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Exploitation of puerulus settlement for the development of tropical spiny lobster aquaculture in the Indo-West Pacific

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Abstract

Development of tropical spiny lobster aquaculture has occurred in Vietnam and more recently in Indonesia based on the collection of naturally settling puerulus. Strong market demand for spiny lobsters and static fishery production has driven such development. High availability of lobster seed has been identified for exploitation particularly in some locations and fishing methods have been developed which make capture of these post-larval lobsters quite straightforward. Such pueruli availability may exist throughout the South East Asian region providing opportunity of industry expansion. A research project is supporting assessment of pueruli resources in Indonesia and providing baseline data on puerulus catch. Capture data over several years is now available which provide a comprehensive picture of spatial distribution, species composition, seasonality, inter-annual variability, catch per unit effort, pricing and total production. Methods of puerulus capture, their innovation and evolution are described. The delicate nature of pueruli has resulted in high mortality through the production chain and the processes involved in their handling and improvements recommended are discussed. In particular, a nursery phase close to the point of capture is advisable to produce robust juveniles suitable for transport to grow out locations. Management of the puerulus resources of Vietnam and Indonesia is advisable, but difficult given lack of information about the source breeding populations and effectiveness of the catching methods. Sustainability of the wild catch is of concern but may be offset by development of a hatchery supply. The lobster aquaculture industry of Vietnam has provided demonstrable benefit to coastal fishing communities and is likely to provide equivalent benefit in Indonesia. Such benefits may be expanded to other parts of South East Asia and hopefully can be achieved on a sustainable basis.

Keywords: Lobster, *Panulirus ornatus, P. homarus*, aquaculture, puerulus, post-larval collection

Introduction

Aquaculture of lobsters is an attractive proposition given the great demand and high prices paid in traditional markets and a static or decreasing supply from wild-capture fisheries (Booth and Kittaka, 2000; Jones, 2009). To date, the only established lobster aquaculture industry of any magnitude is in Vietnam which has developed over the past 15 years based on the on-growing of spiny lobsters (Palinuridae) in sea cage systems. The source of seed for this production is naturally settling post-larval lobsters or 'pueruli' and small juvenile lobsters which are captured using a variety of techniques and equipment. Lobster farming is a particularly attractive opportunity for Vietnam and potentially for other developing countries because capture of seed lobsters and their grow out involves simple technology, moderate capital and is ideally suited to village-based enterprises (Hambrey *et al*., 2001). It can provide significant benefit to the economic and

social fabric of impoverished communities (Petersen and Phuong, 2010). However, the sustainability of such on-growing is of concern because it is based on a natural resource for which there is currently no management (Core, 2004; Williams, 2004a). Clearly the future for lobster aquaculture will demand technologies that are independent of wild populations, involving hatchery production of seed and that are economically and environmentally sustainable. In the meantime, however, the farming of lobsters using natural settlement of seed is expanding and it should be managed carefully to maximise the benefit to the coastal communities who have embraced it, while providing sustainability.

This paper will outline the current status of lobster puerulus exploitation in South-East Asia for the purposes of aquaculture. It will provide a historical perspective on the development of this sector, the nature of the resource, opportunities for expansion, the methods used for puerulus capture and management options for its sustainability.

The bulk of the information and data presented here has been derived from international aid projects provided by the Australian Government and administered through the Australian Centre for International Agricultural Research (ACIAR). Some of the information has previously been published in two symposium proceedings (Williams, 2004b; Williams, 2009), while more recent data is derived from a current project (ACIAR SMAR/2008/021), initiated in 2010.

Natural puerulus settlement: The puerulus is the post-larval stage of spiny lobsters (Butler and Herrnkind, 2000). This stage is nocturnally active, swimming in the water column and often close to the surface at night (Phillips, 2006). The swimming appears to be directional, although it remains uncertain as to how they orientate toward suitable habitat (Booth and Phillips, 1994). The puerulus is a non-feeding stage, reliant on stored energy reserves until it moults to the first instar benthic juvenile (Booth and Phillips, 1994).

Although substantial research has been published on aspects of puerulus ecology of the various species supporting valuable fisheries (*P. argus, P. cygnus, P. japonicus, Jasus edwardsii* and others, Butler and Herrnkind, 2000)), little is known about the puerulus ecology of the various tropical species of the Indo-West Pacific. We do know from the experience of the Vietnam industry that puerulus settlement for several species along the central south coast is particularly abundant, with several million pueruli caught each year. This is in stark contrast to northern Australia, for example, where comprehensive efforts to gauge the abundance of settling pueruli, within a region inhabited by a large population of adults, found very few (Dennis *et al*., 2001; Dennis *et al*., 2004). How this compares with settlement in other parts of the species range is not known, although attempts are now underway to assess this in Indonesia as part of a new ACIAR research project. For example, puerulus settlement on the southeast coast of the island of Lombok in Indonesia appears also to be relatively abundant (Priyambodo and Jaya, 2009; Priyambodo and Sarifin, 2009; Priyambodo and Jaya, 2010,). It is conceivable that specific areas of high abundance occur where ocean currents, coastal geomorphology and other conducive circumstances facilitate a concentration of settling pueruli (Booth and Phillips, 1994).

In Vietnam, sufficient fishing effort has been applied over more than a decade to be confident that the full geographical extent of settlement there is being exploited. However, in Indonesia, Lombok is the only island to date where any focussed effort has been made to assess the puerulus resource. Other locations of especially high abundance of settling pueruli, so called 'hot spots', may be identified through a concerted sampling programme.

Drivers of development: Development of spiny lobster aquaculture is driven by high market value and demand exceeding supply (Hart, 2009). *Panulirus ornatus* is particularly sought after in China markets for sashimi presentation at celebratory banquets (Hart, 2009). A wholesale price of > US$ 60/kg for large lobsters of > 1 kg, as well as demand far exceeding the available fishery production and a reduction in wild harvested lobsters, provides a strong foundation on which to build an aquaculture industry. *Panulirus homarus*, for which an abundance of seed has already been identified in Lombok, is also high in value (US$ 30/kg) for small lobsters (100 to 300 g) and will be equally or more profitable

than *P. ornatus* for aquaculture production (Jones, 2009).

In Vietnam, the demand from China for market-sized *P. ornatus* (>1kg) stimulated increasing effort in the fishery during the mid 1980's that led to a progressive decline in mean harvest size, as the fishery was over-exploited (Thuy and Ngoc, 2004). To ameliorate the small size of the lobsters, fishers began holding the lobsters and feeding them to facilitate their growth to the premium market size and thus the lobster aquaculture industry was born. The ease with which *P. ornatus* lobsters could be held captive and on-grown using simple net cages in the sea, and a diet of chopped trash fish led to rapid growth in the sector and increased demand for lobsters to stock. The mean size of lobsters captured declined further through the mid 1990's until small juveniles and post-puerulus became the bulk of the catch. Lobsters (primarily *P. ornatus*) greater than 100g became very scarce and to this day their numbers remain very low.

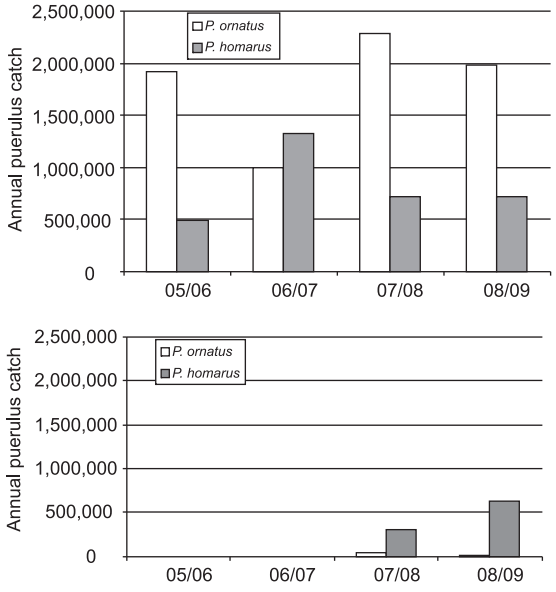

Fig. 1. Annual catch of lobster pueruli for Vietnam (a) and Lombok (b) based on census data

Vietnam fishers developed methods to capture swimming pueruli and now the vast majority of farmed lobsters produced are captured as pueruli. In 2007/08 more than 3 million lobster pueruli were captured in Vietnam for aquaculture (Fig. 1).

In 2010 the industry which is entirely village-based, comprises more than 30,000 sea cages along 1,000 km of coastline producing in excess of 1,500 tonnes of lobster worth approximately US$ 80M per annum (Hung and Tuan, 2009). It has provided social and economic benefits to coastal communities and the same opportunity may exist throughout the natural range of the various tropical species, and particularly where natural settlement of seed is most abundant.

Expansion of opportunity: Vietnam remains the only country in the world with such a well developed lobster aquaculture industry and little effort has been made until recently to assess puerulus settlement in other countries within the South-East Asian region with a view to developing aquaculture. On the island of Lombok in eastern Indonesia in the early 2000's spiny lobster seed were observed settling on sea cages used for grouper culture and on seaweed rafts (Priyambodo and Sarifin, 2009; Priyambodo and Jaya, 2010). The fish and seaweed farmers began collecting these lobster pueruli and stocking them to dedicated lobster cages. By 2010 this had expanded and there are now about 1,500 cages for lobster utilising puerulus captured locally which in 2008/09 exceeded 600,000 (Fig. 1). There may be opportunity to expand the industry in Lombok as the extent of the puerulus resource is assessed and more pueruli are caught. Recent research using specially designed puerulus sampling devices has revealed that puerulus settlement does not occur on the west coast of Lombok and appears to be concentrated along the south and southeast coastline (Priyambodo and Jaya, 2010). This may be the result of eddies from the strong Indonesian throughflow current which flows southwards between Bali and Lombok carrying the late stage planktonic phyllosoma. The research supporting these puerulus resource assessment investigations is continuing and now expanding to other regions of Indonesia including South Sulawesi, East Sumbawa, West Timor and Aceh. Exploitable lobster seed resources are likely to occur throughout the Indonesian archipelago, although they may only be concentrated enough for exploitation in areas particularly conducive to settlement.

Beyond the well-established Vietnam industry and the emerging Indonesian industry, information on puerulus settlement elsewhere in the Asia-Pacific region is scant. There are a range of spiny lobster species endemic to the region which are commercially fished adding significant value to exports and for which increased production would be very attractive. Because these countries have limited fisheries management and are supportive of small-holder industry development, the issue of sustainability of puerulus capture is likely to be of lesser priority than it is for developed countries with intensively managed fisheries. Nevertheless, sustainability is a foundational premise to the research and development programme. As Bell (2004) has clearly articulated, there are several key issues which need to be addressed to ensure sustainability. These include identification of the source of the settling seed, effective management of the breeding populations and understanding the extent of the puerulus catch relative to natural abundance. Given the likelihood that survival of captive puerulus in culture systems is likely to be far higher than in the wild, the management goal is to strike a balance between taking some puerulus from the wild for aquaculture while leaving enough for natural replenishment of breeding populations.

In India, Vijayakumaran *et al.* (2007) reported that a small lobster grow out industry had become established in the southeast also based on a natural seed supply, but this was devastated by the 2004 tsunami and has not re-established. Similarly, in Taiwan (Chen, 1990) and the Philippines (Juinio-Menez and Gotanco, 2004) there have been reports of grow out of wild caught spiny lobsters, although this appears to be based on larger lobsters greater than 200 g rather than puerulus. A programme of resource assessment using specialised puerulus sampling equipment will be necessary to identify locations of high pueruli abundance in the other parts of South East Asia, to determine if grow out industries like those of Vietnam are possible.

Although Australia has demonstrated a strong commitment to lobster aquaculture development, collection of wild seed for *Panulirus ornatus* will not be pursued because seed settlement is very dispersed in both time and space (Dennis *et al*., 2004; Griffin, 2004; Jones and Shanks, 2009), and there is great sensitivity to the impact that collecting wild seed may have on the commercial fishery. For this reason, development of larval rearing methods, *i.e.* hatchery technology to produce juvenile lobster in captivity has been pursued and is now on the threshold of commercialisation (Jones, 2009).

Puerulus resource assessment: To better understand the puerulus resource in Vietnam and explore opportunities for untapped resources in Indonesia to be exploited, the ACIAR project has supported an annual census and sampling programme in both countries. For Vietnam this extends back to 2005/06 (Long and Hoc, 2009) and for Indonesia it was initiated in 2007/08, although restricted just to Lombok (Priyambodo and Sarifin, 2009).

The methods applied have been equivalent in both Vietnam and Indonesia, although in Vietnam the primary source of information and catch statistics come from dealers ('middlemen') who purchase the pueruli from the village fishers and then distribute them to growers. In Indonesia (Lombok only), a dealer sector has yet to emerge, and the fishers generally sell the pueruli to growers directly or hold and nurture them through to juvenile before selling them at a higher price.

Catch data is retrieved from structured logbooks and questionnaire and accounts for the vast majority of the annual catch. In Vietnam between 87 and 100% of all dealers were interviewed each year, and in Indonesia all of the puerulus fishers were interviewed.

In Vietnam, the lobster species settling along the coast include *Panulirus ornatus*, *P. homarus, P. versicolor, P. longipes, P. stimpsoni* and *P. polyphagus* (Hung and Tuan, 2009; Hoc, pers.com.). Identification of the species at the puerulus stage is problematic as the morphology is similar for all species and those characteristics that can be used, such as coloration, change substantially over the first few weeks of development. The nektonic pueruli are effectively un-pigmented, with some banding apparent on the antennae which permit species identification. The colour of the eyes and the relative length of the antennae are also somewhat diagnostic. As the body becomes pigmented, colour differences

between species also change. Notwithstanding these identification difficulties, the most abundant species, *P. ornatus* and *P. homarus* are clearly discernable. For the purposes of the census, separate counts were provided for these two species and all the others are grouped as 'other'. Similarly in Lombok, the census has identified that *P. ornatus* and *P. homarus* dominate the catch, accounting for more than 98% of all puerulus captured. The other species represented among the puerulus there have not yet been confirmed, but are likely to reflect the species known to occur in the region as adults which include the same species as above with the exception of *P. stimpsoni* and the addition of *P. penicillatus*.

Catch data for *P. ornatus* and *P. homarus* for Vietnam and Lombok are summarised in Fig. 1a, b. The total catch for Vietnam exceeded 3 million lobsters in 2007/08 and is substantially higher than for Lombok, however, the spatial extent of the fishing area in Vietnam is much larger and consequently, the relative catch is comparable. *Panulirus ornatus* tends to dominate in Vietnam, while *P. homarus* is the most abundant species caught in Lombok.

Long and Hoc (2009) provided detailed seasonality data for pueruli catch in Vietnam indicating a distinct peak in settlement for all species during the monsoon season from October through to March (Fig. 2a,b). In Lombok, the seasonality was bimodal with peaks in catch corresponding to August / September (dry spring season) and April / May (late summer wet season) (Fig. 3) and some pueruli were captured throughout the year. The difference in modality between the locations may reflect differences in the breeding source of the settling pueruli. In Vietnam, the distinct single peak in settlement suggests recruits are coming from a single breeding stock, likely to be located somewhere in the South China Sea. It is reasonable to assume that summer breeding during the period May through September would facilitate recruitment of puerulus in the period October through February as observed, given the 4 to 6 month larval phase (Dennis *et al*., 2001; Dennis *et al*., 2004). In Lombok, however, the recruitment pattern is less distinct; there are two peaks and protracted settlement throughout the year. This suggests that the source of breeding is more widespread and may include breeding populations to the north, breeding in the summer period May to September, and from the south, breeding in summer period October to February.

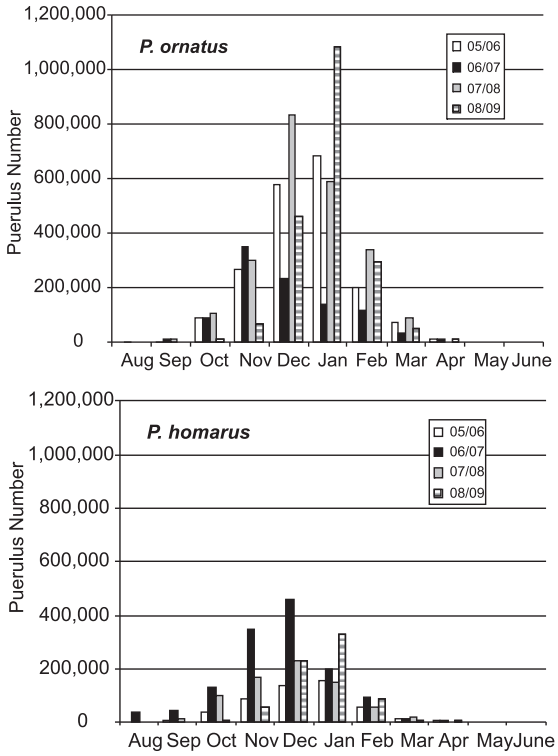

Fig. 2. Monthly puerulus catch in Vietnam over four years for *P. ornatus* (a) and *P. homarus* (b) as determined from dealer census

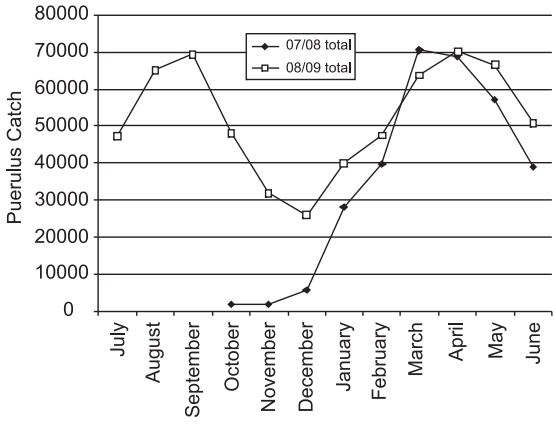

Fig. 3. Monthly total catch of puerulus from fisher census in southeast Lombok, Indonesia from October 2007 to June 2009

Butler and Herrnkind (2000) summarise what little is known about the lunar periodicity in settlement of various spiny lobster species. For some species there is a clear lunar pattern in which puerulus movement towards suitable settlement habitat, is prevalent during the new moon phase when tidal currents are maximal. This appears to be the case for the palinurid species settling along the coast of Vietnam, as the catch data demonstrate that maximum catches occur in the period between the 25th and 10th days of the lunar cycle (Long and Hoc, 2009). Notwithstanding the clear pattern of increased swimming during the dark moon phase, the pueruli are attracted to light, and some of the fishing methods that have been developed exploit this trait (see below). The same pattern of new moon peaks in catch rates has been observed in Lombok (Priyambodo, pers.com.).

The census also provided opportunity to examine prices paid for the pueruli. The lobster industry of Vietnam operates in a free enterprise market where supply and demand factors have at times elevated the price paid per puerulus to extraordinary levels. Given the tiny size and delicate nature of puerulus and the poverty within the environment in which they are traded, it is surprising that at times of particularly high demand, an individual puerulus may attract a price of more than US$ 15. Supply and demand have been exposed to many influences over the 15 year history of the development of the lobster aquaculture industry in Vietnam. Naturally the price paid per puerulus was much lower at the outset, although data from 1999 onwards (Tuan and Mao, 2004) suggest that the price became quite elevated early on. Since 2005 when price data have been recorded, dramatic fluctuations have occurred (Fig. 4) reflecting variance in supply issues including the number of fishers, weather – particularly typhoons and fishing methods. On the demand side, urgency at the beginning of the puerulus catch season, an expanding farm sector and impact of disease in grow out systems have all influenced on price. In Indonesia, where the lobster aquaculture industry is relatively new, the comparative price is much lower, averaging <USD 1 per lobster (Priyambodo and Sarifin, 2009). It is yet to be seen if supply/demand there pushes prices to the levels seen in Vietnam. These pricing economics also have a bearing on the viability of hatchery production which is now close to commercial production (Jones, 2009). The economics of lobster farming in Vietnam has recently been examined (Petersen and Phuong, 2010) and clearly a viable industry has arisen based on a supply of puerulus from a wild catch sector for which catch per unit effort is extremely low. Long and Hoc (2009) provide catch data indicating that the average monthly catch of puerulus per boat is between 3 and 14 individuals. Despite the low numbers, the relatively high price makes this an attractive commercial enterprise and the fishers are relatively wealthy people.

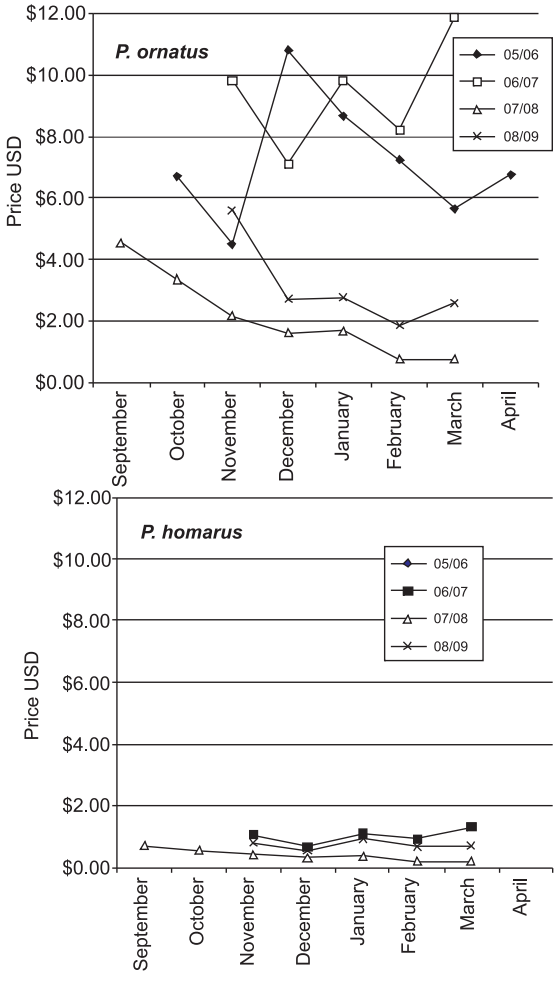

Fig. 4. Price per puerulus (USD) paid to the fishers in Vietnam over the past four seasons. No data for *P. homarus* were available for 2005/06

Capture methods: In Vietnam seed capture involves both active and passive methods to target either the swimming pueruli stage, or newly settled puerulus and early juveniles. Given that commercial fishing for lobster puerulus has not yet established elsewhere, the methods and equipment employed have had to be invented, and have evolved and changed considerably since pueruli were first targeted in the mid 1990's (Thuy and Ngoc, 2004).

Methods also vary according to the location of their deployment. In Vietnam the puerulus are found in a variety of locations from close inshore waters, with some protection from wind and waves and depths less than 10 m (Thuy and Ngoc, 2004), to exposed offshore areas. Consequently, the equipment used to catch the pueruli varies although it is generally relatively simple and easily deployed. In the deeper water locations, powered vessels may be used to access the fishing area, while for the very shallow sites which may be less than 200 m from the shore, fishing equipment can be deployed from non-powered vessels or may be fixed to the bottom, semi-permanently.

In the more open waters, active methods are employed involving the setting of seine nets, generally between two vessels. The seine net is generally made of 5 mm mesh, 100 to 150 m long, and 4 to 6 m deep and is set across the prevailing current, suspended from a float line. In the centre of the stretched net, a light source is positioned using a powerful (1000 to 2000 W) fluorescent light. The principle is that the swimming pueruli, which generally swim with the current and are attracted to light will move towards the net. These nets are usually set at 8 to 9 pm and retrieved 3 to 4 hours later, then set again for a second period until 4 am. At the time of retrieval, the net is progressively pulled on to one of the vessels and the pueruli removed by hand. The puerulus captured in this way are primarily nektonic pueruli, 7 to 8 mm in overall length and transparent, so the procedure to see and retrieve them is quite painstaking. The most productive areas for this method are bays, channels and inlets with a southerly facing opening and a northward flowing current. Such currents are presumably eddies off the broader southerly flowing Vietnam Coastal Current, part of the South China Sea Gyre (Long, 2004). The incidence of the swimming pueruli may be further concentrated by coastal land forms, bays and islands (Yeung *et al.*, 2001). In the past 2 to 3 years this method has diminished in frequency, in favour of light traps. Its reduction may be attributed to the relatively high costs for fuel for the vessels and the labour involved. These have become more important factors since demand for puerulus dropped since 2005 with the increasing incidence of disease in grow out farms (Hung and Tuan, 2009).

The light trap employs the same principle of light attraction, in a passive way that involves less or no fuel and much less labour. The most common light trap comprises a timber tripod of triangular pyramidal shape with floatation attached to its base, from which shelter materials are suspended at various depths below the surface. The shelter materials may include bundled fishing net and timber with drilled holes. Along one side of the triangular frame above the water, a fluorescent tube is attached as the light source. These tripods are deployed at high density, sometimes exceeding 1 per 25 m^2. Swimming pueruli attracted to the light settle on the shelter materials and from there can be retrieved during daylight hours. The power source for the fluorescent lights is provided by electric cable attached from one tripod to the next, extending to the shore to a mains power outlet, or from a gasoline generator which may be positioned on a floating pontoon adjacent to the tripods. Variations around this theme abound and tend to reflect localised innovation. Nevertheless, news travels quickly and the most effective methods are soon adopted elsewhere. Catch rates are generally low, between 1 and 10 pueruli per fisherman per night, but can on occasion reach as high as 50.

Other passive methods are also employed using similar shelter traps that are left in the water and regularly inspected by divers. These are clearly visible from the shore as the submerged shelters are marked by floats, or are attached to timber poles or frames fixed into the sediment. This method often provides early juveniles of up to a few grams in weight which attract higher prices. Despite the higher price less than 10% of seed traded is collected as settled juveniles, the vast majority being captured at the nektonic puerulus stage.

In Lombok, the methods for pueruli capture are mostly passive, arising initially from the observation of natural settlement of puerulus on existing aquaculture structures including seaweed frames and floating cages used for grouper (Priyambodo and Sarifin, 2009). Targeted fishing for pueruli then followed using shelter traps made from bundles of rice bags or netting material suspended from floats. Some pueruli are also captured by the light fish traps (Bagang) which are common in eastern Indonesia. Although the tripod light trap from Vietnam has recently been used as a resource assessment tool in Lombok, it has not yet been embraced by the fishing villages.

Puerulus handling and transport: One of the biggest sustainability challenges of the Vietnam industry has been high mortality of the puerulus, within the first 30 days after capture (Ngoc *et al.*, 2009). In Vietnam, much of the grow out infrastructure, i.e. the farms are located some distance from the puerulus fishing areas. Consequently, the pueruli, from the point of capture are usually held on land for 1 to 2 days in perforated plastic baskets in small tank systems, generally with aeration but often without biological filtration. These systems are the domain of the dealers, the 'middlemen' who then sell the pueruli to lobster growers. From the dealers place, the pueruli are transported in seawater in plastic bags in small styrofoam boxes, usually by motorbike over a period which may extend beyond 12 hours.

The capacity of pueruli to withstand the stresses of this holding and transport period are very limited, and it is not surprising that mortality is often high, generally 40 to 60% and often 100% (Ngoc *et al.*, 2009). For those pueruli that do survive to the point of delivery, where they are stocked into nursery cages, mortality remains high for at least the subsequent month as a legacy of the prior stress.

The puerulus is a non-feeding stage, living from stored energy resources which have been amassed during the larval phase (Booth and Phillips, 1994). At the point of capture, each puerulus may be up to 20 days post-metamorphosis, may have swum a considerable distance and its energy reserves are likely to be depleted. Until the puerulus moults to the first juvenile stage, it is unable to eat to recover from the stresses of its metamorphosis and journey to find suitable settlement habitat. From an aquaculture perspective, a nursing phase immediately post capture is advisable, during which the pueruli can progress to an early stage benthic juvenile of 5 to 10 gm individual weight, when it would be far more tolerant of handling and transport.

In Lombok, this approach has become a common practice. The puerulus fisher usually keeps the catch and stocks it directly to nursery cages adjacent to the shelter traps from which the puerulus were captured. Nursing may extend over a month or more and involve regular feeding with chopped fish and provision of some seaweed shelter. Juveniles generated in this manner are usually 1 to 5 g in weight and quite robust, and they fetch a higher price than puerulus.

In Vietnam, considerable research effort has been applied to understanding the physiological requirements of the puerulus and juvenile stages to improve the survival of them through the handling and transport process, including aspects of aeration, transport duration, packaging, water quality, temperature, provision of shelter and density (Ngoc *et al*., 2009; Thuy *et al*., 2009). To date, none of this increased knowledge has provided any measurable improvement in survival within the industry, and the introduction of a nursery phase, immediately post capture is likely to provide far more benefit.

Resource management: Vietnam's lobster aquaculture industry is now well established and good information is now available on its processes and the resources that make it work and from this efforts are being made to improve efficiencies and profitability (Hung and Tuan, 2009). The primary challenges are environmental degradation within farming areas, disease and poor feeding practices, which involve specific issues and interdependencies. Notwithstanding efforts to improve farming practices, it remains an industry based on a natural resource, where effective management is highly inadequate. The census information provides a detailed database of the resource, its magnitude and variability but no information regarding the resources origin nor its capacity to withstand the fishing

pressure it is subjected to. Such information is difficult to obtain given the protracted and spatially dispersed larval phase. This issue was clearly identified at the outset of the ACIAR funded research project in 2004 and the lack of any progress on it since is a reflection of the difficulty of collecting the necessary information (Bell, 2004; Williams, 2004b). A population genetics study to identify the source of the lobster seed settling in Vietnam, Lombok and new locations as they are found, is an obvious first step, and is now part of the new ACIAR funded project initiated in 2010. Advances in DNA analysis techniques should enable some discretion in assigning seed lobsters to their source. The genetic results will allow us to visualise for the first time how geographical populations of *P. ornatus* within the South China Sea, Indonesian archipelago and northern Australia are genetically interconnected and whether the harvested recruits can be identified as originating from a common pool, or from local recruitment. A key follow-on from such research will be to manage and protect identified breeding populations to ensure they continue to generate the seed upon which the aquaculture industry is based (Bell, 2004).

Understanding the spatial genetic structure of this species may aid in the development of management plans to avoid over-exploitation of the reproductive stock, particularly if recruitment is derived from small, localised, spawning populations. However, the idea of setting catch limits on settling puerulus will remain problematic, as a healthy spawning population does not necessarily guarantee healthy recruitment. In the time and space necessary for the larval phase to be completed, survival of larvae can be impacted in many ways (Bell, 2004).

Given the very simple way in which pueruli are caught, using light as an attractant and providing suitable shelter to stimulate settlement, it is unlikely that the method is particularly effective. That is, it is commercially effective, providing a catch rate that sustains a village based enterprise, but may actually catch only a small proportion of the puerulus available in a given area. Adult *P. ornatus* stocks along the south central coast of Vietnam were decimated by over-fishing more than 15 years ago and have never recovered (Thuy and Ngoc, 2004). Whether the annual removal of 1 to 2 million pueruli by fishers is a factor in the absence of any recovery to adult stocks is unknown. Presumably the natural mortality of such settling pueruli would be very high in any case. It is more likely that successful recruitment is still occurring, but the bulk of recruits fail to reach maturity because of on-going exploitation of juveniles and sub-adults and no management of the fishery. Despite the annual fluctuations that have been observed in puerulus catch, there is no evidence to date of any recruitment failure. In light of the very sparse population of adult lobster stocks in Vietnam it is reasonable to assume the source of the recruitment is located elsewhere, where adult populations are more abundant. If such populations were ever identified, their protection might be the most effective management tool to ensure a sustained supply of seed (Bell, 2004).

The difficulties of managing a resource such as the lobster puerulus may be of little concern if hatchery production eventuates. Pueruli of *P. ornatus* have been successfully produced in captivity at a research level (Calverley, 2006; Jones, 2009), and plans are now being developed to establish the world's first commercial spiny lobster hatchery. Given the high price often paid for pueruli in Vietnam, the economics of producing them in a hatchery are likely to be commercially viable. Managed production of pueruli has a number of distinct advantages including consistent supply and therefore more uniform pricing, capacity to supply robust juveniles rather than delicate pueruli and improvements through selective breeding. The concerns about managing the sustainability of wild pueruli exploitation may soon be nullified by the advent of a hatchery supply.

In the meantime, on-going concern has been expressed about applying resource protection management such as a puerulus catch limit (Bell, 2004). Aside from the difficulty of estimating what that limit might be, the provincial and national governments of Vietnam have shown reluctance to embrace any management regime that may impact on the livelihoods of the poor communities which

are the basis of the puerulus fishing industry and the associated dealers and lobster farmers, even though such management might ensure the long term sustainability of the industry. At this time, there is insufficient data upon which to base any kind of catch limit, so it is unlikely in the short term that any kind of management will be applied.

In Indonesia, the industry is small and developing, and the same lack of necessary data will prevent any particular management being applied. Nevertheless, if or when management limits were to be applied, Pahlevi (2009) has suggested that mechanisms involving joint government / community collaborations could be effective.

Social dimension: Development of sea cage culture of lobster in Vietnam was a direct response to increasing demand from markets in China and declining catches of market-size lobsters. Initially it just involved the lobster fishers but over time, discrete sectors developed for puerulus fishers, dealers who bought lobster seed and arranged delivery to farmers and the farmers themselves. The bulk of the jobs thus created were in coastal villages where commercial enterprise opportunity was very limited. In terms of alleviating poverty for poor coastal villagers, lobster farming has been an outstanding success, creating relative wealth for many (Hambrey *et al*., 1999, Hambrey *et al*., 2001; Thuy and Ngoc, 2004).

Hambrey *et al.* (2001) confirms that the socio-economic impact of lobster sea cage farming to communities across several south central coastal provinces is significant. In the period over which the ACIAR projects have operated, it is evident from personal observation that improvements to the communities engaged in lobster farming have included improved roads, extension of mains electricity supply and improved and expanded housing. It is likely that further less obvious benefits will have occurred possibly including improved human nutrition and education. To date, no company-based enterprises have become established, so all benefits tend to flow directly to the villages.

The opportunity to replicate such socio-economic benefit in Indonesia is very attractive. In Lombok, the evidence of increased wealth is not yet so apparent although it is likely over coming years. Eastern Indonesia is a generally impoverished region and it is hoped that puerulus resources will be identified in other localities beyond Lombok. Given the now well established grow out technologies, it should be straight-forward to extend the opportunity into other localities. The same of course is true through the entire South-East Asian region.

Future considerations: Much of what we know about the exploitation of naturally settling spiny lobster pueruli for aquaculture has come from research for development projects funded by ACIAR involving Vietnam, Indonesia and Australia. That initial project completed in 2008 (Anon., 2009) generated good baseline and the new project initiated in 2010 will address outstanding issues and help to progress industry development. The new project seeks to develop sustainable production of tropical spiny lobster in Indonesia; to assist in consolidating production in Vietnam, and to facilitate commercial grow out production in Australia. For Indonesia and Vietnam a key component is the sustainability of pueruli collection.

In Australia where puerulus capture has not been pursued, the focus has been on the development of hatchery technology. The research has achieved successful puerulus production in captivity and will now move to a commercialisation phase to confirm the commercial viability of a hatchery. The purpose of the hatchery will be to produce not just pueruli, but on-grown juveniles that are sufficiently robust for transport to grow out sites that may be a considerable distance away, including to established grow out sectors in Vietnam and Indonesia. The impact that a hatchery supply of puerulus / juveniles may have on the current wild puerulus fishery is unknown, but can only have a positive impact in reducing fishing pressure and possibly replacing wild catch altogether.

The recent developments in Indonesia suggest that a nursery phase for puerulus applied at the point of capture may be the most successful way of minimising post-capture mortality which in Vietnam is generally very high. Efforts will be made to encourage the uptake of this approach in Vietnam

and elsewhere where puerulus resources are identified for aquaculture.

For countries in the South-East Asian region with an interest and opportunity for lobster farming, an expansion of the current collaboration involving Indonesia, Vietnam and Australia may be possible to ensure that they access the most up to date information and techniques for puerulus assessment and lobster grow out.

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