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Tropical spiny lobster aquaculture development in Vietnam, Indonesia and Australia

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Abstract

Of the various tropical spiny lobster species in the Indo-West Pacific region, *Panulirus ornatus* and *P. homarus* are emerging as the favoured species for aquaculture. This is based on a number of factors including market demand and pricing, availability of naturally settling seed (for on-growing), development of hatchery technology, suitability for captive growout and adaptability to a variety of production systems. Production to date is based only on naturally settled puerulus which in some areas of Vietnam and Indonesia are particularly abundant and easily caught. In Vietnam, more than 1,500 tonnes of *P. ornatus* are farmed each year in sea cages, while in Indonesia lobster farming has begun in Lombok where large numbers of *P. homarus* seed settle each year. Further resources of seed are likely to be identified elsewhere in the archipelago. In Australia, exploitation of wild puerulus is uneconomic and the focus has been on hatchery technology which is now poised for commercialisation. Aquaculture production of lobsters is an attractive proposition worldwide, as the species are generally of high value, are in great demand and fishery production cannot be increased. Active research and development programs throughout the world have sought to develop this sector, but to date none have been successful, outside the developments referred to here. Tropical species of spiny lobster are likely to remain at the forefront of aquaculture production development because of the availability of wild seed, development of commercially viable hatcheries and their highly economic growout characteristics. This paper summarises the opportunity for tropical spiny lobster aquaculture, developments to date and the challenges yet to be overcome.

Keywords: Lobster, *Panulirus ornatus*, *P. homarus*, aquaculture, puerulus

Introduction

Development of lobster aquaculture has received increased attention in recent years as fishery catches have stabilised or declined, while demand continues to increase (Jones, 2009a). To date the only significant production of spiny lobsters from aquaculture has come from Vietnam. The on-growing of the ornate lobster *P. ornatus* has been a successful village-based industry along the central south coast of Vietnam since 1995, based on an abundance of naturally settling lobster seed and the establishment of up to 49,000 lobster sea cages (Hung and Tuan, 2009). Production of cultured lobsters in 2008/09 was estimated to be about 1,500 tonnes worth more than US 60$ million (Thuy, personal communication).

The positive experience of Vietnam has led to similar interest in Australia and Indonesia and is likely to spread elsewhere within the natural distribution of this species. Of particular significance is the positive impact the industry has on impoverished communities and the opportunity to extend such benefit to other poor areas (Petersen and Phuong, 2010). Notwithstanding the success Vietnam has recently faced some setbacks in its lobster farming industry including disease and environmental degradation (Anon, 2009a). Research is underway to resolve these problems and to support extension of sustainable practices to new lobster farming areas.

This paper describes the history of tropical spiny lobster aquaculture development in Vietnam,

Indonesia and Australia and the opportunity that may be realised in the next decade.

History: Development of lobster culture has been actively pursued for many decades (Wickins and Lee, 2002) and several species well established in the marketplace from significant fishery production have been the subject of intensive research and development aimed at establishing commercial aquaculture to supplement wild fishery catches, and to meet ever increasing demand. The most prominent of these are the two clawed lobster species *Homarus americanus* and *H. gammarus* from the north-west and north-east Atlantic, for which aquaculture technology was ardently pursued but was ultimately unsuccessful due to biological constraints (primarily aggressive behaviour) (Conklin, 1983; Aiken, 1988; Addison and Bannister, 1994; Aiken and Waddy, 1995, Factor, 1995, Waddy *et al*., 1998, Tlusty, 2004;). Nevertheless, a number of *Homarus* hatcheries in North America and Northern Europe continue to produce juveniles for restocking purposes.

Interest in developing aquaculture technology for spiny lobsters (Palinuridae) has been equally strong (Phillips, 1985; Anon., 1989, 1994; Kittaka and Booth, 1994; Rahman and Srikrishnadhas, 1994; Anon., 1997; Jeffs and Hooker, 2000; Kittaka and Booth, 2000; Wickins and Lee, 2002; Jeffs and Davis, 2003), although advances have been slower to realise because of the protracted larval phase.

To date the only significant established lobster aquaculture industry is that of Vietnam, based on the growout of wild caught juveniles, a practice which may not be unsustainable (Bell, 2004). Its development was entirely market driven and dates back to the late 1970's and early 1980's when demand for lobsters from China grew rapidly. Prior to that time a small lobster fishery of a less than a hundred tonnes of annual catch operated along the Vietnam coast (Thuy and Ngoc, 2004) operated by divers and supplying a local market only. *Panulirus ornatus* was part of the supply but demand was only moderate as this species was of less value than others because its eating quality was less revered. However, Chinese consumers were specifically interested in *P. ornatus* as a sashimi product, served as a centrepiece for celebratory banquet dining. Only *P. ornatus* with its colourful shell satisfied the visual appeal, was large enough (over 1 kg) for such presentation and possessed the flesh characteristics (pearly lustre, sweet taste and firm texture) required for sashimi (Hart, 2009). Increasing demand from China heralded increased fishing effort throughout the South China Sea and beyond. In Vietnam, fishing effort increased by way of larger vessels equipped with trawl nets that could operate further offshore and spiny lobster yields increased to more than 700 t (Thuy and Ngoc, 2004). For several years much of the catch was of large lobsters, *P. ornatus* up to 5 kg per individual, *P. homarus* over 1 kg per lobster and *P. longipes* and *P. stimpsoni* up to 1 kg per individual (Thuy and Ngoc, 2004). By the 1990's, the fishing pressure and lack of any regulatory management led to decreasing catch and diminishing mean size. For *P. ornatus*, the Chinese demand was for larger lobsters, and price paid for lobsters less than 1 kg was lower (Thuy and Ngoc, 2004). Vietnamese fishers were adaptive and inventive and soon began holding the smaller lobsters to fatten them to the preferred market size. Although the initial methods and equipment to do this was necessarily rudimentary, *P. ornatus* in particular demonstrated to them it was well suited to captivity. Growth rates and survival of lobsters held in simple enclosures staked into the seafloor in shallow waters off the beach and fed low value trash fish were excellent and the practice proved to be very profitable. By 2004 over 30,000 net cages had been established along the south central coastline producing more than 2,000 t of farmed lobsters, primarily *P. ornatus* (Tuan and Mao, 2004; Thuy and Ngoc, 2004).

In less than a decade a small but valuable fishery for market sized lobsters in Vietnam had been decimated (Thuy and Ngoc, 2004). The catch of smaller lobsters destined for fattening farms decreased in volume but increased numerically as the mean size of lobsters caught continued to drop. By the mid 1990's Vietnamese fishers had developed techniques and identified locations to capture lobsters at the swimming puerulus stage and in the period since 1996, the bulk of lobsters marketed from Vietnam have been farmed from an initial capture

size of less than 5 g. The sustainability of capturing lobsters at the puerulus stage without limit and driven by unsatisfied demand was clearly of concern (Williams, 2004) but despite fears it might soon collapse, catches have been relatively stable through to the present time (Long and Hoc, 2009; Jones *et al*., 2010). A comprehensive, annual lobster seed capture census has been performed in Vietnam since 2005, indicating an overall catch of between 1.5 and 3 million pueruli per year (Jones *et al*., 2010). Notwithstanding the sustained puerulus yields for more than a decade, some form of management is clearly advisable to ensure long term sustainability. A key component of this will be a broader understanding of the reproductive source of the pueruli settling along Vietnam's coast and research towards this goal is now underway (Bell, 2004; Williams, 2009; Jones *et al*., 2010).

Vietnam has suffered significant conflict and upheaval over its history and it is a credit to the Vietnamese people that they remain so industrious and development focussed. The development of lobster farming is a prime example of their motivation and inventiveness as demonstrated in the very fast evolution of the cage structures for lobster growout. In the mid to late 1990's lobster farms were primarily located in shallow waters 100 to 500 m off the beach and consisted of net cages staked into the seafloor (Fig. 1) (Thuy and Ngoc, 2004). The framework for the cage support was made from cheap materials locally available including bamboo and rough-cut timber from adjacent forests, fixed together with rope lashing. Cages were made from fishing net, dimensions were typically 3 m square and 2 m deep, and the cage floor was in direct contact with the substrate. Issues with fouling and build-up of uneaten food and waste soon motivated farmers to move their cages to deeper water to ensure they were held well above the seafloor. Such sites were more exposed to wave and wind action and materials for the cage frames and cages themselves became more robust including milled timbers, steel fixings and stronger netting. The staked cages soon gave way to floating pontoon structures suitable for even deeper water, anchored to the seafloor with moorings of steel or concrete. The profitability of the industry allowed farmers to invest in bigger cages made from more durable materials so that by the mid 2000's, floating farms were often as sophisticated as any in the world (Fig. 2) (Hung and Tuan, 2009).

Fig. 1. Photo of Vietnam lobster grow out farm representing the earliest form (circa 2000), with net enclosures staked into the seafloor in shallow water

Fig. 2. Photo of recent lobster sea cage structure (circa 2009) consisting of floating pontoon with suspended cages made from durable materials and relatively long lasting

Despite the well known success of farming lobsters in Vietnam, similar large-scale development has not occurred elsewhere within the region. Taiwan and the Philippines had both embraced the concept of fattening smaller lobsters (Arcenal, 2004; Juinio-Menez and Gotanco, 2004), but for both the supply of such lobsters was small and did not extend to an identified puerulus resource. In India, Vijayakumaran *et al*. (2007) reported on the development of lobster

farming based on capture of wild seed, but this was devastated by the 2004 tsunami and has not since re-established. To date, Indonesia appears to be the only other country in the South East Asian region to initiate lobster farming using a wild puerulus supply (Priyambodo and Jaya, 2009; Priyambodo and Sarifin, 2009; Jones *et al*., 2010). In Lombok in the early 2000's, pueruli (primarily *Panulirus homarus*) had been observed settling naturally on seaweed farms and floating cages used for grouper culture. The seaweed and fish farmers soon recognised the opportunity given the high value of market-size lobsters and began to actively seek out the pueruli and stock them to dedicated cages. By the mid 2000's, active puerulus fishing had developed using methods similar to Vietnam and more than 600,000 were caught in 2008/09 (Jones *et al*., 2010). Clearly a local and abundant supply of naturally settling puerulus is a pre-requisite for such lobster farming and a programme of assessing puerulus availability elsewhere in Indonesia is now underway (Jones *et al.*, 2010). Puerulus resource assessment in Lombok has clearly shown that settlement is not widespread and appears to be focussed specifically in the south-east of the Island presumably where local ocean and tidal currents facilitate the delivery of the late stage phyllosoma. Other localities with high puerulus abundance so called 'hot-spots', may exist in Indonesia and beyond and provide the basis for local growout industries.

Lobster farming in Vietnam and more recently in Indonesia has provided significant benefit to the communities who have developed it (Petersen and Phuong, 2010). They have exclusively been impoverished areas, and the enterprises established are entirely family and village-based. Because the socio-economic benefits are significant (Hambrey *et al.*, 2001), local and national governments have been highly motivated to expand and sustain the industry. Therefore, it is unfortunate that problems have arisen and impacted on productivity and environmental sustainability. In Vietnam there are clear signs of substantial environmental degradation in many of the lobster farming areas (Vinh and Huong, 2009), the cause of which is likely to include lobster farming practices. Feeding of lobsters is based entirely on use of trash fish, a combination of low value fish, mollusc and crustaceans, and food conversion ratios are often in excess of 20:1, meaning an enormous input of organic matter to the farming environment (Hoang *et al*., 2009). Probably linked to this degradation, is an increasing prevalence of lobster disease manifested in a variety of symptoms and negative impacts on survival, growth and product quality (Hoang *et al*., 2009). Some farming areas have been decimated by disease and farmers have lost their business and had to move to alternative industries. However, for the vast majority disease has not destroyed their business but reduced productivity and profitability. Current annual production in Vietnam has dropped to around 1,500 tonnes (Hoang *et al*., 2009).

Species: Spiny lobster farming was initiated in Vietnam in direct response to market demand from China for *P. ornatus*, which was specifically sought for celebration dining. As the farming industry in Vietnam has developed to the extent that puerulus were targeted, several species were represented in catches including those of lesser interest to farmers because of their lower market value or poorer growing characteristics. Nevertheless to the great benefit of the farmers, *P. ornatus* has emerged as the dominant species settling along the Vietnam coastline. *Panulirus homarus* is the second most common species caught as puerulus and the other species are generally not differentiated (Long and Hoc, 2009). They include *P. stimpsoni, P. longipes, P. versicolor* and *P. polyphagus*. Because of the unregulated fisheries in Vietnam, the lobster fishery for market-size lobsters is in a poor state and adult populations are scarce and this is particularly so for *P. ornatus*. The abundance of the settling puerulus appears to bear no relationship to breeding populations from the same locality. Because of the 4 to 8 month larval duration of this species, the planktonic larvae may originate in locations far from Vietnam, being carried by the ocean currents over long distances (Villanoy, 2004).

In Indonesia, the fishery for puerulus is most active in the southeast of Lombok Island where their natural abundance is sufficient to support the fishery. As in Vietnam the adult lobster stocks in Lombok are scarce as a result of fishing pressure. Also the island is volcanic and surrounded by

relatively deep water and there are few reef areas suited to spiny lobster habitation. In Lombok, more than 90% of the puerulus caught are *P. homarus*, the remaining 10% are mostly *P. ornatus* with very few of other species which include *P. versicolor* and *P. longipes*.

Although Indonesia's adult lobster stocks are under some fishing pressure, there are exploitable populations of *P. ornatus*, *P. homarus*, *P. longipes, P. versicolor, P. penicillatus* and *P. polyphagus*. To sustain these populations, clearly there is successful annual reproduction and puerulus recruitment. However, it remains to be seen whether there are other focal points like southeast Lombok for such recruitment that will facilitate commercial harvest of pueruli for aquaculture. Research is now underway to assess puerulus abundance in other localities throughout the Indonesian archipelago with a view to establishing growout industries where they are found.

Panulirus ornatus is advantaged by having existing strong market demand that is significantly less than supply. The abundance of *P. ornatus* pueruli in Vietnam has been eagerly exploited and provided strong profitability to those farming it. In Lombok the local puerulus settlement is predominantly *P. homarus* which is of significantly less value in the market (Hart, 2009). However, *P. homarus* is marketed as a small lobster, mostly 150 to 300 g and satisfies a different market segment. Growth rates for *P. homarus* to 300 g are rapid, equally as fast as those of *P. ornatus*, so a commercial crop can be produced in 6 to 9 months from puerulus, relative to 18 to 22 months for *P. ornatus* (Jones, 2009a). Although there is a significant price differential (*P. homarus* US $ D30 /kg , *P. ornatus* US $ D50 /kg wholesale) (Hart, 2009), the much shorter growout period facilitates equal if not better profitability.

If puerulus resources for other tropical lobster species are found, it remains unclear whether any of them will be suited to aquaculture. Hart (2009) suggests the 're-tanking' capacity of *Panulirus longipes*, *P. versicolor* and *P. polyphagus* that is, their suitability to and robustness for handling and being held in captivity prior to live export, is much more limited than for *P. ornatus* and *P. homarus*. The production characteristics of these other species in captive systems have not been assessed and may prove to be less conducive to commercial growout. Combined with the price they will receive in the market, the opportunity for profitable production remains uncertain.

Puerulus collection: Aquaculture based on natural seed supply is not unique to spiny lobster. Substantial industries have been established for other crustaceans and fish (Lucas and Southgate, 2003), although in most cases their long term future can only be assured if a hatchery supply is established. Nevertheless, the relatively new tropical spiny lobster farming industries of Vietnam and Indonesia based on a wild seed supply, appear to be quite robust. The biology of spiny lobster may be a contributing factor to this by virtue of high fecundity and a protracted oceanic larval phase which may lead to significant mixing of populations. Reproductive failure in any one population amongst many within a given region may have little or no impact on subsequent recruitment. This is of course speculation and efforts are now underway to identify the source of lobster recruits for *P. ornatus* and *P. homarus* within their Australasian range (Jones *et al.*, 2010) which may provide information to more sustainably manage the resource.

The exploitation of the puerulus resource in Vietnam and now in Indonesia are without precedent within the lobster fisheries of the world. In several jurisdictions, fishing of puerulus for growout has been mooted or trialled, but none have persisted (Gardner *et al*., 2006; Jeffs and Davis, 2009). The notion of biological neutrality from taking pre-reproductive lobsters from wild populations for input into alternative production systems and then returning sufficient to ensure no net loss (Gardner *et al.*, 2006) has little application to Vietnam where the fishery remains largely unmanaged and little understood. To date, fishing effort has simply grown to the natural limits of the recruitment and total production for the past few years appears to be stable (Jones *et al.*, 2010), with some 2 to 3 million pueruli caught each year. The long-term sustainability of this fishery and therefore the farming industry is uncertain and is of concern. However, these concerns

may be nullified by the impending establishment of a hatchery supply of pueruli.

Hatchery technology: In Australia, lobster farming is not yet established although a concerted research and development effort has been underway for more than a decade to develop the appropriate technology. Dedicated hatchery technology research programmes have been successful and pueruli have now been produced from eggs reared in laboratory tank systems for *Jasus edwardsii*, *Sagmariasus verreauxi* and *P. ornatus* (Jones, 2009a). In New Zealand, the first successful puerulus production of *S. verreauxi* occurred in 1995 (Booth, 1995), and followed previous success for various other species in Japan over preceding decades (Jones, 2009a).

In Australia the concept of harvesting pueruli from the wild for input to aquaculture production has been debated (Phillips *et al*., 2003; Gardner *et al*., 2006) and trialled, but has proven too politically sensitive to be sustained. For *P. ornatus*, no attempt has been made to commercially harvest settling pueruli in Australia, as they appear to be particularly dispersed in space and time (Dennis *et al.*, 2001), quite unlike the circumstance of Vietnam. This is despite there being a substantial *P. ornatus* population between New Guinea and northeast Australia which supports a valuable and well managed fishery (Dennis *et al.*, 2004). Australia's only option for the establishment of lobster aquaculture is to develop hatcheries for the supply of puerulus.

Panulirus ornatus pueruli were first produced from captive breeding in a commercial prawn hatchery in 2006 (Calverley, 2006), and the business responsible soon after established a new company, Lobster Harvest Pty Ltd. to commercialise the technology. Preliminary planning is now underway to establish a tropical spiny lobster hatchery in North Queensland in partnership with the Queensland Government, with a view to supplying juvenile *P. ornatus* to a growout industry in northern Australia and elsewhere in south -east Asia. If successful, this may help to supplement the wild supply of pueruli and ultimately replace it. Such an outcome would have the benefits of reducing or removing the pressure on wild stocks and enable improvements in productivity that will flow from selective breeding and consistent supply of high quality stock.

Markets: Being a luxury seafood the aquaculture of spiny lobsters is not driven by food security, as much of global aquaculture is. Although Vietnam and Indonesia have food security issues, their interest in lobster aquaculture is principally about wealth creation, particularly for impoverished communities (Hambrey *et al*., 1999; Hambrey *et al*., 2001; Pahlevi, 2009). The attraction of lobster farming is that it involves simple technology, moderate capital input and produces a very high value product. Markets for lobster around the world are generally characterised by unmet demand (Hart, 2009). The Chinese market for *P. ornatus* is unique with quite explicit product specifications. Accordingly, the price per kilogram paid by wholesalers is very high and possibly higher than for any other lobster species in the world. It is perhaps fortunate that in Vietnam the lobster species that is in the greatest supply as naturally settling puerulus is in such market demand at such high price. However, there is clearly a resource of other species that might also provide the basis of increased production of marketable lobsters. This has been demonstrated in Indonesia where *P. homarus* as the dominant species settling in Lombok is now being produced through aquaculture. Unpublished market intelligence suggests that the farmed *P. homarus* product from Lombok attracts a lower price than wild caught product of the same species. This is attributed to pale shell coloration of the farmed lobster and poor vigour which makes live transport difficult and the product unattractive to the customer. Fortunately both problems can be rectified in aquaculture through improved nutrition and husbandry and ultimately farmed product may attract a premium because of consistency in supply and quality (Hart, 2009).

The opportunity to make more use of puerulus resources is very strong because demand for lobsters continues to grow (Hart, 2009). In Vietnam the resource of *P. ornatus* puerulus appears to be fully exploited (Jones *et al.*, 2010) but the opportunity to gain value from the substantial quantity of *P. homarus* also caught is not yet being realised. Although *P. homarus* is a lower value product, its smaller market size and therefore shorter production period make it an attractive proposition. Further, *P. homarus* has broader market appeal than *P. ornatus* and its farming

could potentially grow to be of greater significance. In Indonesia to date, only *P. homarus* pueruli have been caught in substantial numbers but it is likely that as puerulus resources are assessed elsewhere across the full extent of the island nation, other species may also present an opportunity. From a market perspective, the other species of interest because of demand and good pricing are *P. penicillatus* and *P. longipes* (Hart, 2009). Slipper lobsters (Scyllaridae) might also factor in the development of lobster aquaculture if supplies of their post-larvae, 'nistos' are identified or generated from hatcheries. Preferred species in the market include those of the genera *Scyllarides*, *Thenus* and *Parribacus* (Hart, 2009).

Lobster aquaculture based on a wild puerulus supply is limited by what nature provides in natural settlement from year-to-year. Nevertheless, aquacultured lobsters provide a distinct advantage over a wild fishery product because they can meet the key market requirements of live product, preferred size, consistent supply and quality, all of which can generate improved pricing, new markets and therefore increased demand and reduction in buyer risks (Hart, 2009).

Growout characteristics: Although the supply of pueruli has been a critical perquisite to the establishment of tropical spiny lobster aquaculture, the production characteristics in captivity were also of great importance. For *P. ornatus*, the Vietnamese quickly confirmed this species excellent credentials for growout in sea cages by simply trialling it and modifying their husbandry along the way to incrementally optimise their aquaculture practises. In Australia, where *P. ornatus* aquaculture is also being pursued, confirmation of captive growout capacity was important to underwrite the significant investment in developing larval rearing technology. This confirmation has come through a research approach based on experimentation much of which is now published (Jones, 2009a; Jones and Shanks, 2009; Williams, 2009).

The key characteristics of *P. ornatus* for captive production are that it is amenable to high density, its growth rate is relatively fast and it will readily accept a variety of food. Jones *et al*. (2001) demonstrated that good growth rates of *P. ornatus* at densities as high as 5 kg m^{-2} could be sustained and enable a 1 kg harvest size to be achieved in 18 months from a 3g stocking size. This concurs with the experience of the Vietnam farmers who generally harvest >1 kg lobsters after 18 to 20 months of growout at densities of up to 80 lobsters per cage (4 × 4 m). *Panulirus ornatus* is a particularly social lobster (Dennis *et al.*, 1997), so high density production is not problematic however, other spiny lobster species are known to be much more territorial and aggressive, such as *P. versicolor* which may not be so conducive to culture (Hart, 2009). The experience of farm production of *P. homarus* in Indonesia suggests that it is equally amenable to high density production (Priyambodo and Jaya, 2009). *P. homarus* appears to grow faster than *P. ornatus* up to 100 g but thereafter *P. ornatus* growth is faster (Priyambodo and Sarifin, 2009).

One of the key issues of all aquaculture is feeding, requiring balancing considerations of nutrition of the culture species, cost-effectiveness of the feed, environmental impacts of the feeding practice and protein and lipid conversion ratios. A substantial body of information has now been compiled on nutrition and feeding for *P. ornatus* (Williams, 2004 and citations therein) which will enable the farming industry of Vietnam to transition from traditional use of trash fish feeding to a manufactured diet (*i.e.* pellet). Use of trash fish comprising various fish, mollusc and crustacean species, has supported excellent growth rates of *P. ornatus* in Vietnam farms and nutritionally a manufactured diet will aim to be as effective (Irvin and Williams, 2009). The most significant gain from use of pelleted feeds will be diminishing the environmental impact that trash fish feeding has because of the substantial organic input. More than 20 kg and in some cases as much as 50 kg of trash fish are required to produce a kilogram of lobster using the traditional trash fish mix applied in Vietnam. Clearly much of such input is not consumed by lobsters and the waste has both a localised and broad negative impact on water quality (Hoang *et al.*, 2009). It is likely that this has in turn contributed to the increasing prevalence of disease, so moving to pellet feeds is likely to have multiple benefits.

Indonesia's fledgling lobster aquaculture industry is advantaged by having access to the Vietnam experiences and it is hoped that the industry there will immediately embrace a pellet food approach thus avoiding the negative impacts of using trash fish. In Lombok and probably elsewhere in Indonesia, the variety of low value trash fish appears to be much lower and achieving nutritional adequacy with this food source would be difficult. The relatively poor coloration and low vigour of the *P. homarus* lobsters produced there, as identified by wholesale marketers, is likely a reflection of nutritional deficiency. Pellet food specifications, while still developmental are sufficiently advanced to inform commercial feed mills to initiate pellet production for industry use.

Panulirus ornatus appears to have other advantages for aquaculture with regard to its tolerance of environmental fluctuations. For temperature, salinity, turbidity and other water quality parameters, the species has clear optima but also broad tolerance (Jones, 2009b; Jones and Shanks, 2009) to variations. This reduces risk and broadens the opportunity for commercial production. Although specific assessment of environmental tolerances of *P. homarus* has not been made, the production success to date in sea cage culture in Lombok suggests that it is also tolerant of environmental perturbations which are common in captive production systems.

Production systems*: Panulirus ornatus* is likely to be amenable to production in different types of culture systems because of its broad environmental tolerances.. This is an important issue for Australia where sea-cage culture is much less likely to be established (Kenway *et al.*, 2009) and alternative production systems, such as ponds or tanks, need to be considered. Kenway *et al.* (2009) described a number of obstacles to the use of sea-cages in Australia including access to sites within the Great Barrier Reef Marine Park, prevalence of larger predators including sharks and crocodiles, strong tidal currents and cyclones. Although some of these may be mitigated through engineering solutions, the expense is prohibitive. Consequently, consideration has been given to land-based production systems such as earthen ponds, as used for shrimp and barramundi farming, raceways or tanks.

Much of the early research on aspects of husbandry and feeds development has been performed in tanks with flow through or recirculating water supply (Jones and Shanks, 2009). Growth and survival in such systems was generally good and suggests commercial production could be done in tanks, although the cost of this approach is likely to be relatively high. Jones and Shanks (2008, 2009) reported on a production trial of *P. ornatus* on a shrimp farm in northern Queensland. Lobsters were contained in cages held in the intake channel of a typical shrimp farm, where salinity and temperature fluctuated, turbidity was often high and dissolved oxygen was maintained with paddle-wheel aerators. Although the trial represented growth from 750 g to 1 kg only, growth rate was good (8 g /week), survival 78% and colour and vigour at harvest were excellent, demonstrating that *P. ornatus* can be grown in shrimp pond systems. Further research of land-based systems including ponds and raceways is now underway to more comprehensively explore this opportunity. In Vietnam, there is considerable interest in assessing shrimp pond production as an alternative to sea-cages to avoid disease. The use of trash fish as the source of food would be inappropriate for pond or tank systems where stocking density may be quite high and the system does not have the capacity for dispersal of discharges that sea-cages afford. Manufactured pellet feeds which provide good nutrition and minimal waste would necessarily be part of the land-based approach. The pond trial reported by Jones and Shanks (2008, 2009) used a laboratory manufactured moist pellet diet, which was readily accepted and generated good results.

Economics*:* The discussion in this paper has focussed mostly on biological and human cultural factors which are integral to the success of lobster farming, however, without a profitable economic basis the industry would not have established, nor will it expand. An economic analysis of lobster farming in Vietnam (Petersen and Phuong, 2010) indicates that all industry participants, be they puerulus fishers, dealers or growout farmers, are economically successful. Indeed many have become

wealthy as they have leveraged their input of time, labour and skills off the relatively high price of the lobster. The price paid for pueruli has at times exceeded US $15 per individual, within communities where the average monthly income is perhaps US $60. Puerulus price is subject to normal free enterprise supply and demand forces, and to a large extent is driven by the high price paid for the market-sized lobster which may be as high as US $50 per kilogram. Disease within the growout production in recent years and its significant negative impact on productivity has pushed the puerulus price down, although average prices per piece are still US $2 to US $5 and much higher than in Indonesia, where price per puerulus is usually much less than US $1.

Between purchase of puerulus and selling of marketable 1 kg lobster, there are all the costs associated with production. Relative to other forms of farming, they can be quite modest as there is no land cost and modest capital costs for cage structures (Hambrey *et al*., 2001; Petersen and Phuong, 2010). Feeding costs using the traditional trash fish food source can be quite high because of poor food conversion ratio, resulting from inappropriate composition and poor quality, and uptake of manufactured pellet feeding will likely ultimately decrease the feeding cost (Irvin and Williams, 2009; Tuan and Hung, 2009). In Vietnam, labour should be factored as an opportunity cost, as all lobster farming enterprises are family owned and operated, and hired labour as such is not used. The same will apply to Indonesia. There are few other operating costs, although the increasing prevalence of disease may add costs associated with treatments.

In Australia, the economic equation will be quite different by virtue of the production system used (land-based rather than sea-cage), much higher labour costs and compliance costs associated with operating permits. As such, a more intensive approach will be necessary with greater output per unit of production area. Land-based systems are more amenable to such output as they provide more opportunity to manage the production environment to increase growth rate, survival and productivity. No such production systems have yet been established in Australia, so the economic viability will remain theoretical until commercial investment tests the opportunity.

There is also great interest in Australia to explore the opportunity for establishing lobster farms in indigenous communities where economic enterprise is stifled. The experiences of Vietnam and Indonesia suggest lobster farming is well suited to indigenous communities and can provide economic and social benefits. For Australian indigenous communities, the economic benefits are of lesser significance than the social ones, and the economic equation acceptable for establishing enterprises there may be quite different to that of corporate businesses established elsewhere. Fortunately, the market demand for lobsters that drives this economic opportunity is sufficiently large to accommodate both.

Research program: Much of the information presented in this paper has been generated through a research for development project supported by the Australian Government and administered through the Australian Centre for International Agricultural Research (ACIAR) (Anon., 2009b; Williams, 2009), and many of the knowledge gaps and issues which have recently arisen are to be addressed through a new project.

The proposed project will adapt existing technology from Vietnam, apply it in Indonesia where lobster seed resources have been identified and assist in its further expansion throughout Indonesia. Negative environmental impacts experienced in Vietnam will be minimised by facilitating immediate uptake of pellet diet feeding which is likely to be both cost-effective and much cleaner, and by effective planning for growout development that meets carrying capacity benchmarks defined from research in Vietnam. Beyond the substantial lobster seed resource identified in Lombok, exploitable seed resources are likely to exist elsewhere in the archipelago, upon which a significant lobster farming industry might be developed. The research will provide quantified assessment of lobster seed resources at a range of sites throughout Indonesia (Nusa Tenggara Barat, Nusa Tenggara Timor, South Sulawesi and Aceh), through application of standardised seed collectors. In sites where seed availability is

confirmed, 'best management practice' demonstration grow-out farms will be established to extend the technology to local communities and to stimulate farming activity. The Indonesian Directorate General for Aquaculture will have a core role in lobster farming development planning to ensure carrying capacity of proposed farm areas is not exceeded and local environments are sustained. Pahlevi (2009) contends that a collaborative approach between central government and communities can provide effective management.

The sustainability of puerulus fishing for aquaculture development is of concern, as it may lead to negative impacts on adult populations that currently support fishers. However, the natural mortality of the puerulus is likely to be high, so their exploitation for growout may be a reasonable trade-off.

A component of new research will be performed in Vietnam in response to issues and problems impacting there, primarily environmental and disease related. Linkage to Vietnam will provide significant benefit to the Indonesian activities by facilitating on-going adaptation of Vietnam lobster farming technologies for Indonesia. The Vietnam-based work will consist of environmental assessments to gauge the impact of lobster sea cage farming and specifically the relative contribution from traditional trash-fish feeding practices as compared with use of manufactured pelleted feeds. The output of this will include confirmation of the cost and environmental effectiveness of pellet feeds (cf trash fish feeding) and measurement of carrying capacity for lobster sea-cage farming, of particular value to the developing Indonesian industry. An assessment of land-based farming systems for lobsters will provide a possible alternative to sea-cage systems. Results will have application in Vietnam, Indonesia and particularly Australia where sea cage farming faces substantial constraints.

The Australian component of the research will assess commercial-scale, land-based growout systems to prepare the Australian aquaculture sector for the likely availability of hatchery-reared lobster seed. In the first instance, lobster growout will be developed as a potential diversification or alternative for pond-based production on shrimp and barramundi. Development for indigenous communities will also be pursued.

Opportunity: Lobster farming is a particularly attractive opportunity in many parts of South-East Asia because capture of seed lobsters and their growout involves simple technology, minimal capital and is ideally suited to village based enterprises. It can provide significant benefit to the economic and social fabric of impoverished communities. Existing export market chain infrastructure exits in many ports throughout the region used for wild captured lobsters, and this can be used for farmed lobsters (Hart, 2009). Growout technologies trialled, tested and optimised in Vietnam can be transferred to other localities, to avoid problems and ensure sustainable practices are initiated. Market opportunity for farmed lobsters is strong and growing, and there is a strong likelihood that farmed lobster production from an increasing number of South-East Asian countries will increase substantially over the next decade.

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