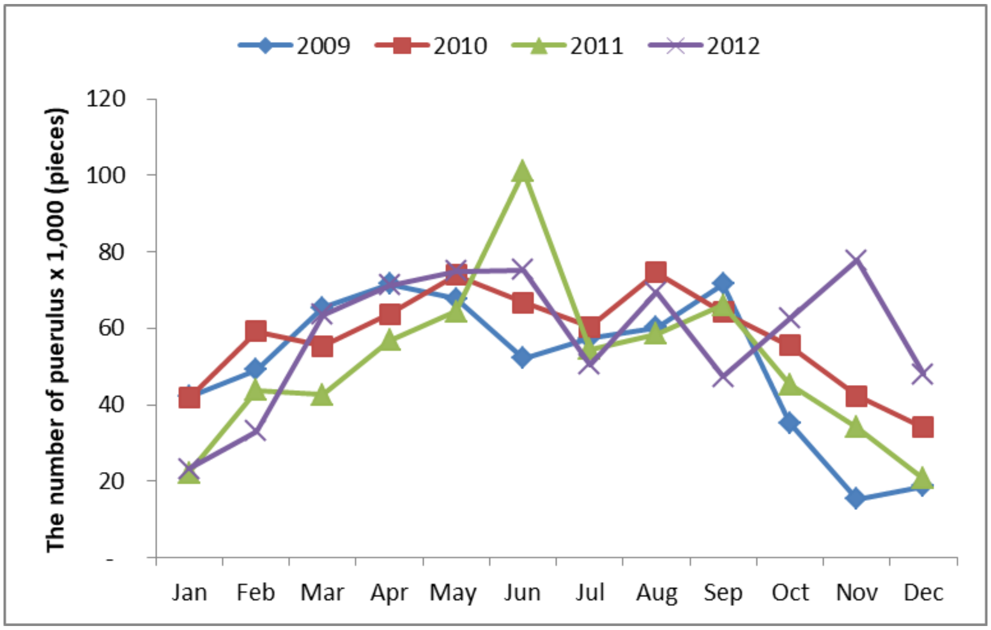

Figure 4.4. Total lobster pueruli catch by month for each year, 2009–2012, on a finer scale than in Figure 4.3

Figure 4.3 suggests a distinct peak in puerulus catch in the period May–July, with a possible secondary but much weaker peak in November. When examining the catch data for 2009– 2012 on a different scale, as in Figure 4.4, the same peaks are evident, although there is considerable inter-annual variability. This suggests that the peak in puerulus abundance in May–July corresponds with early summer reproduction and release of newly hatched phyllosoma larvae in mid-summer (around November–January in the southern hemisphere). This accounts for the 5–6-month larval duration for the tropical species caught. The secondary peak of puerulus abundance in November–December may relate to reproduction occurring in northern hemisphere stock, where breeding and release of newly hatched phyllosomas would occur around May–July. This pattern contrasts with a distinct single peak in puerulus abundance in Vietnam from November to March (Dao & Jones, 2015).

Within the lobster puerulus catch, there are two dominant species, *P. homarus* and *P. ornatus*, which account for >99% of seed caught. The species composition appears to fluctuate between years: 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%. In 2014, the proportions of *P. homarus* and *P. ornatus* were 79.26% and 20.74, respectively.

Although lobster seed of both *P. homarus* and *P. ornatus* were caught throughout the year, the data for 2012 indicated two peaks, April–June and October–November, as shown in Figure 4.5. 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 discernible peak at all for *P. ornatus*, as shown in Figure 4.6.

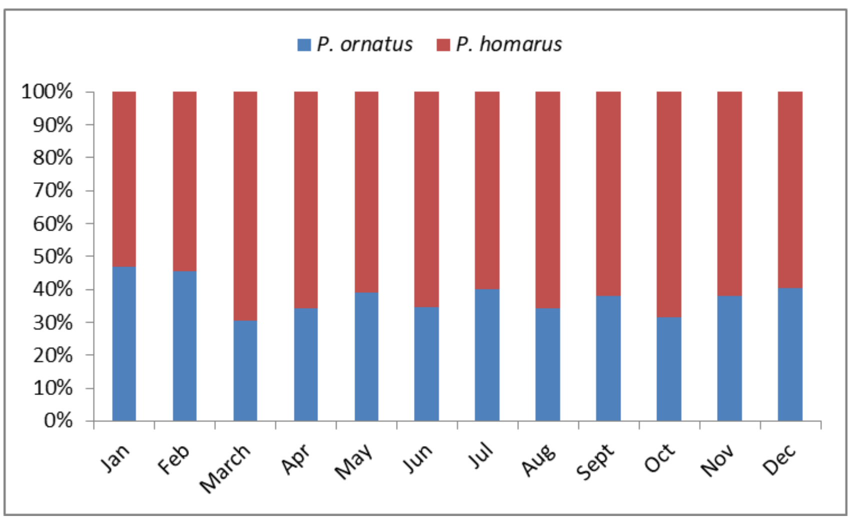

Figure 4.5. Lobster puerulus catch by month for *P. homarus* and *P. ornatus* in 2012

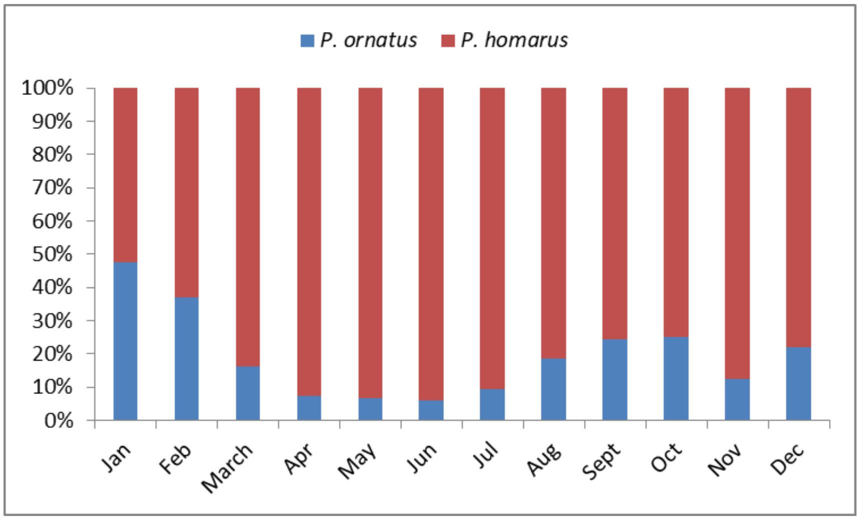

Figure 4.6. Lobster puerulus catch by month for *P. homarus* and *P. ornatus* in 2013

4.3.2 Field Assessment

Survey results from Java and Sumbawa where pueruli were fished are presented in Tables 4.2 and 4.3. A number of environmental characteristics were shared between the locations surveyed: they were all embayments protected from strong wind and waves, with the presence of rivers that resulted in low to medium turbidity. It was also evident that fishers placed their collectors in areas of similar depth from 20 to 40 m with a sandy mud substrate. However, the method of fishing varied from place to place with some fishers using modified fishing boats to deploy their collectors and others using fixed floating sea-cages. Nevertheless, the use of lights and the type of collector materials were common to all. The puerulus fishers in Banyuwangi and Trenggalek declared that they gained their knowledge of puerulus fishing methods from Lombok puerulus fishers who trained them in their home villages. The training was performed by middle persons/exporters.

Table 4.2

Survey Results from Java and Sumbawa Where Pueruli Were Fished: General Environmental Characteristics

	Location		
Description	**Banyuwangi 8°36'8.50"S 114°13'29.75"E**	**Trenggalek 8°17'11.60"S 111°43'42.02"E**	**Sumbawa 8°53'19.3527"S 117°47'55.6889"E**
Depth (m)	20–30	20–30	20–40
Turbidity	Low to medium	Low to medium	Medium to high
Freshwater intake	Episodic rivers available in the puerulus locations	Several rivers available	Rivers upland
Current	Medium to strong	Medium to strong	Strong to very strong
Wave height (m)	2–5	2–5	2–5
Wind	Strong to very strong	Strong to very strong	Strong to very strong
Bottom type	Sandy mud	Sandy mud	Sandy mud
Coral reef	Coral reef in some parts of the bays, but not touched as villagers used surface nets for fishing. They were also very strict about protecting their sea from diving fishers who caught adult lobsters	No information about coral reef but a tour agent ran a snorkelling tour	No information about coral reef. The area look likes suitable for wind surfing
Health status of local environment	Water seemed highly pristine No source of pollution	Pristine water but a possible source of pollution was the fishing port crowded with fishing boats	Water seemed highly pristine although turbidity was relatively high Possible sources of pollution were an agriculture company cultivating industrial plantations and several nearby shrimp ponds

Table 4.3

Survey Results from Java and Sumbawa Where Pueruli Were Fished: Fishing Methods and Catch

Description	**Location** **Banyuwangi** **8°36'8.50"S 114°13'29.75"E**	 **Trenggalek** **8°17'11.60"S 111°43'42.02"E**	 **Sumbawa** **8°53'19.3527''S 117°47'55.6889''E**
Puerulus fishing characteristics and methods			
Method used	Puerulus fishing boats combined with lights; 2–3 operators per boat	Puerulus fishing boats and floating sea-cages, both combined with lights; 2–3 operators per boat, 1–2 operators per floating sea-cage	Puerulus floating sea-cages combined with lights; 1–2 operators per floating sea-cage
When collection began	March 2015	End of 2013	End of 2013
Targeted species	*P. homarus* and *P. ornatus*	*P. homarus* and *P. ornatus*	*P. homarus* and *P. ornatus*
Species composition (%)	95:5	90:10	80:20
Puerulus hotspot	200–300 m from the beach	200–300 m from the beach	100–200m from the beach
Type of collector	120 bowtie–cement bag paper collectors attached to both sides of a piece of net 60 × 300 cm. Corn husk and coconut fibre were also attached to the bowtie–cement bag paper	100-120 Bowtie–cement bag paper collectors attached to both sides of a piece of net 60 × 300 cm.	Bowtie–cement bag paper collectors attached to both sides of a piece of net 60 × 300 cm.
Type of puerulus fishing	Collectors hung from a boat combined with lights	Collectors hung from a boat or special puerulus fishing raft made of bamboo; both combined with lights	Collectors hung from a special puerulus fishing raft made of bamboo, combined with lights

Table 4.3 (continued)

Catch results and other relevant information			
Average number of pueruli caught per night	20–30,000	50–60,000	5,000–25,000
Number of work days per month	22–25	22–25	22–25
Number of dark moon work days	15–17	15–17	15–17
Number of full moon work days	5–7	5–7	5–7
Largest number of pueruli caught on dark moon days (with lights)	30,000	50,000	25,000
Smallest number of pueruli caught on full moon days (with lights)	3,000	10,000	1,000
Puerulus season	March–November	March–November	March–November
Number of puerulus fishers	1,000	3,000	300–400
Number of puerulus boats and fishing cages	700–800 boats	2000 boats and 300 cages	500 puerulus cages
Number of local middle persons	5	11	8
Interest among puerulus fishers to grow-out	All participants interested	9 of 10 participants interested	Not interested at all because of unsuitable location

4.3.3 Identification of Puerulus Fishing Locations Using Google Earth

In total, 83 main villages were identified that are likely to support lobster puerulus catch, based on macrogeographical features using Google Earth. The number of identified locations in Sumbawa, Lombok, Bali and Java is presented in Table 4.4.

Table 4.4

Total Area and its Proportions Distributed among Predicted Puerulus Fishing Locations

No	Location	Number of puerulus hotspots (locations)	Proportion of puerulus hotspots (%)	Area (km^2)	Proportion of area (%)
1	Sumbawa	14	17	249.93	16
2	Lombok	9	11	80.94	5
3	Bali	2	2	68.00	4
4	Java	58	70	1,198.36	75
Total		83	100	1,597.23	100

Of the four islands where pueruli are in high abundance (Priyambodo & Bahrawi, 2015, 2016a, 2016b), Java dominated with 75% of the total fishable area, followed by Sumbawa, Lombok and Bali, accounting for 16%, 5% and 4%. Java also dominated the proportion of puerulus hotspots, accounting for 70% (58 villages). This was followed by Sumbawa, Lombok and Bali, accounting for 17% (14 villages), 11% (9 villages) and 2% (2 villages). The details of each location and their area suitable for puerulus fishing in Sumbawa, Lombok and Bali are provided in Table 4.5, and for Java in Table 4.6.

Table 4.5

Details of Puerulus Locations and Their Area in Sumbawa, Lombok and Bali Islands as Estimated Using Google Earth

No	**Village**	**Latitude Longitude**	**Area (km^2)**
Sumbawa			
1	Cempi	8°47'3.61"S 118°58'49.07"E	93.30
2	Lakey	8°49'5.13"S 118°22'11.18"E	31.50
3	Pantai Ria	8°41'23.60"S 118°21'25.68"E	77.80
4	Jotang	8°51'36.54"S 118° 1'58.39"E	8.95
5	Jotang Beru	8°51'17.99"S 118° 1'35.17"E	8.56
6	Labangka	8°55'19.15"S 117°43'46.83"E	3.67
7	Lunyuk	9° 5'17.87"S 117°12'57.02"E	17.10
8	Tongo	9° 2'32.00"S 116°48'14.30"E	6.93
9	Sekongkang	8°59'5.94"S 116°43'22.96"E	2.12
Lombok			
10	Kelongkong	8°51'14.86"S 116°24'35.97"E	8.45
11	Ujung	8°50'13.75"S 116°27'36.52"E	4.40
12	Bumbang	8°54'57.56"S 116°22'20.78"E	1.64
13	Gerupuk	8°54'39.65"S 116°20'55.23"E	3.10
14	Kuta	8°54'40.05"S 116°16'50.14"E	0.64
15	Are Guling	8°54'32.68"S 116°14'51.68"E	0.32
16	Mawun	8°54'24.37"S 116°13'46.23"E	0.51
17	Tampah	8°54'37.81"S 116°12'26.50"E	1.63
18	Selong Belanak	8°52'36.20"S 116° 9'0.92"E	4.67
19	Pengantab	8°53'31.67"S 116° 5'29.91"E	8.78
20	Sepi	8°52'54.61"S 116° 2'8.97"E	10.40
21	Serewe	8°53'49.83"S 116°30'43.23"E	4.20
22	Ekas	8°51'49.32"S 116°26'54.28"E	14.70
23	Awang	8°53'25.81"S 116°24'44.76"E	17.50
Bali			
24	Perancak	8°25'7.70"S 114°36'22.50"E	28.50
25	Pekutatan	8°26'2.35"S 114°48'21.40"E	39.50

Table 4.6

The Details of Puerulus Locations and Its Area in Java Island Using Google Earth

No	Village	Latitude Longitude	Area (km^2)	No	Village	Latitude Longitude	Area (km^2)
26	Brassan	8°28'8.11"S 114°22'17.32"E	16.00	55	Chikalong	7°46'43.49"S 108°0'32.18"E	43.00
27	Grajagan	8°36'51.76"S 114°14'29.62"E	72.00	56	Pelabuhan Ratu	6°59'51.64"S 106°32'15.12"E	9.10
28	Pantai Pancer	8°35'50.42"S 114°0'5.14"E	17.20	57	Ciletuh Bay	6°57'44.55"S 106°13'58.36"E	19.90
29	Rajegwesi	8°34'34.48"S 113°57'14.12"E	19.10	58	Muarabinuangeun	6°49'51.07"S 106°1'12.97"E	26.30
30	Permisan	8°32'3.63"S 113°49'54.89"E	8.39	59	Bangbajang	7°41'58.02"S 107°43'20.26"E	15.40
31	Turtle beach	8°29'43.21"S 113°47'32.97"E	16.00	60	Pemeungpeuk	7°38'15.79"S 107°37'14.57"E	18.80
32	Bande Alit	8°29'31.44"S 113°42'32.23"E	9.59	61	Pantai Jayanti	7°30'24.32"S 107°23'39.17"E	15.20
33	Papuma beach	8°26'3.87"S 113°33'58.18"E	4.26	62	Pantai Sidangbarang	7°28'7.92"S 107°7'37.11"E	16.90
34	Puger	8°23'17.81"S 113°28'29.45"E	8.33	63	Agrabinta	7°26'26.55"S 106°52'31.65"E	6.77
35	Pugiharjo	8°23'6.04"S 112°54'2.83"E	3.53	64	Lingkungsari	7°26'34.36"S 106°47'25.57"E	5.83
36	Anjlok	8°22'42.64"S 112°49'31.80"E	9.38	65	Muara Cikaso	7°26'0.41"S 106°40'48.04"E	15.20
37	Tambakasri	8°23'29.39"S 112°46'31.47"E	5.35	66	Ujung Genteng	7°23'10.90"S 106°28'58.06"E	14.10
38	Sempu Island	8°26'1.29"S 112°41'11.28"E	0.45	67	Pantai Cibantang	7°10'50.71"S 106°25'58.50"E	24.60
39	Teluk Sene	8°17'10.58"S 111°56'43.97"E	10.60	68	Balewer	7°6'28.02"S 106°28'14.39"E	12.30
40	Pantai Popoh	8°16'0.67"S 111°46'54.79"E	17.80	69	Karangaji Bay	6°57'26.85"S 106°26'29.82"E	1.00
41	Prigi	8°18'15.56"S 111°43'24.04"E	19.20	70	KudaLaut Beach	6°57'41.80"S 106°25'38.32"E	0.84
42	Munjugan	8°20'2.20"S 111°36'57.71"E	6.25	71	Paseban Beach	8°19'8.69"S 113°17'44.84"E	49.40
43	Teluk Pacitan	8°13'57.66"S 111°5'8.77"E	3.57	72	Pantai Blado	8°19'9.73"S 111°33'56.88"E	5.73
44	Pantai Cilacap	7°43'56.01"S 109°3'11.77"E	42.50	73	Pantai Panggul	8°16'23.37"S 111°26'18.73"E	7.76
45	Pangandaran	7°44'39.40"S 108°33'48.28"E	66.30	74	Cibareno Beach	6°58'51.08"S 106°23'47.45"E	0.64

Table 4.6 (continued)

46	Pesanggaran	8°38'2.14"S 114°5'50.33"E	19.50	75	Djepring	8°19'28.21"S 112°11'4.51"E	0.22
47	Watu Ulo	8°26'47.61"S 113°36'31.59"E	5.58	76	Tambakrejo	8°19'2.05"S 112°8'32.90"E	0.52
48	Ngliyep	8°21'16.83"S 112°20'1.81"E	10.60	77	Brumbun beach	8°16'1.94"S 111°50'31.82"E	3.00
49	Lebaksari	8°22'52.79"S 112°58'6.32"E	11.70	78	Pasir Putih	7°45'54.05"S 108°54'42.92"E	31.50
50	Balekambang	8°24'49.88"S 112°32'45.21"E	11.20	79	Citeluk	6°50'51.03"S 105°42'13.57"E	55.30
51	Gatra beach	8°27'8.22"S 112°39'49.73"E	3.45	80	Cilograng	6°59'52.91"S 106°21'48.77"E	3.42
52	Karangbolong	7°46'43.03"S 109°27'57.19"E	194.00	81	Pidakan	8°15'26.78"S 111°14'48.34"E	19.50
53	Ayah beach	7°44'14.26"S 109°22'27.21"E	42.30	82	Sadeng	8°11'41.65"S 110°47'43.11"E	39.80
54	Penanjung Timur	7°44'3.89"S 108°42'46.16"E	34.50	83	Baron	8°8'3.07"S 110°32'50.90"E	47.70

Based on the puerulus census in Lombok, the total number of pueruli caught in 2014 was estimated at 5,243,887. The 2014 puerulus fishing season was assumed to represent maximum fishing effort for catching pueruli as it involved the highest number of fishers, puerulus catching devices and fishing locations. Data were collected from nine main villages where pueruli were fished. In contrast, he previous season involved only four main villages. Using Google Earth, it was estimated that the total area fished for pueruli in 2014 in Lombok was 80.94 km^2. Therefore, the mean catch of pueruli was estimated as 64,787.34 individuals per km^2. Extrapolating this estimate to the 83 identified locations (Tables 4.5 and 4.6) representing 1,597.23 km^2 provides an estimate of 103,480,283.07 pueruli available per year. Maps showing each location described in Tables 4.5 and 4.6 are presented in Figures 4.7 and 4.8. Additionally, more detailed maps of puerulus fishing locations in Sumbawa, Lombok, Bali and the eastern, central and western parts of Java are presented in Figures 4.9, 4.10, 4.11, 4.12, and 4.13, respectively.

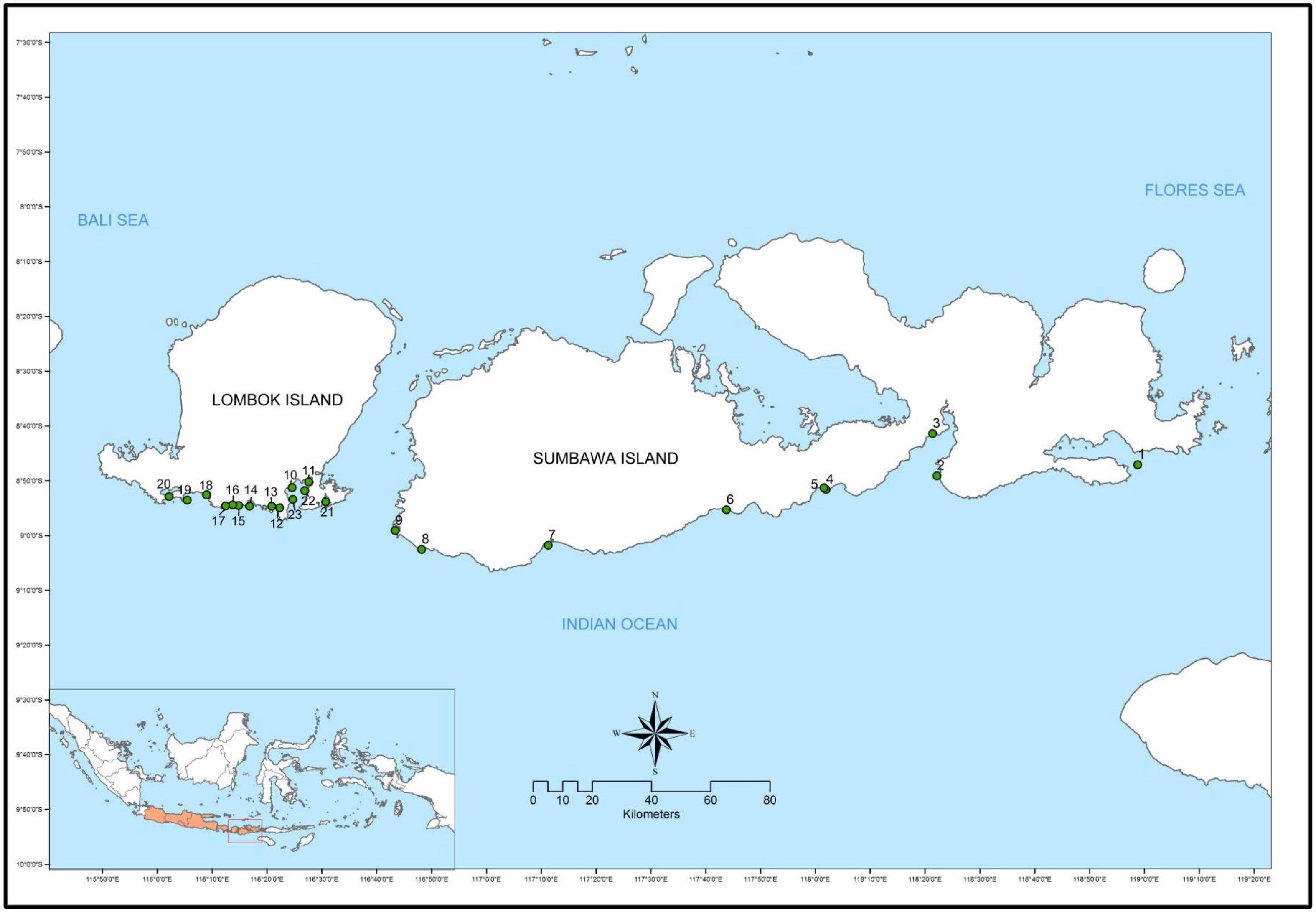

Figure 4.7. Puerulus fishing locations in Sumbawa and Lombok Islands

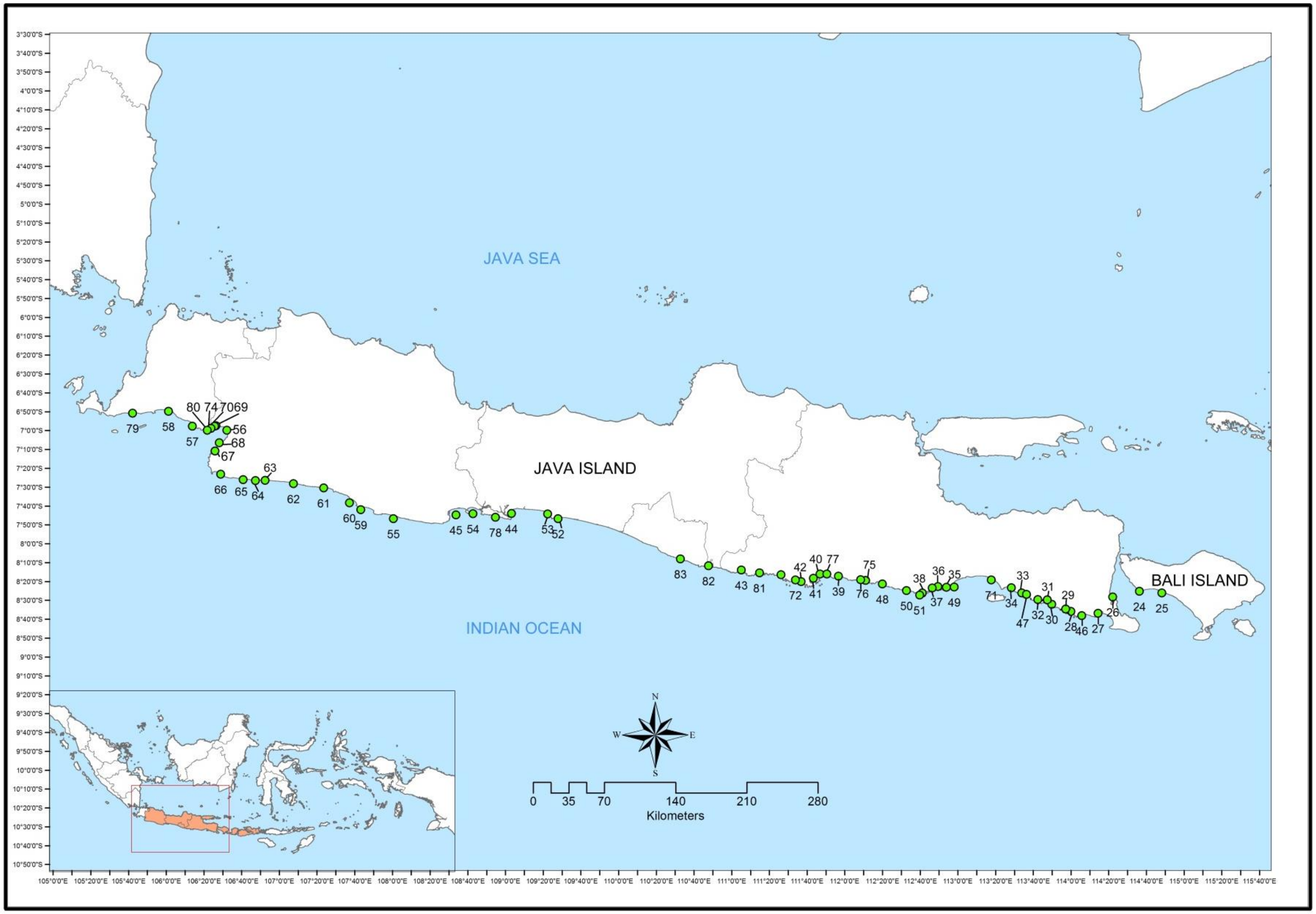

Figure 4.8. Puerulus fishing locations in Bali and Java Islands

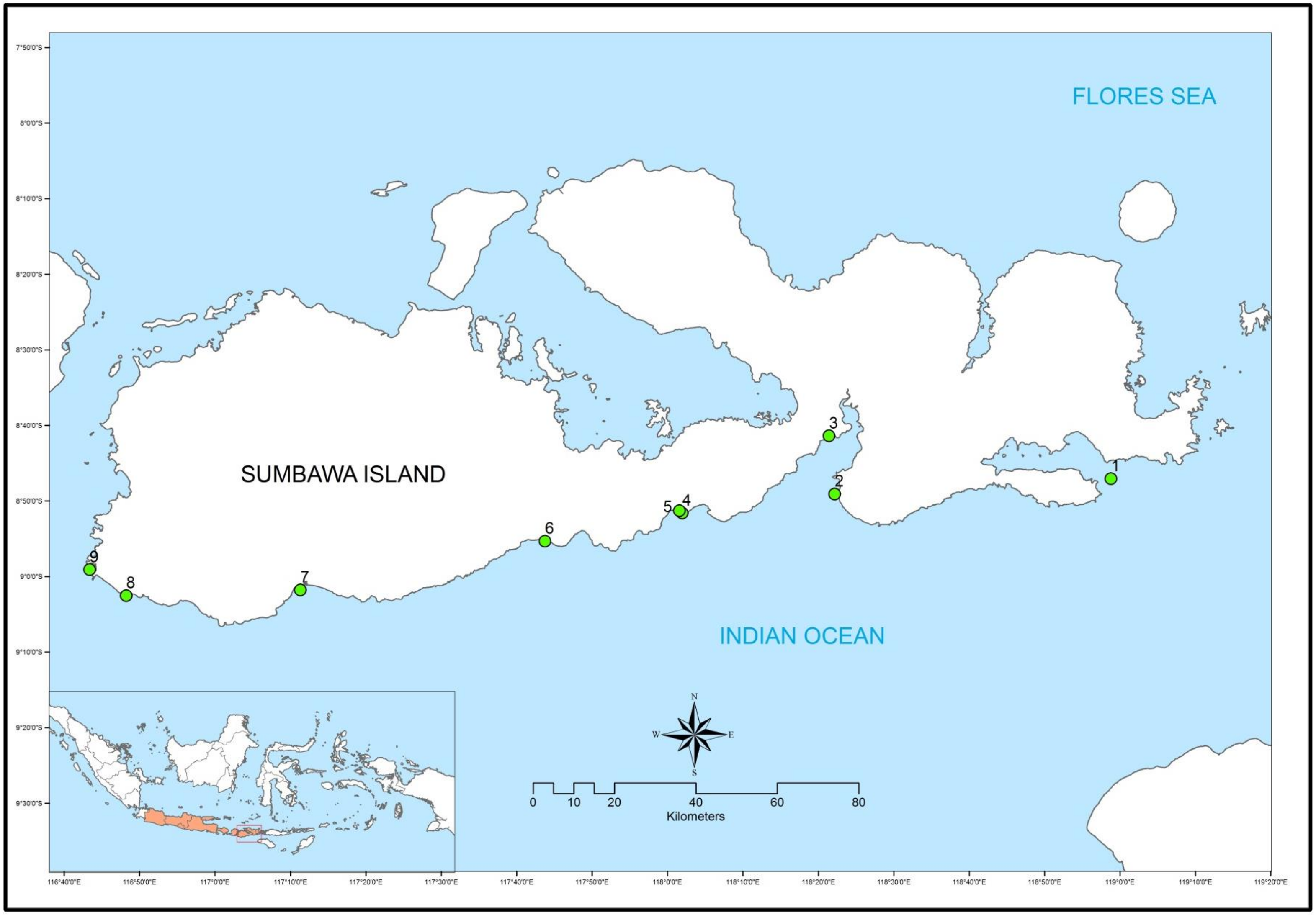

Figure 4.9. Puerulus fishing locations in Sumbawa Island

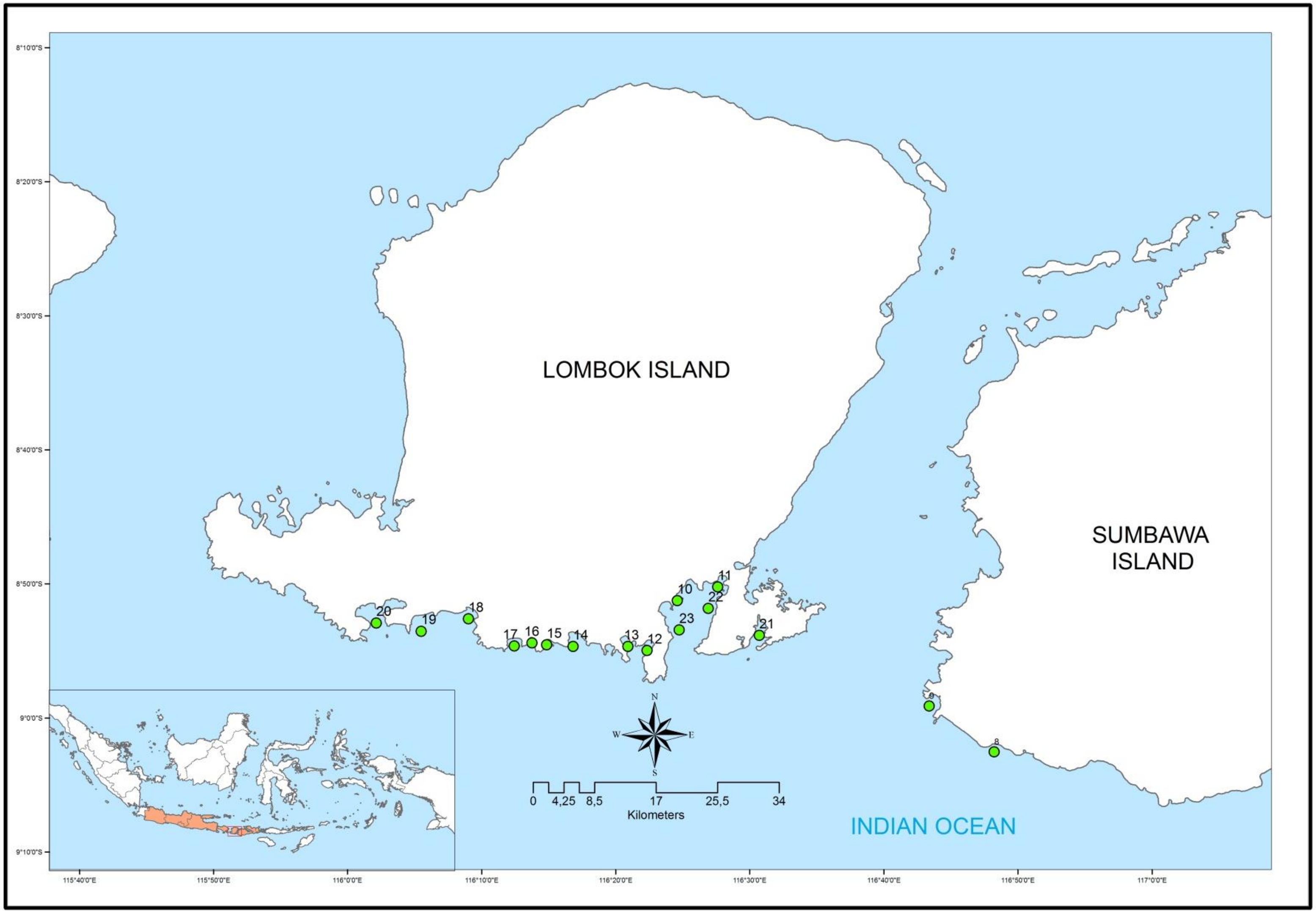

Figure 4.10. Puerulus fishing locations in Lombok Island

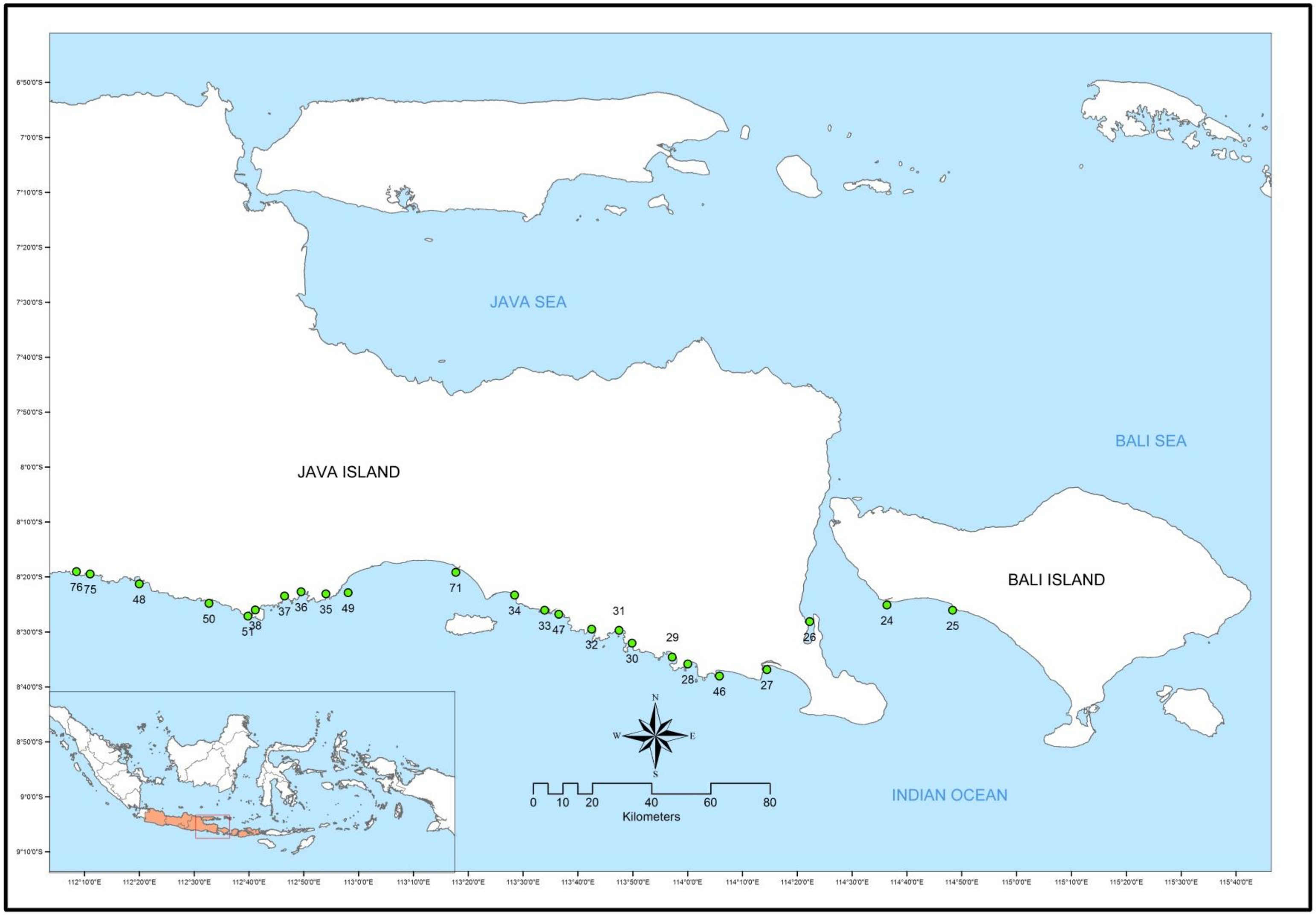

Figure 4.11. Puerulus fishing locations in Bali and the eastern part of Java Island

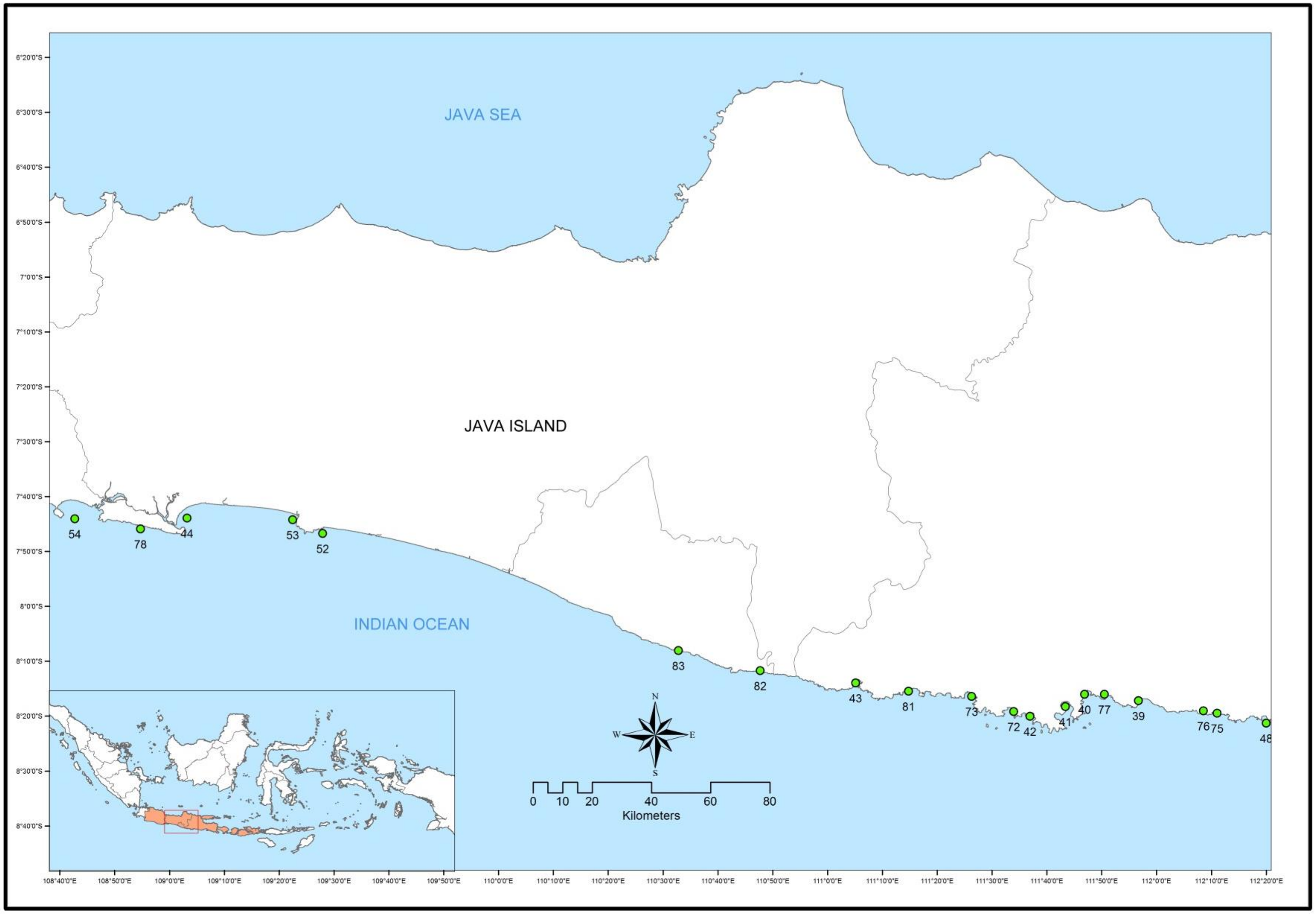

Figure 4.12. Puerulus fishing locations in the central part of Java Island

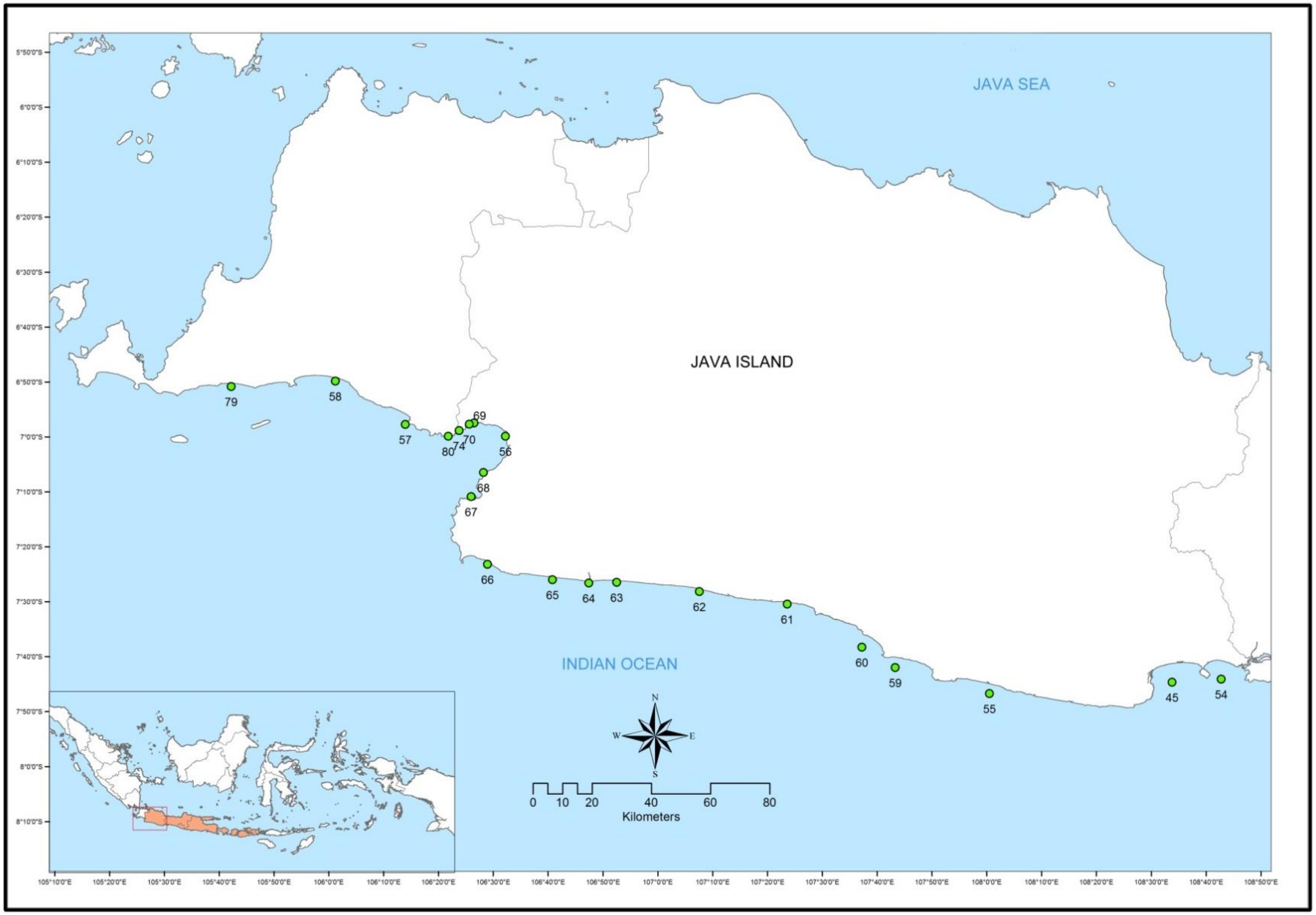

Figure 4.13. Puerulus fishing locations in the western part of Java Island

4.4 Discussion

In the absence of commercially viable hatchery technology, spiny lobster aquaculture relies on supply of seed lobsters from the wild. Natural settlement occurs widely throughout the distribution of the species of primary interest, *P. ornatus* and *P. homarus*. The nature of the reproduction and larval development of these species produces a dispersal pattern that generally takes these phyllosomas far from the location of spawning, carried by ocean currents for up to 6 months, as the larvae progressively develop and grow until metamorphosing to the puerulus stage. Pueruli are likely to settle on all parts of the coastline—so extensive is their dispersal. However, in some areas it is now evident that relatively large numbers are present, aggregated by the nature of ocean and coastal currents and their behaviour, which appears to involve directional swimming towards preferred environmental conditions (Jeffs and Holland, 2000, Caputi et al., 2001, Underwood et al., 2004). It is likely that habitat suitable for pueruli is different from that suitable for adults. This study compiled knowledge of the environmental conditions associated with high numbers of pueruli, gathered from the puerulus fisheries of Vietnam and Lombok, and applied it more widely in Indonesia to predict where additional resources of pueruli may be found.

In Lombok, what began as a chance finding of a few pueruli settling on sea-cages or seaweed farms in the early 2000s, progressively grew to a targeted puerulus fishery that evolved with increasing knowledge and skills among the fishers. The growth was also bolstered by exposure to the advanced puerulus fishery of Vietnam, with catch rates growing year by year until it was revealed that two relatively small bays—Ekas and Gerupuk Bays in south-east Lombok—were generating an annual catch of pueruli of >3 million; equivalent to the entire puerulus fishery of Vietnam. The basis for a significant lobster farming industry was provided by this one small area. However, other factors have intervened to constrain the fulfilment of the opportunity. Limited farming skills, the attractive ease of selling seed as a cash crop to meet ever-growing demand from Vietnam and fisheries policy restrictions have been the most influential factors withholding further development of lobster farming in Indonesia. Nevertheless, the potential remains and has grown in magnitude as the puerulus fishery of Indonesia has expanded, beyond Lombok, where it has been revealed that the conditions that deliver the very high numbers of pueruli extend a significant distance to the east and west, providing a puerulus resource perhaps 20 times larger than that of Vietnam.

There is necessary wisdom in carefully managing the exploitation of natural resources, including those of a renewable nature such as fisheries that are cyclically replenished through annual reproduction. For tropical spiny lobsters, such resource management is complicated by the broad distribution of the species and homogeneous populations that span multiple countries and ocean regions. It is evident in Vietnam that the puerulus fishery is stable and sustainable—based on its longevity and steady catch—despite there being no resource management interventions. The puerulus fishery of Indonesia is relatively new, appears to be much larger and has a different species composition (*P. ornatus* pueruli are less than *P. homarus*). Knowledge of the Indonesian puerulus resource's biological and physical dimensions as generated during the current study will help resource managers and policy makers to make informed decisions to most effectively manage the fishery.

4.4.1 Definition of Indonesia's Puerulus Resource

Data gathered during this study have enabled, for the first time, definition of the puerulus resource of Indonesia. Comprehensive data collected on fishery catch of pueruli from Lombok over several years has generated robust knowledge of species composition, daily catch rates, seasonality and lunar periodicity along with an estimate of annual productivity. This, in turn, has allowed rigorous extrapolation to locations beyond Lombok where pueruli are known to fished, but for which detailed data were not previously available.

4.4.1.1 Quantity

This study has provided an estimate for the total fishable resource of southern Indonesia of 103,480,283 pueruli per year and density of 64,787 pueruli per square kilometre. Without knowledge of the catch efficiency of the fishing gear used, it is not possible to accurately determine the actual abundance of pueruli. However, the catch efficiency of the gear is likely to be <50% and so total abundance of pueruli may exceed several hundred million.

4.4.1.2 Distribution

P. homarus and *P. ornatus* dominate the lobster puerulus captured, with relative proportions of the two varying from year to year and between locations. Overall, the ratio is approximately 80% *P. homarus* to 20% *P. ornatus*. Although other lobster species natives to Indonesia are represented in the puerulus catch, their absolute numbers are very low. It may be that they do not settle in the same locations as the two predominant species and/or the fishing gear used is not attractive to these species.

This study, in combination with that of others (Bahrawi et al., 2015a), confirms that settlement of pueruli is patchy and irregular, and does not appear to be associated with proximity to adult lobster populations. Puerulus assessment studies in Sumatra and Sulawesi demonstrated that relatively low numbers of pueruli settle in the locations examined (Idris & Bahrawi, 2015; Syafrizal et al., 2015,). Similarly, in Lombok, it has been demonstrated that the west coast has a relatively low abundance of pueruli, while the south and particularly the south-east coast has very high abundance (Priyambodo & Bahrawi, 2012). It appears that two conditions must be met to render an area suitable for high puerulus abundance: presence of late-stage phyllosoma as provided by ocean and coastal currents; and local environmental conditions conducive to puerulus settlement. These conditions are met along the southern coastline of Indonesia, from west Java to eastern Sumbawa.

Sufficient data were collected in this study to confirm that *P. homarus* and *P. ornatus* pueruli are most abundant in coastal environments characterised by enclosed bays with distinct currents, relatively high turbidity often attributable to nearby terrestrial inflows, and muddy/sandy substrates. The data support the hypothesis that late-stage phyllosoma along the coastal fringe likely respond to the proximity of such environmental characteristics, metamorphosing to the puerulus stage and actively swimming towards preferred habitat, as suggested for other species (Jeffs & Holland, 2000).

4.4.1.3 Seasonality

The puerulus catch along the southern coastlines of Java, Bali, Lombok and Sumbawa occurs throughout the year, although with increased catch rates from May to July and from November to December that appear to correspond with likely summer breeding in populations in both southern and northern hemispheres. The pueruli settling in southern Indonesia are likely to have originated from several breeding populations with spawning events likely to be spread over time. Given that larval development can range from 4 to 6 months (Booth, 2002; Booth & Phillips, 1994), the supply of pueruli is protracted and seasonality is less distinct than in Vietnam where the supply is likely to have come solely from northern hemisphere spawning.

4.4.2 Sustainability of Puerulus Capture

The sustainability of puerulus fishing is one of the most important considerations in the management of lobster resources. There may be little effect on adult populations and the fishery of removing them from the wild (Jones, 2015a; Phillips et al., 2003b). Research on the Caribbean rock lobster *P. argus* (Lipcius et al., 1997) showed that in some locations adult abundance is low and post-larval (puerulus) abundance is high. The nature of regional and local oceanic currents plays a pivotal role in the presence of pueruli in such locations (Booth, 1979; Briones-Fourzán et al., 2008; Lipcius et al., 1997). These are termed 'sink' populations, because most of those pueruli will not survive or contribute to adult populations (Briones-Fourzán et al., 2008; Lipcius et al., 1997). The puerulus supply is effectively disconnected or decoupled from adult abundance. Occurrence of such sink populations of lobster pueruli is greatly enhanced by the biology of the species, particularly the long duration (4–6 months for tropical species) of the larval phase. The phyllosoma larvae are released where they are subject to oceanic currents that physically transport them very long distances from where they were spawned (Dias, 1996; Pulliam, 1988, 1996).

The *P. homarus* and *P. ornatus* puerulus resource of southern central Indonesia (along the southern coastline of Java, Bali, Lombok and Sumbawa) is likely to represent a sink population. In Indonesia, there is a confluence of geographic and oceanographic conditions that would likely lead to a concentration of late-stage phyllosoma larvae (particularly of *P. homarus* and *P. ornatus*) in the Java Sea generated by the pull of the Indonesian Throughflow—a powerful current running south through the strait between Bali and Lombok (Dao et al., 2015). As this current enters the Timor Sea to the south, it slows and eddies west to Java and east to Lombok and Sumbawa, where late-stage phyllosomas likely complete their development, transform into pueruli and then settle along the coastline in this region. Their concentration along this coastline appears to be far higher than elsewhere, based on semi-quantitative surveys undertaken in other Indonesian provinces (Bahrawi et al., 2015a; Idris & Bahrawi, 2015; Syafrizal et al., 2015). In addition, there is very limited suitable natural habitat in the settlement locations to support juveniles and adults. The southern coastlines of Java, Bali, Lombok and Sumbawa are characterised by steep topography, with narrow strips of fringing reef adjacent to the coast before immediate drop off to depths unsuitable for lobster habitation. Consequently, the bulk of the lobster seed settling in these locations are likely to die from natural attrition. Such high natural mortality of settling pueruli has been suggested for other species (Gardner et al., 2006; Herrnkind & Butler, 1994; Phillips et al., 2003a), with estimates of natural survival of lobster puerulus ranging from 1.3% to 3.0% from settlement to 1 year. The lobster seed population of southern Indonesia can accurately be described as a "sink population" as it is disconnected from the reproductive stock from which it arose (Dao et al., 2015; Jones, 2015a). An additional factor affecting natural survival of pueruli in Indonesia is the nature of the environment where they settle. The habitat in much of the settlement area in Lombok, Java and Sumbawa is sub-optimal for lobsters, with highly turbid water, reduced salinity and muddy substrate; thus, survival of lobster seed there is likely to be even lower than it may be in other locations, possibly <1%. The proposition of low pueruli survival due to habitat factors is hypothetical, but is nevertheless presented with confidence based on documented habitat data (Milton et al., 2012; 2014) for the species involved. There have not been any such laboratory studies, and such research is strongly justified. The pueruli of *P. homarus* and *P. ornatus*, are likely to be quite resilient. However, their survival is low in regard to the post-puerulus stages, the juveniles which would presumably actively seek different, preferred habitat with coral or rocky reef substrate, low turbidity and full marine salinity. Such habitat is in limited supply within near proximity, so it is reasonable to assume mortality would be high in the absence of such habitat. Nevertheless, further research is warranted to assess the puerulus resources more quantitatively and to understand the movement of phyllosoma and pueruli to verify the sink population hypothesis.

If the sink population hypothesis is supported, the lobster seed resource can be exploited to supply seed for farming with no significant effect on adult lobster populations (Jones, 2015a). Although Milton et al. (2014) suggested a high degree of local recruitment in the south-central coast of Java, this is not inconsistent with the hypothesis of a sink, as their modelling also suggested that >25% of recruitment to their study location was sourced remotely. It is noteworthy that Milton et al. (2014) recorded very few *P. ornatus* within the commercial catch in the area, and yet *P. ornatus* pueruli are a significant component of the puerulus settlement in southern Java (Priyambodo & Bahrawi, 2015). Presumably the *P. ornatus* pueruli originated elsewhere and were transported to this location according to the Indonesian Throughflow model as suggested.

Based on the surveys of this PhD study, the puerulus resource (of *P. homarus and P. ornatus*) in south-central Indonesia is particularly abundant and substantially greater than other coastal areas of Indonesia. This can be explained by a concentration of pueruli generated by the power and volume of the Indonesian Throughflow (Dao et al., 2015). There is very limited suitable adult habitat in the region where this puerulus population occurs, and on balance there is a high probability that the bulk of these pueruli perish. Their exploitation for the purposes of aquaculture is thus likely to be sustainable.

4.4.3 Puerulus Fishery Management

Indonesia's lobster puerulus fishery originated on the island of Lombok where annual puerulus catch is estimated to have peaked at around 3 million pieces in 2013/14 (Bahrawi et al., 2015b). Based on the primary data generated in the current study, the number of puerulus caught in 2014 was estimated at 5,243,887. However, in 2015, the Indonesian government introduced new fishery regulations specifying a minimum legal size for rock lobster of 200 g (all species) (see Chapter 2). Although this was aimed at management of adult resources, it effectively made fishing of pueruli illegal.

At this time a burgeoning lobster puerulus export industry was developing, as Indonesian puerulus dealers became aware of the high demand for lobster pueruli in Vietnam. From 2015 to 2017 enforcement of the regulations increased, as did the frequency of seizure of shipments and the magnitude of penalties for offenders. Consequently, there was a decrease in puerulus fishing activity and of catch, and current catch data are uncertain. Data collected in Lombok from 2007 to 2014 revealed some seasonality to the catch. Figure 4.4 shows the peak catch was between March and November, although fishing continued throughout the year. Monthly catch data for each of *P. homarus and P. ornatus* in 2013 presented in Figure 4.6 show the relative proportions of the two species. The marked increase in price from 2012 to 2013 is attributed to increased demand as export from Indonesia to Vietnam began. Interestingly, although catching and trading of pueruli is illegal, their price continued to increase into 2015 with greater disparity between the species. Higher demand for *P. ornatus* saw the price increase to >5 USD per piece, while that for *P. homarus* reached a high of 2 USD.

Marine aquaculture based on natural seed supply is not unique as the seed resources are typically abundant (Sadovy & Lau, 2002). Throughout South-East Asia, artisanal aquaculture of mud crabs and reef fish species is largely based on wild seed supply (FAO, 2009). This applies also to spiny lobster aquaculture for which hatchery technology has yet to be developed. Substantial aquaculture operations have been established for other crustaceans and fish (Lucas & Southgate, 2012) using wild seed supply, although in most cases their long-term sustainability can only be assured if a hatchery supply is established. In the case of tropical spiny lobster farming, Vietnam has demonstrated that aquaculture based on a wild seed supply can be successful and sustained (Hung & Tuan, 2009; Jones, 2009, 2010; Tuan & Jones, 2015b). For Indonesia, a significant puerulus resource has been identified upon which a significant grow-out industry could be established (Priyambodo, 2015a; Priyambodo & Jones, 2015).

Because mortality of <25% can be achieved for pueruli captured and on-grown under best practices (Jones, 2015c), aquaculture may provide a way of increasing lobster production, including enhancement of natural populations. Given that the natural mortality of pueruli in Indonesia is likely to be >99% (Jones, 2015a), combining lobster grow-out of wild-caught pueruli and restocking a certain number of farmed lobsters back into the wild may represent a win–win situation. This solution may promote aquaculture as the best option to increase Indonesian lobster production. The three options discussed below provide a quantitative example of how lobster aquaculture might provide an economic stimulus and enhance natural populations. The calculations are based on capture of 1 million pueruli:

1. **Restocking only.** Translocate 1 million pueruli to a new habitat with a 1% survival rate = 10,000 lobsters. Lobster fishers catch 50% of these = 5,000 at 500 g = 2,500 kg × 50 USD/kg = 125,000 USD, with benefits to around 25 fishers (100 kg each).
2. **Aquaculture only.** 1 million pueruli are farmed with 50% survival (500,000) to 300 g = 150,000 kg at 50 USD/kg = 7,500,000 USD, with benefits to around 1,000 household farmers (150 kg each): 150 kg × 50 USD = 4,500 USD for each household farmer.

3. **Combination of aquaculture and restocking.** 1 million pueruli are farmed with 50% survival (500,000) to 300 g; 10,000 of the 500,000 farmed lobsters are released into the wild. The restocked lobsters are large and robust, so their survival is likely to exceed 50%. Thus, the economic benefit will be 5,000 lobsters (50% of 10,000) at 500 g = 125,000 USD of fishery lobsters plus 490,000 (500,000 less 10,000 used for restocking) farmed lobsters = 147,000 kg at 50 USD/kg = 7,350,000 USD. Thus, the combined economic benefit of farming lobsters with 1% returned to the wild is 125,000 + 7,350,000 USD = 7,475,000 USD.

Although the comparative economic benefits of options 2 and 3 are similar, option 3 has the least impact on wild adult populations, thus benefiting the environment and providing benefit to the greatest number of aquaculture and fisheries stakeholders involved. As the natural mortality of pueruli is very high (Jones, 2015a; Phillips et al., 2003a, 2003b), utilisation of the pueruli for the purpose of aquaculture is a viable solution to increase the production of market-size spiny lobster (Booth & Kittaka, 2000; Kittaka & Booth, 1994; Phillips & Kittaka, 2000; Phillips & Liddy, 2003; Phillips & Matsuda, 2011). The enormous number of pueruli available in Indonesia, as revealed in this study, presents an ideal opportunity to develop spiny lobster aquaculture. However, it will be necessary to revise fisheries regulations for this opportunity to be realised. An important consideration is determining how many pueruli can be sustainably removed from the wild.

Removal of pueruli for the purpose of aquaculture has been considered for some rock lobster species in relation to the potential effect on future fishery production and breeding stock, and to achieve 'biological neutrality'—that is, no net effect (Gardner et al., 2006). In New Zealand it was determined that retiring of 1 tonne of quota (fishery catch of adult lobsters) of *J. edwardsii* would allow 40,000 pueruli per annum to be taken for aquaculture (Booth et al., 1999). For *P. cygnus*, the effect of puerulus removals on the subsequent catch was estimated to be slight (Phillips et al., 2003a). For example, the removal of 20 million *P. cygnus* pueruli in Western Australia in a year in which the puerulus settlement size was 600 million pueruli would result in a reduction in adult catch of 0.62%.

This study has revealed that in Indonesia, >100 million pueruli can be fished in one year. It is likely that this number represents a fraction of the actual number of pueruli available, as the fishing equipment used is highly unlikely to catch every puerulus. Nevertheless, this 100 million pueruli figure provides a basis for consideration of how many should be allowed to be taken for aquaculture purposes. In Vietnam, a large, successful lobster farming industry has been established on an annual catch of 3–5 million pueruli (Hung & Tuan, 2009; Long & Dao, 2009; Dao & Jones, 2015; Tuan & Jones, 2015a, 2015b). In Indonesia, if 50% of the fishable lobster seed resource (i.e. 50 million pueruli) was permitted to be fished, this would be sufficient to support production of 12,500 tonnes, assuming 50% survival from puerulus to harvest size of 500 g. This could provide a livelihood for more than 50,000 households.

4.4.4 Policy Recommendations

To best achieve a viable and sustainable lobster aquaculture industry, Indonesia should establish a policy and regulatory framework that sustains existing adult lobster populations; protects and where possible enhances adult lobster habitats; and enables exploitation of puerulus resources for the purpose of farming them to marketable size. Such a framework may consider inclusion of the following: 1/ marine protected areas throughout the country to conserve breeding populations of lobsters; 2/ habitat protection through banning of destructive fishing techniques (explosives and cyanide);

3/ habitat enhancement through strategic placement of artificial lobster habitats; 4/ minimum size regulations that are species specific to allow all species to mature and breed at least once before capture; 5/ a regulated puerulus fishery that allows pueruli to be captured using a standardised habitat trap/collector method in all locations, but restricted to 2 weeks per month—1 week before and after each new moon phase; 6/ the strategic solution should be developed by promoting a better (more efficient and effective) lobster grow-out technology in Indonesia that can be globally competitive. This will create more domestic or national demand for pueruli. However, if the national puerulus demand for aquaculture is fulfilled, then there is scope to export the excess of pueruli given the already high demand in other countries, such as Vietnam. This would enable a local grow-out and pueruli export industry to co-exist. There is also scope to use excess pueruli for stock enhancement where wild lobster catches are allowable; and 7/ permission to farm wild-caught pueruli in sea-cages to a minimum size of 300 g with the requirement that 5–10% of farmed lobsters (of minimum size 50 g) are surrendered for restocking.

By permitting puerulus fishing for 2 weeks in each month around the time of the new moon, catch rates will be maximised as discussed in Chapter 5, benefiting the fisher; 2 weeks of no fishing allows a proportion of seed to avoid being fished and to potentially recruit to local adult populations. Pigmented post-puerulus juveniles are rarely found in collectors, so it is safe to assume that pueruli do not reside in habitats for more than a day or two. Rather, having settled in the habitat provided by the collector, they molt to the first, pigmented, post-puerulus stage and then drop out of the collectors to adopt a benthic existence. Such a short-term, temporal management approach, rather than seasonal or spatial closures, would provide maximum benefit to fishers while protecting the puerulus resource.

4.5 Conclusions

Indonesia has a puerulus resource exceeding 100 million pueruli per year, which is 20 times greater than that of Vietnam where a large, stable and sustainable lobster farming industry based on its own puerulus resource is established. Indonesia's puerulus resource is dominated by *P. homarus* with around 20% *P. ornatus.*

The high abundance of pueruli is confined to an area of coastline along the southern perimeter of Java, Bali, Lombok and Sumbawa and is likely generated by prevailing ocean and coastal currents—particularly the Indonesian Throughflow—and suitable settlement habitats. Indonesia has a strong opportunity to sustainably exploit its puerulus resource to support a large lobster farming industry, with benefits to many thousands of coastal communities.

Chapter 5: The Effect of Collector Type and Water Depth on Puerulus Settlement in the Spiny Lobster Aquaculture Industry in Indonesia

5.1 Introduction

As discussed in Chapter 2, in the global supply of spiny lobster, the capture fishery for market-size spiny lobsters (Palinuridae) is either stable or in decline (Booth & Kittaka, 2000, Jones, 2009b, Phillips et al., 2006b). It is tenuously linked to the supply of puerulus caught from the wild until hatchery technologies are developed, but remains a lucrative and viable alternative to wild capture of market-size lobster (Jones, 2010). At the time this study was initiated, Vietnam and Indonesia were the main growing areas for spiny lobsters, followed by the Philippines and Singapore; production is now largely abandoned in Cuba and Taiwan (Phillips, 2013). However, Indonesia's spiny lobster market-size production is now influenced by the recent implementation of regulations as outlined in Chapter 2. Nevertheless, there is scope for growth, particularly if regulations are amended to enable the industry to recommence puerulus collection and grow-out of lobsters in Indonesia. Given that decision making should be informed by science, this study has undertaken approved research to test technologies that improve farming efficiency as part of the overall quest for a better understanding of optimal practices for lobster farming in Indonesia, with potential application in countries already undertaking or considering lobster farming as a livelihood for their citizens.

Between 2000 and 2012, puerulus capture in Indonesia was undertaken only in Lombok, where it was meeting local demand for seed for grow-out in sea-cages (Priyambodo & Sarifin, 2009; Priyambodo & Suastika-Jaya, 2009, 2010). Puerulus fishers in Lombok use a variety of collectors made from inexpensive recycled materials set in areas where pueruli are known to settle (Priyambodo & Sarifin, 2009). Demand is now exceeding the capacity of fishers to supply puerulus due, in part, to inefficient collection methods. Knowledge from Vietnam, where a lobster aquaculture industry is well developed (Jones & Tuan, 2013) has been transferred to Indonesia, resulting in increased catch (Bahrawi et al., 2015b (and see Chapter 3), but there is very little scientific knowledge on the efficiency of different types of collectors and the depths at which they should be set.

Accordingly, this chapter addresses the research question: “Which collector types are most effective for collecting pueruli and what effect does collector depth have on the puerulus catch rate?” The main focus here is on examining the effect of depth and different collector types on puerulus collection at the end of the wet season, when pueruli are in abundance (Bahrawi et al., 2015a).

This study applied six floating frames on which the collectors tested were submerged. Similarly, basket floats were used to hang crevice collectors; natural and artificial seaweed collectors as reported in Ewing et al. (2013), Ewing and Frusher (2015) and Phillips and Booth (1994). The bamboo frames are inexpensive to construct using locally available materials, relatively strong when tied together and easy to handle. Collectors built from cheap, lightweight materials may be more cost effective in commercial operations than collector designs currently used in scientific studies of puerulus settlement (Mills & Crear, 2004; Phillips & Booth, 1994). Through trial and error, the materials and design of puerulus collectors used by Lombok lobster farmers have evolved and improved, but there is no standard approach to the depth at which collectors are set. Based on the literature (Butler & Herrnkind, 2000; Ewing et al., 2013; Griffin et al., 2001) on puerulus settlement for a range of species, depth may be a critical variable in the catch of lobster puerulus in Lombok. Puerulus fishers report variable success that they believe may be associated with collector type and depth.

This study investigates the effect of the type and depth of deployment of four collector types made from locally available materials, which are similar to those commonly used in Vietnam as reported in Hung and Tuan (2009) and Jones et al. (2010b). The study was conducted in Southeast Lombok, where wild puerulus collection for grow-out and export has become the dominant mariculture activity. The field experiments were conducted at the end of the wet season when wild puerulus settlement is greatest (Bahrawi et al., 2015e). The goal of the study was to develop better practices for collection of wild lobster pueruli in Indonesia using low-technology approaches, recycled and locally available materials and more effective location of collectors.

5.2 Materials and Methods

5.2.1 Materials

5.2.1.1 Collector materials

The study employed six floating frames (the term here is used for the replacement of puerulus sea-rafts, where the collectors attached to the frames) (Figure 5.1), made from bamboo (1.5 × 1.5 m) supported by four buoys made from polystyrene foam balls and anchored to the sea floor from two adjacent corners of the frames with ropes and heavy weights. The six floating frames, representing six replicates, were randomly placed among puerulus sea-rafts owned by local farmers in Awang Bay (8°52'44.1"S 116°24'01.2"E) (Figure 5.2). The water depth at the position of each frame ranged from 5 to 17 m, which is common for the industry. The nature of the sea floor where the collectors were set was mostly sandy with some mud, and the bottom water was moderately turbid. Booth (2001) pointed out that both pueruli and first instar juveniles of palinurid species are capable of almost completely burying themselves in sand, but are intolerant of deep silt.

Four puerulus collector types (timber poles, monofilament nets, rice bags and cement bag paper) were suspended (one on each corner) from the frames. For each collector type, a unit of that collector was suspended at i) 1 m below the surface; ii) 2 m below the surface; iii) in the middle of the water column; iv) 1 m above the sea floor; and, v) touching the sea floor, from a single line. Each collector line was held in place with a 5-kg sand-filled bag as ballast.

Therefore, each of the four collector lines had five collector units positioned at the designated five depths, providing a total of 20 collectors on each frame on which pueruli might settle.

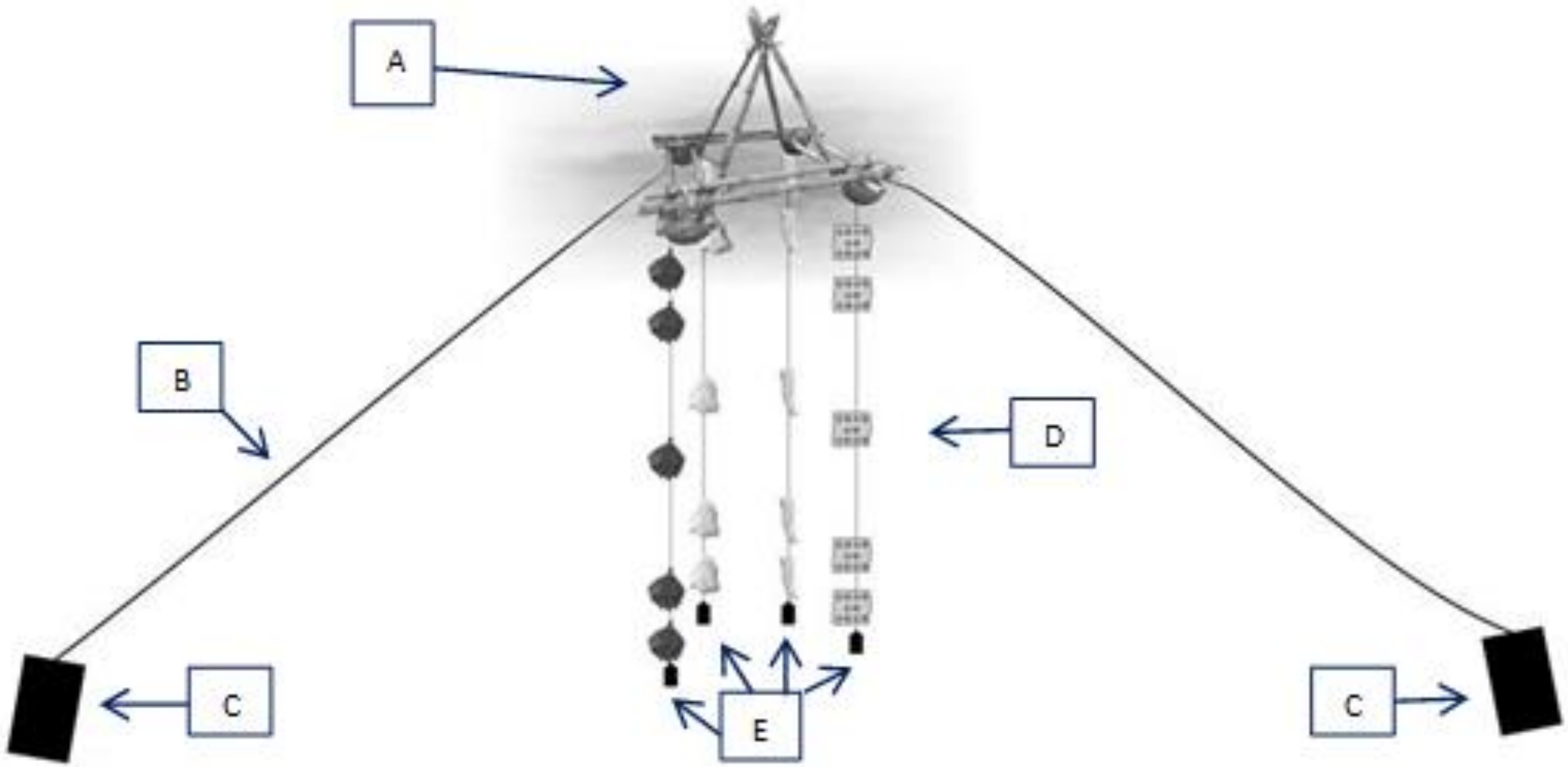

Figure 5.1. Illustration of a floating frame showing the four trap types used in the experiment, (A) floating frame called tripod, (B) anchor rope, (C) anchors, (D) 4 (four) type collectors hung at monofilaments which are lined in each corner of the tripod.

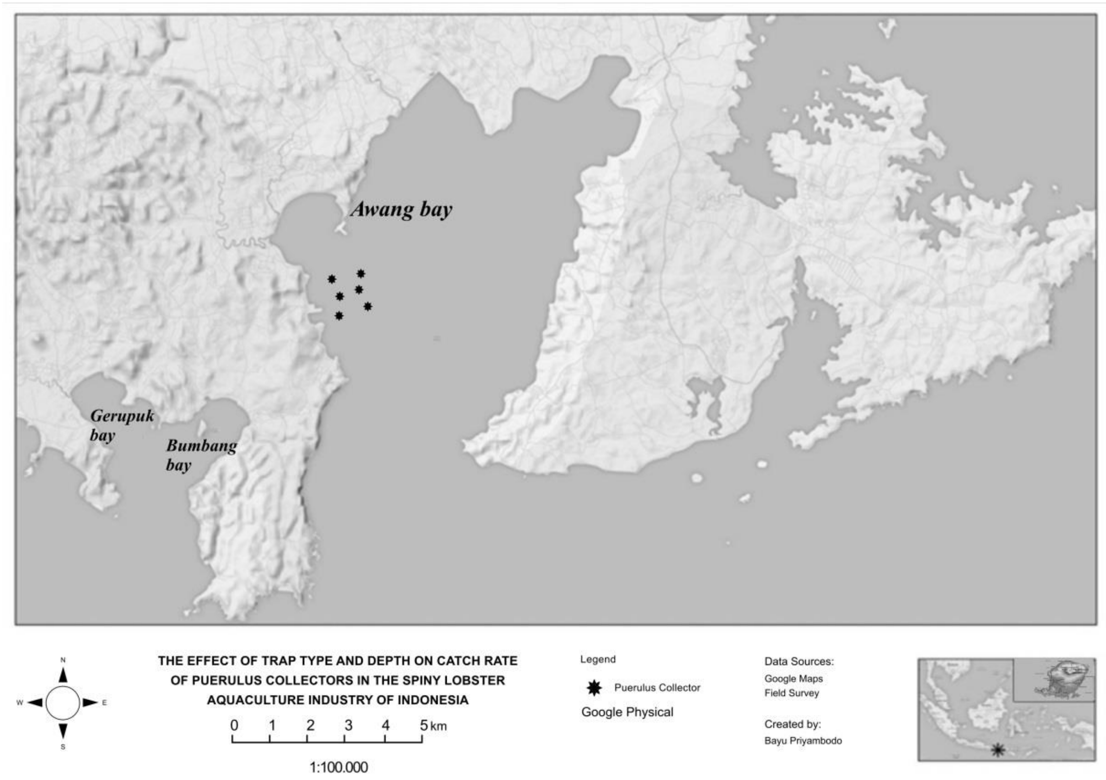

Figure 5.2. Location of puerulus fishing area and site of the experiment in Southeast Lombok, Indonesia

5.2.1.2 Collector types

The collector types used for this assessment are shown in Figure 5.3. Each timber pole collector consisted of a piece of tree trunk, approximately 60–70 cm in length and 70–100 mm in diameter, in which 30, 10-mm diameter holes were drilled at regular intervals (Figure 5.3A). Each monofilament collector was made from monofilament fishing net with a mesh size of 50 mm and a filament diameter of 0.2 mm, formed by folding in half 1 × 1-m pieces of net (Figure 5.3B). Each rice bag collector consisted of a common double-layer rice bag (50 × 70 cm) folded in the middle (Figure 5.3C). The cement bag paper collector was made from disused paper cement bags folded in concertina fashion and fixed in the centre to form a 'bowtie' shape. A unit cement bag paper collector consisted of 10 'bowties' attached to a frame of monofilament net with the dimension of 50 × 50 cm. Bowtie collectors were arranged in arrays on both sides of the frame, that is, five on each side. The frame's purpose was primarily to attach the bowties, but served a secondary function as a barrier to intercept the swimming pueruli, leading them to settle in the collectors. The space between the collectors is illustrated in Figure 5.3D. The design and quantity of materials used represented the researchers' best efforts to ensure that the collectors were of similar dimensions and to minimise differences in the available area for settlement.

Figure 5.3. The four trap types used in the study: timber poles (A), monofilament fishing nets (B), rice bags (C) and cement bag paper (C)

5.2.2 Methods

5.2.2.1 Site selection and sampling schedules

Before Decree 1/2015 was implemented as described in Chapter 2, there were three main puerulus fishing areas; Gerupuk, Bumbang and Awang Bays located on the south-central and south-east coasts of Lombok (Figure 5.2). Awang Bay was chosen for this study because a census of catch rates in 2013 (Bahrawi et al., 2015b) showed this location to be the most productive collecting area in Lombok. The experimental collectors were set up at the study site on 7 March 2014 during the peak season for puerulus (Bahrawi et al., 2015e; Jones, 2010; Priyambodo & Sarifin, 2009). Collectors were submerged at the site one week prior to commencement of the experiment. The main purpose of the one-week gap was to enable bio-organisms to grow on the surface layers of the artificial collectors. These bio-organisms, then, will provide a natural environment, similar to the biofilm and biome of surfaces in the wild, which may be preferred by pueruli to settle. The collectors then had been checked regularly every two days until 21 April, providing 20 data points over the 46-day experiment. Dennis et al. (1997) suggested the depth preference for newly settled *P. ornatus* is 3–21 m.

Lombok has a wet (west monsoon) and dry season (east monsoon). The wet season usually commences in October, intensifies during November and may last until March of the following year (Keast et al., 1997). From January to February, a predominant gentle breeze blows from the west to north-west. By March to April, when the experiment was conducted, a light breeze blows from the east to the north-west. Current velocity during the east monsoon averages 0.048–0.130 m/sec and current direction is to the south-west (182–262º) (Ismunarti & Rochaddi, 2013).

Collectors were checked from a boat in the morning. Pueruli were collected from each collector once every two days by manually retrieving each collector line and examining it carefully by hand. Each puerulus was removed from the collector by grasping its body, which has total length of about 30mm, with two fingers, or if it was positioned deep within a crevice, by grasping its antennae. Each puerulus was then placed carefully in a clean seawater in a bucket. Pueruli were counted on board the boat to minimise escape during handling. The recorded data included date of capture, frame number, type of collector, water depth, position of collector in the water column and species and number of pueruli on each collector. After counting, pueruli were transferred to a sea-cage to avoid re-settling and potential re-counting. It took approximately 3 hours to cover all collectors, starting from 7 am.

5.2.2.2 Data analysis

A two-way analysis of variance (ANOVA) using SPSS (version 20) was used to analyse the effect of depth and collector type. Comparison of means was made using least significant differences. Significance was attributed to p values <0.05.

5.2.2.3 Species determination

To identify the species, diagnostic characteristics of the antennae and body morphology were assessed as per Table 5.1 and Figure 5.4, based on well-established criteria used in Vietnam (Hoc Tan Dao, Institute of Oceanography of NhaTrang, personal communication). Only the puerulus and post-puerulus of *P. ornatus* and *P. homarus* were identified to species, as shown in Figure 5.4.

Table 5.1

Morphological Characteristics Used for Species Identification of Puerulus and Post-puerulus Lobsters

Species	**Morphological characteristic**
P. homarus (puerulus)	Antennae—transparent along the entire length with initially a single distinct pigment band in the proximal half, developing to banding along the entire length. Initial pigment band remains darker than the others. No terminal bulb. Length of antennae is 1.5–2 times the length of the body. Abdomen—as pigmentation develops, mottled brown with no white stripe.
P. ornatus (puerulus)	Antennae—first third from base is transparent, followed by a narrow pigmented band, then opaque white to terminal end, which is bulbous. The terminal bulb is opaque along the proximal half and brown/black for its distal half. Length of the antennae is 1.5–2 times the length of the body. Abdomen—a distinct white stripe along the proximal half of the abdomen develops during pigmentation, otherwise it is mottled brown.
P. homarus (post-puerulus)	Antennae distinctly banded. Dark bands 2–3 times longer than white bands. Abdomen—mottled with no white stripe. Distinct red eyespot between eyes.
P. ornatus (post-puerulus)	Antennae—distinctly banded, with club ends still present. Abdomen—distinct white stripe along proximal half of abdomen, otherwise mottled brown.

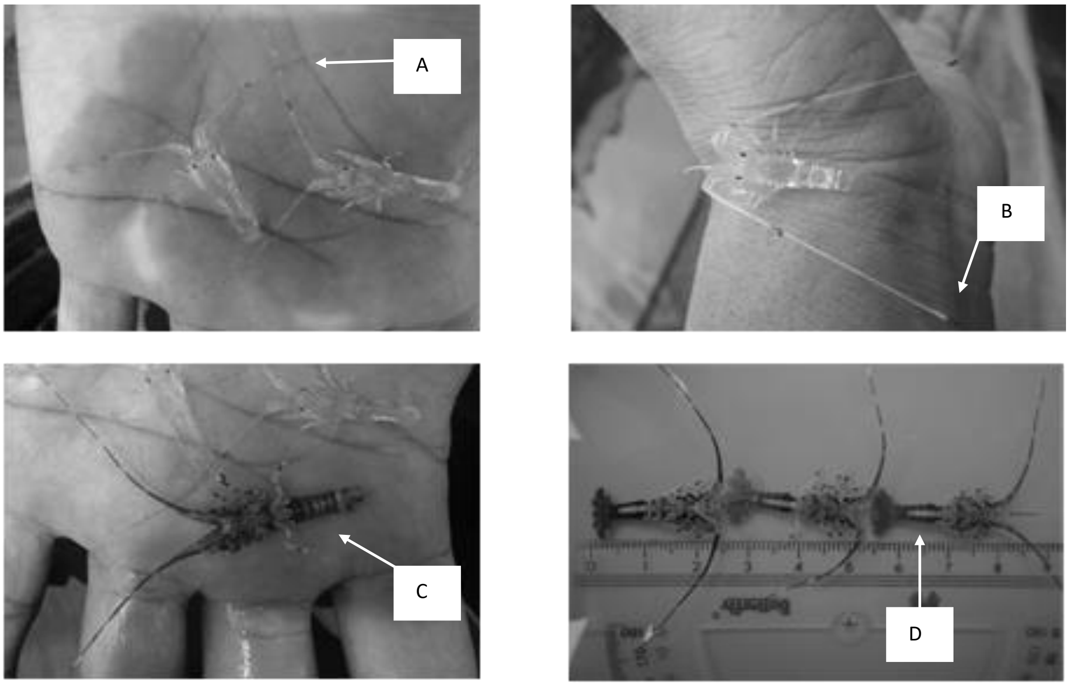

Figure 5.4. Puerulus (A) and post-puerulus (B) stages of *P. homarus,* and puerulus (C) and post puerulus (D) of *P. ornatus* stages with arrows showing the difference parts of the antennae and abdomens between the two different specimens

5.3 Results

5.3.1 The Effect of Collector Type on Settlement

A total of 518 pueruli were collected from all the collectors: 93 *P. ornatus* and 425 *P. homarus*. The total number of pueruli caught indicates the high level of variation in catches from collectors at a single site over a two-month sampling period. The average size of captured pueruli was 7.7±0.3 SE (mm) in total length.

For *P. homarus* there was a significant interaction between the effects of collector type and depth on puerulus catch ($F(12, 100) = 10.16$, $p < 0.001$). Simple main effects analysis showed that both collector type ($p < 0.001$) and depth ($p < 0.001$) had a significant effect on the number of puerulus caught. The comparison of means for *P. homarus* data showed there was no significant difference in catch between depths 1, 2 and 3, but significantly higher catches at depth 4 and the highest catch at depth 5.

There were significant differences in catch among all collector types, with catch increasing significantly from timber collectors to netting to rice bags and the highest catch being for cement bag paper collectors. Overall, maximum depth (i.e., touching the sea floor) combined with the cement bag paper collector produced a significantly higher catch than any other combination.

For *P. ornatus* there was no significant interaction between the effects of collector type and depth on puerulus catch, but there were significant main effects for collector type ($F(3, 100) = 3.20$, $p = 0.026$) and depth ($F(4, 100) = 20.38$, $p < 0.001$). Comparison of means for *P. ornatus* data showed there was no significant difference in catch between depths 1, 2 and 3 but significantly higher catch at depths 4 and 5. The only significant difference among collector types in catch was between cement bag paper and timber collectors. It is difficult to achieve statistical significant because these results are likely to have been influenced by the relatively small numbers caught for this species. Nevertheless, catch of *P. ornatus* was highest for cement bag paper collectors when positioned on or near the sea floor. An ANOVA summary table of these interactions is presented in Table 5.2.

Table 5.2

ANOVA Interaction Data for Comparative Interactions within Collectors, Depths, and Collectors v. Depths for P. ornatus and P. homarus Pueruli

Comparisons	**Interaction**
A. *P. ornatus*	
1. Collectors	$F(3, 100) = 3.205$, $p = 0.026$
2. Depths	$F(4, 100) = 20.385$, $p < 0.001$
3. Collectors *v*. Depths	$F(12, 100) = 0.969$, $p = 0.483$
B. *P. homarus*	
1. Collectors	$F(3, 100) = 31.310$, $p < 0.001$
2. Depths	$F(4, 100) = 70.075$, $p < 0.001$
3. Collectors v. Depths	$F(12, 100) = 10.160$, $p < 0.001$

No pueruli of either species were caught at 1 m below the surface, and very few were caught at 2 m below the surface. Similarly, very few pueruli of either species were caught with the timber pole collector. Collectors set near the shore caught many fewer pueruli than those set offshore, although comparisons of the mean catch among locations identified no significant difference in puerulus catch among the shallower and deeper depths of the collectors, that is, “depth 1’’ vs. “depth 2” etc. The figures for mean catch of *P. ornatus and homarus* over the 46 nights are presented in Figures 5.5 and 5.6, respectively.

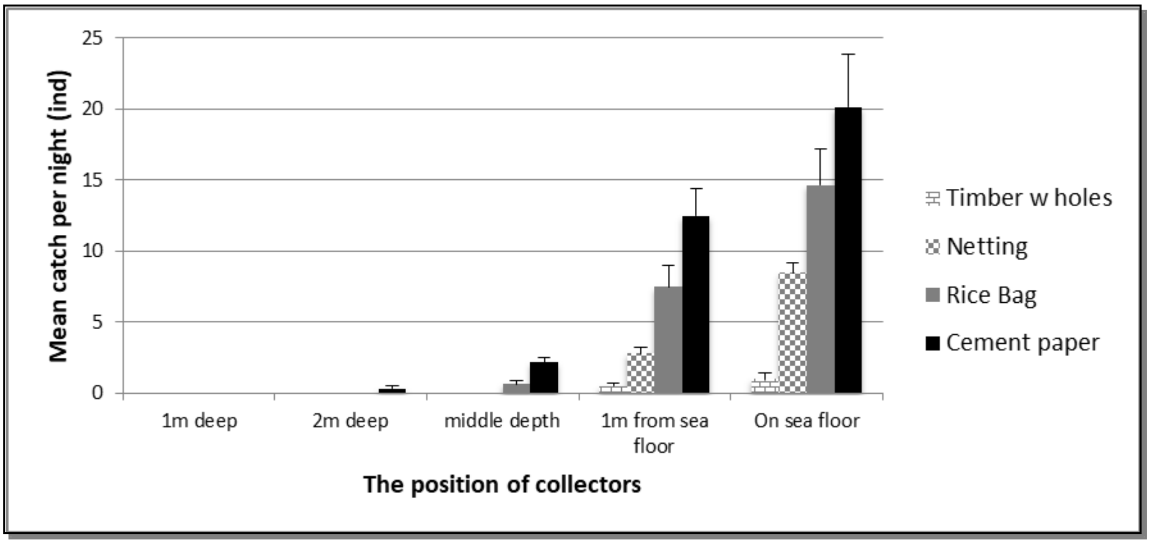

Figure 5.5. Mean catch of *P. homarus* over 46 nights (20 data points) from different depths and collector types

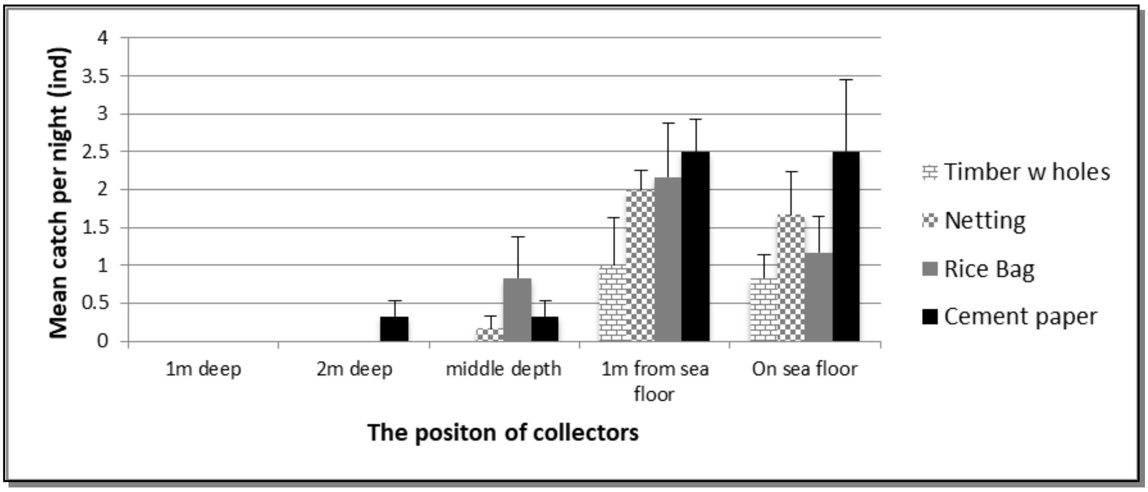

Figure 5.6. Mean catch for *P. ornatus* over 46 nights (20 data points), which represents wider array of depth compared to *P. homarus* from different depths and collector types.

5.3.2 The Effect of Lunar Phase on Settlement

An examination of the data to identify any lunar periodicity in puerulus settlement was made via an ANOVA on catch numbers. Data were pooled for depths 4 and 5, and for rice bag and cement bag paper collector types as they represented substantially number of settlement , and assigned to one of four moon phases: full moon (±3 days), 3rd quarter (±3 days), new moon (±3 days) and 1st quarter (±3 days). There was no significant difference in catch according to lunar phase for either species. The examination of the data using average catches for each moon phase, however, showed no significant difference (F (12, 30) = 1.440, p = 0.277). Average catch +/- Standard Deviation per night is shown at Table 5.3.

Table 5.3

Mean Number of Catches for Each Moon Phase

No	Lunar Period	Standard Deviation
1	Full moon	0.71 +/- 0.24
2	1st quarter	0.70 +/- 0.34
3	New moon	0.69 +/- 0.33
4	3rd quarter	0.62 +/- 0.31

The duration of the experiment was not long enough to be conclusive, and future studies could examine this factor. Anecdotal data from Vietnam suggests new moon catches are higher (Long and Dao, 2009). Therefore, attempts should be made in future work to examine moon phases relative to settlement, with a view to explaining localised differences in settlement pattern, and achieving a more quantitative measure of settlement.

5.4 Discussion

The results demonstrate increasing settlement with collector depth and show that cement bag paper traps are significantly more effective than rice bags, nets and timber pole traps, which have different shape and texture. For both species, the majority of pueruli caught in the cement bag paper trap settled at depths 4 and 5. The lack of settlement at 1 m below the surface indicates that settlement is unlikely at shallow depths for both species. This contrasts with results reported by Phillips et al. (2001), who investigated a modification of a sandwich trap, deployed at different depths and distances offshore. In their study, only surface traps set in shallow inshore water (<5 m) caught pueruli of *P. cygnus*. Montgomery (2000) highlighted factors that may affect catches of pueruli on collectors, including the position of the collector in relation to its place in the water column, its proximity to a reef and its exposure to sea-swell. Other factors include the level of light, strength of water flow, type and texture of the substrate and the presence of predators.

Booth (2001) studied the habitat preferences of Palinuridae, reporting that for most species pueruli are found in small holes and crevices in hard substrates. These include the pueruli of *P. japonicas, P. cygnus, P. guttatus, P. longipes, P. versicolor, P. penicillatus* and *J. edwardsii.* However, hard substrates, which in the experiments here were represented by the timber poles with holes, may not be preferred by *P. ornatus* and *P. homarus* in the environments of the study site. They were not preffered by the pueruli because most timber poles were fouled with barnacles. Similarly, although net and rice bag traps caught more pueruli than timber traps, these traps are not recommended for these species in this particular settlement area because they were easily covered by mud and bio-fouling organisms, respectively. Hence, it is concluded that timber pole, net and rice bag traps are inefficient compared with cement bag paper traps at the study site.

Anecdotal information from puerulus fishers in Lombok suggests the size of the cement bag paper traps and concertina design affects the settlement of pueruli. They identified a 3-cm width as the most effective size for the concertina. In addition, the positioning and attachment of the 'bowties' to a net frame increases the trap's efficiency. Over time, there has been a trend towards a larger surface area for net frames. Similarly, more bowties are added per frame to improve the efficiency of the traps. For example, it is not unusual to have up to 20 bowties on a 1.2 × 2.0-m layer net frame.

Phillips et al. (2006a) indicated that pueruli of some species are exclusively captured in dark new moon while for other species no lunar effect is evident. Anecdotal information from puerulus fishers from Vietnam and Indonesia supports the correlations, as fishers suggest there is a greater abundance of pueruli of both *P. homarus and P. ornatus* at times of the new moon. The data from this study provide no evidence for such periodicity, although it should be noted that the duration of the experiment covered only 1.5 lunar cycles. To fully explore lunar periodicity, sampling over several months would be required.

Dennis et al. (1997) and Butler and Herrnkind (2000) suggested that the natural habitat of juvenile *P. ornatus* and *P. homarus* includes small holes in rocks or reefs scaled to their body size. This study found that the pueruli did not prefer structures simulating small holes in rocks or reefs do not argue against the natural habitat including small holes in rocks or reefs. The equivalent structured habitat, the timber pole with holes, was less attractive than other collector types. However, there is likely to be differential preferences for newly settling pueruli and juveniles. The present study suggests the pueruli of both *P. ornatus and P. homarus* seek settlement habitat close to or on the sea floor, in crevices rather than holes. Booth et al. (1991) and Booth (2001) stated that when pueruli transform to juveniles they may seek different microhabitat structures.

There is also little published information pertinent to the species examined in this study in relation to depth preference, other than that from Dennis et al. (1997) who suggested the depth preference for newly settled *P. ornatus* is 3–21 m. The present study suggests both *P. ornatus and P. homarus* are most likely to settle at depths 5–17 m. In addition, these pueruli may have preferred even deeper water; however, this present study did not have traps set any deeper. When offered suitable habitat at different depths, pueruli displayed a clear preference for habitat close to or on the sea floor. The reason for this may be related to specific factors such as how depth affects light penetration, water pressure and proximity to food resources on the sea floor. It is interesting to note that *P. ornatus* pueruli settled over a broader depth range than that of *P. homarus*. The reasons for this are not clear. Oceanographic processes that are controlled by depth require investigation to explain the depth effect observed during the present study.

5.5 Conclusions

Significant differences for depth and trap type in the size of catch were found for the primary species caught, *P. homarus* and *P. ornatus*. The greatest catch of *P. homarus* was on the sea floor using a cement bag paper trap. For *P. ornatus*, catch size was less strongly correlated with a specific depth or trap type, although catch was highest at or near the sea floor in cement bag paper traps. This particular study helps advance spiny lobster aquaculture in Indonesia by improving the puerulus collection industry to become more cost efficient and profitable. Therefore, in future Indonesia lobster farming could supply substantial market size lobster products for global markets.

Chapter 6: Improved Collector Design for the Capture of Tropical Spiny Lobster *P. homarus* and *P. ornatus* (Decapoda: Palinuridae) Pueruli in Lombok

6.1 Introduction

With the recent development of puerulus fisheries to supply seed lobster for aquaculture purposes (Booth & Kittaka, 2000; Jeffs & Davis, 2004; Jones, 2010; Phillips et al., 2005a), there is growing interest in improving fishing techniques and maximising the catch through a better understanding of puerulus settlement preferences. Manufactured puerulus collectors are intended to simulate 'natural' substrates and maximise settlement rates (Phillips et al., 2001, 2005a). Studies on the settlement behaviour of spiny lobster pueruli have examined the natural marine environment and the variety of natural habitats and substrates that are available to guide decisions on the design of artificial substrates (Butler & Herrnkind, 1991; Hayakawa & Nishida, 2002). Further, there have been many studies on lobster recruitment that have employed various collectors that simulate natural habitat and provide scientific tools to measure abundance and to describe spatial and temporal patterns of settlement (Booth, 2001; Ewing et al., 2013; Phillips & Booth, 1994; Phillips & Olsen, 1975; Phillips et al., 2001). A considerable body of knowledge exists regarding these research-focussed collectors (Ewing et al., 2013; Mills & Crear, 2004).

As an extension to such research, there have been various proposals to collect significant numbers of pueruli for aquaculture, although most have not been realised because of concerns about effects on recruitment, such as the decrease of adult population (Gardner et al., 2006). In Vietnam, where a substantial lobster aquaculture industry is established (Petersen & Phuong, 2010), 1.5–4 million pueruli are caught each year and used for grow-out to market size (Jones et al., 2010; Tuan & Jones, 2015b). The effect of puerulus removal on the wild fishery for market-sized lobsters is assumed to be slight because of the high natural mortality of pueruli. Phillips et al. (2003a) suggested that the removal of 20 million pueruli of *P. cygnus* in Western Australia in one year, in which the puerulus settlement size was 600 million, would result in only a 0.62% reduction in catch of adult lobsters. Therefore, the capture of pueruli for the purpose of farming represents an insignificant impact on the environment and a significant net gain in the volume of marketable-size lobsters (Jones, 2015b).

A variety of techniques and materials are used in Vietnam to fish for pueruli. Collectors, sometimes called traps (Priyambodo et al., 2015), are placed in areas of known high abundance (Long & Dao, 2009). Similarly, in Indonesia, particularly in Lombok (Jones, 2010; Priyambodo & Sarifin, 2009), a significant source of naturally settling lobster pueruli has been identified, and the associated industry captures around 3–5 million pueruli each year (Bahrawi et al., 2015a). Over the last decade, through trial and error, puerulus fishers in Lombok have achieved consistent catch rates to support their livelihoods using limited resources (Petersen et al., 2015). A recent study compared the effectiveness among commonly used puerulus fishing collectors in Lombok (Priyambodo et al., 2015; see Chapter 5) revealed that collectors made from cement bag paper, particularly when made into the shape of a concertina bowtie, were the most effective among those examined. Further assessment of the bowtie-style collector made with different materials and angles may lead to greater catch rates.

In Lombok, significant numbers of pueruli of *P. homarus* and *P. ornatus* settle in the inshore waters of Ekas Bay and nearby embayments (Priyambodo & Bahrawi, 2012; Priyambodo et al., 2015). The physico-chemical cues that attract pueruli from oceanic water to these near-shore estuarine waters are not fully understood. In contrast, there is research that had dealt with this in different species, *P. argus* (Butler and Herrnkind, 1991). The settlement areas are characterised by lower salinity, high turbidity, high nutrients and low-energy tidal currents and coastal eddies, and it may be a complex of stimuli that results in puerulus settlement. Although a better understanding of these cues may be useful to increase catch rates, the current research focussed on structures upon which swimming pueruli settle; specifically the materials, depth level and surface characteristics of the collectors (Hinojosa et al., 2015; Pardo et al., 2010; Priyambodo et al., 2015). As for the materials that maximise settlement and catch rate, little is known about the effects of lunar periodicity on the settlement of spiny lobster, particularly *P. ornatus* and *P. homarus*.

The literature on late-stage larval and puerulus settlement of spiny lobsters suggests that a broad range of visually-assessed variables influence preference for settlement substrates. These variables include light level, luminosity, degree of exposure and availability of edges, crevices and clefts (Jeffs & Holland, 2000; Lecchini et al., 2010; Radford et al., 2007). Tactile properties of substrates that may influence settlement include texture, smoothness, porosity, grip, hardness, rugosity and availability of corrugations, ridges and furrows (Herrnkind & Butler, 1994; Phillips et al., 2001; Stevens, 2003). To maximise catch rates of pueruli, habitat enhancement can be used to increase its suitability of settlement substrate, thereby increasing the overall catch rate compared with natural settlement rates. Such habitat can provide protection from predation and mitigate the effects of environmental perturbations; enhanced habitats have been shown to increase survival of settled pueruli (Herrnkind & Butler, 1994; Johns & Mann, 1987).

The present study aims to build on knowledge gained on the behaviour and material preferences of settling pueruli of tropical spiny lobster species by examining aspects of collector design and material surface characteristics that enhance catch rates. This chapter addresses the research question: What collector materials are locally available and the most effective? What crevice angles are the most effective? Are there any other factors that control puerulus settlement? A series of tank-based experiments was used to examine puerulus preference for various aspects of collector materials. Preferred material characteristics were then tested in a field experiment to verify the laboratory results. This study also provided the opportunity to examine lunar periodicity in relation to the settlement pattern of pueruli during the peak settlement season. Better understanding of pueruli abundance in the water in relation to lunar phase may improve utilisation of this resource to enhance tropical spiny lobster production from aquaculture.

6.2 Materials and Methods

6.2.1 Materials

6.2.1.1 Tank experiment

6.2.1.1.1 Substrate surface

The experience of fishers and findings from a scientific study recommend cement bag paper bowties as the most effective collector type for capture of *P. homarus* and *P. ornatus* pueruli in Indonesia (Priyambodo et al., 2015). These bowties are so named because the way they are folded to fashion a concertina-like, multiple-creviced structure resembles a bowtie. In Indonesia they are made using recycled paper bags originally used for cement powder, as this is a cheap and readily available material and can retain their structure for up to 1 month. The cement bags have two layers: the outer is made of paper and the inner of plastic. Such paper is referred to by the manufacturers as 'sack kraft paper', a porous paper with high elasticity and high tear resistance. The paper is designed for packaging products that require strength and durability (Yam, 2009). The plastic lining is standard polyethylene material.

The observations of fishers suggest that the paper layer is the key ‘attractant’, as the bowtie collectors become ineffective after 1 month of immersion when the paper has degraded and sloughed away. Standard cement bag paper was used as the control material for this study and assessed against other materials chosen to provide a variety of texture, smoothness and rugosities. Five materials were used as substrates (see Figure 6.1) and a qualitative description of their characteristics is provided in Table 6.1.

Figure 6.1. Materials used for the collectors in the tank experiment: A, cement bag paper; B, weed fabric; C, PVC rubber; D, insect mesh; E, cement bag plastic

Table 6.1

Characteristics of the Five Materials Used in the Experiment

No	Material	Description	Characteristic			
			Hardness	**Rugosity**	**Smoothness**	**Density**
1	Cement bag paper	Recycled from cement bags and consisting of both layers: paper and cement bag plastic, with paper side exposed	++++	++++	+++	+++
2	Weed fabric	A lightweight, non-woven polypropylene fabric as used for weed-proofing garden beds	-	-	+++	-
3	PVC rubber	Extruded PVC in a mesh pattern used for non-skid matting	+	+	+	+
4	Insect mesh	Standard fibreglass insect screen mesh	++	++	-	++
5	Cement bag plastic	Recycled from cement bags but consisting of only the plastic layer	++++	+	-	+++

Notes: (+) represents strength level, (-) represents weakness level

6.2.1.1.2 Bottom substrate type

Beach sand (particle size averaging ~0.1 mm) from the vicinity of the commercial puerulus fishing grounds was used as a bottom substrate in the experimental aquaria. A 3 cm deep layer of sand covered the aquarium floor to provide a similar environment to the locations in which pueruli settle. The sand was thoroughly cleaned by washing in freshwater and then placed into the aquarium. The sand was vigorously shaken to ensure finer sediment was flushed away. All organic material, such as seaweed and small organisms, was removed manually, and the sand was dried in the sun for 2–3 days before being placed into aquaria. In addition, sea-water was filtered through a sand filter and filter bags.

6.2.1.1.3 Aquaria

Three identical aquaria were used with dimensions 0.7 × 0.4 × 0.6 m. The aquaria were placed in a dark room. A single air stone was positioned in the middle of each aquarium and supplied with air from an aquarium aerator adjusted to provide a gentle stream.

6.2.1.1.4 Experimental stock

Pueruli of *P. homarus*, which is the most abundant in the study area and therefore of most available to the experiment, from the local area were purchased from a lobster seed dealer each morning for use in the experiments. Twenty pueruli were used per experiment for each tested collector material, thus requiring 60 pueruli across three replicate aquaria each night. Each experiment used newly captured pueruli to ensure the experimental animals were at the same developmental stage. The pueruli were first placed in three 220-ml plastic containers (20 pueruli per container) submerged in a concrete tank filled with aerated seawater at an ambient temperature of 29.5^{o}C (±1.0 SD), salinity of 31 ppt and pH 7.5–7.8.

In total, 5,400 pueruli of *P. homarus* were used for the series of experiments. The series employed all 10 pairwise combinations of the five selected substrate materials; three crevice angles (10^{o}, 20^{o}, 30^{o}); 20 pueruli stocked per tank; three replicate tanks; and each repeated over 3 nights.

6.2.1.2 Field experiment

6.2.1.2.1 Substrate surface

The field study used six floating frames that were larger than those used in the study presented in Chapter 5. They were made from bamboo and supported by nine buoys made from polystyrene foam drums. The dimensions of the frames were 8 × 8 m. These bigger frames provided stronger support for the collector substrates being tested in this study. They are locally called puerulus sea-rafts and are used for suspending collectors. The six puerulus sea-rafts, representing six replicates, were randomly placed among commercial operations owned by local lobster seed fishers in Awang Bay (8º52'44.1"S 11º24'01.2"E) in the south-east corner of Lombok (Figure 6.2). The frames were anchored to the sea floor from two adjacent corners of the frame with ropes and heavy weights (Figure 6.3).

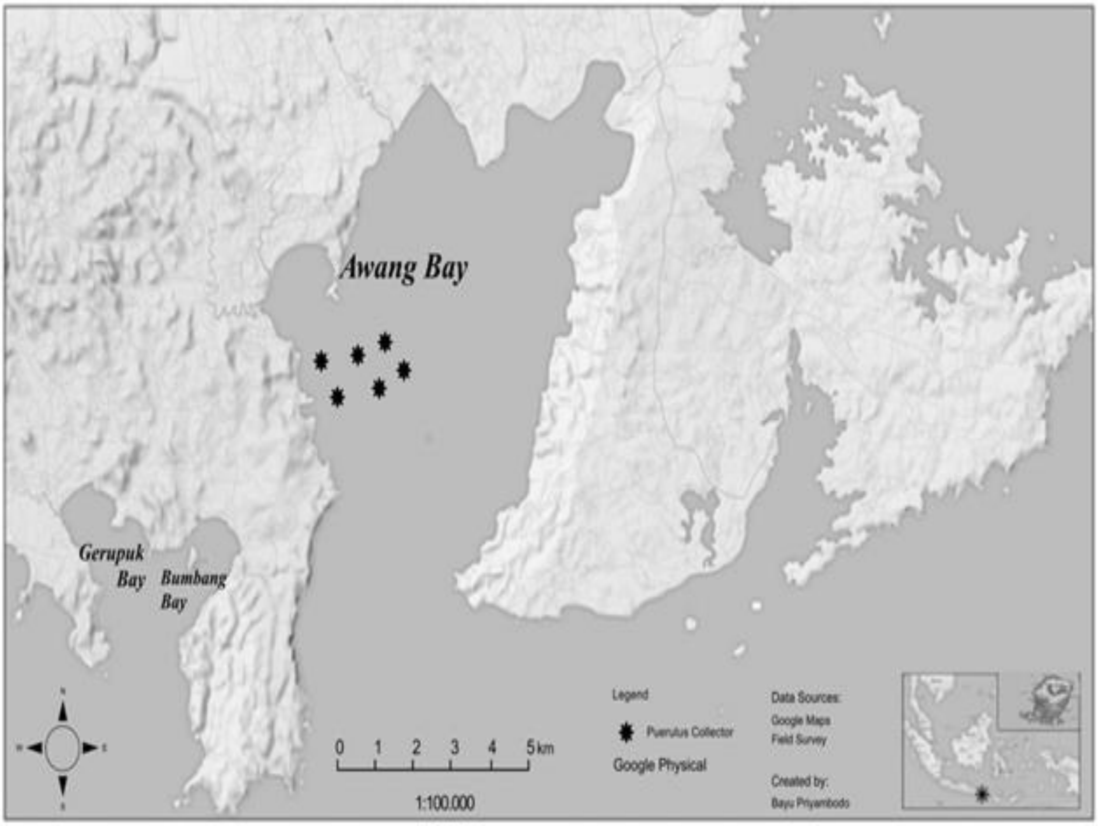

Figure 6.2. Location of the puerulus fishing area and site of the experiment in south-east Lombok

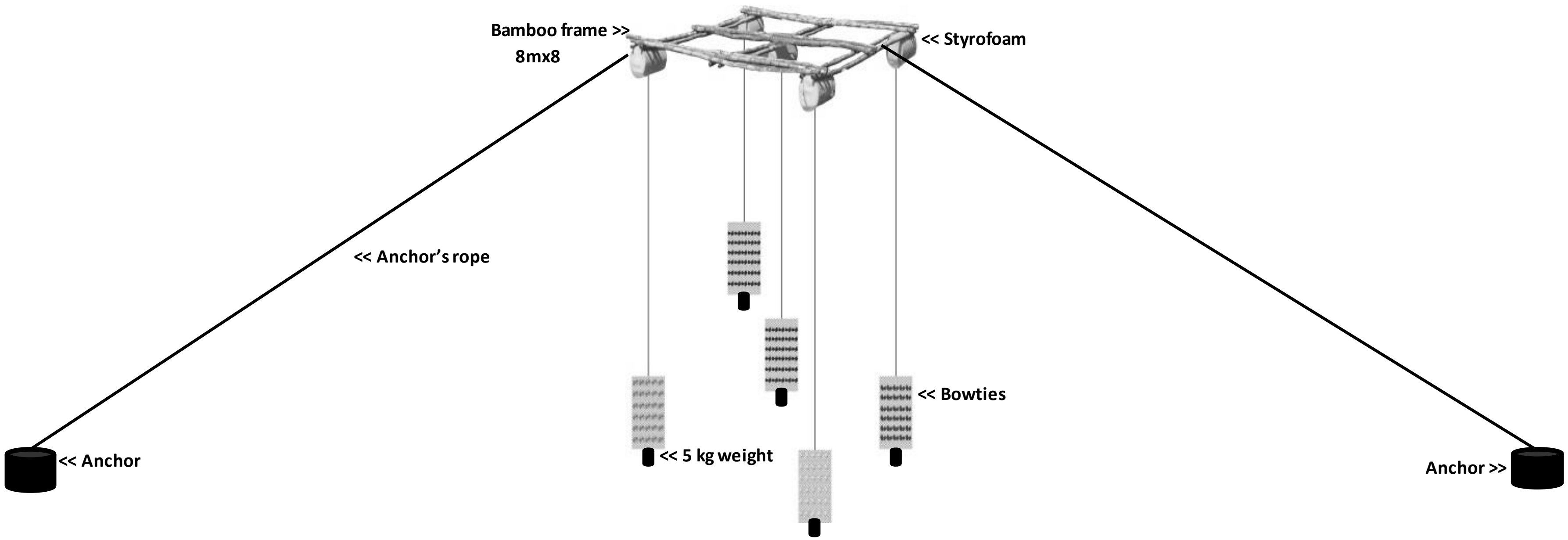

Figure 6.3. A floating puerulus sea-raft with test substrates deployed, as used for the field experiment

The bowtie collector shape was used according to the recommendation of Priyambodo et al. (2015), but made using the same five materials as used for the tank experiments: cement bag paper, weed fabric, PVC rubber, insect mesh and cement bag plastic. For each individual bowtie, a rectangle of material (25 ×40 cm) was folded in concertina fashion and fixed in the centre to form the bowtie shape (Priyambodo et al., 2015).

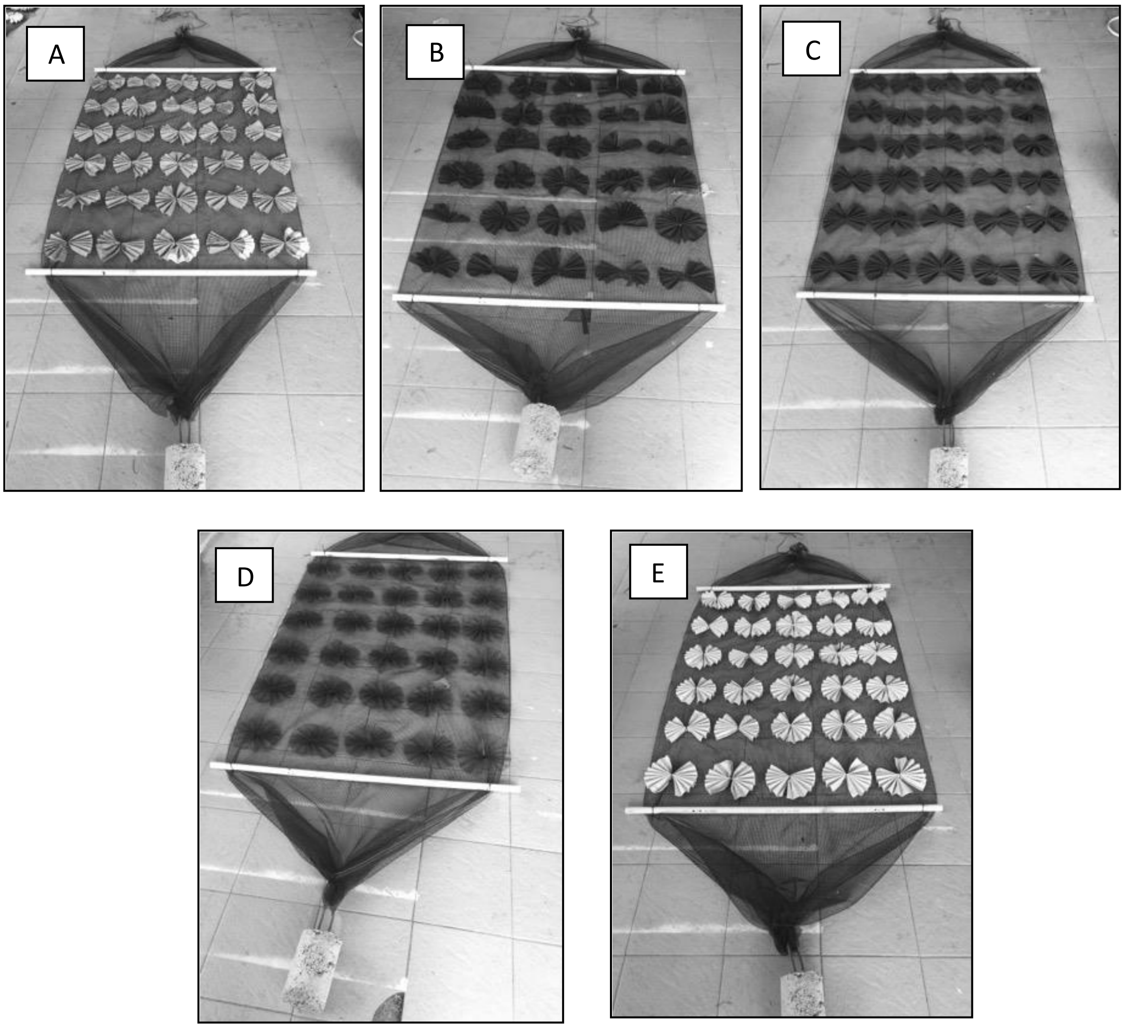

Figure 6.4. Unit collectors consisting of 30 bowties attached to a monofilament net of 1.2 × 3.0 m for the field experiment, showing bowties made of: (A) cement bag paper, (B) weed fabric, (C) PVC rubber, (D) insect mesh and (E) cement bag plastic

For each bowtie, the angle of the crevices ranged between 10° and 20 °. Each collector unit was suspended from the sea-raft with a single line so that its bottom margin touched the sea floor. Each collector unit was weighted with a 5-kg concrete anchor (see Figure 6.3). Each sea-raft, of which there were six in total, had five collector units representing the five substrate materials, allocated at a random position within the sea-raft. In the current study, each collector unit consisted of 30 bowties attached to a frame of monofilament net with a dimension of 120 × 300 cm (see Figure 6.4).

6.2.2 Methods

6.2.2.1 Tank experiments

The research was conducted at the multi-species hatchery of the Lombok MADC located in Gerupuk Bay in Central Lombok, Indonesia. This centre is adjacent to a well-established puerulus settlement area, offering easy access to pueruli for the experiments. Aquaria and concrete tanks with an aeration and filtration system were used for the experiments. Seawater was supplied directly via a submersible pump 100 m from the beach. This experimental puerulus habitat collector was designed based on the concept of the Booth collector (Phillips & Booth, 1994) using five different materials for the surface of the collector. This design enabled easy switching between different substrate materials and manipulation of the crevice angle.

6.2.2.1.1 Preparation

Each collector consisted of eight vertically stacked crevices, 280 mm total height, 300 mm wide and 80 mm deep, made from 3-mm white acrylic plastic held together by four 3-mm stainless steel rods. Test substrate materials were attached to the surface of the collector layers using plastic clips. Each crevice had a designated angle of either 10^o, 20^o or 30^o set by adjusting nuts on the stainless steel rods between each level

(Figure 6.5). For the purposes of distinguishing the vertical position of the crevices, the bottom two crevices were identified as ‘bottom’, the three middle crevices as ‘middle’, and the top two as ‘top’.

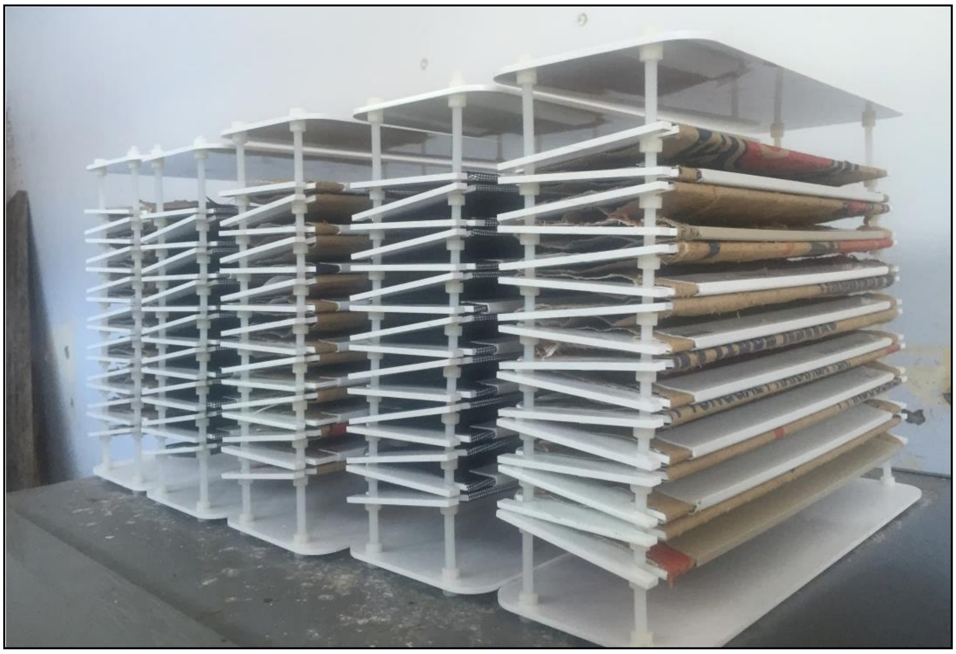

Figure 6.5. Experimental crevice collector made to test different substrate materials and crevice angles in the tank experiments

Two collectors, each equipped with a different material, were placed in each of the three aquaria, one at either end facing each other.

All collectors were conditioned in seawater by hanging them from a floating sea-raft for 1 week prior to commencement of each experiment. The collectors were hung at a position 5 m below the sea surface. This allowed leaching of manufacturing chemicals and enabled biofilm to form, as would occur on collector arrays on commercial sea-rafts.

The aquaria were positioned in a laboratory, isolated from outside noise and illuminated by fluorescent lights. After the pueruli were released, puerulus activity under the fluorescent light was observed until settlement occurred, which took around 10 minutes. The lights were then switched off, resulting in almost total darkness.

Pueruli caught the previous night were held in cylindrical transparent plastic containers (10 cm in diameter, 220 ml in volume), 20 pueruli in each container, until required for the experiment.

6.2.2.1.2 Implementation

The experiment examined two main factors: the substrate material and the angle of the crevice.

A series of binomial experiments was undertaken where two (A and B) of the five material types were tested each time using three replicate aquaria. Each experiment was performed over three successive nights, to provide a total of six replicate measurements. The two different substrate collectors were placed at opposite ends of the aquarium. The left or right position of the two collectors in each aquarium was allocated randomly. To initiate each experiment, pueruli were introduced using the container described above, positioned in the centre, equidistant from each test collector. This procedure followed that described by Lecchini et al. (2010) when examining habitat preference of post-larval crustaceans. The test pueruli were allowed to acclimate for 120 seconds before release. After the removal of the container, the pueruli were free to swim.

The duration of each experiment was approximately 12 hours, starting at 6.30 pm and ending at 6.30 am. Pueruli were observed after release for 10 minutes to ensure 'normal' behaviour (Lecchini et al., 2010). The lights were then switched off and the laboratory closed to all disturbances until 6.30am, when the position of each puerulus was recorded as either:

1. in collector A or B (top, middle or bottom position)
2. on the sand surface
3. buried in the sand

4. on the glass of the aquarium.

6.2.2.2 Field experiment

The Booth collector was not used in the field. Rather, the traditional, hand-made bowtie collector recommended by Priyambodo et al. (2015) was used with bowties being constructed from the same five materials used in the laboratory experiments. The field experiment examined two main factors: substrate material and lunar period effects on settlement.

6.2.2.2.1 Site selection and sampling schedule

The experimental collectors were deployed at the study site in Awang Bay (8º52'54.90"S 116º24'41.08"E) in Lombok from June to September 2015. These months represented the peak season of puerulus settlement in this basy (Bahrawi et al., 2015b; Jones, 2010). Collectors were conditioned at the site for 1 week and then each collector was checked in the morning between 7 and 10 am, once every two days from 1 July to 25 September 2015, providing 44 data points over the 92-day experiment. The site conditions were equivalent to those reported by Priyambodo et al. (2015); that is, there was a bottom substrate of sand with some mud and moderately turbid water.

6.2.2.2.2 Species identification

The diagnostic characteristics of the antennae and body morphology for both puerulus and post-puerulus were assessed as per Table 5.1 and Figure 5.4 in Chapter 5, based on the well-established criteria used in Vietnam (Dao Tan Hoc, Institute of Oceanography of NhaTrang, personal communication). These data were used to identify the puerulus species utilising the test collectors.

6.2.2.3 Data analysis

6.2.2.3.1 Tank Experiments

Pueruli in the tank experiment were recorded as being located either in the collectors or not in the collectors. For pueruli not in test collectors, their position was recorded as 'on the sand', 'buried in the sand' or 'on the glass of the aquarium'. These were categorised as a group of 'other substrate'. The number of pueruli at each of these three 'non-test collector' locations was recorded. There were nine measurements (counts) for the position of pueruli in each experiment: from three replicate tanks replicated three times over successive nights. Data for these nine measurements were generally normally distributed, and ANOVA was applied to discern the extent of variation. Data were analysed with SPSS (Version 22) and least significant difference analysis was applied for means comparison.

Count data on the materials were then examined in regard to the angle of the crevice (excluding 'other substrate' counts as crevice angle did not apply). A two-way ANOVA was applied to each experiment (i.e., a choice of two substrates) with factors being material type and angle of crevice. To examine the effect of position within each collector, count data were analysed in relation to the level on each collector; that is, top, middle or bottom. A two-way ANOVA was applied to each experiment (i.e., a choice of two substrates) with factors being material type and level.

6.2.2.3.2 Field experiments

A two-way ANOVA using SPSS (version 20) was used to analyse the effect of material type of the settlement. Comparison of means was made using least significant differences. Significance was attributed to p values <0.05.

To examine lunar periodicity of settlement, count data were analysed in relation to moon phase categorised as 1 (full moon), 2 (3rd quarter), 3 (new moon) and 4 (1st quarter). A one-way ANOVA was applied to each moon phase with factors being mean catch, collector type and species. Data were analysed with SPSS (Version 22) and least significant difference analysis was applied for means comparison.

6.3 Results

6.3.1 Tank experiments

The series of laboratory-based tank experiments demonstrated that pueruli of the spiny lobster *P. homarus* settled on the cement bag paper in significantly greater numbers than on the other offered materials (Table 6.2). The next most preferred materials in order were insect mesh, weed fabric and PVC rubber, with cement bag plastic being the least preferred. Table 6.2 shows the comparison of each material in the first left column which was compared/tested with materials in the top row. The results of the test match in the meeting point of horizontal and vertical of each column and row. For example, the preferred material test between cement bag paper (in the first left column) and weed fabric (in the top row) is the cement bag paper, etc.

Table 6.2

Preference Matrix of Puerulus Settlement on Collectors in Tank Experiments

Collectors	**Cement bag paper**	**Weed fabric**	**PVC rubber**	**Insect mesh**	**Cement bag plastic**
Cement bag paper	-	Cement bag paper	Cement bag paper	Cement bag paper	Cement bag paper
Weed fabric	Cement bag paper	-	Weed fabric	Insect mesh	Weed fabric
PVC rubber	Cement bag paper	Weed fabric	-	Insect mesh	PVC rubber
Insect mesh	Cement bag paper	Insect mesh	Insect mesh	-	Insect mesh
Cement bag plastic	Cement bag paper	Weed fabric	PVC rubber	Insect mesh	-

Among the three crevice angles tested (10^o, 20^o and 30^o), angles of 10^o and 20^o were the most preferred. Examination of settlement number at the different levels of the collectors (top, middle and bottom) revealed that there was no significant difference in the majority of experiments. However, the number of pueruli settling on 'other substrates' revealed a significant interaction with test substrate type in 18 out of 30 experiments.

6.3.1.1 The effect of substrate material on puerulus settlement

Two-way ANOVA analysis showed that substrate material had a significant ($p < 0.05$) effect on the number of *P. homarus* puerulus settling. Settlement of pueruli was significantly greater on the cement bag paper than the other material choices. The second most preferred material was insect mesh, followed by weed fabric, PVC rubber and cement bag plastic. Paper had 69.0%, 57.1%, 71.1% and 55.6% more settlement than insect mesh, weed fabric, PVC rubber and cement bag plastic, respectively. Weed fabric had 64.9%, 48.6% and 62.6% more settlement than PVC rubber, insect mesh and cement bag plastic, respectively. PVC rubber had 33.8% and 47.5% more settlement than insect mesh and cement bag plastic, respectively. Finally, insect mesh had 64.0% more settlement than cement bag plastic. A table of summary result of substrate materials comparisons is presented in Table 6.3.

Table 6.3

Summary Results of Substrate Materials (the First Left Column Had Greater Number Compared to the Following Columns)

Collectors	Insect mesh	Weed fabric	PVC rubber	Cement bag plastic
Paper	69.0%	57.1%	71.1%	55.6%
Weed fabric	48.6%	-	64.9%	62.6%
PVC rubber	33.8%	-	-	47.5%
Insect mesh	-	-	-	64.0%

When mean settlement on the two materials in each paired experiment was compared with that for 'other substrates' in that experiment, the results were as follows: the experimental pair of cement bag paper *v*. weed fabric, cement bag paper *v*. PVC rubber, cement bag paper *v*. insect mesh, cement bag paper *v*. cement bag plastic, and weed fabric *v*. PVC rubber had 65.6%, 75.0%, 71.6%, 70.0% and 67.8% more settlement, respectively, than other substrates. Further, the experimental pair of weed fabric *v*. insect mesh, weed fabric *v*. cement bag plastic, PVC rubber *v*. insect mesh, and PVC rubber *v*. cement bag plastic had 68.9%, 72.8%, 77.2%, 71.7% and 71.1% more settlement, respectively, than other substrates. The mean settlement values for each experiment on the test materials and other substrates are presented in Table 6.4. The *graphical* representation of preference for the substrates available for puerulus settlement in the tank experiments is presented in Figure 6.6.

Table 6.4

Mean (and Standard Error, SE) Settlement Counts for Each Paired Experiment (Means with different superscripts are significantly different at p < 0.05).

Experiment	**Mean count ± SE Substrate 1**	**Mean count ± SE Substrate 2**	**Mean count Other substrate**	***P***	***F***
1. Cement bag paper *v.* weed fabric (10^0)	8.89 ± 0.59^x	4.22 ± 0.57	6.89 ± 0.35	< 0.05	20.65
2. Cement bag paper *v.* PVC rubber (10^0)	11.78 ± 0.44^x	3.22 ± 0.40	5.00 ± 0.60	< 0.05	86.14
3. Cement bag paper *v.* insect mesh (10^0)	10.22 ± 0.28^x	4.22 ± 0.0.43	5.78 ± 0.52	< 0.05	54.16
4. Cement bag paper *v.* cement bag plastic (10^0)	10.89 ± 0.39^x	4.22 ± 0.43	5.78 ± 0.52	< 0.05	120.19
5. Weed fabric *v.* PVC rubber (10^0)	10.78 ± 0.83^x	2.78 ± 0.28	6.44 ± 0.82	< 0.05	33.52
6. Weed fabric *v.* insect mesh (10^0)	5.56 ± 0.71	8.22 ± 0.74^x	6.22 ± 0.62	< 0.05	4.03
7. Weed fabric *v.* cement bag plastic (10^0)	10.89 ± 0.59^x	3.67 ± 0.50	5.44 ± 0.60	< 0.05	44.26
8. PVC rubber *v.* insect mesh (10^0)	3.33 ± 0.50	12.11 ± 0.54^x	4.56 ± 0.63	< 0.05	72.75
9. PVC rubber *v.* cement bag plastic (10^0)	7.67 ± 0.23^x	6.67 ± 0.50	5.67 ± 0.60	< 0.05	4.32
10. Insect mesh *v.* cement bag plastic (10^0)	8.89 ± 0.31^x	5.33 ± 0.23	5.78 ± 0.40	< 0.05	33.16
11. Cement bag paper *v.* weed fabric (20^0)	4.67 ± 0.58	6.33 ± 0.89	9.00 ± 1.05^x	< 0.05	6.37
12. Cement bag paper *v.* PVC rubber (20^0)	9.78 ± 0.32^x	3.78 ± 0.40	6.44 ± 0.41	< 0.05	62.29
13. Cement bag paper *v.* insect mesh (20^0)	7.78 ± 0.28^x	6.67 ± 0.53	5.56 ± 0.60	< 0.05	5.01
14. Cement bag paper *v.* cement bag plastic (20^0)	8.56 ± 0.65^x	4.11 ± 0.35	7.33 ± 0.58	< 0.05	18.04
15. Weed fabric *v.* PVC rubber (20^0)	9.90 ± 0.81^x	3.11 ± 0.26	7.00 ± 0.73	< 0.05	27.83
16. Weed fabric *v.* insect mesh(20^0)	3.78 ± 0.52	9.90 ± 0.45^x	6.33 ± 0.60	< 0.05	33.66

Table 6.4 (continued)

17. Weed fabric *v*. cement bag plastic (20^0)	10.22 ± 0.52^x	3.78 ± 0.28	6.00 ± 0.41	< 0.05	62.37
18. PVC rubber *v*. insect mesh (20^0)	3.11 ± 0.35	11.44 ± 0.58^x	5.44 ± 0.56	< 0.05	72.14
19. PVC rubber *v*. cement bag plastic (20^0)	7.33 ± 0.44	7.78 ± 0.40^x	5.44 ± 0.34	< 0.05	9.82
20.Insect mesh *v*. cement bag plastic (20^0)	9.33 ± 0.58^x	4.22 ± 0.49	6.56 ± 0.63	< 0.05	20.27
21. Cement bag paper *v*. weed fabric (30^0)	3.44 ± 0.38	4.56 ± 0.56	12.00 ± 0.76^x	< 0.05	62.79
22. Cement bag paper *v*. PVC rubber (30^0)	5.11 ± 0.42	3.44 ± 0.38	11.44 ± 0.73^x	< 0.05	62.74
23. Cement bag paper *v*. insect mesh (30^0)	5.11 ± 0.56	4.67 ± 0.50	10.22 ± 0.86^x	< 0.05	21.79
24. Cement bag paper *v*. cement bag plastic (30^0)	3.33 ± 0.41	3.56 ± 0.67	12.89 ± 0.77^x	< 0.05	73.75
25. Weed fabric *v*. PVC rubber (10^0)	5.22 ± 0.46	4.44 ± 0.34	10.33 ± 0.41^x	< 0.05	61.79
26. Weed fabric *v*. net (30^0)	4.00 ± 0.64	6.56 ± 0.71	9.44 ± 0.82^x	< 0.05	14.00
27. Weed fabric *v*. cement bag plastic (10^0)	4.67 ± 0.58	3.00 ± 0.60	12.11 ± 0.96^x	< 0.05	43.49
28. PVC rubber *v*. insect mesh (30^0)	3.44 ± 0.38	7.22 ± 0.85	9.33 ± 0.97^x	< 0.05	14.59
29. PVC rubber *v*. cement bag plastic (30^0)	5.56 ± 0.56	5.67 ± 0.71	8.78 ± 0.72^x	< 0.05	7.54
30.Insect mesh *v*. cement bag plastic (30^0)	5.89 ± 0.31	5.33 ± 0.78	8.78 ± 0.89^x	< 0.05	6.81

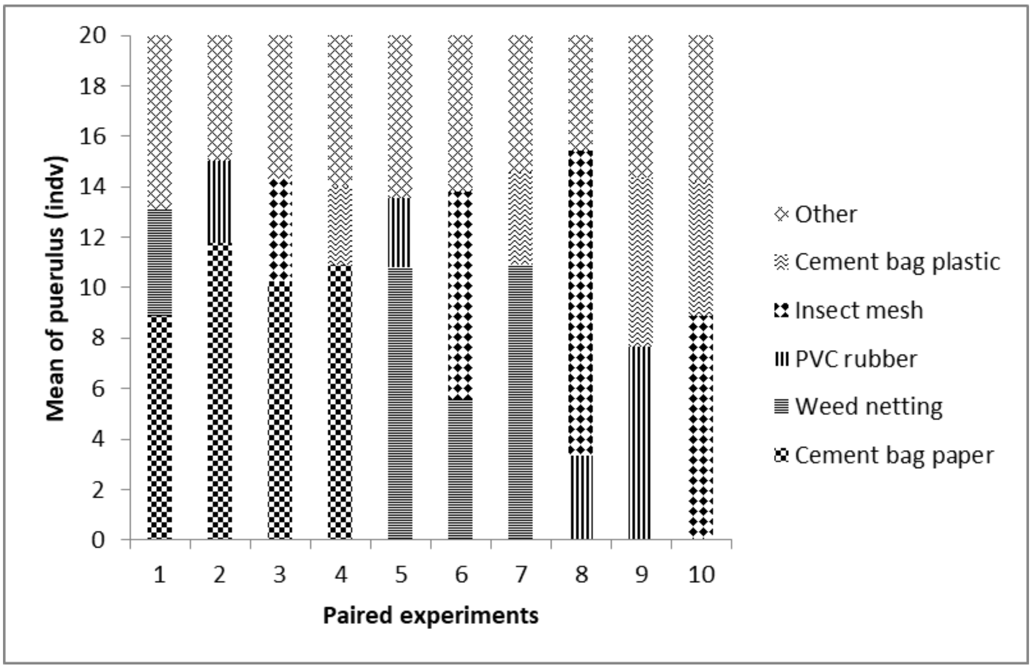

Figure 6.6. Representation of preference for the substrates available for puerulus settlement in the tank experiments from April to June 2015.

6.3.1.2 The effect of crevice angle on puerulus settlement

The results revealed a significant effect on puerulus settlement of collector substrate material ($F (4, 720) = 71.783$, $p < 0.001$). The multiple comparisons of means for collector materials showed that cement bag paper had significantly greater settlement than all other materials tested. A simple main effect analysis showed that cement bag paper was the most preferred collector substrate for settlement, followed by cement bag plastic, insect mesh, weed fabric and PVC rubber. Mean settlement numbers of *P. homarus* and *P. ornatus* on the five collector types from 1 July to 24 September 2015 are presented in Figures 6.12 and 6.13, respectively. A significant interaction between collector type and species was evident ($F (4, 720) = 22.247$, $p < 0.001$).

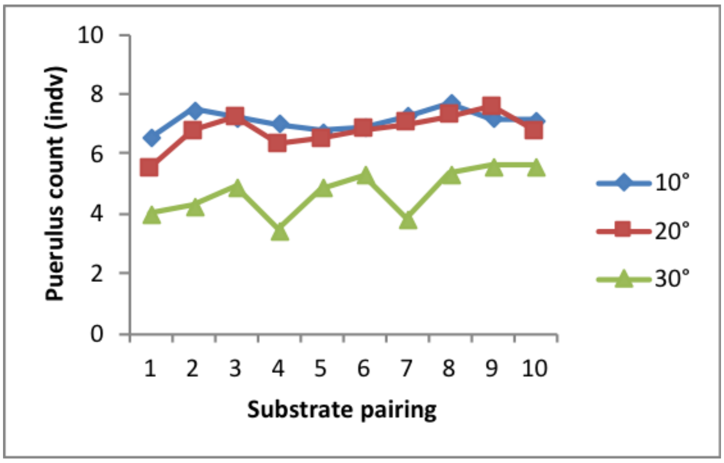

Figure 6.7. Numbers of pueruli settling on test collectors with different crevice angles in the tank experiments

6.3.1.3 The effect of level within collector on puerulus settlement

Overall, there was no significant effect of the depth at which pueruli settled in the experiment collectors (top, middle and bottom) in 7 of the 10 paired experiments (substrate pairing). The ANOVA interaction data are presented in Table 6.5. The overall collector height of 280 mm may have been too small to influence a depth-related preference for settlement. However, in 3 of the 10 paired experiments there was a significant interaction between the number of settled pueruli at the top and bottom, and also for the middle and bottom (Figure 6.8).

Table 6.5

ANOVA Interaction Data for Puerulus Settlement Level in Each Paired Experiment

Paired experiment	**Interaction**
1. Cement bag paper *v*. weed fabric	F (2, 162) = 0.695, p = 0.501
2. Cement bag paper *v*. PVC rubber	F (2, 162) = 0.126, p = 0.881
3. Cement bag paper *v*. insect mesh	F (2, 162) = 4.404, p = 0.014
4. Cement bag paper *v*. cement bag plastic	F (2, 162) = 0.140, p = 0.869
5. Weed fabric *v*. PVC rubber	F (2, 162) = 0.380, p = 0.684
6. Weed fabric *v*. insect mesh	F (2, 162) = 2.097, p = 0.126
7. Weed fabric *v*. cement bag plastic	F (2, 162) = 1.061, p = 0.349
8. PVC rubber *v*. insect mesh	F (2, 162) = 0.931, p = 0.396
9. PVC rubber *v*. cement bag plastic	F (2, 162) = 4.863, p = 0.009
10. Insect mesh *v*. cement bag plastic	F (2, 162) = 7.737, p = 0.001

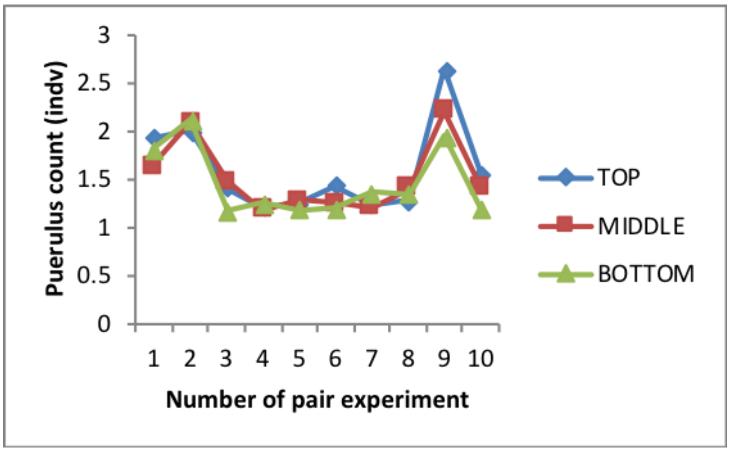

Figure 6.8. Mean puerulus settlement number at different levels in the collector, for each paired experiment in the tank experiments

6.3.1.4 The effect of other substrates on puerulus settlement

A proportion of pueruli did not settle on the collectors but chose to settle on other substrates available within the tank: on the sand, buried in the sand or on the glass of the aquarium. In 6 of the 10 paired experiments there was a significant interaction between settlement on the non-test substrates and the test substrates (Table 6.6). Data for the settlement of pueruli on other substrates for each of the crevice angles tested are shown in Figures 6.9, 6.10 and 6.11.

Table 6.6

ANOVA Interaction Data for Puerulus Settlement on Non-test and Test Substrates in Each Paired Experiment

Paired experiment	**Interaction**
1. Cement bag paper *v*. weed fabric	F (2, 81) = 3.882, $p = 0.025$
2. Cement bag paper *v*. PVC rubber	F (2, 81) = 11.251, $p < 0.001$
3. Cement bag paper *v*. insect mesh	F (2, 81) = 8.743, $p < 0.001$
4. Cement bag paper *v*. cement bag plastic	F (2, 81) = 5.529, $p = 0.006$
5. Weed fabric *v*. PVC rubber	F (2, 81) = 8.736, $p < 0.001$
6. Weed fabric *v*. insect mesh	(2, 81) = 0.521, $p = 0.100$
7. Weed fabric *v*. cement bag plastic	F (2, 81) = 0.393, $p = 0.676$
8. PVC rubber *v*. insect mesh	F (2, 81) = 0.393, $p = 0.676$
9. PVC rubber *v*. cement bag plastic	F (2, 81) = 1.632, $p = 0.203$
10. Insect mesh *v*. cement bag plastic	F (2, 81) = 10.815, $p < 0.001$

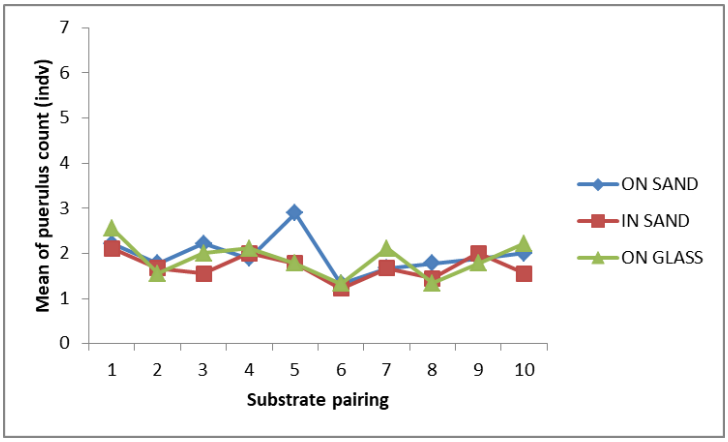

Figure 6.9. Mean count of pueruli settling on non-test substrates in tank experiments with collector crevice angle of 10^0 in the tank experiments

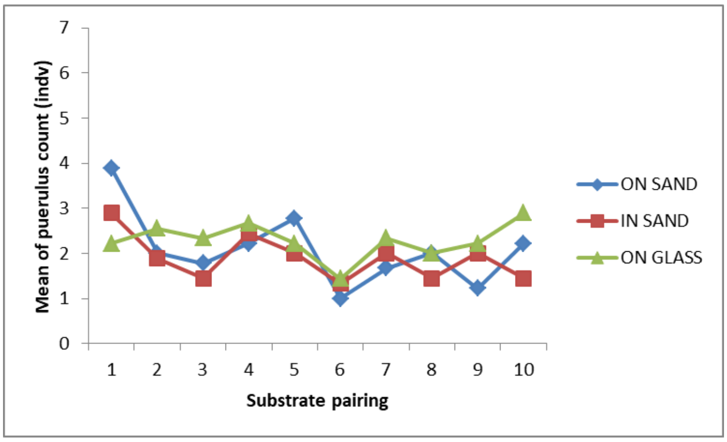

Figure 6.10. Mean count of pueruli settling on non-test substrates in tank experiments with collector crevice angle of 20^0 in the tank experiments

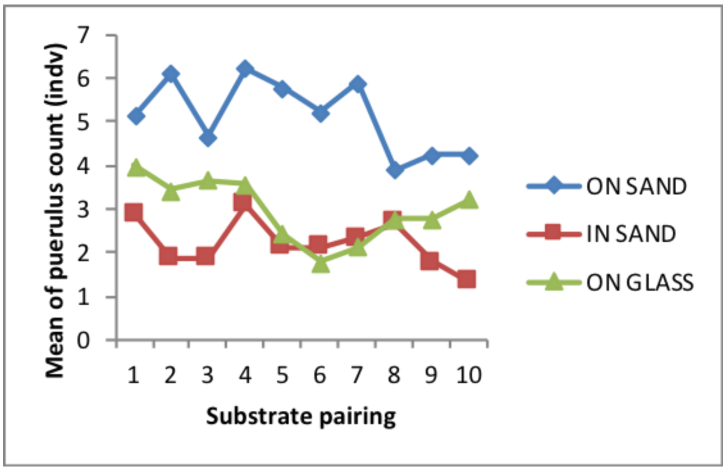

Figure 6.11. Mean count of pueruli settling on non-test substrates in tank experiments with collector crevice angle of 30^0 in the tank experiments

6.3.2 Field Experiments

In the field experiment the most preferred material type chosen by the pueruli was the cement bag paper, consistent with the results of the tank-based experiment. However, the second most preferred material in the field was cement bag plastic, in contrast to the tank-based experimental results, which showed cement bag plastic to be the least preferred. The field experiment also demonstrated a clear lunar periodicity for settlement, with significantly greater numbers of pueruli settling during the new moon phase (i.e., within 3 days before and after the new moon).

6.3.2.1 The Effect of Material Type on The Settlement

The results revealed a significant effect on puerulus settlement of collector substrate material ($F(4, 720) = 71.783$, $p < 0.001$). The multiple comparisons of means for collector materials showed that cement bag paper had significantly greater settlement than all other materials tested. A simple main effect analysis showed that cement bag paper was the most preferred collector substrate for settlement, followed by cement bag plastic, insect mesh, weed fabric and PVC rubber. Mean settlement numbers of *P. homarus* and *P. ornatus* on the five collector types from 1 July to 24 September 2015 are presented in Figures 6.12 and 6.13, respectively. A significant interaction between collector type and species was evident ($F(4, 720) = 22.247$, $p < 0.001$).

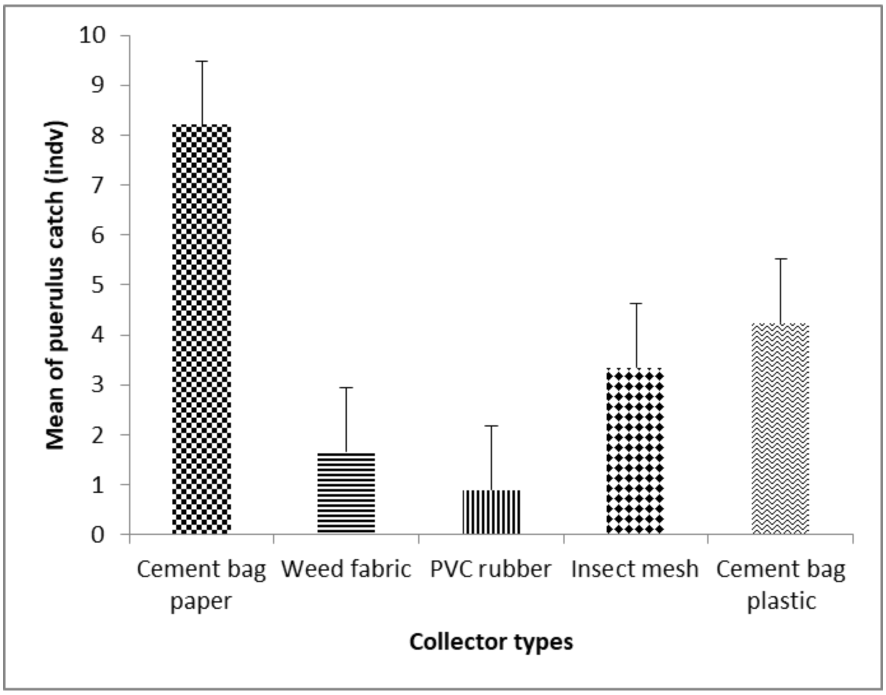

Figure 6.12. Mean count of *P. homarus* pueruli based on collector type over 3 months in the field (total sample 1340 pueruli/80.67%)

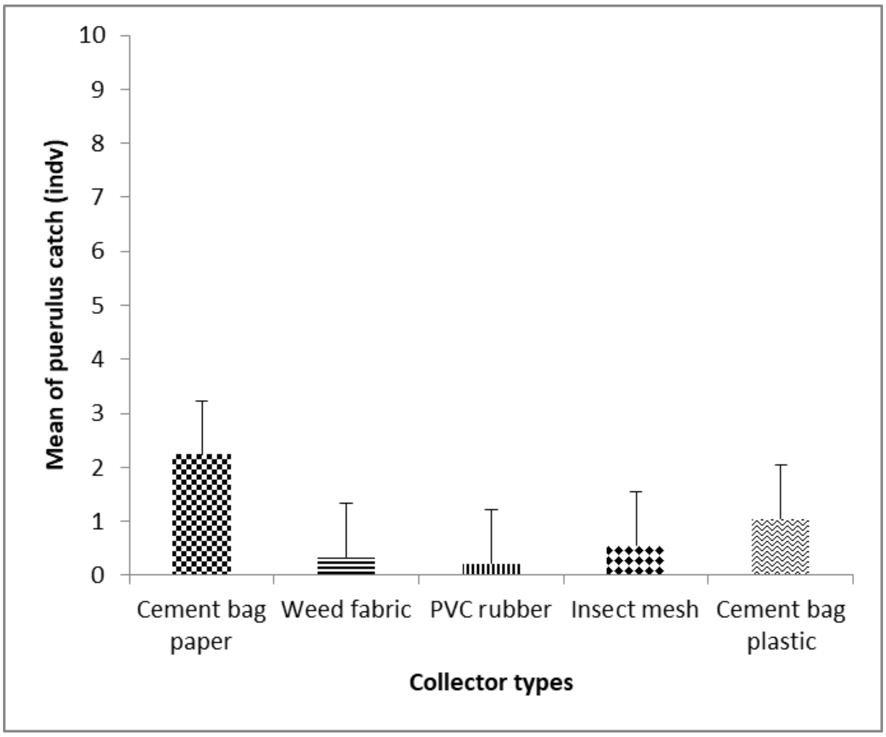

Figure 6.13. Mean count of *P. ornatus* pueruli based on collector type over 3 months in the field (total sample 312 pueruli/19.33%)

6.3.2.2 The Effect of Lunar Phase on The Settlement

An examination of the data to identify any lunar periodicity in puerulus settlement was made by ANOVA on catch numbers, with data pooled for all collector materials, assigned to one of four moon phases: full moon (±3 days), 3rd quarter (±3 days), new moon (±3 days) and 1st quarter (±3 days). There were 1,321 pueruli of *P. homarus* and 317 of *P. ornatus* found settled on the collectors over the 3-month period (July–September 2015). The results revealed the daily settlement of *P. homarus* across all collectors was 45.5% higher during the new moon than during the full moon phase. Similarly, the new moon catch was 27.4% and 22.79% higher than catches for the 3rd quarter and 1st quarter moon phases. For *P. ornatus*, the equivalent results showed that the settlement during new moon was 42.59% higher than that during the full moon, 31.23% higher than the 3rd quarter and 22.4% higher than the 1st quarter catch.

ANOVA ($F(1, 719) = 137.029$ $p < 0.001$) and multiple comparisons of means showed that puerulus settlement was greatest at the new moon and lowest for the other moon phases. Mean catch for *P. homarus* and *P. ornatus* based on moon phases from 1 July 2015 to 24 September 2015 is presented in Figures 6.14 and 6.15, respectively. For *P. homarus,* there was a significant interaction between moon phase and settlement ($F(3,359) = 56.575$, $p < 0.001$). The multiple comparisons showed that there was a significant difference between the full moon and the other moon phases, but no significant difference between the 1st and 3rd quarters. Likewise, for *P. ornatus,* there was a significant interaction between moon phase and settlement $F(3,359) = 16.867$, $p < 0.001$. These similar settlement patterns suggest similar behaviour of the two species in regard to moon phase.

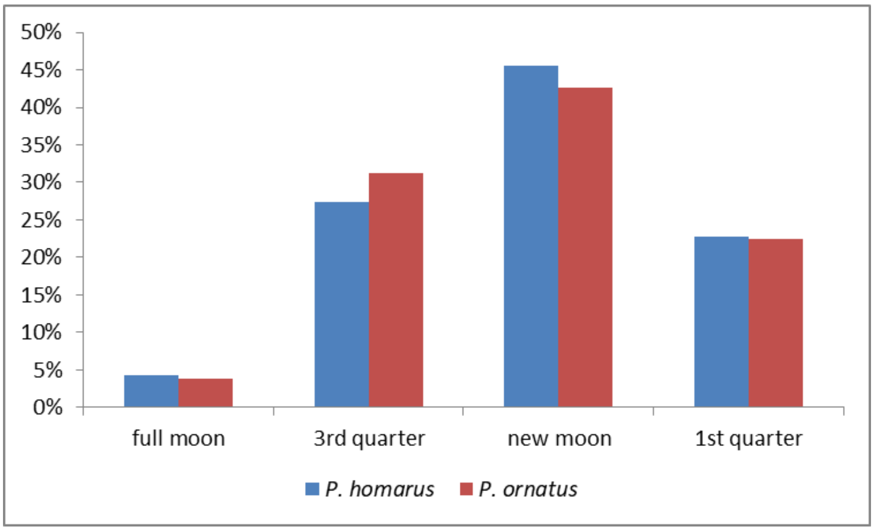

Figure 6.14. The percentage of *P. homarus* and *P. ornatus* pueruli based on lunar phase.

6.4 Discussion

6.4.1 Comparison of Materials

Identifying the best collector design is crucial to maximise catch rate of puerulus for grow-out and scientific purposes. For shallow-water palinurids, such as *P. argus* and *P. cygnus,* settlement occurs in inshore waters a few metres deep, and settled pueruli are found on hard substrates, in small crevices or objects on the substrate that provide shelter (Booth, 2001). A laboratory-based study by Ewing and Frusher (2015) found that pueruli prefer to settle in habitat with crevices. The current tank-based experiments showed that puerulus of *P. homarus* settle in crevices with a diverse range of substrate materials.

In general, pueruli habitat preferences indicate *P. homarus* and *P. guttatus* pueruli settle in natural habitats characterised by rock or coral crevices (Berry, 1971b; Sharp et al., 1997). In contrast, pueruli of *P. cygnus* prefer to settle on rock crevices amidst seagrass or macroalgae (Jernakoff et al., 1993) and those of *P. ornatus* prefer to settle on rock crevices among colonial invertebrates and microalgae (Dennis et al., 1997). Finally, Edmunds (1995) and Lewis (1977) found that pueruli of *J. edwardsii* prefer to settle on rock crevices sometimes associated with seagrass-covered rock reefs or caves with brown macroalgae.

The cement bag paper used in these experiments most closely mimics the texture of macroalgae/seaweed or seagrass that pueruli would presumably settle on under natural conditions, which may explain the higher settlement on this material in the tank and field experiments. Booth (2001) indicated that for some of the shallow-water palinurids, the greatest settlement is on algae or other vegetation. This includes *P. argus* and *P. interruptus*, which mainly settle in beds of structurally complex algae and seagrass (Kough et al., 2014; Marx & Herrnkind, 1985; Withy-Allen & Hovel, 2013) . In contrast, the pueruli of *P. japonicus, P. cygnus, P. guttatus, P. longipes, P. versicolor*, *P. penicillatus* and *J. edwardsii* are generally found in small holes and crevices, mostly because some of these species are obligate reef dwellers, like *P. guttatus* (Berry, 1971a; Booth, 1979; Butler & Herrnkind, 2000; Lewis, 1977; Jernakoff, 1990; Norman et al., 1994; Yoshimura & Yamakawa, 1988).

In the tank-based experiments, the second most preferred material for settlement was insect mesh. This may suggest that insect mesh provides a textured surface that can be gripped by a puerulus' walking legs better than the other materials. In contrast, in the field experiment, the insect mesh was less preferred and cement bag plastic, which was the least favoured in the tanks, achieved the second highest abundance measurement in the field. The cause of these differences in results may be the higher growth of biofilms and other organisms on field-based test substrates compared with test materials maintained in dark conditions in the laboratory. The environment of the field experiment, where puerulus catch is naturally high, is characterised by highly turbid and nutrient-rich waters that promote rapid colonisation and growth of bio-fouling species. This is likely to have altered the test substrates' physico-chemical nature and attractiveness to pueruli. Mills and Crear (2004) pointed out that spaces provided within the netting of a mesh collector have little in common with a rocky reef, which may explain why such collectors are of limited effectiveness for *J. edwardsii*. Priyambodo et al. (2015) found that net collectors became heavily covered in mud and bio-fouling at the same site as used in the current field study. It may be concluded that the insect mesh material provides a suitable settlement substrate while it is relatively clean, but its textured nature exacerbates silt build up and bio-fouling to an extent that in the field it soon becomes less attractive for puerulus settlement.

The third most preferred material in the tank experiments was weed fabric. This light weight but robust material used for weed-proofing garden beds has a non-woven, fibrous nature similar to that of hand-made paper. It was assumed that the physical characteristics of this weed fabric were similar to the algae and seagrass in the natural habitat of the species studied. The smoothness and fibrous nature of the weed fabric and cement bag paper are similar (see Table 6.1). However, once immersed in water, the weed fabric appeared to soften and quickly degrade such that its effectiveness for attracting pueruli was reduced. Similarly, for the PVC rubber and cement bag plastic as the fourth and fifth preferred materials, the majority of puerulus tended to avoid them as a place to settle in the tank experiments. More than 50% of the seed in those experiments chose other substrates available (in sand, on sand and on glass) suggesting actual avoidance. PVC rubber and cement bag plastic have distinctly different characteristics from cement bag paper, insect mesh and weed fabric. The PVC rubber used was quite porous and soft, and the cement bag plastic was hard and slippery. There may be aspects of these characteristics that repel pueruli or that are not conducive to settlement. As the tank experiments were run only with *P. homarus,* there may be aspects of substrate preference that are different for pueruli of other species like *P. ornatus*. This should be tested in further research, to determine what factors control the temporary behaviour of settlement.

In the field experiment, the results showed cement bag plastic to be the second most preferred material for puerulus settlement, followed by insect mesh, weed fabric and PVC rubber. Specific observations indicated that the cement bag plastic maintained a more consistent bowtie shape and crevice angle over the duration of the experiment than did weed fabric, insect mesh and PVC rubber. As was seen in the tank experiments, weed fabric appeared to degrade quickly, altering its integrity and affecting the crevice angle. Insect mesh and PVC rubber were robust in the field with their integrity consistent over the period, but they were affected by heavy siltation and bio-fouling, which may have rendered them less attractive for puerulus settlement.

Factors that may be involved in the tactile response of pueruli to substrates, including texture, smoothness, porosity, grip, hardness, rugosity and availability of corrugations, ridges and furrows, were not specifically quantified or measured in this study. It would be worthwhile to assess these factors in more high-resolution investigations to examine the fine-level interactions of pueruli with the substrate surface (Herrnkind & Butler, 1994; Phillips et al., 2001; Stevens, 2003).

6.4.2 The Effect of Crevice Angle and Other Substrates on Puerulus Settlement

In the tank experiments, it was observed that once the pueruli were released into the water, they swam freely in any direction. It appeared that swimming was affected primarily by the beating of the pleopods–the swimming legs. In the first 2–5 minutes, the pueruli swam constantly, making brief contact with the various substrates available. Afterwards, they began to settle on the collector or non-test substrates provided in the aquaria.

Angles of $10^{-}20^{o}$ may afford better physical protection from predation than 30^{o}. In all experiments with a 30^{o} crevice angle, the proportion of pueruli choosing the non-test substrates was significantly higher than in the experiments with 10^{0} and 20^{0} crevice angles. At a 30^{o} crevice angle, when the pueruli were more inclined to settle on other substrates, there was a significant difference in settlement among the other substrates. It is assumed that pueruli prefer to avoid 30^{o} crevice angle as it is too open. It seems reasonable to conclude that there is a strong correlation between crevice angle and the puerulus body size (Dennis et al., 1997).

It was found that there were more pueruli burying into the sand than settled on the sand, although there was no significant difference between the number in the sand and on the glass. Booth (2001) suggested that both pueruli and first instar juveniles of Palinurid species are capable of almost completely burying themselves in sand, but they are intolerant of deep silt. It would appear from the current experiments that when presented with a choice of a substrate offering a crevice with a suitable substrate surface and angle, pueruli of *P. homarus* will choose that rather than in preference to burying into the sand.

6.4.3 The Effect of Lunar Phase on Puerulus Settlement

A better understanding of puerulus settlement patterns in relation to lunar phase will contribute to more effective utilisation of a puerulus resource by expending maximum fishing effort when settlement is highest. Most settlement of spiny lobster pueruli occurs at night or possibly around dawn for *P. cygnus* (Phillips, 1975), *J. edwardsii* (Booth & Tarring, 1986) and *P. argus* (Little & Milano, 1980; Lyons, 1980; Witham et al., 1968). According to Phillips and Booth (1994), lunar periodicity plays an important role in the settlement of most palinurids, with peak settlement occurring near the time of the new moon. For example, *P. cygnus* and *P. argus* were caught in greater numbers at night near the new moon than other times (Phillips, 1981). In contrast, lunar periodicity does not affect the settlement of *P. interruptus* (Serfling & Ford, 1975). Similarly, *J. edwardsii* in New Zealand and Australia appear to settle throughout the lunar phase (Booth, 1989; Hayakawa et al., 1990). Lunar periodicity may reflect other environmental factors such as tides or currents that are responsible for inducing settlement (Monterossa, 1991). Clearly, there is little information available on behavioural aspects of pueruli of *P. homarus* and *P. ornatus* in relation to their settlement response to the lunar phase, and further research is justified.

Phillips et al. (2001) examined the effect of different collectors on the settlement of *P. cygnus* over a 4-month period. The study found that the number of pueruli settling over 7 days around the new moon was 170% higher than for the rest of the month. Pueruli of some species are exclusively found when there is a new moon, while for other species there is no lunar periodicity effect evident (Acosta & Butler, 1999; Acosta et al., 1997). Settlement of *P. cygnus* follows a lunar periodicity, with the highest abundance during the new moon phase, and lowest when the moonlight intensity rises above 10% of full moonlight (Phillips & Sastry, 1980). Settlement of *P. argus* follows a similar pattern, with the greatest settlement occurring from the new moon to the first quarter (Briones-Fourzán, 1994; Little, 1977; Sweat, 1968).

In this current observation over three lunar phase periods, the absolute catch of the two species was in the proportion of 80.65% for *P. homarus* and 19.35% for *P. ornatus*. Further, the statistical analysis showed that there was a significant difference in settlement between the full moon and the other moon phases, but there was no significant difference between the 1st and 3rd quarters for the two species observed. Clearly, moon phase affects settlement.

The results presented here provide support for anecdotal evidence from puerulus fishers from Vietnam and Indonesia of a positive new moon correlation; the fishers report a greater abundance of pueruli of both *P. homarus and P. ornatus* when there is a new moon. In addition, with the common usage of lights on the collectors allowing fishers to catch puerulus every single night, the average number of caught puerulus tends to be much higher compared with previous periods when lights had not been used. However, whether the use of artificial light significantly affects puerulus settlement requires further investigation.

6.5 Conclusion

The experiments reported here provide valuable insights into the settlement of tropical rock lobster pueruli. The species examined, *P. homarus* and *P. ornatus*, are able to distinguish between different substrates in regard to their physical characteristics, particularly surface texture and crevice angle, and their abundance varies significantly according to lunar phase. Further research at finer levels of resolution may help to better understand their preferences and settlement behaviour, but current knowledge is sufficient to make useful recommendations for collecting pueruli to maximise catch in support of aquaculture. Further research should in particular examine substrate surface characteristics and how pueruli interact with them. For example, to understand why cement bag paper is superior to the other materials tested, it would be useful to make observations (video recording) of puerulus behaviour within the crevices and compare this with other materials. This finer-level research may not be so important to increase catch, but will help to better understand the attraction and mechanisms of settlement. Clearly, collection of pueruli in Indonesia can be improved and made more cost effective by utilising cheap, locally available materials.

Chapter 7: General Discussion and Conclusion

7.1 Introduction

The purpose of this chapter is to synthesise the main findings of this study in the context of the overriding objective of improving lobster puerulus collection in Indonesia. As stated in Chapter 2, during the course of this study there was a change in legislation that effectively closed the lobster farming industry. At the beginning of this study, lobster farming was a legal activity; it became an illegal activity based on a ruling that banned catch of lobsters <200 g, which clearly makes puerulus collection illegal and lobster grow-out economically unsustainable because of the large legal stocking size and sparse population of wild lobsters above this minimum size limit. Furthermore, the second decree of 2016 (Decree 56/2016) specifically banned the farming lobsters. Despite the regulations, an international black market for puerulus has nevertheless emerged, and the industry has persisted, albeit illegally. It is reiterated that this study was able to operate legally, as the regulations included clauses that allowed for research, education and development. The research is likely to be of great importance as it provides scientific information that can underpin future decision making related to this industry.

This thesis concerns only some of the key elements of lobster puerulus collection in Indonesia and adds to the broader understanding of spiny lobster farming. Although this thesis originally was focussed on the industry in Indonesia, the technologies that were tested and developed are applicable to other countries that have similar opportunity for farmers and fishers with low capital and finance. There have been other studies working with rock lobster species used more sophisticated and expensive puerulus collection technology for the purpose of aquaculture in developed countries where the lobster stakeholders and fishers are different to those of Indonesia

(Ewing et al., 2013; Oliver et al., 2006; Phillips et al., 2005b; van der Meeren, 2005). In this study it was demonstrated that new simple and inexpensive technology for puerulus collection, adapted from Vietnam, was effective and could potentially be applied in other developing countries in South East Asian. Similarly, the technology may have application in developed countries like Australia, particularly for the indigenous people in the North Territory, and in Papua New Guinea where there are known lobster seed settlement areas (Arcenal, 2004; Jaragun, 2015; Jones & Shanks, 2009; Juinio-Menez & Gotanco, 2004; Kenway et al., 2009).

This study gathered data and provided evidence that there is unlikely to be any significant environmental impact arising from wild puerulus removal. This contention is supported by other studies that have shown that the natural mortality of puerulus is very high (Phillips et al., 2003a, 2003b). By catching pueruli that would otherwise die, for the purpose of aquaculture, natural resources of adult lobsters can be sustained, while providing a seed resource for farming that enhances livelihoods. Additionally, there is scope to reinvigorate the traditional lobster fishing industry, by means of using wild-caught puerulus for farming and returning a proportion of those on-grown for stock enhancement. In the absence of hatchery technology, wild-caught puerulus is the only means of enhancing stock in habitats that support the wild lobster fishing industry, and such stock enhancement may improve the sustainability of the adult lobster fishery.

The overall aim of this research was to contribute to the development of lobster aquaculture in Indonesia through three activities. Firstly, by addressing the development needs of the spiny lobster industry in Indonesia, through understanding its status over the time and identifying barriers to puerulus collection technology transfer and dissemination. Secondly, the research addressed the need for better understanding of puerulus behaviour, largely by developing the collection devices and techniques to improve puerulus catch. This research had the additional benefit of providing a greater understanding of settlement behaviour. Finally, the research addressed the need for assessment of the lobster puerulus resource and its potential sustainable exploitation for the purpose of aquaculture. This is critically important for management and changes to policies. These research activities were conducted through 5 objectives.

Chapter 2 satisfied the first objective by reviewing the profile and status of the development of the Indonesian spiny lobster aquaculture. The second objective was addressed in Chapter 3 where the effects of puerulus collecting technology transfer from Vietnam to Indonesia on the development of lobster farming were discussed. The third objective was addressed in Chapter 4 by investigating the sustainability of puerulus capture in the context of improving the potential for a sustainable, local grow-out industry. The fourth and five objectives were addressded in Chapters 5 and 6 by determining the effects of different puerulus collector types and optimal depths for deployment; examining the effects of different materials and crevice angles used in puerulus collectors; recording lunar patterns in settlement; and adding to understanding of puerulus behaviour. This knowledge is essential for the small-scale operators that tend to dominate the industry in Indonesia, and for whom the economic and social benefits are greatest.

7.2 Synthesis

7.2.1 The Development of Indonesian Spiny Lobster Aquaculture and Technology Uptake

As described in Chapter 2, Indonesia has opportunities to develop spiny lobster aquaculture for socio-economic benefits without significant environmental impact. Indeed, Indonesia stands to be a leading exporter of this resource in the region, which would enable poor rural communities to participate in a lucrative international market, as was the case before regulatory changes shut down the industry. These opportunities include extracting puerulus from an abundant resource, competing well against other supplying nations, and creating employment for people, with low production costs, and across a broad geographic area. Additionally, puerulus collection may have the benefit of reducing pressure on wild fish stocks by providing an alternative livelihood for fishers. Lobster seed fishers make sufficient income to diminish their need to fish for other products. The great abundance of wild puerulus resources in Indonesia, particularly along the entire south coast of the middle part of the country from east Sumbawa to western Java, is now being exploited by puerulus fishers who have adopted and adapted methods transferred from Vietnam facilitated by the ACIAR study tour. Previously, puerulus exploitation for the purpose of lobster aquaculture occurred only in Lombok (between 2000 and 2012). The industry now benefited thousands of smallholders, both grow-out farmers and puerulus fishers, as described in Chapters 2 and 4. Unfortunately, the government has implemented regulations which although designed to conserve the adult lobster stocks, have unintentionally stopped puerulus fishing (regulation of 2015), and subsequently banned grow-out lobster (regulation of 2016) as described in Chapter 2. It is noted that this decision is contentious and has been challenged by the industry, but without success.

This study found that for Indonesia to be the world leader in spiny lobster aquaculture will require uptake of better farming technologies and government regulations that support the grow-out industry and improve opportunity for investment. The establishment of best farming practices is a long process for economic development as it involves human capacity building. The knowledge is available, but implementation is needed, and this must be fostered by government. One viable strategy to accelerate this process is through technology transfer programmes, as has occurred for other commodities in Indonesia, such as shrimp and grouper culturing. As puerulus collection techniques were successfully transferred through a study tour, as described in Chapter 3, knowledge of improved grow-out gained on the study tour was not utilised further in Indonesia because of the collapse in grow-out, so that it has been lost. Study tours are widely used as a tool for transferring new technology in aquaculture and agriculture industries (Anonymous, 2012; Chang, 2015; Davis et al., 2016; Holmes, 2010). The study tour that featured in this PhD research appeared to be very effective in improving the knowledge of participants, particularly in regard to detailed technical information on puerulus collection, as described in Chapter 3.

Numerous recent studies in the field of aquaculture have concerned the adoption of a new species or a new technique by fish farmers (Doraszelski, 2004; Kshirsagar et al., 2002; Ofuoku et al., 2008; Wetengere, 2011). The factors that have been identified as important include farm size, risk exposure and capacity to bear risks, human capital, labour availability, credit constraints, tenure and access to commodity markets (Feder et al., 1985). However, three possible factors were identified to explain the choices made by the study tour participants here: personal risk attitude; knowledge spillover; and access to credit (Miyata & Manatunge, 2004). At the community level, Walton-Hespe (2009) found that technology adoption is influenced by socio-cultural, economic and political factors as well as risk perception, which may also affect the suitability of dissemination strategies for new technologies. However, the influence of ‘opinion leaders’ in the community, motivation for change, attitude towards change and risk and past experience with technology, are also important personal attributes (Guerin, 1999).

Lobster farming in Vietnam has provided significant benefits to the communities involved (Petersen & Phuong, 2010; Williams, 2009). The level of success can be measured from the farmers’ ability to gain and apply farming technology. Therefore, an understanding of technology dissemination and adoption, and how their success or failures are tracked, is important to optimise the sustainability of lobster farming. More importantly, ensuring that information about new technologies reaches the right recipients will play a significant role in successful technology transfer. With education, training and capacity building, farmers can gradually improve their knowledge and farming skills (Brummett & Williams, 2000; Brummett et al., 2008).

This study found that improved puerulus collection was driven by the adoption of lights combined with particular types of puerulus collection devices, which was an example of technology uptake that was fostered by the study tour described in Chapter 3. To some extent, using light is a very simple approach but it is a meaningful because without the participants seeing this application in Vietnam, it would not have been adopted. Although the change of practice was simple, it provided significant benefit to puerulus fishers' livelihood as their income has increased significantly compared to the use of earlier puerulus fishing methods. More generally, the effect of adopting use of lights to collect the puerulus has become a national issue as many new puerulus hot spots were found when this practice was applied.

Regarding policy, the government's support is essential to ensure economic sustainability of the industry and on-going applied research that improves productivity, minimises impact and provides financial support for farmers who do not have financial assets to be able to participate in the industry.

7.2.2 Improved Knowledge of Puerulus Behaviour

To understand puerulus behaviour, various collection devices and techniques were developed. The tank and field-based experimental approaches using different collector types, materials, depths and crevice angles of puerulus fishing equipment were used to compare the most effective design for collectors. The present study builds on knowledge gained on the behaviour and substrate preferences of settling pueruli by examining aspects of collector design and substrate surface characteristics in regard to catch rates.

It is known that settlement areas are characterised by lower salinity, high turbidity, high nutrient concentrations and low-energy tidal currents and coastal eddies, and it may be a complex of stimuli that results in puerulus settlement. The field-based study assessing the effectiveness of the most common puerulus fishing equipment used in Lombok revealed that collectors made from cement bag paper, in particular those based on the shape of a concertina bowtie, were the most effective among those examined. The greatest catch of *P. homarus* was on the sea floor using cement bag paper collectors. For *P. ornatus*, catch rate was less strongly correlated with a specific depth or collector type, although it was highest at or near the sea floor in cement bag paper collectors. It is known that the settlement of *P. homarus* and *P. ornatus* mainly occurs on the sea floor whereas that for other spiny lobster species, such as *P. cygnus*, occurs near the sea surface.

A series of tank-based experiments were used to examine preferences for various attributes of collector materials, and preferred material characteristics were then tested in another field experiment to test whether the laboratory results were representative of wild puerulus preferences. In the tank experiment the most preferred substrate was cement bag paper, followed by insect mesh, weed netting, PVC rubber and cement bag plastic. Crevice angles of 10^{o} and 20^{o} were significantly preferred over 30^{o}. The substrate level and other substrates had less influence on settlement. However, both the lunar phase and type of materials tested in the field had a significant effect on settlement. Significantly greater numbers of pueruli were caught at the time of the new moon than during other moon phases. Cement bag paper was the most preferred material in the field, followed by cement bag plastic, insect mesh, weed fabric and PVC rubber. The abundance and low cost of cement bag paper makes it an ideal choice for puerulus fishers in Indonesia, and most likely in other developing countries.

The puerulus resource (of *P. homarus* and *P. ornatus*) in south-central Indonesia is particularly abundant, and significantly greater than in other coastal areas of Indonesia, which can be explained by the concentration of pueruli generated by the power and volume of the Indonesian Throughflow (Dao et al., 2013, 2015). However, there is very limited suitable adult habitat in the region where this puerulus population occurs (Asin, an experienced lobster diver/fisher, personal communication), and on balance there is a high probability that the bulk of these pueruli perish (Jones, 2015b). Exploitation of them for the purposes of aquaculture is likely to be sustainable.

It is also known that using low-technology methods of puerulus collection is successful, along with the utilisation of inexpensive locally available material for collectors and efficient methods of deployment. In addition, this low technology is adoptable and adaptable for smallholders in other areas where pueruli can be found.

7.2.3 Assessment of the Lobster Puerulus Resource and its Potential Sustainable Exploitation for the Purpose of Aquaculture

The effect of puerulus collection on the catch of adult lobsters was projected to be insignificant based on evidence that as few as 0.9–3% of settling pueruli survive to recruit into the fishery (Phillips et al., 2003a, 2003b). Jones (2015b) pointed out that spawning populations of *P. ornatus* and *P. homarus* in Indonesia are likely not supported by the puerulus resources of the central south coast of Indonesia, and the low natural abundance of adults in the locality of puerulus populations in Lombok suggests natural survival to adulthood is very low, predicted at 0.01%. Therefore, for example, if in excess of 5.2 million pueruli are caught each year as described in Chapter 4, it is estimated that fewer than 0.01% (~520) of these—which is only equal to 262 kg (500 g each)—would have survived to adult stage in nature. By retaining them for managed grow-out in sea-cages, and assuming an average of 70% survival (as achieved in Vietnam), 1,750 tonnes of lobster could be produced at an average weight of 500 grams, worth 87.5 million USD and assisting many thousands of Indonesian smallholders.

In the broader area of puerulus collection in Indonesia, this study estimated a total number puerulus catch exceeding 100 million pueruli each year. This means that the opportunity for lobster aquaculture is large, both in terms of a legal puerulus fishery and a grow-out industry. Take for instance, if each grow-out and puerulus exportation industries would legally be allowed to manage 50 million caught pueruli, the grow-out industry, based on the scenario described in the previous paragraph, would produce as many as 17,500 tonnes of market size lobster, worth 875 million USD. And, for the exportation of 50 million pueruli, which comprises of 80% of them (*P. homarus*) at a price of USD 1.32/individual and 20% of them (*P.ornatus*) at a price of USD 2.4/individual, would generate 77 million USD. Therefore, both grow-out and puerulus fishing industries would be worth 952 million USD per year. The high value from the industry is slightly greater than the National Gross Domestic Product (GDP) in 2016, where the GDP accounted for 932.442 million USD (BPS, 2017). Thus, it is clear that this industry could potentially double the country's GDP. Therefore, there is opportunity to revise the regulation to allow the grow-out and some puerulus fishing, potentially with an export management or an export quota. The policy should strongly promote the domestic lobster farming industry to gain maximum value from the available seed. Thus, government and stakeholders would benefit through economic growth. If Indonesia does not take this opportunity, it is likely that other countries will.

As spiny lobster is a premium product, the proximity of Indonesia to markets in Asia and Australia provides a comparative advantage.

Spiny lobster aquaculture will be more attractive to fishery managers if it is combined with restocking as described in Chapter 4. The combination of farming and restocking using a small proportion of the farmed lobsters to suitable habitats could potentially ensure the local adult stocks are more sustainable. To clarify, these potential stocking areas would be locations where puerulus collection is not an industry, but where adult lobster are known to inhabit. The government, through its policies, could control puerulus fishing and export, and the grow-out sector by managing and providing best management farming practices for the farmers, and also creating opportunities for stock enhancement in the wild fishery. This can be done utilizing the governments' resources such as marine research centers and technical implementation units under the management of MMAF. Additionally, extension staff spread throughout the districts within the regions managed by the MMAF could also be assigned to monitor the implementation of best management farming practices.

It is recognised that the cash flow and revenue from puerulus fishing are more attractive than that of grow-out farming in Indonesia. Nevertheless, it is the on-growing of the lobsters to market size where the greatest benefit lies. This must be the driver for a stakeholder campaign to revise the legislation. Lobster growout in Indonesia can be sustainable and significant with positive multiplier effects, particularly for rural areas where urban-based livelihood options are limited. Thus, re-focussing on lobster grow-out in Indonesia is an important issue. It must be noted that in the last 4 years, significant numbers of Indonesian pueruli (possibly more than 50 million) have been exported and farmed abroad as discussed in Chapter 2. If actions in Indonesia do not address this to stimulate and support a domestic growout industry then it is likely that

Indonesian lobster aquaculture will be left behind by the other surrounding countries where there is interest and government support to develop spiny lobster grow-out, eg in the Philippines, Malaysia, PNG and Timor Leste. It is essential that the Indonesian lobster growout industry be allowed to restart, so farmers can legally purchase seed, set up farms and conduct grow-out. If this can be achieved, then Indonesia can build a lobster farming industry that can achieve the size of that in Vietnam and beyond, become the largest in the world.

7.3 Conclusion

The knowledge gained from this research was applied to address the planning needs of spiny lobster aquaculture development in Indonesia. Indonesia could become the world leading lobster producer because of its abundant puerulus resource. Therefore, the short-term and mid-term goals of its development strategies should include 1/ improved policies, research and funds that support spiny lobster aquaculture; 2/ management and control of puerulus exportation through export quotas; 3/ improved capacity building programmes for grow-out farmers to master the technique of lobster grow-out through training, education and knowledge dissemination; 4/ technology transfer; and 5/ engagement of corporate investors in the lobster farming industry through tax and credit initiatives for the development of spiny lobster aquaculture and creation of opportunities for small-scale farmers.

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Appendices

Appendix A: A structured questionnaire for puerulus fishers

1. General information

1.1 Demography

Respondent code : _____ Gender : ___ Age: ____ Mobile number: ___

Sub village : ___________________
Village : ___________________
Sub district : ___________________
District : ___________________
Date of interview : ___________________

1.2 Educational level

Grade	Status (complete/incomplete)
1-6 year schooling	
7-9 year schooling	
10-12 year schooling	
Diploma	
Bachelor	
Master	
Ph.D	

1.3 Household structure

Family member and age	Gender (M/F)	Involved in puerulus collection (Y/N)	Educational level

2. History, adoption and reasons, cost and financial supports for upgrading the puerulus collection technology

2.1 History and characteristic of the puerulus collection activity

1. When did you start collecting puerulus? (month/year)
2. What were the reasons for you to collect the puerulus in that year?
   a. Low risk
   b. Less effort and time-consuming
   c. Good as a source of income
   d. I could do other activities
   e. Provided better revenue (income) compared to my previous job.
   f. Other reasons, please specify:
3. How many puerulus fishing rafts you had when you started?

4. How many puerulus fishing rafts you have now?
5. What methods did you use when started collecting puerulus (Please, describe the method!)
6. Have you changed your techniques since that year following the latest technique using lights?
   a. No! Still use the old version
      i) Why have not you adopted the new technology?
         a) The results are not different!
         b) I am interested but I do not have the money to buy generators, etc.
         c) I am interested but other fishers do not allow others to use it.
         d) Complicated
         e) Too expensive
         f) Happy with the current method
         g) Do not believe it would make any difference
         h) Do not trust the study tour participants
         i) Difficult to implement
         j) Too technical
         k) Would have to employ more people
         l) Other:

      ii) Yes!
         Go to the next question No. 7

7. If yes, what are the new techniques have you adopted:

Adopted new techniques	When have you adopted (month and year)	How did you get the information about the new techniques	Why did you chose the adopted techniques (list all that apply)	Traps/collectors		The number of puerulus collected (cage/boat)	
				Type	Number	Before (unit)	After (unit)
	5	6	7	8	9	10	11
1. Raft with lights		(1) Other farmers (2) Buyers (3) Lombok MADC Extension (4) DKP Extension	(1) Easy and simple to apply (2) Effective and efficient (3) The results are promising (4) I have collected more peurulus compared to the old technique (5) It requires shorter time to collect puerulus (6) Other…..	(1) Cement paper (2) Rice bag (3) Netting (4) Other			
2. Boat without lights		(1) Other farmers (2) Buyers (3) Lombok MADC Extension (4) DKP Extension	(1) Easy and simple to apply (2) Effective and efficient (3) The results are promising (4) I have collected more peurulus compared to the old technique (5) It requires shorter time to collect puerulus (6) Other…..	(1) Cement paper (2) Rice bag (3) Netting (4) Other			
3. Boat with light		(1) Other farmers (2) Buyers (3) Lombok MADC	(1) Easy and simple to apply (2) Effective and efficient	(1) Cement paper (2) Rice bag			

		Extension (4) DKP Extension	(3) The results are promising (4) I have collected more peurulus compared to the old technique (5) It requires shorter time to collect puerulus (6) Other…..	(3) Netting (4) Other			
4. Others:							

This is the question for those who adopted new techniques (boat, long line, and light) only.

2.2 Please rank your level of satisfaction in utilizing the new methods? Please rank the level of satisfaction from 1 (most) to 5 (least), please circle the corresponding answer.

	1	2	3	4	5
Level of satisfaction	Very unsatisfied	Not satisfied	Cannot decide	Satisfied	Very satisfied

2.3 What are the reasons that encourage you to choose the answer?

a. Easy and simple to apply
b. Effective and efficient
c. The results are promising
d. Others:

2.4 Investment costs for upgrading the new techniques (How much money did you spend for the following items to upgrade the technology?)

1. Puerulus fishing rafts

Components	Volume	Unit	Unit Cost (IDR)	Amount	Expiration
Sea-cages construction					
Traps/collectors					
Electricity generator set + Lights					
Others:					
TOTAL					

2. Puerulus fishing boats

Components	Volume	Unit	Unit Cost (IDR)	Amount	Expiration
Boat + engine					
Traps/collectors					
Electricity generator set + Lights					
Others:					
TOTAL					

3. Longline

Components	Volume	Unit	Unit Cost (IDR)	Amount	Expiration
Construction					
Traps/collectors					
Electricity generator set + Lights					
Others:					
TOTAL					

2.5 Financial support for the upgrading and ability to access credit

1. How did you get the financial capital to upgrade?
   a. Savings or cross-fund from other businesses such as selling property, livestock,
   b. Borrowed money from banks
   c. Borrowed money from farmer groups
   d. Money lender
   e. Borrowed money from middle person (*Toke*)
   f. Borrowed money from neighbors
   g. Borrowed money from relatives
   h. Others:
2. What were the reasons you borrowed money from them?
   a. Secured
   b. I could get the money immediately
   c. Easy
   d. Happy with the process
   e. Others:
3. Have you ever borrowed money from banks
   a. Yes go to the question No.4
   b. No (go to the question No. 6
4. Did you receive a support to borrow money from the bank?
   a. Yes (go to question No.5)
   b. No (go to question No. 6)
5. What kind of support did you receive?
   a. Assistance from bank officers in filling the form, write and submit the loan proposal.
   b. Assistance from village officers in filling the form, write and submit the loan proposal.
   c. Assistance from other farmers or farmer groups in filling the form, write and submit the loan proposal.
   d. Others:
6. Why you have never borrowed money from the banks?
   a. The process is too long and complicated.
   b. I do not have collateral.
   c. The interest is too high
   d. I don't know how to borrow money from the banks.
   e. Others:

2.6 Access to technical assistance and technology

1. If you face a problem, how do you find the possible solution or advice?
   a. I will first try to find a solution by trying a new method I invented.
   b. Ask other fishers
   c. Ask researcher/extension staff from Lombok MADC/MMAF
   d. Ask extension staff from DKP District
   e. Ask extension staff from DKP Province
   f. Reading from news media
   g. Publication
   h. Brochures, pamphlets, leaflets.
   i. Others:

2. Have you received endowment from the government since 2010? ______ (1) Yes; (2) No, *if No*, [*skip to next page*]

Who provided the extension?	What year did you receive this extension ? (year)	How frequently did you receive extension?		What commodity did the extension concern?	What type of extension was it?	What do you think about their knowledge or skills?	What do you think about the extension?
1	2	3		4	5	6	7
1. MMAF /MADC 2. DKP province 3. DKP district		Count / Unit		1. Lobster 2. Grouper 3. Milkfish 4. Seaweed 5. Mangroves 6. Shrimp 7. Other shrimp 8. Other fish 9. Other: Specify ________ [list all that apply]	1. Puerulus collection, nursery, grow-out 2. Feed use & nutrition 3. Vitamins / Probiotic use 4. Disease Identification / prevention 5. Harvest methods	1. They are knowledgeable; I have learnt a lot from them. 2. I have learnt little bit from them but they still cannot give us appropriate method or solution. 3. We have better knowledge than them, they do not have enough knowledge 4. Other	1. Very appropriate 2. Sufficiently appropriate 3. I am not sure 4. Inappropriate 5. Not appropriate at all 6. Other: …..
		Count	Year/Month				

3. Impacts of puerulus collection and the technology upgrading on livelihoods

3.1 Productivity

1. Productivity in both low and peak seasons

Seasonal types	How many months the low and peak seasons lasted annualy (month)	How many days of "new moon" each month during this season?	How many puerulus do you catch during the "new moon" (individual)	How many days of "full moon" each month during this season?	How many puerulus do you catch during the "full moon" every day? (individual)
1	2	3	4	5	6
Low season					
Peak season					

2. For each type of collecting method and species, how many puerulus did you catch before and after the adoption of the new technology presented above every day?

Types of collectors	The number of species caught per day (average)			
	P. ornatus		*P. homarus*	
	Before*	After*	After*	Before*
1. Raft with light				
2. Boat without lights				
3. Boat with light				
4. Raft with light				

*Before and after adopting new techniques

3. What were the prices of puerulus species before and after the technology adoption (IDR)

P. ornatus		*P. homarus*	
Before (2013)	After*(last crop price before the new regulation)	Before (2013)	After (last crop price before the new regulation)

3.2 Efficiency in production cost between the new and old technique

For those who have adopted the new techniques, what were the differences regarding the components below before and after the implementation of the techniques (please illustrate!)

1. Operational cost before the adoption

Components	Volume	Unit	Unit Cost	Sub Total
Fuel				
Food				
Number of hour/day you spent before getting the puerulus				
TOTAL				

2. Operational cost after the adoption (current)

Components	Volume	Unit	Unit Cost	Sub total
Fuel				
Food				
Cigarettes				
Number of hour/day you spent before getting the puerulus				
TOTAL				

4. *Responds to the new regulation (Decree 1/2015) and puerulus fishers' interests in lobster sea-cage farming*

4.1 Perceptions and livelihood impacts of the new regulation and practice

1. Do you know the new regulation of MMAF related to the banning of catching berried eggs lobsters, mud crabs and swimming crabs (Decree No 1/2015)?
   a. I know
   b. I do not know
   c. I do not care/others
2. Where did you learn about the information?
   a. Other fishers
   b. Middle persons, my buyer
   c. Head of village
   d. Friends
   e. Other:
3. What do you think about the new regulation?
   a. Angry
   b. Protest to the authorities
   c. Agree
   d. Support
   e. Do not agree
4. What are your responses in relation to colleting puerulus after the regulation?
   a. I'm still catching and still obtain the similar yield
   b. I am still catching but I have reduced the number of traps
   c. I have stopped collecting puerulus at all
   d. Other
5. How many puerulus have you collected per day after the regulation?

6. If you are still catching the puerulus, what is the price of puerulus after the regulation?

4.2 The immediate impacts of the new regulation (Decree 1/2015)

1. In addition, what are other impacts you have experienced due to the regulation?
   a. I lose my capital input (IDR)
   b. I cannot afford to paybackthe banks/money agencies' loan and interests
2. Have the regulation affected your ability to sell your puerulus?
   a. Yes (next question)
   b. No
3. How have the regulation affected your ability to sell your puerulus?
   a. I cannot sell the puerulus to the local buyers, so I have to sell them to buyers located at the other islands on my own risks
   b. I can only sell partially the puerulus I collected because the buyer cannot buy in big (volume) quantity
   c. I have to sell to illegal market chains
   d. The buyer cannot give assurance that they can buy the puerulus I collected.
   e. I still can sell the puerulus, but I do not know who the next buyers are.
   f. Other
4. What risks have you been encountering?
   a. Fear of being arrested by the police
   b. The seeds taken by the officers
   c. Other:
5. What is your expectation?
   a. The government allows me to catch the puerulus again
   b. I can still sell the puerulus although the price drops
   c. Government takes more attention on fishers's life.
   d. Government supports local (domestic) grow out sector by giving: Capital, Technical assistance, Demonstration farms, etc.
   e. Other:
6. What is your opinion about the future of spiny lobster aquaculture (puerulus collection)?
   a. It has a strong potential to generate income
   b. It has a medium potential to generate income
   c. It has a weak potential to generate income
   d. Less chance to generate income, I am looking for other commodities with better opportunity
   e. Least chance to generate income, I am looking for other commodities that offer much better opportunity

4.3 Puerulus fishers' interest on lobster grow-out

Because of the new regulation (Decree 1/2015), are you interested in growing the puerulus you catch?

1. If yes, what proportion
   a. All of them
   b. 50%
   c. 10%
   d. Specify:

2. If yes, why are now interested in growing them?
   a. I want to get much more benefit
   b. I want to try to make something different
   c. Because selling the puerulus is now prohibited
   d. I am confident with the grow-out technique
   e. It's promising
   f. Other:
3. If not, why not? (list all apply)
   a. Too risky
   b. Insufficient skill
   c. Lacking knowledge
   d. Because of disease
   e. No suitable food
   f. Not enough feed available in the area.
   g. I have to spend too much time to catch natural feed.
   h. Market price is very low, so it is not too profitable.
   i. Others:
4. Have you done grow out before
   a. No. why?
      i. I was not interested in doing grow-out
      ii. I did not have the capital inputs
      iii. I have insufficient skill
      iv. Too risky
   b. Yes! Was it successful?
      i. Yes. But, why it is stop now?
         a) I cannot afford buying the seeds anymore
         b) Marketable size's price was too low
         c) Disease
         d) Loss of profit due to the SR issue
         e) Too risky business
         f) Too Long duration in getting the return of investment/profit
         g) I cannot deal with the grow-out technique
         h) Capital input problems
         i) Other:
      ii. No! Why?
         a) I lost profit due disease
         b) I lost profit due to the SR issue
         c) I lacked of the technique
         d) I lacked of capital inputs
         e) I was not interested in the grow-out sector, so it was abandoned
         f) Other:

5. Interest in learning about grow-out technologies

Would you be interested in learning more about lobster grow-out?		Which aspects of farming technology you would like to learn more specifically?
Yes. Why?	No. Why?	
(1)	(2)	(3)
1. I am optimistic to succeed 2. want to get much more benefit 3. I want to try to make something different 4. Because selling the puerulus is now prohibited 5. I am confident with the grow-out technique 6. It's promising 7. Other:	1. Too risky or too many risks 2. I do not want to experience business losses again 3. I am pessimistic 4. It's kind of complicated business 5. Long term high risk business, I have to avoid 6. The disease cannot be avoided 7. Others:	1. Nursery 2. Feeding technique 3. Cage construction 4. Husbandry 5. Cages management 6. Other: specify

6. If there is a new technology in lobster cage farming, what are the main reasons for you in adopting the technology? Please rank from 1 (most important) to 10 (less prefer).

No	Reasons	Level of importance									
		1	2	3	4	5	6	7	8	9	10
1	Production cost										
2	Profits										
3	It is not feasible to adopt the technology										
4	Level of obstacles										
5	Others:										

Appendix B: A structured questionnaire for grow-out and ex-grow-out farmers

1. General information

1.1 Demography

Respondent code : _____ Gender : ______ Age: ____ Mobile number: _______

Sub village : ___________________
Village : ___________________
Sub district : ___________________
District : ___________________
Date of interview : ___________________

1.2 Educational level

Grade	Status (complete/incomplete)
1-6 year schooling	
7-9 year schooling	
10-12 year schooling	
Diploma	
Bachelor	
Master	
Ph.D	

1.3 Household structure

Family member and age	Gender (M/F)	Involved in puerulus collection (Y/N)	Educational level

2. History, upgrading impacts of grow-out techniques to the livelihood after the technology upgrading in 2013

2.1 History and characteristic of the grow-out activity

1. When did you start cultivating lobsters?
2. How many cages you had when you started?
3. What were the reasons for you to cultivate lobsters in that year?
   a. Good as a source of income
   b. Low input high product
   c. Less time consuming and effortless
   d. Good price of products
   e. I can do other activities

f. Other reasons, specify:

4. How many cages you had when you started?
5. How many cages you have now?
6. Have you changed your techniques since that year following the latest technique?
   a. No! Still use the old version
      iii) Why have not you adopted the new technology?
         a) The results are not different!
         b) I am interested but I do not have the money to buy generators, etc.
         c) I am interested but other fishers do not allow others to use it.
         d) Complicated
         e) Too expensive
         f) Happy with the current method
         g) Do not believe it would make any difference
         h) Do not trust the study tour participants
         i) Difficult to implement
         j) Too technical
         k) Would have to employ more people
         l) Other:
   b. Yes!
      What are the kind of practices have you adopted? (List all applied)
         a) Nursery
         b) Grow-out practice
         c) Feeding and feeding practices
         d) Post-harvest/packaging
         e) Lobster disease prevention and management

3. Socio-economic factors and contributions of spiny lobster grow-out

3.1 Production system

1. How many lobsters did you farm? And, how many cages/frames of sea-cages do you have? Estimation!

Year	*P. ornatus* (pieces/unit)	*P. homarus* (pieces/unit)
2010		
2011		
2012		
2013		
2014		
2015		

In what month do you start the grow-out?	What are the stages of lobster grow-out including nursery?	How long is each stage conducted? (number of month)	What are the obstacles you perceive in each stage?
1	2	3	4

What species do you farm	How many lobster seeds did stock in a cage in the last cycle? (number of seed/puerulus)	What is the initial size of the seeds (cm/gram)
5	6	7
P. *ornatus*		
P. *homarus*		

3.2 Ability to access seed/puerulus

Species	How do you obtain the puerulus for cage farming for each species	If you buy if from suppliers, where are they	Is there any condition required by seed suppliers in purchasing puerulus/seed	Is there any fluctuation in seed availability?	If yes, What months?	How do you identify the quality of the puerulus/seed	What are the constraints to obtain seed; if possible for every production cycle/year? (open answers)
1	2	3	4	5	6	7	8
P. *ornatus*	1. Lobster fisher 2. Lobster middle persons 3. Catch by myself	1. Same village 2. Other village in same sub district 3. Other village in different sub district	1. Minimum quantity 2. Sell the harvest to the seed supplier 3. None	1. Yes 2. No		1. From a specific location 2. Type of seed production (wild caught vs. reared juvenile 3. Size	
P. *homarus*	1. Lobster fisher 2. Lobster middle persons 3. Catch by myself	1. Same village 2. Other village in same sub district 3. Other village in different sub district	1. Minimum quantity 2. Sell the harvest to the seed supplier 3. None	1. Yes 2. No		1. From a specific location 2. Type of seed production (wild caught vs. reared juvenile 3. Size	

3.3 Output and ability to access markets

1. How many kilograms did you harvest in the following years? (Estimation)

Type	2010 (kg)	2011 (kg)	2012 (kg)	2013 (kg)	2014 (kg)
P. homarus					
P. ornatus					

2. Harvested lobsters

What were the sizes of lobster harvested? (cm/grams)	How did you identify the size for harvesting?	How much was the price of lobster in the latest harvest for each size? (IDR)	How was the latest price compared to price you received 5 years ago (IDR)
1	2	3	4
	1. Asked by buyer 2. When I cannot get feed 3. Others:	1. 100g: 2. 200g: 3. 300g: 4. 500g-1kg:	1.100g: 2.200g: 3. 300g: 4. 500g-1kg:

3. Who did you sell your lobster to?
   a. Buyer from village
   b. Buyer from sub-district
   c. Buyer from district
   d. Buyer from Bali or other province
4. Where do they sell the lobster to?
   a. Buyer from closest city
   b. Directly to exporter to Lombok
   c. I don't know
   d. Farmers' cooperative
5. How did you sell your lobster?
   a. I bring the lobster to a buyer
   b. A buyer come to me
   c. A buyer makes a collective agreement with several lobster farmers and informs me
6. How do you access the buyer?
   a. I called several buyers and compare the price
   b. They come to my farm and offer the price
   c. I sell to the same buyer
7. What are the requirements from buyers?
   a. Live lobster
   b. Disease free
   c. Minimum size of seeds
8. How the price is determined based on the requirement from buyers?
   a. 10% cheaper

b. 11-20% cheaper
c. 20-30% cheaper
d. 30-40% cheaper
e. 40-50% cheaper

9. What kind of services provided by the buyers?
   a. Nothing
   b. Packaging to keep the lobster alive
   c. Other:

3.4 Investment and production costs per cycle per cage

1. Investment costs (IDR):

Investment cost	Volume	Unit	Unit Cost	Amount	Expiration
Sea-cages construction					
Boats					
Nets					
Others:					
TOTAL					

2. Operational cost per cycle per cage (frame)

Components	Volume	Unit	Unit Cost	Amount	Expiration
Seeds					
Fuel					
Electricity generator set + Lights					
Food for operator					
Tool/work equipment					
Labors					
Others:					
TOTAL					

3.5 Ability to access natural feed

1. What kind of natural feed used in lobster grow-out (list of the name and answer the following questions for each type of natural feed used)
2. What stage of lobster grow-out this type of natural feed is being used
   a. All stage
   b. Nursery
   c. Small mesh (3x3cm)
   d. Trawl (1 inch)
3. How many kg of natural feed is being used per cage per day
4. Who do you buy the natural feed from?

a. Fishers
b. Retailers at wet markets
c. Catch by myself

5. How much is the price of the natural feed per kg (IDR) if you buy
6. How many hours did you spend if you have to catch fish as the feed?
7. What are the problems to obtain the natural feed?

3.6 Financial support for the upgrading and ability to access credit

1. How did you get the financial capital to upgrade?
   i. Savings or cross-fund from other businesses such as selling property, livestock,
   j. Borrowed money from banks
   k. Borrowed money from farmer groups
   l. Money lender
   m. Borrowed money from middle person
   n. Borrowed money from neighbors
   o. Borrowed money from relatives
   p. Others:
2. What were the reasons you borrowed money from them?
   f. Secured
   g. I could get the money immediately
   h. Easy
   i. Happy with the process
   j. Others:
3. Have you ever borrowed money from banks
   a. Yes go to the question No. 4
   b. No (go to the question No. 6
4. Did you receive a support to borrow money from the bank?
   c. Yes (go to question No. 5)
   d. No (go to question No. 6)
5. What kind of support did you receive?
   e. Assistance from bank officers in filling the form, write and submit the loan proposal.
   f. Assistance from village officers in filling the form, write and submit the loan proposal.
   g. Assistance from other farmers or farmer groups in filling the form, write and submit the loan proposal.
   h. Others:
6. Why you have never borrowed money from the banks?
   f. The process is too long and complicated.
   g. I do not have collateral.
   h. The interest is too high
   i. I don't know how to borrow money from the banks.
   j. Others:

3.7 Access to technical assistance and technology

1. If you face a problem, how do you find the possible solution or advice?
   j. I will first try to find a solution by trying a new method I invented.
   k. Ask other fishers
   l. Ask researcher/extension staff from Lombok MADC/MMAF
   m. Ask extension staff from local DKP
   n. Ask extension staff from provincial level DKP
   o. Reading from news media
   p. Publication
   q. Brochures, pamphlets, leaflets.
   r. Others:

2. Have you received endowment from the government since 2010? ______ (1) Yes; (2) No, *if No*, [***skip to next page***]

Who provided the extension?	What year did you receive this extension? (year)	How frequently did you receive extension?	What commodity did the extension concern?	What type of extension was it?	What do you think about their knowledge or skills?	What do you think about the extension?
1	2	3	4	5	6	7
4. MMAF / MADC 5. DKP province 6. DKP district		Count / Unit	10. Lobster 11. Grouper 12. Milkfish 13. Seaweed 14. Mangroves 15. Shrimp 16. Other shrimp 17. Other fish 18. Other: Specify ________ [list all that apply]	6. Puerulus collection, nursery, grow-out 7. Feed use & nutrition 8. Vitamins / Probiotic use 9. Disease Identification / prevention 10. Harvest methods	5. They are knowledgeable; I have learnt a lot from them. 6. I have learnt little bit from them but they still cannot give us appropriate method or solution. 7. We have better knowledge than them, they do not have enough knowledge 8. Other	1. Very appropriate 2. Sufficiently appropriate 3. I am not sure 4. Inappropriate 5. Not appropriate at all 6. Other:

3. Further interest in learning more on grow-out and aspect of farming technology they would like to achieve.

Would you be interested in learning more about lobster grow-out?		Which aspects of farming technology you would like to learn more specifically?
Yes. Why?	No. Why?	
1	2	3
1. I am optimistic to succeed 2. want to get much more benefit 3. I want to try to make something different 4. I am confident with the grow-out technique 5. It's promising 6. Other:	1. Too risks 2. I do not want to get lose again 3. I am pessimistic 4. It's kind of complicated business 5. Long term high risk business, I have to avoid 6. The disease cannot be avoided 7. Others	1. Nursery 2. Feeding technique 3. Cages construction 4. Husbandry 5. Cages management 6. Other: specify

4. Farmer views on constraints to the development of their lobster farming

No	Constraints type	Level of constraints (1 less difficult – 10 the most difficult)									
		1	2	3	4	5	6	7	8	9	10
1.	Seasonal/climate/weather constraint										
	a. Water temperature										
	b. Water turbidity										
	c. Salinity										
	d. Bio-fouling										
	e. Jelly fish/fish attack										
2.	Insufficient access to credit										
3.	Ability to pay back interest cost										
4.	Access to good-quality feed										
5.	Cost of good-quality feed										
6.	Access to sufficient quantities of seed										
7.	Access to seed of high enough quality										
8.	Access to good information about technology improvements in lobster farming										
9.	Leasing fees and other taxes or charges										
10.	Access to farm labour										
11.	Government regulations or policies										
12.	Constraints to allocation of land or/and marines areas										

5. Recommendation to fisheries authorities to assist improve your grow-out operations

a. Provide support for accessing credit
b. Provide training on lobster disease and the treatments
c. Help reduce interest rates particularly when farmers lose their crops
d. Improve access to training in lobster culture techniques
e. Other:

4. Responds to the new regulations (Decree 1/2015) on lobster grow-out

4.1 Perceptions and livelihood impacts of the new regulation and practice

1. Do you know the new regulation of MMAF related to the banning of catching berried eggs lobsters, mud crabs and swimming crabs (Decree No 1/2015)?
   a. I know
   b. I do not know
   c. I do not care/others
2. Where did you learn about the information?
   a. Other fishers
   b. Middle persons, my buyer
   c. Head of village
   d. Friends
   e. Other:
3. What do you think about the new regulation?
   a. Angry
   b. Protest to the authorities
   c. Agree
   d. Support
   e. Do not agree
4. What are your responses in relation to colleting puerulus after the regulation?
   a. I can re-create my farm
   b. I can buy the seed because its price becomes cheaper (to some extends)
   c. Growing lobster until 200g is difficult, I lost my profit
   d. Limited market
   e. I switch to fishing because growing lobster until 200g is riskier
   f. Others:

4.2 Participants interest on lobster grow-out

Because of the new regulation, are you (still) interested to grow the lobster?

1. If yes, what makes you interested?
   a. I want to get much more benefits
   b. I want to try to make something different
   c. I am confident with the grow-out technique
   d. It's promising business
   e. Other:

2. If not, why not?
   a. Too risks
   b. Insufficient skill
   c. Lacking knowledge
   d. Because of disease

e. No suitable food
f. Market issues due to bigger size allowed to sell
g. Others:

3. Have you done grow-out before
   a. No. why?
      i. I was not interested in doing grow-out
      ii. I did not have the capital inputs
      iii. I have insufficient skill
      iv. Too risky
   b. Yes! Was it successful?
      i. Yes. But, why it is stop now?
         a) I cannot afford buying the seeds anymore
         b) Marketable size's price was too low
         c) Disease
         d) Loss of profit due to the SR issue
         e) Too risky business
         f) Too long duration in getting the return of investment/profit
         g) I cannot deal with the grow-out technique
         h) Capital input problems
         i) Other:
      ii. No! Why?
         a) I lost profit due disease
         b) I lost profit due to the SR issue
         c) I was lack of the technique
         d) I was lack of capital input
         e) I was not interested in the grow-out sector, so it was abandoned
         f) Other:

4. What is your opinion about the future of spiny lobster aquaculture (puerulus collection)?
   a. It has a strong potential to generate income
   b. It has a medium potential to generate income
   c. It has a weak potential to generate income
   d. Less chance to generate income, I am looking for other commodities with better opportunity
   e. Least chance to generate income, I am looking for other commodities that offer much better opportunity

Appendix C: A structure questionnaire for study tour

I. Questions that were asked at the beginning of the study tour

Date	
Name	
Educational level	
Place of origin	
Address	
Contact details (HP/Email)	
Gender	

<table>
<tr><th>A</th><th colspan="2">General information and background</th></tr>
<tr><td rowspan="2">1</td><td colspan="2">Please specify your age</td></tr>
<tr><td colspan="2">a. 18-25 years old   d. 45-54 years old
b. 26-34 years old   e. 55-64 years old
c. 35-44 years old   f. 65 – older</td></tr>
<tr><td rowspan="2">2</td><td colspan="2">How long have you been involving in lobster aquaculture?</td></tr>
<tr><td colspan="2">a. 1-4 years   b. 10-14 years
b. 5-9 years   c. More than 15 years</td></tr>
<tr><td rowspan="2">3</td><td colspan="2">In what capacity are your involvements and how long are they?</td></tr>
<tr><td colspan="2">a. Middle persons, … years. Go to the next question
b. Industry representative, … years. Go to question No.5
c. Extension officer, … years. Go to question No. 6
d. Puerulus fisher/grow-out farmer. Go to question 7
e. Others, specify …</td></tr>
<tr><td rowspan="2">4</td><td colspan="2">If you are middle persons:</td></tr>
<tr><td colspan="2">a. How many lobsters do you buy each year (roughly)?
b. Who do you buy them from (farmers? Where is the locations?)
c. Who do you sell them to? (other assemblers, processors, restaurants, traders)
Go to question No. 7</td></tr>
<tr><td rowspan="2">5</td><td colspan="2">If you are an industry representative:
a. For which company do you work?
b. What is yor role and what are your responsibilities as an industry representative?</td></tr>
<tr><td>Role:</td><td>Responsibilities:</td></tr>
<tr><td>6</td><td colspan="2">If you are an extension officer:
a. For which organization do you work?
b. What is the role and what are your responsibilities as an extension officer?</td></tr>
<tr><td></td><td>Role:</td><td>Responsibilities:</td></tr>
</table>

	c. How do you disseminate new farming techniques information, and to whom do you disseminate the information?

How you disseminate the information?	To whom/where/how often
Visiting farmers	
Oral presentation	
Using media online	
Using telecommunication tools	
Using brochures/leaflet/pamphletes	
Others:	

7	What motivated you to participate in this study tour?
8	What do you hope to achieve from this study tour?
9	What did you do as a livelihood activity before doing lobster aquaculture/puerulus collection?
10	What attracted you to do lobster aquaculture/puerulus collection?
11	What proportion of your income is from lobster aquaculture? Do you have other sources of income?

Source of income	The proportion
Lobster farming: - Nursery - Grow-out Puerulus collection Fish farming Fishing Seaweeds Agriculture (rice, corn, and other farmings) Others:	

B	Basic knowledge on lobster aquaculture (puerulus collection, nursery, grow-out)
	B1. General information
1	Which of these methods do you use to cultivate lobsters?
	a. Stake nets b. Floating cages c. Submerged cages d. Others, please specify:
2	How many cages and production units do you use for each method (in No. 1)?

Stake nets		Floating cages		Submerged cages		Others	
Number of cages (frames)	Number of production units (kgs)	Number of cages (frames)	Number of production units (kgs)	Number of cages (frames)	Number of production units (kgs)	Number of cages (frames)	Number of production units (kgs)

3	How deep is the water column at your farms/cages?	
	a. 0-5 m b. 6-10 m c. 11-15 m d. 16-20 m e. 21-25 m f. Others, specify …	
4	Are your lobster farms affected by storms?	
	a. Yes, in what way?	
	b. No	
	c. Sometimes, how it happens?	
5	Are your lobster farms affected by strong current and wind?	
	a. Yes, in what way?	
	b. No	
	c. Sometimes, how it happens?	
6	How did you select your farming location? And, where did you get this knowledge about the location?	
7	What do you think are ideal environmen conditions for farming?	
	Environmetal conditions	Specify/explain
	Depth	
	Water quality:	
	- Salinity	
	- Turbidity	
	- Temperature	
	- Current	
	Water enrichment	
	Accessibility	
	Type of sea-floor	
	Source of pollutant	
	River mouth	
	Bays/lagoon protection	
	Others:	
8	What do you think the environmental, social or economic threats are to production?	
	Threats	Specify/explain
	Environmental	
	Social	
	Economic	
	B2. Puerulus collection	
9	Do you collect by yourself the lobster seed/puerulus?	
	a. Yes, go to question No. 10 b. No, go to question No. 17 c. Both collect by myself and buy. Go to question No. 19	
10	How many lobster seeds do you collect per season/year? (Approximately)	
11	What methods do you use to collect lobster seed/puerulus?	
12	What collectors' material do you use?	

13	Do you modify your collectors/collection methods to attract lobster seed? If so, what are the modifications or additions?
14	Do you think your collecting method is ideal?
15	If no, do you think your collecting method needs to be improved?
16	Why? Do you need training, extension or endowment? Go to question No. 19
17	If you do not collect your lobster seeds by your own, where do you get them?
	a. Buy from middle persons b. Buy from other fishers c. Others, specify:
18	What price do you pay from your purchased lobster seeds?

	Size (cm)	Price (IDR)
	2-3 3-5 5-7 10 Up	

19	Identify the proportion of lobster seeds you cultivated for your farms.

		Collect by myself	Buy from middle persons	Buy from othe fishers	Others
	Proportion (%)				

20	What kind of lobster seed pesies and what the proportion?

	Species	Proportion (%)
	P. ornatus	
	P. homarus	

	B3. Nursery technique
21	Do you implement nursery technique for your wild caught lobster seeds?
	a. No, go to question No. 22 b. Yes, go to question No. 23
22	Why not? Go to question No. 33
23	How many nursery cages do you have?
24	Describe the nursery technique do you use!

	Parameters	Value
	Size of nursery cage	m^3
	Type of nets	trawl/mesh
	Size of lobster seeds	cm/g
	Density per cages	indv
	Feed and compositions;	
	- Trash fish	%
	- Fresh water fish	%
	- Mollusc	%
	- Golden snail	%
	- Seaweeds	%
	- Others;	%

	Feeding regime Shelter inside the cages (yes/no). If yes, what kind of shelters do you use? Shading net (if you use it, what kind?) Duration Other treatments;	/day Weeks
25	Please rate the outcome of your implementation in terms of growth rate.	
	a. Very slow b. Slow c. Average	d. Fast e. Very fast
26	Which of the following best describes your crop's survival rate?	
	a. Poor b. Average c. Good	d. Very good e. Excellent
27	Which of the following best describes your crop's growth rate?	
	a. Poor b. Average c. Good	d. Very good e. Excellent
28	Overall, how succesful are your nursery techniques?	
	a. Poor b. Average c. Good	d. Very good e. Excellent
29	Do you think your implementation of nursery technique could be improved? a. No, why not? b. Yes, in what way?	
	B4. Grow-out phase	
30	How many grow-out phase do you have?	
34	Please, describe your grow-out method!	
	Parameters	Value
	Size of grow-out cages Type of nets Mesh size of nets Double net (inside and outside) Size of initial stock Density per cage Feed and compositions; - Trash fish - Fresh water fish - Mollusc - Golden snail - Seaweeds - Others; Feeding regime Shelter inside the cages (yes/no). If yes, what kind of shelters do you use?	

<table>
<tr><td></td><td>Shading net (if you use it, what kind?)
Grading
Duration
Other treatments;</td><td colspan="5"></td></tr>
<tr><td>35</td><td colspan="6">Do you do any of these following items? If so, how often?</td></tr>
<tr><td rowspan="3"></td><td rowspan="2">Action</td><td colspan="5">How often</td></tr>
<tr><td>Never</td><td>Every day</td><td>Once a week</td><td>Once a month</td><td>If necessary</td></tr>
<tr><td>Remove uneaten feed
Clean up the dirty cages
Change the dirty cages with the clean ones
Remove your cages to another spot
Others, if any:</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>36</td><td colspan="6">Please rate the outcome of your implementation in terms of growth rate.</td></tr>
<tr><td></td><td>a. Very slow
b. Slow
c. Average</td><td colspan="5">d. Fast
e. Very fast</td></tr>
<tr><td>37</td><td colspan="6">Which of the following best describes your crop's survival rate?</td></tr>
<tr><td></td><td>a. Poor
b. Average
c. Good</td><td colspan="5">d. Very good
e. Excellent</td></tr>
<tr><td>38</td><td colspan="6">Which of the following best describes your crop's growth rate?</td></tr>
<tr><td></td><td>a. Poor
b. Average
c. Good</td><td colspan="5">d. Very good
e. Excellent</td></tr>
<tr><td>39</td><td colspan="6">Overall, how succesful are your grow-out techniques?</td></tr>
<tr><td></td><td>a. Poor
b. Average
c. Good</td><td colspan="5">d. Very good
e. Excellent</td></tr>
<tr><td>40</td><td colspan="6">Do you think your implementation of grow-out technique could be improved?
a. No, why not?
b. Yes, in what way?</td></tr>
</table>

II. Questions that were asked at the end of the study tour

<table>
<tr><td rowspan="6">41</td><td colspan="2">Did you identify any techniques that you are going to apply when you returned home? Rank them in order of importance!</td></tr>
<tr><td>No</td><td>Techniques</td></tr>
<tr><td>1</td><td></td></tr>
<tr><td>2</td><td></td></tr>
<tr><td>3</td><td></td></tr>
<tr><td>4</td><td></td></tr>
<tr><td>42</td><td colspan="2">Why did you select these as techniques that you wish to apply?</td></tr>
<tr><td rowspan="2"></td><td>Consideration</td><td>Rank them in order of importance</td></tr>
<tr><td>Cost
Feasibility
Profitability
Level of difficulty
Others:</td><td></td></tr>
<tr><td rowspan="3">43</td><td colspan="2">What techniques would you like to try but are unable to, and explain the reasons?</td></tr>
<tr><td>Type of techniques</td><td>Reasons</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="3">44</td><td colspan="2">Has your confidence in new technologies of spiny lobster aquaculture increased? Please explain!</td></tr>
<tr><td>Level of confidence</td><td>Reasons</td></tr>
<tr><td>Increased significantly
Increased slightly
It does not increase at all</td><td></td></tr>
<tr><td rowspan="3">45</td><td colspan="2">Are there any technologies, that you have seen during the study tour, that will you abandon on your current activities (grow-out and puerulus collection)? Why?</td></tr>
<tr><td>Type of techniques</td><td>Reasons</td></tr>
<tr><td></td><td></td></tr>
<tr><td>46</td><td colspan="2">What do you now consider to be optimal environmental conditions for lobster puerulus collection and farming?</td></tr>
<tr><td></td><td>Depth
Water quality:
- Salinity
- Turbidity
- Temperature
- Current
Water enrichment
Accessibility
Type of sea-floor
Source of pollutant
Proximity to the river mouth
Bays/lagoon protections
Others;</td><td></td></tr>
</table>

Appendix C: A structured questionnaire used to gather information about puerulus fishing in Banyuwangi, Trenggalek and Sumbawa

Location	
I	Date
	Name of village
	Latitude and longitude
	Qualitative description of general geography of area (e.g., protected bay, islands, river mouths nearby)
	Quantitative estimate of extent of fishing area (km along coast and out from beach)
	Characteristics of the places where fishing equipment is placed—depth, turbidity, current, protected from waves etc.
	Local currents—where are the seed likely to come from? North or south or west or east? Other relevant information about the location
II	Puerulus catch
	Species composition: which species are caught and in what proportion
	Proportion of clear (stage 1) and white/coloured seed
	Describe seasonality of catch, what months, peak month
	Describe lunar catch pattern
	How many fishing households/fishers? How many vessels?
	How many fishing units per vessel (minimum, maximum, average)?
	Describe catching equipment (cement bag paper bowties, rice bag bowties, coconut fibre, other), frame size, range and average number of bowties per frame)
	Range and average catch per night per vessel
	Price paid to fisher (low, high, average), per clear stage and per pigmented stage
	Who are buyers, local middle persons, outside buyers etc.?
	Packaging for transport, describe packing materials, density, mode (by bike, car etc.)
III	Other relevant factors
	Health status of local environment—Is coral reef present? Is it in good condition? Water quality?
	Local populations of adult lobsters—are there local fishery, how much catch per year, which species, what type of fishing equipment?
	Is there opportunity for local grow-out? Are fishers interested in doing grow-out? Do they have any knowledge about it? Where did fishers obtain knowledge about catch puerulus?
	Are they aware of the fishery regulations?
	Do local fisheries agencies staffs support them or tell them to stop?