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# Spiny lobster aquaculture in the Asia–Pacific region

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# 132

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# **Spiny lobster aquaculture in the Asia–Pacific region**

**Proceedings of an international symposium  
held at Nha Trang, Vietnam,  
9–10 December 2008**

*Editor:* Kevin C. Williams



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2009

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Published by the Australian Centre for International Agricultural Research (ACIAR),  
GPO Box 1571, Canberra ACT 2601, Australia  
Telephone: 61 2 6217 0500; email: <[aciarc@aciarc.gov.au](mailto:aciarc@aciarc.gov.au)>

Williams K.C. (ed.) 2009. Spiny lobster aquaculture in the Asia–Pacific region. Proceedings of an international symposium held at Nha Trang, Vietnam, 9–10 December 2008. ACIAR Proceedings No. 132. Australian Centre for International Agricultural Research: Canberra. 162 pp.

ISBN 978 1 921615 51 1 (print)  
ISBN 978 1 921615 52 8 (online)

Technical editing by Mary Webb, Canberra  
Design by Clarus Design  
Printing by Paragon Printers Australasia

Cover photo: Harvesting of seed lobsters from a seine net placed at Xuen Del Bay, Song Cau, Phu Yen province, Vietnam. (Photo credit: Nguyen Thi Bich Ngoc, Research Institute for Aquaculture No. 3, Nha Trang, Khanh Hoa, Vietnam)

# Foreword

In July 2004, the Australian Centre for International Agricultural Research (ACIAR) sponsored a workshop at Nha Trang, Vietnam, as a forum to gather information on the use of lobsters in the South China Sea and the measures that should be taken for sustainable exploitation of lobster stocks in the region. At that time, the lobster aquaculture industry in Vietnam was rapidly expanding, with an annual production of marketed lobsters in excess of 2,000 tonnes and a farm-gate value of around US\$60 million. There was concern that the uninhibited capture of settling wild lobster seed for aquaculture grow-out could reduce natural recruitment processes and lead to a collapse of the lobster resource. A further concern was the impact that uncontrolled expansion of lobster aquaculture in Vietnam was having on the demand for low-value fish used to feed lobsters and the downstream pollution arising from this feeding practice.

To address some of these issues, a collaborative ACIAR project involving Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine and Atmospheric Research, the Queensland Department of Primary Industries and Fisheries, Nha Trang University, Institute of Oceanography, Nha Trang, and the Research Institute of Aquaculture No. 3 commenced in 2005. The project team was expanded in 2008 to include the Marine Aquaculture Development Centre at Lombok, Indonesia, so that lobster aquaculture development in eastern Indonesia could be fast-tracked.

The primary focus of the project was to enhance the sustainable production of tropical spiny lobster in Vietnam (and subsequently in Indonesia) and to develop the technology that would facilitate commercial establishment of spiny lobster aquaculture in Australia. This was achieved by documenting the level of exploitation of lobster seed for aquaculture use in Vietnam, reducing immediate postcapture losses of lobster seed, and developing husbandry best practices for lobster grow-out in Vietnam and Australia. The development of land-based lobster culture systems and pelleted feeds, and the transfer of this technology to Indonesia, were key project activities.

In order to rapidly and widely disseminate the research findings arising from the ACIAR lobster project, an international symposium on spiny lobster aquaculture was held at Nha Trang, Vietnam, on 9–10 December 2008. Twenty papers, 16 reporting ACIAR project research, were presented in four theme sessions: sustainable lobster aquaculture; improving lobster nursery culture; lobster grow-out culture systems; and lobster grow-out feeds and feeding practices. A broad range of people attended the symposium, with participants coming from Australia, India,

Indonesia, Malaysia, New Caledonia, New Zealand, the Philippines and Vietnam. The proceedings detail the rapid advances that are being made in the pursuit of best practices for sustainable lobster aquaculture development.

A handwritten signature in black ink, appearing to read 'Nick Austin', with a long horizontal flourish extending to the right.

Nick Austin  
Chief Executive Officer  
ACIAR

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# Acknowledgments

This symposium would not have been possible without the financial support of the Australian Centre for International Agriculture Research (ACIAR) and the assistance of many colleagues. In particular, I would like to thank collaborators in the ACIAR lobster aquaculture project: in Vietnam at Nha Trang, Dr Lai Van Hung and colleagues at Nha Trang University, Mrs Le Lan Huong and colleagues at the Institute of Oceanography and Dr Nguyen Thi Bich Thuy and colleagues at the Research Institute for Aquaculture No. 3; in Indonesia, Dr Reza Pahlevi of the Ministry of Marine Affairs and Fisheries at Jakarta and Messrs Sarafin and Bayu Priyambodo at the Marine Aquaculture Development Centre at Lombok; and in Australia, Dr Clive Jones and colleagues at the Queensland Department of Primary Industries and Fisheries' Northern Fisheries Centre at Cairns. I was fortunate to lead a team of dedicated aquaculture researchers at CSIRO Marine and Atmospheric Research—David Smith, Simon Irvin, Maggie Barclay and Simon Tabrett—whose support before and during the symposium was very much appreciated. I owe all of you a big vote of thanks for your willingness to contribute to project goals and the joy that you were to work with. Although many people worked hard to ensure the smooth running of the symposium, none did so harder than Dr Le Anh Tuan and his team at Nha Trang University who coordinated all local arrangements for participants, including transport, conference facilities and farm visits. The symposium was hosted by Nha Trang University, and I thank Dr Lai Van Hung, Dean of the School of Aquaculture, for his continued support and commitment to the holding of the symposium. The international eminence of the symposium was greatly enhanced by the contribution of fellow lobster researchers from the Asia–Pacific region and I thank them one and all. I am most appreciative of the help and expertise of David Smith of CSIRO Marine and Atmospheric Research who ensured that contributed papers were of a high scientific standard. I am very grateful to the dedicated ACIAR publishing team without whose efforts this publication would not have been possible. In particular, I would like to thank Mary Webb whose eagle eye and editing skills have greatly improved the accuracy and readability of this publication.

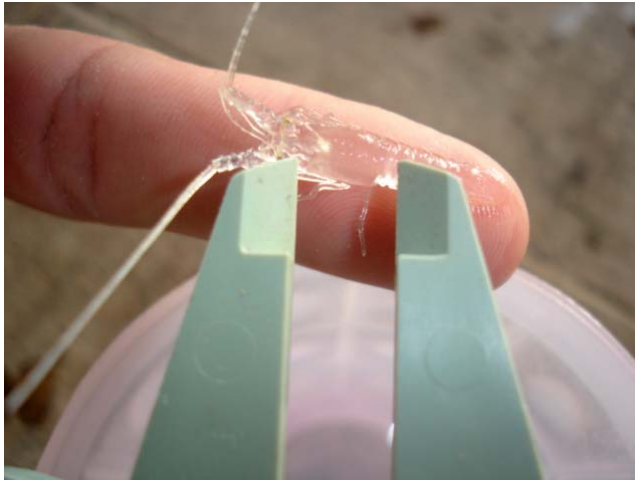
Kevin Williams  
Editor





## Session 1: Sustainable lobster aquaculture

Photo: Kevin Williams, CSIRO Marine and Atmospheric Research



Measuring the carapace length of a pre-settlement *Panulirus ornatus* seed lobster that was caught by seine net

# Lobster seacage culture in Vietnam

Lai Van Hung and Le Anh Tuan<sup>1</sup>

## Abstract

With a coastline of 3,260 km, a coastal area with more than 4,000 islands, and many lagoons giving protection against the waves and wind, Vietnam has great potential for seacage aquaculture. In Vietnam, seacage culture of lobsters started in the province of Khanh Hoa in 1992 and has expanded significantly around south-central Vietnam since 2000. *Panulirus ornatus* (ornate spiny lobster) is the most important cultured species among others (*P. homarus*, *P. stimpsoni* and *P. longipes*). In 2006, there were more than 49,000 cages producing approximately 1,900 t of product, valued at about US\$90 million. However, due to the ‘milky disease’ that appeared in late 2006, lobster production has since declined and the estimate for 2007 was about 1,400 t. This paper reviews the current status of seacage culture of lobsters in Vietnam and identifies major technical and socioeconomic constraints to further development.

**Keywords:** aquaculture; sustainability; disease; market

## Introduction

With a coastline of 3,260 km and an exclusive economic zone (EEZ) of more than 1 million km<sup>2</sup>, Vietnam has great potential for aquaculture development. In 2000, the total annual production of seafood was 2 million t wet weight, of which 1.3 million t were from the marine capture fisheries and 0.7 million t from aquaculture (Hersoug et al. 2002). Even though the Vietnamese authorities have plans to develop the marine fisheries, catches landed today may be close to the maximum sustainable yield (MOFI 2005). Therefore, the future growth of the seafood industry must rely on the development of aquaculture. The objective of the Vietnamese national plan is to produce 2 million t of aquaculture seafood by 2010 (MOFI 1999). The plan focuses particularly on developing aquaculture species with a high export value. In addition to generating foreign exchange earnings, the aquaculture industry is of

vital importance for the livelihood of the population in rural and coastal areas. The development of coastal and marine farming is crucial to creating new jobs for fishers leaving the captured fisheries due to the over-exploitation of fish stocks.

Many areas in the coastal zone of Vietnam are suitable for seacage culture, with more than 4,000 islands and many lagoons and bays giving protection against the waves and wind, which are particularly strong during the winter monsoon (MOFI 1994). Seacage culture of lobsters was developed in 1992, and significant expansion took place in south-central Vietnam in 2000. The main culture areas are Khanh Hoa, Phu Yen and Ninh Thuan provinces (Figure 1).

The main species cultured is *Panulirus ornatus*, ornate spiny lobster, among others such as *P. homarus*, *P. stimpsoni* and *P. longipes* (Tuan et al. 2000; Tuan and Mao 2004). Lobster aquaculture production increased markedly between 1999 and 2006, and reached a peak of approximately 1,900 t in 2006. However, due to ‘milky disease’ that appeared in late 2006, lobster production has since declined and the estimate for 2007 was about 1,400 t. This paper reviews the current status of seacage culture of

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lobsters, and identifies major technical and socio-economic constraints to further development.



**Figure 1.** Major lobster seed catching and grow-out farming areas in Vietnam

### Issues

This section gives an overview of the lobster aquaculture industry as it has developed in Vietnam. This activity developed spontaneously. Fishers used to collect lobsters of less than 300 g/individual and sell them at low prices, if they were able to sell them at all. However, the price for lobster, especially live lobster, increased rapidly in the 1990s. Fishers therefore began to culture lobster in cages and many fishers have invested in lobster cage culture. Basically, all farms belong to the private Vietnamese sector, and joint ventures and foreign investment have not occurred.

### Seed

Lobsters are distributed mainly in the Central Sea from Quang Binh province to Binh Thuan province (see Figure 1). Among nine identified species in the

region, three have rapid growth, large size, bright colour and a high value. These are *Panulirus ornatus*, *P. homarus* and *P. stimpsoni*. *Panulirus longipes* is also cultured, but in small quantities. In general, each species has its own distribution area. For example, *P. ornatus* is found mainly in Ninh Thuan Sea and *P. stimpsoni* in Quang Binh–Quang Tri Sea (Thuy 1996, 1998).

The greatest hurdle in the commercial culture of spiny lobster is the difficulty in growing species through all their larval stages. The large-scale larval culture of spiny lobster has still not been achieved despite significant advances in recent years (Kittaka and Booth 2000). There have been some studies on the seed production of lobster in Vietnam. The Research Institute for Aquaculture No. 3 (RIA3) performed experiments and studied seed production for *P. ornatus* and *P. homarus* but did not succeed in producing juvenile lobsters and did not publish the results. Experiments have also been carried out at the Queensland Department of Primary Industries and Fisheries (QDPIF) in Australia, but positive results have not been published. As the availability of seed is a limiting factor to growth today, a breakthrough in this research could increase the growth of this industry dramatically.

Lobster juveniles are caught mainly by purse seines, traps and divers. One day of fishing yields 3–10 lobsters. The juveniles are 1–15 cm long. The preferred size is 4–6 cm. From December to April, the seed are small (1–2 cm on average), while May to November yields juveniles of 5–7 cm. The larger juveniles are found in deeper water and are mainly harvested by divers. Farmers prefer juveniles from local stocks because the quality improves with a shorter transport distance. The catch of juvenile lobsters increased from 0.5 million in 1999 to 2.5 million in 2003 (Tuan 2004). The estimated figures for the 2004 and 2005 catches were similar to those of 2003, but the figures for 2006 and 2007 were lower at approximately 2 and 1 million, respectively. Knowledge of the fishery is still inadequate for determination of the maximum sustainable yield, and this information is unlikely to be available in time to be useful for management purposes.

### Cages

Cages are designed in various ways depending on the characteristics of the culture area and the farmers' financial circumstances.

### *Floating cage*

The net of the floating cage is normally supported by a frame with buoys (Figure 2). Lobster cages in the Nha Trang Bay (Khanh Hoa) are of this kind. Floating cages are commonly located in waters with a depth of 10–20 m, as occur in Nha Trang Bay.



**Figure 2.** Floating lobster cages in Van Phong Bay, Khanh Hoa province, Vietnam

### *Wooden fixed cage*

The framework 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 so as to create a rectangular or square shape (Figure 3). The bottom area of a farm is normally



**Figure 3.** Wooden, fixed lobster cages in Khanh Hoa province, Vietnam

20–40 m<sup>2</sup>, but may be as large as 200–400 m<sup>2</sup>. The cage size also varies. 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. They are common in the Van Phong Bay in Khanh Hoa.

### *Submerged cage*

The framework is made of iron mesh with a hole diameter of 15–16 mm (Figure 4). The bottom shape is rectangular or square with an area normally between 1 and 16 m<sup>2</sup>. The height is 1.0–1.5 m. The cage has a cover and a feeding pipe. This kind of cage is common for nursing juvenile lobsters in Nha Phu Lagoon, and for grow-out farming in Cam Ranh Bay in Khanh Hoa, and in Ninh Thuan and Phu Yen provinces.

The materials for making cages, such as wood, iron, net etc., are available locally. The marine cages are often of a small size suitable for a family-scale operation. That is why the number of cages has increased significantly in recent years. While individual developments may have no significant impact on the environment or society, a large number of developments, however small, may have significant impacts on the wider social and economic environment, and on each other.



**Figure 4.** Nursery lobster cages which will be submerged in a sheltered bay

### Feed

Lobsters are fed exclusively with fresh whole or chopped fish and shellfish (Figure 5). The most commonly used species for feeding lobsters are *Saurida* spp. (lizardfish); *Priacanthus* spp. (red big-eye); *Leiognathus* spp. (ponyfish); pomfret; snails, oysters and cockles; and small swimming crabs, other crabs and shrimps. Finfish comprise about 70% of the diet, with the remaining 30% being shellfish. The preferred fish (comprising 38% of fish in the diet) is lizardfish. Farmers show active selection

of the preferred fish species, using a consistently higher proportion than present in typical trash fish landings, and using a higher proportion of lizardfish in particular, despite the significantly higher price associated with these species. The feed conversion ratio (FCR) for lobster using this diet is poor at around 17–30 (fresh weight basis).

Small lobsters are fed 3 or 4 times/day. The feed amount is increased in the evening. Trash fish is chopped into small pieces, and mollusc shells are excluded. Large lobsters (>400 g) are fed 1 or 2



**Figure 5.** Fresh fish and crustaceans used as lobster feed

times/day. There is no need to chop trash fish and exclude mollusc shells for the larger-size lobsters. The feeding intensity of lobster is increased strongly just before moulting. In the last few months of the culture cycle, the amount of shellfish (molluscs, crustaceans) is increased while the amount of trash fish is decreased. Feeding lobster with trash fish gives a poorer FCR and has caused some problems with water quality. In 2004, the total nitrogen content in the sea water exceeded the standard level for aquaculture of 0.5 mg/L at some sites in Xuan Tu Sea, Khanh Hoa (Tuan 2005).

Recent efforts in the Australian Centre for International Agricultural Research (ACIAR) project *Sustainable tropical spiny lobster aquaculture in Vietnam and Australia* (FIS/2001/058) to determine a suitable practical pellet feed have resulted in positive outcomes. However, more attention should be paid to developing a pellet feed using local ingredients as well as terrestrial protein.

### Disease

In the past, lobster diseases have rarely occurred. Recently, stocking lower-quality seed (i.e. seed at the puerulus stage, the long distance from the culture area and a harmful fishing method using high-pressure lights) in lower-quality water (caused by the rapid increase in the number of cages) may have contributed to an increased incidence of diseases in cultured lobsters in some areas. A disease referred to as ‘milky disease’ appeared in many lobster culture regions in Vietnam in late 2006 (Figure 6). This disease is considered to be the most serious one so far encountered and has caused lobster production to fall dramatically—from 1,900 t in 2006 to about 1,400 t in 2007. Although there have been efforts to treat the disease in a project funded by the Ministry of Agriculture and Rural Development of Vietnam (MARD) and led by Nha Trang University’s pathologists, no solution has been found to date. Deterioration in water quality at the lobster cage sites is considered to be a contributing factor but the causal agent has not been positively identified. A systematic approach will be necessary to deal with the problem.

### Transportation

The means of transportation varies according to location. Juvenile lobsters are transported from the shore to the farm for grow-out in small boats with

the lobsters held in open, dry containers (Figure 7). Typically, 20–30 juveniles are put into each container and the journey normally takes only 15–20 minutes.



**Figure 6.** Lobster with ‘milky disease’ (right) showing the typical opaque white colour of the lobster’s abdomen compared to a normal lobster (left)

Transport of harvested adult lobsters from the central provinces of Phu Yen, Khanh Hoa, Ninh Thuan and Binh Thuan to Hanoi or Ho Chi Minh City is carried out in open, aerated seawater tanks on a truck (Figure 8). The transportation time is 7–20 hours. Live lobsters for export can be transported in cardboard or polystyrene foam boxes with a suitable packing material such as sawdust. The thickness of the waterproof cardboard and polystyrene foam boxes must be more than 7 mm and 20 mm, respectively. Deep-frozen blocks of ice insulated with thick plastic bags and paper are used to keep the temperature inside the box cool. Finally, the box is lined tightly and waterproofed, especially for air transport, but ventilation should be provided through several holes in the box cover.



**Figure 7.** Transportation of lobsters in an open, dry container



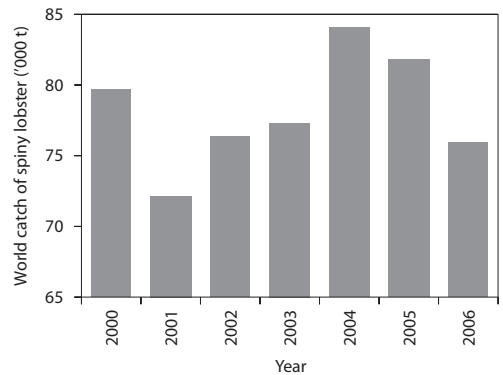
**Figure 8.** Transportation of live adult lobsters to market in open, aerated seawater tanks on a truck in Vietnam

## Markets

In a profitability study of lobster aquaculture, it is important to analyse whether current prices for the harvested product are sustainable. There are examples of newly aquacultured species that obtain high prices initially because of the low quantities produced. However, as investment in the industry increases and production expands, prices fall. In this section, we consider the impact on lobster aquaculture profitability of world production of spiny lobster and particularly production in areas of the Indian and western Pacific oceans. Most spiny lobster production is from the wild fishery, with aquaculture production comprising only a small part of the total production. The main producers of

aquacultured lobster are Vietnam, the Philippines, Malaysia, Thailand, Taiwan and India.

Kittaka and Booth (2000) reported average annual world catches of spiny lobster of 77,000 t in the 1990s. They concluded that spiny lobsters were fully exploited or over-exploited and one of the few ways to expand production was through aquaculture. Figure 9 shows that world production of spiny lobsters was quite stable from 2000 to 2006, varying between 72,000 t and 84,000 t. The average annual production over that period was 78,000 t. The catches in Figure 9 support the conclusion of Kittaka and Booth (2000) that spiny lobster populations on a world basis are fully exploited.



**Figure 9.** World catches of spiny lobster, 2000–06 (source: FAO 2007)

Globally, spiny lobster is mainly exported live or fresh with only a small proportion sold frozen. Aquacultured lobsters from Vietnam are mainly sold live. Due to high prices compared with food prices in general, and other seafood prices in particular in Vietnam, almost all lobsters have been exported. The main markets are China (73%, including 32% to Hong Kong) and Taiwan (26%). However, domestic markets have been increasing recently, particularly in big cities like Hanoi and Ho Chi Minh City. The large producers and exporters in the Indian and western Pacific oceans are Australia, New Zealand and Indonesia. In 2004, their total exports reached about 10,000 t. Vietnam, with an annual export of about 1,500 t, therefore makes up only 15% of the total export of the three main producers. However, these potential competitors export mainly fresh or frozen lobster compared with live lobster from Vietnam. Therefore, they target different segments of the market. In addition, Vietnam can export



lobster throughout the year and deliver when prices are high. The price for aquacultured lobster in Vietnam should therefore not be very sensitive to changes in the supply of wild-caught lobster from countries in the Indian and western Pacific oceans.

## Lobster aquaculture production trends in Vietnam

The number of lobster sea cages in Vietnam increased rapidly from 1999 and reached its peak of approximately 49,000 cages in 2006 (Figure 10a). Because of the milky disease outbreak in late 2006, the number of cages has since declined, estimated to be 47,000 and 41,000 in 2007 and 2008, respectively. Similarly, lobster production and value increased between 1999 and 2006, and peaked in 2006; the production and value has dropped dramatically since 2006 (Figures 10b and 10c, respectively).

Although lobster productivity increased during 1999–2001, production peaked at 57.7 kg/cage in 2001 (Figure 10d). After 2001, productivity declined gradually until 2007 when a rapid decline to 30 kg/cage occurred as a result of the appearance of milky disease. The decline in per-cage produc-

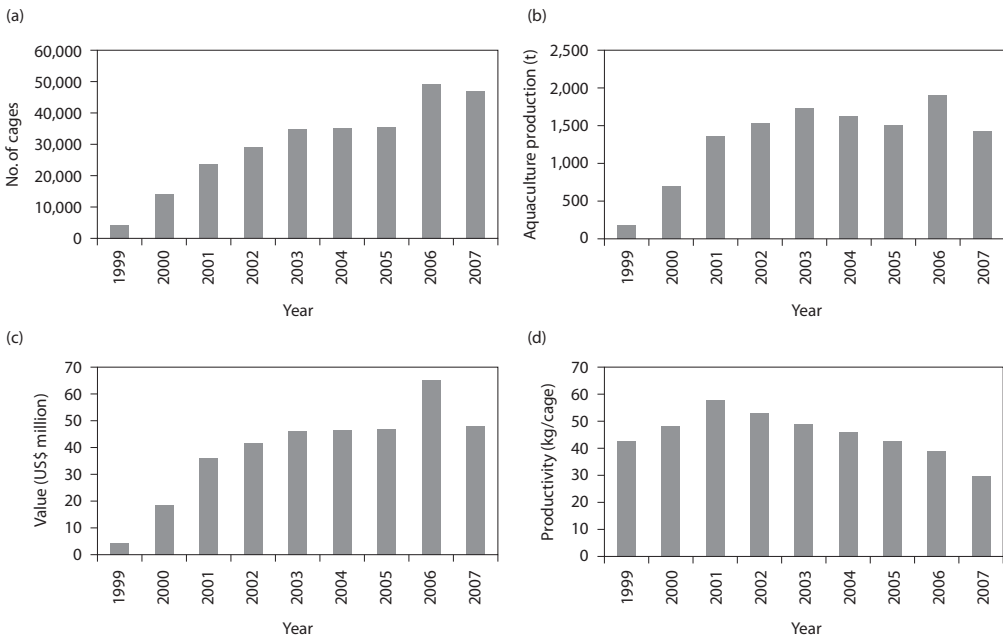
tivity since 2001 could indicate that the quality of farming water and lobster seed had become worse for some time before the milky disease outbreak occurred.

## Further research needs

The maximum sustainable yield of lobster seed should be determined for management purposes. Until lobster hatchery production becomes a commercial reality, the sustainability of lobster seed being caught for aquaculture grow-out should be evaluated on the basis of technical, economic and environmental impacts.

Better lobster seacage and farm designs are needed to improve water exchange through the cage and especially underneath the cage. More attention should be paid to development of pelleted feed using local ingredients as well as terrestrial protein. Best practices for feeding and managing the lobsters need to be determined.

A holistic approach needs to be taken when dealing with lobster diseases, especially milky disease. Allowing farms to develop close to each other increases the vulnerability to disease outbreak.



**Figure 10.** The number of lobster cages (a), aquaculture production (b), value (c) and productivity (d) of the Vietnamese lobster aquaculture industry, 1999–2007

There is no cohesive plan to manage the development of seacage aquaculture in the coastal zone. Therefore, with increased pollution and declining water quality because of overdevelopment in some areas, diseases may occur as the industry grows. A management plan that defines the carrying capacity of a particular area should be developed and enforced. Such a plan should detail farming density and area allocation; farm and cage designs; water-quality improvements; introduction of pelleted feeds to the industry; and disease prevention and treatment practices.

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# Potential of seacage culture of *Panulirus ornatus* in Australia

Matt Kenway, Matt Salmon, Greg Smith and Mike Hall<sup>1</sup>

## Abstract

The rapid development of seacage culture of the spiny lobster *Panulirus ornatus* using wild-caught pueruli or juveniles in Vietnam, and to a lesser extent Indonesia, the Philippines and elsewhere, has generated widespread debate as to whether this form of aquaculture can sustainably meet the predicted increase in global demand for seafood lobsters. Due to the initial success of lobster aquaculture overseas, there is strong interest in Australia in developing spiny lobster aquaculture of one of the six *Panulirus* species found there. To date, attention in Australia has focused on *Panulirus ornatus* (ornate spiny lobster). Although grow-out data are extremely limited for *Panulirus* species, *P. ornatus* is believed to be the fastest-growing tropical species, reported to reach 1 kg after 20 months of culture. The combination of initial success in Vietnam and its fast growth rate has fueled speculation of significant opportunities for *P. ornatus* aquaculture in Australia, particularly for remote northern coastal Indigenous communities. However, infrastructure is limited throughout much of remote tropical Australia. Historically, power supply is sourced from diesel generators, putting a large cost impost on the running of land-based systems. There is also a lack of accurate information on the economics of operating ponds or undercover tanks. Overall, some Indigenous communities believe that seacage culture of *P. ornatus* may be the more viable proposition. This overview assesses the potential of seacage culture of *P. ornatus* in Australia.

**Keywords:** lobster, larval ecology; phyllosoma; Torres Strait, environmental impacts

## Introduction

Development of a lobster aquaculture sector depends on having a reliable supply of seedstock. The production system may be either open life cycle, where seedstock is collected from the wild; partially closed life cycle, where seedstock is supplied by hatcheries from wild-caught adults; or completely closed life cycle, where seedstock is supplied by hatcheries from captive-reared adults. Over the past decade, Australia has made considerable investment in developing hatchery technology for production of

spiny lobsters, initially from wild-caught adults but eventually from captive-reared ones. After some initial interest in culturing temperate *Jasus* species (*J. edwardsii* and *J. (Sagmariasus) verreauxi*) and subtropical *Panulirus* species (*P. cygnus*), most commercial interest is now centred on closing the life cycle of *P. ornatus*. Several Australian research providers, including the Australian Institute of Marine Science (AIMS) and the Queensland Department of Primary Industries and Fisheries, are currently involved in developing this technology for *P. ornatus*. Research by the private sector, including Lobster Harvest Pty Ltd in Western Australia, and by investors and agencies such as the Fisheries Research and Development Corporation also supports the development of closed life cycle production of

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*P. ornatus*. The larval phase has been successfully completed several times in some of these facilities, with upscaling toward commercial production the current focus.

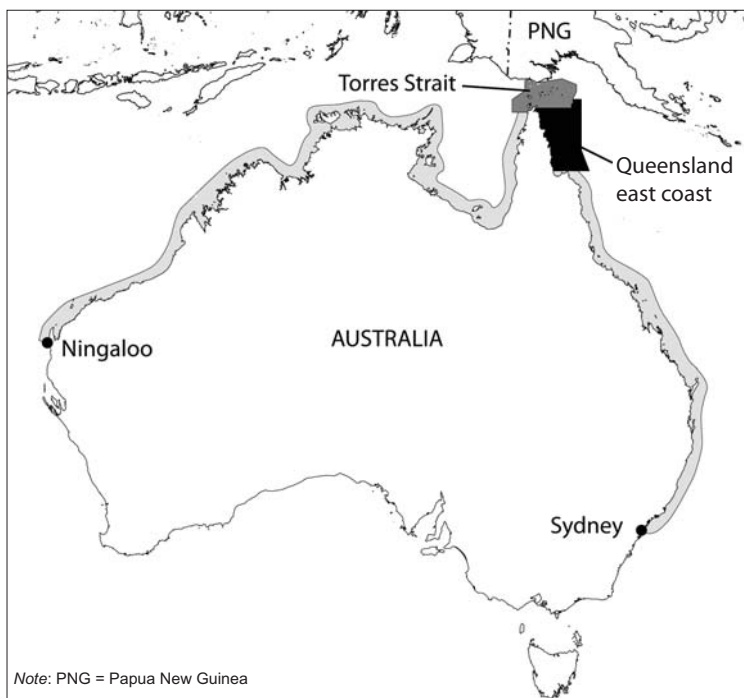
The transition from commercial hatchery production to commercial grow-out will be facilitated by concurrently demonstrating proof-of-concept juvenile grow-out which presently depends on sourcing a reliable supply of wild pueruli or juveniles.

### Geographical distribution and breeding of *P. ornatus*

*Panulirus ornatus* is found in coastal environments throughout most of the subtropical and tropical Southern and Northern hemispheres of the Indian Ocean and western Pacific Ocean. It has an Australian distribution from Sydney in New South Wales, throughout Queensland's eastern waters, through the Torres Strait, across the Top End through the Gulf of Carpentaria and Northern Territory (NT) and down the Western Australian coast to Ningaloo Reef (Figure 1). Throughout most of this range,

*P. ornatus* has a sparse distribution, with the exception of stocks in the Torres Strait and waters of the tropical east coast of Queensland where a commercial fishery of less than 1,000 t/year is shared between Australia and Papua New Guinea (PNG).

The Torres Strait stock forms a fishery that has been extensively studied by Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine Research and PNG Fisheries over many years. Over the past 2 decades, the standing stock has been identified to be composed of 3 year classes: (a) 0+ lobsters in their first year after settling; (b) 1+ lobsters in their second year after settling; and (c) 2+ lobsters (Moore and MacFarlane 1984; Pitcher et al. 1992). A minimum size of 115 mm tail length or 90 mm carapace length limits the fishery harvest almost entirely to 2+ lobsters. In August–September each year, a defining feature of a significant proportion of this stock is the mass migration of 2+ subadults out of the western Torres Strait to spawning grounds 500 km to the north-east, as far as Yule Island in the Gulf of Papua (Moore and MacFarlane 1984; Skewes et al. 1994). Following breeding, this age



**Figure 1.** Range of *Panulirus ornatus* in Australia showing areas of commercial fishing in the Torres Strait and along the east coast of Queensland

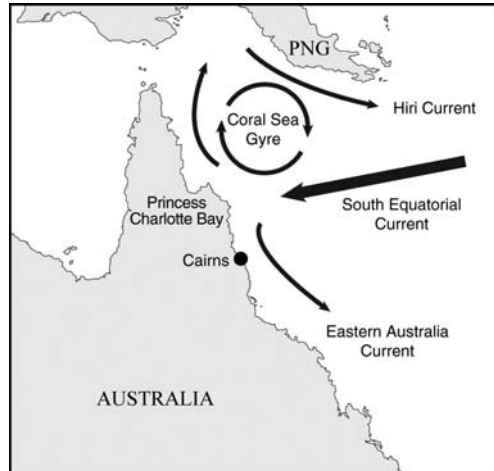
group appears to suffer catastrophic mortality, possibly from the combined stress of migration and reproduction (MacFarlane and Moore 1986; Dennis et al. 1992). Survey results from manned submersibles and deep-water diving have shown that breeding also occurs on the shelf edge outside the far northern Great Barrier Reef (Prescott and Pitcher 1991). Although there is no hard evidence, it is suspected that these stocks also originate from the Torres Strait. In potential contrast, Bell et al. (1987) confirmed that the eastern coastal stock does not join the breeding migration to the Gulf of Papua. This stock may represent individuals that make only nearshore spawning migrations to the continental shelf break, do not suffer mass mortality post-reproduction and hence may be long lived. In the Gulf of Carpentaria, NT and Western Australia, *P. ornatus* is relatively rare and does not support a commercial fishery. Little is known of the breeding ecology of the stocks in these regions.

### Larval ecology of *P. ornatus* in the Coral Sea

Recruitment processes in the Torres Strait and eastern coastal regions are governed by the South Equatorial Current, which brings warm equatorial water from the western Pacific Ocean south of Solomon Islands and westward towards the Australian coastline. When this current reaches the outer barrier reefs of north-eastern Australia, between 14°S and 18°S, it bifurcates and forms the southbound East Australian Current and a northward current that flows along the edge of the northern Great Barrier Reef (Figure 2). This northbound current eventually joins the Hiri Current that flows eastward past the southern edge of PNG and out into the Coral Sea. The resultant gyre, known as the Coral Sea Gyre, is believed to be the key mechanism controlling larval dispersal of *P. ornatus* in this region. Although some loss of larvae from the Coral Sea Gyre into the East Australian Current probably occurs at the point of bifurcation, results from plankton trawls suggest that this may be negligible (Dennis et al. 2001).

Modelling of larval advection patterns suggests that all known breeding areas (i.e. Eastern Gulf of Papua, shelf edge of far northern Great Barrier Reef and east coast of Queensland) are likely to contribute larvae to the Coral Sea Gyre and subsequent settlement back onto the fishery grounds

(Griffin 2004). Initial entry of larvae into the Coral Sea Gyre is probably facilitated by spawning as close to the continental shelf drop-off as possible together with north-westerly winds that prevail during the peak breeding season of November to March. Early-stage larvae are photopositive and hence inhabit the surface layers, facilitating offshore transport into the gyre by wind-driven currents.



**Figure 2.** Map of the north-west Coral Sea showing major near-surface ocean currents governing the larval dispersal of *Panulirus ornatus* (from Dennis et al. 2001)

Once in the gyre, *P. ornatus* larvae (phyllosomata) progress through a maximum of 24 moults over a 5–6 month period (AIMS, unpublished data) before reaching the puerulus settlement phase. Results from plankton trawls by Dennis et al. (2001) and AIMS (unpublished data) show peak abundance of pueruli occurs in surface waters in winter (June to August) along the outer reef edges and channels between reefs. Although settlement cues have not been elucidated, it is thought that inshore transport of pueruli is facilitated by south-east trade winds that prevail in this region during winter, generating surface currents in a north-west direction.

Marine invertebrates with extended planktonic larval phases typically demonstrate recruitment patterns that are influenced by high interannual variability. *Panulirus ornatus* larvae are exposed to oceanographic and biological factors (e.g. south-east current and gyre strength, wind speed, abundance of zooplankton etc.) that impact on larval

dispersal, development rate and time in the plankton. Fisheries data from the Torres Strait based on observed catch rates and fishery independent surveys support the hypothesis that recruitment of *P. ornatus* is highly variable in the region.

Along the coastline west of Cape York in Queensland to Ningaloo Reef in Western Australia, the larval ecology of *P. ornatus* is not understood. Recruitment in this region is unlikely to originate from the Torres Strait and east coast stock, given the prevailing influence of the Coral Sea Gyre and the fact that there is little net flow of water through the Torres Strait. Stocks in this region may self-recruit or originate from *P. ornatus* populations further to the north; even potentially from the Indonesian archipelago.

### **Availability of pueruli and juveniles in the Torres Strait and east coast Queensland**

Based on preliminary results from hatchery-reared stock, the longevity of the non-feeding puerulus phase of *P. ornatus* at 28 °C varies between 20 and 27 days (AIMS, unpublished data). In the Coral Sea, the exact location of puerulus settlement is unknown. Larvae that metamorphose to pueruli outside the outer Great Barrier Reef lagoon may need to traverse a wide shelf area, in some cases more than 100 km, to reach coastal benthic habitat. However, little is known of the transition from a planktonic to benthic phase despite several attempts to catch pueruli using surface collectors similar to those used by Phillips and Hall (1978). Dennis et al. (2004) speculated that the lack of success in catching significant quantities of pueruli in the Torres Strait fishing grounds may result from the abundance of suitable shelf habitat for settlement or from the low density of recruits reaching this area. Diver surveys of newly settled lobsters estimated the average density of lobsters at only 63/ha (Dennis et al. 1997). There is also the possibility of settlement further east or south-east as diving surveys have been largely restricted to shallow Torres Strait fishing grounds.

Further south along the north Queensland coast, a mixture of scientific data and anecdotal observations indicates that some *P. ornatus* settle close to the shore, often in the vicinity of estuaries and often in pulses. Near Townsville (approx. 19°S), *P. ornatus*

pueruli have been captured in pre-fouled collectors. Pulse settlement of early juveniles has been observed on fish cages in a mangrove-lined estuary in Hinchinbrook Island channel (18°S) and on cultured pearl panels in front of the Escape River off the eastern tip of Cape York (11°S). A 4-year survey of *P. ornatus* juveniles settling on wharf pylons in Cairns, Queensland, showed that peak settlement occurred during winter; from June to August (Dennis et al. 2004).

The presence of early-stage juveniles on these vertically suspended structures above the substratum may indicate direct settlement out of the water column onto these structures; possibly through chance encounter. At this stage, it is unknown what cues draw pueruli inshore and what initiates settlement—specific benthic cues or a chance encounter with a fouled vertical object. Also unknown is the degree to which prevailing weather conditions influence settlement patterns—whether they cause settlement aggregations to occur (eddies of pueruli) or whether they contribute to a more broadcast pattern of settlement. Although the east coast and Torres Strait are undoubtedly the prime recruitment areas for *P. ornatus* in Australia, with peak settlement occurring in winter (Dennis et al. 2004), there are almost no scientific data on settlement cues, specific settlement habitat, spatial patterns of settlement or temporal variability, especially interannual.

While settlement cues remain a mystery, those who have observed pulse settlement on fish cages and pearl panels state that early-stage juveniles stay on such structures for only a short period before moving elsewhere. No juveniles larger than 60 mm total length have been found on these structures. One interpretation is that pueruli may briefly use these structures as temporary shelter during the hazardous moult from puerulus to juvenile before moving to a more suitable benthic habitat for feeding and shelter. Some divers have also observed that inshore macroalgal-dominated reefs along the often turbid, far north Queensland coasts are major settlement grounds for *P. ornatus*. However, as no systematic collection has been made along the east coast, the geographical distribution of puerulus habitat and major settlement hotspots remains unknown.

Aquarium experiments by Dennis et al. (2004) revealed that wild-caught pueruli prefer settling in hole shelters (10–15 mm) over cave, crevice or sand shelters. They also observed pueruli on a number of

occasions buried in the sand with their antennae lying on the surface and speculated that this may be a strategy for predator avoidance while searching for suitable habitat. This observation may explain how *P. ornatus* pueruli cross large areas of shelf, often over vast stretches of sand bottom. Hiding in the sand during the day and rising to surface waters at night to take advantage of the inshore drift could be an effective strategy for pueruli to lower their exposure to predation. On the seabed, *P. ornatus* juveniles in the Torres Strait are found in solution holes that are positively correlated with juvenile body size. Typically these holes have associated macroalgae; *Sargassium* sp. and *Padina* sp. would provide additional cover and be an effective strategy to minimise predation.

### Constraints to aquaculture

From published survey data and anecdotal observations, it would appear that even in the Torres Strait fishing grounds, where the abundance of *P. ornatus* is highest, collection of sufficient pueruli and or newly settled juveniles is potentially a key constraint to initiating seacage trials. Further research is required to establish settlement preferences of pueruli and whether crevice collectors, most likely similar to those used in Vietnam, could be deployed to reliably catch seedstock. Based on information to date, it is unlikely that diver collection of juveniles would prove viable given the low density estimate of 63/ha reported by Dennis et al. (1997).

The low population density of *P. ornatus* west of Cape York to Ningaloo Reef and the lack of data on recruitment ecology of the species in this region make it highly unlikely that seacage culture trials could be initiated unless pueruli or juveniles were sourced from the east coast of Queensland or Torres Strait. Aside from the controversy that this would possibly generate amongst commercial fishermen harvesting the Torres Strait and east coast stock, a key impediment would be existing policy on translocation of marine species.

### Translocation of seedstock outside the Torres Strait – east coast region

Australia has very stringent policies on the translocation of stock for aquaculture, primarily aimed at preventing the spread of disease and reducing the risk of genetic pollution. For shrimp and barramundi

grown in ponds, brood-stock from outside the geographical area can be used to supply seedstock but only under strict conditions. In the case of sea cages, where the risk of escape is deemed greater, brood-stock must be sourced from the same area as the grow-out operation. For example, fingerlings in the barramundi farm operating in the Hinchinbrook channel, Queensland, are produced from brood-stock originally sourced from this region. In view of these conditions, it is questionable that permission would be granted to translocate wild-caught *P. ornatus* seedstock from the Torres Strait or east coast to support grow-out initiatives outside this region. Availability of wild seedstock alone would therefore currently limit consideration of seacage culture of *P. ornatus* to the Torres Strait or east coast region.

## Seacage culture of *P. ornatus*

### East coast of Queensland

On Queensland's east coast, most of the marine exclusive economic zone (EEZ)—from Bundaberg in the south to the north-eastern tip of Cape York—lies within the boundary of the World Heritage-listed Great Barrier Reef Marine Park (GBRMP). Within the GBRMP, there is only one seacage farm currently operating. It produces barramundi. This facility was established before the GBRMP Authority was enacted by legislation. Under present GBRMP Authority interpretation, further development of seacage culture is unlikely throughout the entire GBRMP (i.e. most of the east coast of Queensland). Therefore, unless there is a major shift in government policy, seacage culture of *P. ornatus* will not occur on the east coast of Queensland.

### The Torres Strait

Without the zoning limitations of the east coast of Queensland and the high probability that major recruitment of *P. ornatus* occurs in this area, the Torres Strait is possibly the only region in Australia where seacage culture of this species is currently feasible. While further work is required to identify methods for reliably sourcing pueruli or juveniles, the Torres Strait has a range of sites close to island communities that would be suitable for seacage culture of *P. ornatus*.

At a national level, economic development in the Torres Strait is seen as a priority, given the strategic

importance of this area as the bridge between northern Australia and PNG. It is widely recognised, however, that the remoteness of the region and the associated high cost of infrastructure, diesel-generated power and freight severely limit opportunities for economic development for island communities. Many communities currently rely on the additional income provided by the wild fishery for *P. ornatus* but acknowledge that opportunities to increase yield are unlikely. As a consequence, some communities now believe that aquaculture holds new promise as a means of providing external income. In this context, island communities are keen to establish whether aquaculture of their iconic species, *P. ornatus*, is a realistic option for the region.

A considerable advantage for the Torres Strait region is that marketing networks, facilitating the shipment of live product to predominantly Asian markets, are already well established. Although the selling of cultured *P. ornatus* may present challenges, particularly if farmed stock was marketed below the minimum legal size limit for wild stock, it may also present some opportunities, especially if farmed product was marketed during seasonal closures in the wild fishery. Other advantages for establishing seacage culture in the Torres Strait include strong community and local government support, location north of the main area of cyclonic activity and the possibility of some locally available marine ingredients that could form the basis of a formulated diet. Further, in terms of development of skilled labour, the secondary school on the main island (Thursday Island) now has an aquaculture component as part of the curriculum, with training opportunities for Indigenous communities well supported at all levels of government and readily available.

## **Issues for seacage culture in the Torres Strait**

### **Biological factors**

Companies producing fish in sea cages in tropical Australian waters claim that they could not operate without predator-proof enclosures to exclude sharks, crocodiles and dolphins (T.R. Graham, pers. comm. 2008). Presently, some Torres Strait communities understand the potential challenges of seacage culture through their experience of stockpiling wild-

harvested lobsters in small sea cages for short periods before sale. On Yorke Island, although short-term holding cages are now constructed of robust aluminum plate and mesh panelling to exclude predators, they still suffer occasional damage. To overcome predation issues, fish farmers have trialled a range of nets made from galvanised metal mesh and some new high-quality polyester monofilament—polyethylene terephthalate netting (e.g. Kikko nets). Both are expensive and, in the case of galvanised nets, require regular replacement due to corrosion.

The need for predator exclusion means that establishment costs for seacage culture in the Torres Strait would be high, especially when compared to Vietnam where predation of caged lobsters is not considered a problem and low-grade nets are successfully used. At this stage, it is unknown whether other predators, parasites or disease agents would be an issue.

### **Physical factors**

Strong tidal flows, while good for dispersal of discharges and mixing of dissolved gases, require robust mooring systems. Australia's largest seacage farm, producing barramundi, suffered extensive damage during a period of prolonged bad weather and strong tidal flows which led to the loss of most of the standing stock of fish and the eventual closure of the operation. In the Torres Strait, where tidal currents sometimes exceed 9 km/hour (5 knots), appropriately designed mooring systems will be a prerequisite. In addition, although cyclones form close to the Torres Strait, they typically move southward where their greatest influence is felt. Nevertheless, strong prevailing winds can be a feature of the Torres Strait at various times during the year, meaning that cages would need to be robust enough to withstand them. Stocking densities during summer may be limited by low oxygen saturation levels in the water, when neap tides and high temperatures prevail; these are research questions that need to be investigated.

### **Geographical-economic factors**

The remoteness of the Torres Strait and the associated high cost of freight, infrastructure and diesel-generated electricity all negatively impact on options for economic development, including establishment of sea cages. Of particular concern could be the high cost of feed if formulated diets become available and



were shipped to the region. In view of this, a more economical alternative might involve the development of a moist fresh diet processed on site in the Torres Strait and based on locally available ingredients such as trawler by-catch and *Pinctada albina* (bastard shell). At this stage, Torres Strait communities derive little direct benefit from shrimp trawling operations in the region so the use of by-catch in a lobster grow-out feed, although contentious given recent efforts to reduce by-catch in Australian trawl fisheries, may provide a mechanism to redress some of the perceived inequity. In contrast, *P. albina* is primarily viewed regionally as a fouling pest (at least by pearl farmers) and forms extensive beds in the Torres Strait. There is strong anecdotal evidence that it is a primary prey item for wild *P. ornatus*. Divers and collectors of lobsters often focus their fishing effort for *P. ornatus* around extensive beds of this shellfish. Pearl farmers are often forced to water-blast pearl panels each month to remove this species (hence the name 'bastard shell') and other fouling organisms to prevent coverage of their culture stock and these are presently only viewed as unusable waste. In the Torres Strait, it appears feasible that this species could be bulk-harvested and co-cultured in mesh pillows on long lines beside *P. ornatus* cages, thus providing a live food source and potentially a means of reducing nutrient impacts originating from the lobster cages (i.e. through filter feeding by *P. albina*).

### **Cultural factors**

Indigenous communities in the Torres Strait derive most of their fisheries income from wild harvesting of *P. ornatus*. In this fishery, divers catch lobsters on nearby grounds during neap tides when the water is clear and are paid soon after taking their harvest to local processing facilities. Returns from seacage culture would not be as instantaneous, given that juvenile lobsters would need to be grown for more than 1 year before they were harvested for market. Further, operation of sea cages is labour-intensive and continuous, requiring daily maintenance and feeding. Although local communities maintain domestic gardens and are familiar with agricultural practices, it is yet to be demonstrated whether this marine commercial farming of live animals is an activity acceptable to island communities.

One measure of the acceptance of seacage culture by Torres Strait communities may come from devel-

opment of a pilot-scale sponge farm in eastern Torres Strait. While difficult to compare the intermittent activity required for farming sponges to a continuous schedule for operating sea cages for lobsters, early signs are that the community has embraced the project and is committed to making it a success.

### **Environmental impacts of sea cages**

The perceived negative environmental impact of seacage culture by the Australian community is a significant barrier to development of seacage culture of *P. ornatus* in tropical Australia. Although there is abundant literature on the impact of farming fish, particularly salmon, in temperate environments, there are few data available on the environmental impacts of sea cages in tropical ecosystems. However, two recent projects in the tropics have provided much-needed data on the impacts of seacage culture and appropriate tools for planning new developments in tropical ecosystems. These projects were *Planning tools for environmentally sustainable tropical finfish cage culture in Indonesia and northern Australia* (2003–2008; ACIAR Project No. FIS/2003/027), funded by the Australian Centre for International Agricultural Research, and *Environmental impacts of sea cage aquaculture in a Queensland context—Hinchinbrook Channel case study (2007–2008)*, commissioned by the Queensland State Government and co-funded by Lyntune Pty Ltd (trading as Bluewater Barramundi). Counter to public perception, the final report for the latter project demonstrated that a 250 t/year barramundi farm in a mangrove estuary in north-eastern Australia had only very localised impacts, which were largely confined within the boundaries of the farm (McKinnon et al. 2008).

### **Conclusion**

This overview demonstrates that opportunities for seacage culture of harvested wild *P. ornatus* puerili or juveniles in tropical north-east Australia are currently limited to the Torres Strait region. However, there is significant uncertainty as to the consistency of wild seed supply, together with issues of predation, strong tidal currents, suitable feed types, remoteness and cultural issues. Outside the Torres Strait region, where there is extremely limited and sporadic recruitment, seacage culture

would likely be feasible only if seed supply came from hatchery production and if access was granted to use appropriate sites.

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# Potential for co-management of lobster seacage culture: a case study in Lombok, Indonesia

Reza Shah Pahlevi<sup>1</sup>

## Abstract

In the province of Nusa Tenggara Barat (NTB) in Indonesia, there are several community-based lobster grow-out facilities that have been established with the support of the Marine Aquaculture Development Centre (MADC). Furthermore, the strong international market demand for lobster products and the suitability of natural resources within the provincial boundaries indicate strong potential to support further industry expansion.

This opportunity for the development of a sustainable, community-based industry in NTB is constrained by the sustainability of wild-harvested stock for grow-out, limited production management knowledge and capacity, and under-resourced nutrition management for suitable growth rates. Additionally, there is a general lack of market awareness (limited understanding of market specifications and requirements) and poor integration within the supply chain, indicated by a highly fragmented and uncoordinated chain through to market.

Except for the sustainability of wild-harvested stock for grow-out, several of these constraints to industry development are currently being addressed by the Australian Centre for International Agricultural Research (ACIAR) project in Vietnam, *Sustainable tropical spiny lobster aquaculture in Vietnam, Australia and eastern Indonesia* (FIS/2001/058). [Editorial note: the original project was extended by 2 years to include eastern Indonesia.] Related to activities in NTB, this project seeks primarily to: assess the market chain of lobster supply and demand to determine the resilience of the market to an increased supply of aquaculture lobster product; facilitate development of lobster aquaculture at NTB through transfer of the Vietnamese and Australian technology developed in the ACIAR lobster project FIS/2001/058 and through capacity building of staff at MADC in NTB; assess the ecological impact of lobster seed collection at NTB; and examine the potential for hatchery and grow-out culture of *Scyllarides squammosus*, the red slipper (kipas merah) lobster.

The latest research indicates that implementation of co-management arrangements, based on collaboration between government and communities in NTB, is essential in order to ensure the sustainability of wild-harvested stock for grow-out through conserving lobster fishery resources. Two recently developed, community-based co-management initiatives, on the island of Lombok in NTB, provide an opportunity to more effectively address lobster fishery sustainability concerns, using community-based rules or *awig-awig*. These are the LMNLU, *Lembaga Musyawarah Nelayan Lombok Utara* (North Lombok Fishers Consultative Council), located on the north-west coast, and the KPPL, *Komite Pengelolaan Perikanan Laut* (Marine Fisheries Management Committee), situated in the south-east coast.

**Key words:** lobster fishery, co-management, *awig-awig*, MADC, Lombok, Indonesia

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# Spiny lobster resources and opportunity for culture in post-tsunami Aceh, Indonesia

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## Abstract

In an effort to facilitate the restoration of livelihoods that reduce poverty and increase future resilience for the poor coastal communities of Aceh province, we investigated responses related to the pre-existing lobster fishery and the potential for lobster culture. Six species of spiny lobster endemic to the Indonesian archipelago (*Panulirus homarus*, *P. longipes longipes*, *P. ornatus*, *P. penicillatus*, *P. polyphagus* and *P. versicolor*) were identified through random sampling (August 2007 – September 2008) at landing sites in the district of Aceh Jaya. The great variety of benthic habitats (sand, pavement, rock and coral) and oceanographic conditions (clean oceanic water, continental run-off) in the area have combined to facilitate this high diversity. The largest mean carapace lengths and individual masses were represented by *P. ornatus* (89 mm, 817 g) and *P. polyphagus* (84 mm, 463 g) which also represented the smallest portions of the total catch, 6.1% and 1.8%, respectively. *Panulirus homarus* was the most frequently caught (34.9%) while *P. penicillatus* constituted the highest total mass (34.7%). Female to male ratios varied and were sometimes greatly biased towards males (*P. ornatus*, 0.42:1; *P. versicolor*, 0.48:1; *P. penicillatus*, 0.58:1). More than 36% of female lobsters landed were egg-bearing. Regression analyses revealed strong relationships ( $R^2 > 0.81$ ) between carapace length and total mass for all six species despite small sample sizes for some. This is likely due to the unbiased population sampling through fishers who indiscriminately target all lobsters using bottom nets due to their high value. Prices for the largest size class (>300 g) of spiny lobster during 2008 ranged between Indonesian rupiah (Rp)120,000 (US\$13) and Rp180,000 (US\$20) per kilogram.

The presence of suitable habitats, observations of juvenile and adult spiny lobster in those habitats, the steady landings and the availability of a network of buyers and nearby markets (Banda Aceh, Medan, Singapore) have encouraged the design and deployment of experimental lobster puerulus (i.e. larva) collectors. Our puerulus collectors integrate some design elements from Australia (targeting *Jasus edwardsii*), use locally available artificial materials (light plastic fibre, outdoor carpet) and are built quickly (<2 hours) at a reasonable cost (<US\$10). The materials and design attempt to mimic macroalgae and rock crevices. Twenty-eight collectors were randomly deployed in front of a fringing reef just north of an offshore island. Collectors were anchored in 5–6 m of water using reinforced concrete blocks, individually, paired or in quads approximately 1.0–1.5 m below the surface. The collectors appeared quite robust over the 6-month monitoring period (February–July). Although the collectors did facilitate the natural settlement of encrusting organisms and various shrimp, no spiny lobster pueruli were observed. We intend to proceed with design modifications and future deployments in other nearby areas and during other seasons. The deployment of such collectors on lift net (bagan) arrays, where lights are used for night fishing, will also be attempted. Finally, a detailed lobster fisher survey will provide better understanding of fishing and puerulus settlement patterns.

**Keywords:** aquaculture; puerulus collector; bagan; lift net

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## Introduction

The catastrophic effects of the great Sumatra–Andaman earthquake and associated tsunami of 26 December 2004 were most severely felt by the poor coastal communities of Aceh province, Indonesia. These communities, variously engaged in fishing, farming and aquaculture, lost a significant proportion of the population and most of their livelihood assets (e.g. boats, fishing gear, tools, livestock) and supporting infrastructure (landing sites, markets) (Ananta and Onn 2007; Tewfik et al. 2008). The tsunami also severely damaged much of the coastal forest, fish ponds, agricultural lands and associated livelihoods as well as increasing the vulnerability to future extreme weather events and chronic sea-level rise. Examination of the impacts of this event across the Indian Ocean region highlights that systems with healthy natural environments and diversified livelihoods are more resilient to shocks and thus recover more quickly (Danielsen et al. 2005; Olsen et al. 2005). In an effort to facilitate the restoration of livelihoods that reduce poverty and increase community resilience<sup>2</sup> we investigated possible responses related to the pre-existing lobster fishery as well as the potential for the development of lobster culture. These activities included the compilation of biological details on local lobster populations in support of both the management of the capture fishery and future activities of puerulus collection and grow-out. Such work adds to broader efforts that include an array of habitat (e.g. mangroves) and livelihood (e.g. crab fattening, tilapia cage culture, postharvest) restoration activities as well as support to traditional and government resource-management bodies.

### Study site, marine habitats and fisheries regulations

Aceh province lies at the western tip of Sumatra island and is surrounded by a range of nearshore habitats and substrates including mud, rubble, coral reefs and macroalgae beds with sand and pavement

predominating on the north-east and south-west coasts, respectively (Long et al. 2006) (Figure 1). Our specific study area, in Sampoinet subdistrict, faces south-west towards the Indian Ocean within the district of Aceh Jaya (4°53'N, 95°24'W) (Figure 1). The dominant physical features of the nearshore area include the shallow and gently sloping (<1.4°) embayment (lhok) of Kruet (coarse sand and pavement bottom) and the island (pulo) of Raya. The discharge of the Kreung No River may have a strong influence on nearshore turbidity and benthos during certain times. The area around Pulo Raya is notable for its fringing reef habitat, including a number of hard-coral morphologies (3.5%: encrusting, massive, tabulate) as well as soft corals and sponges (together 1.3%), macroalgae (11.1%) and numerous rocky reefs (Long et al. 2006). Populations of spiny lobster (*Panulirus* spp., 32/ha) and reef-associated fish (coral trout, humphead wrasse, grouper, snapper and sweetlips) have been surveyed down to 15 m and constitute important fisheries resources in the study area (Long et al. 2006). In general, tsunami damage to coral and other subtidal habitats around Aceh is considered minimal (Baird et al. 2005). However, observations of a fine silt layer in sheltered locations of patch reef may be evidence of tsunami-related run-off. Such terrestrial materials may have long-term impacts that may be difficult to assess or predict given the lack of pre-tsunami data. Annual rainfall in the area is abundant (>2,500 mm), with two major seasons prevailing: wet (south-west monsoon from April to September), also associated with strong winds, rough seas and flooding; and dry (north-east monsoon from October to March) (Whitten et al. 2000). These two seasons, and related patterns of terrestrial sediment discharges and nearshore currents, often dictate the pattern of fishing activities and may also significantly influence the recruitment patterns of marine organisms (coral, lobster) to local benthic habitats. Local fisheries regulations are limited to: (1) restriction of specific fishing gears on specific grounds; (2) prohibition of destructive gears (e.g. cyanide, trawl, explosives); (3) prohibition of surface-supplied diving for lobster; (4) an obligation for outsiders to obtain permission to fish; and (5) prohibition of fishing on Fridays. Lobsters are exclusively caught using nets set on and around a variety of benthic habitats.

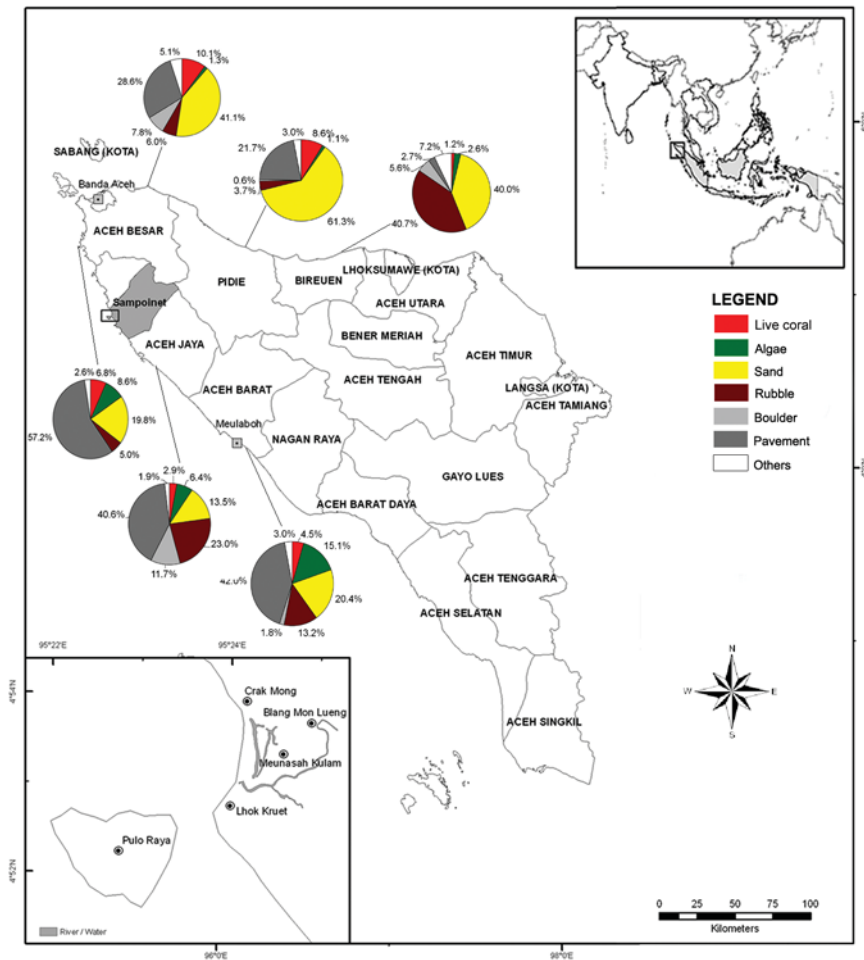
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<sup>2</sup> Resilience is 'the potential of a system to remain in a particular configuration and to maintain its feedbacks and functions, and involves the ability of the system to reorganize following disturbance driven change' (Walker et al. 2002).

## Lobster landings

Six species of spiny lobster endemic to the Indonesian archipelago (*Panulirus homarus*, *P. longipes longipes*, *P. ornatus*, *P. penicillatus*, *P. polyphagus* and *P. versicolor*) (see Figure 2) were identified through random sampling (August 2007 – September 2008) at landing sites in and around Lhok

Kruet (Table 1). The general habitat preferences of Indo-West Pacific spiny lobsters of the equatorial zone are strongly influenced by hydrodynamics and turbidity and have been previously grouped as: 1. oceanic species in areas of strong surge (seaward side of coral or rocky reefs) and waters ‘uncontaminated’ by terrestrial run-off (*P. penicillatus*); 2. species strongly associated with coral reefs in



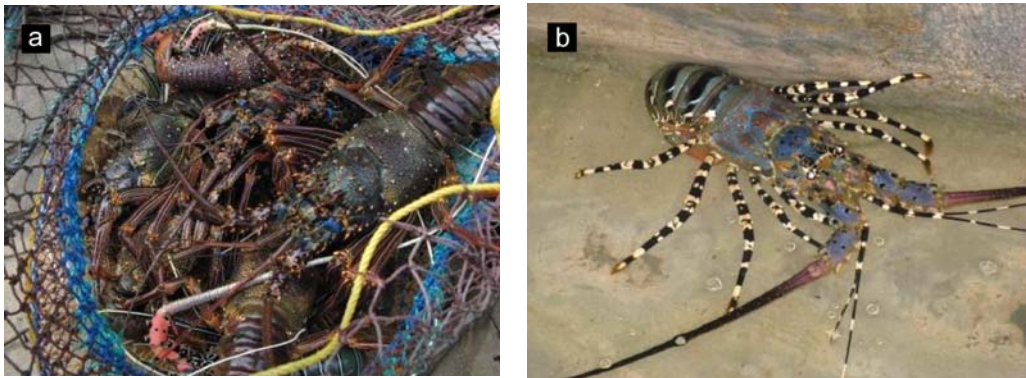
**Figure 1.** Map of Aceh province, Indonesia, showing its districts, including the study site located in Sampoinet subdistrict (grey area) of Aceh Jaya, and distribution of dominant nearshore benthic cover in surveyed districts. Inset top right: position of the main map within South-East Asia. Inset lower left: focal communities and permanent water bodies of the study area (detail of box in main map).

Notes: Benthic cover survey included over 550 transects (20 × 2 m) (Long et al. 2006). ‘Others’ category includes dead coral, soft coral and sponge. In the survey, Aceh Besar district was divided into north-east and south-west coasts.

areas sheltered from oceanic swells (*P. l. longipes* and *P. versicolor*); and 3. continental species found in coastal areas with soft sediments and variably influenced by terrestrial run-off (George 1974; Holthuis 1991; Coutures 2000). The continental species habitat niche may be further subdivided into: 1. lagoons dominated by silty bottoms and scattered coral (*P. ornatus*); 2. mixed sand/low terrestrial detritus substrates (*P. homarus*); and 3. areas where substrates are dominated by high levels of terrestrial detritus near discharges of rivers (*P. polyphagus*) (George 1974). The Bahasa Indonesian names for certain species—*P. homarus*, pasir (sand) lobster and *P. penicillatus*, batu (stone) lobster—may have evolved in fishing communities due to observations

of strong habitat affinities. The great variety of benthic habitats (sand, pavement, rock and coral) and oceanographic conditions (clean oceanic water, continental run-off, strong currents) as well as the central position of the study site within the broader Indo-West Pacific region have likely combined to facilitate the high diversity of equatorial spiny lobster species we observed.

The largest mean carapace lengths and individual mass were represented by *P. ornatus* (89 mm, 817 g) and *P. polyphagus* (84 mm, 463 g). *Panulirus polyphagus* also represented the smallest portion of the total catch in both number of individuals and total mass landed, followed by *P. ornatus* (Table 1). The smallest mean carapace length and individual



**Figure 2.** (a) Single fisher landing of *Panulirus longipes longipes*, *P. penicillatus* and *P. versicolor*; (b) *P. ornatus* in an onshore holding tank

**Table 1.** Summary of *Panulirus* spiny lobster data collected at Lhok Kruet, Aceh Jaya, Aceh Province (August 2007 – September 2008)

Attribute	<i>P. homarus</i>	<i>P. longipes longipes</i>	<i>P. ornatus</i>	<i>P. penicillatus</i>	<i>P. polyphagus</i>	<i>P. versicolor</i>
Total sampled	251	88	17	203	9	152
Mean CL (mm)	66	59	89	74	84	67
Min. CL (mm)	32	37	42	34	52	37
Max. CL (mm)	106	95	129	138	120	123
Total mass (g/individual)	281	223	817	388	463	261
Total mass caught (%)	31.1	8.7	6.1	34.7	1.8	17.5
Total individuals caught (%)	34.9	12.2	2.4	28.2	1.3	21.1
Females (%)	45.4	53.4	29.4	36.9	44.4	32.5
Egg-bearing (%)	24.6	61.7	40.0	40.0	25.0	32.7
CL at 50% maturity (mm) <sup>a</sup>	73	55	107	74	101	77
Min. CL at maturity (mm) <sup>a</sup>	45	44	92	46	101	43
Average price (US\$/kg) <sup>b</sup>	19.90	14.50	20.15	13.40	16.40	16.30

<sup>a</sup> Mature females were considered as those in egg-bearing state

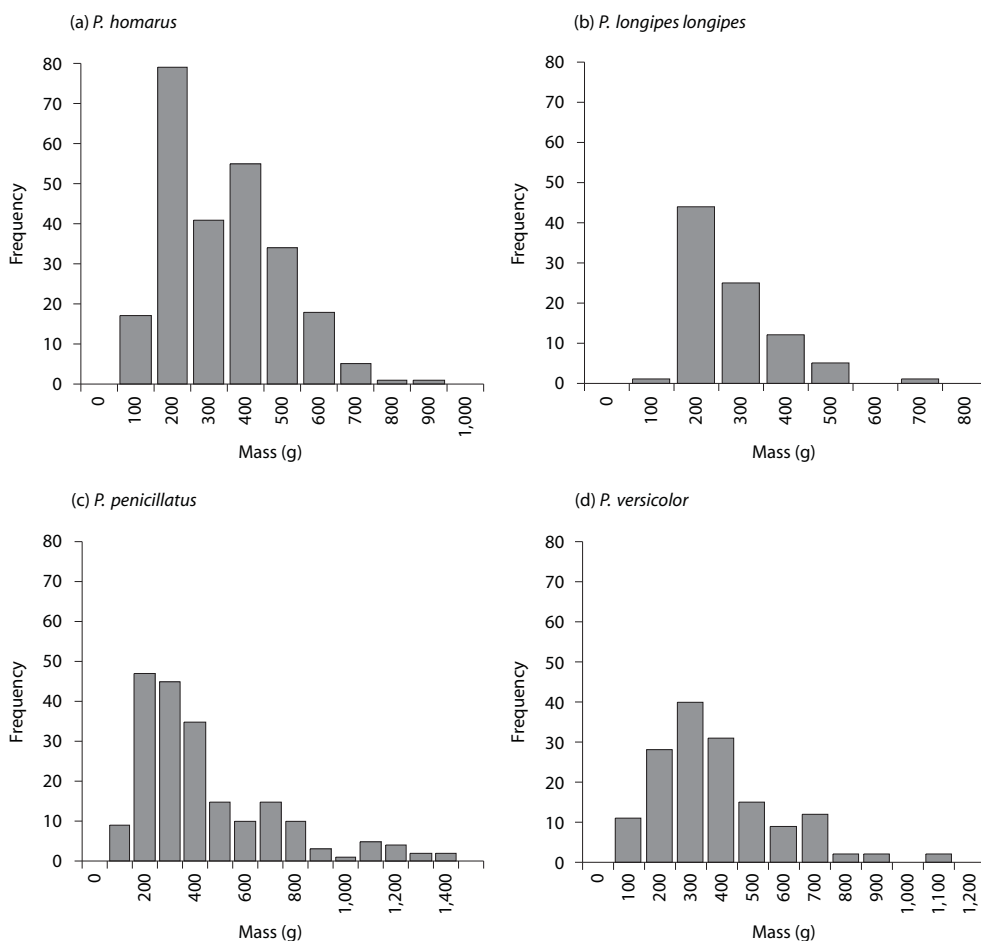
<sup>b</sup> Mean value for largest size class (>300 g) (January – November 2008)

Note: CL = carapace length; Min. = minimum; Max. = maximum

mass was found for *P. l. longipes* (59 mm, 223 g). Individuals of *P. homarus* were the most frequently caught (34.9%) while *P. penicillatus* constituted the highest total mass caught (34.7%). Sixty-one per cent of the total catch was landed during the north-east monsoon period (October – March). This may simply be due to fishers switching to other marine resources (reef-fish, small pelagics) during the south-west monsoon. Total mass frequency distributions for the four most commonly landed species may indicate disproportionate impact on the larger size classes given the broad range of lobsters targeted using nets (Figure 3). Females often accounted for less than half of the catch, which was

sometimes greatly biased towards males (*P. ornatus*; *P. versicolor*) and may be of a particular concern for *P. penicillatus*, which represents a significant portion of the total catch (Table 1). More than 37% of all female lobsters landed and almost 62% of female *P. l. longipes* were egg-bearing. Most egg-bearing females were landed during the north-east monsoon period (63%) with peaks occurring in April and October (Figure 4).

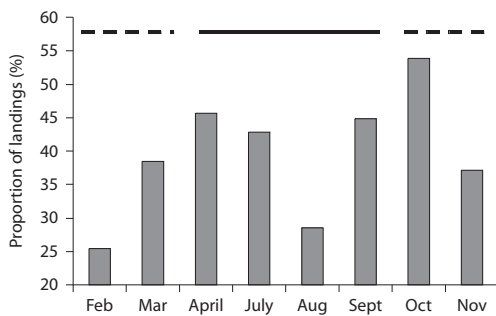
The fisheries-dependent data collected in this study are considered quite representative of the wild population. This is due to the fact that fishers indiscriminately target all lobsters using small mesh bottom nets due to their high value regardless of size.



**Figure 3.** Total mass (g) frequency distributions for the most commonly landed species of spiny lobster at Lhok Kruet, Aceh Jaya, Aceh province: (a) *Panulirus homarus* ( $n = 251$ ), (b) *P. longipes longipes* ( $n = 88$ ), (c) *P. penicillatus* ( $n = 203$ ) and (d) *P. versicolor* ( $n = 132$ )



Such fishing practices result in landings of small juveniles, egg-bearing females and a by-catch of other low-value crustaceans (e.g. *Carpilius maculatus*) that are usually discarded. After being landed, lobsters are weighed and sold to local buyers who may hold them for several days in floating pens or onshore in concrete ponds (Figure 5). When a sufficient number of lobsters has been accumulated, they are rolled in clean sand and packed live in cardboard boxes with frozen bottles of water. Land transport to markets and export points in Banda Aceh (120 km away) may take 4–5 hours depending on road conditions. Prices for the largest size classes (>300 g) in premium condition (live, undamaged) during 2008 ranged between rupiah (Rp)120,000 (US\$13) and Rp180,000 (US\$20) per kg (Table 1). A number (approximately 11%) of non-palinurid lobsters (e.g. *Parribacus antarcticus*—kipas hitam) is also landed and constitutes the lowest-value portion of the lobster catch (Rp25,000 or US\$2.50/kg).



**Figure 4.** Occurrence of egg-bearing females ( $n = 122$ ) amongst all female spiny lobsters caught ( $n = 341$ ) between April 2007 and September 2008. Bold horizontal line indicates north-east (dashed) and south-west (solid) monsoon periods when 63% and 37%, respectively, of egg-bearing females

### Puerulus collector testing

The presence of suitable habitats and associated observations of lobster, dependence on lobster-generated income for some households and the availability of a network of buyers and nearby markets (Banda Aceh, Medan, Singapore) have encouraged the design and deployment of experimental puerulus (i.e larva) collectors (Figure 6). Such collectors may facilitate local grow-out

options presently being trialled elsewhere in Indonesia (Jones 2007) and well practised in Vietnam (Tuan and Mao 2004). Our puerulus collectors integrated design elements from Australia (Phillips et al. 2001; Mills and Crear 2004), used locally available artificial materials (light plastic fibre, outdoor carpet) and were built quickly (<2 hours) at a reasonable cost (<US\$10) (Figure 6a). The materials and design attempt to mimic macroalgae settlement for pueruli and crevices to shelter recently settled juveniles as well as providing appropriate substrate for other invertebrates that may serve as food for early lobster life-history stages. Twenty-eight collectors were randomly deployed over the fringing reef just north of Pulo Raya (Figure 1). Collectors were anchored in 5–6 m of water using steel-reinforced concrete blocks individually, paired or in quads approximately 1–1.5 m below the surface (Figure 6b). The collectors appeared quite robust over the 6-month deployment period (February–July). One year after deployment, fouling as well as damaged or missing floats caused the collectors to sink before being removed from the water. Although the collectors did facilitate the natural settlement of encrusting organisms and various shrimp, only a single juvenile *Scyllarides squammosus* slipper lobster was observed during four monitoring events (Figure 6d).

### Future work

Our lobster landings data collection program revealed that *P. homarus* (pasir lobster) and *P. penicillatus* (batu lobster) are the most important species caught. These species appear not to associate directly with coral habitats but rather on sand bottoms or rocky reefs in more oceanic or turbid water conditions, respectively (George 1974). Therefore, the deployment of our collectors over coral reefs may have possibly limited our target range to coral-dependent species (*P. l. longipes*, *P. versicolor*). The limited period of the collector monitoring (February – July) may have missed peak puerulus settlement periods. Given the importance of lobsters to local communities and potential livelihood opportunities through grow-out, we intend to proceed with collector design variants, future deployments and more frequent monitoring. Future deployments will take place over various habitats, and during various seasons as well as from lift net (bagan) arrays (Figure 6e). Deployment from

bagans, operated by lobster fishers, will benefit from being in a secure location that can be easily monitored and moved to other locations. The use of bagans as puerulus collector platforms also eliminates the need for individual collector anchor systems and benefits from bagan lighting traditionally meant to attract small pelagics during night-fishing operations. A detailed lobster fisher survey is also underway and should provide a more complete understanding of fishing patterns, observations of puerulus settlement and attitudes on the prospect of culturing and management of the lobster fishery. Finally, the long-term success of lobster seed collection and development of lobster grow-out may be well suited to the experience of local people who already practise short-term, postcapture lobster

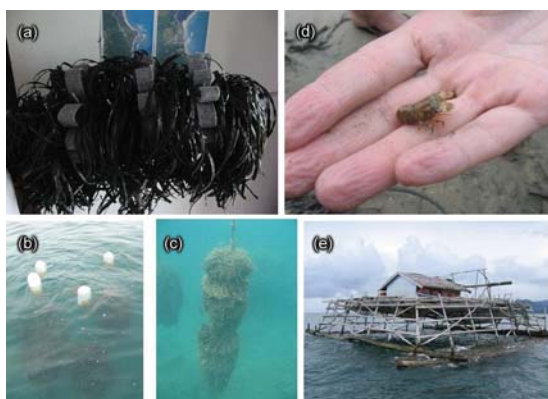
care (Figure 5) and other types of aquatic husbandry (tilapia, milkfish).

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**Figure 5.** Short-term lobster holding systems: (a) floating pen off Lhok Kruet; (b) concrete pen using closed circulation with (c) simple biological filtering (coral rubble) system (Samatiga, Aceh Barat, see Figure 1 for location)



**Figure 6.** Puerulus collectors: (a) newly constructed; (b) anchored quad of collectors with surface floats; (c) collector after 12 months in situ; (d) juvenile *Scyllarides squammosus* (slipper lobster) retrieved from collector after 12 months and (e) lift net (bagan) array set north of Pulo Raya

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# Contributions to the life-history study of the Palinuridae of the south-west lagoon of New Caledonia

Emmanuel Coutures<sup>1</sup>

## *Abstract*

The life history of shallow-water palinurids was studied in the south-west lagoon of New Caledonia between 1995 and 1999. Plankton sampling carried out in three different habitats (the lagoon, a passage through the barrier reef and the open ocean above the outer slope) indicated that *Panulirus* spp. phyllosomata develop only in the open ocean. High densities of stage I of *P. ornatus* larvae caught in the passage and nearby ocean suggested that the reproductive adults of this species migrate from coastal areas towards more oceanic areas to hatch their phyllosomata. Pueruli of *P. ornatus* and *P. longipes bispinosus* were caught with a fixed plankton net installed on the crest of the barrier reef. While metamorphosis occurs in the ocean, these pueruli come into the lagoon by crossing the barrier reef, through the breakers at night, to settle in inshore waters. Some of these pueruli have the ability to swim several kilometres across the lagoon, as young juveniles were observed in lagoonal fringing reefs near Noumea.

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# Lobster aquaculture industry in eastern Indonesia: present status and prospects

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## Abstract

The activities of some farmers to on-grow small spiny lobsters started in early 2000 at several sites in the south of Lombok island. Wild catch of undersize lobsters were stocked in floating cages in the vicinity of the subtidal zone and fed with trash fish. After 7–8 months, they were harvested at the marketable size of 150–300 g. Lobster farming continued even though it depended on wild-caught seed. Good prices and less-expensive transport to the exporter in Bali made the farming attractive to the smallholder. Catching the lobster juveniles then became a business segment in the industry chain after success of some farmers to grow these juveniles to a marketable size. The price of transparent seed is about rupiah (Rp)3,000/piece (US\$0.27), and Rp5,000–7,000/piece (US\$0.46–0.64) for a size of 25–50 mm.

Species of spiny lobsters exported from Indonesia include *Panulirus homarus*, *P. ornatus*, *P. longipes*, *P. versicolor*, *P. polyphagus* and *P. penicillatus*. In the southern part of Lombok, where the juveniles were found, the farming of lobster in floating net cages has made a significant contribution to the market (local and export). More than 1,500 small-scale farm units are established and produce about 4–5 t of lobsters per month. The strong market for lobsters and the success of lobster grow-out by the smallholder will ensure that lobster aquaculture will remain a profitable business.

Traders prefer larger lobsters than those being produced by the lobster farmers. As the existing lobster farming methods are generating good profits for the small-scale farmers, there is not a strong incentive for farmers to produce bigger (~1 kg) lobsters. To respond to the market demand for more lobster product, the government needs to be actively engaged in developing rural coastal aquaculture. The crucial questions to be answered are: what is the strategic way to push the development; what constraints must be overcome in order to increase production and productivity; and who will be the stakeholders that control the business? This paper provides an account of the lobster farming development that has occurred in the Lombok region and efforts that are needed to sustain and enhance this development.

**Keywords:** *Panulirus*; pueruli; settlement; feeding; lobster culture

## Introduction

The eastern part of Indonesia is rich in solar radiation, has low precipitation and relatively short periods of rain, all of which favour mariculture development. Lobster cage culture has great

potential to develop in Indonesia. Indonesia has 5.8 million km<sup>2</sup> of marine area, 17,504 islands and 81,000 km of coastline, including many lagoons and bays that are suitable for seaweed culture. The area utilised is still very low compared to that available. Lobster culture in eastern Indonesia began in the province of West Nusa Tenggara (Nusa Tenggara Barat) in 2000 as a by-product of seaweed and grouper culture which had been in operation since the 1990s. Swimming pueruli (i.e. the final larval

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stage of the lobster) and juvenile lobsters were often observed settling on the floats, cages and other materials associated with seaweed and grouper culture. They were captured by hand and retained in separate cages, in which they grew well, and thus was born lobster aquaculture. Most of the lobster aquaculture occurs in combination with other species, primarily *Cromileptes altivelis* (humpback grouper) and *Eucheuma* seaweed. There are three main lobster culture areas: Telong Elong Bay, Awang Bay and Gerupuk Bay, which are located in the south-central and eastern regions of Lombok island (Figure 1). Lobster farming involves more than 400 farmer/households and has a flow-on benefit for local village people.

## Current lobster aquaculture

### Cage facilities

There is considerable variation in raft and cage specifications, reflecting the novelty of the industry and its developmental stage. All cages are supported on floating rafts 100 m or more off the beach. The materials used vary from less-sophisticated structures made from bamboo to better-engineered platforms made from milled timber. Floats consist of plastic or steel drums, some of which are covered in canvas, presumably to reduce corrosion. Rafts vary in dimensions but typically are 10 m<sup>2</sup> and up to

25 m<sup>2</sup>. Cages are supported within the raft in a grid pattern of varying specifications. Cages vary from small (1.5 m<sup>3</sup>) to large (4 m<sup>3</sup>), depending on species (grouper or lobster) and size of stock, i.e. smaller cages for juveniles and larger for grow-out. Cage nets to hold lobsters are made from nylon fishing-net materials—generally of a fine mesh size, less than 12 mm. Larger cages tend to use larger mesh size, although none is larger than 20 mm. The total industry presently consists of about 1,000 small-scale farm units.

### Species cultured

The species of lobsters cultured is a direct product of the seed caught. Two lobster species are prevalent: *Panulirus ornatus*, (ornate spiny lobster, locally known as mutiara lobster; Figure 2) and *Panulirus homarus* (pasir lobster; Figure 3), with the latter being 10 times more abundant than the former. Very small numbers of *P. versicolor* (bamboo lobster) and *P. longipes* (batik lobster) are also caught. *Panulirus homarus* and *P. ornatus* are two of the more valuable lobsters for marketing.

### Seed collection

There appears to be development of a separate seed-collecting sector, although currently most seed is captured by the lobster farmers and used directly in their own grow-out cages. The methods of collec-



**Figure 1.** Major sites of lobster aquaculture in Lombok island, West Nusa Tenggara province, including numbers of sea cages at each site

tion vary and can be separated into those targeting the swimming puerulus stage and those targeting the larger juveniles (Figure 4). For pueruli, many are collected as a by-product of a light trap used for catching fish (Figure 5). These traps, known as *bagan*, are common along the coastline and consist of a bamboo frame structure secured to the sea floor by posts or moorings, and supporting a rectangular net which is lowered by rope to the sea floor. They are deployed at night, and a lamp is lit over the trap to attract fish. The lamp may be powered by kerosene, oil or electricity supplied by a small petrol generator. The trap is raised four times through the night to retrieve fish, and pueruli are often caught as well. Many of the fish are used for direct human consumption, but those deemed unsuitable for this purpose, i.e. trash fish, are used as feed for lobster (and grouper) aquaculture.



**Figure 2.** *Panulirus ornatus* (ornate or mutiara spiny lobster) of marketable size

Now that lobster aquaculture is developing, more attention is being paid to finding pueruli within the *bagan* catch, although it is apparent that villagers in many areas where the *bagan* is used are not involved in aquaculture and are not aware of the pueruli. This

latent capacity could be developed very quickly. There are three main sites with potential as seed sources in Lombok island (see Figure 1)—these are Awang Bay (Figure 6), Gerupuk Bay (Figure 7) and Telong Elong Bay.

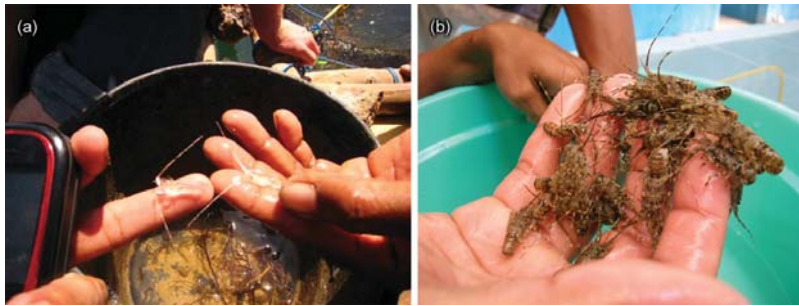


**Figure 3.** *Panulirus homarus* (pasir lobster) of marketable size (300 g), with eggs indicating maturity

There is also considerable use of shelter traps for swimming pueruli. The most common materials used are bundles of rice bags (Figure 8a) or canvas (Figure 8b), with these materials hung into the water from rafts (Figure 9) and onto which the pueruli settle. These are generally inspected every second or third day and a raft with 25 to 50 bundles may generate up to 100 pueruli at a time. This number is likely to be an exception, with the average catch per retrieval more likely to be around 20. Small numbers of pueruli are also caught as they settle on the cages and floats of the rafts. These are collected by hand as they are observed.

Availability of pueruli is seasonal, with a peak catch rate during November and December. This suggests that the source of the spawning stock that produces the seed is located north of Indonesia where summer breeding occurs around June and July. In addition, catches are relatively higher over periods of new moon (i.e. dark moon phase).

Juvenile lobsters are collected in much smaller numbers, but are more valuable as they are more robust and more likely to survive. There does not appear to be any targeted catching method, and they are taken as a by-product of other fishing activity, particularly seine netting in the shallows off the beach. Some juveniles are also observed on the floats and cages of the rafts and are collected as they are observed.



**Figure 4.** Transparent puerulus stage (a) and pigmented juvenile stage (b) of *Panulirus homarus*



**Figure 5.** A fish trap, or bagan, common in the study area—pueruli are collected in such traps as by-catch when catching fish

As the industry has developed, knowledge of the puerulus and juvenile stages has increased and, in some areas, the seed are collected for subsequent sale to lobster farmers. In addition, some farmers collect more than their facility can accommodate and on-sell them to other farmers. The price is about Indonesian rupiah (Rp)3,000/individual (US\$0.27) for transparent seed; Rp5,000–7,000/individual (US\$0.46–0.64) for pueruli of 25–50 mm; and up to Rp10,000 (US\$0.90) per juvenile depending on size. The current practices for seed collection indicate that lobster seed collection is sparse and not well targeted. There is significant capacity to increase seed volume available through increased effort (gear and areas) and improved catching methods.

### Grow-out methods

Lobster grow-out involves periodic grading, generally at three stages: a nursery phase, from postpuerulus to 2 cm total length; a juvenile phase, from 2 cm total length to 50–100 g; and a grow-out phase, to market size which appears to be 200–300 g for *P. homarus* and 300–500 g for *P. ornatus*. *Panulirus homarus* matures at 200–300 g, so the targeted grow-out size is appropriate. Growth slows significantly beyond 300 g, and further grow-out would be unprofitable. Furthermore, *P. homarus* fetches a maximum price of around Rp150,000 (US\$14) per kg at 200–300 g. In contrast, *P. ornatus* does not mature until well in excess of 1 kg, at which size it will receive its maximum price. However, at



Lombok, *P. ornatus* is harvested at a maximum size of 500 g and this attracts a low price of about Rp130,000 (US\$12) per kg. There is clearly capacity to increase farmers' income by educating them about the value of growing *P. ornatus* to 1 kg or more.

The postpuerulus phase is characterised by its short duration of 2–4 weeks and high mortality. There is no particular husbandry applied to this stage. Postpueruli are housed in small cages, generally 3.5 m<sup>3</sup>, stocked at up to 100/cage (28/m<sup>3</sup>),

and fed finely chopped trash fish. Juveniles are transferred to larger cages, up to 9 m<sup>3</sup> (Figure 10), at densities of up to 20/m<sup>3</sup> and fed trash fish. In turn, the larger juveniles at around 100 g are transferred to larger cages for growth through to market size at densities of up to 10/m<sup>3</sup>. Some seaweed may be placed in the cages to provide refuge (Figure 11), although it is unlikely to be very effective, and indeed may be consumed by the lobsters. Its effectiveness, if any, would be more important for the



**Figure 6.** Landscape of Awang Bay, Lombok, showing newly established net sea cages used to on-grow juvenile fish or lobsters to a size that best suits the market requirements



**Figure 7.** Landscape of Gerupuk Bay, Lombok, showing expanse of floating net sea cages for lobster and fish grow-out

puerulus to juvenile phases. Shading over the cages is common, and is provided using palm-frond thatching or synthetic shadecloth material.

### Feed

Lobsters are fed entirely with trash fish caught as a by-product of other fishing activity, particularly from fish traps (bagan). Although none of this

material was observed directly, it is understood to consist almost entirely of small fish, with almost no mollusc or crustacean species. Food material is very fresh (Figure 12), as there is no delay from catch to use. It is roughly chopped and fed each morning after the night's fishing activity is completed. Because relatively fine mesh netting material is used in the cages, a significant proportion of uneaten food



**Figure 8.** Puerulus shelter traps made of rice bags (a) or canvas (b) are suspended off rafts



**Figure 9.** Seed-collecting raft from which hang many puerulus shelter traps

remains in the cage, unable to fall through the mesh. In all cages observed, from 10 am through 5 pm, there was a large amount of waste material. This is not conducive to good hygiene or growth, and larger mesh sizes may be beneficial. Based on the estimates made by farmers, it seems likely that the feed conversion ratio (FCR) is around 12:1 to 15:1 (i.e. 12 to 15 kg of trash fish for each kg of lobster produced).

The current trash fish diet is not ideal, and may explain the pale pigmentation of the grown-out lobsters. There may be an opportunity to catch additional species of molluscs and crustaceans specifically to supplement the trash fish. A more thorough assessment of the trash fish composition and its nutritional quality is required before recommendations can be made about what other feed items should be added to the diet. This might also include



**Figure 10.** Simple raft with suspended cages for on-growing lobsters



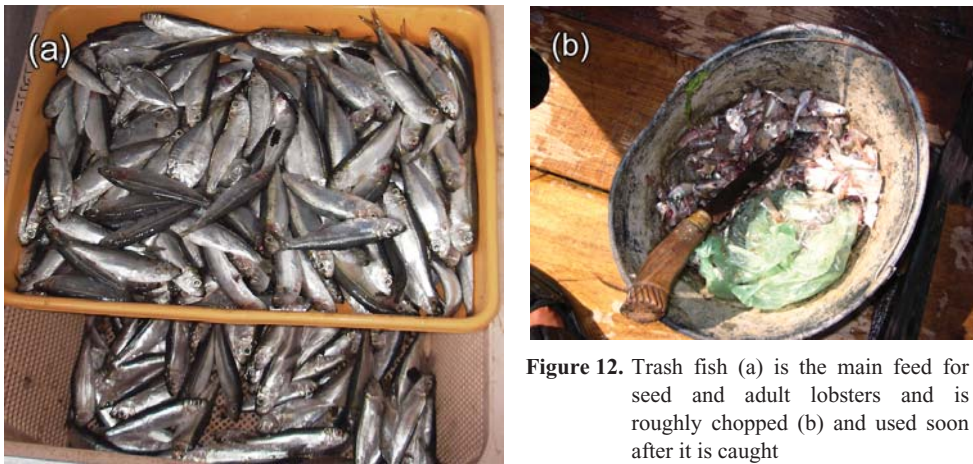
**Figure 11.** Seaweed placed in the cages of juvenile lobsters to provide refuge

a locally made compounded diet using the trash fish and other fresh materials, along with specific essential ingredients such as binders and vitamin/mineral pre-mix.

### Productivity

Mortality during the postpuerulus phase is very high, 50–60%, and is thought to be primarily attributable to cannibalism. Survival of lobsters through the juvenile phase is likely to be 60–90%. Although the grow-out phase should have the least problems, there have been varying accounts of survival, with

some farmers experiencing very good (>90%) while others have seen very poor (<50%) survival. The proven track record of Vietnamese lobster farmers suggests that, with good husbandry and nutrition, grow-out survival should consistently be above 90%. It takes about 6 months for a 2 cm juvenile to reach market size of 200 g for *P. homarus* and 8 months for *P. ornatus* to reach a marketable 350 g. It was apparent that *P. homarus* initially grows faster than *P. ornatus*, perhaps through to 100 g, but thereafter the growth rate of *P. ornatus* increases faster than that of *P. homarus*.



**Figure 12.** Trash fish (a) is the main feed for seed and adult lobsters and is roughly chopped (b) and used soon after it is caught



**Figure 13.** Experimental seed-collecting devices consisting of a bamboo-framed tripod mounted on styrofoam floats from which shelter traps are suspended

It is difficult to estimate overall production or yield per unit because of the marked variability in the information on number of seed available, survival, growth rates, harvest size and number of cages dedicated to lobster rather than grouper. On average, it seems 50 kg of marketable lobsters are produced per average cage (3 m<sup>3</sup>) per annum. The number of cages in which lobster are grown may be in the order of 250, hence total annual production is likely to be around 12.5 t.

### Improving catches of postpueruli

In order to assess the expansion capacity of lobster aquaculture in the Lombok region, a reliable estimate of the abundance of lobster seed for lobster grow-out is necessary. An experiment is being carried out to assess the lobster seed resource in the region by applying fishery-independent and standardised seed collectors, deployed at locations within the existing seed-collecting areas and in currently unfished areas. Lobster seed being collected include both the swimming final larval stage (puerulus), and recently settled juveniles, which are found attached

to substrates. The experiment is employing a light trap collector of a design equivalent to those used in Vietnam. Four collectors have been deployed at each of 10 locations, such that they represent four replicates to ensure robust data are collected. Each collector consists of a bamboo-framed tripod mounted on styrofoam floats (Figure 13). From the apex of the tripod, a kerosene lantern is secured as the light source (Figure 14). From each of the three corners of the frame, three trap structure materials are suspended. The first consists of bundles of rice bags suspended by a rock weight (Figure 8a); the second structure is canvas strips that are weighted to ensure they remain submerged (Figure 8b); and the third is a timber pole of approximately 1 m in length and 100 mm diameter into which 50 × 10 mm diameter holes have been drilled at regular intervals (Figure 15). Other materials may be attached to the timber pole to provide additional settlement structure. Thus, each collector has many different shelter structures to encourage the highest possible rate of lobster seed settlement. Collectors are anchored to the bottom with a heavy-duty rope and large rock weight. For each location, the four collectors have



**Figure 14.** Kerosene lantern as the light source to encourage pueruli to swim closer to the shelter traps



**Figure 15.** Length of wooden pole with holes drilled at regular intervals and some other materials attached: one of the three types of trap structure materials used in the puerulus collector

been placed approximately 50 m apart in a square pattern. Results from this study will be reported in due course.

### **Further research needs**

After several surveys on the farming activities, seed collecting and product marketing, it is apparent that the most important issues that must be addressed to foster lobster aquaculture industry development are to:

1. carry out a market-chain assessment of lobster supply and demand for South-East Asia to determine the resilience of the market to an increased supply of aquaculture lobster product
2. assess the ecological impact of lobster seed collection by
  - (i) analysing the impact of increasing the catch rate of wild seed lobsters used for aquaculture
  - (ii) identifying new lobster settlement sites and using fishery-independent surveys to establish baseline seed catch data for areas of southern and eastern Lombok
  - (iii) increasing the survival rate of captured lobster seed, especially in the first few weeks after capture where losses typically are 50% or higher (puerulus husbandry to improve survival rate)
  - (iv) carrying out an annual census of lobster seed collection at the established sites of lobster aquaculture industries
3. improve feed quality so as to promote better lobster growth and survival, stronger immunity to disease and better cuticle colour (development of formulated feed or pellets to improve the cultivation technique).

# The potential for harvesting seed of *Panulirus argus* (Caribbean spiny lobster)

Andrew Jeffs<sup>1</sup> and Megan Davis<sup>2</sup>

## Abstract

There is growing international interest in the aquaculture of spiny lobsters as the market demand for lobster increases beyond what wild fisheries are capable of producing at a sustainable level. A significant hurdle for spiny lobster aquaculture is the supply of 'seed' lobsters, or early juveniles. Larval development in spiny lobsters is long and complex, therefore it is difficult to complete in a hatchery. Consequently, there is growing interest in developing methods for the efficient harvest of large numbers of wild, early juvenile lobsters. This is especially true for tropical lobster species, which have attributes well suited to aquaculture, such as rapid growth rates.

Spiny lobster aquaculture has been flourishing in recent years in countries such as Vietnam, based on the large-scale harvesting of early juveniles of several lobster species, but mostly targeted at *Panulirus ornatus*, which grows rapidly in culture to a large commercial size. Opportunities exist to explore other tropical regions for the aquaculture potential of spiny lobsters based on the harvest of wild seed lobsters. *Panulirus argus*, the Caribbean or Florida spiny lobster, is a species with considerable potential because of its fast growth in culture and well-developed markets as the largest spiny lobster fishery in the world.

This paper reviews the available data on postlarval survival for this species in the wild and finds high rates of natural mortality. Therefore, overall lobster production could be increased by harvesting seed lobsters for aquaculture while supplying sufficient seed lobsters to maintain wild fisheries. A review of the available information on the patterns of seed lobster settlement suggests that while there is some information on the physical processes, as well as the behaviour and ecology of *P. argus* postlarvae, there is still a need to verify these data to improve the efficiency of harvesting seed lobsters of this species for aquaculture.

**Keywords:** aquaculture; puerulus; postlarval survival; grow-out; settlement; recruitment

## Introduction

There is growing interest in the aquaculture of spiny lobsters as the world market demand for lobster increases beyond what wild fisheries are capable of producing sustainably. As a result, spiny lobster aquaculture has recently begun in a few countries,

such as Vietnam, based on the large-scale harvesting of early juveniles of several lobster species (Williams 2004). Most of this aquaculture effort is currently targeted at *Panulirus ornatus*, the ornate spiny lobster, which grows rapidly under culture conditions to a large commercial size ( $\geq 1$  kg). There are good opportunities to explore other tropical regions of the world to assess the potential for the aquaculture of other species of spiny lobster based on the harvest of wild seed lobsters. *Panulirus argus*, the Caribbean or Florida spiny lobster, is one species with considerable potential for aquaculture development (Lellis 1991; Jeffs and Davis 2003).

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This species has an extensive natural range from North Carolina in the United States of America to Brazil, and is found throughout the Caribbean (Phillips and Melville-Smith 2006). As the largest spiny lobster fishery in the world (total landings ranging between 32,000 t and 38,000 t from 1997 to 2003), it has existing industry infrastructure, such as processing capacity and transport networks, together with well-developed markets with increasing demand over the long term (Phillips and Melville-Smith 2006).

The results of the numerous scientific studies conducted on this species suggest it has excellent potential for aquaculture because of its gregarious nature, naturally diverse dietary habit and fast growth in captivity (Booth and Kittaka 2000; Jeffs and Davis 2003). Despite the potential of this species, there has been little effort to establish commercial-scale aquaculture anywhere within its natural range. A significant hurdle for spiny lobster aquaculture is the supply of 'seed' lobsters, or early juveniles, to start commercial grow-out. Larval development in spiny lobsters is long and complex and, therefore, it is very difficult to complete larval rearing in an aquaculture hatchery. Consequently, there is growing interest in developing methods for the efficient harvest of large numbers of wild, early juvenile lobsters. To assess the potential for harvesting seed lobsters from the wild, this paper reviews some of the available scientific research on the collection of *P. argus* seed.

## Puerulus collectors

Like all spiny lobster species, *P. argus* has a long and complex pelagic larval development which is thought to last for at least 9 months in the wild (Yeung and McGowan 1991). The species has been experimentally cultured from egg to puerulus in 140–198 days after undergoing a total of 18–21 moults (Goldstein et al. 2008). However, the larval ecology of this species is poorly understood with only a small number of published studies (Phillips and Melville-Smith 2006). In contrast, there has been a remarkable number of studies on the biology and ecology of the postlarval stage or puerulus, and early benthic-dwelling juveniles. An extensive literature search undertaken in preparing this paper revealed that more than 50 studies of these early lobster stages have been conducted in 13 different countries throughout the natural range of *P. argus*.

A major focus of these studies has been examining the temporal and spatial characteristics of arrival of pueruli using artificial habitat collectors (Phillips and Booth 1994). The impetus for much of this research activity was a desire to establish a simple method of managing lobster stocks through using a recruitment index derived from the puerulus collectors. This approach to managing lobster stocks has been an important part of the successful management of the Western Australian spiny lobster fishery for *Panulirus cygnus* (Phillips et al. 2003).

A wide variety of artificial habitat collectors has been used for catching pueruli of *P. argus* for research (Phillips and Booth 1994). Although these artificial habitats have taken many forms, they are usually constructed of low-cost materials and designed to provide an abundance of structural complexity on a fine scale in which the pueruli can hide. This includes fibrous material (folded air-conditioning filter fabric made from pigs' hair) in the Witham and Hunt collectors (Phillips and Booth 1994; Phillips et al. 2005) (Figure 1), masses of synthetic fibre tassels (frayed polypropylene rope) in the GuSi collector (Gutierrez-Carbonell et al. 1992) and artificial seaweed or polypropylene tassels in the Phillips and Sandwich collectors (Phillips et al. 2005; Cruz et al. 2006).

The structural complexity of the collector appears to replicate the preferred settlement habitat of the pueruli of this species, which is most typically in benthic mats of fine filamentous red algae, *Laurencia* spp., often found in shallow waters in the region (Phillips et al. 2006). The pueruli of *P. argus* are also known to settle among mangrove roots and other marine vegetation, which would also provide a naturally complex physical structure in which to hide from potential predators. Puerulus collectors for research have mostly been deployed in shallow coastal waters (<10 m depth) where the majority of natural settlement habitats, such as beds of *Laurencia* spp. and mangroves, are found. However, puerulus collectors have also been deployed in deeper waters with some success (M. Davis, unpublished data). The collectors have mostly been deployed on or near the surface of the sea, suspended beneath surface floats; however, collectors suspended in the water column or attached to the seabed have also been successful in catching pueruli (Witham et al. 1968). There is some indication that surface-floating collectors may be more effective at catching lobsters due to the strong surface-swimming behaviour of the pueruli of *P. argus*.



(Calinski and Lyons 1981; Jeffs et al. 2005). Several studies indicate that once pueruli reach shallow waters as they move toward the coast from ocean waters they will settle out relatively quickly, such that collectors placed further inshore will have progressively reduced catches, which has been described as a ‘shadow effect’ (Butler and Herrnkind 1992).

### Temporal and spatial variability in catches of pueruli

The results of the many studies examined through this review indicated that seed lobsters (Figure 2) were caught at almost every location throughout the natural range of this lobster where collectors were deployed. However, there was an enormous amount of spatial and temporal variability in the catch rates of seed lobsters. Longer term studies using puerulus collectors have identified that while seed lobsters usually arrive all year, there are invariably seasonal influxes of seed lobsters that tend to occur around the same time each year (Acosta et al. 1997; Yeung et al. 2001). These seasonal influxes are usually significant in their scale. For example, in one study in Antigua, around half the total number of seed lobsters were caught at four times of the year: late

September – early October, December, February and May (Bannerot et al. 1991, 1992). The seasonality of lobster catches appears to differ by location, and even within relatively short distances the seasonality can vary. For example, the seasonality of influxes of seed lobsters from two locations separated by less than 2 km in the Florida Keys was found to be different (Acosta et al. 1997; Yeung et al. 2001). Similar differences in the seasonal influxes of pueruli also operate on a much larger scale, such as between countries separated by hundreds of kilometres. For example, Acosta et al. (1997) found that the peak puerulus influx was in spring for the Florida Keys, while in Cuba it has been reported to occur in autumn (Cruz et al. 1991). Several studies have examined the timing of seed lobster arrivals in relation to the lunar cycle. The greatest catches of seed lobsters appear to be made around the new moon period, although the precise timing varies with different studies or locations (Acosta et al. 1997; Eggleston et al. 1998).

The causes of the variability in catches of seed lobsters between locations are unclear, but they are probably related to a mixture of factors including the presence of offshore currents carrying late-stage larval lobsters, onshore advection processes, such as local



**Figure 1.** A modified Witham or Hunt collector being cleared of seed lobsters on the deck of a boat. The fibrous panels are air-conditioning filter material made from compressed pigs’ hair. When in water, these panels hang from a polyvinyl chloride (PVC) frame that is suspended just below the surface by the four polystyrene floats.

currents and winds, coastal tidal movements, local coastal contours and seafloor habitat types. Some studies suggest that collection locations with high local current flows, such as at tidal harbour entrances and reef cuts, tend to have higher catches of seed lobsters because of the volume of water passing by, which could potentially carry more pueruli. In a study in the Exuma Sound in the Bahamas, the location with the highest puerulus settlement had a regionally persistent offshore eddy that pushed water onshore (Eggleston et al. 1998). Overall, there is a need to gather further information about the behaviour and ecology of pueruli of *P. argus* if there is to be any attempt to predict suitable locations for commercial-scale collection of seed lobsters for aquaculture.

### Potential impacts on fisheries from harvesting seed lobsters

Several scientific studies have consistently found that in the wild only a very small proportion of juvenile *P. argus* survive to 1 year after settlement

(Marx 1986; Herrnkind and Butler 1994). One study estimated that between 0.6% and 4.1% of all settling pueruli survived to 1 year after settlement (Herrnkind and Butler 1994). These estimates are wholly consistent with equivalent estimates of survival to 1 year ranging from 2% to 20% made for *P. cygnus* (Phillips et al. 2003). More detailed field survey data were used to estimate survival of 2.90% and 2.03% for *P. cygnus* pueruli to 1 year after settlement in each of 2 different years. Overall, these data suggest that there is very significant loss of seed lobsters soon after settlement and, as a consequence, the harvesting of pueruli for aquaculture could provide a means of greatly increasing production of lobsters from a wild fishery. In some countries where wild seed lobster harvesting has been allowed, the potential for reduction in the recruitment of lobsters to wild populations has been offset, either through reduced commercial harvest of adult lobsters, or the release to the wild of larger cultured juveniles which are thought to have higher survival due to their size (Phillips et al. 2003).



**Figure 2.** Early juvenile *Panulirus argus* that have been removed from a puerulus collector. Shortly after settling, the transparent pueruli develop this distinctive red-brown colouration, which is thought to help camouflage them in their settlement habitat.

## Conclusions

The available studies of survival for postlarval *P. argus* in the wild indicate that natural rates of mortality in the first year after settlement are very high. This would suggest that the harvesting of the seed lobsters for aquaculture could be used to increase overall lobster production while maintaining sufficient seed lobsters to maintain wild fisheries. Numerous studies of the patterns of seed lobster settlement using artificial habitat devices as collectors suggest that there is the potential to collect commercial quantities of seed lobsters at some locations within the extensive natural range of this species. However, improving the efficiency of any commercial-scale collection of seed lobsters of this species will rely on improving our knowledge of the behaviour and ecology of *P. argus* pueruli, as well as the physical processes, such as ocean currents, involved in influencing the highly variable spatial and temporal patterns in the arrival of pueruli on the coast.

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# Census of lobster seed captured from the central coastal waters of Vietnam for aquaculture grow-out, 2005–2008

Nguyen Van Long and Dao Tan Hoc<sup>1</sup>

## Abstract

The capture and on-growing of wild lobster seed, predominantly of *Panulirus ornatus* (ornate spiny lobster) is a flourishing village-based industry in Vietnam with an annual harvest production of around 1,500 t and a farm-gate value of US\$90 million. The seed are collected from a settlement zone along the central Vietnamese coastline of about 700 km, from Da Nang in the north to Binh Thuan in the south. To gather information on the level of exploitation, a census of lobster seed capture in Vietnam was carried out during the settlement periods of September 2005 to April 2008. The census used a structured interview and questionnaire/logbook process and targeted both the fishing villages where the seed were captured and the dealers used to distribute the captured seed. Data from some 29–34 lobster farming villages and 71–97 known dealers for each census period for the years 2005–2008 are thought to represent around 90% of annual total seed captured in each period. Total catch of *P. ornatus* for 2005–06, 2006–07 and 2007–08 was 5,196,820 seed, with similar amounts of seed being collected in 2005–06 (1,917,910) and 2007–08 (2,280,289) but only half that in 2006–07 (998,621). The number of seed lobsters caught in 2007–08 was still very high compared to that in previous years although demand for the seed has fallen as a result of the current severe lobster disease problems in Vietnam. *Panulirus homarus* was only a minor catch in 2005–06 (494,165) compared to that collected in 2006–07 (1,328,669) and 2007–08 (729,678). The three south-central provinces of Binh Dinh, Khanh Hoa and Phu Yen were major locations in contributing lobster seed of both *P. ornatus* and *P. homarus* to the annual total catch in Vietnam. The highest total catch and monthly catch of *P. ornatus* were from November to February following the lunar cycle. Catch rates showed a strong lunar pattern, with the greatest numbers caught in the dark phase between the 25th and 10th days of the lunar cycle.

**Keywords:** *Panulirus ornatus*; *Panulirus homarus*; puerulus; settlement; lunar cycle

## Introduction

The lobster farming industry in Vietnam has been operating since the mid-1990s (Tuan et al. 2000). This industry supports more than 4,000 formerly poor households and has created annual export revenues of US\$90 million. The industry is based on

the capture and culture of the postpuerulus larvae (seed) of *Panulirus ornatus* (ornate spiny lobster) collected from a settlement zone along the central Vietnamese coastline of about 700 km, from Da Nang in the north to Binh Thuan in the south. Lobster grow-out aquaculture is well developed in Vietnam where the abundance of lobster seed saw the establishment of more than 35,000 lobster sea cages in 2003 (Tuan and Mao 2004).

Studies relating to lobster seed abundance and exploitation in Vietnamese waters are few. Du et al.

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(1997) studied lobster seed capture in Nha Phu and Binh Cang bays and recorded 35,000 seed of *P. ornatus* collected for seaweed culture. That study also indicated that the main harvest of *P. ornatus* seed occurred from January to May, with the peak period from January to February. Thuy and Ngoc (2004) reported that the most commonly caught spiny lobster pueruli and pre-juveniles from the central coastal waters of Vietnam were *Panulirus homarus*, *P. ornatus*, *P. versicolor*, *P. stimpsoni* and *P. longipes*. *Panulirus homarus* appeared around September while *P. ornatus* occurred in large numbers from the end of October to mid-March of the following year.

Tuan and Mao (2004) roughly estimated that the demand for lobster seed increased from less than 0.5 million in 1999 to around 3.5 million in 2003. Although the industry has developed over a long period, the sustainability of this valuable resource is unknown as reliable data on the level of exploitation are not available. Such data will provide a starting point for determining whether the lobster seed that settle along the Vietnamese coast are, or are not,

critical to natural recruitment processes and thus to the long-term sustainability of lobster seed supplies in Vietnamese waters.

## Materials and methods

A census of lobster seed catch for aquaculture grow-out was carried out in eight coastal south-central provinces of Vietnam, comprising Da Nang, Quang Nam, Quang Ngai, Binh Dinh, Phu Yen, Khanh Hoa, Ninh Thuan and Binh Thuan, from September 2005 to April 2008 (Figure 1). The census was conducted annually and used a structured interview and questionnaire/logbook process, which targeted both the fishing villages where the seed were captured and the dealers used to distribute the captured seed (see Figure 2).

Some 71–97 local dealers from 29–34 fishing communes/villages in 19 cities/districts of the 8 provinces were surveyed (Table 1). The middlemen engaged in this business are well known and were expected to cooperatively supply the data. Data on lobster seed captured for *P. ornatus* and



**Figure 1.** Study locations in the eight coastal south-central provinces of Vietnam where the lobster seed census was carried out

*P. homarus* were calculated from daily logbooks kept for each fishing boat by each of the primary dealers at the fishing village. For a few of the secondary dealers who only gathered lobster seed from the primary dealers, the calculation of the total number of lobster seed captured was based on the daily number of purchased seed as recorded in the logbook of the primary dealer.

Total catch in each province and overall catch were calculated, based on total catch at each location of each province. Monthly catch per fishing boat at each location and each province were estimated by random selection from the daily catch of 30 fishing boats at each location within a certain month.

## Results

### Total catch of lobster seed

Total catch of *P. ornatus* for 2005–06, 2006–07 and 2007–08 was 5,196,820 seed, with similar numbers of seed being collected in 2005–06 (1,917,910) and 2007–08 (2,280,289) but only half that in 2006–07 (998,621). Binh Dinh, Phu Yen and Khanh Hoa provinces recorded the three highest catches of *P. ornatus* of the eight provinces (Table 2). The highest total catch of *P. ornatus* was from November to February (Figure 3), following the lunar cycle. *Panulirus homarus* was only a



**Figure 2.** Images demonstrating some activities associated with the Vietnamese census of lobster seed: (a) fishing at night; (b) fishing nets used to collect lobster seed; (c) *Panulirus homarus* seed lobsters; (d) Australian Centre for International Agricultural Research (ACIAR) T-shirt given to a local dealer as thanks for participating in the census

**Table 1.** Number of fishing villages and dealers contacted and the proportion who provided data in each period of lobster seed census in south-central Vietnam, 2005–2008

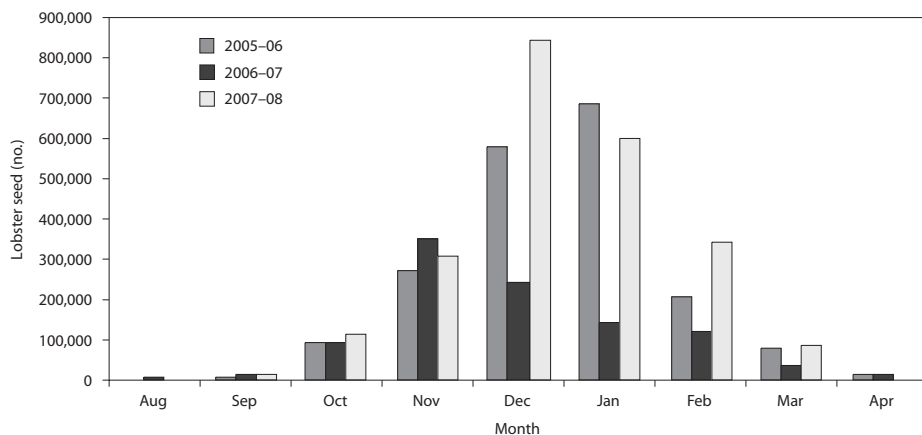
Period	No. of fishing communes/villages	Rate of contacted dealers	Percentage of contacted dealers
2005–06	34	71/82	87
2006–07	29	94/97	97
2007–08	29	97/97	100

minor catch in 2005–06 (494,165) compared to that collected in 2006–07 (1,329,669) and in 2007–08 (729,678). Binh Dinh, Khanh Hoa, Ninh Thuan and Binh Thuan provinces were major locations contributing *P. homarus* seed (Table 3). As the value of *P. homarus* is much lower than that of *P. ornatus*, it was not sought after by fishers or on-grown by farmers when *P. ornatus* seed was abundant.

Because of this, the total number of *P. homarus* as recorded in the notebooks of local dealers may be lower than the actual number caught.

### Monthly catch

Average monthly catch in 2007–08 was 12.0 individuals/boat and was 3.5 times higher than in 2006–07 (3.5 individuals/boat) and twice as high as



**Figure 3.** Monthly catch of *Panulirus ornatus* in each season of the Vietnamese lobster seed census, 2005–2008

**Table 2.** Provincial catch of *Panulirus ornatus* seed for each census season, 2005–2008

Province (north to south)	2005–06	2006–07	2007–08	Total
Da Nang	78,820	184,624	165,604	429,048
Quang Nam	91,270	74,834	76,936	243,040
Quang Ngai	259,290	102,639	180,584	542,513
Binh Dinh	453,450	279,623	561,667	1,294,740
Phu Yen	414,860	154,383	449,077	1,018,320
Khanh Hoa	415,690	110,354	459,077	985,121
Ninh Thuan	154,330	68,954	228,476	451,760
Binh Thuan	50,200	23,210	158,868	232,278
Total	1,917,910	998,621	2,280,289	5,196,820

**Table 3.** Provincial catch of *Panulirus homarus* seed for each census season, 2005–2008

Province (north to south)	2005–06	2006–07	2007–08	Total
Da Nang	877	102,510	25,484	128,871
Quang Nam	17,474	76,000	27,616	121,090
Quang Ngai	36,494	113,689	51,615	201,798
Binh Dinh	75,790	220,780	123,132	419,702
Phu Yen	44,482	96,215	65,815	206,512
Khanh Hoa	140,121	108,587	179,304	428,012
Ninh Thuan	64,663	284,888	90,218	439,769
Binh Thuan	114,264	326,000	166,494	606,758
Total	494,165	1,328,669	729,678	2,552,512



in 2005–06 (6.0 individuals/boat) (Figure 4). The overall peak of monthly catch was from November to February, but in 2007–08 the peak continued into March.

### Daily catch

The greatest numbers of seed were caught in the dark phase between 10 days after full moon and 10 days before new moon (between the 25th and 10th days of the lunar cycle). This pattern was very clear in Quang Ngai, Binh Dinh and Khanh Hoa provinces (Figure 5).

### Discussion

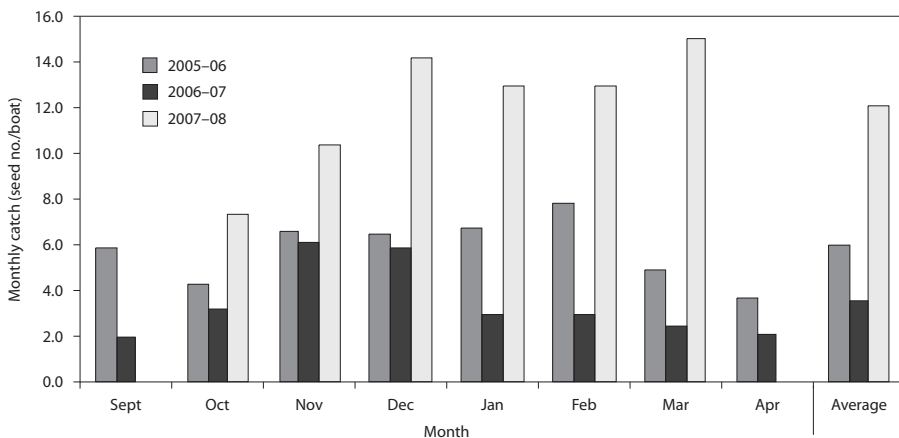
The number of seed lobsters caught in 2007–08 was still very high compared to that of previous years despite lower demand for the seed because of severe lobster disease problems in Vietnam. Low catch of *P. ornatus* in the 2006–07 season may have been due to strong storms during the peak settlement period, which prevented the fishers from venturing out to catch the seed. Likewise, bad weather in January 2008 prevented fishers from collecting lobster seed, which noticeably reduced the number of seed caught in Da Nang, Quang Nam and Quang Ngai provinces in the 2007–08 season. Higher numbers of lobster seed caught in Binh Dinh, Phu Yen and Khanh Hoa than other provinces may be explained by a higher number of fishers and fishing boats recorded for these provinces. On the other hand, these areas may

be considered as better locations for lobster puerulus settlement.

The dark phase of the lunar calendar was the best time for catching lobster seed because lights are used adjacent to the catching nets or structures to attract the swimming seed. Fishers have also found that catch rates are high during periods of tropical low pressure events when winds are mild.

### Conclusions

There was a large variation in annual total catch of *P. ornatus* between the seasons, with highest catches being obtained in the 2007–08 season (2,280,289). Catch rate was comparatively poor in 2006–07 (998,621) and much lower than in 2005–06 (1,917,910). The highest total catch and monthly catch rates were from November to February of each settlement season. Fishers in Binh Dinh, Phu Yen and Khanh Hoa provinces caught more *P. ornatus* lobster seed than other provinces in each of the three seasons. *Panulirus homarus* was only a minor catch in 2005–06 (494,165) compared to 2006–07 (1,328,669) and 2007–08 (729,678). The southern provinces of Binh Dinh, Khanh Hoa, Ninh Thuan and Binh Thuan were major sites for catching *P. homarus* seed. The peaks for both species occurred in the dark phase of the lunar cycle between 10 days after full moon and 10 days before new moon for the three seasons.



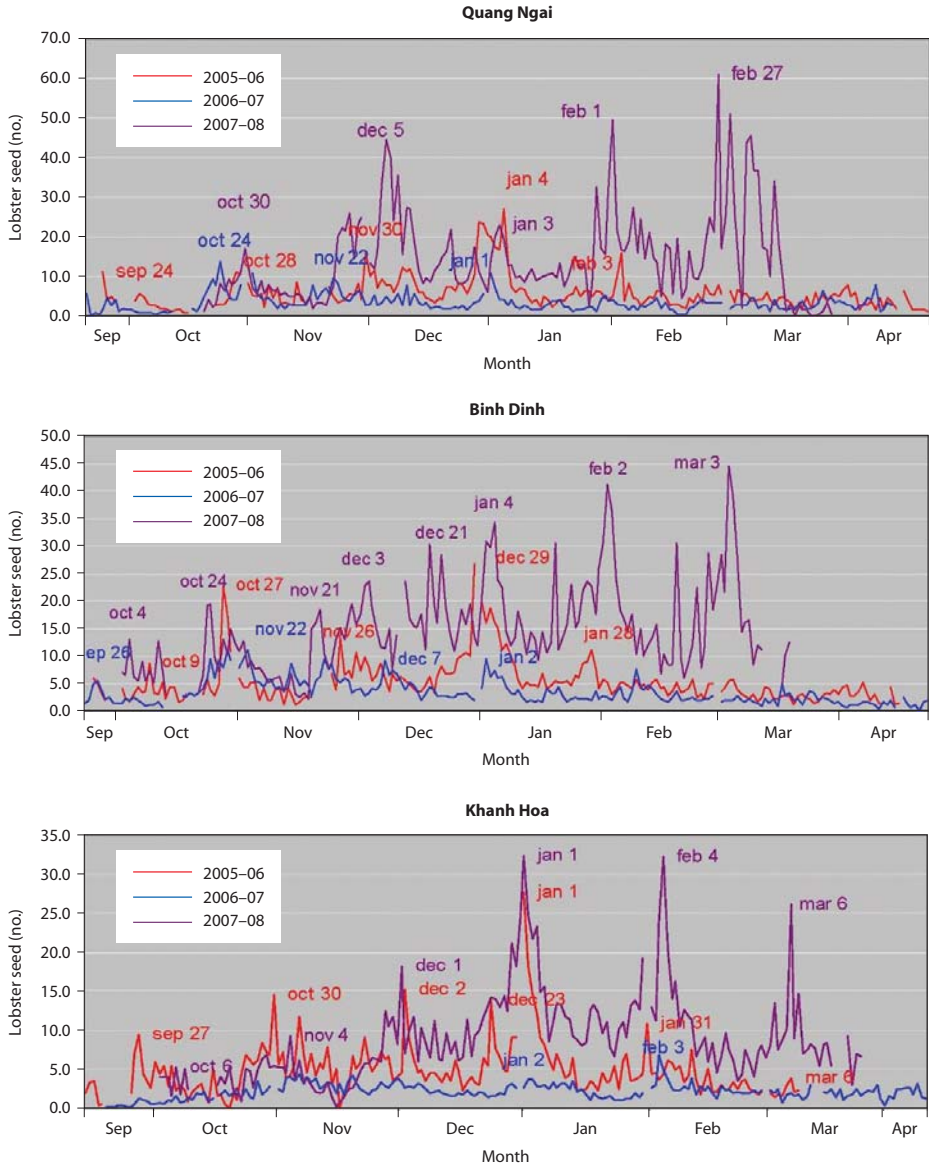
**Figure 4.** Average monthly catch per fishing boat of *Panulirus ornatus* in each season of the lobster seed census, 2005–2008

## Recommendations

An annual census of lobster seed catch should continue so as to provide long-term data on spatial and temporal variations in lobster seed catch at regional and provincial scales. Moreover, information on lobster species other than *P. ornatus* and *P. homarus* should also be obtained as this would

give a better picture about the overall settlement of lobster seed along the Vietnamese coastline. Identifying the spatial distribution of pueruli will help to structure and sustain the industry.

There is a need to examine the genetic make-up of the lobster seed settling in coastal waters of Vietnam to determine if they come from a single or multiple genetic populations. This may help to pinpoint the



**Figure 5.** Daily catch per boat of lobster seed of *Panulirus ornatus* in three provinces of south-central Vietnam, 2005 to 2008

most likely location of the spawning populations that supply the lobster seed being caught in Vietnamese waters. Surveys will then be needed to assess the status of these lobster populations, followed by recommendations on how best to manage this resource to ensure all stakeholders—fishers of wild lobsters and lobster aquaculture farmers in Vietnam—have their needs met without over-exploiting the resource. The sustainability of the lobster aquaculture industry will depend on locating and protecting the adult populations that supply the seed to Vietnam while at the same time ensuring that the capture of seed for aquaculture grow-out does not adversely impact on natural recruitment processes.

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# Improving environmental quality for *Panulirus ornatus* lobster aquaculture in Van Phong Bay, Vietnam, by combined culture with *Perna viridis* mussels

Le Thi Vinh and Le Lan Huong<sup>1</sup>

## Abstract

The most marked environmental effect of lobster cage aquaculture is the output of suspended solids, dissolved nutrients, organic matter and bacteria, and together these are thought to be responsible for deterioration in coastal water quality in Van Phong Bay. To combat this problem, a co-culture system using *Perna viridis* (green mussel) with *Panulirus ornatus* (ornate spiny lobster) was investigated to determine the effectiveness of this practice in Van Phong Bay. From March 2006 to August 2007, lobsters at two sites (1 and 3) were reared without mussel co-culture, while at two other sites (2 and 4) mussels were suspended on lines surrounding the lobster cages. Only trash fish was fed to the lobsters at sites 1 and 2 while at sites 3 and 4, half the lobsters were fed only trash fish with the other half fed trash fish and fresh mussel. Water and sediment samples were collected throughout the experiment. Water samples were analysed for dissolved oxygen (DO), total suspended solids (TSS), biological oxygen demand (BOD), nutrients and bacteria. Sediment samples were analysed for organic matter (nitrogen and phosphorus) and bacteria. Additionally, heavy metals, pathogenic bacteria and phycotoxins in lobster and mussel tissues were analysed for human health safety purposes.

Environmental parameters investigated in the water column and sediment did not differ significantly ( $P > 0.05$ ) between lobster cages with or without mussel co-culture. However, TSS was always lower at sites with mussel co-culture. The water quality inside cages where lobsters were fed with mussels was better, as judged by DO, BOD and TSS, than where lobsters were fed only with trash fish. There were no significant differences in heavy metal concentrations in lobsters fed either fresh fish or mussel. The results indicate that mussel co-culture improves water quality and also provides a source of feed for the lobsters. Further, feeding lobsters with mussels did not pose a human health hazard from heavy metals or phycotoxins.

**Keywords:** *Panulirus*; *Perna*; water quality; sediment; bacteria; heavy metal

## Introduction

Marine lobsters are one of the world's most valuable seafood with high market appeal in Asia, Europe and America. Most capture lobster fisheries are either

over-exploited and in decline or are being managed for their maximum sustainable yield. Aquaculture appears to be the only long-term way to meet the insatiable market demand for lobster. In Vietnam, culture of captured wild spiny lobster seed is an important aquaculture industry in the central coastal provinces, especially Khanh Hoa. In this province, culture first began in the early 1990s with lobsters being held in 100 staked net sea cages in the shallow

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waters of Van Phong Bay (Van Ninh district). Since that time, the industry expanded to more than 5,000 lobster cages in this district in 2003. Lobsters are fed exclusively on wet fishery by-catch, which is not fresh due to long transportation time. According to culturists, more than 20 kg of trash fish has to be fed to rear a 1 kg market-size lobster.

Along with other aquaculture, this expansion of lobster culture has led to deterioration in water quality because of lobster faeces, urinary waste and uneaten feed. Deposition of waste material from intensive lobster cages results in organic accumulation and bacteria in sediment causing increased sediment oxygen consumption. In some cases, this has led to anoxic bottoms, with increased risk of generating comprehensive negative ecological changes (species shift, ecosystem functional changes etc.). In addition, lobster aquaculture is one of the factors contributing over-exploitation of the local fishery to provide by-catch for lobster feed.

*Perna viridis*, the green mussel, is a filter feeder and can process large volumes of sea water (Bryan 1984). Mohlenberge and Riisgard (1978) indicated that *Mytilus edulis* (blue mussel) can filter 60 L/day. Bui (2006) found that *P. viridis* can filter twice as much water as *M. edulis* (Hawkins et al. 1996, 1998). Hence, mussels could be used to replace some of the fishery by-catch fed to lobsters and thus reduce contamination from trash fish. Therefore, a co-culture system of *P. viridis* with the *Panulirus ornatus* lobster could be a cost-effective way to improve the environmental quality of the adjacent area and, ultimately, provide a fresh food source for the lobsters in Van Phong Bay.

One potential problem with this plan is the possibility of contaminating lobsters by using mussels as feed. As mussels are filter feeders, they will accumulate potentially toxic pollutants if these are present in the mussels' environment (Bryan 1984; Rainbow 1990). Contaminants such as heavy metals may be transferred to lobsters, and thus could affect human health when consumed. Ailments related to metal contamination include neurotoxicity and kidney damage while some may be carcinogenic and their effects may become apparent only after long exposure (Nebel and Wright 1996; Crosby 1998).

As there were no quantitative data on the success or human health concerns of lobster and mussel co-culture, we began an investigation of the impact of mussel co-culture on environmental quality in Van Phong Bay.

## Materials and methods

### Experimental design

A comparative pilot study was carried out from March 2006 to August 2007 at four sites in Van Phong Bay near Xuan Tu village, Khanh Hoa province, Vietnam. The distance between the sites was about 1.0 km. Two sites were selected close to the shore (sites 1 and 4) while another two sites were selected as offshore sites (sites 2 and 3). At two sites (1 and 3), *P. ornatus* lobsters were reared without mussel co-culture, while at two other sites (2 and 4), spat of *P. viridis* from Nha Phu Lagoon were settled on rope lines and suspended around the lobster cages. Only trash fish was fed to the lobsters at sites 1 and 2, while at sites 3 and 4, half the lobsters were fed trash fish only with the other half were fed with fresh mussels only. Lobster cage sites are shown in Figure 1.

*Panulirus ornatus* seed were sourced from the wild and reared in cages by fishers until they reached a carapace length of  $11.9 \pm 0.60$  mm. Seed were then transported to Xuan Tu for the experiment. At each site, lobsters were reared in 3 m × 3 m × 6 m sea cages. Culture density was 120 individuals/cage initially but reduced to 60/cage after 3 months until harvest at 18 months. At sites 2 and 4, 200 mussel strings were hung around the farm; the initial weight of each mussel string was 2 kg (~130 individuals/kg).

### Sample collection

Samples were collected from May 2006 to August 2007 when lobsters had been cultured for about 3 to 18 months (before harvest).

#### *Water and sediment samples*

Water and sediment samples were collected in May 2006 and October 2006. At each site, samples were collected at the two opposite corners surrounding each site. When lobsters reached maturity (about 800 g), samples were collected monthly from April to August 2007 at one corner of each site. Water samples were collected using a plastic bathometer and were designated 'surface' (about 20 cm below the surface) or 'bottom' (about 0.5 m above the sea bottom), while sediment samples (5 cm of uppermost layer) were collected by grab. Water and sediment samples were also collected from inside the cages at sites 3 and 4 by diving in August 2007. The water samples were

stored in plastic bottles and kept cold during transport to the laboratory for analysis; sediment samples were placed in plastic bags, kept cold during transport and stored at  $-20^{\circ}\text{C}$  in the laboratory before analysis.

#### Mussel and lobster samples

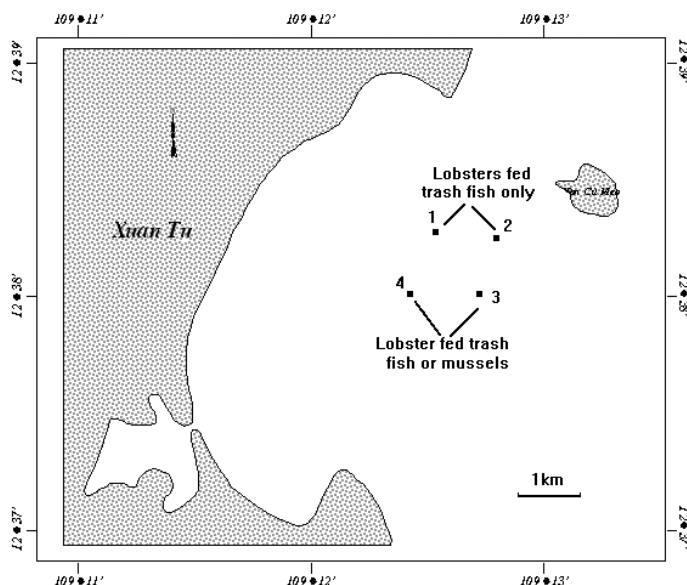
Samples of *P. viridis* and *P. ornatus* were collected in October 2006, April 2007 and August 2007 when lobsters had been cultured for 8, 14 and 18 months, respectively. Mussels and lobsters were cleaned and placed in clean plastic bags, kept cold in the field and then stored at  $-20^{\circ}\text{C}$  in the laboratory before analysis.

#### Sample analysis

Water samples were analysed for pH, temperature and transparency measurements immediately at the cage site while other analyses (salinity, total suspended solids (TSS), particulate organic matter (POM), dissolved oxygen (DO), 5-day biochemical oxygen demand (BOD), ammonia ( $\text{NH}_{3,4}$ ), nitrite ( $\text{NO}_2$ ), nitrate ( $\text{NO}_3$ ), phosphate ( $\text{PO}_4$ ), silicate ( $\text{SiO}_3$ ) and chlorophyll *a*) were done at the Institute of Oceanography's (Nha Trang) laboratory. Standard methods (Cropp and Garland 1988; APHA

1995) were used to identify and count the number of indicator bacteria, with samples for faecal coliform (FC; *Escherichia coli*), *Staphylococcus aureus* and *Vibrio* cultured on the same day of collection and colonies counted after 24 hours for FC and *S. aureus* and after 48 hours for *Vibrio*. Sediment samples were analysed for organic carbon, organic nitrogen and total phosphorus and pelite fraction (grain size  $<0.063\text{ mm}$ ).

Lobster (muscle) and mussel (gut and body) tissue samples were analysed for heavy metals—mercury (Hg), arsenic (As), lead (Pb), copper (Cu), zinc (Zn), cadmium (Cd) and chromium (Cr)—using atomic absorption spectrophotometry. Phycotoxins were analysed using indirect two-step enzyme-linked immunosorbent assay (ELISA) for amnesic shellfish poison (ASP) and paralytic shellfish poison (PSP) toxins and ELISA protein phosphatase 2A (PP2A) for diarrhoeic shellfish poison (DSP) toxin. Pathogenic bacteria were also cultured by inoculation and culture on selective media plates. Overall, water, sediment and biological samples were preserved, digested, and analysed following the procedures of FAO (1975), CNEXO (1983), Parsons et al. (1984), Cropp and Garland (1988) and APHA (1995).



**Figure 1.** Lobster culture sites at Van Phong Bay (Xuan Tu village), Khanh Hoa province, Vietnam

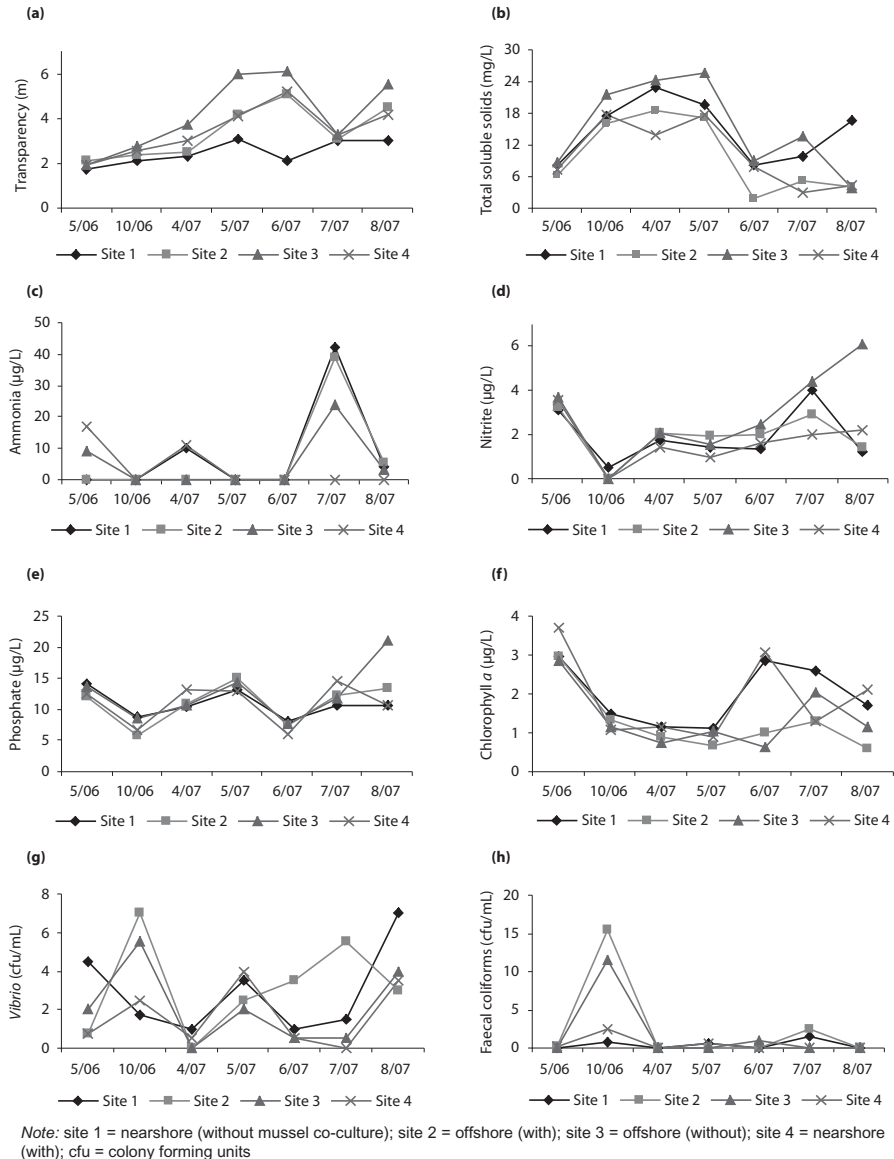
## Results and discussion

### Water

#### *Outside the cages*

Results of the surveys are summarised in Table 1 and Figure 2. Salinity and pH measurements did not

show significant differences between sites even though the water depth at the sites varied from about 5 m at site 1 to 9 m at site 3. The lowest transparency (Figure 2a) and highest temperature (site-specific data not shown) were always observed at site 1. Water temperature at the surface was always slightly higher than at the bottom, while salinity and pH



**Figure 2.** Selected measurements of water quality and bacterial loading in water samples at the four culture sites from May 2006 to August 2007

**Table 1.** Summary of water sample data collected from the four experimental sites at Van Phong Bay during the study period

Attribute	May 2006						October 2006						April–August 2007 (dry season) <sup>a</sup>					
	Surface			Bottom			Surface			Bottom			Surface			Bottom		
	Av	Min	Max	Av	Min	Max	Av	Min	Max	Av	Min	Max	Av	Min	Max	Av	Min	Max
pH	8.03	7.85	8.20	8.13	8.02	8.20	8.09	8.05	8.12	8.12	8.16	7.97	7.84	8.08	8.00	7.86	8.12	8.12
Temp (°C)	30.7	30.2	30.9	30.4	30.3	30.7	29.4	29.3	29.6	29.3	29.5	29.8	25.0	31.9	29.3	24.9	31.6	31.6
Trans (m)	1.9	1.7	2.2	—	—	—	2.4	2.0	2.8	—	—	3.9	6.1	2.1	—	—	—	—
Salinity (ppt)	32	31	33	33	32	33	32	31	32	33	33	34	34	33	34	34	33	33
TSS (mg/L)	5.43	3.73	8.94	9.99	6.31	13.6	15.2	10.2	16.7	21.1	27.7	10.8	26.6	1.1	14.4	34.3	2.30	2.30
POM (mg/L)	1.78	1.08	2.35	2.40	0.97	4.00	5.48	2.70	8.30	6.99	8.00	3.41	9.20	0.57	3.93	8.97	1.03	1.03
POM (%)	33.9	24.1	41.0	25.5	8.8	38.7	35.4	26.3	52.5	34.2	47.4	368	67.7	15.5	32.3	70.2	10.1	10.1
DO (mg/L)	6.04	5.71	6.46	5.60	5.05	5.94	6.74	6.44	6.92	6.87	7.12	6.00	5.20	6.60	6.05	5.33	6.48	6.48
BOD (mg/L)	1.67	1.48	2.20	2.69	1.41	4.43	0.91	0.62	1.15	0.90	1.28	0.98	0.35	2.06	1.01	0.40	1.64	1.64
NH <sub>3,4</sub> (µg/L)	4.5	0	36	8.4	0	67	0	0	0	0	0	8.5	0	55	5.4	0	30	30
NO <sub>2</sub> (µg/L)	2.8	2.5	4.0	4.0	3.0	4.8	0.3	0	0	0	0	1.4	0.4	4.0	2.9	1.1	11.3	11.3
NO <sub>3</sub> (µg/L)	44	37	51	46	37	53	49	39	52	49	45	42	31	48	42	38	49	49
PO <sub>4</sub> (µg/L)	11.2	9.7	13.4	15.1	12.5	17.8	6.6	4.1	11.3	8.3	4.4	10.8	4.7	19.7	12.7	6.9	22.5	22.5
SiO <sub>3</sub> (µg/L)	169	120	194	145	100	180	210	155	197	157	114	233	100	411	181	84	272	272
Chlor <i>a</i> (µg/L) <sup>b</sup>	1.88	1.40	2.30	4.36	2.70	6.20	1.05	0.71	1.92	1.47	1.92	1.19	0.57	3.27	1.42	0.27	4.13	4.13
<i>Vibrio</i> (cfu/mL)	1	0	3	3	0	16	3	0	11	6	1	1	0	6	3	0	13	13
FCs (cfu/mL)	0	0	1	0	0	1	2	0	34	13	34	0	0	4	0	0	3	3

<sup>a</sup> Water samples were collected monthly from April to August 2007

*Note:* Av = average; Min = minimum; Max = maximum; Temp = temperature; Trans = transparency depth; ppt = parts per thousand; TSS = total suspended solids; POM = particulate organic matter; DO = dissolved oxygen; BOD = 5-day biochemical oxygen demand; NH<sub>3,4</sub> = ammonia; NO<sub>2</sub> = nitrite; NO<sub>3</sub> = nitrate; PO<sub>4</sub> = phosphate; SiO<sub>3</sub> = silicate; Chlor *a* = chlorophyll *a*; cfu = colony forming units; FCs = faecal coliforms



were generally higher at the bottom (Table 1). In general, environmental conditions were more variable with sampling time rather than between sites but some site effects were observed. DO values were relatively high and similar at each site but were highest in October 2006 (Table 1). BOD values fluctuated considerably—being high in May 2006, low in October 2006 (Table 1), slowly rising to June 2007 (data not shown) and decreasing to the lowest values in August 2007.

TSS values increased significantly from May 2006 to May 2007 but then fell dramatically to low values by June 2007; site 1 and site 3 values tended to be higher than other sites at most sampling times (Figure 2b). Calculating POM as a percentage of TSS showed that POM was highest in the June 2007 sampling but values did not change significantly between sites (site-specific data not shown). Ammonia was low or below detectable levels in most sampling periods, except for July 2007 when high values were observed, especially at sites 1 and 2 (Figure 2c). Nitrite concentrations were low, especially in October 2006 (Table 1; Figure 2d). Nitrate concentrations were intermediate (Table 1) and values did not differ much between sites or between samplings. Phosphate concentrations were relatively high, especially in August 2007 at site 3 (Figure 2e), while silicate concentrations were moderate (Table 1) and showed little effect of sampling site (data not shown) or time. Chlorophyll *a* values were also relatively high, especially in May 2006 at all sites and again for sites 1 and 4 in June 2007 (Figure 2f). *Vibrio* was found in almost all samples but at low counts; the highest were in October 2006, May 2007 and August 2007 (Figure 2g). FCs were seldom observed in samples except for high counts at sites 2 and 3 in October 2006 (Figure 2h).

In general, the differences between the surface and bottom samples were not large. Surprisingly, silicate values were always higher in water samples taken from the surface than at the bottom while TSS, chlorophyll *a*, phosphate and *Vibrio* were always lower for the surface samples (Table 1). Ammonia, nitrite and FCs were more variable, but often more concentrated in the bottom water sample. The values for nitrate, DO, BOD and POM were similar for the surface and bottom water samples.

Lobster cage wastes, comprising uneaten food and excrement, can adversely affect water quality with enhanced concentrations of ammonia, BOD,

TSS, bacteria, lowered DO etc. However, among the environmental measurements examined, only TSS consistently showed that values at the various sites depended on whether or not mussels were being co-cultured. Values were always highest at sites without mussels compared to its paired site with mussels. For the two nearshore sites, the values at site 4 (with mussel) were lower than for site 1 (without mussel). A similar trend was observed for the offshore pair; values at site 3 (without mussel) were higher than at site 2 (with mussel) (Figure 2b). This may mean that waste materials from lobster cages are being broken down into finer particles that filter feeders are able to ingest. Further evidence of the ability of mussels to capture these wastes is that their growth at these sites was very rapid. Despite the fact that no significant differences were found in other environmental measurements (BOD, DO etc.) in the water column between cage sites, with or without mussel co-culture, the TSS data suggest that co-culture is a useful technique for reducing environmental contamination.

From the experiment, there was evidence that mussels removed suspended solids but there was no evidence that mussels were successful in reducing levels of organic pollutants. Possible reasons why mussels at sites 2 and 4 may not have improved the environmental quality of the water adjacent to the cages include the following:

- Comparatively few lines of mussels were used such that not enough of the water could be filtered by the mussels.
- Environmental quality of the water at the cage sites was also impacted by waste from other aquaculture practices in Van Phong Bay (about 6,000 lobster cages in 2005, culture of sweet snail and grouper etc.).
- Current flow at the mussel sites exceeded the capacity of the mussels to effectively filter the water. At low flow rates, water will be more effectively filtered, thus increasing the efficiency of waste material removal. Water exchange in Van Phong Bay is relatively high with an average current velocity of 17.7 cm/s and 9.8 cm/s in winter monsoon and summer monsoon periods, respectively (Vinh et al. 2004). These flow rates ensure that debris is strongly moved through the area.
- The final numbers of lobsters cultured at the four sites were not the same because of higher lobster mortalities at nearshore sites and sites where

mussels were not fed to the lobsters. These differences in lobster mortality may have confounded the environmental results since they would have impacted on the amounts of organic matter and nutrients entering the water from food and wastes.

- Bacteria present in the water may have been affected by the sanitary behaviour of people living nearby—none of the lobster farms in Van Phong Bay had proper toilets and human excrement was deposited directly into the water.

For mussel co-culture to be an effective way of improving water quality, a community-wide adoption of this practice may be needed. This requires an effective policy to educate fishers toward understanding the advantages of co-culture. Furthermore, large differences in environmental quality of the water were observed between sampling times. For example, in May 2006—at the beginning of the dry season when lobsters were juveniles and the amount of uneaten food and excrement would have been low compared to harvest-size lobsters in June to August 2007—BOD and chlorophyll *a* values were unexpectedly high (Table 1). Bacterial FC loads in the water were highest in October 2006 (Figure 2f) when rain runoff into the bay was high, while TSS values were comparatively low during the dry season, June to August 2007. Thus, natural events such as periods of high rain or storms may have a greater effect on environmental quality of the water in Van Phong Bay than whether or not lobsters are co-cultured with mussels. Table 2 shows data on the environmental quality of water in Van Phong Bay taken at similar cage sites in 2004 but before mussel co-culture had begun. Differences in the data between 2004 and 2006–07 were not great and support the view that mussel co-culture had only a limited effect on water quality in the bay. In companion work at the same sites on lobster productivity, Huu and Sang (2007) found lobsters grew more slowly at site 1

than at other sites. It was suspected that this was due to the shallowness of the water at this site which may have affected its quality.

Samples for water quality assessment were taken from inside and outside the cages and evaluated against criteria set out in the Vietnamese Fishery Standard (MOSTE 1995) for DO ( $\geq 5$  mg/L), BOD (10 mg/L), TSS (50 mg/L), FC and *Vibrio* (each 10 cfu/mL) and Association of Southeast Asian Nations (ASEAN) criteria for nitrate (60  $\mu\text{g/L}$ ), phosphate (15  $\mu\text{g/L}$ ), ammonia (70  $\mu\text{g/L}$ ) and nitrite (55  $\mu\text{g/L}$ ). Based on the above standards, DO, TSS, BOD and nitrate values were all within acceptable levels while phosphate concentrations and FC and *Vibrio* counts were several times higher than acceptable values but the pollution coefficients were not high. Thus, the water during the study period could be considered to be not overly polluted.

#### *Inside the cages*

Water samples were collected from only inside the cages when lobsters were fed mussels or trash fish in August 2007. The data indicated that water quality inside cages where lobsters were fed mussels was noticeably better than from cages in which lobsters were fed trash fish (Figure 3). Higher DO and lower BOD (Figure 3a), TSS, chlorophyll *a* (Figure 3b), nitrate and phosphate (Figure 3c) were observed in cages where lobsters were fed mussels, especially at site 4. Although *Vibrio* counts were moderately high in cages at site 1 and also in cages fed mussels at site 4, FCs were not detected in the water at any of the sites (Figure 3d). Although differences were not large, the consistency of the chemistry and bacterial trends imply that the water quality was better in cages where lobsters were fed mussels.

A possible factor affecting water quality inside cages was whether or not trash fish was used as feed for the lobsters. The trash fish was mostly caught at Binh Thuan (nearly 200 km from Van Phong Bay)

**Table 2.** Mean values for some water quality characteristics in Van Phong Bay in 2004 (Thom 2004)

Date	Salinity (ppt)	TSS (mg/L)	NH <sub>3,4</sub> ( $\mu\text{g/L}$ )	NO <sub>2</sub> ( $\mu\text{g/L}$ )	NO <sub>3</sub> ( $\mu\text{g/L}$ )	PO <sub>4</sub> ( $\mu\text{g/L}$ )	SiO <sub>3</sub> ( $\mu\text{g/L}$ )	Chlor <i>a</i> ( $\mu\text{g/L}$ )	<i>Vibrio</i> (cfu/mL)	FCs
May	30.5	14.8	0	0.6	38	5.5	182	0.90	8	39
Oct	29.8	18.1	0	0.3	44	11.4	264	1.1	1	3

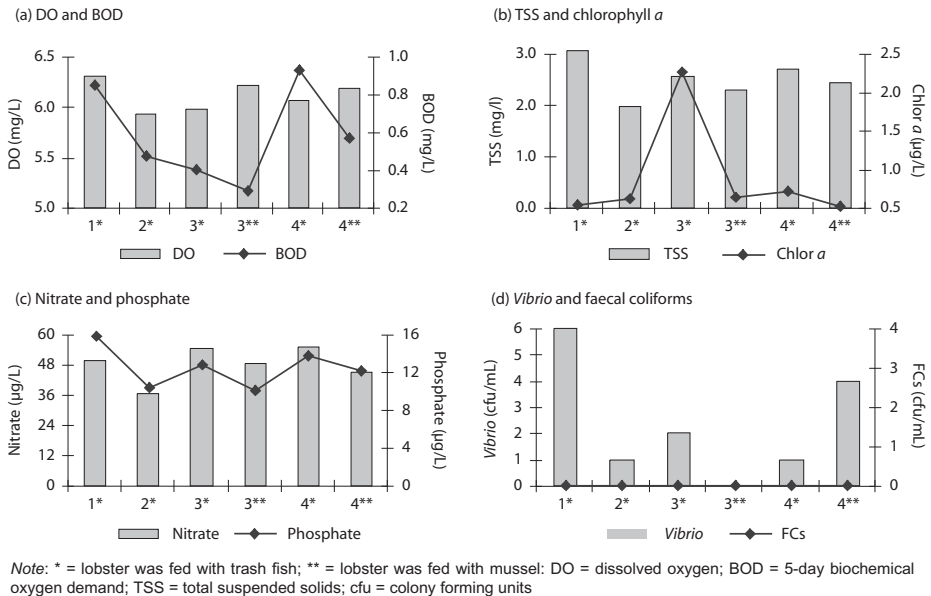
Note: ppt = parts per thousand; TSS = total suspended solids; NH<sub>3,4</sub> = ammonia; NO<sub>2</sub> = nitrite; NO<sub>3</sub> = nitrate; PO<sub>4</sub> = phosphate; SiO<sub>3</sub> = silicate; Chlor *a* = chlorophyll *a*; cfu = colony forming units; FCs = faecal coliforms

and it took more than a day to transport it to the culture site. During this transport, fish quality would have been reduced due to bacterial decay and this would have increased the resultant BOD and TSS levels in the water when fed-out. In contrast, in cages where mussels were fed as fresh food, bacterial spoilage would have been almost non-existent and the amount of uneaten food would have been minimal. The lower values for nitrate and phosphate in samples from cages where mussels were fed clearly support the above conclusion.

## Sediment

### At lobster cage sites

The collected sediments were mainly sand and sandy mud. Thus, organic matter content was not very high (Table 3). Differences between sites are illustrated in Figure 4. Pelite fraction (%) and organic matter content were often lowest at sites 1 and 4 during the study period (Figures 4a and 4b, respectively). Site 1, being nearest to shore with a depth of about 5 m, was most vulnerable to wave action which



**Figure 3.** Selected measurements of water quality inside cages in August 2007

**Table 3.** Mean values of organic matter and bacteria in sediment samples collected from the experimental sites during the study period

Date		Pelite fraction (%)	Organic carbon (%)	Organic nitrogen (µg/g)	Total phosphorus (µg/g)	<i>Vibrio</i> (cfu/g)	Faecal coliforms (cfu/g)
May 2006	Average	30.5	0.32	777	567	3.5	1.2
	Min	10.9	0.15	297	138	0	0
	Max	57.4	0.49	1,027	855	10	5
Oct 2006	Average	33.1	0.36	486	301	19.3	26.4
	Min	14.4	0.27	146	58	0	0
	Max	54.9	0.45	654	491	52	98
Dry season 2007 <sup>a</sup>	Average	33.1	0.36	525	326	30.3	9.3
	Min	6.6	0.12	232	116	1	0
	Max	69.7	0.56	988	657	137	110

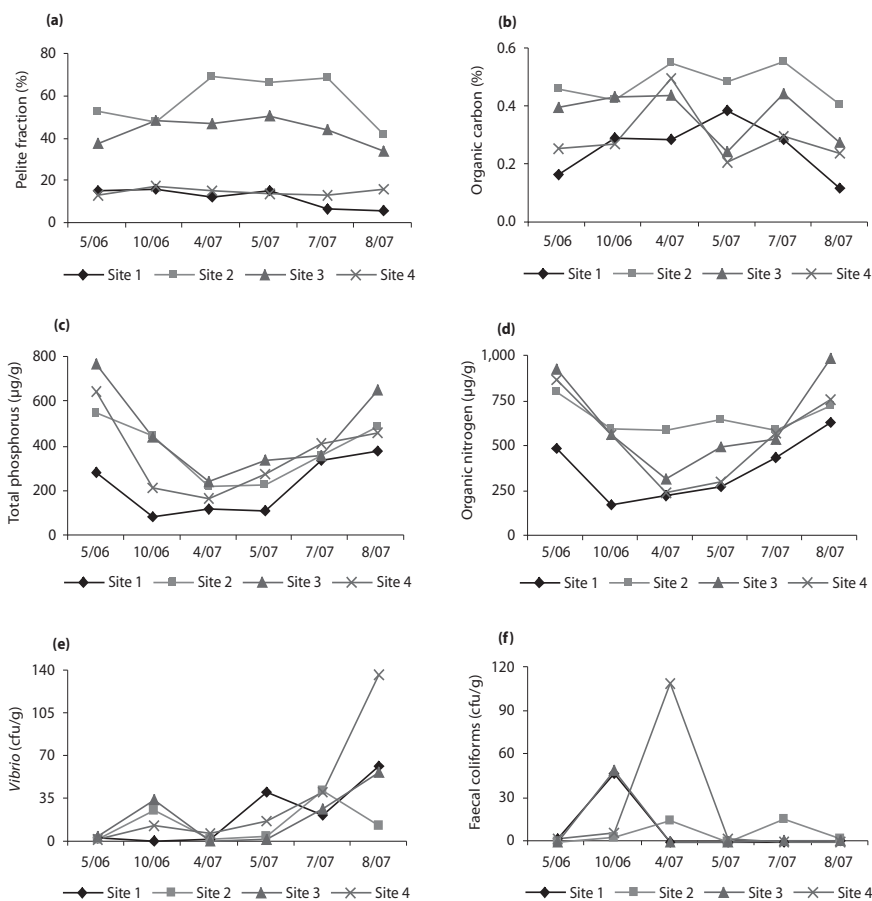
<sup>a</sup> Samples were collected in April, May, July and August 2007

Note: cfu = colony forming units

would assist organic matter present as fine particles in sediment and water being moved further offshore. In general, sediment concentrations of the investigated characteristics did not show significant differences between sites or sampling time. However, some seasonal trends were observed: concentrations of organic phosphorus and nitrogen in samples collected from October 2006 to July 2007 were lower than those collected in May 2006 and August 2007 (Figures 4c and 4d, respectively). Overall, sediment concentrations of organic material were not high, indicating that wastes from lobster culture were being transported away from the cages rather than being deposited as sediment under the cages. The

comparatively high water exchange rate in Van Phong Bay may explain why bottom sediments were not heavily impacted by cage culture.

One factor that affects organic matter concentrations in the sediment is grain size distribution: fine fractions (higher pelite fraction) have higher adsorption capacity than coarser fractions. The pelite fraction at site 1 (no mussel co-culture) was low compared to site 4 (mussel co-culture) and that at site 3 (no mussel co-culture) was low compared to site 2 (mussel co-culture). As a result, sediment at site 1 was generally low in organic matter compared to site 4 and, similarly, it was low at site 3 compared to site 2. According to Thom (2004), sediment



Note: site 1 = nearshore (without mussel co-culture); site 2 = offshore (with); site 3 = offshore (without); site 4 = nearshore (with); FCs = faecal coliforms; cfu = colony forming units

**Figure 4.** Selected measurements of the environmental condition and bacterial presence in sediment samples from May 2006 to August 2007

particles can be re-suspended and this could make it difficult to determine if mussel co-culture had positive benefits on the nature of the sediment under the cage.

Measurements of FC and *Vibrio* counts in the sediment (Figures 4e and 4f, respectively) did not show any significant site effects or differences between sites with or without mussel co-culture. However, bacterial counts were considerably higher at site 4 (mussel co-culture) than at other sites, especially in the 2007 samplings. This may be more a reflection of the sanitary behaviour of people around this site rather than an inability of the mussels to ‘clean-up’ the water.

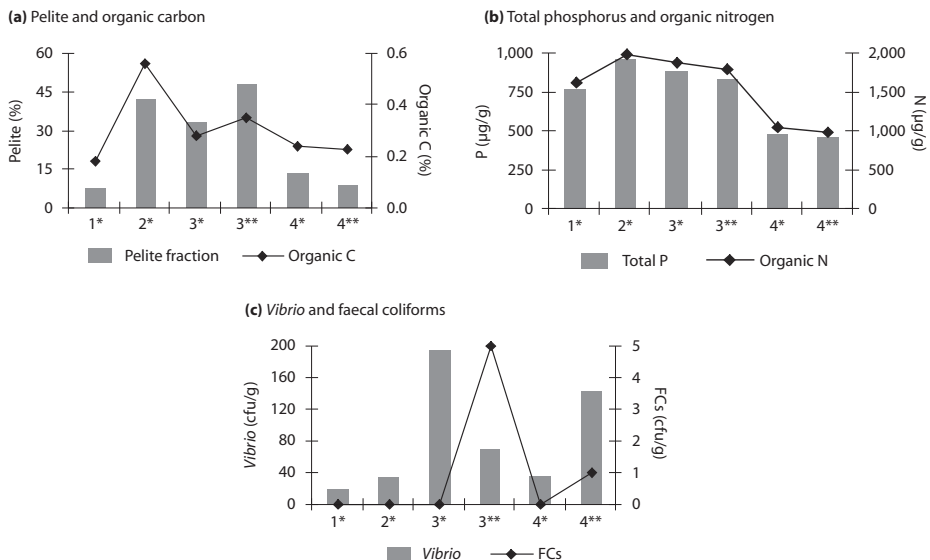
#### Directly under lobster cages

Sediment samples were collected under cages in only August 2007. The primary data (Figure 5) indicated that there were no significant differences between cage sites for the environmental markers examined. Factors that would influence sediment quality under cages are: (i) rates of deposition such as the settling rates of feed, the biomass of lobster under culture, the settling rate of faeces and the amount of excess (uneaten) feed; and (ii) hydrodynamic effects such as current speeds, local bathymetry, wave

conditions at the site, the rate of decay of organic particles on the bottom, and re-suspension of organic particles by currents and waves. As already noted, current speeds and re-suspension of organic particles in Van Phong Bay are relatively good and this is the most plausible reason why sediment quality under the lobster cages was not affected by particulate wastes from the lobster cages.

#### Seafood safety

Heavy metals (Zn, Cu, Pb, As, Hg, Cd and Cr) are cumulative poisons and their effects in humans may become apparent only after a long exposure time (Clark 1997). One of objectives of this study was to see if mussels, and lobsters fed on these mussels, accumulated heavy metals at levels deemed to pose a human health risk. The heavy metal concentrations in *P. viridis* and *P. ornatus* samples collected during the experiment were low and below the maximum permissible levels for seafood safety in Vietnam and Hong Kong (Table 4). Although by August 2007 the concentration of heavy metals in lobsters fed mussels was consistently higher than those fed trash fish, these differences were very minor. Concentrations of heavy metals in the mussels were often slightly higher than for lobsters but still far below



Note: \* = lobster was fed with trash fish; \*\* = lobster was fed with mussel; cfu = colony forming units

**Figure 5.** Selected measurements of the environmental condition and bacteria present in sediment under cages, August 2007

the maximum permissible levels for human consumption. Based on these findings, lobsters fed on mussels do not pose a heavy metal health hazard for consumers.

Analysis of the mussels and lobsters for pathogenic bacteria (*Vibrio*, FCs and *S. aureus*) and phycotoxins (ASP, PSP and DSP) is detailed in Table 5. Other than for the August 2007 sampling where low counts of *Vibrio* and *S. aureus* were observed in lobster tissue, all other samples of lobster tissue were negative for pathogenic bacteria whereas mussel samples were frequently found to contain pathogenic bacteria, mostly *Vibrio* and

occasionally *E. coli* (non-FC) and *S. aureus*. There was a very high count of *S. aureus* (19,517 cfu/g wet weight) in mussels sampled in April 2007. Phycotoxins, particularly ASP, were frequently found at low concentrations (<1 µg/g wet weight) in mussel samples and occasionally in lobsters fed on mussel. The levels of phycotoxins found in the mussel and lobster samples were typical for any algal-feeding marine organism. From these results, it can be concluded that the lobsters and mussels contained no significant contamination of algal toxins.

An earlier study by Huong (2006) examined the heavy metal and phycotoxin concentrations and

**Table 4.** Heavy metals in mussels and lobsters (µg/g wet weight) at the experimental sites during the study period

Time	Sample	Zn	Cu	Pb	As	Hg	Cr	Cd
May 2006	Mussel	14.0	2.2	0.24	0.24	0.07	0.91	0.06
Oct 2006	Mussel	19.4	1.0	0.07	0.20	0.03	0.39	0.13
	Lobster fed on mussel	23.8	0.8	0.04	0.17	0.02	0.38	0.04
	Lobster fed on trash fish	20.5	0.6	0.03	0.21	0.03	0.60	0.08
April 2007	Mussel	17.0	1.0	0.13	0.57	0.04	0.54	0.11
	Lobster fed on mussel	24.4	1.3	0.01	0.45	0.03	0.37	0.01
	Lobster fed on trash fish	18.1	1.1	0.01	0.43	0.03	0.50	0.02
Aug 2007	Mussel	16.2	2.1	0.08	0.42	0.04	0.25	0.09
	Lobster fed on mussel	12.0	1.4	0.12	0.48	0.04	0.12	0.01
	Lobster fed on trash fish	9.6	1.2	0.08	0.30	0.03	0.08	0.01
Maximum allowable value <sup>a</sup>		100	30	2	1	0.5	1	1

<sup>a</sup> Ministry of Public Health, Vietnam and Ministry of Public Health, Hong Kong for Cr

Note: Zn = zinc; Cu = copper; Pb = lead; As = arsenic; Hg = mercury; Cr = chromium; Cd = cadmium

**Table 5.** Bacteria and phycotoxins in *Perna viridis* mussels and *Panulirus ornatus* lobsters

Time	Sample	Pathogenic bacteria (cfu/g wet weight)				Phycotoxins (µg/g wet weight)		
		<i>Vibrio</i>	FCs	<i>S. aureus</i>	<i>E. coli</i> <sup>a</sup>	ASP	PSP	DSP
May 2006	Mussel	3	5	62	1	0.44	0.28	0.17
Oct 2006	Mussel	142	nd	nd	nd	0.53	0.27	0.22
	Lobster fed on mussel	nd	nd	nd	nd	0.70	0.13	0.40
	Lobster fed on trash fish	nd	nd	nd	nd	na	na	na
April 2007	Mussel	73	7	10	nd	na	na	na
	Lobster fed on mussel	nd	nd	nd	nd	na	na	na
	Lobster fed on trash fish	nd	nd	nd	nd	na	na	na
Aug 2007	Mussel	74	na	19,517	34	0.36	nd	nd
	Lobster fed on mussel	3	na	12	8	0.32	nd	nd
	Lobster fed on trash fish	nd	na	1	3	0.05	nd	nd
Maximum allowable value <sup>b</sup>				0	0			

<sup>a</sup> Non-FC *E. coli*

<sup>b</sup> Ministry of Public Health, Vietnam

Note: cfu = colony forming units; FCs = faecal coliforms; *S. aureus* = *Staphylococcus aureus*; *E. coli* = *Escherichia coli*; ASP = amnesic shellfish poisoning; PSP = paralytic shellfish poison; DSP = diarrhoeic shellfish poisoning; na = not analysed; nd = not detected

pathogenic bacterial presence in *P. viridis* mussels collected from Nha Phu Lagoon during dry and wet seasons (Table 6). Her data are similar to those determined in the present study and provide further evidence that feeding mussels to lobsters should not pose a human health concern.

## Conclusion and recommendations

Huu and Sang (2007) examined the feasibility and overall economics of combining lobster and mussel culture. They suggested that co-culture not only improved lobster growth and survival rates by about 10%, especially for lobsters fed on mussel, but feeding the lobsters on mussels reduced feed cost by approximately 20%.

In the typhoon season and at other times when storms limit the amount of fishing, it can be difficult for lobster farmers to get trash fish, while on-site cultured mussels provide a readily available source of food for lobsters. However, the culture of lobsters using a single type of food, such as mussels, is not a good idea since this practice may result in nutritional deficiencies and/or appetite depression. To avoid this problem, it is recommended that trash fish be fed to lobsters on one day of the week and mussels on all other days.

The results from this study on integrated *P. ornatus* – *P. viridis* culture in Van Phong Bay have shown that differences in water column and

sediment analyses between lobster cages with or without mussel co-culture were typically small and not significant. In contrast, large differences were seen between sampling times. Hence, environmental conditions are affected more by natural events, especially wet or dry seasons, rather than whether or not mussels are co-cultured at lobster cage sites.

However, TSS values were always lower at sites with mussel co-culture which suggests that mussel co-culture could have a positive benefit on adjacent water quality. In addition, co-culturing mussels with lobsters provides the lobster farmer with an available and valuable source of fresh food for the lobsters. Co-cultured mussels do not pose a human health hazard with respect to heavy metals, bacteria or phycotoxins. Moreover, greater use of co-cultured mussels for lobster feeding may help to reduce over-fishing while helping to improve the environmental conditions where lobsters are farmed. However, these benefits will arise only if the whole community adopts and applies this practice in Van Phong Bay as part of a coastal zone management plan.

## Acknowledgments

The authors would like to express gratitude to the Australian Centre for International Agricultural Research (ACIAR) for financial support and to Dr Kevin Williams from Commonwealth Scientific

**Table 6.** Average values of heavy metals, bacteria and phycotoxins in mussels (2004–2005) at Nha Phu (Huong 2006)

Sample type	Analysis	Dry season	Wet season
Heavy metals (µg/g wet weight)	Zn	16.06	15.72
	Cu	1.13	1.13
	Pb	0.25	0.08
	Cd	0.06	0.05
	As	0.13	0.17
	Hg	0.05	0.05
Bacteria (cfu/g wet weight)	Vibrio	25	148
	FCs	62	89
	<i>S. aureus</i>	132	158
	<i>E. coli</i> <sup>a</sup>	625	22
Phycotoxins (µg/100g wet weight)	ASP	2.58	1.57
	PSP	13.60	9.91
	DSP	0.04	0.02

<sup>a</sup> Non-FC *E. coli*

Note: Zn = zinc; Cu = copper; Pb = lead; Cd = cadmium; As = arsenic; Hg = mercury; cfu = colony forming units; FCs = faecal coliforms; *S. aureus* = *Staphylococcus aureus*; *E. coli* = *Escherichia coli*; ASP = amnesic shellfish poison; PSP = paralytic shellfish poison; DSP = diarrhoeic shellfish poison

and Industrial Research Organisation (CSIRO) Marine Research for great assistance.

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## Session 2: Improving lobster nursery culture

Photo: Nguyen Thi Bich Thuy, Research Institute for Aquaculture No. 3



Staff of the Research Institute for Aquaculture No. 3, Vietnam, loading polystyrene boxes containing seed lobsters into a van to examine the effect of transport conditions on lobster survival

# Effect of stocking density, holding and transport on subsequent growth and survival of recently caught *Panulirus ornatus* seed lobsters

Nguyen Thi Bich Ngoc, Nguyen Th Bich Thuy and Nguyen Ngoc Ha<sup>1</sup>

## Abstract

The spiny lobster (ornate spiny lobster) aquaculture industry relies on the capture from the wild of swimming pueruli or recently settled juveniles. Upon capture, these seed lobsters are held for 1–2 days in baskets suspended in on-land tanks and then transported for up to 12 hours before being placed into submerged nursery sea cages. There they remain for 30–60 days before being moved to staked or floating grow-out cages. Survival of the seed lobsters during the nursery phase is unpredictable, with losses typically of 40–60% but occasionally as high as 100%. However, lobsters that survive the nursery phase are easily on-grown at high survival rates to reach a desired market size of 1 kg within 18–22 months. Clearly, reducing the high lobster mortality that occurs during the nursery phase would have enormous benefit for the industry. This study, comprising a series of separate trials, examined the effect of immediate postcapture handling procedures on the growth and survival of the lobsters during a subsequent 30-day nursery phase.

The effects of immediate postcapture on-land holding conditions of stocking density (200 or 300 seed/m<sup>2</sup>), holding time (1 or 2 days) and transport duration (1, 6 or 12 hours) on survival of the seed lobsters, and their subsequent survival and growth during the following 30-day nursery culture period, were examined. During nursery culture, all lobsters were fed the same diet of mixed trash fish. Stocking density during on-land holding and transport had no effect on immediate lobster survival or on their growth and survival during the subsequent nursery period. However, survival rate, but not growth rate, was markedly reduced as transport duration increased from 1 to 6 or 12 hours and the effect of 12-hour transport was more severe for lobsters held in the on-land holding tanks for 2 days rather than 1 day. In a simulated 6-hour transport experiment, seed lobsters in styrofoam boxes were subjected to four alternative holding conditions: 1. static and normal air; 2. net shelter and normal air; 3. without shelter but normal air; and 4. no shelter and compressed air. In a subsequent experiment, transport time was extended to 12 hours and water was exchanged every 3 hours with seed lobsters transported either with or without net shelter and compressed air. In both of these experiments, survival rate after 30 days culture was very high (81–97%) and unaffected by treatment. These results suggest that the quality of the seed lobsters when caught rather than husbandry practices per se may be more important factors affecting their subsequent survival during culture.

**Keywords:** rock lobster; pueruli; transport conditions; nursery culture; postcapture

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## Introduction

Spiny lobsters are one of the world's most valuable seafood with high market appeal throughout Asia, America and particularly China, with current farm-gate prices of US\$40–45/kg. Hatchery propagation of spiny lobsters is presently not economically feasible but, in Vietnam, the on-growing of captured postlarval (seed) lobsters is a thriving village-based industry that produced 1,590 t of product worth about US\$90 million in 2005–06. Lobster seed that settle along the Vietnamese coast are heavily exploited and further exploitation may be unsustainable. The survival of seed lobsters during the critical first 30 days of nursery culture is unpredictable and variable: losses of 40–60% are typical but can be as high as 100%. Those that survive the nursery phase can be on-grown to the preferred market size of 1 kg after 18–22 months with losses of about 10% or less. If lobster losses during the nursery stage could be reduced to only 10%, Vietnam's total annual lobster production could be doubled without any more seed lobsters having to be caught.

After being caught by fishers, lobster seed are held for 1–2 days in baskets suspended in on-land tanks and then transported for up to 12 hours before being placed into submerged nursery sea cages. There they remain for 30–60 days before being moved to grow-out cages. The survival and subsequent growth of seed lobsters could be influenced by many husbandry factors such as on-land holding time and stocking density, transport conditions and duration, nursery culture practices, disease etc. The aim of this study was to see if holding time, stocking density, transportation duration and conditions before nursery culture affected survival and subsequent nursery phase growth of captured seed lobsters.

## Material and methods

### Experimental design

Four experiments with seed *Panulirus ornatus* lobsters were carried out. Each experiment used immediately caught seed lobsters which were of a mean ( $\pm$  standard deviation; SD) size of  $0.3 \pm 0.02$  g and carapace length (CL) of  $7.05 \pm 0.26$  mm.

#### Experiment 1

Experiment 1 examined the effect of holding time and stocking density of newly caught seed lobsters

using a two-factor randomised design. The seed were stocked at two densities (200 or 300 individuals/m<sup>2</sup>) into tubs of aerated but static sea water. Half of these tubs were held for 1 day and the other half for 2 days to examine the independent and interactive effects of stocking density and holding time on seed survival. Each treatment comprised three replicates (a total of 12 tubs and 3,000 seed lobsters).

#### Experiment 2

In experiment 2, the same holding time and stocking density effects as examined in experiment 1 were combined with three transport times (1, 6 or 12 hours) using an incomplete factorial design with three replicates per treatment. Surviving seed from this transport stage were maintained in treatment replicates ( $n = 3$ ) and placed into submerged nursery cages at a stocking rate of 17 individuals/m<sup>2</sup> and fed mixed trash fish once daily for the duration of the 30-day nursery period.

#### Experiment 3

In experiment 3, immediately caught seed lobsters were held for 1 day in holding tanks and then transferred to styrofoam boxes (surface area of 0.12 m<sup>2</sup>) at a stocking rate of 200 individuals/m<sup>2</sup> (20 seed/box). Four transport conditions with three replicates were examined: 1. static and normal aeration; 2. with net shelter and normal aeration; 3. without net shelter and normal aeration; and 4. without net shelter and air supplied from a compressed air tank. Except for treatment 1. which was not transported, all other treatments were loaded on to a truck and subjected to transport of 6 hours to simulate typical transport duration. After this transport stage, 2 lots of 10 surviving lobsters from each styrofoam box were transferred into an independent submerged nursery cage and monitored for a 30-day nursery period ( $n = 6$ ). Lobsters were fed trash fish once daily during this nursery phase.

#### Experiment 4

Experiment 4 was an extension of the previous experiment with immediately caught seed lobsters held for 1 day and then placed into styrofoam boxes at a stocking rate of 400/m<sup>2</sup> (40 seed/box). The lobsters were transported for 12 hours under two conditions: 1. with net shelter and supplied with air from a compressed air tank; or 2. without net shelter and supplied with compressed air. The water in each box was exchanged three times during transport and

the lobsters were then transferred to independent submerged nursery cages at a stocking rate of 17 individuals/m<sup>2</sup> for a 30-day nursery period. Each treatment had three replicates.

### Data analysis

Percentage survival was calculated for each replicate as the final number of surviving lobsters divided by the number of lobsters at the start and multiplied by 100. Weight gain was calculated as the replicate mean of average final weight minus average initial weight.

Data were examined for normality and subjected to an analysis of variance (ANOVA) in accordance with the experimental design for each experiment. Significance was set at  $P = 0.05$  and differences between treatment means were tested using Duncan's multiple range test.

## Results and discussion

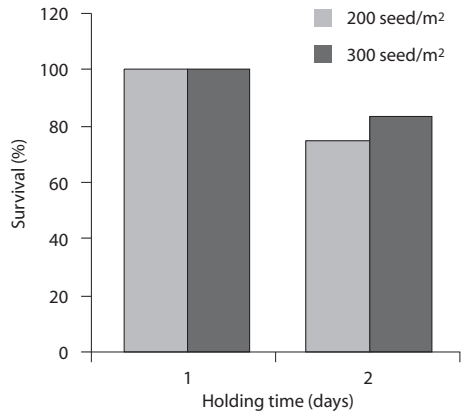
### Experiment 1

Irrespective of the stocking density (200 or 300 seed/m<sup>2</sup>), lobster survival following 1-day on-land holding was 100%. However, when the seed were held for 2 days, there was a significant decline ( $P < 0.05$ ) in survival with a tendency for survival to be lower at the higher stocking rate (83% compared to 75%; Figure 1). This result is very similar to that observed in commercial practice where stocking rates may be even higher. Thus, it is the length of on-land holding rather than stocking density per se that has the greatest (adverse) effect on lobster seed survival.

### Experiment 2

In this incomplete factorial experiment, lobster seed was held in on-land tubs at two stocking densities (200 or 300 seed/m<sup>2</sup>) for either 1 or 2 days and then transported for 1, 6 or 12 hours. However, in the case of seed held for 2 days, only the 12-hour transport duration was tested as insufficient seed were available. Considering seed that were held for 1 day, increasing transport time to 6 or 12 h significantly ( $P < 0.05$ ) decreased survival for seed stocked at 200/m<sup>2</sup> but no such effect was seen for seed at the higher stocking density (Table 1). Similar trends were observed for the seed held for 2 days and transported for 12 hours, although the much lower

survival rate for lobsters held for 2 days strongly suggests that the additional on-land holding was detrimental to lobster survival as was observed in experiment 1.



**Figure 1.** Lobster survival after holding for different lengths of time and at different stocking densities (experiment 1)

Table 2 shows the survival and weight gain of lobsters during 30-day nursery culture following exposure to different handling practices. Growth of the surviving lobsters was unaffected ( $P > 0.05$ ) by handling practice whereas survival decreased markedly when transport duration was 6 or 12 hours; lobsters held on land for 2 days and transported for 12 hours had the lowest survival (22%) but this was not much lower than seed held for 1 day and transported for 12 hours (27%). These results suggest that lobster seed held on land for only 1 day before transport were stronger than those held for 2 days. The absence of any effect of handling practices on subsequent growth of the lobsters was an interesting finding. It may suggest that the surviving lobsters originally had more nutritional reserves or could withstand better the handling stress than the non-surviving seed. Thus, the survivors were better equipped to cope with the conditions and were able to exhibit normal growth during the nursery period.

### Experiment 3

Survival of seed lobsters held for 6 hours under simulated transport conditions of static, with net shelter, without net shelter or without net shelter but compressed air was 100%. The subsequent survival and 30-day nursery growth of these lobsters are shown in Table 3.

The only significant effect was a slight decrease in survival of seed that had been transported in the compressed air treatment (81.5% compared to 85.2–87%). Again, differences in growth of the lobsters were not significant ( $P > 0.05$ ) and ranged from gains of 1.05–1.18 g. The much higher survival of lobsters during the nursery period in this experiment (81.5–87%) following 6-hour transport compared to experiment 2, where lobsters transported for 6 hours showed a survival rate of only 30%, supports our view that seed vitality at capture is as, if not more, important than subsequent handling practices.

#### Experiment 4

Seed lobsters transported for 12 hours with or without net shelters and aerated using compressed

air showed 100% survival. When these lobsters were placed into nursery culture for 30 days, prior transport conditions had no effect on subsequent survival or growth (Table 4). Survival was very high, 96–97%, and growth of 1.2 g was also very good. It can not be confirmed but this excellent result following transport duration of 12 hours may have been due to the three water exchanges that were imposed during transport. The use of compressed air may also have been beneficial but again firm conclusions cannot be drawn.

## Conclusions

- Seed lobsters held for 1 day before transport were more robust than those held for 2 days in on-land tubs.

**Table 1.** Survival ( $\pm$  standard error) of *Panulirus ornatus* seed lobsters immediately after transport and held for different times in on-land tanks before transport in experiment 2

Transport duration (hours)	Holding time and stocking density			
	1 day		2 days	
	200 seed/m <sup>2</sup>	300 seed/m <sup>2</sup>	200 seed/m <sup>2</sup>	300 seed/m <sup>2</sup>
1	98.3 $\pm$ 2.89 <sup>B</sup>	96.7 $\pm$ 1.92 <sup>A</sup>	–	–
6	83.3 $\pm$ 4.41 <sup>A</sup>	90.0 $\pm$ 3.85 <sup>A</sup>	–	–
12	80.0 $\pm$ 5.00 <sup>A</sup>	93.3 $\pm$ 1.92 <sup>A</sup>	75.0 $\pm$ 2.89	88.9 $\pm$ 2.94

Note: <sup>A,B</sup> Within columns, means with a common superscript letter do not differ ( $P > 0.05$ )

**Table 2.** Survival and weight gain ( $\pm$  standard error) of *Panulirus ornatus* seed lobsters after a 30-day nursery period following different postcapture handling procedures in experiment 2

Transport time (hours)	Holding time in on-land tanks			
	1 day		2 days	
	Survival (%)	Gain (g)	Survival (%)	Gain (g)
1	70.0 $\pm$ 1.0 <sup>A</sup>	1.43 $\pm$ 0.09 <sup>A</sup>	–	–
6	30.0 $\pm$ 1.0 <sup>B</sup>	1.42 $\pm$ 0.05 <sup>A</sup>	–	–
12	27.0 $\pm$ 1.5 <sup>B</sup>	1.42 $\pm$ 0.06 <sup>A</sup>	22 $\pm$ 0.06	1.43 $\pm$ 0.08

Note: <sup>A,B</sup> Within columns, means with a common superscript letter do not differ ( $P > 0.05$ )

**Table 3.** Survival and growth ( $\pm$  standard error) of *Panulirus ornatus* seed lobsters after a 30-day nursery period following different transport conditions in experiment 3

Transport condition	Survival (%)	Gain (g)
Static + normal air	85.2 $\pm$ 2.40 <sup>B</sup>	1.12 $\pm$ 0.34 <sup>A</sup>
With net shelter + normal air	85.2 $\pm$ 1.03 <sup>B</sup>	1.18 $\pm$ 0.26 <sup>A</sup>
No shelter + normal air	87.0 $\pm$ 1.17 <sup>B</sup>	1.05 $\pm$ 0.30 <sup>A</sup>
No shelter + compressed air	81.5 $\pm$ 0.80 <sup>A</sup>	1.05 $\pm$ 0.31 <sup>A</sup>

Note: <sup>A,B</sup> Within columns, means with a common superscript letter do not differ ( $P > 0.05$ )

**Table 4.** Survival ( $\pm$  standard error) of *Panulirus ornatus* seed lobsters immediately after transport of 12 hours in tubs with and without net shelters and compressed air and subsequent growth and survival after a 30-day nursery period in experiment 4

Transport condition	Survival immediately after transport (%)	After nursery culture	
		Survival (%)	Gain (g)
Net shelter + air	100	97.2 $\pm$ 1.8	1.2 $\pm$ 0.3
No shelter + air	100	96.0 $\pm$ 1.7	1.2 $\pm$ 0.3

- Survival of seed lobsters immediately after transport was extremely high if they had not been subjected to prior stressful handling.
- Stocking density of the seed lobsters during on-land holding and transport had little to no effect on survival or subsequent 30-day nursery growth.
- Survival of seed lobsters after 30-day nursery culture was markedly reduced as transport duration increased from 1 to 6 or 12 hours.
- The adverse effect of 12-hour transport was more severe for lobsters held for 2 days in on-land tubs.
- The results of this study suggest that the quality and source of the captured lobster seed may be the most important factors determining subsequent survival and growth.

## Acknowledgments

This research was part of the Australian Centre for International Agricultural Research (ACIAR) Project No. FIS/2001/058: *Sustainable spiny lobster aquaculture in Vietnam and Australia*. We would like to thank ACIAR for financial support and especially Dr Kevin Williams from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for his guidance and great help in carrying out and reporting this research. We also very much appreciate the assistance given to us by all other participants from CSIRO, the Queensland Department of Primary Industries and Fisheries, the Institute of Oceanography and Nha Trang University who collaborated in the project.

# Effect of environmental conditions during holding and transport on survival of *Panulirus ornatus* juveniles

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## Abstract

Village-based lobster sea farming in the coastal provinces of central Vietnam is currently the largest lobster aquaculture industry in the world, with an average annual production of about 2,000 t. The seed of *Panulirus ornatus* are caught during the annual settlement season by local fishers from the coastal waters of central Vietnam and transported by seed-lobster merchants to lobster nursery and grow-out farms. Lobsters of 900 g to 1 kg are harvested after a culture period of 20–24 months and on-sold to commercial merchants for distribution to markets predominantly in China.

During the culture period, the first 30 days are most critical for survival and this depends both on the quality (vigour) of the seed at capture and on how the seed is subsequently handled during the nursery phase (until about 30 days postcapture). Seed mortality during the nursery phase has varied from 20% to 90%, and even 100% in some cases. Using semi-structured and structured interview procedures, lobster-seed fishers and seed merchants at 12 landing sites along the central coast of Vietnam were surveyed about how the lobster seed were caught and handled before being placed in nursery cages. Seed lobsters are mostly caught by seine net but habitat traps and scuba diving are also employed. Captured seed are typically held for 1 or 2 days in land-based tanks and then transported in styrofoam boxes for up to 12 hours before placement in nursery cages. The environmental conditions under which the lobsters were held and transported were identified in early experiments as the major factors affecting subsequent survival rates. An experiment was designed to see how water quality changed under simulated commercial lobster seed holding and transport conditions. Seed lobsters were held in holding tanks for 1 or 2 days and then transported in styrofoam boxes for 3 or 5 hours at either low (300 seed/m<sup>2</sup>) or high (2,000 seed/m<sup>2</sup>) stocking densities. Increasing the density of seed from 300 to 2,000 seed/m<sup>2</sup> markedly increased ammonia and decreased dissolved oxygen levels in the water, and more so when transport was extended to 5 hours. This may explain why poor transport conditions can result in high mortalities of the lobster at farms within the first 30 days of nursery culture.

**Keywords:** rock lobster; nursery culture; water quality; fishing methods; ammonia; dissolved oxygen

## Introduction

The geographically sinuous topography of the central provinces of Vietnam (Hieu 1994) has

created many straits, gulfs and bays along the coast with optimal environmental conditions for settlement of spiny lobster seed, which occurs from November to April each year. Recent surveys of lobster seed settlement in Vietnam have reported around 4 million lobster seed are caught annually for aquaculture on-growing, with four species dominating—*Panulirus ornatus*, *P. homarus*,

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*P. polyphagus* and *P. longipes*. The most sought-after species is *P. ornatus*, which typically accounts for 30–50% of the catch (Van 2007). Lobster seed are landed at more than 20 sites along the 700 km central coast of Vietnam, from Da Nang in the north to Binh Thuan in the south. Following capture, most of the lobster seed are transported by lobster-seed merchants for sale to the lobster nursery and grow-out farms. Lobsters of 900 g to 1 kg are harvested after a culture period of 20–24 months, with total annual production of about 2,000 t (MARD 2006).

The first 30 days of nursery culture is the most critical period, during which lobster losses can be very high. Normally, captured seed lobsters are held for 1 or 2 days in land-based tanks at densities of 500–3,000/m<sup>2</sup> and then transported in styrofoam boxes at densities of 1,000–3,000/m<sup>2</sup> for up to 12 hours before placement in nursery cages. Lobster-seed merchants report that survival of the seed during land-based holding and transport is over 99% and 97%, respectively. However, seed losses during the nursery phase (until about 30 days postcapture) have varied from 20% to 90%, and even 100% in some cases. It is speculated that seed mortality during nursery culture is a culmination of several factors with probably the most important being vitality of the seed at capture, environmental conditions (especially water quality, aeration and temperature) during transport and nursery culture, and the quality and nutritional suitability of the lobsters' feed.

This paper reports a survey carried out to identify the methods used to catch lobster seed from the wild and the conditions used by fishers and seed merchants to hold and transport the seed from capture sites to where they are on-grown. Based on the results of this survey, experiments were designed to examine optimal conditions for holding and transporting seed lobsters. Experiments examining land-based holding and transport conditions on lobster seed survival and nursery growth are presented elsewhere in these proceedings (Ngoc et al. 2009). This paper details experiments examining water-quality aspects during holding and transport of lobster seed.

### **Fishing methods for wild *P. ornatus* seed**

Fishing methods were surveyed using semi-structured and structured interviews of fishers engaged in catching lobster seed, and field studies at the seed landing sites of Van Ninh, Dai Lanh, Quy Nhon, De-gi,

Ky Ha, Bang Than and Son Tra in the provinces of Khanh Hoa, Phu Yen, Binh Dinh, Quang Ngai, Quang Nam and Da Nang. The information sought included: catching season; grounds where caught, including depth and conditions of wind and waves; fishing materials used; time of day; number of seed caught per day and month; postcatch survival rate; and seed size for each method of catch. Additionally, farmers purchasing seed from seed merchants were interviewed to obtain information on the condition of the seed and subsequent culture success.

The main fishing season commenced in late November and continued through to April of the next calendar year. However, small numbers of seed were collected opportunistically throughout the year. Three different methods of catching lobster seed were identified—habitat trap, seine net and light source at night, and scuba diving. The mean size of the captured seed did not vary greatly between methods but the success rate (catch per unit effort; CPUE) did, with the seine net being almost 20-fold more successful than the other methods (Table 1).

There were large differences in CPUE on a daily basis within the fishing season, with daily catch of lobster seed with the seine net varying from 0 to 200. While there was some correlation between catch number and moon phase, with fewer being caught around the full moon, other factors such as the prevailing weather, tide flow and settlement abundance also combined to affect catch success rate. Immediate survival of the caught lobster seed was high (92–96%) with perhaps the scuba diving method being slightly better than seine net or habitat trap (96% compared to 92% or 93%, respectively). It was apparent that the origin of the seed, its method of catch and seasonality were correlated. For example, capture by seine net was the predominant source of seed early in the settlement season, by scuba diving in the middle of the season, while seed from habitat traps were caught from nearshore structures throughout the settlement season.

### **Holding and transport of seed**

Information was sought from lobster-seed merchants and lobster farmers to record the method of handling the seed following catching and subsequent culture practices during the critical 30-day nursery phase. We were especially interested in finding out from the seed merchants the conditions used to hold and transport the lobster seed, particu-

larly stocking density and water quality. With the lobster farmers, the origin of the purchased seed, what feed was provided to the lobsters and their subsequent survival success were key questions for which information was sought. Additionally, a field study measured key water-quality characteristics for lobster seed landed at two sites (Van Ninh and Quang Ngai) and transported for either 3 or 5 hours to lobster farms at Vung Ro and Quy Nhon.

The investment in facilities to hold and transport seeds is detailed in Table 2. For the local coastal people, this represents a considerable investment and explains why seed merchants are prepared to hold and transport the seed at very high densities of up to 3,000 seed/m<sup>2</sup>.

Even at these high densities, survival during holding and transport is typically better than 97%. It is only where weak seed are held and transported for long distances that immediate posttransport mortalities occur. The effect on water quality of holding lobster seed for 1 day at a density of 2,000 seed/m<sup>2</sup> and then transporting them at the same density for 3 or 5 hours is shown in Table 3. The temperature of the water increased by 1 °C and 1.5 °C for 3- and 5-hour transport times, respectively, while pH and

salinity were relatively unaffected by transport. However, the dissolved oxygen (DO) level of the water fell by 28% after 3-hour transport (from 6.2 to 4.3 mg/L) and by 33% after 5-hour transport (from 6.6 to 4.0 mg/L) although the water was provided with constant aeration during transport. These posttransport DO levels are well below the minimum standard of 6.0 mg/L for hatchery water. Note that the volume of the water in the transport styrofoam boxes was just sufficient to cover the mass of lobster seed and thus aeration was probably not very effective. This is a common practice to minimise the weight and therefore the cost of transport to the seed merchant.

### Field experiment on *P. ornatus* seed holding and transport

The survey results (above) provided the basis for designing this experiment. In collaboration with a seed merchant who 'loaned' the use of the seed for the experiment, an incomplete 2 × 2 × 2 factorial design with two replicates (*n* = 2) was employed to examine the independent and interactive effects of on-land tank holding time (1 or 2 days), stocking

**Table 1.** Information on seed-lobster fishing methods and catch in Vietnam, 2005–2008

Seed fishing method	Surveyed data				
	Materials	Fishing ground	CL (mm ± SD) <sup>a</sup>	CPUE <sup>b</sup>	Postcatch survival (%)
Habitat trap	Coral, wood, old nets, tree branch	Nearshore	8.1 ± 0.6	5 ± 3	93.0 ± 3.0
Seine net	Synthetic fibre net and neon light	Offshore and nearshore	7.1 ± 0.2	94 ± 97	91.6 ± 4.0
Diving	Scuba	Nearshore	8.8 ± 0.9	5 ± 3	95.5 ± 2.5

<sup>a</sup> CL = carapace length (mm ± standard deviation)

<sup>b</sup> CPUE = catch per unit effort = number of seeds/day/fishing area during the fishing season, November–April

**Table 2.** Information on how *Panulirus ornatus* seed captured from the Vietnam central coast is held and transported, 2005–2008

Survey	Holding	Transport
Materials	Seawater, cement tanks, sand filter, aerating machine, plastic/wire baskets	Styrofoam boxes (30 × 50 × 50 or 60 × 75 × 70 cm/box); portable aerating machine, filtrated sea water or natural sea water; by bus, motorbike and/or boat
Density (no./m <sup>2</sup> )	500 to 3,000	1,000 to 3,000
Duration	1 or 2 days	1 to 12 hours
Survival (%)	99.7 ± 0.49	97.8 ± 1.74

density (300 or 2,000 seed/m<sup>2</sup>) and transport time (3 or 5 hours) on water quality. Lobster seed held for 2 days were not subjected to the transport phase of the experiment as the seed were distributed locally to lobster farmers.

The postpuerulus lobster seed were caught by seine net. The average ( $\pm$  standard deviation; SD) size of the seed was  $7.5 \pm 0.3$  mm carapace length (CL) and  $0.3 \pm 0.12$  g. The seed were transferred to plastic baskets at the designated stocking density and placed in concrete tanks supplied with recirculated, filtered and well-aerated sea water at ambient temperature (23–24 °C). Seed held for 1 day were not fed, while seed held for 2 days were fed minced shrimp meat. Seed that were transported were placed in styrofoam boxes (each 30 × 50 × 25 cm) at their designated stocking densities, provided with constant aeration from a compressed oxygen cylinder and transported in an air-conditioned car ( $21 \pm 1$  °C) for their designated transport times.

The effect of holding conditions on survival and water-quality characteristics is shown in Table 4. Stocking density and holding time had no effect on survival rate, with all seed surviving. The most

noticeable effect of increasing the stocking density from 300 to 2,000 seed/m<sup>2</sup> was a slight decrease in DO (of 0.3 mg/L) at both holding times. Compared with the recommended minimum hatchery standard for DO of 6.0 mg/L, it remained above the standard for seed held for 1 day irrespective of the stocking density, whereas it was below the standard at both stocking densities for seed held for 2 days (Figure 1). Also evident was an increase in ammonia from undetectable levels to 0.27 mg/L, but only for seed held for 2 days. This is 2.7-fold higher than the recommended maximum ammonia levels for hatchery water of 0.1 mg/L. The increase in ammonia level for seed held for 2 days at the highest stocking density may have been due to the feeding of minced shrimp to these seed lobsters.

The effect of transport duration on survival and water quality for seed previously held for 1 day in on-land tanks is shown in Table 5. Again, stocking density and transport duration had no effect on immediate posttransport survival, with all seed alive after transport. However, increasing the stocking density and increasing the transport time compounded to decrease DO (Figure 2) and increase

**Table 3.** Survival and water-quality characteristics for lobster seed held at 2,000/m<sup>2</sup> for 1 day and transported for 3 or 5 hours

Characteristic	After holding	After 3-hour transport <sup>a</sup>	After holding	After 5-hour transport <sup>b</sup>
Survival (%)	100	100	100	100
Salinity (ppt)	31	31	30	31
Temperature (°C)	27.0	28.0	26.0	27.5
pH	8	8	8	8
DO (mg/L)	6.2	4.3	6.6	4.0

<sup>a</sup>Landed at Van Ninh and transported by motorbike to Vung Ro in April 2007

<sup>b</sup>Landed at Quang Ngai and transported by bus to Quy Nhon in March 2007

Note: ppt = parts per thousand; DO = dissolved oxygen

**Table 4.** Survival and water-quality characteristics for land-based tanks holding *Panulirus ornatus* seed at different densities for 1 or 2 days

Characteristic	1-day holding		2-day holding	
	Density (no./m <sup>2</sup> )		Density (no./m <sup>2</sup> )	
	300	2,000	300	2,000
Survival (%)	100	100	100	100
Salinity (ppt)	30 ± 1	30 ± 1	30 ± 1	30 ± 1
Temperature (°C)	23.5 ± 1	23.5 ± 1	23.5 ± 1	23.5 ± 1
DO (mg/L)	6.8	6.5	5.8	5.5
Ammonia (mg/L)	nd	nd	nd	0.27

Note: ppt = parts per thousand; DO = dissolved oxygen; nd = not detected

ammonia (Figure 3) levels to values markedly worse than the recommended hatchery standard. In the case of DO, increasing the stocking density from 300 to 2,000 seed/m<sup>2</sup> reduced DO by 26% and 56% for seed transported for 3 and 5 hours, respectively (from 6.8 to 5.0 and 3.0 mg/L, respectively). Even at the lowest stocking density of 300 seed/m<sup>2</sup>, increasing transport time from 3 to 5 hours decreased DO by 31% (to 4.7 mg/L) and markedly below the hatchery standard of 6.0 mg/L.

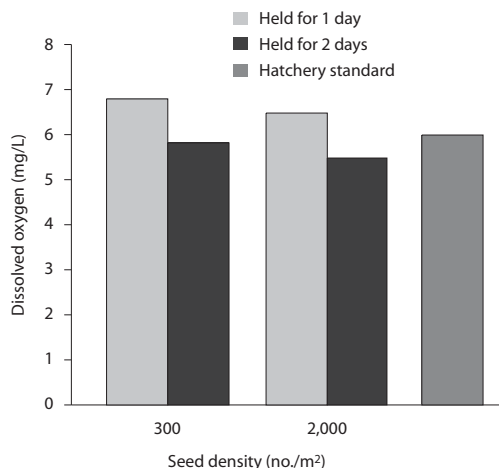
In the case of ammonia, only seed transported at the lowest density and shortest duration remained below the hatchery standard of 0.1 mg/L. For seed

transported for 3 hours, ammonia levels doubled when stocking density was increased from 300 to 2,000 seed/m<sup>2</sup> (from 0.08 to 0.17 mg/L). Increasing the transport duration to 5 hours resulted in a trebling of ammonia levels for seed at 300 seed/m<sup>2</sup> (to 0.26 mg/L) and 6-fold for seed at 2,000 seed/m<sup>2</sup> (to 0.48 mg/L). Whether or not these suboptimal water conditions for transported seed affected survival or growth during the nursery phase could not be determined as the seed were distributed by the collaborating seed merchant to many different lobster farmers.

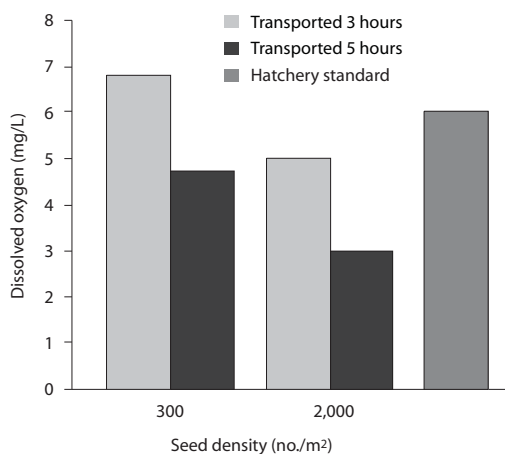
**Table 5.** Survival and water-quality characteristics for *Panulirus ornatus* seed transported for 3 or 5 hours after land-based holding of 1 day at different densities

Characteristic	Transport			
	3-hour		5-hour	
	Density (no./m <sup>2</sup> )		Density (no./m <sup>2</sup> )	
	300	2,000	300	2,000
Survival (%)	100	100	100	100
Salinity (ppt)	30 ± 1	30 ± 1	30 ± 1	30 ± 1
Temperature (°C)	22 ± 1	22 ± 1	22 ± 1	22 ± 1
DO (mg/L)	6.8	5.0	4.7	3.0
Ammonia (mg/L)	0.08	0.17	0.26	0.48

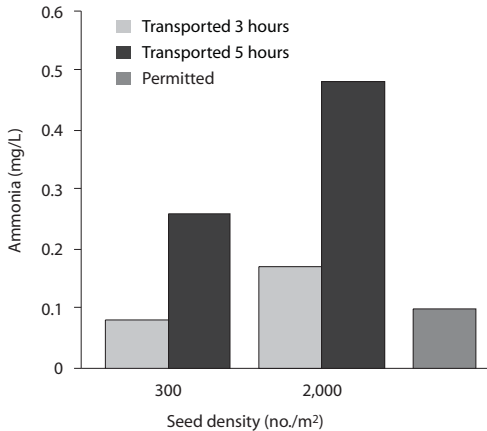
Note: ppt = parts per thousand; DO = dissolved oxygen



**Figure 1.** Dissolved oxygen in the tank water of lobster seed held at stocking densities of 300 or 2,000 seed/m<sup>2</sup> for 1 or 2 days compared to the recommended standard for hatchery water



**Figure 2.** Dissolved oxygen (DO) in the water of lobster seed transported for 3 or 5 hours at stocking densities of 300 or 2,000 seed/m<sup>2</sup> compared to the recommended standard for hatchery water



**Figure 3.** Ammonia level in the water of lobster seed transported for 3 or 5 hours at stocking densities of 300 or 2,000 seed/m<sup>2</sup> compared to the recommended standard for hatchery water

## Conclusions

- The lobster seed fishing industry has a major socioeconomic impact on the coastal communities of the central provinces of Vietnam.
- Seed lobsters are caught mostly using a seine net and a light source at night during the settlement season (November to April) but habitat traps and scuba diving are also used. Captured seed are held in on-land tanks for 1–2 days before being transported at high densities (up to 3,000 seed/m<sup>2</sup>) for up to 12 hours. Survival of the lobster seed immediately after capture and transport is high and usually better than 95%.
- Increasing the on-land holding density from 300 to 2,000 seed/m<sup>2</sup> slightly depressed water DO and more so when the holding period was extended from 1 to 2 days, but ammonia was detectable only when seed were held at the higher density for 2 days.
- Increasing the stocking density from 300 to 2,000 seed/m<sup>2</sup> and increasing the transport time from 3 to 5 hours compounded to decrease DO by up to 56% (to 3.0 mg/L) and increase ammonia levels

up to 0.48 mg/L. These values are markedly worse than the recommended hatchery standard of  $\geq 6.0$  mg/L for DO and  $\leq 0.1$  mg/L for ammonia. This may explain why poor transport conditions can result in high mortalities of the lobster at farms within the first 30 days of nursery culture.

## Acknowledgments

The Research Institute for Aquaculture No. 3 (RIA3) research team would like to thank the Australian Centre for International Agricultural Research (ACIAR) and the ministries of Fisheries and Agriculture and Rural Development of Vietnam (MOFI/MARD) for providing funds and support for this project. We specially thank Drs Kevin Williams, Clive Jones and David Smith for assistance in designing the experiment, preparing the research methods and improving reports in English. We also thank our colleagues at Nha Trang University, the Institute of Oceanography, Nha Trang (ION), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Queensland Department of Primary Industries and Fisheries, the Marine Aquaculture Development Centre and RIA3 for working together during the project.

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# Effect of different types of shelter on growth and survival of *Panulirus ornatus* juveniles

Nguyen Minh Chau, Nguyen Thi Bich Ngoc and Le Thi Nhan<sup>1</sup>

## Abstract

At settlement, lobsters naturally choose cryptic shelters for protection, both from predators and from cannibalism at times of moulting. Some studies with other crustaceans have shown that providing shelters improves their growth and survival during culture. However, there is very little information on the effect of different shelter types on growth and survival of juvenile *Panulirus ornatus* (ornate spiny lobster). An experiment was carried out to determine whether shelter affects the growth and survival of *P. ornatus* juveniles, and which type of shelter is best.

Four shelter types were examined during 40 days of nursery culture: 1. wood shelter with drilled holes; 2. coral shelter with drilled holes; 3. net shelter; and 4. no shelter (control). Each treatment had 6 replicate tanks each with 12 lobsters in a completely randomised design. Lobsters were fed trash fish once daily. Specific growth rate (carapace length and body weight) of lobsters was unaffected by shelter type. However, shelter type significantly ( $P < 0.05$ ) affected survival: highest for the net shelter ( $80.6 \pm 5.6\%$ ), with the no-shelter control ( $62.5 \pm 4.2\%$ ) and the wood shelter ( $54.2 \pm 2.4\%$ ) significantly lower, while the coral shelter ( $68.1 \pm 6.9\%$ ) was not significantly different from all shelter types. These findings suggest that providing net shelters during the nursery phase may reduce cannibalism during moulting and lessen the competition between weak and more dominant lobsters.

**Keywords:** rock lobster; nursery culture; net shelter; coral shelter; wood shelter; cannibalism

## Introduction

*Panulirus ornatus* (ornate spiny lobster) is a marine species that has high economic value, especially in the live fish markets of Hong Kong. Commercial aquaculture production of spiny lobsters has established or is being developed in many countries including Australia, India, Japan, New Zealand, the Philippines, Singapore, Taiwan and Vietnam (Jeffs and Davis 2003). *Panulirus ornatus* seed for aquaculture are presently sourced from the wild because commercial-scale hatchery production is not avail-

able. In Vietnam, most seed are caught as swimming pueruli or postpueruli (pre-juveniles) and a nursery phase of 30–60 days is required before they are on-grown in seacage culture. Mortality of lobster seed during this nursery phase is very high, typically 40–60%, but occasionally can be as high as 100% (Thuy and Ngoc 2004). High mortality during the nursery phase not only reduces farmer profitability but also severely impacts on the potential production of harvestable lobsters.

Lobsters' natural cryptic habit is to settle during the day and to leave these shelters at night to forage for food (Dennis et al. 1997). Additionally, shelters protect the lobsters from predation, particularly during moulting when they are most vulnerable. In nursery culture, lobsters are most susceptible to

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cannibalism at times of moult, which occurs every 2–3 weeks with lobsters of this size. Several studies have shown that shelters have a positive benefit in improving growth and survival of spiny lobsters (Chittleborough 1974; Crear et al. 2000; James et al. 2001). Survival of *Panulirus cygnus* (western spiny lobster) postpueruli was significantly higher in tanks with mesh shelters than brick shelters, and a similar trend was evident for year 1 and year 2 lobsters although not statistically significant (Johnston et al. 2006). Despite this, there is very little information on the effect of different types of shelter on the growth and survival of pre-juvenile *P. ornatus*. For the nursery rearing of lobsters in Vietnam, pre-juveniles are placed in submerged cages, which almost without exception do not have any shelters for the lobsters to use.

The aims of this experiment were twofold: firstly to see if providing shelters during the nursery phase affects growth and survival of pre-juvenile *P. ornatus*; and secondly to compare three different types of shelters.

## Material and methods

### Animals and experimental design

Pre-juvenile lobsters were caught from Nha Trang Bay and were held in a large tank for 2 weeks before the start of the experiment. Three different types of shelters were compared: (i) bundles of netting; (ii) small wood logs with 10 mm diameter drilled holes; and (iii) pieces of hard coral with 10 mm diameter drilled holes (Figure 1). In addition, a control in which no shelter was provided for the lobsters was included in the treatment array. A completely randomised design was used for the experiment. Each treatment (control and 3 shelter types) comprised 6 tanks with 12 lobsters ( $0.59 \pm 0.04$  g and carapace length of  $8.1 \pm 0.28$  mm) randomly distributed to each tank. All tanks were supplied with flow-through filtered sea water at ambient temperature.

The lobsters were fed the same food—a mixture of chopped fresh fish and shellfish—once daily.



**Figure 1.** The four different types of shelters used in the nursery experiment: (a) wood logs with drilled holes; (b) coral pieces with drilled holes; (c) folded net; and (d) control with no shelter

Survival was recorded daily and weight change measured over the course of the 40-day experiment. Two-minute video clips of the behaviour of the lobsters at 30 and 60 minutes after feeding were recorded for two tanks in each treatment every 3 days by overhead digital camera.

### Data analysis

Growth was calculated as specific growth rate by weight ( $SGR_W$ ) and SGR by carapace length ( $SGR_{CL}$ ) using the following equations:

$$SGR_W (\% \text{ weight/day}) = [(\ln W_E - \ln W_S)/n]100\% \quad (1)$$

$$SGR_{CL} (\% \text{ CL/day}) = [(\ln CL_E - \ln CL_S)/n]100\% \quad (2)$$

where:

$W_S$  = initial lobster weight

$W_E$  = final lobster weight

$CL_S$  = initial carapace length

$CL_E$  = final carapace length

$n$  = number of days of the experiment.

Survival was calculated as the number of surviving lobsters as a percentage of the initial number stocked to the tank. Response data were analysed as a one-way analysis of variance (ANOVA) with differences between treatments examined using a least significant difference (LSD) post-hoc test with  $P = 0.05$ .

## Results

Shelter had a significant effect on lobster survival, with the net shelter being better ( $P < 0.05$ ) than either no shelter (control) or wood shelter; survival was intermediate with the coral shelter, which was not significantly different from all other treatments (Table 1). Shelter type did not significantly affect weight or carapace length specific growth rates (SGRs), although there was a strong trend for

growth to be best for the net and wood shelters and worst for the coral and control treatments (Table 1).

## Discussion

Our experiment showed that shelter significantly improved survival of *P. ornatus* juveniles. This accords with findings of Johnston et al. (2006) with *P. cygnus* and those of Crear et al. (2000) with *Jasus edwardsii* but contrasts with those of Kington (1999) who found no benefit of shelters on survival of juvenile *J. edwardsii*. During the nursery phase, juveniles at moulting are most vulnerable to cannibalism and this risk is lessened if shelters are provided. There was a clear indication in the experiment that net shelter, and to a lesser extent also coral shelter, offered more protection than other types of shelters. The folded net possibly provided comparatively more shelter than other shelter types and in a form that more closely met the cryptic needs of the lobster. Johnston et al. (2006) similarly found net to be better than brick shelters for *P. cygnus*, and for *J. edwardsii* a net shelter made from oyster mesh resulted in significantly higher lobster survival than in tanks without shelters (Crear et al. 2000). It is interesting to note in our experiment that survival of lobsters with wood shelter was no better than the control treatment where no shelters were provided.

The absence of shelter or shelter type had no significant effect on weight and carapace length growth of the lobsters in the experiment. This contrasts with the findings of Chittleborough (1974) who found that *P. cygnus* consumed more food and grew faster when shelters were provided. However, neither Kington (1999) nor James et al. (2001) found shelters improved growth of *J. edwardsii*. Although our experiment showed no significant effect of shelter type on lobster growth, there was an indication that the growth of lobsters in tanks without

**Table 1.** Survival and specific growth rate (SGR) ( $\pm$  standard error) of juvenile *Panulirus ornatus* provided with different shelter types during a 40-day nursery period

Shelter type	Survival (%)	$SGR_W$ (%/day)	$SGR_{CL}$ (%/day)
Wood	54.2 $\pm$ 2.40 <sup>B</sup>	3.7 $\pm$ 0.21	1.3 $\pm$ 0.11
Net	80.6 $\pm$ 5.56 <sup>A</sup>	3.7 $\pm$ 0.17	1.2 $\pm$ 0.38
Coral	68.1 $\pm$ 6.94 <sup>AB</sup>	3.3 $\pm$ 0.32	1.0 $\pm$ 0.09
Control	62.5 $\pm$ 4.16 <sup>B</sup>	2.7 $\pm$ 0.39	0.9 $\pm$ 0.11

Note: <sup>A, B</sup> Within response traits, means with a common superscript letter do not differ ( $P > 0.05$ );  $SGR_w$  = SGR by weight;  $SGR_{CL}$  = SGR by carapace length



shelters was less than in tanks with shelters ( $SGR_w$  of 2.7% compared to 3.3– 3.7%/day). Based on these observations, it would be prudent to provide shelters to lobsters during the nursery phase.

## Conclusions

- Lobster survival during the nursery phase was enhanced in the presence of shelters, with net shelters being more effective than drilled holes in wood or coral.
- Weight and carapace length growth of lobsters during the nursery phase was not significantly affected by shelter type but there was a strong trend indicating that growth was better in tanks with shelters compared to tanks without any shelter.

## Recommendation

It is recommended that net shelters be provided in tanks during nursery culture as a simple and effective way of improving lobster survival by lessening the competition between weak and more dominant lobsters.

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# Comparison of the growth and survival of *Panulirus ornatus* seed lobsters held in individual or communal cages

Simon J. Irvin and Kevin C. Williams<sup>1</sup>

## Abstract

Mortality of spiny lobster seed during early nursery stages is high, typically 40–60%. The cause of this high mortality is not known although the majority of deaths appear to occur during, or shortly after, moulting. This experiment examined whether housing of small *Panulirus ornatus* ( $2 \pm 0.3$  g) lobsters either individually or communally affects their survival or growth. The experiment entailed a 60-day comparison of two housing treatments: solitary versus communal, each with six tank replicates. The solitary treatment consisted of a single lobster in a cylindrical net cage (80 mm diameter  $\times$  17 mm high; total surface area of 0.052 m<sup>2</sup>), with a single shelter, with six such cages placed in a tank (experimental unit). The communal treatment consisted of six lobsters placed in a rectangular net cage (600 mm  $\times$  420 mm  $\times$  170 mm high; total surface area of 0.43 m<sup>2</sup>; and 0.072 m<sup>2</sup> per individual), with six single shelters. Lobsters housed communally had a lower survival rate than those housed individually, 72% and 89%, respectively. Communal lobsters grew at a significantly faster rate than those in the solitary treatment with a daily growth coefficient of 1.0%/day and 0.7%/day, respectively. However, due to the higher survival rate of individually housed lobsters, lobster biomass produced was similar for each housing treatment. Results and future directions for this study are discussed.

**Keywords:** cannibalism; moult death; deficiency; crustacean; shelter; housing

## Introduction

Grow-out of *Panulirus ornatus* (ornate spiny lobster) is presently solely reliant on the capture of wild seed. The capture and on-selling of seed is a high-value business with prices in Vietnam commonly exceeding US\$10/piece. In recent years, seed price has fluctuated considerably, primarily due to variable seasonal catch rates and the prevalence of lobster disease affecting demand for the seed. A key factor compounding this issue is that typically 40–

60% and occasionally as high as 100% of the caught seed die during the following 30–40-day nursery stage (N.B.T. Thuy, pers. comm.). Lifecycle closure of *P. ornatus* has been achieved, but economical large-scale commercial production of lobster seed is not likely for another 5–10 years. In Australia, large-scale lobster aquaculture production will not be possible until commercially viable hatchery production of lobster seed is achieved. Survival of recently caught lobster seed will be an equally important issue to overcome in Australia, as it is for the more established lobster aquaculture industries in South-East Asia. The high cost of seed means that any improvement in survival rate during the nursery stage of development will have a major benefit on increasing

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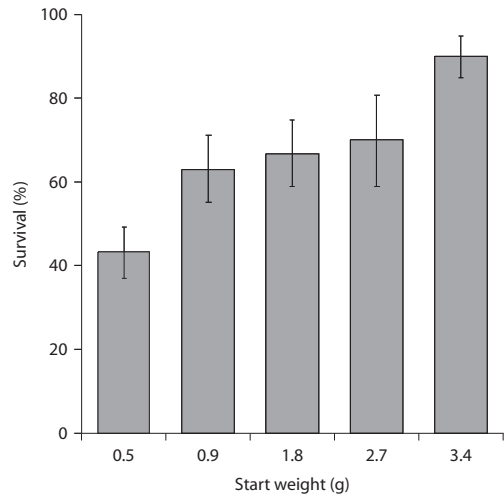
farm profitability and lobster production. Anecdotal evidence suggests the majority of juvenile lobster mortalities occur during or just after moult. This is not remarkable as moulting is a stressful and frequent event for small crustaceans.

### Possible causes of mortality

Why are these deaths occurring? Numerous studies have investigated methods to improve survival rates of very small lobsters (Berrill 1976; James et al. 2001; Jones et al. 2001; Johnston et al. 2006; Chau et al. 2009; Ngoc et al. 2009; Thuy et al. 2009). However, they have not been able to determine the actual cause of mortality. In many cases in Vietnam, the distance between the sites of seed collection and grow-out may be several hundreds of kilometres; therefore capture, handling and transport stress are prime factors likely to feature as contributory causes of high mortality (Ngoc et al. 2009; Thuy et al. 2009). Episodes of low oxygen, temperature change and high ammonia are likely to contribute to the death of lobsters at moult. These stress events typically occur at the fishing vessel or seed middleman stage, though mortality is not likely to become evident until perhaps several weeks later during the nursery stage. Best-practice methods for handling and transport of seed lobsters, specifically investigating effects of dissolved oxygen and water temperature, are reported in these proceedings (Ngoc et al. 2009; Thuy et al. 2009). However, our use of best-practice methods in Australia, involving transport from capture to holding tank within 3 hours, has still resulted in episodes of high mortality (>40%). Another observation from Vietnam is that seed lobster mortality often increases towards the end of the natural settlement period. This suggests that late-settling seed lobsters may not have sufficient nutritional reserves to withstand the stress of capture and subsequent handling.

At the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia, astaxanthin and cholesterol were identified as micronutrients that, when deficient, may contribute to high mortality rates in juvenile lobsters. Astaxanthin plays a role in the maintenance of carapace pigmentation and healthy immunocompetence levels, while cholesterol plays an equally essential role in health and moulting. However, increased dietary supplementation with astaxanthin or cholesterol had no significant effect on the survival or growth of juvenile lobsters (Barclay et al. 2006; S.J. Irvin and

K.C. Williams, unpublished data). What was observed, however, was that the initial size of the lobsters had a significant effect on their subsequent survival rate: as starting size increased from 0.5 g to 3.4 g, subsequent survival similarly improved. In the cholesterol experiment (S.J. Irvin and K.C. Williams, unpublished data), survival in the smallest group of lobsters (0.5 g) was only 40% as compared to 90% for the largest-size lobsters (3.4 g) (Figure 1).



**Figure 1.** Survival of small *Panulirus ornatus* with different start weights, recorded in a cholesterol requirement growth study (S.J. Irvin and K.C. Williams, unpublished data)

### Communal versus solitary housing

Cannibalism during moulting has been widely advocated as a major contributor to high mortality of seed lobsters, but this hypothesis has not been adequately tested. It is difficult to determine the role of cannibalism as lobsters typically moult during the night. After mortality occurs, there is often little if anything of the deceased lobster remaining, leaving the question, was the lobster deceased before it was cannibalised or did it die as a result of cannibalism? One way to answer this question is to remove the opportunity for cannibalism to occur and see if death is the result of some other phenomenon. Dennis et al. (1997) observed juvenile *P. ornatus* to have a solitary seabed existence, compared to more gregarious subadults inhabiting shallow reefs. This suggests that solitary housing of juveniles may be

suitable for the nursery stage of grow-out. The main benefit of solitary housing is the removal of social hierarchy, allowing the individual unlimited access to available food, shelter and the elimination of cannibalism as a cause of death. Alternatively, social interactions present in communal housing may provide triggers or cues that stimulate feeding responses and promote higher growth rates. There have been few studies comparing solitary and communal housing with crustaceans. With the temperate crayfish *Pacifastacus leniusculus*, solitary housing had a significant beneficial effect on growth and survival (Jonsson and Edsman 1998; Ahvenharju and Ruohonen 2007), while in *Penaeus monodon*, the tiger shrimp, solitary housing produced a marked reduction in food intake and growth (S.J. Tabrett, pers. comm.). The object of this experiment was to see if the individual housing of small *P. ornatus* ( $2.0 \pm 0.3$  g) lobsters has a significant survival and growth benefit over communally housed juveniles. The experiment entailed a 60-day comparison of two housing treatments—solitary versus communal housing.

## Methods

### Overview and experimental design

The experiment was carried out to examine the growth and survival response of juvenile *P. ornatus*

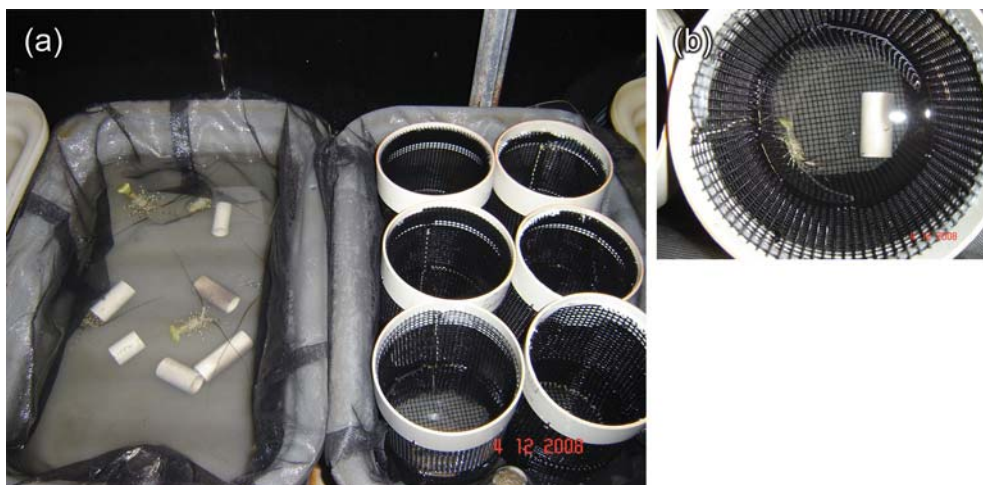
to housing conditions: solitary or communal. A standard growth assay was conducted with two treatments and six replicates ( $n = 6$ ). A randomised design was used, with each treatment randomly allocated to tanks.

### Housing treatments

The solitary treatment consisted of a single lobster placed in a  $0.052$  m<sup>2</sup> cylindrical net cage (80 mm diameter  $\times$  170 mm height), with a single shelter; six of these net cages were placed in a  $0.43$  m<sup>2</sup> rectangular net cage (600 mm  $\times$  420 mm  $\times$  170 (height) mm) and together these constituted a single replicate for the solitary housed treatment. The communal treatment consisted of six lobsters placed in a  $0.43$  m<sup>2</sup> rectangular net cage (600 mm  $\times$  420 mm  $\times$  170 (height) mm; and  $0.072$  m<sup>2</sup> per individual), with six single shelters; this constituted a single replicate for the communally housed treatment (Figure 2).

### Feed formulation and manufacture

Lobsters in all treatments received the same moist formulated feed (Table 1). The feed contained dry and fresh ingredients and was made at the CSIRO Marine Research Laboratory at Cleveland, Queensland, Australia. Fish flesh and mussel meat were placed at  $-20$  °C until semi-frozen and then extruded through a 3 mm die plate of the meat grinder attachment for an A200 Hobart planetary dough mixer



**Figure 2.** (a) Experimental set-up with communally (left) and solitary (right) housed lobsters in tanks; (b) plan view of the solitary cage

(Hobart Corporation, Troy, Ohio, United States of America; USA) to form a homogenous mince. The dry ingredients were finely ground (<710 µm) using a mortar and pestle for small constituents or by hammer mill (Mikro Pulverizer, Metals Disintegration Coy, Summit, New Jersey, USA) for bulk ingredients. The fresh ingredients and transglutaminase binder were thoroughly mixed together using an industrial-kitchen Kenwood KM800 planetary mixer (Kenwood Ltd, Havant, Hants, United Kingdom) for 10 minutes before the remaining ingredients were added followed by a further 10-minute mixing to form a dough of approximately 40–50% moisture content. The dough was extruded through a 3 mm die plate of the meat grinder attachment for an A200 Hobart planetary dough mixer to form spaghetti-like strands. The strands were placed in an airtight bag and set overnight in a refrigerator at 4 °C. The strands were then cut to the required size and stored at 20 °C until required for feeding.

## Experimental animals

Lobsters used in the experiment were hand-collected as recently settled *P. ornatus* from Trinity Inlet, Cairns, North Queensland (16°55'S, 145°45'E)

and airfreighted to CSIRO Cleveland. The experiment consisted of a 60-day growth assay. Lobsters were held for 1 week during which time they were weaned from a fresh diet of fish flesh and green-lipped mussel flesh to the moist formulated feed (Table 1). The lobsters were weighed (mean ± standard deviation (SD); 2.0 ± 0.3 g) and stocked into individual or communal cages—six replicates with six lobsters for each treatment replicate. Cages were installed within a light-controlled laboratory (12:12 hour dark:light cycle) and supplied with aerated and heated flowing sea water (0.3 L/minute), enabling temperatures to be maintained between 28 and 30 °C. Feed was offered slightly to excess three times daily at 8 am, 12 noon and 5 pm with the major portion provided at 5 pm. All uneaten food was removed daily by siphon cleaning and a daily record was kept of water temperature, moults and mortalities in each tank. Individual weights were recorded for lobsters at the beginning and end of the experiment.

## Statistical analysis

Data for survival, weight gain, daily growth coefficient (DGC), tank biomass and number of

**Table 1.** Formulation and chemical composition of the moist feed used in the experiment

Ingredient	Formulation	
	(g/kg as used)	(g/kg on dry-matter basis)
Fishmeal (Aqua-grade) <sup>a</sup>	140	127
Krill (spray-dried) <sup>b</sup>	85	77
<i>Perna canaliculus</i> <sup>c</sup>	268	33
<i>Sillago ciliata</i> <sup>c</sup>	293	33
Wheat gluten <sup>d</sup>	45	41
Starch	4.2	3.6
Supplements <sup>e</sup>	39.0	31.7
Total	875	346
Crude protein (CP; %)		48.0
Digestible CP (%)		43.7
Total lipid (%)		9.3
Phospholipid (%)		1.5
Cholesterol (%)		0.6

<sup>a</sup> Peruvian fishmeal, >67% CP

<sup>b</sup> Antarctic krill, Inual Santiago, Chile

<sup>c</sup> Homogenised *Perna canaliculus* (green-lipped mussel) and *Sillago ciliata* (whiting) flesh

<sup>d</sup> Vital gluten, 76% CP

<sup>e</sup> Provided in the diet (g/kg): carophyll pink (10% astaxanthin), 0.8; cholesterol, 3; soy-lecithin (70%), 12.5; choline chloride (70%), 0.25; ethoxyquin, 0.25; vitamin premix (Williams et al. 2004), 11; and trace mineral pre-mix (Williams et al. 2004), 5

moulted were analysed using a one-way analysis of variance (ANOVA) in accordance with the design of the experiment. Differences between treatments were tested for significance using Fisher's protected *t*-test (Snedecor and Cochran 1989) wherein differences between means were examined only when the *F*-test of the ANOVA was significant ( $P < 0.05$ ).

## Results and discussion

Survival was higher for the solitary compared to the communal treatment, 89% and 72%, respectively, but this difference did not attain statistical significance ( $P > 0.05$ ) (Table 2).

Communal lobsters grew 44% faster ( $P < 0.05$ ) than solitary lobsters but total lobster biomass was not significantly different between housing treatments. Although not significantly different between treatments, the higher survival of solitary-housed lobsters resulted in the two treatments having a similar end biomass although the communally housed lobsters had a much higher final mean weight, 6.4 g compared to 4.7 g, respectively. A comparable survival rate of 75% for communally housed lobsters was observed in a cholesterol requirement experiment study (S.J. Irvin and K.C. Williams, unpublished data) using similar-size small *P. ornatus* (1.8 g).

In the present study, all mortalities in the solitary treatment were due to moult death or incomplete moult (Figure 3). In each case, there was splitting of the carapace dorsally between the cephalothorax and abdomen and the successful withdrawal of the swimming and walking legs from the old carapace. However, complete separation did not occur between the gills and cephalothorax. It is suspected that this may have been due to inadequate energy reserves and/or carryover effects of some recent

near-catastrophic event with death occurring when the lobster attempted to moult. This probably also occurred with the communal lobsters treatment but this was not evident because the deceased lobsters were rapidly cannibalised.



**Figure 3.** Lobster from the solitary housed treatment that died during moulting with incomplete separation of the cephalothorax and gills

## Survival

The difference in the survival of lobsters between the two housing treatments (17%) was most likely due to lobsters in the solitary treatment having sufficient unmolested time to complete the moulting process or to recover after a partial moult. In the latter case, moulting extended over a 24-hour period before complete separation between the gills and cephalothorax was achieved, whereas a normal moult would typically be completed in less than 30 minutes. In the communal treatment, these weak, partially moulted lobsters had no protection to recuperate and likely became the victim of opportunistic cannibalism. The primary cause of mortality is

**Table 2.** Productivity responses of lobsters to housing treatment

Factor	Housing		
	Solitary	Communal	± SEM
Survival (%)	89 <sup>A</sup>	72 <sup>A</sup>	5.93
Mean final weight (g)	4.7 <sup>B</sup>	6.4 <sup>A</sup>	0.25
Weight gain (%)	134.0 <sup>B</sup>	217.5 <sup>A</sup>	7.93
DGC (%)	0.71 <sup>B</sup>	1.02 <sup>A</sup>	0.2
Tank biomass (g)	25.5	27.7	3.54
No. of moults	2.25 <sup>A</sup>	0.70 <sup>B</sup>	0.19

Note: <sup>A,B</sup> Within rows, means with different letters differ significantly ( $P < 0.05$ ); SEM = standard error of the mean; DGC = daily growth coefficient

thus most likely due to a nutrient deficiency and/or insufficient nutrient reserves, with cannibalism a secondary factor affecting weak and susceptible lobsters. None of the lobsters that survived partial moult, moulted again, so the long-term outlook of those lobsters is unknown. However, failure to recover from an unknown nutritional deficiency is likely to result in the recurrence of prolonged moult duration or death. It is possible there is a relationship between lobster vitality and settlement time, with lobsters that settle early in the season being more robust with higher survival rates. This may be due to late settlers arriving in a highly depleted state, after a prolonged journey through to the puerulus stage. This hypothesis could be tested by determining the nutritional and ionic status of the haemolymph of pueruli settling at different times during the season and relating this to subsequent grow-out survival success.

## Growth

There was a marked effect of housing treatment on the growth of lobsters. Those in the communal treatment grew much faster, 62% or 44% as measured by weight gain or DGC, respectively, than lobsters in the solitary treatment. These findings contrast with results for the temperate crayfish *Pacifastacus leniusculus* where growth and food intake decreased when they were housed communally (Ahvenharju and Ruohonen 2007). Their result was attributed to the crayfish having a strong hierarchy with more frequent agonistic interactions when housed communally. The more robust chelipeds of the crayfish would also be likely to cause more damage than the feeding and walking appendages of the spiny lobster. It is possible that the better growth of the lobsters in the communal cage is due to the cannibalised animals providing an unintended fresh-protein source for the surviving lobsters, a theory supported by Thomas et al. (2003) in a study on the behaviour of captive *Jasus edwardsii* lobster. Alternatively, feeding activity in the communal group may have been more actively stimulated by the presence of feed than in the solitary lobsters where there was no competition for food.

## Comparison of housing issues

The final lobster biomass for the two housing treatments was not significantly different—the

higher survival but slower growth of the solitary lobsters being matched by the lower survival but faster growth of the communal lobsters. However, if the trend for solitary lobsters to have higher survival were to continue for some time beyond that examined in this experiment, it is possible that final biomass would be higher for the solitary treatment animals. Nevertheless, as already noted, lobsters with an extended moulting event did not display any further moults during the course of the experiment and thus their long-term survival success is unknown.

Lobsters in the solitary cages appeared to have moulted significantly more times than those in the communal cages, 2.25 and 0.70, respectively. However, this result is an artefact in that the rapid consumption of freshly moulted exuviae for the communal treatment may not have been noticed and recorded as a moult event. Lobsters typically moult during the evening or early morning with the exuviae being rapidly consumed by other lobsters before the morning observations. Lobsters can grow only by moulting: communally housed lobsters more than tripled their weight (218%) as opposed to a doubling for the solitary lobsters (134%). Therefore it is likely that the communally housed lobsters moulted many more times than solitary-housed lobsters but evidence of these events had been eliminated.

## Conclusion

Due to the high market value of *P. ornatus*, solitary housing during the nursery stage is likely to be economical. However, mortalities are primarily due to an unknown nutritional or captivity-related stressor, with cannibalism only a secondary factor. The identification of this primary factor should be the focus area for future investigation. Moreover, future experimentation should concentrate on very small, recently settled lobsters (0.1–0.5 g) as it is at this size that lobsters appear most vulnerable and at which overcoming early mortality will have the greatest industry benefit.

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## Session 3: Lobster grow-out culture systems

Photo: Kevin Williams, CSIRO Marine and Atmospheric Research



Dr Clive Jones, Queensland Department of Primary Industries and Fisheries, examining subadult *Panulirus ornatus* on a lobster farm in Khanh Hoa province, Vietnam

# Requirements for the aquaculture of *Panulirus ornatus* in Australia

Clive Jones and Scott Shanks<sup>1</sup>

## Abstract

Interest in the development of aquaculture of the tropical spiny lobster *Panulirus ornatus* (ornate spiny lobster) has increased markedly over the past 10 years because of strong market demand and high prices. In Australia, economic conditions will necessitate that a semi-intensive approach be taken for grow-out, possibly involving managed environmental conditions, and unlike the seacage approach employed in Vietnam and Indonesia. Identification of environmental requirements, appropriate husbandry, culture systems and feeding specifications will be necessary to establish commercial production technology that will be economic in Australia. Such investigations have been made over the past several years and are summarised here. With the establishment of hatchery technology for this species now close at hand, Australia is in a position to develop a lobster grow-out industry, independent of wild lobster resources and capable of substantially increasing current production from fishing.

**Keywords:** spiny lobster; shelter; stocking density; husbandry; nutrition; culture; grow-out

## Introduction

A small and valuable fishery for the tropical lobster *Panulirus ornatus* (ornate spiny lobster) operates in the coastal waters off the north-east coast of Australia and in the Torres Strait between Australia and Papua New Guinea. Between 500 and 1,000 t of whole lobster are caught each year, which are primarily marketed live into China, where they are consumed as a sashimi (uncooked) product. The market specifically seeks *P. ornatus* because of its large size, vibrant shell colour, and the pearly lustre, firm texture and sweet taste of the flesh. The fishery is well managed and fully exploited (Dennis et al. 2004), so increasing demand for the species can be supplied only from aquaculture.

In Vietnam, this species is successfully cultured in sea cages from wild-caught juveniles (Williams 2004) and an equivalent industry is now developing in Indonesia. This low-technology approach is effective under the prevailing economic conditions but, in Australia, higher costs for labour, materials and legislative compliance will necessitate a more intensive culture method, possibly including managed environmental conditions. This will require a sound understanding of the environmental and biological requirements of the species and identification of optimal conditions for maximum growth and survival.

From 2000 to 2008, investigations were made of the grow-out requirements for *P. ornatus* in Australia. These included assessments of environmental factors, husbandry requirements, culture systems and feeding, which have resulted in a sound understanding of the commercial requirements for development of a grow-out industry in Australia. These investigations and their outcomes and recommendations are summarised here.

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## Research methods

### Tank specifications

The bulk of the information presented in this paper was generated through structured experiments within tanks at the Northern Fisheries Centre in Cairns, Australia. A variety of tanks was used depending on the nature of the treatments and size of lobsters used. Recirculation systems were employed where water-quality characteristics were investigated, e.g. temperature and salinity. In all other instances, clean, filtered sea water was provided on a flow-through basis. For experiments with juvenile lobsters, and running over relatively short durations (<100 days), the tanks were small, less than 1 m<sup>2</sup>, while for experiments with larger lobsters, or extending for long periods, a large tank system was used, providing approximately 2 m<sup>2</sup> per experimental unit. All experiments were conceived and planned with commercial production in mind, including considerations such as relevant densities and practical feeding arrangements.

### Experimental animals

Lobsters used in the experiments were either purchased from the commercial fishery in Queensland or hand-collected by our research team. The minimum legal size for the local *P. ornatus* fishery is approximately 600 g, and such pre-adult lobsters are well suited to experimentation applied to their growth through to the minimum acceptable market size of 1 kg. Production of pueruli from research hatcheries was nonexistent at the outset of this research, and today is still inconsistent and small-scale. For experimentation on postpuerulus and juvenile lobsters, it was necessary to collect them from the wild. A variety of methods and locations was tried over successive years, and the most consistent success came from hand-collection from wharf pylons in Trinity Inlet in the port of Cairns, during periods of extreme low tide. At such times, the biofouling on the pylons becomes exposed and from this, postpueruli and small juvenile lobsters can be easily observed and removed. The bulk of such natural recruitment occurs from July to November each year. Interannual variability in abundance was high, so in some years several hundreds of small lobsters were captured, while in other years less than 100 could be caught. Because

of the small numbers available in some years, some experiments described below had no replication.

### Feeding protocols

Nutrition and feeding practices for *P. ornatus* have been the subject of specific research and over the period encompassed by this report (see papers in these proceedings), diet formulations were developed, as reported below. However, at the beginning, no commercial lobster diet was available so that the standard diet applied to the experiments consisted of commercial shrimp pellets, either those formulated for *Penaeus japonicus* or for *P. monodon*. These pellets appeared to be well accepted by large *P. ornatus* and were fed daily ad libitum, supplemented with fresh fish, crustacean or mollusc flesh once or twice a week. It became clear through the first several experiments using small lobsters that this diet was less than optimal and, in some cases, dietary factors masked treatment effects of the experiments. Where this has been an issue, it is highlighted in the reporting below.

Over the several years of experimentation, sufficient information was accumulated to define commercial production protocols for extension to a commercially relevant scale and setting. At the time of reporting, one field trial had been completed, and a series of such trials are planned for future research.

### Analyses

For most of the experiments, size (weight and/or carapace length) and survival data were analysed using the Genstat software program (Anon. 2007). A variety of growth statistics was used, including specific growth rate (SGR) based on carapace length or weight and daily growth coefficient (DGC) measured using weight data as per Bureau et al. (2000) and Cho (1992). On some occasions, to provide comparative data to other studies, growth was expressed as g/week.

$$\text{SGR} = (\ln FBW - \ln IBW) / D \times 100 \quad (1)$$

where:

$\ln FBW$  = natural log of final weight (or carapace length),

$\ln IBW$  = natural log of initial weight (or CL)

$D$  = duration of the growth period in days.

$$DGC = 100 \times (FBW^{1/3} - IBW^{1/3})/D \quad (2)$$

where:

$FBW$  = final body weight (g)

$IBW$  = initial body weight (g)

$D$  = duration of the growth period in days.

## Environmental requirements

### Temperature

Lobsters are thermo-conformers or poikilotherms and as such their growth rate is directly correlated with the temperature of their environment (Hartnoll 2001) to a point beyond which growth rate may rise further, but mortality increases. Optimal temperature must be identified as that at which growth is maximised relative to survival.

An experiment was performed by Jones (in press) in which juvenile *P. ornatus* lobsters were grown in tanks at five temperatures (19, 22, 25, 28 and 31 °C). Growth was significantly affected by temperature ( $P < 0.01$ ) and maximal growth occurred at 25–31 °C. Examination of the temperature effect on moult increment and intermoult period (Figure 1) indicated that 27 °C was the optimal temperature at which moult increment was greatest and intermoult period the least. Temperature also had a significant ( $P < 0.01$ ) positive effect on apparent feed intake. Overall, growth and survival of lobsters will be maximised if they are cultured at 25–28 °C.

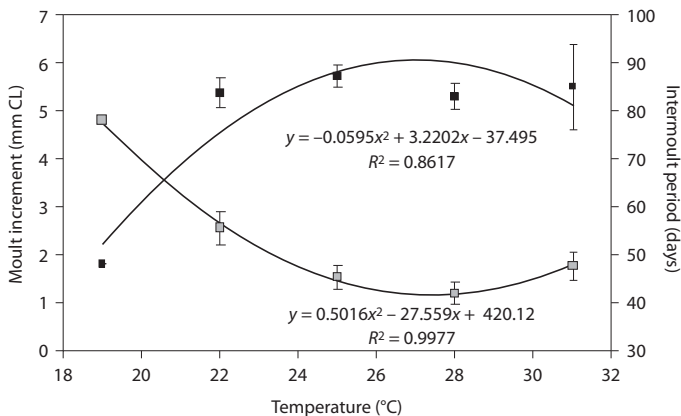
### Salinity

Although *P. ornatus* may be considered a reef-dwelling, fully marine lobster, examination of its capacity to withstand less than fully marine salinities may provide a significant expansion of potential sites and system requirements for commercial cultivation.

In an experiment reported by Jones (in press), juvenile lobsters were exposed to four different salinities (20, 25, 30 and 35 parts per thousand; ppt) for 91 days. Significant differences ( $P < 0.01$ ) were apparent for both survival and growth. Lowest survival occurred at 35 ppt, which was attributed to higher cannibalism at that salinity. Growth was highest at 35 ppt and progressively less at lower salinities. Although full marine salinity (35 ppt) clearly generated the best performance of *P. ornatus*, its capacity to tolerate reduced salinity provides greater opportunity to develop commercial aquaculture. For example, the prospects of lobster grow-out in shrimp-farming water and systems, where salinity fluctuations are common, may be viable.

### Water quality

Other aspects of water-quality requirements for *P. ornatus* have not been specifically assessed. However, a field trial of *P. ornatus* grown in shrimp pond water in northern Australia (Jones and Shanks



**Figure 1.** Moulting increment (mm carapace length (CL)  $\pm$  standard error (SE), solid squares) and intermoult period (days  $\pm$  SE, open squares) of *Panulirus ornatus* juveniles grown at five temperatures. Curves represent polynomial regression equations.

2008) demonstrated that the species is tolerant of turbid water with elevated levels of suspended solids and nutrient loading including high productivity of both phyto- and zooplankton species. *Panulirus ornatus* performed at equivalent growth rates and survival as those in tank systems with clear, filtered sea water, suggesting it can be produced in situations exposed to strong terrestrial influences, such as shrimp ponds.

## Husbandry

### Density

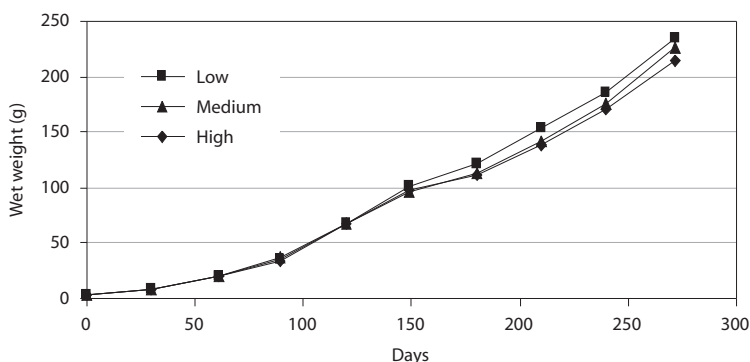
Jones et al. (2001) reported on a density experiment for juvenile *P. ornatus*. Small lobsters ( $3.24 \pm 0.09$  g) were stocked at three densities (14, 29 and 43 lobsters/m<sup>2</sup>) within each of four 4,000 L fibreglass raceway tanks with flow-through seawater supply. They were provided with shelter consisting of opaque plastic sheet (400 mm × 400 mm) supported on 100 mm legs, and were fed continually through the night with a commercial penaeid shrimp (*P. japonicus*) diet, supplemented with prawn flesh once per day. Growth and survival were monitored by monthly sampling of 20 lobsters from each experimental unit. After 272 days, survival was not significantly different between densities, and averaged 52.5%. Lobster size was also unaffected by density, and mean size for all lobsters was 225.3 g at harvest (Figure 2). Mortality was consistent through time, and was almost entirely attributable to cannibalism of postmoult individuals. It is hypothesised that the cannibalism was due to inappropriate shelter and feeding strategy. Despite

higher mortality than anticipated, growth was rapid, representing a specific growth rate of 1.56%/day (equivalent to 5.7 g/week), sufficient to permit growth from 3 g to 1 kg within 18 months. The experiment confirmed the excellent potential of *P. ornatus* for commercial aquaculture.

*Panulirus ornatus* is clearly tolerant of high density conditions, and grew well at all the densities applied (maximum 43 individuals/m<sup>2</sup>) and the biomass levels that those densities represented (maximum 4.7 kg/m<sup>2</sup>). Given the lack of any significant differences in either survival or weight at harvest between densities, there may be scope for increasing density to higher levels than applied in this experiment. From a commercial perspective, higher densities would be more economic, which may offset any concomitant decrease in survival. Figure 3 depicts high-density grow-out of lobster in tank systems.

### Shelter

Culture experiments with *P. ornatus* in land-based systems to date have confirmed the importance of shelter within the culture environment. In the initial work which examined other issues, the degree of importance of shelter was assessed only subjectively by observation (by the authors). Those observations suggested the primary value of shelter to lobsters was in maximising survival through satisfying an intrinsic behavioural requirement and thereby mediating stress, and by minimising agonistic interactions and cannibalism. A further consideration regarding shelter is size-specific requirement. As aquaculture of *P. ornatus* involves



**Figure 2.** Mean weight of *Panulirus ornatus* lobsters grown at three densities over 272 days

growth from small postlarval stages of less than 1 g to in excess of 1 kg, shelter requirements may need to be determined for each of several size ranges. Dennis et al. (1997) showed that shelter specifications and lobster size are strongly correlated. Availability of shelter in relation to density of lobsters must also be considered in maximising the value of shelter provided while minimising the cost (materials, labour, maintenance etc.).

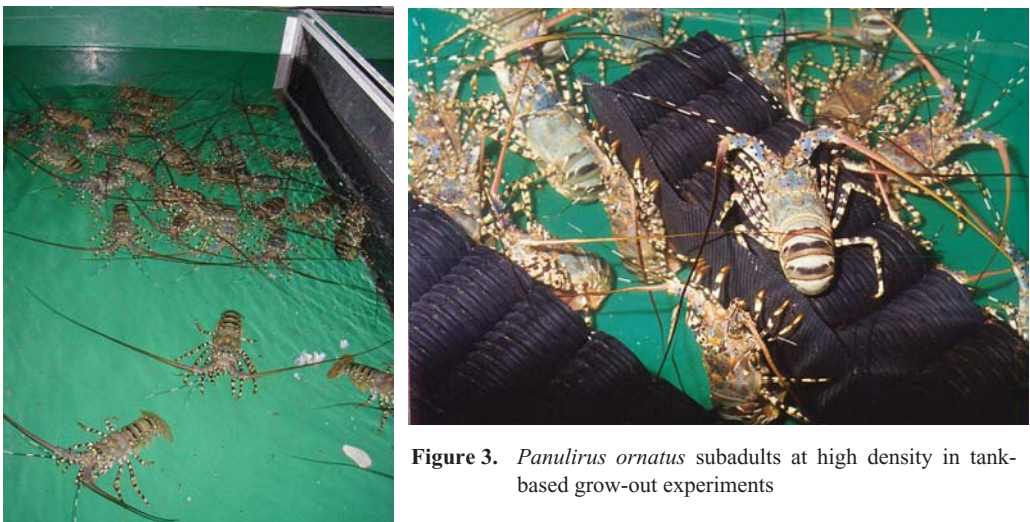
The presence of shelter provides not only a darker environment but one which can be a haven from predators. In juvenile *P. ornatus* rearing, cannibalism usually occurs post moult and adequate shelter type can provide a refuge during this period. Cannibalistic behaviour has been significantly reduced in temperate *Jasus edwardsii* when given a nutritionally adequate diet and provided with shelter (Crear et al. 2000). Requirements and preference for type of shelter in juvenile lobster rearing may be different from those in the wild and may also change with age (Kittaka and Booth 1994).

In our first attempt to specifically assess shelter requirements for *P. ornatus* (Jones 2007), an experiment was performed using a small pool of available lobsters to examine two fixed-structure shelters with different hole diameters to test the hypothesis that hole diameter is an important shelter characteristic. There were insufficient lobsters to enable replication. The two shelter types consisted of a stack of plastic (polyethylene) pipes with 60 mm diameter holes, and clay house bricks with holes of 27 mm diameter (Figure 4a). Lobsters stocked were 7.1 g

(mean  $\pm$  0.9 g standard error; SE), and their maximum width was considerably less than 27 mm, so they were easily able to inhabit either shelter type. Although there were no differences in either survival or growth between the two shelter types, survival overall was high (67–83%) and growth was high (DGC > 2.0%/day). Observation suggested that the brick shelter with the smaller hole was preferred.

Subsequently, for a more rigorous test of the value of shelters, an experiment was performed (Jones and Shanks 2008) to examine the effect of presence or absence of shelter and of shelter type (mesh bundles versus concrete blocks with holes; Figure 4b) for small juvenile lobsters in the range of 1–2 g. This experiment applied a stocking density of 38 lobsters/m<sup>2</sup> and four replications. Shelter did affect survival significantly, with the mesh bundle style shelter enabling survival of 92% (over 48 days) compared to 67% with the concrete block shelter and 59% with no shelter at all. There was no shelter effect on growth.

Other studies of the effects of shelter provision on cultured crustaceans have also shown a significant impact on survival (Crear et al. 2000; James et al. 2001; Jones et al. 2001), and generally little or no effect on intrinsic growth. The improved survival is likely to be related to a reduction in cannibalism, as the shelter affords opportunity to avoid or at least minimise interaction during moulting, when lobsters are most at risk of being attacked. The mesh bundle appears to provide the cryptic habitat preferred by the small lobsters and an extra degree of cloaking that the concrete block does not. This suggestion is



**Figure 3.** *Panulirus ornatus* subadults at high density in tank-based grow-out experiments

well supported by the observations of Dennis et al. (1997) for juvenile *P. ornatus* in the wild. Further confirmation is the findings of Chau et al. (2009), where higher lobster survival was observed when juvenile *P. ornatus* were provided with a mesh bundle shelter rather than other shelter types.

On the basis of results to date, use of mesh bundle shelters is recommended, particularly for the smallest lobsters from postpuerulus through to 10 g. For larger lobsters, the effect of shelter provision may be less significant, although still justified.

### Size grading

Uniformity of size can have a significant impact on the overall productivity of an aquaculture species grown under high-density conditions. Where size-related hierarchical behaviour occurs, the size variation of animals at stocking can have a significant effect on survival and growth. As size grading is not typically applied in the Vietnamese lobster grow-out industry, it is important to determine if the practice would provide a benefit, particularly for Australia where more intensive farming using higher densities might be employed.

An experiment was designed to examine the effect of size grading of juvenile *P. ornatus* lobsters on their growth and survival. The hypothesis was that a narrow size range within a collective group of lobsters may benefit the overall survival and growth of that group, and that regular size grading might be a useful tool in improving productivity of commer-

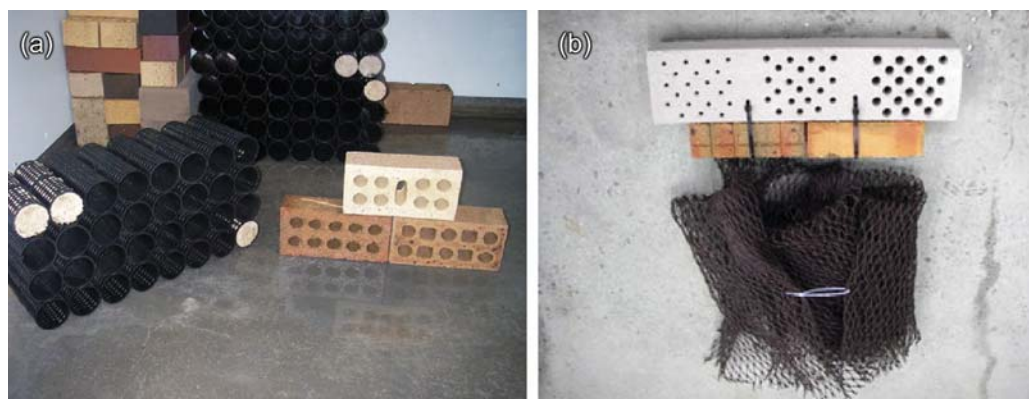
cial operations. Four lobster sizes were selected such that the size distribution was either 20, 40, 60 or 80% from the mean size. Lobsters were equally stocked to the tanks within these size groupings with four tank replicates per treatment. Unfortunately, the pool of lobsters available at the time was too small to enable the treatment groups to be established with equal means. Furthermore, size distribution for treatments was non-normal.

Productivity of lobsters in the experiment was substantially less than would be accepted on a commercial basis. Although there was no significant difference in survival, which ranged from 50% to 65% over 83 days, there was a trend of increasing mortality with increased size variance. Specific growth rates ranged from 1.72%/day to 1.98%/day, but there was no significant difference between treatments. The experiment's results were confounded by the inconsistencies in means and size distribution at the outset. Nevertheless, the results did suggest there may be a survival benefit in grading. Further examination of grading is warranted.

### Feeding

#### Background

Early experience in the culturing of lobsters in tanks demonstrated that cannibalism was particularly acute during the earliest stages of the growth cycle. For larger lobsters, the frequency of feeding had a significant impact on survival (Jones et al. 2003) and this was attributed to a reduction in canni-



**Figure 4.** Shelter types used in shelter experiments with *Panulirus ornatus*. Plastic pipe stacks (hole diameter 60 mm) and bricks (hole diameter 27 mm) (a) were used in the first experiment. A perforated concrete block and mesh bundle (b) was used in the second experiment.



balism. Information from other feeding frequency studies of crustaceans has been mixed. Cortes-Jacinto et al. (2003) found feeding four to six meals per day to juvenile *Cherax quadricarinatus* (redclaw crayfish) improved growth rate and survival relative to fewer meals per day. Similarly, Sedgwick (1979) and Robertson et al. (1993) demonstrated increased growth rates in shrimp fed more frequently each day. In contrast, Thomas et al. (2003) found, for juvenile *J. edwardsii* lobsters, feeding more than once per day provided no benefit to survival or growth. For juvenile *P. ornatus*, it was hypothesised that continuous or frequent introduction of fresh pellet food through the night, when lobsters are most actively foraging, would satiate appetite and minimise predation on vulnerable, postmoult individuals, particularly in light of the limited period for which immersed pelleted feeds remain attractive (Williams et al. 2005).

#### *First feed experiment*

As Williams et al. (2005) demonstrated that a combination of mussel flesh and pelleted shrimp diet generated the best growth for juvenile *P. ornatus*, we also chose to use both food sources. In the first of two experiments, lobsters were provided with mussel flesh each day in the late afternoon, after which a pelleted shrimp diet (formulated for *P. monodon*) was introduced either as a single meal or as a 12-hour trickle from an automatic belt-feeder. In a subsequent experiment, the flesh component was provided either in the late afternoon, or in the early morning, with pellets at the other times.

For the initial experiment, survival was quite poor for both treatments, with almost 40% mortality within the 30-day period of the experiment. The mortality was primarily attributable to cannibalism, as evidenced by lack of moribund individuals that would likely have been seen if death was due to health-related causes. Although the provided shelters were relatively massive given the small size and low number of lobsters, they may have been inadequate in providing refuge for moulting individuals. The provision of a regular supply of food, for the continuously fed treatment, was also inadequate to overcome the cannibalistic tendency of intermoult lobsters to prey on their captive brethren.

Although the particular pellet food used had been effective in other studies of the same species for larger-size lobsters (Jones et al. 2001), in this experiment it appeared not to be attractive, while the

supplemented mussel flesh (fed in the morning) was more completely consumed. The results suggested that the attractiveness and suitability of the diet should be confirmed and alternatives considered before repeating the experiment to conclusively determine the efficacy of frequent feeding for postpuerulus *P. ornatus*.

Growth rates during the experiment averaged 0.48%/day (DGC). This is substantially lower than that of juvenile *J. edwardsii* in which DGC ranged from 0.54%/day to 0.85%/day (calculated by deduction) (Thomas et al. 2003), and of 0.72%/day to 1.38%/day for *P. ornatus* (Smith et al. 2005), although in both cases the data represent considerably larger lobsters with initial weights of 5.3 g and 2.5 g, respectively. Glencross et al. (2001) reported growth rates of 0.31%/day to 1.46%/day DGC for *Panulirus cygnus* initially stocked at 0.5 g. Notwithstanding the likelihood that the growth rate for this immediate postpuerulus stage is less than subsequent stages, as the growth curve follows a typical sinusoidal model (Aiken 1980), the growth of *P. ornatus* in our study was low, and likely to be greatly improved under better conditions. Dennis et al. (1997) reported growth rates equivalent to 1.9%/day DGC for wild juvenile *P. ornatus* (4 g and above), and equivalent growth rates will need to be achieved for captive lobsters before economically viable aquaculture can be established.

Although the experiment did not provide conclusive evidence of the benefit of frequent feeding, further examination of this issue was considered warranted to minimise mortality, particularly in regard to cannibalism.

#### *Second feed experiment*

In the subsequent experiment, there was no significant difference for survival or growth between the two treatments, although feeding of flesh at dusk (instead of in the morning) appeared to provide a small benefit for both survival and growth. Mortality was relatively high for both treatments, and again was attributable primarily to cannibalism. The result, however, suggests that feeding flesh at dusk may help to mitigate against cannibalism by satisfying hunger before the most active evening period when the risk of cannibalism may be at its highest.

Growth rates were in excess of 1%/day expressed as DGC for both treatments, a marked increase over that recorded for the earlier-stage postpueruli in the

first experiment. This suggests that the diet and feeding strategy may have been more effective, although the nutritional influence of cannibalism must also be considered. The relatively high mortality suggests that other aspects of the culture environment and husbandry were not optimal, and that these factors may have masked the effect of the feeding strategy treatments. We hypothesised that these factors were most likely: 1. the suitability of the diet; and 2. the nature of shelter provided.

#### Assessing feed formulations

A subsequent experiment was designed to trial diet formulations arising from parallel nutrition research (Williams 2007). The initial assessment (Jones 2007) aimed at providing a basal diet to provide adequate nutrition for all subsequent experiments. Two formulations manufactured locally in our laboratory were compared with the standard shrimp pellet used previously.

Results were conclusive and demonstrated the newly formulated diets were superior. Isolating what we believed were the best characteristics of the two formulations, we defined a practical diet for further evaluation (Table 1).

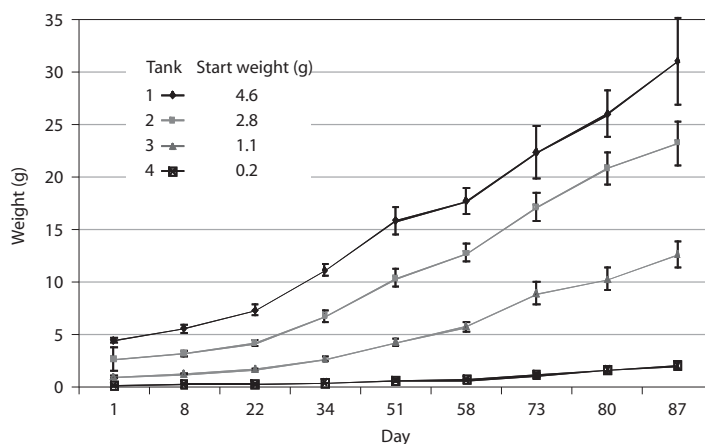
A non-replicated experiment was performed using four tanks stocked at mean weights of 0.23, 1.07, 2.76 and 4.57 g. Survival over 87 days averaged 65% and growth was strong (Figure 5). This diet formulation was considered to be very effective and was used subsequently for all experiments including field trials.

#### Culture systems

Although the grow-out of *P. ornatus* in Vietnam has been successfully developed using sea cages exclusively (Williams 2004; Jones and Williams 2007), the development of a lobster grow-out industry in Australia will necessitate that other

**Table 1.** Ingredient composition of basal diet for *Panulirus ornatus* experimentation

Ingredient	Inclusion (%)	Ingredient cost (A\$/kg)
Ground shrimp pellets ( <i>Penaeus monodon</i> grower)	34.5	1.00–1.50
Krill meal (dry)	15	2.90
Shark or tuna flesh/bloodline (wet)	24	1.00–3.00
Mussel flesh (wet)	24	10.00
Fish oil	1	2.00/L
Transglutaminase binder	1	152
Carophyll pink	0.5	337
Water	1–3	



**Figure 5.** Effect of initial size of juvenile *Panulirus ornatus* lobsters on subsequent growth with lobsters were fed a locally manufactured pellet diet as per Table 1

grow-out systems are assessed. Preliminary economic analysis (Kenway 2009) has suggested that, in Australia, use of sea cages may be significantly more expensive than land-based systems such as ponds, raceways or tanks. Furthermore, the establishment of sea cages along the Queensland east coast may be more problematic than land-based systems because of restrictions within the Great Barrier Reef Marine Park.

Although neither a hatchery-produced nor wild-caught supply of juveniles is currently available, preliminary assessment of grow-out systems is prudent in advance of confirmation of that supply, to expedite industry development. The Australian *P. ornatus* fishery catches lobsters from 600 g upwards, although maximum value (>\$A60/kg) is reached for lobsters over 1 kg. Grow-out trials of lobsters in the 600 g – 1 kg range, which are readily available from the fishery, provide an opportunity to determine the suitability of various culture systems. The first system examined involved the production of lobsters in shrimp pond water.

#### *Pond culture trial*

Earthen ponds are used along the coast of northern Queensland for the commercial production of shrimp (primarily *P. monodon*) and *Lates calcarifer* (barramundi). There is considerable opportunity for expanding this sector and it would likely benefit from diversification to other species. Grow-out of lobsters in such systems is an attractive option as it has immediate commercial viability and will require minimal technology development. The first step was to assess *P. ornatus* capacity to tolerate typical shrimp pond conditions, characterised by variable salinity, high turbidity and nutrient-rich water.

A trial was performed at a commercial shrimp farm north of Cairns, Queensland, which provided access to their seawater-intake channels (Jones and Shanks 2008). Although separated from the shrimp populations in the ponds, the sea water was of equivalent quality. The trial did not involve experimental treatments, but applied best management practice to a number of replicated groups. The objective was to establish baseline growth and survival data for *P. ornatus* under shrimp pond conditions. The trial system consisted of four rectangular cages, 1.8 m × 1.8 m × 0.9 m deep, suspended from the surface using a floating frame. The cage mesh was made from knotless netting of 15 mm mesh size. Each cage was covered with a lid made from 90% shade-

cloth. Cages were each stocked with 20 lobsters (6.17/m<sup>2</sup>) of mean size 750.2 ± 6.0 g. A control group of 13 lobsters (mean size 717.8 ± 9.4 g) was stocked to a fibreglass tank at the Northern Fisheries Centre and managed similarly.

Diet consisted of a manufactured 7 mm pellet food using the formulation described above (Table 1). Food was provided twice daily at an initial ration of 3% of biomass per day (dry weight equivalent), and this was adjusted on the basis of observation. A feeding tray was positioned on the cage floor for the placement of the feed. Aeration was provided by a paddlewheel aerator located within the channel, 10 m upstream from the cages. Cages were removed from the water at monthly intervals for cleaning. Lobsters were removed from each cage, counted and weighed, and then returned to the same cage once cleaning was completed.

The condition of the lobsters at the time of stocking was relatively poor, due to prior protracted holding at low temperature (<20 °C) in a live-holding facility in Cairns. The poor condition at stocking was worsened by the cages being too deep, such that the cage bases, and therefore the lobsters, were positioned on the sediment of the channel for extended periods at low water. Consequently, at the first cage cleaning, lobsters appeared lethargic and in poor condition, and tail fan necrosis was evident. Lobsters were not weighed at this time.

Subsequently, the depth of cages was reduced to lift them from the sediment, and the condition and growth of the lobsters improved significantly. Growth over the entire trial period was good (Figure 6) and comparable with the best previously achieved in tanks (Jones et al. 2001) in Australia and with that in sea cages in Vietnam (Williams 2004). Growth expressed as DGC averaged 0.43%/day for the cages and 0.50%/day for the tank. This was equivalent to 7.9 g/week and 9.2 g/week, respectively. Mean survival 77.5% in the cages and 100% in the tank.

Due to the loss of some pellet food through the cage floor, the use of a standard feed conversion ratio (FCR) statistic does not accurately reflect the consumption nor efficiency of the diet. Nevertheless, as a guide to the relative effectiveness of the diet, FCRs were calculated and compared between the cages and the control tank. FCR across all cages averaged 15.4:1, while that of the tank population was 9.5:1. Although the diet appeared attractive, well bound and was actively sought by the lobsters,

these FCRs would need to be significantly improved for commercial acceptance. A smaller mesh size on the floor of the cage is an obvious first step to minimise losses.

There appeared to be no moulting and no individual growth during the first month. Subsequently, moulting appeared to be synchronised to the extent that distinct peaks in moulting occurred across all cages, with intervening periods of little or no moulting. The cage moult frequency was also synchronised to the tank population. Subsequent to periods of increased moulting, food consumption increased significantly, dropping shortly before the next moulting event. Tail fan necrosis disappeared entirely by the end of the trial. Water quality remained acceptable throughout the trial, although dissolved oxygen levels were variable and ranged from 4.2 to 7.5 parts per million (ppm). Salinity ranged from 28 to 35 ppt.

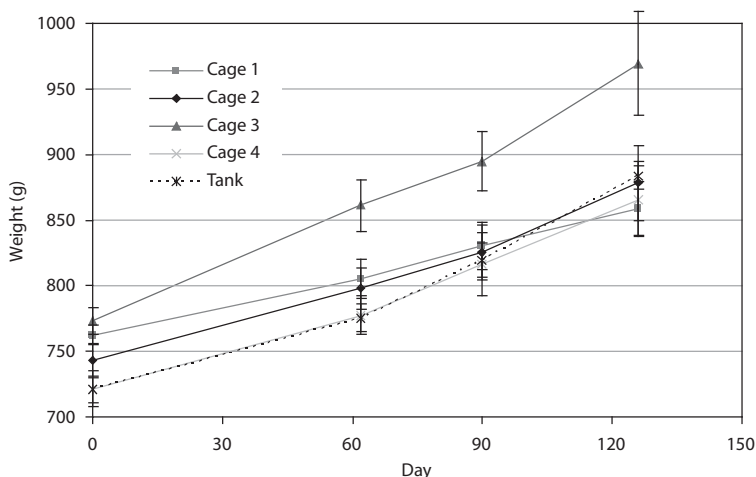
The trial confirmed that subadult *P. ornatus* can be successfully cultured under estuarine shrimp farm conditions. Although salinity remained relatively close to normal marine levels due to the absence of significant rainfall during the trial period, previous research (see above) suggests that significantly lower salinities will be tolerated by this species (Jones, in press). Water-quality conditions were otherwise typical of a shrimp farm environment in northern

Australia, with fluctuating dissolved oxygen, high turbidity and slightly alkaline water. Although this differs substantially from typical *P. ornatus* preferred reef habitat, growth and survival were good, and lobsters harvested after 126 days of culture were vibrant in colour, vigorous and very clean. Subsequent marketing indicated they attracted the equivalent price of wild-caught lobsters in the local marketplace.

## Future studies

Having established that *P. ornatus* will not only tolerate but can thrive under shrimp pond conditions, subsequent trials will need to examine the manner in which they are held. Such examination will necessarily include cages versus free-range, cage materials and specifications, and provision of shelter. The recommended practices as outlined throughout this report from experimentation will need to be verified under pond conditions. Furthermore, the suitability of growing smaller lobsters from postpueruli through to the sizes used in this trial will need to be examined.

Alternative systems should also be assessed. The productivity of lobsters in the various experimental tank systems suggests that commercial-scale tank systems would provide suitable conditions, whether



**Figure 6.** Comparison of the growth of subadult *Panulirus ornatus* lobsters held either in sea cages suspended in the intake water of a north Queensland shrimp farm (cages 1–4) or in an on-land tank at the Northern Fisheries Centre when lobsters were fed a locally manufactured 7 mm pellet diet as per Table 1

on flow-through or recirculation. Clearly, such systems would be more expensive to build and operate than a pond-based approach. Nevertheless, they may also enable higher density and greater system control, resulting in enhanced productivity that is economically justified.

Personal observation of farmed *P. ornatus* from Vietnam in the wholesale fish markets of Hong Kong in 2008 indicated that the product is clearly distinguished from fishery product from Australia, Indonesia and Philippines, due to its dull colouration and poor vigour. If farming of tropical lobster in Australia is to be successful, economics will necessitate that the product is as good as or better than the fishery product to ensure premium market price. The early indications from field trials are encouraging that production of tropical lobsters on a formulated diet, in land-based systems, may be viable.

## Acknowledgments

The authors wish to acknowledge the commitment and enthusiasm of the entire lobster research team at the Queensland Department of Primary Industries and Fisheries (QDPIF) Northern Fisheries Centre, past and present, who contributed significantly to the outcomes detailed above. We also pay tribute to the Australian Centre for International Agricultural Research (ACIAR Project No. FIS/2001/058) project leader Dr Kevin Williams for his stewardship of the project and good counsel throughout. Lastly, we thank our many colleagues and friends who collaborated on the project from the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia; Nha Trang University, Institute of Oceanography and Regional Institute for Aquaculture No. 3, Vietnam; and from the Marine and Aquaculture Development Centre, Lombok, Indonesia.

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# Comparison of biological, economic and environmental efficiency of seacage culture of *Panulirus ornatus* lobsters using different practical diets

Le Anh Tuan and Lai Van Hung<sup>1</sup>

## Abstract

A 19-week seacage experiment was carried out to compare biological, economic and environmental efficiency of farming spiny lobster using four practical diets: 1. fresh fish diet comprising *Saurida* spp. (lizardfish; two-thirds) and *Portulus* spp. (swimming crab; one-third); 2. Nha Trang University (NTU) moist diet; 3. Commonwealth Scientific and Industrial Research Organisation (CSIRO) moist diet; and 4. CSIRO dry diet. Juvenile lobsters with a mean ( $\pm$  standard deviation) starting weight of  $28.8 \pm 5.7$  g were fed twice daily to satiety. Five cage replicates (10 lobsters per cage of 300 L) were used. Cages (300 L) were situated at Bai Tien, in Nha Trang Bay, with temperatures of 27–30 °C and salinity of 27–30 parts per thousand (ppt) during the trial.

Lobster survival was 62–72%. The growth rates of lobsters fed practical diets were not significantly different ( $P > 0.05$ ). Dry matter-based feed conversion ratios (FCRs) of lobsters fed CSIRO moist, NTU moist, CSIRO dry and fresh fish diets were 3.28, 3.40, 3.46 and 3.52 ( $P > 0.05$ ), respectively. On an as-fed basis, the cheapest diet was the fresh fish diet (US\$0.68/kg) while the most expensive was the CSIRO dry diet (US\$2.01/kg). However, on a DM basis, the least expensive diet was the CSIRO dry diet (US\$2.19/kg), which was appreciably cheaper than the fresh fish diet (US\$2.75/kg). Based on the lobster productivity of the different diets and the cost of the feed, the most economic diet, expressed as cost (US\$) of feed consumed per 1 kg of lobster gain, was the CSIRO dry diet (US\$7.51/kg gain), which was significantly better than the next best diet, the NTU moist diet (US\$8.60/kg gain). Economically, the worst diets were the fresh fish diet (US\$10.72/kg gain) and the CSIRO moist diet (US\$10.32/kg gain). Compared to the CSIRO moist diet, the lower cost of the NTU moist diet was due to the *Saurida* spp. (lizardfish) used in the NTU moist diet being much cheaper than the *Thunnus obesus* (tuna) used in the CSIRO moist diet.

The waste nitrogen (N) from rearing lobsters using CSIRO moist (269 g N/kg lobster), CSIRO dry (284 g N/kg lobster) and NTU moist (297 g N/kg lobster) diets was lower ( $P < 0.05$ ) than for the fresh fish diet (402 g N/kg lobster). Good adoption of using pelleted feeds by the lobster farming industry will be essential to ensure the benefits of this research are captured. An effective extension program is needed to ensure lobster farmers appreciate the productivity and environmental benefits that can be obtained from feeding pelleted feeds.

**Keywords:** nutrition; pelleted feed; N discharge; moist feed; trash fish

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## Introduction

Spiny lobsters are typically on-grown in sea cages in Vietnam, the Philippines and Indonesia. Commercial culture of spiny lobsters relies almost entirely on the feeding of low-value fish and fishery by-product ('trash fish') (Arcenal 2004; Tuan and Mao 2004). In Vietnam, lobsters are fed exclusively on fresh whole or chopped fish and shellfish. The most commonly used species/groups for feeding lobster are *Saurida* spp. (lizardfish); *Priacanthus* spp. (red big-eye); *Leiognathus* spp. (ponyfish); pomfret; snails, oyster and cockles; and small swimming crab, other crabs and shrimps. Finfish comprise about 70% of the diet and shellfish 30%. The preferred fish (comprising 38% of fishes in the diet) is lizardfish. The feed supply varies through the year, with shortages common during the rainy season (October – December) and during Tet holidays (January – February) (Edwards et al. 2004; Tuan 2005a). Using fresh fish and shellfish as lobster feeds has resulted in a considerable drop in water quality due to low stability and resultant wastes from these diets (New 1996; Tuan 2005b). This paper reports on the biological, economic and environmental efficiency of feeding lobsters on traditional (trash fish) or compounded feeds prepared as dry or moist pellets.

## Materials and methods

### Experimental design and diets

A 19-week experiment was carried out to compare the survival and productivity of juvenile *Panulirus*

*ornatus* (ornate spiny lobster) fed one of four practical feeds: (i) fresh fish diet—a traditional diet of fresh trash fish comprising two-thirds *Saurida* spp. (lizardfish) and one-third *Portunus* spp. (swimming crab); (ii) NTU moist diet—formulated and prepared at Nha Trang University; (iii) CSIRO moist diet—based on a Commonwealth Scientific and Industrial Research Organisation (CSIRO) formulation but prepared at NTU; and (iv) CSIRO dry diet—identical to the CSIRO moist diet but low-temperature oven-dried. Juveniles with a mean ( $\pm$  standard deviation; SD) starting weight of  $28.8 \pm 5.67$  g were fed twice daily to satiety. Five cage replicates (10 lobsters per cage of 300 L) were used. Cages (300 L) were situated at Bai Tien, in Nha Trang Bay, with temperatures of 27–30 °C and salinity of 27–30 parts per thousand (ppt) during the trial.

The diet formulations are shown in Table 1.

The fresh items were bought fresh and stored at 20 °C until just before use. Items for the fresh diet were coarsely chopped and mixed together in the required proportions. With the compounded diets, the fresh items were finely minced using the mincer attachment on a planetary dough mixer (Chufood CS200 dough mixer, Chuseng Food Machinery Works Co. Ltd, Taichung, Taiwan, Republic of China) and mixed together in the 20 L Chufood planetary dough mixer; dry ingredients were added and thoroughly mixed before adding the oil and sufficient water to make a dough of approximately 40–50% moisture. The dough was twice extruded through a 3 mm die plate of the mincer. For both of the moist diets, which were bound using transglutaminase, the extruded feed strands were refriger-

**Table 1.** Formulation (%) of the experimental feeds

Ingredient	Fresh fish diet	NTU moist diet	CSIRO moist diet	CSIRO dry diet
Monodon feed <sup>a</sup>	–	34.5	34.5	34.5
<i>Acetes</i> spp. (mysid) meal	–	14.5	14.5	14.5
<i>Saurida</i> spp. (lizardfish) flesh	66.7	24.0	–	–
<i>Thunnus obesus</i> (tuna) flesh	–	–	24.0	24.0
<i>Portunus</i> spp. (crab) flesh	33.3	–	–	–
<i>Perna viridis</i> (mussel) flesh	–	24.0	24.0	24.0
Fish oil + lecithin	–	1	1	1
Vitamin pre-mix	–	1	1	1
Binder <sup>b</sup>	–	1	1	1
Total	100	100	100	100

<sup>a</sup> Commercially manufactured pelleted feed for *Penaeus monodon* shrimp that was ground to provide a base mixture for the diet

<sup>b</sup> Binder was transglutaminase (supplied by Kerry Ingredients, Australia) for the Nha Trang University (NTU) moist and Commonwealth Scientific and Industrial Research Organisation (CSIRO) moist diets and Aquabind (supplied by Ridley Aqua-Feed, Narangba, Australia) for the CSIRO dry diet



ated overnight to allow the binder to set, after which the strands were reduced to a length of 10–20 mm and held at –20 °C until required for feeding. For the CSIRO dry diet, which was bound using the polymer binder Aquabind, the moist strands were steamed for 5 minutes in a commercial steaming oven (Stoddart Metal Fabrication Pty Ltd, Sunnybank, Queensland, Australia), then dried overnight at 40 °C in a forced-draught oven, broken into pellets of 10–20 mm length and stored at 20 °C until just before use.

### Experiment management

During the experiment, lobsters in each cage were weighed individually at the start and end of the 19-week experiment and bulk-weighed at intervening fortnightly periods. Stress at weighing was minimised by mild sedation of the lobsters using the aquatic anaesthetic iso-eugenol (AQUI-S, Aquatic Diagnostic Services International Pty Ltd, Wilston, Queensland, Australia) provided in an aerated water bath at 27 mg/L. Lobsters were offered their respective diets to satiety twice daily (nominally at 7.30 am and 4.30 pm) except on the day of weighing when the morning feed was not given. At each feeding, a weighed amount of diet was offered to excess during a feeding period of about 1 hour. All uneaten diet was collected and dried. Feed intake was calculated as the difference between the amount of diet offered and the amount of uneaten refusal, after correcting for the dry matter (DM) of the diet and leaching loss. At the end of the experiment, a representative sample of two lobsters was taken from each cage for determination of whole body (WB) chemical composition.

### Chemical analyses

For determination of WB composition, whole lobsters were weighed and frozen in treatment lots, then minced twice through a 3 mm diameter die plate

of the screw mincer attachment of the Chuford mixer/mincer. The minced sample was freeze-dried, then ground with a mortar and pestle to a uniform powder. Samples of finely ground diets and homogenised lobster were analysed in duplicate by standard laboratory methods, essentially in accordance with AOAC International (1999). DM was determined by drying at 105 °C to constant weight and ash by ignition at 600 °C for 2 hours. Total nitrogen (N) was determined by a macro Kjeldahl technique using mercury as the catalyst in the digestion and titration to an end point pH of 4.6. Crude protein (CP) was calculated using the conversion factor of 6.25 irrespective of the nature of the N. Total lipid was determined gravimetrically following chloroform–methanol (2:1) extraction using the method of Folch et al. (1957). The determined chemical composition of the diets is shown in Table 2.

### Measurements and statistical analysis

Weight gain (WG%) was determined as the difference between end ( $W_e$ ) and start ( $W_s$ ) weights divided by the start ( $W_s$ ) weight. The daily growth coefficient (DGC) was calculated as:

$$\text{DGC (\%/day)} = (W_e^{1/3} - W_s^{1/3}) \times 100/\text{day} \quad (1)$$

Nutrient (or energy) retention was calculated as the net gain of the nutrient (or energy) by the lobster over the experimental period, divided by the corresponding intake of the nutrient (or energy) by the lobster over the same period. The gross energy content of the diet was calculated from the determined chemical analysis using the conversion factors of 17.2, 23.4 and 39.2 kJ/g for carbohydrate, protein and lipid, respectively (Cho et al. 1982); carbohydrate was determined as the difference between the total and the sum of moisture, ash, protein and lipid contents.

**Table 2.** Moisture, crude protein, lipid, ash and carbohydrate composition of the experimental feeds

Composition (%)	Fresh fish diet	NTU moist diet	CSIRO moist diet	CSIRO dry diet
Moisture	75.3	42.9	40.1	8.0
Protein (DM basis)	70.3	55.5	52.1	52.0
Lipid (DM basis)	23.7	17.8	15.4	15.1
Ash (DM basis)	3.9	1.6	1.5	1.5
Carbohydrate (DM basis)	2.1	25.1	31.0	31.4

Note: DM = dry matter; NTU = Nha Trang University; CSIRO = Commonwealth Scientific and Industrial Research Organisation

For the environmental impact assessment of seagee farming of lobster, the waste amounts, particularly total N, discharged into the environment were estimated according to Beveridge (1996):

$$N_{\text{Feed}} = N_{\text{Retention}} + N_{\text{Waste}} \quad (2)$$

To compare economic efficiency, only feed cost (US\$/kg feed and US\$/kg lobster gain) was considered. A completely randomised design with five replicates per treatment was followed and results were compared using one-way analysis of variance (ANOVA) and Duncan's multiple range test at  $P = 0.05$ .

## Results and discussion

### Biological efficiency

No water-quality problems were observed during the experiment. Out of the initial placement of 200 lobsters, 61 died over the course of the experiment (survival of  $70 \pm 12.8\%$ ); many apparently due to 'milky disease'. Differences between treatments for growth rate (WG% and DGC) and survival of the lobsters were not significant ( $P > 0.05$ ) (Table 3). Although the wet matter-based feed intake of lobsters fed fresh fish was higher than for lobsters fed other diets ( $P < 0.05$ ), the DM-based feed conversion ratios (FCRs) were similar ( $P > 0.05$ ) for all treatments.

Although the higher wet-matter feed intake of lobsters fed fresh fish may suggest that the fresh diet was more attractive to the lobsters than the other diets, it is more likely a response to energy needs of the animal since DM FCRs were similar for all diets. This accords with many other studies where intake is

related to the energy density of the diet—for example, *Salvelinus alpinus* (Arctic charr; Jobling and Wandsvik 1983), salmonids (Boujard and Medale 1994; Kaushik and Medale 1994; Rasmussen et al. 2000; Gelineau et al. 2002), *Sparus aurata* (gilthead seabream; Lupatsch et al. 2001), *Scophthalmus maximus* (turbot; Saether and Jobling 2001) and *Dicentrarchus labrax* (European sea bass; Boujard et al. 2004).

### Environmental efficiency

Table 4 details the nitrogen budget for each of the practical diets fed to lobsters in the experiment. The amount of discharged N was highest for the fresh diet (402 g/kg lobster) and significantly higher than for all other diets, which were similar (269–297 g/kg lobster). However, the pollution rate of using the compounded diets was still very high compared with other aquaculture practices. For example, *Oncorhynchus mykiss* (rainbow trout) farming in Europe was reported to have an N discharge of 45–77 g/kg fish (De Silva and Anderson 1995) while Tuan (2009) reported a discharge of 168 g N/hg for *Epinephelus malabaricus* (malabar grouper). Clearly, to reduce the pollution rate from seagee farming of lobster, improvements in feed manufacture as well as feeding management are necessary.

### Economic efficiency

The cost of the practical diets examined in the experiment and critical information for determining the economic efficiency of feeding the diets to the lobsters are detailed in Table 5. The diet cost includes both the cost of the individual ingredients used and an estimate of manufacturing and/or freezer cost as

**Table 3.** Biological efficiency of seagee farming of *Panulirus ornatus* lobsters using different practical diets

Trait	Fresh fish	NTU moist	CSIRO moist	CSIRO dry	± SEM
Start weight (g)	29.6	28.2	29.6	27.7	1.27
WG (%)	272	258	261	216	22.7
DGC (%/day)	1.22	1.12	1.21	1.04	0.064
FI <sub>af</sub> (g/animal)	1221 <sup>B</sup>	379 <sup>A</sup>	423 <sup>A</sup>	218 <sup>A</sup>	103.1
FI <sub>dm</sub> (g/animal)	271	216	254	201	18.6
FCR <sub>dm</sub>	3.52	3.40	3.28	3.46	0.116
Survival (%)	72	74	70	62	2.9

Note: <sup>A,B</sup> Within a row, means with a common superscript letter do not differ ( $P > 0.05$ ); SEM = standard error of the mean ( $n = 20$ ); WG = weight gain; DGC = daily growth coefficient; FI<sub>af</sub> = feed intake, as fed; FI<sub>dm</sub> = feed intake, dry matter; FCR<sub>dm</sub> = feed conversion ratio, dry matter basis; NTU = Nha Trang University; CSIRO = Commonwealth Scientific and Industrial Research Organisation

appropriate for the particular diet. On an as-fed basis, the cheapest diet was the fresh fish diet (US\$0.68/kg) while the most expensive was the CSIRO dry diet (US\$2.01/kg). However, on a DM basis, the least expensive diet was the CSIRO dry diet (US\$2.19/kg), which was appreciably cheaper than the fresh fish diet (US\$2.75/kg). There was no significant difference in the amount of feed eaten by the lobsters in the experiment when feed intake was expressed on a DM basis. However, there was a strong suggestion for intake of the NTU moist and CSIRO dry diets to be lower than for the other two diets.

Based on the lobster productivity of the different diets and the cost of the feed, the most economic diet, expressed as cost (US\$) of feed consumed per 1 kg of lobster gain, was the CSIRO dry diet (US\$7.51/kg gain), which was significantly better than the next best diet, the NTU moist diet (US\$8.60/kg gain). Economically, the worst diets were the fresh fish diet

(US\$10.72/kg gain) and the CSIRO moist diet (US\$10.32/kg gain). Compared to the CSIRO moist diet, the lower cost of the NTU moist diet was due to the *Saurida* spp. (lizardfish) used in the NTU moist diet being much cheaper than the *Thunnus obesus* (tuna) used in the CSIRO moist diet.

## Conclusions

- Growth rates of *P. ornatus* lobsters were not significantly different between any of the diets compared in the experiment. FCR on a DM basis was also similar for all diets and ranged from 3.28 to 3.52.
- The economic efficiency (cost of feed consumed per 1 kg of lobster gain) of rearing the lobsters was highest for the CSIRO dry diet, significantly better than the NTU moist diet, with the lowest being the fresh fish diet and the CSIRO moist diet.

**Table 4.** Nitrogen (N) budget for *Panulirus ornatus* lobsters fed different practical diets

Attribute	Fresh fish	NTU moist	CSIRO moist	CSIRO dry	± SEM
Initial lobster					
Weight (g)	29.6	28.2	29.6	27.7	1.27
Whole body N content (%)	0.24	0.24	0.23	0.24	0.004
Final lobster					
Weight (g)	106.2	95.9	105.7	86.5	5.55
Whole body N content (%)	0.37	0.38	0.37	0.36	0.007
As fed food allocated (g/lobster)	1,221 <sup>B</sup>	379 <sup>A</sup>	423 <sup>A</sup>	218 <sup>A</sup>	103.1
Dietary N in allocated food (g)	31.3 <sup>B</sup>	19.2 <sup>A</sup>	21.2 <sup>AB</sup>	16.7 <sup>A</sup>	2.11
Dietary N retained by lobster (g)	0.32	0.29	0.33	0.25	0.020
Discharged N (g/kg lobster)	402 <sup>B</sup>	297 <sup>A</sup>	269 <sup>A</sup>	284 <sup>A</sup>	15.6

Note: <sup>A,B</sup> Within a row, means with a common superscript letter do not differ ( $P > 0.05$ ); SEM = standard error of the mean ( $n = 20$ ); NTU = Nha Trang University; CSIRO = Commonwealth Scientific and Industrial Research Organisation

**Table 5.** Cost and intake of diets fed to juvenile *Panulirus ornatus* lobsters in the experiment and derived economic efficiency of each diet

Trait	Fresh fish	NTU moist	CSIRO moist	CSIRO dry	± SEM
Diet cost (as fed; US\$/kg)	0.68	1.42	1.99	2.01	
Diet cost (DM; US\$/kg)	2.75	2.50	3.36	2.19	
Feed intake (as fed; g/lobster)	1,221 <sup>B</sup>	379 <sup>A</sup>	423 <sup>A</sup>	218 <sup>A</sup>	103.1
Feed intake (DM; g/lobster)	271 <sup>A</sup>	216 <sup>A</sup>	254 <sup>A</sup>	201 <sup>A</sup>	18.6
Total feed cost (US\$/lobster)	0.83 <sup>B</sup>	0.54 <sup>AB</sup>	0.84 <sup>B</sup>	0.44 <sup>A</sup>	0.064
Weight gain (g/lobster)	77	68	76	59	5.4
Economic efficiency (US\$ feed/kg lobster gain)	10.72 <sup>C</sup>	8.60 <sup>AB</sup>	10.32 <sup>BC</sup>	7.51 <sup>A</sup>	0.31

Note: <sup>A,B,C</sup> Within a row, means with a common superscript letter do not differ ( $P > 0.05$ ); SEM = standard error of the mean ( $n = 20$ ); NTU = Nha Trang University; CSIRO = Commonwealth Scientific and Industrial Research Organisation; DM = dry matter

- The amount of nitrogen discharged into the environment was similar for the CSIRO moist, CSIRO dry and NTU moist diets (269–297 g N/kg lobster) and significantly less than for the fresh diet (402 g N/kg lobster).

## Acknowledgment

The research was carried out as part of the Australian Centre for International Agricultural Research (ACIAR) lobster project (FIS/2001/058) and this financial support is acknowledged. We thank Dr Kevin Williams (CSIRO) for his advice, Mr Ha Huu Dung for technical assistance in the conduct of the experiment and Mr Nguyen Thanh Son for the chemical analyses.

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## Session 4: Lobster grow-out feeds and feeding practices

Photo: Clive Jones, Northern Fisheries Centre, Queensland Department of Primary Industries and Fisheries



Vietnamese lobster farmer examining a string of *Perna viridis* (green mussel) being co-cultured with lobsters to improve water quality and provide a food source for the lobsters

# Culture of *Panulirus ornatus* lobster fed fish by-catch or co-cultured *Perna viridis* mussel in sea cages in Vietnam

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## Abstract

In order to evaluate the benefit of combining culture of mussel and lobster on lobster farming, a study was conducted at Van Phong Bay (near Xuan Tu village, Van Ninh district, Khanh Hoa province). Four culture sites, two offshore sites (sites 2 and 3) and two nearshore sites (sites 1 and 4), were selected for the study. At sites 2 and 4, strings of *Perna viridis* (green mussel) were hung around the lobster cages, whereas no mussels were cultured at sites 1 and 3. The lobsters were fed by-catch at all four sites, but three of the lobster cages at sites 3 and 4 were additionally fed mussel. The growth and survival of the lobsters were measured monthly.

Lobsters were harvested after 15 months of culture at site 4 because they had attained an acceptable average harvest weight of about 900 g. At the other three sites, the experiment was terminated after 17 months of culture irrespective of the size of the lobsters so as to avoid further losses due to disease. At the end of the experiment, the average weight of the cultured lobsters fed only by-catch was 772 g or higher at sites 2, 3 and 4 and highest at site 4 (864 g); while the average weight of the lobsters at site 1 was 557 g and significantly lower than lobsters at all other sites ( $P < 0.05$ ). Carapace length (CL) of lobsters at site 1 was also significantly smaller than those at other sites. There were no significant differences in either average weight or CL for lobsters that were fed only by-catch at sites 2 and 3 ( $P > 0.05$ ). Comparing lobsters that were fed mussels as well as by-catch (sites 3 and 4), the mean weight of lobsters fed mussels at site 3 was significantly higher ( $P < 0.05$ ) than those fed only by-catch at that site, although no significant difference was seen for mean CL. Survival of lobsters was very high for the first 4 months, with no deaths being observed at any of the sites. However, after this time, lobster deaths occurred, initially due to black gill disease, and subsequently due to 'milky disease'. At site 4, survival was very high for lobsters fed mussels (99%) while cages with lobsters fed only by-catch exhibited losses as early as 9 months, with a total survival of 85% at the end of the trial at 15 months. After 17 months at the three other sites, mean percentage survival was 75, 73 and 79% for sites 1, 2 and 3, respectively, and not significantly different ( $P > 0.05$ ). Similar to site 4, lobsters at site 3 that were fed mussels and by-catch had a higher ( $P < 0.05$ ) survival rate (91%) than those fed only by-catch (67%). Despite the disease problems, the experiment demonstrated that lobsters fed mussels as a supplement to the fish by-catch grew and survived better than those fed only by-catch. There was a tendency for lobster performance to be better at offshore compared to nearshore sites.

**Keywords:** rock lobster; environmental impact; milky disease; water quality; seaweed culture

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## Introduction

Spiny lobsters (Family Palinuridae) are found in the reefs along the central coast of Vietnam, predominantly from Quang Binh province in the north to Binh Thuan province in the south. Lobsters are valuable seafood that command high prices in domestic and world markets. Because of high market demand, lobster aquaculture has developed rapidly and most noticeably in Vietnam where some 30,000 sea cages were in lobster production in 2001–02 and this had increased to 35,000 cages in 2003. Most (~20,000) of these lobster cages were located in the central provinces of Khanh Hoa and Phu Yen. Total production of cultured lobster in 2003 was estimated to be 1,500 t, worth US\$40 million (Tuan and Mao 2004). There are seven species of spiny lobster found in Vietnam, however *Panulirus ornatus* is the main culture species due to its high market value and rapid growth rate. Other species that are less often cultured are *P. hormarus*, *P. simpsoni*, and *P. longipes*.

Lobster aquaculture can be a highly profitable business and has a significant flow-on benefit for the local community where lobsters are farmed. However, a recent problem affecting the profita-

bility of lobster farming is the occurrence of a disease known as ‘milky disease’ in which the ventral muscle beneath the carapace is pale and soft. The disease can result in significant losses and these losses usually occur in lobsters that have been cultured for many months, thereby severely impacting on farm profitability. The cause of this disease has not yet been elucidated but poor water quality has been implicated, perhaps compromising the ability of the lobster to withstand the disease challenge.

In Vietnam, lobsters are fed almost exclusively on fish by-catch; to reach a desired lobster market size of 1 kg requires more than 20 kg of by-catch to be fed. It is estimated that at least 6,000 t of by-catch were used in 2002 to culture lobsters in Van Phong Bay. Uneaten food and lobster discharges resulted in severe pollution in the bay which necessitated lobster farmers at Xuan Tu village relocating their sea cages into deeper water to get better water quality for rearing the lobsters (Figure 1). One possible way of improving water quality in the bay is to co-culture mussels and lobsters. The indigenous green mussel *Perna viridis* is easily cultured and can withstand heavily polluted water (Huang et al. 1985). The ability of this mussel to markedly



**Figure 1.** Floating lobster sea cage at Xuan Tu village, Van Phong Bay, Van Ninh district, Khanh Hoa province, Vietnam



improve the quality of heavily eutrophied waters has been demonstrated in a number of studies (Cranford and Grant 1990; Gao et al. 2006, 2008).

The objective of the work reported in this paper was to examine the feasibility and overall economic and environmental benefit of combining mussel and lobster culture at various sites in Van Phong Bay, Van Ninh district, Khanh Hoa province.

## Materials and methods

### Culture sites and experimental procedures

Four cage sites at Xuan Tu village (Van Hung commune), Van Phong Bay, Van Ninh district, Khanh Hoa were chosen as being representative of seacage lobster culture in the region (Figure 2). Sites 1 and 4 were located close to the shore (nearshore sites) while sites 2 and 3 were located in deeper

water and further from the shore (offshore sites). Sea cages consisted of nets of 3 m × 3 m × 6 m (deep), supported by a cage frame of 4 m × 4 m. At sites 2 and 4, 200 strings each holding 2 kg of *Perna viridis* (green mussel) spat (130 individuals/kg) were hung outside each net cage.

During the first 3 months of culture, cage net aperture was 5 mm, lobsters were stocked at 120 individuals/cage and all lobsters were fed solely on fish by-catch. For the remainder of the experiment, cage net aperture was increased to 20 mm and lobster stocking was reduced to 60 individuals/cage. Two cages at sites 3 and 4 were fed mussels in addition to fish by-catch. A summary of the differences between sites is given in Table 1.

Lobster seed were collected from the wild as settled postpueruli by commercial fishers and on-reared to a mean ( $\pm$  standard deviation; SD) carapace length (CL) of 11.9  $\pm$  0.6 mm at which time



**Figure 2.** Position of the four sites used in the seacage culture experiment at Xuan Tu village, Van Phong Bay, Van Ninh district, Khanh Hoa province

**Table 1.** Summary of differences in culture practice applied in the experiment

Detail	Site 1	Site 2	Site 3	Site 4
Location	Nearshore	Offshore	Offshore	Nearshore
Mussels cultured on strings outside cage	No	Yes	No	Yes
No. of cages, 0–3 months	3	3	6	6
No. of cages, 4 months to trial end	2	2	4	4
Fed only fish by-catch	2	2	2	2
Fed fish by-catch and mussel	0	0	2	2

they were purchased for the experiment. Lobsters were fed their respective food to apparent satiety twice daily in the morning and afternoon. Uneaten food was taken out before the morning feeding of the following day. The net cage was cleaned every 15 days to minimise biofouling of the nets.

## Data collection and analysis

Lobster weight (W) and CL were recorded at monthly intervals and deaths noted when observed. The experiment continued for 15 months at site 4 when the collaborating farmer decided to harvest rather than risk losses to disease. At other sites, the experiment was terminated after 17 months of culture. Raw data were entered into Excel spreadsheets (Microsoft Corporation) and statistical analysis carried out using SPSS version 10 software, using analysis of variance (ANOVA;  $P = 0.5$ ).

## Results

A summary of survival, weight gain and CL increase of the lobsters during culture at each site is shown in Table 2.

### Survival

No lobster deaths occurred at any of the sites during the first 4 months of culture. Two deaths occurred at site 2 after 6 months and one death at site

1 after 7 months (Figure 3). These deaths were attributed to black gill disease. After 9 months, lobsters numbers began to decline more steadily at most sites, with this being more profound for cages where lobsters were not fed mussels. At site 4, survival was very high for lobsters fed mussels (99%) while cages with lobsters fed only by-catch exhibited losses as early as 9 months, with a total survival of 85% at the end of the trial at 15 months. After 17 months at the three other sites, mean percentage survival was 75, 73 and 79% for sites 1, 2 and 3, respectively, and not significantly different ( $P > 0.05$ ). Similar to site 4, lobsters at site 3 that were fed mussels and by-catch had a higher survival rate (91%) than those fed only by-catch (67%). In the last 2 months, all sites and feeding treatments experienced many deaths due to milky disease.

### Growth

In the first 3 months of the experiment, there was little difference in growth traits (W or CL) between sites (Table 2), except that growth was significantly lower at site 1 than site 2. After that, lobsters at most sites grew well, except those at site 1 where the shallow water and nearshore location may have affected water exchange. Data for the mean increase in W over the experimental period are shown in Figure 4, and CL results were similar.

After 17 months of culture (15 months for site 4), the average weight of the cultured lobsters fed only

**Table 2.** Mean ( $\pm$  standard deviation) survival, weight (W) and carapace length (CL) of *Panulirus ornatus* lobsters reared at four cage sites at Van Phong Bay, Xuan Tu, Khanh Hoa

Attributes	Site 1	Site 2	Site 3		Site 4	
Location	Nearshore	Offshore	Offshore	Offshore	Nearshore	Nearshore
Mussel co-culture	No	Yes	No	No	Yes	Yes
Initial CL (mm)	12 $\pm$ 0.6	12 $\pm$ 0.6	12 $\pm$ 0.6	12 $\pm$ 0.6	12 $\pm$ 0.6	12 $\pm$ 0.6
<i>0 to 3 months</i>						
Survival (%)	100	100	100	100	100	100
W (g)	50 $\pm$ 8 <sup>B</sup>	77 $\pm$ 11.8 <sup>A</sup>	63 $\pm$ 7.8 <sup>AB</sup>	59 $\pm$ 1.2 <sup>AB</sup>	64 $\pm$ 14.9 <sup>AB</sup>	63 $\pm$ 12.6 <sup>AB</sup>
CL (mm)	38 $\pm$ 2.5 <sup>A</sup>	43 $\pm$ 2.7 <sup>A</sup>	39 $\pm$ 3.0 <sup>A</sup>	39 $\pm$ 2.8 <sup>A</sup>	40 $\pm$ 4.0 <sup>A</sup>	42 $\pm$ 7.6 <sup>A</sup>
<i>4 months to end<sup>a</sup></i>						
Fed mussel	No	No	Yes	No	Yes	No
Survival (%)	75 $\pm$ 2.4 <sup>C</sup>	73 $\pm$ 1.2 <sup>C</sup>	91 $\pm$ 1.4 <sup>B</sup>	67 $\pm$ 0 <sup>D</sup>	99 $\pm$ 1.2 <sup>A</sup>	85 $\pm$ 4.3 <sup>B</sup>
W at end (g)	557 $\pm$ 93 <sup>C</sup>	807 $\pm$ 109 <sup>AB</sup>	912 $\pm$ 114 <sup>A</sup>	772 $\pm$ 140 <sup>B</sup>	910 $\pm$ 159 <sup>A</sup>	864 $\pm$ 128 <sup>AB</sup>
CL at end (mm)	85 $\pm$ 4.5 <sup>B</sup>	96 $\pm$ 5.2 <sup>A</sup>	101 $\pm$ 5.9 <sup>A</sup>	95 $\pm$ 5.1 <sup>A</sup>	101 $\pm$ 6.4 <sup>A</sup>	97 $\pm$ 4.4 <sup>A</sup>

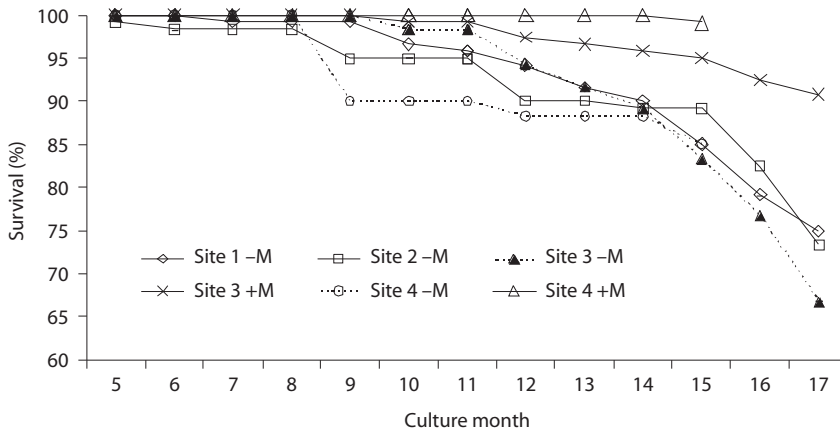
<sup>a</sup> Lobsters were harvested after 15 months of culture at site 4 and after 17 months at sites 1, 2 and 3

Note: <sup>A,B,C,D</sup> Within rows, means with a common superscript letter do not differ significantly ( $P > 0.05$ )

by-catch was 772 g or higher at sites 2, 3 and 4 and highest at site 4 (864 g); average weight of the lobsters at site 1 was 557 g and significantly lower than lobsters at all other sites ( $P < 0.05$ ) (Table 2). CL of lobsters at site 1 was also significantly smaller than those at other sites (Table 2). There were no significant differences in either average W or CL for lobsters that were fed only by-catch at sites 2 and 3 ( $P > 0.05$ ).

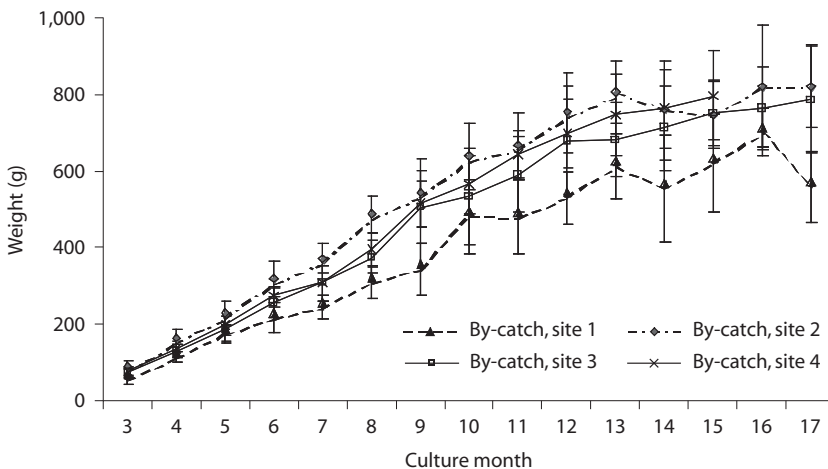
Comparing lobsters that were fed mussels as well as by-catch (sites 3 and 4; Figure 5), there was no

significant difference in growth rate of the lobsters from 3 to 7 months. However, from the 9th month to the end of the experiment at site 3, the mean weight of lobsters fed mussels was significantly higher ( $P < 0.05$ ) than those fed by-catch only at the same site (Figure 5), although no significant difference was seen for mean CL. At the end of the trial at site 3, there were significant differences ( $P < 0.05$ ) for W, but not CL, between lobsters fed mussels and by-catch compared to those fed only by-catch (Figure 5).



Note: see Table 1 for site conditions; +M = fed mussel and fish by-catch; -M = fed by-catch only; error bars have been removed for clarity

**Figure 3.** Survival of *Panulirus ornatus* lobsters at each site and according to type of food fed



**Figure 4.** Weight ( $\pm$  standard error) of cultured *Panulirus ornatus* lobster fed only by-catch at four sites over the course of the experiment

## Discussion

### Survival and disease problems

Lobster survival was almost 100% for the first 8 months of culture irrespective of the location of the culture site or feeding practice adopted. Farmer experience has shown that the size of the lobster seed at the start of the grow-out phase is a critical determinant of ultimate survival rates, with the larger the seed, the better the survival. The size of the lobster seed at the start of this experiment was bigger than the seed that are usually farmed at Van Phong Bay and thus the high survival rate of the lobsters during this early culture period in the experiment was not unexpected. However, lobster deaths increased markedly after the 9th month with these deaths being attributed to milky disease. The first signs of the disease are lobsters that are very weak, have poor appetite and the appearance of a milky line in the ventral abdominal muscle. Later, the whitish line that is visible through the membrane between the ventral cephalothorax and the first abdominal plate expands and appears on both the ventral and dorsal sides of the abdomen. At this stage, the lobster stops eating and usually dies 2–5 days after the first sign of the disease. In the dead lobster, scratching of the ventral membrane between the shell plates results in the oozing of a milk-like liquid (haemolymph) with a necrotic smell. This disease was reported to occur in nearly every lobster

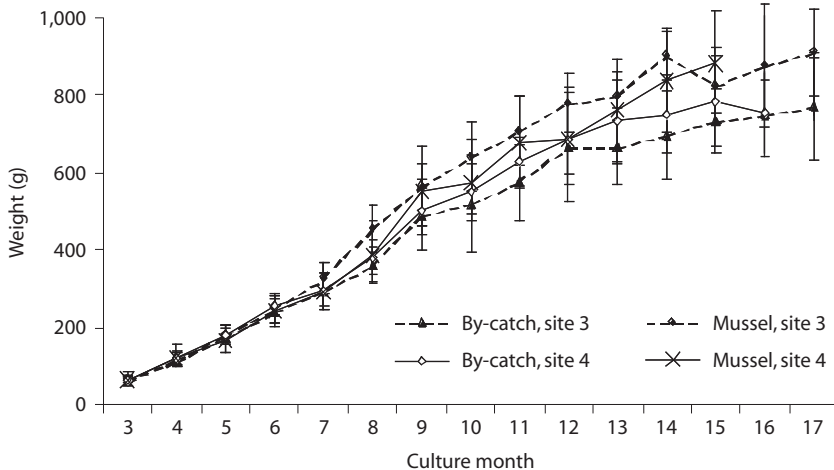
cage in Van Phong Bay and in many other areas in the central coast of Vietnam in late 2007.

### Growth comparison

At the beginning of the experiment, the amount of discharged nutrients (body discharges and uneaten feed) was small and probably did not compromise the water quality in the cages where the lobsters were being cultured. This may explain why there were no significant differences in growth of the lobster between sites 1 and 3 (without mussel) or between site 4 (with mussel).

However, as the lobsters grew and the amount of discharged nutrients increased, the value of combining lobster and mussel culture became apparent with improved water quality (Vinh and Huong 2009) contributing to better lobster productivity while the feeding of fresh mussels may also have benefited the lobsters. The ready availability of co-cultured mussels may have been a beneficial factor, especially in stormy weather when fish by-catch was difficult to obtain. This is one of the most important advantages of combining lobster and mussel culture.

The growth of lobster in the first 9 months was about 36–61 g/individual/month. This is lower than the findings of Du et al. (2004) who observed values of 79–81 g/individual/month. However, in the study of Du et al. (2004), the initial size of the lobster was 30 g, much bigger than lobsters in the present work



**Figure 5.** Weight ( $\pm$  standard error) of cultured *Panulirus ornatus* lobster fed solely on by-catch or on by-catch and mussel

which could explain the differences between the two studies. The growth rate of lobster at site 1 was lower than at other sites and this may have been due to the poor water quality because of the shallowness of the bay at this location. Water depth at site 1 was 5 m whereas lobster farmer experience is that lobsters prefer depths of not less than 6 m. Whether or not other factors such as water exchange rate, water temperature and water current strength may have affected lobster growth is impossible to know.

#### *Contribution of mussel to the diet*

The better growth of lobsters fed mussels as compared to those fed only fish by-catch at sites 3 and 4 suggests that the mussels provide a valuable addition to the lobster diet. While feeding fish by-catch is a popular practice for culturing lobsters in Vietnam, it may not be a nutritionally adequate diet because of either lack of freshness or variable nutrient composition. Chinh et al. (1997) reported that the protein content of mussel was about 5.5–7.5% of wet weight (27.5–37.5% on a dry matter (DM) basis), while lipid was quite low at 0.2–0.8% of wet weight. According to shrimp feed manufacturers in Vietnam, the total DM protein content of fish by-catch is typically 45–55%. Guillaume (1997) has suggested that the protein requirement of crustaceans can be met with diets providing from 25–55% DM protein. Although the protein content of mussel is much lower than fish by-catch, this experiment has demonstrated that co-feeding of mussel and fish by-catch results in superior lobster growth than feeding by-catch alone.

#### *Feed supply, quality and cost*

In this experiment, the fish by-catch was caught mainly in Binh Thuan province and it takes more than 1 day to transport it to Van Phong Bay. During this transport, quality of the fish may deteriorate since it is a low-value product and the cost of suitable preservation may outweigh its sale price. Poor-quality fish by-catch not only will be nutritionally inferior but it may also potentiate bacterial disease in the lobsters. Twenty-two lobsters fed only fish by-catch at site 4 died as a result of a bacterial disease affecting the gut of the lobster. Although not confirmed, feeding of rotten fish by-catch was strongly suspected as being the source of the disease. That survival of lobsters after 9 months of culture was significantly higher in cages where mussels were additionally fed also supports the view

that fish by-catch alone is not an optimal food source for lobsters. The cost of growing and feeding lobsters with mussels is lower than buying fish by-catch if the mussels are grown at the lobster cage site. An important advantage of combining mussel and lobster culture is that mussels will be available when fish by-catch may be limited because of supply problems.

#### **Environmental benefit**

In terms of environmental improvement, mussels have considerable capacity to remove large amounts of nutrients from heavily eutrophied waterways. For example, Du et al. (2004) reported that the organic matter content of the bottom layer of water and sediment in lobster cages with mussel co-culture was significantly lower than where mussel co-culture was not practised. Moreover, the levels of potentially pathogenic coliform and *Vibrio* bacteria in the sediment under lobster cages were much lower at sites of mussel co-culture than sites without mussels. However, in a companion study on environmental quality (Vinh and Huong 2009), no clear difference in environmental quality was found between lobsters reared with or without mussel co-culture. This may be due to physical dynamics that were operating during this study compared to that of Du et al. (2004).

The total filtering capacity of mussels cultured in Van Phong Bay was relatively small in relation to the total water mass in Van Phong Bay. Moreover, Van Phong Bay is also subjected to nutrient outflows from other non-lobster aquaculture activities in the bay, and from upstream discharges from industrial, agricultural and aquacultural activities. In addition, the filtering capacity of *P. viridis* mussel is impaired if the concentration of suspended particles becomes too high or the size of the particles is too high. For *P. viridis*, the optimal particle size is 4 µm while particles above 16 µm are not cleared (Hawkins et al. 1998). Moreover, the filtering capacity of bivalves is influenced by temperature, salinity and physical characteristics of the suspended particles.

#### **Conclusion**

The study has demonstrated that lobsters fed mussels as an additional component to fish by-catch showed better survival and growth than those at the same site fed only fish by-catch. Whether or not this benefit

was due to the mussel providing the lobster with some nutrient that was inadequately supplied by the fish by-catch or because it lessened the effect of feeding by-catch of suboptimal quality is not known. The study also demonstrated that site differences in lobster productivity unrelated to feeding practice were also evident. Again for inconclusive reasons, the worst lobster productivity in terms of growth and survival occurred at site 1, which was the most shallow of the cage sites investigated. The shallowness of this site may have reduced water exchange and thus exasperated a deteriorating water-quality effect of heavy eutrophication in Van Phong Bay.

## Acknowledgments

This work was a part of a collaborative Australian Centre for International Agricultural Research (ACIAR) project involving Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine and Atmospheric Research, the Queensland Department of Primary Industries and Fisheries, the Institute of Oceanography, Nha Trang (ION), the Research Institute for Aquaculture No. 3 (RIA3) and Nha Trang University (NTU). We would like to express our gratitude to ACIAR for financial support and particularly to thank CSIRO staff, especially Dr Kevin Williams for acting as a very energetic project leader and David Smith, Simon Tabrett and Simon Irvin for their support. We also appreciate the collaboration of local lobster farmers at Xuan Tu village, particularly four households, Nguyen Van Chim, Tran Hai, Nguyen Van Dung and Nguyen Van Hung, who were directly involved in the project. In addition, the experiment and project has received high support from local authorities including the Van Hung commune and the Agricultural Office of Van Ninh district. Finally, the work benefited from constructive inputs from fellow colleagues at ION and other project participants at RIA3 and NTU.

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# Effect of trash fish species and vitamin supplementation on productivity of *Panulirus ornatus* juveniles fed moist diets

Le Anh Tuan and Nguyen Dinh Mao<sup>1</sup>

## Abstract

Spiny lobsters cultured in Vietnam are presently fed exclusively on low-value (trash) fish. This is chopped up according to the size of the lobsters and fed to them once or twice daily. The species of trash fish used, and its quality (freshness) at the time of feeding, can vary seasonally and daily depending on cost and what is available. A 10-week experiment was carried out to see if the species of trash fish fed, with or without vitamin supplementation, affected the growth performance of juvenile *Panulirus ornatus* (ornate spiny lobster).

Three species of trash fish—*Saurida* sp. (lizardfish), *Nemipterus* sp. (bream) and *Stolephorus* sp. (anchovy)—were examined, with or without a complete fish vitamin pre-mix in a 3 × 2 factorial experiment with four replicate tanks of lobsters per treatment. The trash fish was incorporated at amounts (40–49%) with Peruvian fishmeal and wheat flour, with or without a vitamin pre-mix and made into moist pellets of ~60% dry matter (DM) using 1% transglutaminase as the binder. The crude protein and total lipid DM contents of the diets were 50–51% and 9–10%, respectively. Lobsters (120 of 2.8 ± 0.39 g) were stocked equally to the 24 tanks (100 L) and provided with biofiltered sea water in a flow-through system. Lobsters were fed twice daily. Uneaten food was collected and feed intake determined 1 hour after feeding. There was no significant ( $P > 0.05$ ) interaction between treatment main effects, and lobster survival was high and unaffected by treatment. Lobsters grew better with lizardfish and anchovy than bream ( $P < 0.05$ ), with anchovy somewhat inferior to lizardfish. Dry matter feed conversion ratio (FCR) tended to be better with lizardfish. Adding vitamins resulted in a marked improvement ( $P < 0.05$ ) in lobster growth and DM FCR. These results demonstrate the importance of vitamin supplementation even when feeding high-quality trash fish and why bream is not recommended as a sole food source for lobsters.

**Keywords:** rock lobster; nutrition; feeding; moist feeds; lizardfish; anchovy; bream

## Introduction

In Vietnam, lobsters are fed exclusively with fresh whole or chopped fish and shellfish. The most commonly used species/groups for feeding lobster are *Saurida* spp. (lizardfish), *Priacanthus* spp. (big

red-eye), *Nemipterus hexodon* (bream), *Leiognathus* spp. (ponyfish), *Stolephorus* spp. (anchovy), pomfret and shellfish, including snails, oyster, cockles, small swimming crab, other crabs and shrimps. Finfish account for about 70% of the diet and shellfish the remainder. The preferred fish, comprising 38% of all fish fed, was lizardfish (Tuan and Mao 2004).

Currently, there are few data on the preference and growth performance of spiny lobsters fed different species of trash fish. Moreover, since

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vitamins are likely to be readily destroyed if the trash fish is not handled correctly after capture, adding a vitamin supplement to the trash fish may be beneficial. We report an experiment in which three different species of low-value fish, with or without vitamin supplementation, were compared when prepared as bound moist feeds for feeding to juvenile *Panulirus ornatus* (ornate spiny lobster).

## Materials and methods

### Experimental design, feeds and tanks

The experiment entailed a 3 × 2 factorial to examine moist feeds based on lizardfish, bream or anchovy trash fish, with or without vitamin supplementation. There were four tank replicates per treatment. The vitamin supplement was a multivitamin custom formulation intended to meet the requirements of marine crustaceans and finfish (Medical Materials and Medicines Co., Can Tho, Vietnam). The formulation of the experimental diets is shown in Table 1.

For all diets, fish flesh was frozen and minced twice through a 2 mm die plate fitted to the meat mincer attachment of a 200 L planetary dough mixer (Chufoods, Taiwan). Dry ingredients, including the vitamin pre-mix for vitamin-supplemented diets,

were thoroughly mixed together in the dough mixer before the minced fish was added along with transglutaminase binder (Ajinomoto Food Ingredients, Japan). The ingredients were thoroughly mixed together and deionised water was added if necessary to produce consistent dough of about 55–60% dry matter (DM). The dough was cold-extruded through the mincer and the spaghetti-like noodles set overnight in a refrigerator. The noodles were reduced in length and held at –20 °C until required. The experiment utilised 24 fibreglass tanks of 200 L capacity (0.6 m diameter × 0.8 m depth) with a black gel coat on the inside to provide a non-slip floor surface. Tanks were provided with biofiltered sea water in a flow-through system at a flow rate of not less than 0.5 L/minute. Each tank had an air-stone for aeration and sufficient shelters for the number and size of the lobsters.

### Lobsters and management

One hundred and fifty juvenile *Panulirus ornatus* lobsters were purchased from local fishers in Khanh Hoa and transported to the Nha Trang University's seawater laboratory. After an initial acclimation period of 1 week during which lobsters were fed a common diet of fresh food items (anchovy), 120 lobsters of a similar size were randomly and equally

**Table 1.** Formulation and chemical composition of the experimental diets comparing *Saurida* sp. (lizardfish; L), *Nemipterus* sp. (bream; B) and *Stolephorus* sp. (anchovy; A) trash fish, with (+) or without (–) vitamin supplementation

Attribute	Diet					
	L–	B–	A–	L+	B+	A+
<i>Formulation (% as used)</i>						
Trash fish	49.2	39.4	47.8	49.2	39.5	47.0
Fishmeal	31.4	38.0	33.7	31.3	38.1	34.4
Wheat flour	18.4	21.6	17.5	17.2	20.5	16.5
Vitamin pre-mix <sup>a</sup>	0	0	0	1	1	1
Binder <sup>b</sup>	1	1	1	1	1	1
<i>Chemical composition (% dry matter)</i>						
Dry matter	56.1	62.6	57.2	59.2	60.8	58.8
Crude protein	50.9	50.0	50.7	50.8	50.4	50.3
Total lipid	8.9	9.7	9.8	8.4	10.0	9.6
Ash	1.8	1.6	1.7	1.7	1.5	1.6
NFE <sup>c</sup>	38.4	38.7	37.8	39.1	38.1	38.5

<sup>a</sup> Provided in the final diet (mg/kg): retinol (vitamin A), 9.3; ascorbic acid (C), as ascorbyl-2-polyphosphate, 100; cholecalciferol (D3), 0.25; D/L -tocopherol (E), 300; thiamine (B1), 10; riboflavin (B2), 15; pyridoxine (B6), 6; biotin, 0.5; cyanocobalamin (B12), 0.05; folic acid, 5

<sup>b</sup> Transglutaminase TG-Activa (product of Ajinomoto Food Ingredients, Japan and supplied by Kerry Ingredients, Sydney, Australia)

<sup>c</sup> NFE = nitrogen-free extract



distributed to the experimental tanks (5 lobsters/tank). Lobsters started feeding on their respective experimental feeds and the experiment continued for 10 weeks with lobsters being individually weighed every 4 weeks. All lobsters were fed twice daily (nominally 7.30 am and 4.30 pm) with allocation adjusted to minimise food wastage. Tanks were siphoned clean of uneaten food and faecal matter once daily; tanks were cleaned as necessary to maintain tank hygiene. Moults were recorded and removed when first noticed and water temperature was measured daily in the morning.

### Analyses

Samples of finely ground diets were analysed in duplicate by standard laboratory methods, essentially in accordance with AOAC International (1999). DM was determined by drying at 105 °C to constant weight and ash by ignition at 600 °C for 2 hours. Total nitrogen was determined by a macro Kjeldahl technique using mercury as the catalyst in the digestion and titration to an end point pH of 4.6. Crude protein (CP) was calculated using a conversion factor of 6.25 irrespective of the nature of the nitrogen. Total lipid was determined gravimetrically following chloroform-methanol (2:1) extraction using the method of Folch et al. (1957). Nitrogen-free extract was measured as the difference between the total and the sum of moisture, ash, protein and lipid content. The determined chemical composition of the diets is shown in Table 1.

Per cent weight gain (WG%) was determined as the difference between end ( $W_e$ ) and start ( $W_s$ ) weights divided by  $W_s$  and expressed as a percentage. The feed conversion ratio (FCR) was calculated on a DM basis. Lobster productivity response data were analysed as a two-way factorial

using the SPSS (Chicago, Illinois, United States of America) package's General Linear Model (Univariate, Full Factorial). In the absence of a significant interaction between main effects (trash fish species × vitamin supplementation), differences between treatments for the trash fish species effect were examined using Duncan's multiple range test ( $P = 0.05$ ), while differences between the vitamin supplementation effect were examined using Student's  $t$ -test at  $P = 0.05$ .

## Results and discussion

No water-quality problems (nitrite,  $\text{NO}_2$ , <0.3 mg/L; ammonia,  $\text{NH}_3$ , <0.03 mg/L; pH, 7.8 to 8.3) were observed during the experiment, with water temperature averaging 29 °C (standard deviation (SD) ± 0.5). The lobsters remained healthy throughout the experiment with nine deaths from the initial placement of 120 lobsters (survival of  $93 \pm 12.9\%$ ). There were no significant differences in survival among treatments. The interaction between the main effects of fish species and vitamin supplementation was not significant ( $P > 0.05$ ) for each of the measured response traits but there were significant treatment differences within main effects (Table 2).

Lobsters fed diets based on *Saurida* sp. (lizardfish) grew significantly better than those fed *Nemipterus* sp. (bream) diets; weight gain of lobsters fed *Stolephorus* sp. (anchovy) diets was intermediate. Although there were no significant differences between fish species for DM FCR, similar trends as seen for growth were observed, with lizardfish the best and bream the worst. It is difficult to find a satisfactory explanation for these differences in lobster productivity. The lipid content of bream was higher than that of anchovy and lizard-

**Table 2.** Main productivity responses of lobsters fed different trash fish diets based on *Saurida* sp. (lizardfish; L), *Nemipterus* sp. (bream; B) or *Stolephorus* sp. (anchovy; A), with or without vitamin supplementation

Trait	Treatment responses <sup>a</sup>						
	Fish species				Vitamin supplementation		
	L	B	A	± SEM	With	Without	± SEM
Survival (%)	90.0 <sup>A</sup>	90.0 <sup>A</sup>	97.5 <sup>A</sup>	2.64	93 <sup>X</sup>	92 <sup>X</sup>	5.1
End weight (g)	13.3 <sup>A</sup>	10.8 <sup>B</sup>	12.4 <sup>A</sup>	0.36	13.2 <sup>X</sup>	11.1 <sup>Y</sup>	0.29
Gain (%)	402 <sup>A</sup>	278 <sup>B</sup>	333 <sup>AB</sup>	17.5	392 <sup>X</sup>	284 <sup>Y</sup>	9.3
FCR (DM basis)	2.14 <sup>A</sup>	2.82 <sup>A</sup>	2.48 <sup>A</sup>	0.138	2.11 <sup>X</sup>	2.86 <sup>Y</sup>	0.167

<sup>a</sup> As the interaction between main effects was not significant ( $P > 0.05$ ), only the mean data for each of the main effects are shown  
 Note: A,B: X,Y Within treatment effects and rows, means with a common superscript letter do not differ significantly ( $P > 0.05$ ); SEM = standard error of the mean; FCR = feed conversion ratio; DM = dry matter

fish (14.4% compared to 5.4% and 7.6% on a DM basis, respectively; Table 3).

Since marine crustaceans do not tolerate high lipid diets—doing best on diets containing not more than 10% total marine lipid (D’Abramo 1997; Glencross et al. 2002a,b)—it was necessary when formulating the diets in this experiment to reduce the inclusion rate of the bream so that the total lipid content of the diet did not exceed 10% (Table 1). This also meant including more fishmeal and wheat flour in the bream-based diet to maintain dietary CP relatively constant (50–51%) across all diets. The higher inclusion of fishmeal and wheat flour in the bream diet may have reduced the palatability of the diet and thus growth may have suffered because of a lowered intake of food. However, the intermediate growth performance of lobsters fed the anchovy diet could not be explained by the lipid content of that fish species since it was lower than for lizardfish (Table 3). While lobster growth differences between the trash fish species might be explained on the basis of diet palatability, this does not explain the apparent, if not significant, differences in DM FCR of lobsters fed the various diets. Comparison of the essential amino acid composition of the experimental diets (Table 4) shows that the amounts of lysine, threonine and valine in the bream diet were lower than for the other diets. As lysine and threonine are commonly the most limiting essential amino acids in compounded feeds, this may explain the poor FCR observed for the bream diet. However, the lysine and threonine values for the anchovy diet were higher than for the lizardfish diet and yet the FCR of lobsters fed the anchovy diet was worse, though not significantly, than for the lizardfish diet. Clearly, other factors, possibly other micronutrients or contaminants, must be affecting the nutritional quality of the diets.

Adding a vitamin pre-mix to the diets markedly improved both growth rate and FCR of the lobsters (Table 2) and this was independent of the species of

trash fish used in the diets. The vitamin pre-mix was a custom formulation intended to meet the vitamin requirements of marine crustaceans and finfish. It is important to note that the trash fish used in the experiment was of the highest possible quality, having been purchased directly from the fishers upon landing of the catch and then immediately placed in a freezer at –20 °C. That a very positive response to vitamin supplementation was observed when using high-quality trash fish emphasises the importance of vitamin supplementation and this may be even more important when feeding trash fish that typically would be of much lower quality and freshness.

**Table 4.** Essential amino acid (EAA) composition of diets based on *Saurida* sp. (lizardfish; L), *Nemipterus* sp. (bream; B) and *Stolephorus* sp. (anchovy; A) trash fish

EAA	Composition (g/16 g nitrogen)		
	L	B	A
Arginine	2.67	3.28	4.00
Histidine	1.28	1.46	1.78
Isoleucine	3.14	2.82	2.96
Leucine	3.97	4.34	5.31
Lysine	5.05	4.18	5.38
Methionine	1.61	1.72	2.01
Phenylalanine	2.71	2.44	2.84
Threonine	2.57	2.40	2.90
Tryptophan	0.57	0.64	0.79
Valine	3.26	3.10	3.59

## Conclusions

Lobsters grew best when fed diets based on *Saurida* sp. (lizardfish) and worst on *Nemipterus* sp. (bream) with *Stolephorus* sp. (anchovy) based diets somewhat inferior to lizardfish.

Adding a complete vitamin pre-mix resulted in a marked improvement in lobster growth and FCR.

**Table 3.** The proximate and total lipid analyses of the trash fish used in the experiment, expressed on a wet and dry matter (DM) basis

Analysis (%)	<i>Saurida</i> sp. (lizardfish)		<i>Nemipterus</i> sp. (bream)		<i>Stolephorus</i> sp. (anchovy)	
	Wet	DM	Wet	DM	Wet	DM
Moisture	79.2		77.8		78.6	
Crude protein	18.0	86.6	18.0	81.2	18.2	85.1
Total lipid	1.6	7.6	3.2	14.4	1.2	5.4
Ash	1.0	4.7	1.0	4.4	2.0	9.3
Crude fibre	0.01	0.05	0.01	0.05	0.04	0.20

## Acknowledgments

The research was carried out as part of the Australian Centre for International Agricultural Research (ACIAR) lobster project (FIS/2001/058) and this financial support is acknowledged. We thank Dr Kevin Williams (Commonwealth Scientific and Industrial Research Organisation; CSIRO) for technical advice and Mr Nguyen Duc Doan for technical assistance in the conduct of the experiment. We thank Mr Nguyen Thanh Son for chemical analyses.

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# Nutritional requirements of juvenile *Panulirus ornatus* lobsters<sup>1</sup>

Kevin C. Williams<sup>2</sup>

## Abstract

Efforts to develop palatable and high-performance pelleted grow-out feeds for spiny lobster have not met with much success until recently. Renewed research over the past decade has added considerably to our knowledge about the capacity of spiny lobsters to digest alternative marine and terrestrial feed ingredients. Additionally, attention has focused on defining the lobsters' requirements for protein and energy, and the key essential micronutrients of cholesterol, essential fatty acids and carotenoids. Spiny lobsters do not have a good tolerance to high dietary lipid levels, with levels above about 12% typically causing a significant growth depression. However, in contrast to the lower dietary protein requirements of penaeid shrimp, *Panulirus ornatus* grows best when fed diets that contain at least 56% dry matter digestible protein (about 58–60% of crude protein based on marine sources). The ability of lobsters to utilise dietary carbohydrate as an energy source, thereby sparing dietary protein or lipid for this purpose, has received some attention from researchers. The optimal dietary carbohydrate to lipid ratio for *Jasus edwardsii* (southern spiny lobster) was found to be about 2:1 and work with *Homarus americanus* (American clawed lobster) has also confirmed its capacity to utilise some dietary carbohydrate. Recent New Zealand studies have shown that temperate *J. edwardsii* has considerable capacity to digest various types of carbohydrates but whether or not tropical spiny lobsters have a similar capacity to utilise dietary carbohydrate is unknown. Recent work on the dietary cholesterol requirement of juvenile and subadult *P. ornatus* lobsters has shown that a dietary level of 0.35% cholesterol in the presence of 2.5% phospholipid is adequate for good growth and high survival. Work at Nha Trang University in Vietnam has examined the requirement of juvenile *P. ornatus* for highly unsaturated fatty acids. At constant dietary linoleic + linolenic acid levels of 1.9%, a dietary eicosapentaenoic (20:5n-3) plus docosahexaenoic (22:6n-3) fatty acid specification of 1.8% was optimal for lobster growth and survival. There is little, if any, direct information on mineral or vitamin requirements of spiny lobsters but requirements determined for marine shrimp will be a useful guide until more specific information is available for lobsters.

This paper presents recent data on the digestive capacity of spiny lobsters and reviews the accumulating knowledge on the nutritional requirements of *P. ornatus*. Priorities for further research that would benefit the development of compounded lobster grow-out feeds are also suggested.

**Keywords:** rock lobster; nutrition; pelleted feed; digestibility; protein; attractants

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<sup>1</sup> The contents of this paper, although updated and revised, have been extensively extracted from an earlier paper published by Elsevier B.V., Amsterdam, The Netherlands: Williams K.C. 2007. Nutritional requirements and feeds development for post-larval spiny lobster: a review. *Aquaculture* 263, 1–14.

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## Introduction

Spiny lobsters (Palinuridae) are one of the world's most valuable seafoods with high market appeal in Asia, Europe and America. Most capture lobster fisheries are either over-exploited and in decline or are being managed for their maximum sustainable yield (Phillips 2000, 2005). Aquaculture appears to be the only long-term way of meeting market demand for spiny lobsters. Although laboratory-scale rearing of the larvae from egg to puerulus has been achieved for many species of temperate and tropical spiny lobsters (Kittaka 2000; Matsuda and Yamakawa 2000; Ritar et al. 2006), including *Panulirus ornatus* (R. Barnett, M.G. Kailis Lobster Harvest, Western Australia, pers. comm.), commercially viable hatchery production of spiny lobsters is still thought to be a long way off. Until successful hatchery technology is developed, the only practical way of increasing the volume of marketed lobster is to capture juveniles from the wild and on-grow them to market size, thereby circumventing the high natural mortality that otherwise occurs (Phillips et al. 2003). *Panulirus ornatus* (ornate spiny lobster) and *P. argus* (Caribbean spiny lobster) are undoubtedly the best candidate species for aquaculture as they have the shortest oceanic larval development phase of 4–8 months (Acosta et al. 1997; Cruz et al. 2001; Dennis et al. 2001) and the fastest postlarval growth rate—in the case of *P. ornatus*, attaining a market size of 100–105 mm carapace length (~1 kg) within 18 months after settlement (Phillips et al. 1992; Dennis et al. 1997; Skewes et al. 1997; Hambrey et al. 2001).

The on-growing of spiny lobsters is a flourishing industry in many parts of South-East Asia and notably in Vietnam where the abundance of settling *P. ornatus* postpueruli has enabled lobster aquaculture to develop into a significant export industry producing about 2,000 t, worth US\$65–70 million, annually (Hung and Tuan 2009; Thuy et al. 2009). In Vietnam, lobsters are fed exclusively on fresh fishery by-catch. However, the diminishing supply and increasing cost of the by-catch, together with the downstream environmental impacts of this type of feeding, are strong incentives for the development of more eco-friendly pelleted lobster feeds.

Despite more than 30 years of research to develop a suitable compounded (artificial) feed for rearing juvenile spiny lobsters (see Conklin 1980; Booth and Kittaka 1994; Brown et al. 1995), progress has

been slow and our knowledge of the nutritional requirements of these animals remains sparse. However, progress in developing suitable pelleted dry feeds for spiny lobster grow-out has gained considerable momentum in the last 10 years or so. This paper reviews this more recent research and identifies areas where further research is critically needed.

## Natural diet

Knowing what the animal prefers to eat in the wild is a useful guide when developing an artificial feed. Analysis of the contents of the foregut of postlarval spiny lobsters reveals a wide variety of molluscs (predominantly bivalves, gastropods and chitons), crustaceans (predominantly barnacles, crabs and other decapods), polychaete worms, echinoderms and occasional (incidental?) amounts of macroalgae (Joll and Phillips 1986; Booth and Kittaka 1994; Barkai et al. 1996; Cox et al. 1997; Griffiths et al. 2000; Mayfield et al. 2000; Goni et al. 2001). This diet selection characterises spiny lobsters as opportunistic carnivores of predominantly benthic invertebrates. Thus, they most likely have evolved to most efficiently utilise foods that are high in protein, low in lipid and moderate to high in starch since glycogen is the major energy store of molluscs and typically 14–24% of the ash-free dry matter (Dall et al. 1991; Lodeiros et al. 2001; Orban et al. 2002).

## Chemoreception and feed acceptance

Knowing what food is attractive to the animal, and whether its physical characteristics (size, shape, texture etc.) influence the animal's selection preferences, are important considerations when developing an artificial feed. The natural food of spiny lobsters shows an enormous diversity in prey type, typical of a savaging benthic carnivore. Spiny lobsters are well equipped to efficiently prise open live mussels, though with a preference for small over large sizes, to consume sea urchins but with a low preference, or to devour softer-bodied prey such as gastropods, decapod crustaceans and polychaetes (Griffiths and Seiderer 1980; Joll and Phillips 1986; Barkai et al. 1996; James and Tong 1998; Mayfield et al. 2001). Thus, providing an artificial feed in the form of a pellet should not in itself be a deterrent to

feeding provided that the feed is perceived to be palatable to the lobster. However, the size of the pellet in relation to the size of the animal and perhaps the texture of the feed may be important for maximising consumption rates and to minimise wastage (Sheppard et al. 2002; Smith et al. 2009). Of greater importance will be what attracts the lobster to its feed and what stimulates ingestion.

Much is known about chemoreception in marine decapods (see Lee and Myers 1997; Grasso and Basil 2002) and feeding preferences of spiny lobsters are also becoming better understood (Derby 2000; Derby et al. 2001; Grasso and Basil 2002). Like homarid lobsters, spiny lobsters have a well-developed antennular chemosensory system for locating food, finding shelter and social interactions with other lobsters. Characteristically, feed attractants for crustaceans are low molecular weight, water and ethanol soluble, and amphoteric or basic compounds that are released from potential prey items. Thus, to ensure an artificial feed will be perceived by the lobster as something suitable to eat, it should leach a steady plume of attractants rich in free amino acids, especially taurine, glycine, arginine, glutamic acid and alanine, and other low molecular weight organic compounds such as organic acids, nucleotides and nucleosides, betaine or small peptides (Lee and Meyers 1997).

Since shrimp and lobsters show similar behavioural responses to chemical cues (Daniel et al. 2001), it is not surprising that commercial shrimp pellets have been tested to see if lobsters would eat and grow well on them. In Australian work with juvenile *P. ornatus*, *Panulirus cygnus* (western spiny lobster) and *Jasus edwardsii* (southern spiny lobster), the lobsters readily ate formulated shrimp pelleted feeds but growth and survival were generally much poorer than when mussels were fed (Crear et al. 2000, 2002; Glencross et al. 2001; Smith et al. 2003b). These observations suggest that the shrimp pellets were either nutritionally inadequate for, or not sufficiently attractive to, the lobsters. The latter appeared to be the most likely explanation as lobsters would cease feeding on the shrimp pellets within 1–2 hours of their being offered, whereas the attractiveness of mussel flesh persisted for 10 or more hours (Glencross et al. 2001; Tolomei et al. 2003; Williams et al. 2005).

These observations prompted experiments to examine why the attractiveness of pelleted feed diminished after such a short time of immersion.

Working with juvenile *J. edwardsii*, Tolomei et al. (2003) measured the excitatory capacity and the attractability of shrimp pellets and mussel flesh after these had been immersed in water for up to 8 hours. They also examined the chemoattraction of different concentrations of glycine, taurine and betaine. The lobsters' attraction to shrimp pellets and mussel flesh declined with increasing immersion time. However, feeding shrimp pellets that had been soaked for periods of 0.5, 2, 4 or 8 hours did not affect the growth, feed conversion or survival of the lobsters during a 12-week growth trial. The greatest feeding behavioural response (antennule flicking) of the lobsters occurred with glycine at concentrations of  $10^{-4}$  to  $10^{-6}$  mol/L while the concentration of taurine had to be increased to  $10^{-2}$  mol/L to get a similarly high behavioural response; the response to betaine remained low at all concentrations over the range  $10^{-8}$  to  $10^{-2}$  mol/L.

A quite different response was observed with juvenile *P. ornatus* (Williams et al. 2005). In this study, Williams et al. sought to characterise feeding cues by quantifying the nitrogenous compounds leaching from mussel flesh or pelleted dry feeds following immersion in water over 7.5 hours and correlating the leachate with the preference of the lobsters to the same soaked or non-soaked feeds. Homogenates of natural prey items, either polychaete blood worm, shrimp, mussel or squid, were included in the pelleted feed so that the chemical signatures of the leachates would be different. The lobsters' feeding preference, measured as the proportional intake when presented with a choice between a reference and a test feed, was most positively correlated with the amount of soluble protein, glycine and taurine that leached from the feeds. However, lobsters showed a much higher preference for mussel flesh than for the pelleted dry feeds even when 5 hour-soaked mussel was compared with non-soaked pelleted feed. These results suggested that increasing feeding frequency and including protein hydrolysates and other ingredients rich in free amino acids in the dietary formulation might be practical ways for increasing feed intake when using pelleted artificial feeds. Floreto et al. (2001) used krill hydrolysate to enhance the acceptance of soybean-based feeds for *Homarus americanus* (American clawed lobster) and found that soybean could provide almost 90% of the dietary protein with no adverse effects on growth relative to feeding mussels.

## Digestive capacity and nutritive value of feed ingredients

Studies on the digestive enzymes of juvenile and adult spiny lobsters attest to their carnivorous feeding preference, with high proteolytic (trypsin, chymotrypsin and carboxypeptidase A), moderate carbohydrase ( $\alpha$ -amylase,  $\beta$ -glucosaminidase, laminarinase and cellobiase) and comparatively low lipase activities (Barkai et al. 1996; Johnston 2003; Radford et al. 2005). Interestingly, amylase- and laminarinase-specific activities were reported to decrease as a function of lobster size, implying that carbohydrate might be a more important dietary constituent for juveniles than adult spiny lobsters (Johnston 2003). In recent work examining the carbohydrate digestive capacity of *J. edwardsii* using in-vitro digestive gland enzyme homogenates, Simon (2009) found that soluble storage polysaccharides, such as gelatinised starches, dextrin and mussel glycogen, were well digested; while native starches and the disaccharides sucrose and trehalose were poorly digested. When the more digestible carbohydrate sources were incorporated at 27% in semi-purified diets and fed to juveniles, the resultant high haemolymph glucose concentrations (>5 mmol/L) and long hyperglycaemic responses (>24 hours) indicated that these carbohydrates were well digested and absorbed but most likely only poorly utilised. However, when the gonad of fresh *Perna canaliculus* (green-lipped mussel) containing 27% glycogen on a dry matter basis was fed as the test ingredient, the short hyperglycaemic response (<12 hours) implied a better utilisation of this carbohydrate source.

In considering the usefulness of a feed ingredient as a source of nutrients for assimilation by the animal, the likelihood of growth inhibitors or contaminating toxins being present must be considered. A thorough critique of this aspect is beyond the scope of this review. For an account of naturally occurring growth inhibitors and toxic contaminants, readers are referred to reviews by Hardy (1999), Francis et al. (2001), Hendricks (2002) and Burgos-Hernandez (2005). Inappropriate storage conditions or poor handling of the ingredient can also diminish its value since bacterial contamination and/or oxidative decomposition during or after production can destroy critical nutrients or produce toxins such as biogenic amines (Aksnes and Mundheim 1997; Opstvedt et al. 2000; Shakila et al. 2003). However,

from a purely nutritional perspective, nutritive value of an ingredient is typically first assessed by measuring its apparent digestibility. Sadly, very little information is available on the apparent digestibility of feed ingredients for spiny lobster and this is an area where further work is needed.

Table 1 provides data on the apparent digestibility of some feed ingredients that have been used in feed development research for spiny lobsters. As for penaeid shrimp (Smith et al. 2001) and mud crab (Catacutan et al. 2003), spiny lobsters digest the protein of animal and some plant meals with high efficiency. Particularly interesting is the high apparent digestibility of lupin and wheat gluten protein—a finding that is similar to that observed for fish and other crustaceans (Smith et al. 2001). However, the apparent digestibility of the protein in commercial squid meal measured in *J. edwardsii* was unexpectedly low (7%) and suggests that excessive heating and protein denaturation during the manufacturing process may have been the cause. Whether or not this is typical of processed squid meal or due to an aberrant batch of the product is unknown. Clearly, more work needs to be done to measure the digestibility of feed ingredients that have potential to be used in artificial feeds for spiny lobsters. With *P. ornatus*, difficulties in collecting a representative sample of faeces have been overcome by using a novel balloon method, which prevents voided faeces coming in contact with the water (Irvin and Tabrett 2005).

## Protein and lipid (energy) requirements

A coordinated Australian growth study examined the dietary protein and total lipid requirements of very small (<4 g initial weight) *P. cygnus*, *P. ornatus* and *J. edwardsii* lobsters (Glencross et al. 2001; Smith et al. 2003b; Ward et al. 2003b). Six pelleted dry feeds were prepared centrally to contain, on a dry matter (DM) basis, incremented amounts of crude protein (CP) from 35% to 60% at each of two levels of total lipid (6% and 10%). These feeds were distributed to the collaborating laboratories and fed to the respective lobster species. An additional diet of either fresh *Mytilus edulis* (blue mussel) or a *Penaeus japonicus* (kuruma) shrimp feed was included in the experimental array as a reference. In each of the experiments, lobster survival was good (>75%) and growth improved curvilinearly with

increasing dietary CP but the response depended on both the lipid content of the feed and the species of lobster. With *P. cygnus*, the best growth occurred with feeds containing 55% CP and was better for the low- than the high-lipid feeds (Glencross et al. 2001). With *P. ornatus*, the best growth occurred at calculated dietary DM CP asymptotes of 47% and 53% for the 6% and 10% lipid feeds, respectively; at the higher protein levels, lobster growth was better for the high- compared to the low-lipid feeds (Smith et al. 2003b). With *J. edwardsii*, dietary lipid level had no significant effect on the response to protein with growth being best at calculated dietary DM digestible protein asymptotes of 33–35% (equivalent to 42–47% CP) (Ward et al. 2003b).

Eight pelleted feeds containing serially incremented protein (from 35% to 60% DM) at a constant total lipid content of 9% DM were examined in another study with larger *J. edwardsii* (initial weight of ~70 g) (Crear et al. 2001). As with small lobsters, growth rate of the larger lobsters improved curvilinearly with increasing dietary CP but the response flattened out only when dietary CP was greater than 50%. In all four studies, the reference feed (*M. edulis* flesh or *P. japonicus* shrimp pellets) resulted in significantly better growth, often twice as good, as the best experimental feed. These results

suggest that different spiny lobster species have different dietary protein and lipid requirements and thus may require feeds specifically tailored for each species. However, as the growth of the lobsters on the pelleted experimental feeds was well below that achieved on the reference feed and much less than that observed for lobsters in the wild, it is questionable whether these results truly were a reliable measure of the animals' dietary protein and lipid requirements.

The dietary protein requirements of *P. ornatus* were re-examined by Smith et al. (2005) using a basal formulation that had been shown to be well accepted by the lobsters. Freeze-dried krill hydrolysate and freeze-dried krill meal were used at a constant inclusion rate of 8% and 30%, respectively, and the protein content of the feed serially increased by adding incremental amounts of fishmeal at the expense of starch to produce five isolipidic feeds that varied from 34% to 61% CP DM (31–56% digestible CP). An additional diet of thawed *P. canaliculus* mussel was included in the treatment array as a reference. The formulation and determined chemical composition of these feeds are detailed in Table 2. During the 8-week experiment, the growth rate of the lobsters, fed the pelleted feed four-times daily, continued to increase with

**Table 1.** Apparent digestibility (mean ± standard error; SE) of ingredients of potential use in artificial grow-out feeds for spiny lobsters

Ingredient	Dry matter	Crude protein	Total lipid	Gross energy	Ref <sup>a</sup>
	Apparent digestibility coefficient (%)				
<i>Marine protein sources</i>					
NZ blue mussel meal	–	97.6 ± 0.10	–	–	1
NZ green-lipped mussel meal	76.4 ± 3.0	88.8 ± 1.98	63.7 ± 6.04	83.3 ± 2.45	2
Shrimp head meal	–	77.2 ± 19.10	–	–	1
Crustacean meal (Lango)	53.2 ± 3.0	85.2 ± 1.98	53.4 ± 6.04	72.0 ± 2.45	2
Fishmeal (67% CP)	–	62.5 ± 1.40	–	–	1
Fishmeal (67% CP)	67.4 ± 3.0	84.2 ± 1.98	78.1 ± 6.04	80.7 ± 2.45	2
Squid meal	–	7.3 ± 2.30	–	–	1
Krill meal	68.5 ± 3.0	88.6 ± 1.98	64.4 ± 6.04	77.5 ± 2.45	2
<i>Terrestrial protein sources</i>					
Lupin flour	–	100.1 ± 6.0	–	–	1
Wheat gluten	–	90.1 ± 9.7	–	–	1
Soybean meal	–	60.5 ± 19.0	–	–	1
Pea meal	–	52.0 ± 8.7	–	–	1
Canola meal	–	38.3 ± 13.7	–	–	1

<sup>a</sup> References: 1 = measured in *Jasus edwardsii* (Ward et al. 2003a); 2 = measured in *Panulirus ornatus* (Irvin and Williams 2007)



increasing dietary CP with no suggestion of the response reaching a plateau even at the highest examined level (61% CP, equivalent to 56% digestible CP) (Figure 1). Thus, juvenile *P. ornatus* require high dietary protein specifications (i.e. >60% CP DM; that is >56% digestible CP) to achieve high growth rates on pelleted feeds.

## Essential micronutrients

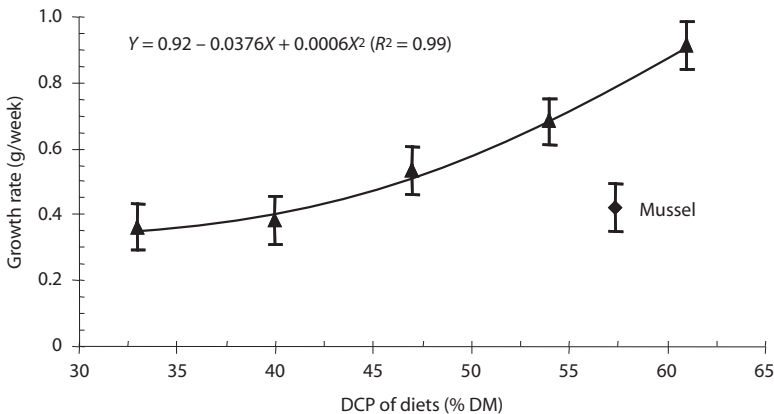
The dietary essentiality of long-chain n-6 and n-3 fatty acids, sterols, carotenoids and vitamins for crustaceans is well recognised, with a considerable body of work having been done with marine shrimp (D'Abramo et al. 1997). However, work to define

**Table 2.** Formulation and key chemical composition<sup>a</sup> of feeds used in re-evaluating the dietary protein requirement of juvenile *Panulirus ornatus* (Smith et al. 2005)

Attribute	Feed label					
	33CP	40CP	47CP	54CP	61CP	Mussel
<i>Formulation (% as used)</i>						
Fishmeal	0	9.0	18.0	27.0	36.0	
Starch	27.1	20.4	13.6	6.8	0	
Fish oil	4.4	3.3	2.2	1.1	0	
Diatomaceous earth	5.6	4.4	3.3	2.2	1.1	
Wheat flour	14.0	14.0	14.0	14.0	14.0	
Krill meal	30.0	30.0	30.0	30.0	30.0	
Krill hydrolysate	8.0	8.0	8.0	8.0	8.0	
Other <sup>a</sup>	10.9	10.9	10.9	10.9	10.9	
<i>Composition (dry matter basis)</i>						
Crude protein (CP) (%)	33.8	40.4	46.6	53.6	61.2	57.4
Digestible CP (%)	31.0	36.8	41.9	48.9	56.3	nd <sup>b</sup>
Lipid (%)	13.0	13.7	13.8	12.8	12.8	11.5
Gross energy (kJ/g)	19.6	19.6	20.2	20.5	20.8	19.6
Digest. energy (kJ/g)	17.9	18.2	18.4	18.7	19.0	nd <sup>b</sup>

<sup>a</sup> See Smith et al. (2005) for more information on the other ingredients and the chemical composition of the feeds

<sup>b</sup> nd = not determined



**Figure 1.** Relationship between the digestible crude protein (DCP) content of the feed (on a dry matter (DM) basis) ( $X$ ) and growth rate ( $Y$ ) of *Panulirus ornatus* juvenile lobsters fed pelleted feeds. The growth rate of lobsters fed thawed *Perna canaliculus* (green-lipped mussel) is shown at its corresponding crude protein DM content. Error bars are  $\pm$  SEM. Data of Smith et al. (2005).

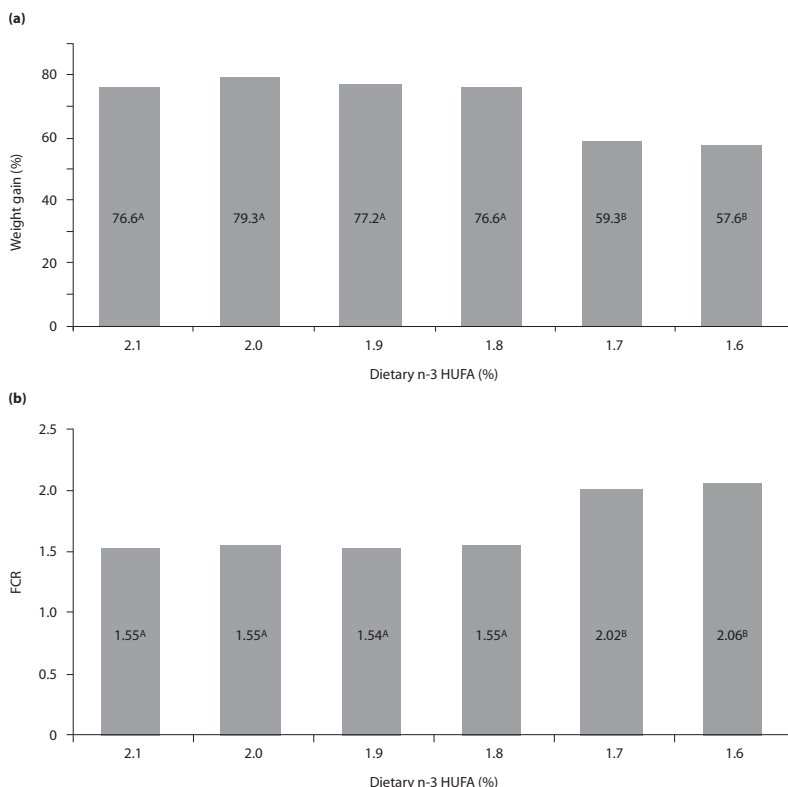
specific requirements for spiny lobsters is far from complete. Information that is available is summarised in the following sections.

### Essential fatty acids

Information on the essential fatty acid requirements of spiny lobsters is sparse. In an unpublished study of Tuan (L.A. Tuan, Nha Trang University, Vietnam, pers. comm.), juvenile *P. ornatus* lobsters were fed six pelleted feeds that provided serially increasing amounts of n-3 highly unsaturated fatty acids (HUFA) (sum of n-3 fatty acids, eicosapentaenoic (EPA; 20:5n-3) and docosahexaenoic (DHA; 22:6n-3)) ranging from 1.6% to 2.1% (1.7–2.2% DM). In that study, the dietary levels of protein (51% DM), total lipid (12% DM) and linoleic (LOA; 18:2n-6) plus linolenic (LNA; 18:3n-3) fatty acids (2.0% DM) were held constant. Increasing the

dietary amount of n-3 HUFA from 1.6% to 1.8% resulted in a significant improvement in feed conversion and lobster weight gain but no further productivity gains were observed with higher dietary levels (Figure 2).

More information has been published on the essential fatty acid metabolism of homarid lobsters. Zandee (1967) demonstrated that *Homarus gammarus* (the European lobster) is unable to synthesise LOA, LNA, EPA or DHA de novo. The dietary essentiality of the long-chain n-3 fatty acids and arachidonic acid (AA; 20:4n-6) for *H. americanus* can be inferred from the work of Castell and Covey (1976) and Castell and Boghen (1979). However, the quantitative requirements of these fatty acids for marine lobsters have not been elucidated (Conklin 1980; Kanazawa and Koshio 1994; Teshima 1997).



**Figure 2.** Weight gain (a) and feed conversion ratio (FCR) (b) responses of juvenile *Panulirus ornatus* lobsters fed pelleted feeds providing a range of n-3 highly unsaturated fatty acids (HUFA) at constant levels of dietary linoleic and linolenic acids. Data from L.A. Tuan, pers. comm.

In the absence of definitive information for lobsters, the essential fatty acid requirements of marine shrimp may be a useful guide. A comprehensive study of the essential fatty acid requirements of *Penaeus monodon* has been reported by Glencross and colleagues (Glencross et al. 2002a,b). They concluded that essential fatty acid requirements are a function of both the amount of lipid and the proportion of the total fatty acids in the diet. At an optimal dietary lipid content of 7.5%, the advocated ideal dietary specifications for LOA, LNA, EPA and DHA were 0.9, 1.5, 0.3 and 0.3%, respectively. A dietary source of AA was not essential for maximising growth and survival of juvenile *P. monodon* other than by way of contributing to the total supply of n-6 fatty acids for maintaining an optimum n-3 to n-6 fatty acid balance of 2.5 to 1.

### Phospholipid and cholesterol

The dietary essentiality of sterols and the inter-relationship with phospholipids for crustaceans generally, and spiny lobsters in particular, is still a vexed question (Coutteau et al. 1997; Teshima 1997). In addition to their role as structural components of cell walls, phospholipids act as surfactants for efficient emulsification of ingested lipid and thus assist the uptake of sterols (and other lipids) from the gut (Teshima 1997). They also are a component of high-density lipoproteins that are essential for the efficient transport of cholesterol from the digestive gland to target tissues during the moulting process (Conklin et al. 1980, 1983; Teshima 1997). Thus, dietary cholesterol requirements may depend on the amount of phospholipid in the diet. However, the essentiality of dietary phospholipid for sterol absorption is also equivocal. Reviewing earlier studies, Teshima (1997) concluded that the cholesterol requirement of marine shrimp was unaffected by dietary phospholipid. However, more recent work by Gong et al. (2000) found that the dietary cholesterol requirement of *Litopenaeus vannamei* shrimp decreased from 0.35% to 0.05% as the amount of phospholipid in the diet increased from zero to 5% but this contradicted the findings of Paibulkichakul et al. (1998) who observed no interaction between dietary phospholipid and cholesterol with *P. monodon*. For homarid lobsters, somewhat similar conflicting findings have been reported. Conklin et al. (1980, 1983) reported the inclusion of soy lecithin in a purified diet was essential for good growth and high survival of homarid juveniles and

advocated a dietary level of not less than 7.5% of dry weight. This differed from earlier findings of Kean et al. (1985) who found that dietary lecithin had no effect on growth or survival of *H. americanus* juveniles fed diets that varied serially in cholesterol between zero and 1.0%.

There have been very few studies examining the dietary cholesterol requirement of marine lobsters. Castell et al. (1975) found a diet providing 0.5% (dry weight) cholesterol resulted in the best growth and survival of juvenile *H. americanus* lobsters whereas levels of 0.2% and 2.0% both depressed growth. D'Abramo et al. (1984) found a dietary cholesterol specification of 0.12–0.19% was optimal for very small homarid lobsters (4th stage juveniles, probably of 30–50 mg initial size), although the slow growth of these lobsters—a gain over 120 days of <1 g—is reason enough to question whether this is a true indication of the animal's cholesterol requirement. Kean et al. (1985) fed juvenile *H. americanus* (initial weight of 120 mg) for 14 weeks on dry diets that provided a factorial comparison of five levels of cholesterol (0, 0.02, 0.25, 0.5 or 1.0%) and three levels of refined soy lecithin (0, 3 or 6%). All lobsters fed the 'zero' cholesterol diet died, regardless of the amount of lecithin in the diet, and increasing the amount of cholesterol above 0.25% or varying the amount of soy lecithin in the diet had no significant effect on growth or survival of the lobsters. As noted in the work of D'Abramo et al. (1984), the growth rate of the lobsters in the study of Kean et al. (1985) was poor, with the best gains being only about 700 mg over the course of the 14-week experiment.

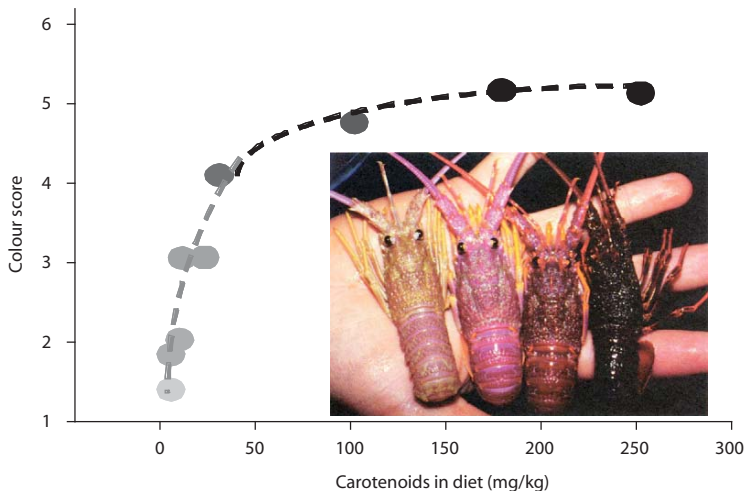
Considerably more work to elucidate dietary cholesterol requirements has been done with other crustaceans but again the findings are equivocal. For penaeid shrimp, estimates typically range from 0.25% to 1.5% (dry weight) of the diet (Teshima 1997) while work with *P. monodon* (Smith et al. 2003a) has shown a dietary specification of 0.17% cholesterol was adequate in the presence of 1.7% dietary phospholipid. Sheen (2000) found a dietary cholesterol level of 0.51% optimised growth and survival of juvenile *Scylla serrata* (mud crabs) when they were fed a purified diet devoid of soy lecithin (but containing 6% of a 2:1 cod liver oil and corn oil mixture) but diets with cholesterol concentrations of <0.2% or >1.1% depressed growth.

### Carotenoids including astaxanthin

Carotenoids are expensive (about US\$3,000/kg of active astaxanthin) and critical components of crustacean feeds but little is known of the carotenoid requirements of spiny lobsters. Most crustaceans are unable to synthesise carotenoids *de novo* and thus are dependent on an exogenous dietary supply to meet their requirements (Meyers and Latscha 1997; Linan-Cabello et al. 2002). In crustaceans and fish, astaxanthin is the predominant carotenoid. It is stored as free astaxanthin or as astaxanthin esters where the astaxanthin molecule is attached to a fatty acid. Astaxanthin has many functions in crustaceans apart from its obvious role in exoskeleton pigmentation. It has been implicated as having a role in sexual maturation and possibly other reproductive functions (Pangantihon-Kuhlmann et al. 1998; Linan-Cabello et al. 2002; Perez-Velazquez et al. 2003) and in larval and postlarval development (Petit et al. 1997; Pan et al. 2001). It also has an important role as an antioxidant and in maintaining the animal's immunocompetence and stress tolerance (Meyers and Latscha 1997; Linan-Cabello et al. 2002; Chien et al. 2003). In crustaceans, astaxanthin is not readily synthesised from other ingested carotenoids; with  $\beta$ -carotene having the highest bioconversion efficiency of about 50% (Meyers and Latscha 1997; Linan-Cabello et al. 2002).

Crear et al. (2002) evaluated six commercial shrimp pelleted feeds and fresh *M. edulis* (blue mussel) as feeds for juvenile *J. edwardsii*. Three of the shrimp feeds were formulated for *P. japonicus* (kuruma shrimp) and the other three for *P. monodon* (black tiger shrimp). These feeds were fed to slight excess for 134 days and measurements made of growth performance, carapace colour and body composition of the lobsters. Lobsters grew significantly better on the mussel than on the shrimp pelleted feeds but other productivity traits did not differ greatly between the various feeds. However, at the conclusion of the experiment, carapace colour of the lobsters differed markedly between the feeds, with colour scores being markedly higher for the three *P. japonicus* feeds (4.2–5.0), lowest for the three *P. monodon* feeds (1.4–1.8) and intermediate for *M. edulis* (4.0) (Figure 3). Highly significant curvilinear and linear relationships were found between dietary carotenoid content and the lobster's carapace colour and tissue carotenoid content, respectively. These authors concluded that lobsters need a dietary carotenoid level of around 115 mg/kg to ensure a carapace colouration score of >4.0, equivalent to that of wild-caught juvenile *J. edwardsii*.

The poor growth, low survival and pale exoskeleton colouration of juvenile *P. ornatus* fed frozen *P. canaliculus* in the work of Smith et al. (2005)

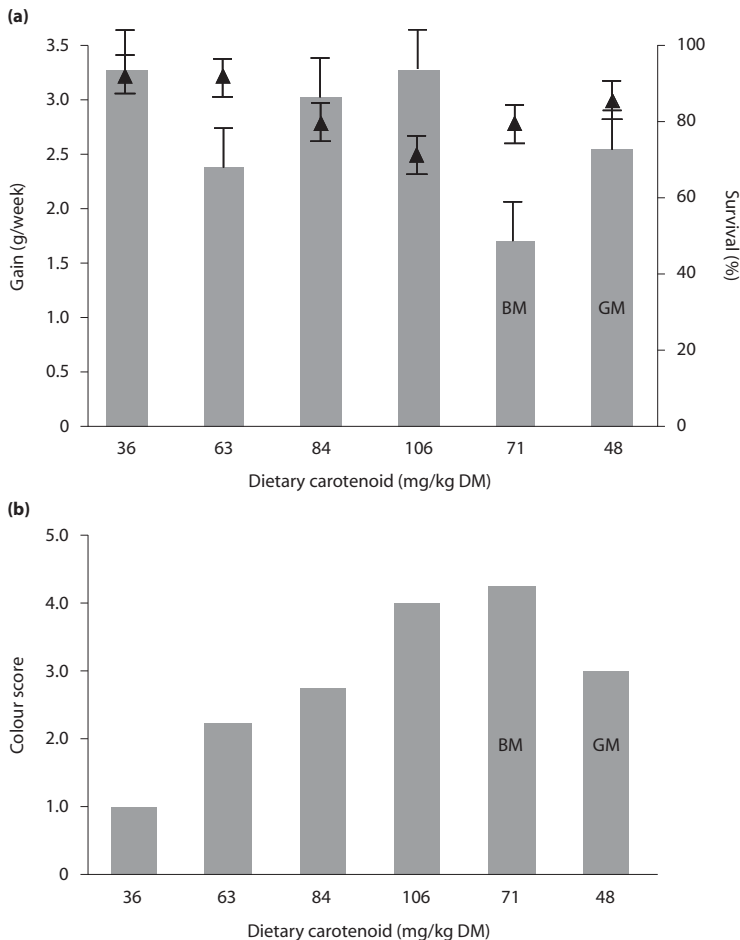


**Figure 3.** Carapace colour score for juvenile *Jasus edwardsii* lobsters fed commercial shrimp feeds containing different analysed amounts of total carotenoid. Insert photo shows colour range of the lobsters. Data and photo from Crear et al. (2002) and B. Crear, pers. comm.

prompted a further study to examine the dietary astaxanthin requirement of this species (Barclay et al. 2006). They carried out a 12-week experiment with juvenile *P. ornatus* fed either pelleted feeds supplemented with astaxanthin (providing total dietary carotenoid contents of 30, 60, 90 or 120 mg/kg) or one of two frozen mussel reference feeds; either *M. edulis* or *P. canaliculus*. The pelleted feeds were based on the formulation of the best feed in the earlier study (feed 61CP; Table 2) except that astaxanthin was incrementally added to produce the desired dietary astaxanthin specifications. Neither growth rate nor

survival showed a dose response to dietary astaxanthin but lobsters fed the two mussel feeds consistently grew more slowly and survival tended to be lower (Figure 4a), especially during the last 4 weeks of the experiment. Exoskeleton colour increased directly as the dietary carotenoid content of the pelleted feeds increased but the colour of lobsters fed the mussel was only poorly related to the carotenoid content of the mussel (Figure 4b).

Similarly, whole body total carotenoid content of the lobsters increased linearly with increasing dietary carotenoid for the pelleted feeds but the

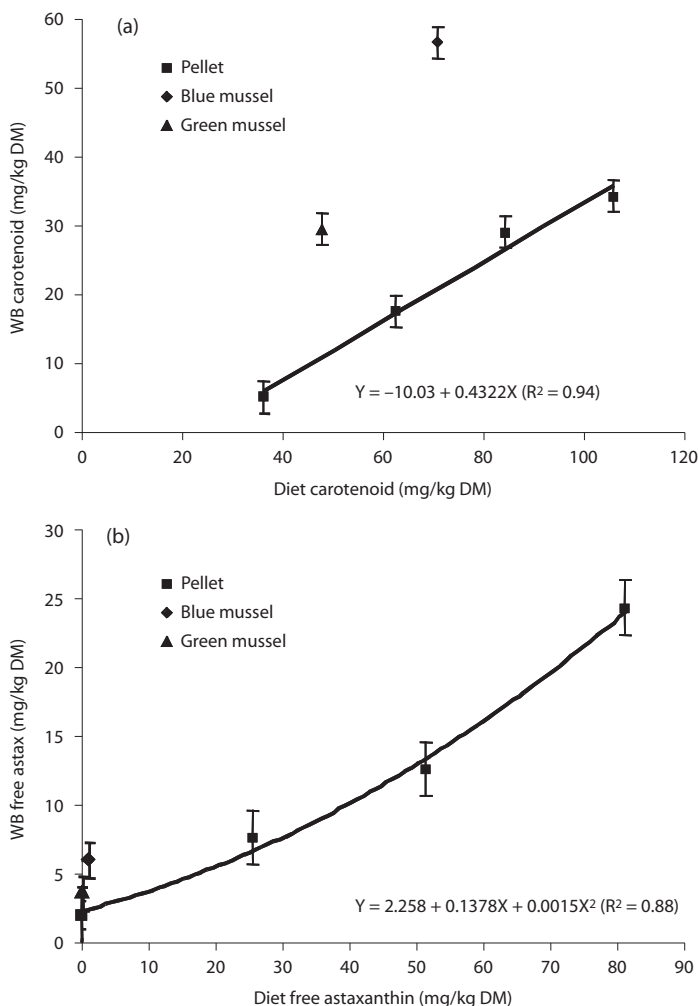


**Figure 4.** Effects of dietary carotenoid on growth (bars) and survival (▲) (a) and on exoskeleton colour score (b) of juvenile *Panulirus ornatus* fed either pelleted feeds providing incremental supplements of free astaxanthin or frozen *Mytilus edulis* (blue mussel; BM) or frozen *Perna canaliculus* (green-lipped mussel; GM). Data from Barclay et al. 2006.

relationship was less clear for the mussel-fed lobsters (Figure 5a). However, most of the carotenoid in the mussel was not astaxanthin, but other pigments most likely originating from the consumed microalgae. When whole body astaxanthin content of the lobsters was examined in relation to the free astaxanthin content of the feed, an excellent curvilinear relationship was seen for all feeds (Figure 5b). Although the range of dietary astaxanthin examined in the experiment did not affect lobster productivity, it did markedly affect exoskeleton colour and tissue astaxanthin content, which could have important

implications on the animal's immunocompetence and on the market acceptance of the cultured lobster. Moreover, the study confirmed the findings of the earlier study (Smith et al. 2005) that frozen mussels are not a suitable sole feed for *P. ornatus*.

Neither the study of Crear et al. (2002) nor that of Barclay et al. (2006) was able to demonstrate an improved productivity response to dietary carotenoid, and thus could not define a true requirement. However, both studies showed dietary carotenoid supply had a clear and marked effect on lobster colouration, a feature that has considerable impact on



**Figure 5.** Effects of dietary carotenoid content and whole body (WB) carotenoid content (a) and dietary free astaxanthin content and free astaxanthin content (b) (data from Barclay et al. 2006)

the marketing and the price paid for the lobster. If for this reason alone, a total dietary carotenoid specification of at least 100 mg/kg, and an astaxanthin equivalent of not less than 70 mg/kg, is recommended for *P. ornatus*.

### Vitamin and mineral requirements

The vitamin and mineral requirements of lobsters have not been examined to any great extent. Studies by Kean et al. (1985) suggested that juvenile *H. americanus* do not have a requirement for dietary ascorbic acid. Subsequent work by the same researchers (Desjardins et al. 1985) demonstrated that juvenile *H. americanus* were capable of synthesising [<sup>14</sup>C]dehydroascorbic acid following the oral administration of uniformly labelled [<sup>14</sup>C]glucose. However, an inability of *Panulirus japonicus* (Japanese spiny lobster) to synthesise ascorbic acid from [<sup>14</sup>C]glucose was reported by Kanazawa (1994). The essentiality of a dietary source of ascorbic acid has been irrefutably demonstrated for marine shrimp (Conklin 1997) and it would seem unlikely that within the Decapoda such fundamental differences in metabolism would exist. Requirements of marine lobsters for other vitamins have not been reported and, in the absence of such information, levels advocated for shrimp (Conklin 1997) are a useful guide when developing lobster feeds. No clearly defined requirement for minerals has been demonstrated for marine lobsters (Kanazawa 1994).

Since marine lobsters are strict osmoconformers (Lucu et al. 2000) and can be reared only in salinities close to that of sea water, they are likely to satisfy their mineral requirements from the water or the food they eat.

### Conclusions

Much progress has been made in the last decade to better define the nutritional requirements of postlarval spiny lobsters and to develop suitable pelleted dry feeds. This research has shown that the tropical *P. ornatus* grows best when provided with feeds that are high in digestible protein (>56% DM) and with 10–11% total lipid DM. More temperate species such as *P. cygnus* and *J. edwardsii* do not appear to need as high a dietary protein or lipid specification as *P. ornatus* but this conclusion needs further validation. Very little recent research has been done to quantify the lobsters' requirements for essential lipids, especially cholesterol, phospholipid and essential fatty acids, and this will assume greater importance when terrestrial feed ingredients are used to replace marine sources in cheaper dietary formulations. Until more definitive information is available on the nutrient requirements of lobsters, it is recommended that diets for juvenile *P. ornatus* be formulated to the specifications summarised in Table 3.

A pelleted feed that is well accepted by *Panulirus* and *Jasus* lobsters and which produces good growth

**Table 3.** Recommended nutrient specifications for pelleted grow-out feeds for *Panulirus ornatus* lobsters

Nutrient/energy	Specification (dry matter basis)
Crude protein (g/kg)	560–580
Digestible crude protein (g/kg)	550
Gross energy (MJ/kg)	20
Digestible energy (MJ/kg)	16
Ash (g/kg)	<120
Total lipid (g/kg)	80–100 (tolerate up to 120)
Linoleic fatty acid (g/kg)	≥5
Linolenic fatty acid (g/kg)	≥1
Arachidonic fatty acid (g/kg)	≥0.75
Eicosapentaenoic fatty acid (g/kg)	≥7.5
Docosahexaenoic fatty acid (g/kg)	≥11.5
Phospholipid (g/kg)	≥25
Cholesterol (g/kg)	≥2.5
Astaxanthin (mg/kg)	50
Essential amino acids	No requirement studies; deficiencies are unlikely because of high protein content
Vitamins	No requirement studies; use vitamin levels for shrimp feeds as a guide
Minerals	No information available; trace mineral needs should be met from sea water

and survival has been developed (Table 2). However, this formulation presently requires high inclusion rates of krill products, which are expensive. The task ahead for researchers will be to develop less-expensive feed formulations that lobsters readily accept and on which they grow well. This will require more information on the apparent digestibility and acceptability of alternative and cheaper feed ingredients, most likely of terrestrial rather than marine origin, and further definition of the lobsters' requirements for critically important nutrients and energy.

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# *Panulirus ornatus* lobster feed development: from trash fish to formulated feeds

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## *Abstract*

The development of pelleted feeds is a priority for the long-term sustainability and advancement of the *Panulirus ornatus* (ornate spiny lobster) industry. This paper outlines the steps taken in the development of moist and dry pelleted feeds for juvenile (<10 g) and subadult (>600 g) *P. ornatus* lobsters. A goal of the project was to develop formulated feeds that promoted growth and survival rates comparable to those achieved by lobsters fed with fresh feed items and trash fish. This challenge required a multifaceted approach to develop feeds that were attractive, easily ingested, water stable and cost-effective in meeting the animals' nutrient requirements. Feed development with subadult lobsters has progressed rapidly, culminating in the development of a practical, high-performing, dry feed that promotes high survival (>95%) and growth rates comparable to those achieved by lobsters fed on trash fish in seacage culture experiments in Vietnam. Feed development with juvenile lobsters was more problematic due to large seasonal variations in settlement numbers, coupled with incidences of high mortality. However, a moist formulated feed has been developed that promotes survival and growth rates superior to lobsters fed on a mixture of *Perna canaliculus* (green-lipped mussel) and *Sillago ciliata* (whiting) fish flesh.

**Keywords:** moist diet; pelleted diet; nutrition; binder; rock lobster

## **Introduction**

Throughout Asian–Pacific aquaculture, trash fish (low-value fishery product) is still the major source of nutrition for large marine crustaceans. This feeding practice typically originates in the infancy of an industry and becomes entrenched as the industry is established. The development of a *Panulirus ornatus* (ornate spiny lobster) industry in Vietnam is a prime example of this practice. While trash fish is effective and economical in establishing an aquaculture industry, it is unsustainable. The nutritional profile of trash fish is variable and suboptimal; therefore its use as the feed source is likely to

result in poor feed conversion ratios and negative environmental impacts. High seasonal variability in the availability of trash fish reduces the ability to effectively vary feed rates and frequency. These are important factors in optimising growth and minimising waste. The progression from trash fish to dry feeds is a complex process—starting with the incorporation of trash fish with dry ingredients to produce a moist feed, and ultimately the total removal of fresh items to produce a dry feed. Dry feeds have many advantages, such as the ease and cost-effectiveness of storage and conversion to marketable flesh, flexibility of feeding strategies and, critically, better environmental sustainability. This paper describes the improvement and progression of feed formulation and manufacture techniques that have successfully been applied to develop pelleted moist and dry lobster feeds.

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## Control and basal diet

For the majority of the feed development, either a commercial *Penaeus japonicus* shrimp feed or a high-quality trash fish diet (fresh items) was used as the control diet in each experiment. Throughout the course of the feed development program, *Perna canaliculus* (green-lipped mussel), *Mytilus edulis* (blue mussel), *Sepioteuthis* spp. (squid), *Sillago ciliata* (whiting) fish flesh and *Metapenaeus bennettiae* (school shrimp) were all tested for their efficacy in supporting lobster growth and survival. The best results were achieved when a combination of *S. ciliata*, *P. canaliculus* and *Sepioteuthis* spp. was used as the control diet. However, in all but the first experiment, survival and growth of the lobsters were better when fed the developed moist and dry feeds than the control diet. The basal diet used in the experiments was initially based on a high-specification shrimp feed. A single variable (nutrient) was manipulated in the basal diet in each experiment to provide dietary treatments. Throughout the project, the basal diet was progressively modified as requirements for macro- and micronutrients were determined and the essentiality of fresh and expensive ingredients was assessed.

## Binders

The use of high-quality binders was critical for producing stable and palatable moist and dry feeds. Transglutaminase (Activa® Ajinomoto, Japan)—a strong cross-linking protein binder—was critical for the effective binding of fresh ingredients such as *P. canaliculus* and *S. ciliata* flesh. It was used typically at an inclusion rate of 1% (dry to wet weight). Transglutaminase is expensive (US\$80/kg) and is more typically used to bind meats such as ham and fish for human consumption. In making dry feeds, a synthetic copolymer binder (Aquabind, DuPont Speciality, Wilmington, United States of America; USA) that is commonly used in shrimp feeds was effective for producing stable and palatable lobster feeds at inclusion rates of 2–3% (dry to dry weight).

## Experimental animals

The focus of the early feed development work was on the small *P. ornatus* juveniles (<10 g), as this is the critical stage following settlement and likely to

be the more difficult stage to have artificial feeds accepted. However, due to seasonal variability of settlement time and numbers from the north Queensland coastline and episodes of high mortality in captivity, larger (>600 g) subadult lobsters, which could be bought from the commercial lobster fishery, also became an important part of our feed development program.

## Methodology

### Experimental animals and systems

Juvenile lobsters (<10 g) were hand-collected as recently settled *P. ornatus* from Trinity inlet, Cairns, north Queensland (16°55'S, 145°45'E) and air-freighted to the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Cleveland, Queensland; subadults (>600 g) were sourced from seafood exporter M.G. Kailis, Cairns (Figure 1). Experimental tanks were provided with individual air-stones and supplied with heated ( $29 \pm 0.5$  °C) and filtered (20 µm) flow-through (60 L/hour) sea water (33–35 ppt (parts per thousand) salinity) and sufficient brick hides for all lobsters.

### Diet manufacture

All the diets were made at the CSIRO Marine Research Laboratory at Cleveland. A summary of the dietary formulations used in this series of experiments is detailed in Table 1.

Moist feeds were made using the following procedures. Fresh ingredients such as *P. canaliculus*, *S. ciliata* and *Marphysa sanguinea* (polychaete blood worm) were placed at –20 °C until semi-frozen, then extruded through a 3 mm die plate of the meat grinder attachment for an A200 Hobart planetary dough mixer (Hobart Corporation, Troy, Ohio, USA) to form a homogenous mince. The dry ingredients were finely ground (<710 µm) using a mortar and pestle for small constituents or by hammer mill (Mikro Pulverizer, Metals Disintegration Coy, Summit, New Jersey, USA) for bulk ingredients. The fresh ingredients and transglutaminase binder were thoroughly mixed together using an industrial-kitchen Kenwood KM800 planetary mixer (Kenwood Ltd, Havant, Hants, United Kingdom) for 10 minutes before the oil and remaining dry ingredients were added, followed by a further 10-minute mixing to form dough of approximately 40–50% moisture content.



**Figure 1.** Juvenile (5 g; a) and subadult (>600 g; b) *Panulirus ornatus* lobsters used in the feed development experiments

**Table 1.** Basal diet formulation for all reported experiments

Ingredients	Base formulation (g/kg dry matter basis)					
	Juvenile experiments			Subadult experiments		
	Expt 1	Expt 2	Expt 3	Expt 4	Expt 5	Expt 6
Fishmeal <sup>a</sup>	21	31	29	–	–	–
Fishmeal (de-fatted) <sup>a</sup>	37	–	–	16	–	–
Shrimp starter mash <sup>b</sup>	–	–	–	–	32	40
Crustacean meal	4	–	–	–	–	–
Krill products <sup>c</sup>	–	32	31	10	15	9
Diatomaceous earth	5	1	1	–	–	–
Wheat products <sup>d</sup>	15	17	11	5	–	–
<i>Fresh ingredients</i> <sup>e</sup>						
<i>M. sanguinea</i>	–	2	2	–	–	–
<i>P. canaliculus</i>	9	–	–	5	–	–
<i>S. ciliata</i>	–	–	–	5	9	10
<i>Binders</i>						
Alginate	5	–	–	–	–	–
Transglutaminase	–	2	2	2	2	1
Other <sup>f</sup>	4	7	5	9	7	1

<sup>a</sup> Peruvian or Chilean fishmeal, >67% crude protein (CP)

<sup>b</sup> Shrimp (*Penaeus monodon*) starter mash, >45% CP

<sup>c</sup> Antarctic krill, Inual, Santiago, Chile and krill hydrolysate, Speciality Marine Products, Vancouver, British Columbia, Canada

<sup>d</sup> Vital gluten, 76% CP; wheat flour

<sup>e</sup> Homogenised *Marphysa sanguinea* (polychaete blood worm), *Perna canaliculus* (green-lipped mussel) and *Sillago ciliata* (whiting) fish flesh

<sup>f</sup> Provided in the diet at varying levels (g/kg): carophyll pink (8% astaxanthin), 0.8; cholesterol, 3; soy lecithin (70%), 12.5; choline chloride (70%), 0.25; ethoxyquin, 0.25; vitamin pre-mix (Williams et al. 2004), 11; and trace mineral pre-mix (Williams et al. 2004), 5

The dough was extruded through a 3 mm die plate of the meat grinder attachment for the A200 Hobart planetary dough mixer to form spaghetti-like strands. The strands were placed in an airtight bag and set overnight in a refrigerator at 4 °C. The strands were stored at 20 °C until required for feeding.

The method used to make dry feeds was similar to that used for moist diets except that after the dry and oil ingredients were thoroughly mixed together, sufficient distilled water was added to produce dough with 40–50% moisture content. This dough was twice extruded through a 3 mm die plate and the spaghetti-like strands set in a commercial steamer for 5 minutes when Aquabind was used as the binder. Where alginate (Manucol) was used as the binder, the strands were placed in a bath of 10% calcium chloride (CaCl<sub>2</sub>) for 2–3 minutes to activate the alginate setting process. The moist extruded strands were dried in a force-draught oven at 40 °C for 24 hours and then stored at 20 °C until required for feeding.

## Juvenile lobster experiments

### Protein and lipid requirement (experiment 1)

The first experiment tested the growth response of juvenile lobsters to serially incremented protein (casein) at either of two levels of lipid, 6% or 10%. The dry feeds were alginate-bound and contained fresh *P. canaliculus* mussel (Table 1, experiment 1). The feeds produced a clear dose response to protein with a maximum growth response at 47% and 53% dry matter (DM) crude protein for the 6% and 10% lipid diet series, respectively (Smith et al. 2003). However, growth of the lobsters was suboptimal, with a daily growth coefficient of only 0.5%/day as compared to that observed for lobsters in the wild where growth typically exceeds 1.0%/day. The poor lobster growth on the dry feeds was attributed to a decline in the attractiveness of the pellet within a short time of it being immersed in water.

### Preference testing

A preference study by Williams et al. (2005) addressed the decline in feed attractiveness by assessing the ability of alternative fresh prey items, and dry feeds incorporating these prey items, to sustain the lobsters' feeding interest. The approach

was to include fresh food items in the pelleted feeds as a source of natural feeding chemical cues and to relate the rate at which these chemicals leached from the feed with changes in the observed feeding preference of the lobster. We individually tested *P. canaliculus*, *M. bennettiae*, *M. sanguinea* and *Sepioteuthis* spp. as homogenates at inclusion rates equivalent to 5% DM. Analysis of the relative feed intake of each feed type against the rate at which nitrogenous compounds leached from the immersed feed showed strong correlations for soluble protein and the free amino acids taurine and glycine (Williams et al. 2005). It was concluded that the provision of a moist feed containing elevated levels of peptides and free amino acids was likely to prolong the lobsters' feeding on the pellets.

Complementing this study was an assessment of alternative binders, as the alginate binder used in experiment 1 was not optimal in producing a feed that was sufficiently stable for a prolonged period. Preliminary testing of the protein binder transglutaminase showed that it was highly effective in the binding of fresh items with dry ingredients to produce a palatable and water-stable pellet. Based on these results, a new reference test diet was formulated which contained moderate inclusion of krill products and some fresh marine constituents (*M. sanguinea* or mussel) that could be presented as either moist or dry pellets (Table 2). The efficacy of this basal formulation was tested and confirmed in subsequent experiments with refinements incorporated to lessen the ingredient cost as knowledge of the lobsters' nutritional requirements became better known.

### Re-evaluation of protein requirement (experiment 2)

The second experiment reported by Smith et al. (2005) re-evaluated the dietary protein specification for juvenile *P. ornatus* and used a transglutaminase-bound basal feed containing fresh *M. sanguinea* blood worm and dry krill products to improve and prolong acceptance (Table 1, experiment 2) As in the first protein requirement study, a clear dose response to increasing dietary protein content was observed (Figure 2), with lobsters fed the highest protein diets achieving the best growth, with a daily growth coefficient of 1.38%/day—significantly higher than those fed *P. canaliculus* and the best performing test diet from experiment 1, 0.8%/day and 0.5%/day, respectively. It was clear that the

lobsters require a high protein diet of at least 60% crude protein DM (Smith et al. 2005). In the mussel-fed control animals, growth rate and survival were depressed in the final 4 weeks of the experiment. The majority of these deaths occurred during moult, with the carapace of the surviving lobsters found to be pale in colour.

### Dietary carotenoid requirement (experiment 3)

The low survival and paleness of lobsters fed *P. canaliculus* in experiment 2 prompted the need to determine the optimal dietary carotenoid requirement. Astaxanthin is the active carotenoid in marine

decapods and is a critical and expensive micro-nutrient (>US\$3,000/kg), which plays a role in carapace colouration, immunocompetence and stress tolerance. Astaxanthin was added to a basal formulation (Table 1, experiment 3), at incremental rates of 25 mg/kg, to produce four pelleted diets with a total carotenoid content ranging between 30 and 105 mg/kg. These four pelleted feeds were fed to juvenile *P. ornatus* lobsters for 12 weeks and compared with others fed reference foods of *P. canaliculus* or *M. edulis*. Increasing the astaxanthin content of the feed had no significant effect on lobster growth or survival, but correlated with an increase in the astaxanthin concentration of the

**Table 2.** Formulation and chemical composition of a pelleted dry feed supporting excellent growth and survival of juvenile *Panulirus ornatus* lobsters that was developed from the observations of experiments 1 and 2

Ingredient	Formulation	
	As g as used	As g/kg on dry matter basis
Fishmeal (Aqua-grade) <sup>a</sup>	360	328
Krill (spray-dried) <sup>b</sup>	300	273
Krill hydrolysate <sup>c</sup>	80	74
Wheat flour	140	123
Wheat gluten <sup>d</sup>	55	50
<i>M. sanguinea</i> (or <i>P. canaliculus</i> ) <sup>e</sup>	100	20
Starch	3.2	2.8
Diatomaceous earth	7.0	6.5
Supplements <sup>f</sup>	33	32
Total	1,078	909
<i>Chemical composition</i>		
Crude protein (CP; %)		61.2
Digestible CP (%)		56.3
Total lipid (%)		12.8
Phospholipid (%)		1.5
Cholesterol (%)		0.6
Fatty acids (%)		
18:2n-6		0.65
18:3n-3		0.1
20:4n-6		0.06
20:5n-3		0.8
22:6n-3		0.75
Gross energy (kJ/g)		20.8
Digestible energy (kJ/g)		19.0

<sup>a</sup> Peruvian or Chilean fishmeal, >67% CP

<sup>b</sup> Antarctic krill, Inual, Santiago, Chile

<sup>c</sup> Speciality Marine Products, Vancouver, British Columbia, Canada

<sup>d</sup> Vital gluten, 76% CP

<sup>e</sup> Homogenised fresh *Marphysa sanguinea* (polychaete blood worm) or (*Perna canaliculus* (green-lipped mussel)

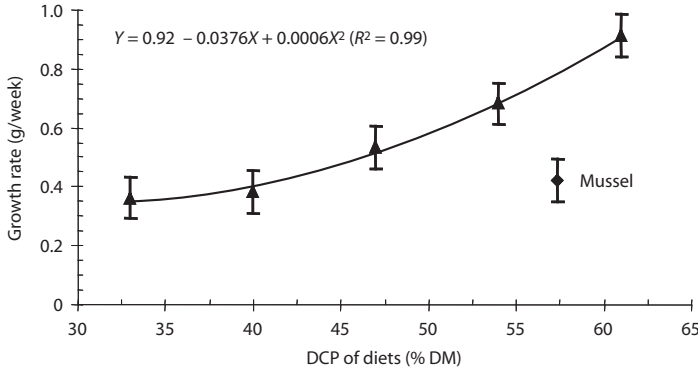
<sup>f</sup> Provided in the diet (g/kg): carophyll pink (8% astaxanthin), 0.8; cholesterol, 3; soy lecithin (70%), 12.5; choline chloride (70%), 0.25; ethoxyquin, 0.25; vitamin pre-mix (Williams et al. 2004), 11; and trace mineral pre-mix (Williams et al. 2004), 5



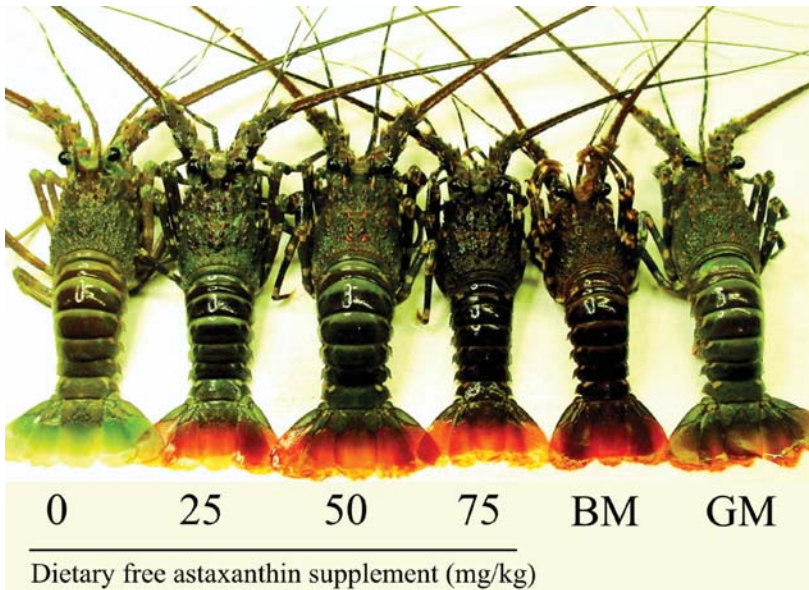
lobster's body tissue and an increased darkening of the exoskeleton (Figure 3).

Again, lobsters fed on pelleted diets achieved excellent growth rates with a daily growth coefficient of 1.38%/day which was significantly faster

than those fed either *P. canaliculus* or *M. edulis*, 0.87%/day and 1.17%/day, respectively. A dietary astaxanthin inclusion of 50 mg/kg is advocated for the provision of good lobster colouration and nutritional support for enhanced immunocompetence



**Figure 2.** Relationship between the digestible crude protein (DCP) content of the feed (on a dry matter (DM) basis) ( $X$ ) and growth rate ( $Y$ ) of *Panulirus ornatus* juvenile lobsters fed pelleted feeds. The growth rate of lobsters fed thawed *Perna canaliculus* (green-lipped mussel) is shown at its corresponding crude protein DM content. Error bars are  $\pm$  SEM. Data of Smith et al. (2005).



**Figure 3.** Exoskeleton colouration of *Panulirus ornatus* lobsters fed either pelleted diets that provided incremental supplementation of free astaxanthin or a diet solely of thawed *Mytilus edulis* (blue mussel; BM) or *Perna canaliculus* (green-lipped mussel; GM). From Barclay et al. (2006).

and stress resistance (Barclay et al. 2005). As in the previous study, lobsters fed mussels experienced a depression in growth after 4–6 weeks of feeding. The cost-effectiveness of the basal diet was improved by removing the fresh *M. sanguinea* and this exclusion caused no change in growth and survival of the lobsters.

### **Dietary cholesterol requirement (experiment 4)**

As the dietary carotenoid requirement trial (experiment 3) did not determine why lobsters fed fresh mussel had poor growth and survival, the objective of this experiment was to see if the low cholesterol content of mussel was a factor and thus a critical nutrient when formulating manufactured feed. Cholesterol is an essential micronutrient, having a critical role in healthy ecdysis (moulting), growth and survival in crustaceans. In order to determine the optimal dietary cholesterol specification for lobsters, it was necessary to formulate a basal diet that was as low as practical in cholesterol. This was achieved by de-fattening fishmeal to reduce its cholesterol content and selecting a low-fat fish (*S. cilliat*a, whiting) as a source of fresh food for increased palatability and effective pellet binding. The fish flesh was added at an inclusion level equivalent to 10% DM. Cholesterol was added to a basal formulation at five incremental levels varying between 0.13 and 0.41 g/kg DM (Table 1, experiment 4). Juvenile *P. ornatus* lobsters of ~2 g initial weight were fed the low cholesterol diet for 1 week to deplete their cholesterol reserves and then fed their respective experimental diet for 7 weeks. Included in the experiment for comparison were two reference foods of *P. canaliculus* and *M. edulis*, respectively. The daily growth coefficient achieved by the best performing experimental diet of 1.59%/day exceeded that of the best diet in the astaxanthin experiment (1.38%).

Although we observed a trend for lobster growth to improve with dietary cholesterol supplementation, the absence of a significant growth or survival response precluded a firm conclusion about the dietary cholesterol requirement of the lobsters. However, a dietary specification of 0.41% DM cholesterol is recommended for juvenile *P. ornatus*. Feeds that contain normal sources of marine proteins are likely to contain this amount of cholesterol and thus should not require supplementary

cholesterol—a significant cost saving in feed formulation. Again, episodes of high mortality occurred, but this was not treatment specific. However a strong correlation was found between lobster starting weight and subsequent survival: the smaller the starting size, the lower the survival rate. Lobster survival ranged from 40% for the 0.4 g lobsters to 90% for the 3.4 g lobsters. Again, improvements were made on the cost-effectiveness of the basal diet as supplemental cholesterol was found to be unnecessary.

### **Essentiality of krill products—pilot experiment**

The preference experiment addressed the need to sustain the lobster's feeding interest in the pelleted feed following immersion. This resulted in the addition of krill products to the basal feed to increase the supply and prolong the release of peptides and free amino acids. Krill products are expensive. The krill fraction in the feed was made up of spray-dried whole krill and krill hydrolysate (an enzymic treatment of de-fatted krill) at a ratio of 3:1. As krill hydrolysate is the most expensive of all of the major ingredients used in the improved formulation (Table 2), its essentiality in the formulation for maintaining high lobster productivity was assessed. Unfortunately, very low settlement along the north Queensland coastline and subsequent high mortalities of the collected juveniles allowed the completion of only a low replication pilot study.

The basal diet retained fresh items of fish flesh (*S. cilliat*a) at an inclusion level of 44%. Krill hydrolysate was added to the basal formulation at four serial levels from 0 to 80 g/kg at 20 g/kg increments. These three pelleted feeds were fed to *P. ornatus* for 6 weeks. Daily growth coefficient of lobsters fed the highest inclusion of krill was 1.07%/day and significantly higher than lobsters fed the diet containing zero krill hydrolysate (0.90%/day). This suggested that the current inclusion in the formulation of 8% krill hydrolysate was necessary to maintain high lobster productivity. We hypothesised that the inclusion of krill product, rather than the fresh items, is the main driver stimulating growth performance. Therefore, the following experiment looked at the essentiality of including fresh ingredients in the formulation. However, further incidences of very low settlement along the north Queensland coastline and high mortalities in captivity continued. This forced us

to work with commercially available subadult *P. ornatus* ( $\geq 600$  g). In a preliminary nutrient requirement study with subadult lobsters held in shallow rectangular tanks (1,500 mm  $\times$  600 mm  $\times$  350 mm (water depth), they grew poorly but survival was high (95%). This necessitated determining the optimal size and shape of the tank that would permit subadult lobsters to grow and survive at optimal rates. This was addressed in the following experiment.

## Subadult lobster experiments

### Optimal tank type (experiment 5)

The cause of the earlier observed poor lobster growth was thought to be due to the shallow depth (500 mm) of the tanks used to hold the lobsters. To test this hypothesis, a 16-week growth study comparing three different tank types was carried out with eight replicates per treatment. Tank types were: 1. 400 L fibreglass-bottom rectangle tank (1,500  $\times$  600 mm) with a water depth of 350 mm and stocked with two lobsters; 2. 200 L plastic-bottom conical tank (800 mm diameter at surface) with a water depth of 500 mm and stocked with one lobster; and

3. 2,000 L sand-bottom round tank (2,000 mm diameter at surface) with a water depth of 750 mm and stocked with three lobsters. In this experiment, a common diet was fed to all lobsters twice daily (8 am and 4 pm). The logistics of producing large quantities of feed prompted the use of a high-protein shrimp (*Penaeus monodon*) starter mash as the base for the formulation, to which was added the krill, fresh fish fillet and other supplements (Table 1, experiment 5). The growth rate of the lobsters in the 2,000 L sand-bottom round tank (750 mm depth) was excellent, 11.8 g/week, and significantly better than for lobsters in either the conical or rectangular tanks; 6.0 g/week and 5.1 g/week, respectively. The daily growth coefficient achieved by the lobsters in the 2,000 L sand-bottom round tank was 0.64%/day which is similar to lobsters fed a trash fish diet under experimental seacage culture conditions in Vietnam (0.67%/day) (Hoang et al. 2009).

### Essentiality of fresh items (experiment 6)

The selection of a suitable tank system enabled the evaluation of the essentiality of the fresh item, *S. ciliata* fish flesh. The *P. monodon* starter mash

**Table 3.** Formulation and chemical composition of a pelleted dry feed supporting excellent growth and survival of juvenile *Panulirus ornatus* lobsters

Ingredient	Formulation	
	As g as used	As g/kg on DM basis
Fishmeal (Aqua-grade) <sup>a</sup>	140	127
Krill (spray-dried) <sup>b</sup>	85	77
<i>P. canaliculus</i> <sup>c</sup>	268	33
<i>S. ciliata</i> <sup>d</sup>	293	33
Wheat gluten <sup>e</sup>	45	41
Starch	4.2	4.0
Supplements <sup>f</sup>	33	32
Total	868	347
<i>Estimated chemical composition (%)</i>		
Crude protein (CP)		48.0
Digestible CP		43.7
Total lipid		9.3
Phospholipid		1.5
Cholesterol		0.6

<sup>a</sup> Peruvian or Chilean fish meal, >67% CP

<sup>b</sup> Antarctic krill, Inual, Santiago, Chile

<sup>c</sup> Homogenised *Perna canaliculus* (green-lipped mussel)

<sup>d</sup> Homogenised *Sillago ciliata* (whiting) fish flesh

<sup>e</sup> Vital gluten, 76% CP

<sup>f</sup> Provided in the diet (g/kg): carophyll pink (8% astaxanthin), 0.8; cholesterol, 3; soy lecithin (70%), 12.5; choline chloride (70%), 0.25; ethoxyquin, 0.25; vitamin pre-mix (Williams et al. 2004), 11; and trace mineral pre-mix (Williams et al. 2004), 5

**Table 4.** Formulation and chemical composition of a pelleted dry feed supporting excellent growth and survival of subadult *Panulirus ornatus* lobsters

Ingredient	Formulation	
	As g as used	As g/kg on DM basis
Shrimp starter mash (Aqua-grade) <sup>a</sup>	330	300
Krill (spray-dried) <sup>b</sup>	60	55
Cod liver oil	2.0	1.8
Astaxanthin <sup>c</sup>	0.25	0.23
Aquabind	2.0	1.8
Total	394	359
<i>Estimated chemical composition (%)</i>		
Crude protein (CP)		50.8
Total lipid		11.7
Phospholipid		1.2
Cholesterol		0.8

<sup>a</sup> Shrimp (*Penaeus monodon*) starter mash, >45% CP

<sup>b</sup> Antarctic krill, Inual, Santiago, Chile

<sup>c</sup> Carophyll pink (8% astaxanthin)

was retained as the high-protein base for the feed (Table 1, experiment 6). Fish flesh was added to a basal formulation, at incremental rates of 250 g/kg to make three pelleted diets with total fresh item content ranging between 0 and 500 g/kg. An inexpensive copolymer binder, Aquabind, was used instead of transglutaminase as the binder in the feed containing no fresh items; other diets with fish flesh were bound using transglutaminase. The pelleted feeds were fed to subadult *P. ornatus* for 16 weeks.

Growth was excellent at 12 g/week in the best treatment, and similar to that of subadult lobsters fed trash fish under seacage culture conditions in Vietnam. There was no significant difference in the growth or survival rate of lobsters fed the various diets. This result suggests that fresh feed items are not essential in the formulation for subadult lobsters provided an adequate amount of krill product is included. The removal of fresh feed items from the basal feed negates the need for the expensive transglutaminase binder. The total removal of fresh items from the basal feed diet has a major cost benefit in relation to production, storage and the conversion of feed to marketable flesh.

## Conclusions

### Juveniles

Feed development with juvenile *P. ornatus* lobsters was problematic due to large seasonal variations in settlement numbers, coupled with

incidences of high mortality. However, a moist formulated feed (Table 3) has been developed that promotes high survival and growth of lobsters superior to feeding a mixed diet of *P. canaliculus* (green-lipped mussel) and *S. ciliata* (whiting) flesh.

### Subadults

Feed development with subadult *P. ornatus* lobsters has progressed rapidly, culminating in the development of a practical high-performance dry feed (Table 4) which promotes high survival (>95%) and growth rates comparable to those of seacage culture experiments in Vietnam.

### Future work

A dry pelleted feed has been developed for subadult *P. ornatus* lobsters, producing excellent growth and survival rates equal to those seen in seacage culture experiments in Vietnam. The results have been achieved with >600 g lobsters; however, it is likely that this feed will also be practical for >100 g lobsters. This dry feed is ready to be tested at a pilot-scale commercial operation. Further cost benefits may be realised by evaluating the partial replacement of expensive marine proteins with terrestrial proteins. For juvenile *P. ornatus*, future work must focus on determining the nutritional deficiency or captivity stressor which causes the high mortality of very small (<1 g) lobsters.

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# Optimising the physical form and dimensions of feed pellets for tropical spiny lobsters

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## Abstract

The physical form and size of feed pellets provided to any species of crustacean have a significant effect on the proportion of the feed item that is ingested by the animal and how much is wasted as small fragments. This has a direct bearing on the feed conversion ratio and the amount of nutrients released into the culture system. The efficiency of ingestion of feed items, including soft, semi-moist pellets of approximately 1 mm, 3 mm and 9 mm in diameter and hard, dry pellets, was evaluated with *Panulirus ornatus* (ornate spiny lobster) ranging in size from small juveniles (~2 g) to adults (maximum size 700 g). The behavioural response of the lobsters and the feed ingestion process were recorded using video cameras. When the meal quantity exceeded satiation, lobsters were wasteful feeders, preferentially grazing on intact pellets rather than pieces of fragmented feed. When fed at or below satiation, they tended to feed more efficiently, retrospectively recovering and consuming pieces of fragmented feed. The 2 g lobsters appeared to feed most efficiently on the 1 mm diameter pellets. However, the larger lobsters consumed the 3 mm diameter pellets with significantly less wastage than the 9 mm pellets. There were no feed fragments recovered after feeding on 3 mm diameter pellets by any size of lobster used in this study. The 2 g lobsters appeared to feed on the 1 mm soft, semi-moist pellets more efficiently than 1 mm hard, dry pellets, whereas the larger lobsters appeared to consume the hard, dry 3 mm diameter pellets more efficiently than the soft, semi-moist feeds.

**Keywords:** rock lobster; *Panulirus ornatus*; feeding behaviour; nutrition; moist feed

## Introduction

To be profitable, intensive animal production systems require a balance between maximising production and minimising the costs of production. Feed is the major cost component of most animal production systems and in intensive aquaculture systems represents up to 50% of production costs (Lawrence and Lee 1997; Jeffs and Hooker 2000).

Intake of a nutritionally adequate diet is directly related to growth, and hence production. In most aquaculture production systems, growth rate is a major economic driver in the profitability of the system, so there is direct benefit for the farmer to maximise feed intake, while minimising feed wastage.

A frequent question among lobster nutritionists has been: 'What is the most appropriate form that artificial feeds should be made into for spiny lobsters?' However, there have been few systematic studies to address this question. The issues are whether the form of the feed will affect the efficiency of ingestion; whether the lobster will need to fragment the pellet to ingest the feed particles; and the extent that this affects the rate of ingestion and

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ultimately the intake of nutrients. Conklin et al. (1977) compared moist, soft feed pellets and hard, dry pellets of 2 mm initial diameter (length not reported) with juvenile *Homarus americanus* (American clawed lobster) of approximately 150 g live weight. The hard, dry pellets resulted in better growth performance than the soft, moist pellets. Brown et al. (1995) evaluated various combinations of ingredients with soybean meal as a feed and bait for lobsters in the Bahamas, using blocks of feed. However, in most cases where formulated feeds have been provided to lobsters, pellets of dimensions similar to shrimp grow-out feed (i.e. 2 to 3 mm diameter, 4 to 6 mm in length) have been used. In a review on feed composition, preparation and utilisation for Crustacea, Cuzon et al. (1994) noted that the same feed manufacturing processes are used across the crustacean feeds and fish feeds, and that dry diets are most widely used.

Sheppard et al. (2002) carried out the first reported systematic study into the optimal feed pellet size for spiny lobsters with *Jasus edwardsii*. Three class sizes were studied (mean live weight: 14 g; 38 g; and 135 g) with three sizes of feed pellet (3 × 3 mm; 5 × 5 mm; and 7 × 7 mm). There were no differences in the consumption of the different size pellets by the smallest size class of lobsters. However, the 38 g animals consumed the 5 × 5 mm pellets most efficiently and the 135 g size class consumed the 7 × 7 mm pellets most efficiently. There does not appear to be any published information about the most appropriate length, diameter and

hardness of feed pellets for *Panulirus ornatus*, the ornate spiny lobster. This paper reports a study in which video observations were used to define the feeding behaviour of three size classes of *P. ornatus* (small juveniles, juveniles and adults) when fed a range of soft and hard pellets of various sizes. In addition, a grow-out experiment was carried out to compare the growth response and feed intake of 700 g lobsters fed hard, dry or soft, moist pellets.

## Materials and methods

### Feeding behaviour

The three size classes of *P. ornatus* used in the study were: (a) 2 g, (b) 50–60 g and (c) 700 g. The smaller lobsters had been previously captured as postpueruli in Cairns harbour, Queensland, and on-grown to the size used in the experiment. The adult lobsters had been purchased from a commercial fishing company based in Cairns. Lobsters were maintained in a 2 m diameter × 0.9 m deep, circular holding tank with brick shelters, at the same salinity and temperature as the water in the aquarium tank that was used for observing the feeding behaviour.

The feeding behaviour experiment was carried out in a temperature-controlled laboratory maintained at 28 °C. A glass aquarium tank (length × width × depth: 900 mm × 300 mm × 450 mm), located in an enclosure lined with black plastic or black-painted timber sheeting, was used to observe the feeding behaviour (Figure 1). A fibre-cement



**Figure 1.** The aquarium tank system used for recording *Panulirus ornatus* feeding behaviour

sheet (6 mm thick) was fitted to the bottom of the tank to provide a non-slip surface for the lobsters. Two clear acrylic sheets (perspex) were used as internal, front to rear, partitions in the tank to contain the lobster within the field of view of the video camera. An additional acrylic sheet, painted matt black, was placed between the internal partitions to act as a backdrop and provide contrast for the field of view. This sheet was moved closer to the front of the tanks when recording smaller lobsters so as to keep them within the focus range of the video camera. A light source (Portaflood) was placed on each side of the tank to provide sufficient lighting to record details of the lobsters' feeding. A sheet of white paper was attached to each side of the tank to diffuse the light. The front of the enclosure was covered with a curtain of a non-reflective fabric to conceal from the lobster any movement and activity within the laboratory.

The feeding behaviour of the lobster was recorded using a Panasonic HD digital movie camera with the lens of the camera passing through a hole in the curtain. This allowed the operator to observe the lobster indirectly using the camera screen. Recorded data were edited using PC-based software (Windub).

The observation tank was supplied with flowing sea water (35 parts per thousand (ppt), 28 °C, 500 mL/minute) from a recirculating system within the laboratory. Inflowing water was filtered through a fine plankton mesh sock (20 µm) to remove particulate material. The volume of water in the recirculating system was about 300 L and was replaced on a daily basis or more often if there was any sign of discolouration of the water from the feed.

Lobsters were transferred from the holding tank into the observation tank and left until their stance and behaviour suggested they had recovered from the stress of handling (generally 1–2 hours). Once the lobsters appeared to have settled, a feed pellet was placed in the tank. Only one lobster was placed in the tank at any one time.

Feed pellets were all prepared from the same formulation (Table 1) that had been used successfully in earlier studies with *P. ornatus* (Smith et al. 2005). The feed pellets were prepared by pressing the moist, mixed ingredients through various pieces of equipment to produce moist noodles at one of three diameters: (a) 1 mm, (b) 3 mm, or (c) 9 mm. The 9 mm pellet was used as a soft, semi-moist pellet of approximately 35 mm length. The 3 mm

and 1 mm diameter pellets were used as soft, semi-moist and as hard, dry pellets of various lengths from 10 to 35 mm.

**Table 1.** Ingredients and formulation (g/kg as used) of the feed pellets used in the *Panulirus ornatus* feeding behaviour and feeding efficiency experiments

Ingredient	Formulation
Fishmeal <sup>a</sup>	360
Diatomaceous earth	11
Wheat flour	140
Krill meal <sup>b</sup>	300
Krill hydrolysate <sup>c</sup>	80
Gluten <sup>d</sup>	55
Lecithin <sup>e</sup>	12
Other dry ingredients <sup>f</sup>	42

<sup>a</sup> Peruvian fishmeal, 68% crude protein (CP), supplied by Ridley Aqua-Feed Pty Ltd, Narangba, Queensland, Australia

<sup>b</sup> Antarctic krill, Inual, Santiago, Chile

<sup>c</sup> Krill hydrolysate, Specialty Marine Products Ltd, Vancouver, British Columbia, Canada

<sup>d</sup> Wheat gluten, 76% CP, Janbak Industries Pty Ltd, Brisbane, Queensland

<sup>e</sup> Soybean lecithin, 70% lipid, Janbak Industries Pty Ltd, Brisbane, Queensland

<sup>f</sup> Other ingredients (g/kg): blood worm, 120 (equivalent to 21 g/kg of 95% dry product); cholesterol (80 g/kg), 3; choline chloride (700 g choline/kg), 0.25; astaxanthin (carophyll pink, 80 g/kg, donated by Roche Vitamins Australia), 1; ethoxyquin (Banox E), 0.25; vitamin pre-mix (Williams et al. 2004), 11, manufactured by Rabar Pty Ltd, Beaudesert, Queensland; and trace mineral pre-mix (Williams et al. 2004), 5

## Growth response experiment—soft versus hard feed pellets

The comparison of the growth response of lobsters fed either soft or hard feed pellets was a subset of treatments from a large experiment evaluating a number of different feeds. Reported here are the results of the growth response to the following treatments: (a) 3 mm hard pellet (20–40 mm in length), and (b) 3 mm soft pellet (20–40 mm in length).

The two diets were prepared according to the formulation in Table 2. Fresh *Sillago ciliata* (whiting) fish flesh was placed at –20 °C until semi-frozen, then extruded through a 3 mm die plate of the meat grinder attachment for an A200 Hobart planetary dough mixer (Hobart Corporation, Troy, Ohio, United States of America; USA) to form a homogenous mince. The dry ingredients were finely ground (<710 µm) using a mortar and pestle for small constituents or by hammer mill (Mikro Pulverizer, Metals Disintegration Coy, Summit,



New Jersey, USA) for bulk ingredients. The fresh ingredients and transglutaminase binder (Ajinomoto Food Ingredients, Japan; supplied by Kerry Ingredients, Sydney, Australia) were thoroughly mixed together using an industrial-kitchen Kenwood KM800 planetary mixer (Kenwood Ltd, Havant, Hants, United Kingdom) for 10 minutes before the oil and remaining dry ingredients were added, followed by a further 10-minute mixing to form dough of approximately 40–50% moisture content. The dough was screw-pressed through a 3 mm die plate of the meat grinder attachment for the A200 Hobart planetary dough mixer to form spaghetti-like strands. The strands were placed in an airtight bag and set overnight in a refrigerator at 4 °C. The strands were separated into two equal portions, one of which was used without further treatment while the other was dried at 40 °C for 24 hours. The strands were stored at 20 °C until required for feeding.

One hundred and twenty subadults *P. ornatus* lobsters (>600 g) were purchased for this experiment from seafood exporter M.G. Kailis, Cairns. A large number of the lobsters (25%) died shortly after arriving at the laboratory due to salinity stress before capture. In order to assess whether the remaining lobsters were suitable for use in an experiment, they were held for an 8-week recovery period. As a result of the initial mortality and rejection of some of the surviving lobsters, the experiment was started with fewer than the intended number of replicate tanks and at a lower stocking density (four replicates per treatment with four lobsters per tank). The experimental units were circular, fibreglass tanks of 2,500 L capacity (2.0 m diameter × 1 m deep). The

tanks were provided with individual air-stones and supplied with heated ( $29 \pm 0.5$  °C) and filtered (20 µm) flow-through (60 L/hour) sea water (33–35 ppt). A 50 mm deep layer of fine sand was placed in each tank to provide a non-slip surface for the lobsters. Sufficient brick hides of the appropriate size were provided for all lobsters in the tank. At the start of the experiment, lobsters (average weight  $\pm$  standard deviation = 744 g  $\pm$  61 g) were randomly allocated to tanks and tanks were randomly assigned to treatments. The experiment was run for 16 weeks and the animals fed to excess twice daily at 8 am and 5 pm.

## Results and discussion

### Feeding behaviour

The ~2 g *P. ornatus* lobsters were offered 1 mm and 3 mm diameter pellets that were hard, dry or soft, semi-moist. They clearly had difficulty with the 3 mm pellets but the 1 mm pellets were readily accepted. The optimal length of the 1 mm pellets appeared to be 10–15 mm. The lobsters tended to drop fragments of the soft pellets whereas they produced far fewer fragments with the hard pellets and could ingest them whole without breaking them up. However, it appeared that these small lobsters preferred the soft pellets. Pellet length of 10–15 mm was more readily manipulated than pellets that were 3–4 mm (the size of shrimp feed pellets) and enabled the lobster to substantially fill its foregut from the one feeding event. The lobsters dropped a significant proportion of a soft, 3 mm feed pellet as fragments but appeared to feed off the surface of the

**Table 2.** Formulation of the pelleted moist or dry feed used in the growth response experiment to compare response to soft, semi-moist pellets and hard, dry pellets by *Panulirus ornatus* lobsters

Ingredient	Formulation g/kg as used
Fish flesh ( <i>Sillago ciliata</i> , whiting)	500
Monodon shrimp feed mash (Aqua-grade) <sup>a</sup>	399
Krill (spray-dried) <sup>b</sup>	90
Cod liver oil	5
Carophyll pink (8% astaxanthin)	1
Transglutaminase	10

<sup>a</sup> Starter feed mash formulated for juvenile *Penaeus monodon* (>45% crude protein) prior to its pelleting. Mash was kindly supplied by Ridley Aqua-Feed, Narangbar, Queensland, Australia.

<sup>b</sup> Antarctic krill, Inual, Santiago, Chile

3 mm hard pellets as the pellet absorbed water and softened. However, overall, they appeared to lose interest in the 3 mm pellets before filling their foregut.

The 50–60 g class of lobsters were offered the 3 mm hard and soft pellets and 9 mm × 35 mm soft pellets. They clearly had difficulty with the 9 mm pellets and created a large amount of wastage with these pellets. However, 3 mm diameter pellets appeared to be quite suitable for these lobsters. A large amount of fragmentation and wastage occurred with soft pellets while the hard pellets were eaten with minimum fragmentation and wastage. The optimal length of 3 mm pellets for this size of lobster appeared to be about 20–25 mm. Casual observation of larger lobsters (~100 g) showed that they could feed on, and ingest, whole 3 mm pellets of about 35 mm in length without breaking them up, though they would handle the 20–25 mm pellets quite effectively. The 700 g lobsters were given 3 mm soft and hard pellets and 9 mm × 35 mm soft pellets. The lobsters fragmented and created a significant amount of wastage with both the 3 mm and 9 mm soft pellets. The 3 mm hard pellets were readily manipulated and ingested essentially without fragmentation.

An observation that was consistent across the range of sizes of *P. ornatus* lobsters was that if the lobsters were fed below satiation, they would pick up and eat small feed fragments that remained on the bottom of the tank after they had eaten the larger pieces of the feed. This observation is consistent with that made by Sheppard et al. (2002) with *Jasus edwardsii*. However, when *P. ornatus* lobsters were fed to excess, they appeared to break up and waste feed pellets after they had satisfied their appetite. Hence, good feed management is critical in the culture of this species of lobster. Though the lobsters picked up and ingested small fragments of feed when fed below satiation, these fragments would not have the nutrient composition of the diet as it was formulated, having lost most, if not all, of the soluble components, particularly the water-soluble vitamins. Hence, these fragments are likely to be nutritionally deficient and not the optimal source of nutrition for the lobsters.

### **Growth response experiment—soft versus hard feed pellets**

The growth of *P. ornatus* lobsters fed the soft, semi-moist diet and the hard, dry diet over the 16 weeks of the experiment was excellent. The mean

initial weight across treatments was 744 g and there was no significant difference in the growth of the lobsters fed the two types of feed pellet. The growth of lobsters fed the soft, semi-moist diet was  $20.0 \pm 1.9$  g/week, while that of lobsters fed the hard, dry feed pellets was  $20.0 \pm 2.4$  g/week. None of the lobsters died during this experiment. As a semi-moist feed and a dry feed were compared in this study, the apparent feed intake would give a distorted view of feed intake. As a result, the apparent dry matter (DM) intake has been used to compare feed conversion ratios (FCRs). There was no significant difference between treatments with the DM FCR for the semi-moist diet at 3.5 whereas that for the dry diet was 4.0. Hence, it appears that there is no benefit in growth response with feeding lobsters the soft, semi-moist feed pellets. However, there are distinct advantages of the dry feed for transportation and storage because of its higher nutrient density and ability to be stored without refrigeration.

## **Conclusions**

Though 2 g *P. ornatus* lobsters can ingest hard pellets, they appear to feed more effectively with soft diets. The 1 mm diameter × 10–15 mm long pellets appear optimal for these lobsters. Juvenile lobsters of 50–60 g appear to feed best with 3 mm diameter pellets of 10–20 mm in length. Pellets that are 3 mm in diameter and 10–35 mm in length appear suitable for *P. ornatus* over 100 g. Feed pellets of 9 mm diameter are not eaten efficiently. Soft, semi-moist pellets and hard, dry pellets had similar acceptance and ingestion efficiency with lobsters that were >50 g and produced similar growth rates when fed to 700 g lobsters.

The diameter of the pellet is the most important dimension and should suit the mouth size of the lobster. However, short pellets (~4 mm in length) are more difficult for the lobsters to manipulate whereas longer pellets are picked up more quickly and manipulated to the mouth more readily. The ideal size of a single pellet would be one that equates to a full meal; that is, it completely fills the foregut. In practical terms, it might be better for two shorter pellets to be equivalent to a full meal. In conclusion, the dimensions of the feed should suit the size of lobster. In an aquaculture situation, irrespective of the size of the pellet, the floor of the cage or of the feeding tray should be designed to minimise loss of whole or crumbled feed pellets.

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