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Lobster aquaculture a commercial reality: A review

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Abstract

Lobster Harvest Ltd, an Australian company, was formed in May 2007 to progress the commercial development of lobster aquaculture technologies. The species of major commercial interest include both slipper lobster (*Thenus* spp.) and tropical rock lobster (*Panulirus ornatus*). This followed earlier research and development carried out by the MG Kailis Group. Lobster Harvest Ltd at December 2009 is now ready to initiate commercial aquaculture of slipper lobster and expects to be in a similar position to commence commercial hatchery production and grow-out of tropical rock lobster within ~3 years. This paper outlines the reasons for selecting these two species as candidates for lobster aquaculture and also reviews the company's achievements at a broad strategy level against the business model key input assumptions for slipper lobster, along with insights as to why tropical rock lobster aquaculture will be successful in the future.

Keywords: Aquaculture, lobster, lobster harvest, *Panulirus ornatus*, *Thenus* spp.

Introduction

Lobster aquaculture is often seen as the "jewel in the crown" for companies involved in the farming of sea foods. This status has been recognised due to spiny lobsters (Palinuridae), and to a lesser extent slipper lobsters (Scyllaridae) as valuable seafood throughout the world with high market appeal in Asia, Europe and America (Williams, 2007). Most wild lobster fisheries are either over-exploited and in decline and hence this concern and increased consumer demand has prompted intensified research into commercial hatchery production (Phillips, 2000, 2005; Cox and Johnston, 2003). The settlement of juveniles in the wild is variable and generally declining, providing impetus for the development of an aquaculture industry based on hatchery production seed-stock (Kittaka and Booth, 2000; Booth, 2006; Smith *et al*., 2009).

To enable the expansion of commercial lobster aquaculture, seed-stock independent from wild sources must be established. In what is believed to be a world-first, Roger Barnard (Aquaculture Manager) and his technical team first reared *Panulirus ornatus* from egg to juvenile in June 2006. This success followed the experience of rearing *Thenus australiensis* from egg to juvenile in 2004. Since these achievements, Lobster Harvest has continued to progress research and development (R & D) into propagation of these species to this time, and has now reached "commercial ready status" for the production of *Thenus* spp. and anticipates being in the same position for *P. ornatus* within ~3 years.

The work completed by the Lobster Harvest research team has gone beyond successfully producing juvenile lobsters from egg producing females at a research scale toward achieving commercial scale production. Since its formation in 2007, the company has paid particular attention to developing commercial lobster aquaculture technologies and validating the assumptions of business modeling through focused R & D. The bio-economic model provides a tool for the research team to plan and prioritise research program projects and objectives and further enhances understanding of the value chain at all stages of a commercial lobster aquaculture business including scenario analysis.

Aspects of these research outcomes and species selections for commercialization are reviewed, and areas where future research is needed, are identified with views on the future of commercial lobster aquaculture.

Species selection and their favorable attributes for aquaculture

In developing a commercial aquaculture species there are a number of characteristics which are considered desirable. These include the shortest possible larval duration, high fecundity, fast growth rates, high market value and a lack of cannibalism, all of which will impact directly on bottom line profits in a commercial aquaculture enterprise.

***Slipper lobster (Thenus* spp*)*: *Thenus* spp. in particular are acknowledged for their high fecundity amongst the *Scyllaridae* (20,000 – 30 000 eggs per spawning) and a short planktonic larval phase (27 – 45 days) consisting of 4 larval stages before metamorphosing to the brief, free-swimming, post-larval phase called the "*nisto*" (equivalent to the palinurid "*puerulus*") (Mikami and Kuballa, 2007; Sekiguchi *et al*., 2007). The fast post-larval growth rates, attaining an average cohort weight exceeding 200g within 12 months from juvenile stage V, makes this species an ideal aquaculture candidate (Table 1). Unlike many lobster and crab species there is no significant cannibalism occurring in *Thenus* spp., except for in late larval stages during molting. Management practices in relation to nutrition and husbandry remove this risk.

Food conversion ratios (on intake) of 1.9-3.9:1 on a wet basis with fresh feeds have been achieved and 4.1:1 on a dry matter basis for formulated grow-out feeds. Further development for better performing economic FCR is continuing. Market values for this species range between US $18 and 32 /kg depending on frozen, chilled or live markets. World supply (principally as by-catch from trawl and trap fisheries) is estimated between 10 000 – 15 000 tonnes annually. Market potential and price uplift as a new category seafood item from aquaculture supply is thought to be considerable with improvements in consistency of quality, grading and appropriate branding (Wild Oceans, 2009).

***Tropical spiny lobster* (*Panulirus ornatus*)**: Tropical spiny, or seven-colour, lobster as commonly known throughout south-east (SE) Asia with its mixture of green, blue, orange, black, white, purple and yellow decorations is recognised in the market place from Dubai (Arab Emirates) in the middle east, across the tropics with significant lobster markets in China, Taiwan and Japan. Wild-stock fisheries exist within eastern Australia (Queensland) and throughout many countries including Malaysia, Indonesia, Vietnam, Thailand, India and Oman. Total world supply of TRL from wild fisheries, including those sourced for fattening and grow-out of wild-caught juveniles between 2003 and 2007 have ranged between 5100 and 6600 tonnes annually (FAO Global Fisheries Statistics). Prices exceeding A$100 per kg have been achieved especially during certain seasons for large live lobster (1kg + animals). The live tropical rock lobster market is well established, large scale and at the premium end of the market with Queensland wild caught export annual average prices in the order of A$ 55/kg and higher across all market grades (live, frozen, chilled).

Similar to slipper lobster, the tropical rock lobster is highly fecund, capable of producing 5,00,000 - 7,00,000 eggs (MacDiarmid *et al.,* 2006) and, average 2-3 spawnings/female/year. However, 1,400,000 larvae from one spawning has been recorded by *Lobster Harvest Ltd* at their R&D facility in Exmouth, with spawnings of in excess of one million are regularly achieved. The species also has a short larval phase of 4–8 months (Acosta *et al.,* 1997; Cruz *et al.,* 2001; Dennis *et al.,* 2001; Williams, 2007) relative to other spiny lobster species (Phillips *et al.,* 2006). Viable pueruli have been produced within 120–150 days from egg hatching. Similar to other species of spiny lobster, *P. ornatus* is observed to have 11 phyllosoma life stages and proceeds through 21–23 moults before metamorphosis to a puerulus under hatchery conditions. The other inherent advantage of *P. ornatus* compared to temperate and other tropical spiny lobster species is a fast post-larval growth rate, reaching in excess of 1 kg within 18 months after settlement (Phillips *et al*., 1992; Dennis *et al*., 1997; Skewes *et al*., 1997; Hambrey *et al*., 2001; Jones *et al*., 2001).

Experience to date has shown higher feed conversion ratios for tropical rock lobster relative

Table 1: Slipper Lobster Model Assumptions

	Model Assumption	Gap
Hatchery		
Larval survival stage 1 - Juvenile (batch)	42%	✓
Tank Stocking Density		
Day 24, Stage 4	4/L	✓
Nisto	11/L	development on-going
Stocking Density - Juv 1	8.4/L	development on-going
Frequency of stocking per cell (continuous)	protocol developed	non-critical
Culture time to Juvenile	40 days	✓
Larval Feeds		
Fresh feed seasonality	consistent quality	development on-going
Formulated diet (outside model parameter)	N/A	development on-going
Tanks		
Tank sizes - early stages (litres)	1,000	✓
Tank sizes - late stages (litres)	1,000	development on-going
Water exchange (%/hr)	protocol developed	✓
Water Quality		
pH	parameter limits defined	✓
Temperature	parameter limits defined	✓
D.O	parameter limits defined	✓
Salinity	parameter limits defined	✓
Water heating / cooling	parameter limits defined	✓
Nursery		
Juvenile stage 1 - 3		
Initial wt J1 (kg)	0.0006	✓
Final weight J3 (kg)	0.003	✓
Mortality	15%	✓
Initial stocking biomass kg / m2	protocol developed	✓
Initial stocking density animals / m2	protocol developed	✓
Final stocking biomass kg / m2	3.5	✓
Final Density animals / m2	1,167	✓
Time days	28	✓
Juvenile stage 3 - 5		
Initial wt J3 (g)	3	✓
Final weight J5 (g)	12	✓
Mortality	5%	✓
Initial stocking biomass kg / m2	protocol developed	✓
Initial stocking density animals / m2	protocol developed	✓
Final stocking biomass kg / m2	5.7	✓
Final Density animals / m2	475	✓
Time Days	28	✓
Nursery Feed		
Fresh Feeds	protocol developed	✓
Fresh feed seasonality	consistent quality	development on-going
Formulated diet (outside model parameter)	N/A	development on-going
Broodstock		
Broodstock fecundity (larvae per spawning)	20,000	✓
Number spawings / broodstock / year	1	✓
Sex Ratio (M:F)	protocol developed	non-critical
Stocking Density (broodstock / m2)	protocol developed	non-critical
Mean weight - female (g)	protocol developed	✓
Feed rate (wet weight)	protocol developed	✓
Spawning - months / year	12	✓
Grow-out		
super-intensive tank grow-out		
Grow out time months juvenile stage 5 to 200 g	12	✓
Maximum Final Biomass kg / m2	10	✓
Grow-out Survival (%)	79.5%	✓
Feed type	Pellet	development on-going
Feed Conversion Ratio (intake) - Pellet (:1)	2	development on-going
Feed Conversion Ratio (intake) - Fresh (:1)	5	✓
Mean Harvest Wt (kg)	0.2	✓
Tank area m2	20	Scale-up untested
cage grow-out		Concept proven; scale-up required overseas
pond grow-out		Concept proven; scale-up required overseas

to slipper lobster when using fresh feeds. Considerable diet development is progressing within Lobster Harvest to remove dependence on fresh feed for slipper lobster. This research has generated formulations and technologies for adaptation to tropical rock lobster formulated diets. Cannibalism is not an issue in the larval and adult stages of the life-cycle. Cannibalism within juvenile populations in the nursery is mitigated by husbandry techniques developed since 2006 by Lobster Harvest and Queensland Department of Primary Industry (Northern Fisheries Research Institute) (Jones *et al*., 2001). Furthermore *P.ornatus* is a hardy species that is readily transported out of water and 'tanks' well in holding tanks. The combination of these favorable attributes for aquaculture presents *P. ornatus* as the lobster species that has the most commercial potential. All of these attributes for culture affect the design parameters for a commercial hatchery, as well as the capital required and operational performance.

An equally important aspect of establishing Lobster Harvest from a commercial perspective is the inherent difficulty of lobster aquaculture itself. Specifically, interest in developing techniques to propagate stock from eggs is tempered with the knowledge that spiny lobsters have a complex and extended larval phase (Kittaka, 1994, 2000; Smith *et al*., 2009). This was recognised as an opportunity to gaining first mover strategic advantage, followed by maintaining industry leader status. Progress in successful hatchery propagation across a range of 8 spiny lobster species (Phillips *et al*., 2006) builds confidence for commercial success of lobster aquaculture in the near future.

Certainly, the independent success of closing the life cycle of *P. ornatus* and consistent supply of post-larvae by Lobster Harvest, the Australian Institute of Marine Science and the Queensland Department of Primary Industry builds even greater confidence in the development of successful commercial hatchery technologies.

Discussion

Background and research performance of Lobster Harvest Ltd:. In just 3.5 years, Lobster Harvest and its R&D team has reached a point in its evolution where we believe that commercial slipper lobster hatchery production is now feasible (Table 2) and that tropical rock lobster (Table 3) will be in the same position within ~3 years.

The business approach adopted by the company has focused on financial modeling, market analysis and linking the research program to the inputs developed for each species' bio-economic model. This approach, which includes both adaptive and intuitive changes in R & D, has driven research priorities. This facilitates the move from the R&D phase to commercialization.

Performance against each of the high level model assumptions is reported in Table 1 (some parameters

Table 2. Summary of progress and achievement made towards commercialization of slipper lobster

	Achievements and progress towards commercialization of slipper lobsters
1.	All stages of the slipper lobster life cycle have been completed.
2.	Tank scale-up has been successful, with 63% survival to juvenile achieved using 1 000 L tank in October 2009.
3.	Grow-out of slipper lobster to 200 g within 12 months from juvenile stage V (~12.5g) at final density of >10 kg/m^2 and 95% survival.
4.	Excellent efficiency of feed conversion (input) using fresh feeds (1.9-3.9:1 wet weight basis)
5.	Juvenile and adult solutions have been successfully developed for transport durations of >24h^{-1}.
6.	In excess of fifty standard operating procedures and protocols have been developed for slipper lobster production, plus unique tank designs for larvi-culture of slipper lobsters.
7.	Significant progress being made recently by Dr. Matthew Johnston with formulated diet development for grow-out of slipper lobster.
8.	Increased understanding of nutrients required for larval diet development.

Table 3. Summary of progress and achievements made towards commercialization of tropical spiny lobsters.

	Achievements and progress towards commercialization of tropical spiny lobsters
1.	LH has repeatedly achieved 30 – 50% survival of *P. ornatus* larvae to 120 days (13 groups over 3 year period). These survival rates are governed "commercial".
2.	Achieved survival rate of 6% from day 1 larvae to juvenile (again regarded a "commercial" rate).
3.	As experienced in other research organizations, the critical issue to commercial viability is consistent production from stages IX to XI; metamorphosis to puerulus and juvenile.
4.	LH has succeeded in producing pueruli/juveniles at sufficient rates of survival to warrant commercial investment with an emphasis on development.
5.	The key to success is increasing access to scientific knowledge, technological development, innovation research capacity scale (greater number of production runs and capacity for replication).
6.	LH is testing commercial scale larval tank designs which are expected to substantially increase survival of larvae to pueruli adapting in-trial experiences from slipper lobsters.
7.	Achieved egg to adult production at R&D scale.
8.	Grow-out production already established using fresh diets; formulated diets developed by LH have been used successfully at R&D scale.
9.	Manipulation of breeding stock to successfully produce larvae over all months reducing seasonality of egg production.

and the details of specific assumptions have been omitted as they form part of the company's intellectual property). Lobster Harvest has repeatedly achieved 30 – 50% survival of spiny lobster larvae to 120 days (13 groups over 3 year period) (Fig. 1). These survival rates are "commercial" rates, and the next stage is to consistently achieve high survivals through metamorphosis (5 – 10% from Stage I larvae to juvenile) at scale. The company has designed and developed a novel larval tank design to facilitate consistent survival rates through metamorphosis at commercial scale.

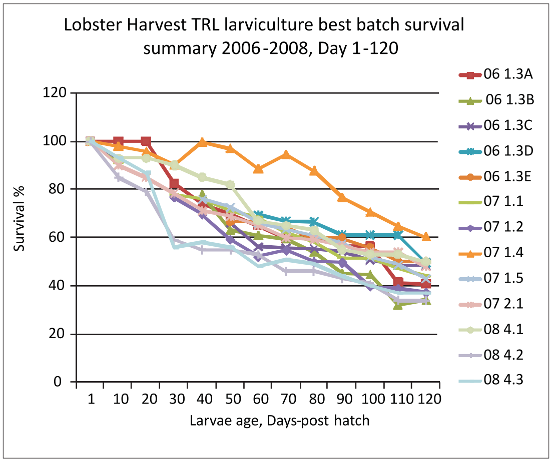

Fig. 1. Lobster Harvest Ltd best batch survivals for larval culture of *Panulirus ornatus* 2006-2008

Performance results presented in Table 1 indicate that hatchery production of slipper lobsters at commercial scale is technically feasible. Future development of grow-out is currently planned to be in Asia culturing *T. orientalis* rather than within Australia due to the former's lower labour, operating and capital costs. Research to date, suggests that there is little difference between the life histories of *T. australiensis* and *T. orientalis*. In both species the embryos hatch as advance-stage phyllosoma compared to other scyllarid species, and pass through 4-stages over 28 days before metamorphosing to the post-larval (*nisto*) stage (Mikami and Kuballa, 2007; Sekiguchi *et al.*, 2007; Kumar *et al.*, 2009). Bio-economic models developed provide an estimated earnings before interest and tax, depreciation and amortisation (EBITDA) of A$12.13/kg. An internal rate of return (IRR) yield 41% for slipper lobsters and business modeling undertaken for TRL given realistic modeling assumptions estimates EBITDA at between $ 20–25/kg and IRR exceeding 55% (full details of the modeling undertaken are not presented for commercial reasons and are continuing to be refined) (Table 4).

One of the significant advantages for tropical rock lobster aquaculture is presence of a substantial

Table 4. Financial comparison of key aquaculture species*

Market Size Product	Slipper lobster	TRL	TRL Juvenile	Tuna	Salmon	Barramundi (Australia)	Prawns *(Penaeus vannamei)*
Sale price A$ / kg	31.50	45	14 (per piece 10- 15 cm seed)	16	20	10	4
Price basis	Live, C&F Hong Kong	Live (FOB)	Beach	ex works Australia estimate	ex works Australia estimate	Farm gate	Farm gate
EBITDA A$ / kg	12	25	9.66 (per piece 10-15 cm seed)	6–9	3	1–3	0.67
Cycle length egg to market size	14–16 mths	22–24 mths	6–11 mths depending on size	3–5 yrs	2–3 yrs	1–2 yrs	6 mths
EBITDA margin	32%[1]	55%[2]	69%[3]	37–55%[4]	15%[5]	10–30%	16%[6]

*. To the best of Lobster Harvest's knowledge, based on information available up to the time of the conference. Obviously prices and returns depend on exchange rates and financial conditions at the time, including country assumptions the stage of industry development, and therefore the table provide an indicative comparison.

1. ACIAR: Assessing the South-East Asian tropical lobster supply and major market demands 2009.
2. ABARE: Australian Fisheries Statistics.
3. Clean Seas Tuna Ltd (Appendix 4D Statement – Half Year Report 2009). pp 24.
4. Tassal Group Ltd. 2009 Annual Report. pp 96.
5. FAO, Cultured Aquatic Species Information.
6. ACIAR, presentation by Iwan Sutanto, chairman of Shrimp Club Indonesia.

wild-stock-based grow-out industry using sea cages in Vietnam, and some parts of Indonesia, Malaysia, and Thailand (Williams, 2007). Viable markets for the production of tropical rock lobster as juveniles already exist, and whole-sale seafood markets, where depending on seasonality and market demands can fetch prices in excess of A$80 – 100/ kg for large (1kg +) live tropical rock lobster. Further collaborative work is planned for the development of sustainable cage culture technology and other approaches (e.g. pond and raceway culture) using wild-caught animals in Indonesia through an Australian Centre for International Agricultural Research (ACIAR) funded program (C. M. Jones, 2009, personal communication.).

Parallels between culture of tuna and lobsters: It is of considerable interest that substantial commercial development is now proceeding in the aquaculture of tuna, a species of iconic value and significant commercial challenges. The production of fingerlings from hatchery-held adult tuna reported (in press) by Kinki University of Japan for northern blue fin tuna and by *Clean Seas Tuna Ltd*, an Australian company for southern bluefin tuna, provides promise of substantial commercial success for the aquaculture of tuna in the next few years. The observation that tuna is an attractive aquaculture species is without challenge and enterprises have been able to attract substantial capital to proceed with commercialisation, like all industries whose ultimate success is dependent on management. This capital is an essential requirement for commercial production of any species. In order to understand relative comparisons with other aquaculture industries (Tables 4–6) a review of available information was extracted from a range of commercial sources to provide indicative species comparisons. These suggest that rates of return for

Table 5. Industry comparison*

	Tropical rock lobster *(Panulirus ornatus)*	Slipper lobster *(Thenus spp)*	Southern blue fin tuna *(Thunnus maccoyii)*
Wild Stocks Under Threat	☑	☑	☑
Eggs to Market Size (Adult)	☑	☑ 3 prototype systems – tank, cage, pond (further R&D)	☒
Commercial hatchery technology developed	☑ Proof of concept achieved (needs scale / consistency)	☑	☑* Proof of concept achieved (needs scale / consistency)
Nursery / early grow-out Phase	☑	☑ 3 prototype systems – tank, cage, pond	?
Grow-out – Full scale commercial	☑ Grow-out achieved from wild-caught puerulus / small juveniles in Vietnam industry	☒ Grow-out achieved under test conditions	☑ Grow-out achieved wild -caught fish >2 years old, not for hatchery sized juveniles
Strong market demand	☑ Primarily China - Expanding	☑ China (live), USA, Australia	☑ Japan - fluctuates

*. To the best of Lobster harvest knowledge based on information available at time of conference.

Table 6. Similar parallels can be drawn between aquaculture of tuna with tropical spiny lobsters

	Parallels between tuna and tropical spiny lobsters
1.	Both species, i.e. Southern blue fin tuna and TRL are iconic species and attract high values in the market place as they are both premium sea foods
2.	Commercial grow out technologies for southern blue fin tuna for 2 year old juvenile fish and older are well established as a major industry at Port Lincoln, Australia and elsewhere for blue fin tuna. Commercial grow-out technologies producing in excess of several thousand tonnes per year of TRL have been established in Vietnam and other areas of Asia. Both of these industries currently depend on wild sourced juveniles. In relation to TRL there already exists active trade in collection and cage grow-out of pueruli and juveniles to larger sizes for sale into the world lobster food market.
3.	Supplies of both lobster and blue fin tuna come from stocks that are either fully exploited or over exploited, with little opportunity to increase world supply except through aquaculture. In the case of lobster, wild stock fisheries may even be at long term risk from increasing ocean acidification as a result of higher fossil fuel consumption leading to increased atmospheric and ocean carbon dioxide concentrations. Increasing acidification of our oceans may impact on the survival of lobster phyllosoma especially for temperate lobster species where acidification through greater absorption of carbon dioxide is expected to be greater.
4.	Tuna and lobsters command significant seafood categories in the world trade with total lobster supplies comprising 220 000 tonnes.
5.	Tuna and TRL have greater value in the sashimi grade larger size categories, which is at 20 + kg size for tuna and 1 + kg size for lobster. The intermediate market for TRL of any size from puerulus and older is already established, although the same could be expected for tuna as commercial aquaculture continues to proceed.
6.	Tuna and TRL have, in similar ways, developed and proven their own pioneering technologies and have enormous potential for successful commercial aquaculture.

lobsters are attractive once commercialisation is achieved.

Conclusions

Considerable research to date supports the immediate potential for commercial production of slipper lobsters, noting that there appears to be little difference between *T. australiensis* (local australian species) and *T. orientalis* (local asian species). Desktop modeling and analysis for commercial aquaculture of slipper lobster points to the requirement for investment in Asia to gain a sufficiently attractive profit margin flowing from lower production and capital costs. Furthermore, tropical rock lobster aquaculture is expected to be extremely profitable and to be technically and commercially feasible within ~3 years from December, 2009. It is technically and economically feasible for tropical rock lobster aquaculture to occur in Australia or any other location in the world where the species is found naturally due to a high IRR. At research level, lobster harvest has developed technological and scientific outcomes that point to commercially feasible tropical rock lobster production. The challenge remains with technical refinement to increase consistency of hatchery production through metamorphosis to post-larvae and juvenile phases. This will be achieved through a focused research program to remove the larval-puerulus-juvenile metamorphosis *"bottleneck"*. This will include: tank designs specific to lobster larviculture, improved husbandry protocols, optimizing nutrition for late-stage larvae (>Stage IX), further pro-biotic development for larvae, development of formulated larval diets.

The leading principle in lobster harvest's path towards commercialisation has been to design research programs focused on commercial outcomes that were derived from bio-economic modeling. This has resulted in having the confidence to raise capital for commercial roll-out following the key assumptions in these bio-economic models having been achieved. Lobster harvest expects to progress with the build of a commercial *Thenus* hatchery under a joint-venture arrangement in SE Asia during the next 12 months. It is no longer a question as to whether commercial aquaculture of lobster will occur; it is clearly how soon, and slipper and tropical spiny lobsters will be the leading species.

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