Mud crab aquaculture in Australia and Southeast Asia

Proceedings of the ACIAR Crab Aquaculture Scoping Study and Workshop
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Preface

Mud crab aquaculture has been practised for many years in Southeast Asia, based primarily on capture and fattening of juvenile crabs from the wild. There is an unmet demand for mud crabs and this has led to over-exploitation in many areas. Difficulties with obtaining wild caught juveniles for farming operations, plus concerns of further over-exploitation, have led to major investment in research into hatchery techniques.

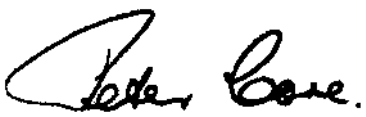
ACIAR began investigating mud crab aquaculture in 1992 with most investment being in hatchery technology. Following success of early research and the commencement of a project to assist dissemination of the technology ACIAR encouraged development of a project to develop cost-effective formulated diets to replace trash fish, as feeds and feeding were perceived as the next major bottleneck to mud crab aquaculture after commercial hatchery technology was developed and adopted.

To review mud crab aquaculture in Australia and Southeast Asia, ACIAR funded a scoping study, followed by a workshop to review the study and discuss status and problems in different regions of Australia and Southeast Asia.

The primary conclusion from the scoping study, verified by workshop discussion, was that the substantial crab farming operations which exist throughout Southeast Asia are still mainly based on wild caught crablets. Much of the workshop was devoted to determining the reasons for slow commercial uptake of hatchery technology.

The results of the study and the workshop presented in this report will allow more informed decisions to be made in the way ACIAR commits further funds to crab research.

This report is the latest publication in ACIAR's working paper series and is also available on ACIAR's website: www.aciar.gov.au.



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Director
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Acknowledgments

The scoping study and workshop were funded by ACIAR in connection with project no. FIS/1999/076 'Development of Leading Centres for mud crab aquaculture in Indonesia and Vietnam' and proposed project no. FIS/2000/065 'Mud crab aquaculture: improving grow-out nutrition'. The editors would like to thank Dr John Skerritt, Deputy Director, ACIAR R&D Programs, and Mr Barney Smith, ACIAR Fisheries Program Manager, for their continuing support and encouragement. We would also like to thank Dr Emilia Quinitio and Dr Ketut Sugama for travelling from the Philippines and Indonesia respectively at short notice; and for their excellent contribution to the workshop. Thankyou also to our hosts Dr Brian Paterson and Mr David Mann from Queensland Department of Primary Industries (QDPI), Bribie Island Aquaculture Research Centre, for making us so welcome. We are most grateful for assistance from Mr Pedro Bueno and Dr Michael Phillips of the Network of Aquatic Centers in the Asia Pacific (NACA) in seeking information on the status of mud crab aquaculture for the review. The enthusiastic participation of all delegates, including industry representatives, was greatly appreciated and contributed greatly to the success of the workshop. We would also like to thank Helena Heasman for organising the workshop and assistance with the preparation of these proceedings.

Glossary

ACIAR	Australian Centre for International Agricultural Research
ADC	apparent digestibility coefficients
BIARC	Bribie Island Aquaculture Research Centre, Australia
CIV	Collaborative Innovation Venture program (Queensland Government)
CW	carapace width
CFR&DC	Coastal Fisheries Research and Development Centre, Thailand
CAS	Coastal Aquaculture Station, Thailand
COMB	Center of Marine Biotechnology, University of Maryland, USA
FAO	Food and Agriculture Organisation
FCR	feed conversion ratio
FRDC	Fisheries Research and Development Corporation, Australia
ELISA	Enzyme-Linked Immunosorbent Assay
GCMA	Gold Coast Marine Aquaculture
GCMH	Gold Coast Marine Hatcheries
GRIM	Gondol Research Institute for Mariculture, Indonesia
HUFA	highly unsaturated fatty acids
JASFA	Japan Sea Farming Association
JCU	James Cook University
NACA	Network of Aquaculture Centres in the Asian Pacific
NFE	nitrogen free extract
OTC	oxytetracycline
PCR	polymerase chain reaction
QDPI	Queensland Department of Primary Industries, Australia
R&D	Research and Development
RIA No. 3	Research Institute of Aquaculture, No. 3, Vietnam
SBV	Scylla Bacilliform Virus
SEAFDEC	Southeast Asian Fisheries Development Center
UPV	University of the Philippines in the Visayas
VND	Vietnamese Dong (currency)
WESAMAR	Western Samar Agricultural Resources Development Programme

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1. Executive Summary and Recommendations

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Mud crab aquaculture has been practised for many years in Southeast Asia, based primarily on capture and fattening of juvenile crabs from the wild. There is an unmet demand for mud crabs and this has led to over-exploitation in many (but not all) areas. Difficulties with obtaining wild caught juveniles for farming operations, plus concerns of further over-exploitation, have led to major investment in research into hatchery techniques. Of the four species of mud crabs (*Scylla serrata, S. paramamosain, S. tranquebarica* and *S. olivacea*), hatchery technology is only being developed or researched for *S. serrata* and *S. paramamosain*.

ACIAR began investigating mud crab aquaculture in 1992 with most investment being in hatchery technology (FIS/92/17 Development of improved mud crab culture systems in the Philippines and Australia; FIS/1999/076 Development of Leading Centres for mud crab culture in Indonesia and Vietnam). Feeds and feeding were perceived as the next major bottleneck to mud crab aquaculture after commercial hatchery technology was developed and adopted. ACIAR encouraged development of a project to develop cost-effective formulated diets to replace 'trash fish'.

Unfortunately, despite indications of success at laboratory scale, large-scale commercial hatchery development for *Scylla serrata* has been very slow. In Australia and Southeast Asia only the Northern Territory Department of Primary Industries (NTDPI) hatchery has produced *S. serrata* with >10% survival of zoea to crablet stage 1 on a consistent basis. Vietnam has been successful in consistently producing *S. paramamosain* with >10% survival of zoea to crablet stage 1.

Concerns were expressed that further research to develop more cost-effective and sustainable feeds and feeding practices (as an alternative to the often unsustainable use of trash fish) might accelerate over-exploitation of wild crabs unless commercial hatcheries adopted hatchery technology. Consequently, the nutrition project was postponed until the situation could be thoroughly reviewed.

To review mud crab aquaculture in Australia and Southeast Asia, ACIAR funded a scoping study, followed by a workshop. The terms of reference were:

1. What is the current status of industry development and to what extent has mud crab hatchery technology been adopted?
2. What problems are being experienced with hatchery technology and what measures are being taken to overcome them?
3. What is the likelihood and time frame for large-scale hatchery production?
4. What feeds and feeding practices are currently being used; and are these feeding practices limiting industry development or economic viability?
5. What are the potential impacts of improving feeds and feeding practices including economic and environmental impacts (positive and negatives)?
6. What are the other constraints to successful crab grow-out and marketing?

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The scoping study was mainly a desktop review with interviews (by email, letter, telephone and in-person) completed with key people by consultant to ACIAR, Professor Don Fielder. The Network of Aquaculture Centres in the Asian Pacific (NACA) assisted by recommending key people and using their extensive network to seek information from people working on crabs. The workshop was held to review the scoping study and discuss status and problems in different regions of Australia and Southeast Asia. The focus was on mud crabs, but because of similarities information on swimmer crabs was also considered.

The primary conclusion from the scoping study, verified by workshop discussion, was that the substantial crab farming operations which exist throughout Southeast Asia are still mainly based on wild caught crablets. Much of the workshop was devoted to determining the reasons for slow commercial uptake of hatchery technology. The most encouraging results were reported in Vietnam where hatchery production of *S. paramamosain* has been consistently achieved with survival for Z1 to C1 of 10–15%. This has been adopted by private (commercial) hatcheries that now produce more than 1.5 million crablets per year with technology support provided by the Vietnam Ministry of Fisheries, Regional Institute of Aquaculture No. 3 (RIA No. 3).

Representatives from the NTDPI reported that consistent survival of >20% of zoea to crablet 1 was being achieved with *S. serrata* and that the technology was ready for commercialisation.

By contrast, the other participants stated that their hatchery protocols for *S. serrata* were not consistent enough for commercial exploitation. Many of the problems cited appeared to be site specific but water quality and bacterial infestation are still major stumbling blocks. All hatcheries still depend on antibiotics for reasonable success, although much less so in Vietnam. The need to use live feeds makes the process expensive and subject to total collapse due to crashes of feed cultures. Live feed can also act as a disease vector. Development of a suitable manufactured inert feed for hatchery stages would be a major breakthrough.

Nursery culture of crabs is most often undertaken in Southeast Asia in nets or cages. These appear to give good growth and survival of mud and blue swimmer crabs. In Australia and Philippines shallow ponds, sometimes with nets or other structures for shelter, have also successfully been used for nursery culture. Cannibalism and highly variable growth rates are the major problems with nursery culture of mud crabs (all species) and blue swimmer crabs. Research into substrate and shelters may help address this, and routine regular harvest of larger crabs is recommended, although both practices are labour intensive and expensive.

Grow-out feeds are mainly based on trash fish in Southeast Asia and pelleted, commercially available prawn feeds in Australia. Trash fish gives rapid growth rates but it can be expensive and in many areas it is not available at all times of the year. Reducing the reliance on use of trash fish as an aquafeed is a high priority research issue in Southeast Asia. Pelleted prawn diets, especially those available for *Penaeus japonicus*, the *kuruma* prawn, have given acceptable growth in Australia but are very expensive. Finding cheaper feeds would significantly affect cost of production. Preliminary results indicating that *S. serrata* can utilise carbohydrates and perform well on low protein diets augurs well for eventual development of a low-cost, high-performance pellet. The pellet size, shape, buoyancy and hardness were listed as important issues and prawn pellets are deficient especially with regard to size and shape. Participants at the workshop listed development of a formulated diet as the highest priority research issue for mud crab aquaculture.

Expansion of mud crab farming in most areas is still restrained by lack of large-scale adoption of hatchery technology (except in Vietnam where this occurs) and by availability of suitable, cost-effective feeds. In Vietnam, adoption of hatchery technology (in conjunction with nursery

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culture) should relieve pressure on wild collection as farmers prefer the reliability and increased performance achieved with hatchery seed. Other countries are likely to experience the same pattern of development as they adopt hatchery technology.

S. paramamosain appears to be an 'easier' species for hatchery culture than *S. serrata* although the recent results with NTDPI are encouraging.

The lack of cost-effective diets is limiting expansion of mud crab farming everywhere and may be limiting commercial efforts to adopt/develop hatchery technology.

Participants interviewed, and at the workshop, did not believe that developing a formulated diet would significantly affect exploitation of wild mud crabs as in most areas wild-caught juveniles were already fully or over-exploited and availability was already restricting culture.

Key recommendations from the workshop were:

Seed Production

- Transfer/evaluate methods used at RIA No. 3 and NTDPI to Bribie Island Aquaculture Research Centre (BIARC), Southeast Asian Fisheries Development Center (SEAFDEC) and Gondol Research Institute for Mariculture (GRIM) for *S. serrata* and at RIA No. 3 to Gondol for *S. paramamosain*.
- Improve/control water quality
- Reduce need for antibiotics during larval stages
- Develop alternatives to live feeds
- Improve larval health and increase survival to crablet stages.

Nursery Production

- Improve methods for reducing cannibalism in nursery stages (better shelters and continuous harvesting methods)
- Improve diets and feeding strategies.

Grow-out

- Develop formulated diets (ingredient selection, nutritional requirements, pellet size, shape and stability)
- Reduce cannibalism through improved shelters, continuous harvesting techniques and optimum feeding strategies.

Overall

The Workshop participants unanimously voted that diet development to reduce dependence on trash fish in Indonesia, the Philippines and Vietnam, and to allow grow-out in Australia, was the highest overall priority for mud crab aquaculture.

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2. Crab Aquaculture Scoping Study and Workshop

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Introduction

ACIAR first became involved with aquaculture of mud crabs through project FIS/92/17 'Development of improved mud crab culture systems in the Philippines and Australia'. This project was completed and reviewed in 1998. The review panel considered that 'the research teams had identified and developed remedies for several bottlenecks in seed stock production of mud crabs'. However some of the more exciting results came late in the project and needed verification. An 18-month extension was funded to: enable this verification; produce a practical handbook based on project results; and to facilitate the transfer of research to semi-commercial crab production facilities in the Philippines. The review panel also considered that much research was still required before large-scale mud crab farming should be considered. One of the projects suggested developing a cost-effective, formulated diet, which incorporates minimal fish/shellfish meal, as a requirement for commercial farming.

ACIAR has since funded a second crab program FIS/1999/076 'Development of Leading Centres for mud crab culture in Indonesia and Vietnam'. This project is yet to be completed.

Subsequent to FIS/1999/076 and in line with the review panel recommendations for FIS/92/17, ACIAR commissioned a proposal for funding a nutrition project aimed at developing an optimal grow-out crab feed. The initial proposal was deemed not to meet crab farmers needs for a practical feed and has subsequently been rewritten and resubmitted. This second proposal was paused following a study tour by the then director of ACIAR through Southeast Asia. Although he observed many crab farms apparently running effectively, he found no evidence that any were using hatchery-produced seed stock. They were still tied to crablets supplied from the wild. ACIAR had contributed substantial funding to develop effective hatchery protocols, which had apparently been developed but not adopted. He reasoned that if ACIAR went forward with the nutritional project and developed an affordable practical feed, but farmers persisted in using wild caught seed, the demand for wild-seed might become great enough to negatively influence wild crab populations. Consequently, this scoping study was commissioned, the results of which will allow more informed decisions to be made in the way ACIAR commits further funds to crab research.

Overall Objective and Specific Issues

To determine the status of and constraints to mud crab aquaculture and how ACIAR should support its development.

1. What is the current status of industry development and to what extent has mud crab hatchery technology been adopted?
2. What problems are being experienced with hatchery technology and what measures are being taken to overcome them?
3. What is the likelihood and time frame for large-scale hatchery production?

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4. What feeds and feeding practices are currently being used and are these feeding practices limiting industry development or economic viability?
5. What are the potential impacts of improving feeds and feeding practices including economic and environmental impacts (positive and negatives)?
6. What are the other constraints to successful crab grow-out and marketing?

Focus

The species focus is on mud crabs but developments with other species, especially swimmer crabs, need to be considered to look for opportunities for adopting successful technology to other species.

Country focus is Australia, Indonesia, the Philippines and Vietnam, but development in other Southeast Asian countries, e.g. Thailand may also be considered where relevant. Stakeholder focus is on small-scale farmers, except for Australia where all commercial developments are to be considered.

Known Current Crab R&D Projects Relevant to the Scoping Study

1. Fisheries Research and Development Corporation (FRDC) 2000/210 – 'Development of commercial production systems for mud crab (*Scylla serrata*) aquaculture in Australia.
Part 1 hatchery and nursery'.
Joint NTDPI and BIARC
Key personnel: Colin Shelley and Brian Paterson.
3-year project.

2. ACIAR 1999/076 – 'Development of leading centres for mud crab culture in Indonesia and Vietnam'.
BIARC plus collaborating overseas institutions.
Basically an extension/training project.
Initially 2-year project – now extended.

3. Queensland Government Collaborative Innovation Venture program (CIV) – 'Soft-shell Crab Development Venture'.
Aimed at developing and marketing soft-shell, blue swimmer crabs.
BIARC
Gold Coast Marine Aquaculture P/L
Watermark Seafoods P/L
Bundaberg Crabs P/L
Aquacrab Systems
2-year project.

4. Aquaculture Industry Development Initiative project – 'Moult synchrony in high value aquacultured crustacean species'.
Fundamental research on genes controlling moulting – results lead to new FRDC proposal for developing protocols controlling moulting in farmed crustaceans.
BIARC plus Austec P/L (associate of Aquacrab Systems P/L).
3-year project

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Known Recent Crab R&D Projects Prior to Scoping Study

1. ACIAR FIS/92/17 'Development of improved mud crab culture systems in the Philippines and Australia'.
BIARC
NTDPI
SEAFDEC
University of the Philippines in the Visayas (UPV)
3-year project.

2. FRDC 1998/333 'Husbandry of the blue swimmer crab in aquaculture'.
Based in South Australia Ocean Gold Investments
Key person: Martin Smallridge (Complete Marketing and Management)
1-year project.

Methods Used for Gathering Information

Contact addresses of key personnel concerned with crab farming Research and Development (R&D) were obtained initially from research workers known to be involved actively with the development of crab hatchery and grow-out protocols. Where possible, contacts were made by email or fax to provide written records of interactions. In some cases, commercial producers were only available by phone. In each case, contacts were invited to submit a concise description of their involvement (past, current, future) in crab aquaculture through a standard set of questions based on the scoping study guidelines.

Additional information was gained from Internet searches, one-on-one interviews and provision of printed material by ACIAR staff. (See Appendix 1 for a list of contacts).

Information Provided by Target Countries

Philippines

Overview

Production of mud crabs from brackish water ponds has risen steadily from 2,440 t in 1996 to 4,495 t in 2000. Coincidental with this rise, wild stocks appear to be declining due to unregulated and intensive collection. Regular training courses for hatchery technicians, aimed at stimulating hatchery production of mud crabs and reducing pressure on wild stocks, have been conducted by SEAFDEC since 1996.

Protocols

(a) Broodstock to spawning

Crabs with mature gonads are sourced from the wild and stocked in large tanks of running water. They are disinfected and optionally ablated. Tanks are provided with a sand bottom and shelters and crabs are fed fresh fish, green and brown mussels, marine polychaetes, and squid @ 10–15% BW/day.

(b) Larval Rearing

Zoea larvae are reared in 5–10 t tanks treated with oxytetracycline (OTC) and fungicide. Rotifers @ 10–15/ml are fed to Z1-Z4 (d1-d10). Artificial feed is fed @ 1–1.5 g/t/d from Z2 to

M1 (d4-d18). *Artemia* @ 0.5–3/ml are fed from Z2-C (d5-d21). *Nannochloropsis* @ 50,000 cells/ml is fed from Z1-M1 (d1-d19). Survival from Z1-M1 ranges from 1.5 to 8% whilst survival from M1-C1 can be as high as 70%. Overall survival from Z1-C1 is quite low i.e. >3% is considered a good result.

Z1 develop to M1 within 17d, M1-C1 within a further 7–8 d.

(c) Nursery

Megalopae are moved to 2 m^2 hapa nets sited in earthen ponds which allow greater surface area for gripping. Trash fish, mussels, *Acetes*, and adult *Artemia* are fed twice daily to satiation.

(d) Grow-out

Hatchery-reared juveniles are reared in ponds and pens with survival rates ranging from 45 to 70%. However crabs are farmed in several ways:

- Monoculture: Ponds are stocked @ 0.5–1.5/m^2 with crabs and fed 5–30 g/individuals unprocessed food depending on BW
- Polyculture: Ponds are stocked @ 1.0–1.5/m^2 with mud crabs and up to 0.3/m^2 milkfish or 1–2/m^2 shrimp
- Integrated mangrove; crab culture: Mangrove ponds are stocked @ 0.5–1.5/m^2 with crabs $\geqslant$ 4cm carapace width (CW)
- Fattening: Thin crabs are fattened in ponds, cages, or pens for 15–30 d.

Advantages of hatchery reared crabs

- Farmers are assured of rearing a known species
- Seed stock will be of uniform size
- Growth is comparable with wild caught seed stock
- Hatchery stock is available all year.

Constraints

- Egg loss in berried females due to bacterial/fungal infection and epibiotic infestation
- Non-fertilisation of eggs
- Collapse of natural food cultures
- Bacterial/fungal infection and ciliate infestation in larvae
- Incomplete moulting from Z5-M
- Cannibalism at all stages.

Reasons for slow adoption of mud crab hatchery technology:

- Large-scale production of natural foods must be maintained
- Compared with *P. monodon,* mud crabs require a longer culture period and operational costs are higher
- Survival from Z to C is very low.

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Financial Projections

HATCHERY

Two cost scenarios for hatchery production were outlined in the workshop presentation, both based on recognized and achievable assumptions.

(a) Brood stock to Megalopa – Return on investment approximately 36% with a payback period of 2.6 years if the hatchery is owner-operated, or 1.3 years if the hatchery is leased

(b) Integrated Hatchery-Nursery System – Return on investment approximately 56% with a payback period of 1.4 years if the hatchery is owner-operated, or 0.8 years if the hatchery is leased.

GROW-OUT

The workshop summary of profitability studies for grow-out cultures indicated that all culture systems are profitable with minimal risks, provided crabs are reared at low densities. Two independent financial feasibility studies for grow-out ventures were provided. The following are synopses of these studies. Both were published, but publication details were missing from the submission. They are difficult to reconcile since they are based on different assumptions. One was calculated on a per year basis and 0.5 hectare (ha) ponds, whilst the other was calculated on a per crop basis and 200 m^2 ponds.

(a) *Scylla serrata* – Brackish water ponds: 0.5 ha partitioned with nylon mesh; stocking density = 1/m^2; average size of seed stock = 13.7 g; average culture period = 130 days; average survival = 67%; average weight at harvest = 215 g; average yield @ 2 crops per year = 2.9 t/ha/y; average FCR = 5.2 : 1. N.B. trash fish was used as food – average application = 15.06 t/ha/y.

When the above results were used as assumptions to cost a 0.5 ha farm, the following projection was obtained. Required investment was estimated at P 194,450. Costs for first year operation = P 164,730. Returns = P 246,160 @ P 180/kg, giving a net profit of P 81,430 which equals a 49% return on investment and a payback period of 2.0 years.

(b) *Scylla serrata* – No details are given of the field trials upon which the working assumptions were derived. 'Giant' and 'Native' species are cited but not specified. Harvest results are based on a single crop but two crops are proposed per year. Brackish water ponds: 0.02 ha pens; stocking density = 2/m^2; average culture period = 4–5 months; average survival = 85%; average weight at harvest = 400 g (giant), 250 g (native); average yield = 136 kg = 13.6 t/ha/y (giant), and 85 kg = 8.5 t/ha/y (native). Food provided at 37.5 t/ha/y (giant), and 25.5 t/ha/y (native). Annual Net profit @ PA 310 per kg = P 65,945 (giant), and P 42,396 (native).

Projection (a), based on 0.5 ha ponds, indicates a yield of 14.5 g/m^2, whilst projection (b), based on 200 m^2 ponds, indicates a yield of 1,360 g/m^2 (giant) and 850 g/m^2 (native). The disparity is enormous and would lead to an annual net profit per hectare of P 81,430 in (a) compared with P 3,297,250 (giant) and P 2,119,800 (native) in (b). It is very difficult, if not impossible, to reconcile these results. However if the most conservative estimate is used, then the financial projection is favourable. The amount of trash fish used as food is enormous.

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Specific Comments

RESEARCH ORGANISATIONS

1. SEAFDEC (Quinitio) – Existing hatchery technology for mud crabs is claimed to be a commercially viable one. SEAFDEC runs regular, short courses on crab hatchery techniques. Despite this, few hatcheries are involved with producing crablets.

OTC and fungicides are both used during larval development.

Rearing tanks range from 5 to 10 t with survival of Z1 to megalopa = 3 to 10%; megalopa to juvenile = 30 to 60%. It is estimated that survival of megalopa to C1 is >50%, but such survival is never measured at this level.

Most crab farming still relies on wild caught seed, but Dr Quinitio did provide the names of several crab farmers who had used hatchery grown crablets. SEAFDEC has also used their own hatchery-reared crablets in grow-out trials yielding similar results as wild caught seed. Grow-out feed is usually trash fish.

2. UPV (Fortes) – Reliable hatchery technology for mud crab crablet production is in place and is used routinely by post-graduate students. UPV is currently publishing a guide to hatchery production. OTC is still used for one hour prior to placement of Z1 in rearing tanks. Currently they are developing methods for lessening stress at handling of Z1 to Z3 that are most prone to bacterial attack.

Survival of Z1 to megalopa = not more than 25%; megalopa to C1 is up to 80%; Hatch to C3 = 1 to 1.5%. The technology is claimed to be viable at this level.

Grow-out using hatchery reared seed is currently zero. Names were given of two local farms that had run grow-out trials using UPV seed, but trials were only done once.

3. EU-INCO Program (Le Vay) (Philippines and Vietnam) – No commercial crab hatcheries currently exist in Vietnam. Mud crab farming is well established but is based on wild caught seed. A few hatcheries exist in the Philippines that produce mud crab crablets occasionally. The protocols are not yet reliable enough to be viable – hatchery stock is still more expensive than wild caught stock.

4. Phillips blue swimmer hatchery (near Iloilo, Philippines) – Clive Keenan apparently developed this hatchery to a commercial stage, but the current status of this venture is not known.

Synopsis

SEAFDEC are confident enough about their hatchery technology to run courses for prospective farmers. OTC is still necessary and results are still not consistent. Little evidence exists that hatchery technology has been taken up by commercial hatcheries on a regular or large-scale basis.

Indonesia

Overview

Mud crab has been an important fishery since 1980, but production has fallen significantly during 1995 to 2001 – from 8756 t to 5322 t, and partitioned as 70% wild fishery and 30% aquaculture. Most of this production decrease can be attributed to overfishing, which in turn has stimulated crab farming and research into seed production and grow-out. Of the four mud crab species available, all aspects of crab farming have focused on *S. paramamosain* as it is considered easier to manage than *S. olivacea, S. tranquebarica* and *S. serrata*.

Protocols

(a) Broodstock – Spawning

Pairs of wild caught crabs (250–400 g) are maintained in bamboo cages, immersed in tanks of running water on sand floors. They are fed fresh squid or trash fish.

(b) Egg incubation – Hatching

Spawners carrying 1–3 million eggs are removed to 0.5 t tanks and treated with 30 ppm OTC. Newly hatched zoea larvae are removed to 1–5 t tanks and are treated with 7–8 ppm Prefuran.

(c) Larval Rearing

Z1-Z3 are fed rotifers @ 15–20/ml. Z3-Z5 are fed rotifers @ 10/ml and *Artemia* @ 0.5–1/ml. M1-C1 are fed 3 to 5 day old enriched *Artemia* @ 1–2 /ml and micro-diets. Bacterial infections are controlled with OTC or probiotics.

Survival from Z1 to M1 with no antibiotics is poor at 1.3 to 1.5% but is much better at 30% with OTC. Survival from M1 to C1 is very good at 70–80%.

Z1 develop to M1 within 12 to 17 days. M1 develop to C1 within a further 10 to 14 days.

(d) Grow-out

Crabs are grown in ponds either from juveniles to market size, or for fattening adult crabs/ production of gravid females.

(i) In a recent trial, juvenile crabs @ 15 g were stocked in a disused prawn pond at 1, 2, and 5/m^2 and fed trash fish, snails and clams @ 3% BW/day. After 3 months, survival was 80%, 45% and 32.9% and average weights were 146, 159 and 158 g, respectively.

(ii) In the fattening process, 25 crabs of equal size, weighing 150–250 g, are placed in a 2 m^3 bamboo cage, immersed in a running stream and fed trash fish, snails, clams @ 5 to 6% BW/day. Crabs are harvested after 3 to 5 weeks and some females will be gravid.

Constraints

(a) Hatchery: diseases, water quality management, quality management of natural feed, micro-diets, cannibalism during M1 to C1.

(b) Grow-out: seed supply, inadequate feed.

Planned research

(a) Environmentally friendly health management during hatchery phase

(b) Design of properly constructed, affordable hatcheries

(c) Research and development of artificial diets.

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Specific Comments

Research Organisations

1. Agency for Marine Affairs and Fisheries Research (Sugama) – Viable hatchery technology is available for mud crabs but has not been taken up by commercial hatcheries. Crab farming is well established but is based on wild caught seed. Antibiotics are still necessary. Rearing tanks between 1 and 5 t usually yield 30 to 60% survival to megalopa of which 14 to 32% may survive to C1.

2. Gondol Research Institute (Hanafi) – Viable hatchery technology is available but has not been taken up by commercial hatcheries and some farmers have made some enquiries, but as yet a price has not been determined. OTC is still necessary and survival figures are as for Sugama above. Currently, a grow-out trial is being run and growth after three months appears good.

3. BADC – Jepara (Djunaidah) – Hatchery production is still not consistent enough for commercial hatcheries even though the government has run extension programs to stimulate interest.
Crab farming is well established but is based on wild caught seed. BADC has also produced blue swimmers successfully from zoea to >100 g. In one hatchery trial, using four replicate 250 l tanks, survival was 3.3 to 7.3% from hatch to first crabs; and survival increased as number of *Artemia* nauplii per zoea larva increased. In a similar trial, using 4×6 t tanks, survival from Z1 to first crabs ranged from 5.4 to 12.6%. In a grow-out trial, using three ponds ranging from 800 to 1,000 m^2 and stocked with megalopae @ 15 to 19/m^2, the average weight per crab at harvest after 100 days ranged from 109 to120 g @ 2.6 to 3.4 m^2.

Synopsis

Hatchery technology is not yet consistent enough to be adopted seriously by the commercial sector. Well-established crab farming exists, but it is all based on wild caught seed. There is some interest and expertise in culture of blue swimmers.

Thailand

Overview

Repeated attempts to elicit specific information were unsuccessful. However a synopsis of crab based research being conducted in Thailand was provided by the Thailand Department of Fisheries.

Fifteen projects were listed for 2002 (11 mud crab projects, 2 blue crab projects, 2 *Sesarma* projects). Fifteen projects were listed for 2003 (10 mud crab projects, 1 blue crab project, 4 *Sesarma* projects). The scope of this ongoing research appears to be considerable and is being conducted at nine Research Institutes: Aquatic Animal Health Institute (1); Suratthani Coastal Fisheries Research and Development Centre (CFR&DC) (2); Ranong CFR&DC (5); Samutsakorn CFR&DC (6); Chanthaburi CFR&DC (11); Rayong Marine Fisheries R&D Center (2); Phang-Nga Marine Fisheries R&D Center (1); and Trang CFR&DC (2). Whilst the projects undertaken at Rayong Marine Fisheries R&D Center appear to be ecology/fisheries based, all others concern some aspect of crab culture. With 31 listed project leaders, the research input is obviously considerable and interest in development of crab farming must be quite serious (see Appendix 2).

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Australia

Overview

Some interest in commercial crab farming has developed in the Northern Territory and Queensland over the past two years. In the Northern Territory, a proposed mangrove pen mud crab operation with indigenous communities is at an advanced planning stage. In Queensland, interest has moved away from mud crabs to blue swimmer crabs, especially for soft-shell production with several automated shedding ventures either built or at the licensing stage. Whilst NTDPI appear to have developed a reliable hatchery protocol for mud crabs, QDPI protocols still produce inconsistent yields. Hatchery production of blue swimmer crabs has fewer problems and existing protocols can be relied upon to produce consistently high yields.

Protocols

Australian protocols are basically similar to those described previously for Indonesia and the Philippines. Both of those procedures were modified from BIARC procedures, but no one procedure has been equally successful at BIARC and NTDPI.

(a) Broodstock – spawning

Mature crabs are placed in 10–20 t communal tanks with shelters, sand bottoms and provided with high quality water. Yields are reliable enough for commercial production but the process is quite inefficient.

(b) Egg incubation – hatching

Egg bearing females are removed to small 100 L tanks provided with high quality water.

(c) Hatching

Females with eggs close to hatching are removed to 1 t tanks provided with high quality water.

(d) Larval culture

Harvested Z1 are removed to 4–10 t tanks provided with high quality water. Yields of mud crab megalopae are still unpredictable at BIARC but are said to be reliably reasonable at NTDPI.

(e) Nursery

Early C mud crabs generally spend some time in a nursery system.

(i) Short period: Tanks of >20 t or small ponds to 0.5 ha are used to house hapa nets within which crablets to 10–15 g are produced.

(ii) Long period: Earthen ponds stocked @ 10/m^2 produce 10–20 g crablets.

(f) Grow-out to large juveniles

Either earthen ponds to one hectare or cellular recirculation modules are used to produce crabs to 100 g, which are then used to produce shedders.

(g) Extended grow-out

Earthen ponds to one hectare are used to produce crabs >600 g from <1 g in 6 months.

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Constraints

(a) As a new industry, no tested business model exists which leads to perceived risks

(b) Competition for space/resources with prawn aquaculture

(c) Profitability – especially production costs and high labour input

(d) Feed availability – No custom grow-out feeds have been devised; and commonly used prawn feeds are either too expensive or are physically not suitable

(e) Mass mortality during hatchery stages remains a destabilising problem.

Specific Comments

RESEARCH ORGANISATIONS

NTDPI (Dr Colin Shelley) and QDPI-BIARC (Dr Clive Keenan, Mr David Mann, Dr Brian Paterson) have past and current research interests in mud crab culture and have largely been responsible for the current state of hatchery development through Southeast Asia. BIARC have become more focussed on the blue swimmer crab and soft-shell production over the past few years.

Both organisations have the ability to produce crablets and both have an interest in grow-out:

1. NTDPI (Shelley) – One tonne tanks are used in hatchery rearing. Much emphasis is placed upon keeping larvae suspended singly within the water column. Clumping and/or contact with biofilms lead to high mortality. Airlifts have been designed to provide gentle circulation that maintains larval suspension and also helps maintain a constant water temperature, which is also essential for high survival. OTC is used during the first three days during rotifer feeding.

When 30,000 Z1 are stocked, 12,000 megalopae (40% survival) are produced and from these 7,200 C1 (60% survival) result. The above yields are achieved consistently.

Absence of a commercial crab diet has been identified as a bottleneck in the process. This is being researched in a Master of Science (MSc.) project funded by ACIAR. Bacteriological problems have been identified; and remediation, using probiotics, is being addressed through a Doctor of Philosophy (PhD) program.

It is proposed that indigenous communities become involved in grow-out of mud crabs using mangrove-associated technology developed in Southeast Asia.

2. BIARC (Paterson) – Rearing tanks range from 0.5 to 1.3 t. OTC must still be used, but it is believed that a solution will soon be available.

When 50,000 Z1 are stocked in 0.5 t and 130,000 Z1 in 1.3 t tanks, yield is between 5–10% survival. That is, the yield of megalopae from 0.5 t tanks = 2,500 to 5,000; and the yield from 1.3 t tanks = 6.500 to 13,000. BIARC staff working with *S. paramamosain* in Vietnam managed 10% survival to C1/C2.

N.B. Technology still considered to be yielding inconsistent results.

BIARC uses the same technology to produce serial batches of blue swimmer crabs. These are subject to the same problems as mud crabs, but with generally better outcomes although percentage survival is still variable. Grow-out trials have been promising in their 0.016 ha sand-based, lined-ponds. For example, starting from 9 g individuals harvested at 8.2/m^2, the average weight is 42 g. In one carry through trial, 80 g individuals were achieved at 3–4/m^2. However it is considered that going beyond 50 g will not be feasible as size range and therefore cannibalism becomes problematic. Currently, *kuruma* prawn food is used, which appears to be satisfactory, but contains probably more protein than required.

3. James Cook University (Chaoshu Zeng) – The following research programs were outlined:

(a) Broodstock conditions and larval quality

A semi-lunar spawning rhythm (mostly during new and full moon) has been identified. Of 16 physical and biochemical parameters tested, only protein levels of newly hatched zoea larvae were positively correlated with viability. Between 85–93% of initial lipid, and between 35–50% of protein, originally in newly extruded eggs were used during incubation.

(b) Disease related larval mortality

Scylla Bacilliform Virus (SBV) has been isolated from wild populations and laboratory cultured larvae. Virulent strains of *Vibrio* have also been detected from larval cultures. Several potential probionts have been identified and tested with promising results.

(c) Development of artificial feeds for crab larvae

Research into developing a micro-bound artificial diet for all hatchery stages is well advanced.

(d) Ontogeny of larval mouthparts and digestive system

This study has been conducted using a novel method of processing larvae to improve visibility of mouthparts.

(e) Effect of background colour on larval survival and development

Larval survival increases progressively as the background is darkened from white to black.

(f) Combined effects of salinity and temperature on larval survival and development.

Survival and development was generally low at S15 and 35. At 30–34°C, larval tolerance to low salinities reduced. Early zoea larvae generally survive best at S20 to 25 and also tolerate a wider range of temperature and salinity conditions than later stage larvae.

(g) Substrates and shelters as refuge for early juvenile mud crabs

Early indications are that substrate types have little impact on cannibalism but shelters that provide refuge reduce cannibalism substantially.

Comment: The above projects appear to overlap similar programs either completed or currently being investigated at NTDPI and BIARC. However, discussions regarding collaboration are underway.

COMMERCIAL VENTURES

1. Seafarms – Cardwell (Mal Smith) – Basically a prawn farm. Seafarms has run one test pond culture of mud crabs. They had problems supplying food which may have explained what they considered a too slow a growth rate. They are no longer interested in pursuing mud crab farming in their open ponds, as it is far too labour intensive at harvest. Their belief is that high cost of Australian labour will prevent economic viability.

2. Gold Coast Marine Aquaculture P/L – S.E. Queensland (Noel Herbst) – Basically a prawn farm. GCMA has only been interested in blue swimmers for the soft-shell market. Acceptable hatchery runs can be produced. Until recently, grow-out in open ponds has not been satisfactory due to a high level of cannibalism, even though a purpose-built 600 m^2 pond was being used, containing shallow and deep regions plus moult shelters, as recommended by BIARC. They believe that they require 5/m^2 at harvest, and until the last harvest, the best result was 1/m^2. However, just prior to writing this report, a heartening 5/m^2 harvest was obtained. GCMA also cite high labour costs during handling and at harvest as deterrents for future operations.

This is the type of farm that will have to supply shedding operations with 25+ g stock. Even if GCMA could produce economic harvests, they could probably only produce one crop per year and shedders will require all-year stock. Prawn pellets are currently used as food – a different food may reduce cannibalism, but the farmers are not convinced that it will stop it significantly. At a CIV meeting on 15 February 2003, Noel Herbst indicated that he probably would not continue with the project, although the improved harvest recently may mean he will continue.

3. Tropical Mariculture P/L – Cairns (Quan) – Basically a prawn hatchery. This company advertises mud crab crablets on their web site. They have done three hatchery runs since May 2001 – each run yielded 30,000 to 50,000 crablets. Hatchery tanks range from 1 to 5 t. Survival of Z1 to C1 = 20%. The advertised price of CD10 = AU$200.00 + GST /1,000 ex Cairns hatchery, with a minimum order of 100,000 crablets.

It was stated that no real orders have been received as yet, but the names of five prawn farms were provided that had shown some interest. A minimum outlay of $20,000 is a significant deterrent for many small farms.

4. Watermark Seafoods P/L – Brisbane (Angus Cameron) – A purpose-built recirculation system has been built at Pinkenba based on a system developed in a partnership operation at BIARC. When fully operational it should be able to process 40,000 individuals at a time. This is a shedding operation and will concentrate on providing soft-shell blue swimmers for the soft-shell market. Mud crabs also for the soft-shell market can also be accommodated. In the first instance, seed stock will be produced at BIARC and maybe Gold Coast Marine Hatcheries (GCMH). There is potential significant difficulty here even though this venture is a small one. Without a guaranteed consistent supply of shedder stock, how can this operation be viable?

This venture is not yet in full production, but at 15 February 2003 a prototype system at BIARC has been working for some time and the factory at Pinkenba is complete and licensed.

5. Aquacrab Systems P/L – Bowen (Bill Painter) – A purpose built recirculation system has been designed for a site at Bowen. Once in production, it will aim at producing soft-shell mud crabs and blue swimmers for the soft-shell market. It is understood that a major part of the operation will be in harvesting cast skins for chitin production. This operation is yet to be built so is not in operation, but apparently all permits etc. have now been approved (27/6/03) and the proposed plan of action will now be put into place. The stated investment in this operation will be between $16–23 million. The principal of the company is Bill Painter who is an engineer.

The shedding plant will be high-tech with most, if not all procedures, automated. As the venture has only recently been licensed, start-up time is yet to be determined. This system will apparently use mud and blue swimmer crabs and will require 80,000 × 25+ g crabs every two weeks even in the first phase of operation. Many more will be required once in full production. As the nearest point of crablet production is Tropical Mariculture P/L in Cairns and nobody appears to be farming crabs, it is difficult to see how the supply of shedders can be supplied even partially in the near future.

6. Bundaberg Crabs P/L – Bundaberg – Plans are apparently paused.

7. Bluefin Seafoods – Hervey Bay (Ross Meaclem) – Primary interest is in sea slugs but apparently has intentions of branching into crabs.

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Synopsis

Workable hatchery technology is currently available for both crab types but requires OTC and is still inconsistent. To date, very little commercial activity has been stimulated but several new factory type ventures are projected to be running during 2003. Since no wild caught crablets are available, these ventures must rely on hatcheries, either their own or outside hatcheries such as Tropical Mariculture P/L. Aquacrab P/L in particular is projected to be a major player and will require large quantities of crablets on a year round basis. If successful, the new crab farm requirements could stimulate hatchery production of crabs and might also reduce some of the uncertainty in the existing prawn hatchery business.

The main problem will be providing shedding operations with sufficient stock, as it will have to be produced in ponds and this is currently not being done. In southeast Queensland, winter pond production will not be possible due to low water temperatures. This will probably be a problem even in northern Queensland. Blue crabs also require very careful handling as they need to be chilled immediately at harvest and cannot survive even short exposures to air. Transport of crabs to the shedders will be difficult and probably costly. I could not find any interest in grow-out of crabs for hard-shell marketing. Most interest appears to be in producing blue swimmers for marketing as soft-shell individuals at 50 g.

NTDPI is persisting with mud crabs and hopes to develop grow-out strategies with indigenous groups.

Vietnam

1. RIA No. 3 (Nguyen Co Thach) – Relatively consistent mud crab hatchery technology is available in the two government hatcheries, Research Institute for Aquaculture No. 3 (RIA No. 3), and Can Tho University. Survival of Z1 to C1 = 10 to 15%. Price of seed crabs CW 1.5–2.0 cm varies from AU12.5 to 44 cents per individual. It was implied that OTC is still required during the hatchery process.

Crab (*S. paramamosain* is the preferred species) farming is well established at approximately 1,000 ha based on wild caught seed, although hatcheries can currently provide 10–20% of this requirement. Crab farming has been combined successfully with prawn farming allowing one crop of each, per year. Conflicting estimates of yields per harvest were given in two separate communications but the interpretation of the information is: when young are grown to adults in extensive culture, yields are approximately 270 kg/ha/crop. However in intensive cultures, the yield is 1 to 3 crabs per m^2 of 10 g to 100 g in 5–6 months, which equates to 1 to 3 t/ha/crop. In fattening operations, 200 g crabs are raised to 400 g at 3 to 5 crabs/m^2 in 25 days. Trash fish are used as food but quality, availability and price all vary. The price per kilogram ranges from AU44c to $1.50 with a Food Conversion Ratio (FCR) of 3–5.

A list of crab farming areas was given without contact names as follows: RIA NO.3 has 3 centres – South Central (Khank Hoa Province), North Central (Nghe An Province), and Northern (Hai Phong Province). Each has the ability to produce up to one million crablets per year.

Thach appears to be very active in promoting crab farming and predicts 1.5 t/ha plus one crop of *P. monodon* each year for northern farms.

Outstanding problems in the crab farming industry were listed as: nutrition and development of a commercial feed; diseases and disease prevention; and development of viable hatchery technology.

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2. Can Tho University (Truong) – The two government institutions are currently able to produce mud crab crablets, but both are in pilot stages of production. However, it was forecast that with existing technology hatchery, production of crablets would become commercial within three years. Currently all crab farming is based on wild caught seed. Antibiotics are not used. Rearing containers range from 0.5 through 1.0 to 4.0 t. Maximum survival to date = 10 to 15% from hatch to C1 and on this basis each institute has produced 100 to 200,000 button sized crablets per year. In good batches, survival of Z1 to Z5 = 70 to 80%; Z1 to megalopa = 30 to 40%; Z1 to C1 = 10 to 15%. It was stated that the main causes for mortality at metamorphoses are: poor nutrition, especially in highly unsaturated fatty acids (HUFA) in live food; and cannibalism of megalopae and crabs.

Synopsis

Mud crab farming is well established but is based on wild caught seed. Hatchery technology is considered to be still at pilot production and commercial hatchery production is predicted to take another three years. Both research groups cited nutrition as a limiting problem in development of a viable hatchery technology. Cannibalism at megalopa and crab stages was also cited as a major problem. This is similar to blue swimmer grow-out trials at BIARC, where ponds are stocked with megalopae rather than lose a high percentage in hatchery moult to crab stage.

Japan

1. Japan Sea-Farming Association (Hamasaki) – No crab farming industry exists in Japan but *Portunus spp., Scylla,* and *Eriochier* have all been produced by local government hatcheries for restocking and stock enhancement. Antibiotics are still necessary but work is ongoing investigating possible use of probiotics to eliminate this need. Rearing tanks are often in 30 to 200 t range and survival from hatch to megalopa = ca. 30 to 40% and to C1 = 15 to 25%.

Malaysia

1. University Putra Malaysia (Kamarudin) – One joint government/private hatchery produces mud crab crablets in East Malaysia and supplies one farm for grow-out. One farm in West Malaysia is producing blue crabs from hatchery-reared seed. Antibiotics are not used in hatchery production. Rearing containers are 1 to 2 t and best production runs have yielded 2% survival of C1 from hatch. The most pressing problem currently is nutrition and development of a satisfactory commercial feed.

2. Sepang Today Aquaculture Center – Advertises courses in crab hatchery technology on the Internet.

South Africa

1. Rhodes University (Jerome Davis) – No mud crab hatchery activity exists in South or southern Africa. Attempts to produce hatchery reared mud crab crablets were deemed unsuccessful commercially as the technology was not sufficiently predictable to warrant further investment. Trials have been paused, but this does not rule out future attempts.

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USA

1. Center of Marine Biotechnology (COMB) – University of Maryland (Zohar) – Repeated attempts to make useful contact with Professor Zohar have failed, but COMB has posted a lot of information regarding their blue crab projects on the Internet. They have concentrated on hatchery production of crablets for restocking and stock enhancement of Chesapeake Bay populations. Success, at least at the level of BIARC, trials is indicated. This is a major research program supported by crab fishers as well as by government funding.

Scoping Study and Workshop Conclusions

1. What is the current status of industry development and to what extent has mud crab hatchery technology been adopted?

Australia

An adequately reliable hatchery technology for mud crabs is claimed for the NTDPI system, whereas it is still not predictable for the BIARC system.

Currently no mud crab farms exist although one prawn farm has trialled mud crabs on one occasion. This farm has no plans to proceed further. Two shedding ventures are in the pipeline for soft-shell production. One is built and licensed; the other is about to be licensed.

Only one commercial hatchery claims it can produce mud crab crablets but has not yet had orders. If mud crab grow-out ventures are to develop successfully in Australia, then they will probably happen in the Northern Territory – maybe in co-operation with indigenous communities.

It seems that mud crab hatchery production is still unpredictable, but that grow-out is probably possible with acceptable survival. The main problem seems to be at harvest where individuals have to be collected and tied, a process deemed too labour costly at this time.

Blue swimmer hatchery production is apparently much easier than it is for mud crabs – at least to megalopa. Ponds are stocked with megalopae as deaths, due to cannibalism and other reasons, are too high in the megalopa to C1 to C+ moults in hatcheries. Early pond grow-out is subject to small mortality but large growth differentials quickly develop and deaths due to cannibalism escalate to unacceptable levels. At least this has been the case in a 600 m^2 pond at GCMH. In 160 m^2 ponds at BIARC, cannibalism has not been such a crucial problem. Currently there are no hatcheries in business producing blue crab crablets – apart from BIARC. However, if demand developed, this could change quite radically and very quickly. The two shedding companies in the pipeline are based mostly on blue swimmers but they will require year round seed stock. At the moment there is no source for this stock. Winter crops will not be possible from ponds in southern Queensland, and even in northern areas, production will be interrupted by cold weather over winter.

The status of the industry is still only potential and is mostly focused on the soft-shell market, which is yet to be tested locally. Export contracts will probably not develop until a critical production mass is reached and that is years away.

Southeast Asia

Mud crab farming is well established throughout Southeast Asia and there is an apparent unmet market for mud crabs wherever crab farms exist. Viable mud crab hatchery technology has been achieved on a large scale in Vietnam for *Scylla paramamosain*. For *S. serrata*, while hatchery production has been achieved in the Philippines, Indonesia and Thailand, large-scale adoption by private farmers is yet to occur. The big picture status of crab farming in Asia was developed at the workshop. The following questions were addressed in particular:

What are the major restraints for seed production? Is there evidence that: (a) wild caught stock is diminishing; and (b) removal of seed stock has any negative influence on wild populations?

What are the major restraints for grow-out operations? This includes: what is availability of seed from the wild; would a reliable source of hatchery seed stimulate crab farming; would pelletised food be feasible economically for small crab farms; and is any use being made of disused prawn ponds as has been suggested in previous forums?

*Workshop outcomes:

1. (a) and (b): Yes – see Clive Keenan's workshop presentation (Section 6).

2. Hatchery reared seed is certainly preferable to wild caught crablets in that the farmers are assured of the species and the age of the crablets they stock. However, wild caught crablets are significantly larger than those obtained from hatcheries. Stocking mortalities are likely to be less and grow-out periods shorter. Provided wild caught crablets are available at reasonable cost, they will be used to stock crab farms. Development of grow-out practices using megalopae may well alter this approach considerably and it is likely that crab farming would be enhanced accordingly.

2. What problems are being experienced with hatchery technology and what measures are being taken to overcome them?

The main problems in *Scylla serrata* hatchery technology still seem to be bacterial/fungal losses during the zoea stages. Losses at metamorphosis are still quite large especially with blue crabs. Live foods are used exclusively in the hatchery stages, so nutritional problems are likely to be similar to those encountered during the early days of prawn farming. A project aimed at development of artificial food for hatchery production is currently underway at JCU.

All research institutes are working to improve hatchery hygiene. At present most apparently have to use OTC. Most research institutes seem to be working with probiotics to alleviate the problem. Losses due to cannibalism are minimised by stocking ponds with megalopae rather than crab stages. This of course also saves money for the hatcheries.

3. What is the likelihood and time frame for large-scale hatchery production?

Whether large-scale hatchery production of mud crabs eventuates in Australia depends on whether commercially viable crab farms can be developed. The one large prawn farm to trial mud crab grow-out has deemed it unprofitable. Soft-shell production is yet to be proven commercially; and mangrove grow-out as suggested by NTDPI, although viable in Southeast Asia, has not been tried in Australia. Only one hatchery claiming to be ready for mud crab production was found and it has yet to receive orders. Large-scale hatchery production of mud crab crablets appears to be a long way off in Australia.

Throughout Southeast Asia, mud crab farming is well established but is still mainly based on wild caught seed. With the notable exception of *S. paramamosain* in Vietnam, even production from research institutes seems still to be uncertain and there is little evidence that commercial hatcheries are producing significant numbers of crablets. Where wild caught seed is readily available, it is difficult to see this situation changing radically, at least in the short term. Those mud crab farms

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which are 'fattening operations' are less interested in stocking ponds with megalopae or C1. The shortage of wild crabs in many areas will, however, continue to stimulate hatchery production.

Hatchery production of blue swimmers in Australia will depend on whether the shedding operations develop into profitable ventures. These will have to be supplied by hatcheries and nursery operations, as they will require crabs at 25 g and over. The one prawn farm that has trialled blue swimmers has only recently managed to obtain a harvest yield indicative of commercial viability. Confirmation trials will not be possible until the spring of 2003. Results from BIARC trials seem to be more optimistic but it is too early to predict their results. Blue swimmers have also been trialled in several Southeast Asian countries with varying success. Internet reports and press releases from USA also indicate that hatchery production of blue crabs has been very successful, but the aim here is to produce crablets for restocking purposes.

4. What feeds and feeding practices are currently being used and are these practices limiting industry development or economic viability?

All crab hatcheries use live food to produce megalopae or early crab stages. Alga enhanced rotifers are followed with *Artemia*. Whilst the nutritional content of such feed can no doubt be enhanced (e.g. Truong suggested that HUFA deficiencies may exist), hatchery-feeding protocols appear to be at least adequate for viable hatchery production. However, in most cases antibiotics are still a necessary inclusion in the protocol. It is unlikely that nutrition is currently the primary factor preventing expansion of the crab hatchery sector.

Provision of feed to crabs in grow-out systems is a completely different scenario. In Australia, those ventures that have run grow-out trials have used commercially available prawn pellets e.g. *kuruma* pellets are used at BIARC. BIARC personnel have deemed growth on these pellets as good, but *kuruma* feed is expensive and they believe that it probably contains too high a level of protein. Problems other than nutritional ones are probably much more likely to be retarding expansion of crab farming in Australia.

Southeast Asian crab farmers either: farm their crabs extensively in which case supplementary food is not provided; or use trash fish, clams, farm waste or offal as feed. Such use may lead to ecological and fisheries problems and cost, and the availability of such foods is quite variable. However, collection and sale of trash fish is an established employment and income base, so providing that trash fish is available at a reasonable price it will be used. Development of a crab pellet is obviously desirable, but it is unlikely that its absence is currently a serious deterrent to expansion of crab farming in Southeast Asia.

5. What are the potential impacts of improving feeds and feeding practices including economic and environmental impacts (positives and negatives)?

Elimination of the need for antibiotics in hatchery production is not only desirable but in the long run it is probably essential for a sustainable crab hatchery industry. Probiotics are being investigated as one way in which antibiotic dependence can be reduced. Maybe these can be administered with the food organisms used as food by crab larvae. If nutritional deficiencies do exist in the commonly used food chain, as suggested by Truong, survival will be enhanced once such deficiencies are corrected.

The *kuruma* pellets used by Queensland crab farmers as feed in grow-out situations, whilst effective were developed specifically for *kuruma* prawns and are very expensive. The probable returns for aquacultured crabs may not warrant this expense. However, as with *kuruma* prawns, a custom-developed feed may be essential to maximise aquaculture crab production.

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In the Asian context, a commercial feed may not be affordable by small-scale farmers. On the other hand, the cost of clam meat will exceed the final return on a crab crop. Trash fish is not always available, such as during monsoon rains. It does not keep well even when refrigerated; and the cost of adequate refrigeration is usually beyond the consideration of small-scale farmers. Removal of large numbers of trash fish from natural populations may impact negatively on important food fisheries. If left uneaten, trash fish rapidly causes a downturn in water quality as will farm wastes and offal. A strong case can be made for development of a commercial pelletised food if it can be incorporated into the crab farm economy. A properly developed pelletised food, possibly with attractants that negate those of moulting crabs, should reduce losses through cannibalism.

6. What are the other constraints to successful crab grow-out and marketing?

In Australia, the few trials done on crab grow-out indicate that the following points are major constraints in the viable farming of crabs.

1. Whilst mud crabs can tolerate low levels of water quality, blue swimmers cannot, so special care has to be exercised in this area.
2. Mud crabs can live for long periods out of water provided they are kept cool. Blue swimmers die very quickly if exposed to air. This has major ramifications in their harvest. That is, they have to be placed into chilled water for any handling procedures.
3. In the American blue crab, it has been shown that adult crabs are major predators of juveniles. This is borne out in the few Australian grow-out trials that have been run to date. Aquacultured crustaceans are often subject to uneven growth and populations containing bolters and runts are common. Bolter blue swimmers apparently cause major losses once a size differential develops within the cultured population. Cull harvests are indicated but such harvests are labour intensive and in a large-scale grow-out they may not be practical.
4. It is likely that crab ponds will need to be purpose built to provide specially constructed shelter areas to minimise moult deaths. This could include shallow areas, and artificial shelters raised from the pond bottom etc. Such construction will obviously add to start-up costs and will inject an unknown labour cost for their maintenance. Prawn farmers, already licensed for coastal aquaculture, may not be willing to dedicate any of their ponds to such practices. New aquaculture licences for pond production are, to say the least, difficult to obtain and the feasibility of factory-type rearing systems is yet to be verified. The culture of mud crabs using the mangrove impoundment techniques developed in Southeast Asia require manipulation of natural mangrove stands which will certainly not help a licensing application.
5. A soft-shell crab market has never existed in Australia so that a local market will have to be developed. Indications are that farming of crabs for the hard shell market will not be able to produce crabs even near to the current legal size. The question of 'Will there be a market for smaller crabs?' remains.

Closing Comment

The primary reason for this study was to evaluate the need for development of a practical feed for crab aquaculture. Based on the information provided during the initial study, and complemented with further information obtained during the workshop, my perceptions follow:

1. All hatchery protocols rely on live foods as do prawn hatcheries after many years. I doubt that this will change in the near future. It is not known whether nutritional deficiencies exist in the

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current use of live feed, but at least one participant in this study provisionally identified HUFA deficiencies. Once deficiencies are identified, fortifying rotifers etc can presumably rectify most of them. Of more concern at this time is the injection of deleterious micro-organisms with the live feed.

Poor water quality is still a serious bottleneck in most hatcheries and much of this problem can be related directly to microbiological problems – some of which are associated with the live feed. I place solution of this problem at a higher priority than determination of ideal nutritional components in feed. Use of probiotics is a promising solution aimed at eliminating use of antibiotics. Development of probiotics is being researched in several R&D programs.

2. The situation with grow-out is somewhat different. In Southeast Asia, natural feed such as trash fish, molluscs, farm waste etc is almost universally used. Such practice is potentially bad ecologically and fish, molluscs etc are probably better utilised for human consumption. A manufactured practical feed should therefore be a better option. However one needs to look at this in context. The supply of trash fish and the other natural feed items constitutes a well established and far reaching industry, and the natural feeds are certainly much cheaper than the existing prawn feeds. For small farmers, artificial feed may not be affordable.

   In Australia, existing prawn feeds are being used in the few farming ventures now in operation. Nutritionally these appear to be adequate if not ideal. However the pellet sizes are generally too small for efficient uptake and much food appears to be wasted because the pellets are not bound sufficiently. One of the most pressing problems appears to be production of a different type of pellet, which the crabs can hold in their mouthparts, and manipulate without too much fragmentation, and therefore dissipation, into the surrounding water.

3. All participants at the workshop were convinced that lack of a custom produced crab pellet was a major constraint to the development of crab aquaculture.

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3. Development of Leading Centres for Mud Crab Aquaculture (FIS/1999/076)

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Introduction

The successful conclusion of the mud crab project (FIS/92/17) stimulated a great deal of activity in Australia and Southeast Asia. This ACIAR small project, the 'Leading Centres' project, was one of several projects that grew from that founding ACIAR study. At this workshop, we will also learn about other projects that built upon that earlier work, including the FRDC-funded work in Australia and SEAFDEC's work in the Philippines. It is worth noting that the earlier ACIAR work also spawned the current interest in blue swimmer crab aquaculture and production of soft-shelled crabs in Australia.

Mud crab farming is a significant business throughout Southeast Asia, though it is still based upon the harvesting of juvenile crabs or 'crablets' from the wild. The reliance upon this wild 'seed' poses serious questions about the long-term sustainability of the industry; and provides the fundamental justification for establishing commercial seed production in the countries concerned.

The premise behind the 'Leading Centres' project was that the two countries, Vietnam and Indonesia, showing rapidly developing interest in mud crab larviculture were funding their own national programs. The proposal addressed the need to get information to private sector hatcheries in these countries by assisting with the establishment of leading centres for mud-crab extension and training.

This presentation will cover:

- the background justification for the project
- the aims of the project and the components
- the schedule of activities to date and reasons behind delays
- other work and reporting remaining.

Justification

Mud crab farming in Southeast Asia has become so well established that demand for juvenile crabs or 'seed' has in some countries exceeded the capacity of the crab fishery. Hatchery production of seed will ensure the sustainability of the trade, but to bring this about, private sector hatcheries need information about mud crab larval rearing techniques. The 'Leading Centres' project focused upon the transfer of research results to industry to maximise the flow of benefits arising from the earlier mud crab aquaculture project (FIS/92/17).

The project concentrated upon two countries, Vietnam and Indonesia, that were likely to derive substantial benefit from extension of these technologies and which were already funding national mud crab aquaculture research.

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Aims and Components

The main objective was to develop 'Lead Centres for Crab Aquaculture' at key institutions undertaking nationally funded mud crab research programs in Vietnam and Indonesia. The leading centres were the Research Institute for Aquaculture No.3 (RIA No.3), Nha Trang, Vietnam; and the Gondol Research Institute for Mariculture (GRIM), Bali, Indonesia.

To achieve this aim, training and extension programs were to be developed within these countries to allow immediate dissemination of outcomes of the previous project; and to confer timely support for these nationally funded mud crab aquaculture programs.

A series of eight activities were planned to support the Leading Centres. These activities were arranged into three components:

- establish additional infrastructure for training and larval rearing trials
- run pilot extension workshops with institutional staff
- run locally organised workshops for hatchery operators.

The first two components involved exchanges of staff between BIARC and the institutions to develop the technical capacity, training manual and procedures to be used in the local extension program.

The planned outcomes of the leading centres project include:

- capacity building in training and extension methods
- development of Lead Centres for in-country extension
- improvements to commercial hatchery technology
- higher seed crab production
- mud crab hatchery manuals translated into Vietnamese and Indonesian.

The Schedule of Activities

Establishment and initial training

Australian and Vietnamese larval rearing methods were compared in Vietnam, giving project staff initial information on both methods prior to developing the hatchery manuals. Key staff from both Vietnam and Indonesia visited Australia for commercial-scale larval rearing trials at BIARC. Apart from training in hatchery techniques, drafting of the manual began and the extension workshops were planned.

Institutional and *industry extension workshops*

The institutional workshop in Vietnam was well received by those who participated. This activity was important because it enabled a comprehensive update on the status of mud crab larval rearing methods and other aspects of crab aquaculture to the personnel responsible for the wider extension of the information, beyond the context of the current project. At this institutional extension workshop, it was noted that while this project could initiate extension activities, a larger extension program was needed to accommodate the rapid development of the industry in the north of Vietnam. Four industry extension workshops have since been conducted. RIA No.3 is also helping to establish two seed production centres in the north, with considerable support from the Vietnamese Government.

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Changes in project leadership in Australia and Indonesia delayed the initial training activity at GRIM, however this was conducted successfully in August 2002 and the follow up workshop, a combined institutional/industry extension workshop was held in March this year. Crablets produced at GRIM are being trialled by one of the workshop participants.

The Work Remaining

With all the primary extension activities of the project concluded, the experience gained during the project is in the process of being compiled into a draft international mud crab hatchery manual. The manual will cover seed production of two species, *Scylla serrata* and *S. paramamosain*. The final report will include, apart from reports of all the activities in the project, the final version of the manual.

Conclusion

Extension of information about hatchery production of mud crab seed continues to be important in order to establish a sustainable supply of seed to crab farms. This project addressed that need by creating centres for training and extension in two countries best placed to make maximum use of the benefits of the previous ACIAR project.

The workshop program has now finished and Vietnam with assistance from its leading centre, RIA No.3, is constructing crab hatcheries to meet the demand for seed, particularly in the north. While the pressure to expand seed production appears less intense in Indonesia, GRIM has begun supplying seed to farmers and we await further developments there with interest.

As David Mann will note later, commercial hatcheries in Australia have also trialled batches of mud crabs and blue swimmer crabs and it will be interesting to learn what stage other countries are at in this respect. Of course, this is just the beginning. Addressing the question of commercial seed crabs then naturally leads on to questions about whether there are better ways to raise and feed the crabs, which this workshop will have an opportunity to address.

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4. Development of Commercial Production Systems for Mud Crab Aquaculture in Australia: Part 1 Hatchery and Nursery

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Abstract

The Fisheries Research and Development Corporation (FRDC) funded the commercialisation of mud crab aquaculture production systems for a three-year period, the practical component of which will be completed by the end of 2003. It is focused on developing hatchery and nursery technology for the commercial sector. The partners in this project are the Darwin Aquaculture Centre (Department of Business, Industry and Resource Development), the Bribie Island Aquaculture Research Centre (Queensland Department of Primary Industries), Seafarm Pty Ltd, and McRobert Aquaculture Systems, with support from the Australian supplier of Aquamats®, Proaqua.

The development of a larval culture system has focused on water quality, bacteriology and to a lesser extent feeds.

Water Quality

The effect of a range of water quality parameters on mud crab larval culture has been examined in a multi-variate format. In summary, it has been established that the following factors enhance mud crab larval survival:

- water settled for at least 4 days
- foam fractionation
- surface skimming
- constant temperature
- maintain larvae in suspension.

High survival rates (averaging over 40% from z1-megalopa) have been obtained with both batch and flow-through water systems. Whilst it had been considered that McRobert's dual tank system might be advantageous in controlling biofilm in larval production, no significant difference was found when compared to larval production in standard fibreglass tanks.

Bacteriology

It has been considered for some time that the bacteriology of mud crab larval production systems is very important. The biofilm on tanks had previously been implicated in mortalities in small-scale culture. In this project, the bacteriology of inputs (feeds), surfaces and water were sampled to gain a better understanding of the bacteriology of such systems.

Virulent bacteria linked to larval mortality have been isolated from rotifer cultures in particular. The effect of rotifers has been minimised by restricting their use to the first four days of larval culture. Virulence testing of different bacterial isolates has identified several pathogenic strains. In addition, at least one *Vibrio* spp. was identified as a potential probiotic. Its use has caused the suppression of some pathogenic bacteria in larval culture systems.

Oxytetracycline (OTC) has been used as a research tool to better understand the bacteriology of mud crab larval systems. Whilst it was initially used throughout some trials (at 50 ppm), its use has now been restricted to the first four days of culture only. Total elimination of the need for OTC is a goal of the project.

Megalopa – crablet

Several trials examining the settlement of crablets from the megalopa stage examined different settlement substrates (aquamats, shade cloth, plastic mesh) and bare fibreglass tanks. The bare tanks had survival as high as any other substrate. In a trial to examine the density of settlement that could be achieved, we examined 1000–8000 megalopae per m^2 and found that settlement was best at 1000–2000 megalopae per m^2 (35–45% survival).

Crablet nursery work

Various shelters including aquamats were investigated for their ability to improve crablet survival. Aquamats in tanks was shown to increase survival with 35% survival being achieved to C5 when stocked at $300/m^2$. A specific growth rate of 21% per day was achieved. A recent trial looking at variation in growth in juveniles (C2–C5) at various temperatures and salinities demonstrated that best growth occurred at approximately 31°C and salinities of 20–40 ppt supported good growth.

Students and their work

The crab project at the Darwin Aquaculture Centre has supported three students. Luke Neil from Curtin University undertook an Honours project on the effect of ammonia on mud crab larval growth and survival. He found that ammonia at levels experienced in commercial culture systems would have no deleterious effect on the growth or survival of larvae.

Maurizio Pizzutto is studying the bacteriology of mud crab larval systems for a PhD. He has identified changes in the bacteriology of systems maintained under a variety of regimes and tested the virulence of strains isolated. He has also found and utilised successfully a probiotic.

Tuan Vu has commenced work on development of a commercial feed for mud crabs for a Masters degree. He will investigate the digestibility coefficients of a number of potential nutrient sources. He will also examine the optimum protein level and determine whether α-cellulose can reduce the optimum protein requirements of mud crabs.

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5. Status of Crab Seed Production and Grow-out in Queensland

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Commercial Activity

Commercial activity in crab farming increased in Queensland over the last two years. This activity includes two species of portunid crabs: the mud crab, *Scylla serrata;* and the blue swimmer crab, *Portunus pelagicus*. There are currently six companies pursuing some or all of the crab aquaculture production cycle, covering hatchery seed production, grow-out and soft-shell production. There is now one prawn hatchery that has developed mud crab larval rearing to the point where they are confident to accept orders for small crablets. There is also another prawn hatchery that has been successful in mass-producing blue swimmer post-larvae for commercial grow-out trials. There is currently little activity in mud crab grow-out, despite pilot trials being completed although production is planned to come on line within the next 12 months.

One of the biggest developments is the commencement of soft-shell crab production. This has occurred as part of the state government sponsored Collaborative Innovation Venture (CIV) project run by BIARC and a number of commercial partners. Currently, one company has produced soft-shell blue swimmer crabs in pilot facilities for sale to restaurants. Another has completed construction of a purpose-built, automated shedding facility. A large-scale mud crab production facility, using automation for some production steps, is also in the latter stages of development.

BIARC continues to be closely linked with industry through CIV and Fisheries Research and Development Corporation (FRDC) project linkages. BIARC have supplied commercial operators with significant quantities of seed and larger stock for further culture but have not undertaken any commercial production.

Summary of crab production cycle

A summary of the crab production cycle from broodstock to harvestable product is outlined in Figure 1. The reference to high, good or moderate water quality is a relative term to indicate the more critical requirements of some production steps. Status of each step refers to the current level of success achieved relative to that which is desirable for commercial production in Australia. Note that there is some variability in the duration of the nursery and grow-out cycles depending on the size of crab that is most suitable for the next step in the cycle. This production cycle is relevant to both mud and blue swimmer crabs. The larval culture step for blue swimmer crabs has achieved a status suitable for broad commercial application, but mud crab larvae culture success is not as consistent and therefore has a lower reliability and efficiency rating.

The practice at BIARC has been to stock grow-out ponds with blue swimmer crab megalopae transferred straight from the hatchery. This has proved successful under our conditions. A nursery step between hatchery and grow-out is retained for mud crabs due to the typically experienced unreliability of metamorphosis from megalopa to crablet.

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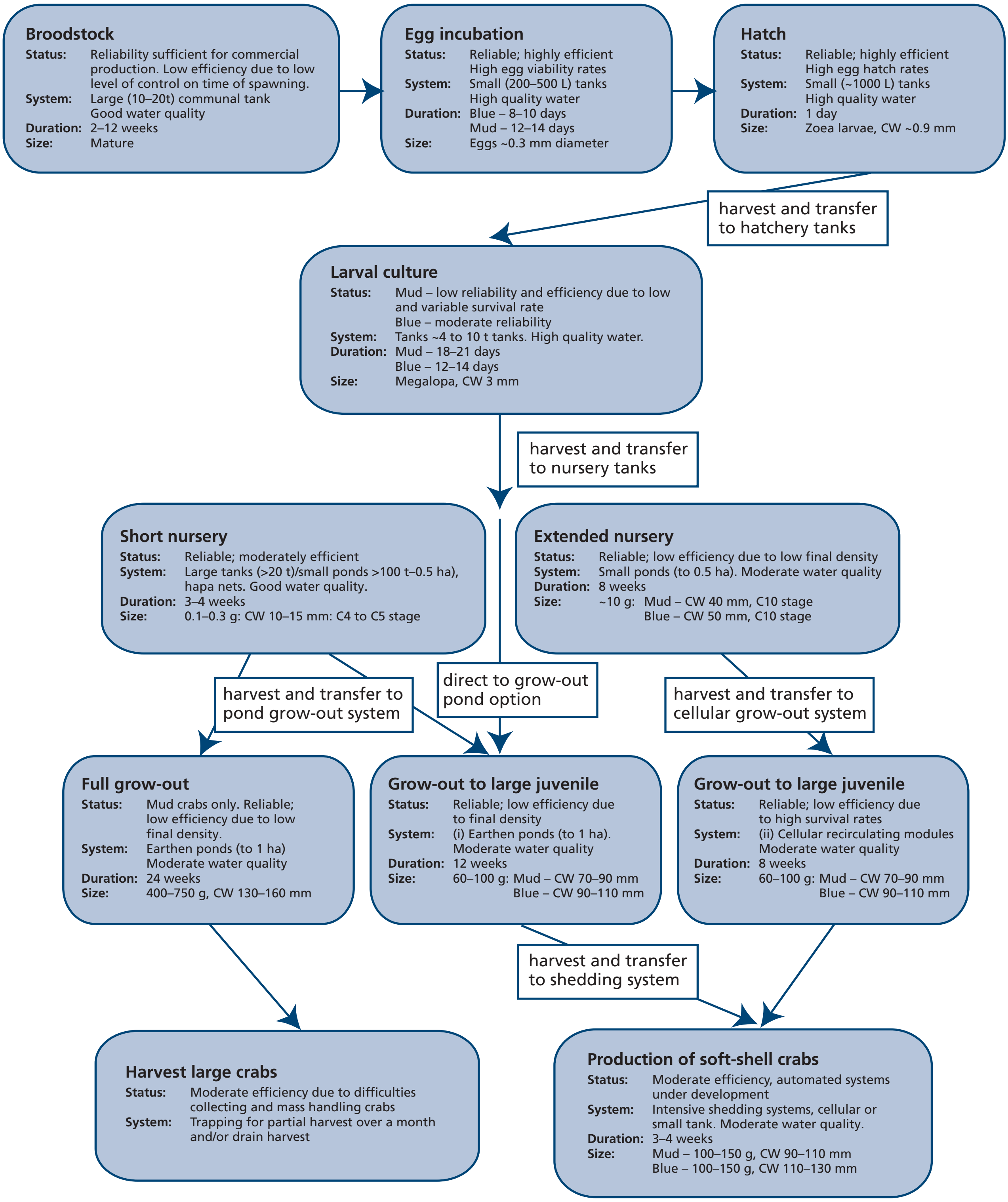

Figure 1: Production cycle for mud crabs and sand crabs in Queensland, Australia

Status refers to the current level of success achieved relative to that which is desired for commercial production in Australia. High, good or moderate water quality are relative terms to indicate the more critical requirements of some production steps and is a guide to siting of facilities used for the different production steps.
CW = carapace width: "Mud" and "Blue" refer to mud crab (*S. serrata*) and blue swimmer crab (*P. pelagicus*) respectively.

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Industry development issues for crab aquaculture

Some of the main issues currently influencing development and growth of a crab aquaculture industry in Queensland include:

- new industry, not well tested
- perceived risk, uncertainties in business model
- competition for space/resources with prawn aquaculture in hatchery and pond use
- comparative profitability/attractiveness (particularly to prawn aquaculture)
- production costs are uncertain
- labour requirement perceived to be high, particularly harvest and handling
- potential for automation of production steps, however capital investment is high
- seed supply uncertain in terms of quantity/reliability of supply (particularly for mud crabs)
- feed availability
- crab grow-out diets needed at acceptable costs.

The experience base for crab aquaculture in Australia is small with most activity confined to R&D institutions until recently. Numerous examples of successful approaches to mud crab aquaculture can be drawn from throughout Southeast Asia. However differences in government policy and economic conditions mean that Australia is taking a different approach to crab aquaculture industry development. It requires more technology and therefore further R&D.

Current R&D themes

The industry development issues listed above can be summarised into two main themes:

1. Increase grow-out productivity[a] and lower inputs[b]
   a. number of units produced per area; income produced per area and value
   b. cost of production.

Improving the productivity of grow-out systems and lowering the cost of production will make the industry more profitable and therefore more attractive to investors. The level of pond productivity is still considered too low for commercial operators, particularly in comparison with other potential uses of viable marine farming areas, such as prawn aquaculture. A pilot commercial mud crab grow-out trial in North Queensland grew crabs to 650 g at a final density of approximately one crab per m^2. Blue swimmer crabs have been harvested at a final harvest density of 1.6 to 4 per m^2, depending on the final size in the range 50 to 150 g.

2. Increase seed supply productivity and reliability in both hatchery and nursery systems

Grow-out operations need a reliable source of seed that can be delivered at the required quantity and time to make the most of the growing season. Seed production systems will typically be a two-step process of hatchery larval culture and nursery systems for culture of post-larvae to crablet stage for transport and stocking into grow-out systems. While the seed supply issue requires improvement for both mud and blue swimmer crab production, it is most critical for the mud crab industry.

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The following topics are currently the subject of R&D activity or projects under development in Queensland and that address aspects of the two main industry R&D themes.

1. Increase grow-out productivity and lower inputs

   - Cannibalism

     Cannibalism is the greatest constraint to productivity in all the communal growing systems. BIARC and commercial operators are addressing this issue. This has primarily included investigation of various habitat systems incorporated into the pond design to provide shelter areas for moulting crabs and to reduce the incidence of crab interaction. BIARC has also conducted some detailed investigations into the behaviour of crabs to gain further understanding that will lead to implementation of management procedures to mitigate the effects of cannibalism. It is apparent that production has been enhanced through the application of additional habitat to ponds however further improvement is still required.

   - Intensive cellular systems

     A method of increasing the final numbers of crabs retrieved is to harvest them at an earlier stage, as cannibalism is continuous throughout the nursery and grow-out cycles. While still in their infancy, recirculating cellular systems have been designed to stop cannibalism while holding large crabs at high densities under controlled conditions. The crabs are therefore protected at a time when their individual value to the farmer has become high and trials have shown that losses due to mortality are very low in these systems. Such growing/finishing systems are relatively complex and labour intensive unless automation is employed. A large commercial system is to be commissioned in Queensland in the near future.

     Labour is a significant component of production costs. The cellular systems used for shedding or grow-out utilise a high level of automation to reduce the requirement for labour.

   - Crab diets

     Apart from implementation of best practice culture techniques, improving the growth rate of crabs in culture is an area that has received relatively little investigation. The need for development of least cost, high performing diets for crabs is currently the subject of an ACIAR project proposal developed by Queensland University of Technology and BIARC.

     Feed forms a dominant proportion of the cost of production, but this can be minimised through the efficient application and the use of high performance, least cost diets. To date there has been little attention to this aspect of production, but some improvements have been made through reduction of over-feeding.

   - Selection program

     Under normal grow-out conditions a wide range of sizes occurs. This indicates a great potential for selection of genetic strains that perform best in aquaculture conditions. BIARC is currently developing a selection program for enhancement of growth rate and survival under communal growing conditions.

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- Markets/products

  The standard Australian mud crab product is a large (> 700 g) live, hard-shell crab and in the open market is worth approximately AU$10 to AU$18 per kg. Cultured crab has the opportunity to take advantage of markets for other crab products. One of the main products currently being pursued commercially is soft-shell crab. Soft-shell crabs are becoming popular worldwide and have a high value, AU$30 to AU$50 per kg. To date, there has been a small amount of aquacultured soft-shell blue swimmer crab sold to restaurants. The amount is expected to increase rapidly over the next year. BIARC has been conducting research into moulting and its control in aquaculture systems, aiming to greatly enhance the efficiency of the soft-shell industry.

- Chitin extraction

  Crab shell, a potential by-product of crab culture, has a high chitin content and there has been interest in this resource to form a valuable associated industry. For crab shell to form the basis of a local chitin extraction industry, crab aquaculture will need to first reach a high level of production in order to provide the critical mass of raw shell.

2. Increase seed supply productivity and reliability

   In Queensland there are now commercial hatcheries involved in seed production of both mud and blue swimmer crabs. BIARC is conducting small-scale production of both species. However, the seed production cycle requires further improvement to become a reliable and sustainable supply to grow-out operations. For mud crabs in particular, BIARC, as part of a FRDC project, has been addressing the issue of frequent mass mortality of larvae during the hatchery phase. Other R&D activities have been directed at commercialisation of the hatchery and nursery systems for both mud and blue swimmer crabs, as part of FRDC and CIV projects respectively.

   - Larval mortality

     Mass mortality of mud crab larvae during the two-to-three week hatchery cycle from zoea1 to megalopa stage has a long history. However, there is still only a basic understanding of the phenomenon. It is clear that bacteria are strongly implicated in larval mortality as shown by improvements achieved through application of antibiotics to cultures. This line of research has led to the common practice of using antibiotics during the hatchery phase to improve the reliability of culture success. In general, various groups conducting mud crab larvae culture agree that routine application of antibiotics to cultures is not desirable. However it is recognised as the only way, using current technology, that commercial production can be viable. Recently BIARC has been achieving a hatchery production level of 7.5 to 10 megalopae per litre, a level sufficient for commercial production. However subsequent megalopa viability can be as low as 10%.

     Blue swimmer crab larvae culture is not affected as much by unexplained mass mortality as mud crab larvae, so production is more consistent. It has been observed at BIARC however that a similar phenomenon can still occur.

     Research addressing the mortality issue is continuing within the FRDC project, particularly on the influence of bacteria on crab larvae and bacteriological control. This work is occurring at BIARC through basic bacteriological monitoring and control techniques. At the Northern Territory Darwin Aquaculture Centre, it is receiving

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rigorous examination within a PhD study. The objective is to eliminate the need for prophylactic use of antibiotics. Improvements to culture management and application of probiotic strains of bacteria have not yet been successful in achieving this objective.

Future seed production R&D direction

The central question still remains: How is crab larval health being compromised? Bacteriological studies still underway have determined the presence of pathogens but the mechanisms remain obscure, particularly as histological examination of moribund larvae does not reveal evidence of significant tissue or organ disruption. BIARC proposes that an additional approach to the mortality issue is required, one that will seek to answer the question: What is occurring within the larvae? To date larval survival has been used as the measure of the benefit or otherwise of changing environmental or nutritional variables.

Bacteriological monitoring of the culture has provided basic abundance data for bacterial groups but without knowing the significance of the findings. The proposed new approach will utilise what is now known about the influence of these variables and bacteriology but utilise sensitive tools to quantify physiological changes within the larvae involved with key metabolic pathways. This approach will greatly enhance the likelihood of achieving practical outcomes. A similar approach has been applied successfully to marine finfish larviculture, for example the sea bass (*Dicentrarchus labrax*), sea bream (*Sparus aurata*) and the (difficult to rear) turbot (*Scophthalmus maximus*). Investigation of a wide range of metabolic processes in the larvae of these species provided the detailed biological information used to improve hatchery survival rates and robustness of the larvae.

BIARC has been working towards this new direction, starting with the addition of a new larval biologist to the group to assist particularly with the laboratory analysis of larvae. Funding is still to be sourced for the proposed study.

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6. World Status of Portunid Aquaculture and Fisheries

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Summary

Fisheries exploitation and aquaculture production of the world's portunid crabs has increased seven fold over the past thirty years. The Food and Agriculture Organisation's (FAO's) latest data (2001) show that in many countries in the Asian region production has risen rapidly, while in some developed and exploited fisheries (USA, Taiwan) there has been a gradual decline. [FAO define aquaculture as farming where "Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated."]

This decline from over-exploitation is starting to also have an impact in several Asian countries, more so for the mud crab (genus *Scylla*) than the blue-swimmer crab (genus *Portunus*). Exploitation of the blue-swimmer crab began in 1989 on an international commercial scale in the Philippines and has rapidly spread to other countries (Indonesia, Thailand, Malaysia, and most recently India).

Market driving forces

There are two very different types of crab markets. There is a strong traditional local market for mud crabs based on their ability to stay alive out of water for 4–5 days (under optimum conditions), which has also enabled their shipment to distant markets. This market is diversified and there are distinct size and sex classes attracting widely different prices. Many larger sized mud crabs brought on the local market end up in the larger cities or are exported to major markets in Singapore, Hong Kong, Taipei and Malaysia. The high price for ovigerous female crabs, as compared to immature females and small male crabs, in countries like Malaysia, Singapore, Thailand, the Philippines and Indonesia, is of serious concern due to its implications for recruitment to natural populations. Large male crabs, >600 g, exported from Australia also command a premium price in these markets as most crabs traded are smaller than this.

Since the early 1990s a new market has emerged for blue-swimmer crabs, based on training in capture methods, the supply of ice to outlying regions and better quality control. This market is size class differentiated, with slightly higher prices for larger sizes. Crabs are cooked under controlled conditions and either the crabs are sold onto the local market or the meat is picked and shipped on ice to packaging plants for export. In 2000, I estimate that the total Asian production for the USA crabmeat market was slightly over 13 million pounds, based on a fishery of approximately 26,000 tonnes. Depending on the country, this represents between 10% and 50% of the country's total catch.

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Status of industry (excluding Southeast Asia)

Japan

The Japan Sea Farming Association (JASFA) from April 1999 to March 2000 produced 51,356,000 and released 34,225,000 *P. trituberculatus* crablets. Also crablets of several *Scylla* species are being produced, with over one million *S. serrata* released last year by Yaeyama Station. Large-scale production of *S. serrata* crablets is still under research.

China

Production of Chinese *P. trituberculatus* (Gazami crab) has rapidly increased with annual production at over 330,000 tonnes in 2000 and 2001 (FAO). No aquaculture production of *P. trituberculatus* has been reported to date and there are no data available about the level of production of *Scylla* in the south of the country.

USA

Dr Yonathon Zohar and the Blue Crab Advanced Research Consortium partners' proposal, 'The Blue Crab, *Callinectes sapidus*: An integrated Research Program of Basic Biology, Hatchery Technologies and the Potential for Replenishing Stocks' was awarded US$1,425,000 by the NOAA-Chesapeake Bay Office, COMB (2003).

India

Waterbase Ltd, India's largest supplier of aquaculture prawns "has established a complete mud crab hatchery facility and has dedicated it with adequate manpower. All related activities are well in progress."

Australia

There are several Australian companies involved in developing commercial scale crab culture: blue-swimmer crabs for soft-shell production; and production systems for both hard- and soft-shell mud crabs. In Queensland, there are six operations, three researching blue-swimmers and three working with mud crabs. I am not sure of the current situation in other states, but there has been commercial interest in South Australia, the Northern Territory and Western Australia.

Predictions about growth and opportunity

Portunid crab aquaculture has only just started. With increased demand and new products becoming available, there will be steadily increasing pressure on existing fisheries stocks, which in some regions are not yet exploited. In exploited regions, particularly Southeast Asian countries, aquaculture will forge ahead. Another area that will also be seriously examined is restocking of depleted fisheries. If proven successful in the Chesapeake Bay, other regions will follow their example. Recently, a Norwegian law on stock enhancement and sea ranching was passed in early 2001 – in principle it states, "Those who sow also have the right to harvest." This may spread to other fisheries if proven to be useful.

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Research problems

Basic biology

Surprisingly, there is very little information readily available on the basic biology of the various aquacultured portunid crab species. Information still needing to be collected includes: growth and survival at different salinities; oxygen tolerance limits; temperature tolerance limits for normal growth, etc.

Feed

There has been some work done on the nutritional requirements of mud crabs, but much more needs to be done, particularly in the area of protein substitution and alternatives for fishmeal. With the omnivorous nature of a crab's diet, it should not be too difficult to find suitable substitutes.

Hematodinium

Little is known about the potential for disease problems in aquacultured crab species. *Hematodinium* is a commonly occurring parasitic dinoflagellate in blue-swimmer crabs and also mud crabs. Its presence in mud crabs has not been described. Several papers on *Hematodinium* were presented at the Fifth International Crustacean Congress in 2001 and it was likened to the bubonic plague in humans – with a higher mortality rate. It may already be an unrecognised problem in blue-swimmer crab aquaculture in the Philippines. Research on the application of ELISA and PCR tests is being conducted.

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7. Status of Marine Crab Culture in Vietnam

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Introduction

Marine crab culture in Vietnam is well established in regions such as Hai Phong, Quang Ninh, Thanh Hoa, Nghe An, Hue and Minh Hai. The most commonly practised culture method was traditionally extensive with seed collected in the wild, and then grown in ponds to yield approximately 200–300 kg/ha/crop. At present there are three main forms of crab aquaculture:

Extensive farming culture: Stocking density is one crab/5–10 m^2 with seed crabs of 30–50 mm carapace width; and for seed crabs of 1–1.5 mm carapace width, the stocking density is one crab/2–5 m^2. Crab hatcheries supply seed to the fishermen. It takes 2.5–6 months for crabs to reach a commercial size of 300–500 g. Crabs are fed trash fish, small crustaceans and molluscs.

Intensive farming culture: Stocking density is 1–1.5 crabs/m^2, achieving 1.5 t/ha for each crop. After 4–6 months, the crabs achieve an average weight of 300–450 g. Crabs are fed trash fish and molluscs.

Cage culture: This is carried out in small cages with stocking densities of 3–5 crabs/ m^2. Crabs reach between 200–400 g in weight over a period of 25–30 days. They are fed trash fish and molluscs.

Institutes conducting research on artificial reproduction and hatchery rearing

At present in Vietnam there are two research institutes and three hatcheries carrying out research. The Research Institute for Aquaculture (RIA) No. 3 has supported three crab hatcheries, which, in total, produce 1.5–2 million *Scylla paramamosain* crablets per year (technical support still provided by RIA No. 3). The Research Institute of Can Tho University has succeeded in artificial sea crab reproduction of *S. paramamosain* species.

Crab culture

During 2003 and 2004, RIA No. 3 is aiming to produce 1.5 t/ha of crabs funded by a grant from the Vietnamese Government of 1.35 billion VND (US$90,000). Research to date is progressing very well.

Some problems associated with sustainable crab culture

The use of trash fish to feed crabs is questionable because, in intensive culture, it pollutes the environment and causes disease. Also, trash fish is not a sustainable resource; and regular and reliable supply is a problem.

To address these problems, the following areas of research are suggested:

1. Research on crab nutrition, formulated feeds and feeding strategies, in particular:
    - understanding nutritional requirements of crabs including protein, energy, lipids and carbohydrates
    - determining the effects of essential nutrients on crab composition and growth

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- developing formulated feeds suitable for each crab stage
- developing effective methods to control moulting and prevent cannibalism.

2. Studies on disease and disease prevention.
3. Development of hatcheries and crab farms in Northern Vietnam.

Cost of crab feed

Farmers presently use fresh molluscs such as small bivalves to feed crabs. The cost of these molluscs is approximately 1000–2000 VND/kg or 1–2 million VND/t. Sometimes trash fish is also used (when available). The price of trash fish is about 2000–5000 VND/kg (2–5 million VND/t). However, reliability of supply is frequently a problem.

The use of formulated feeds by crab farmers

It is difficult to say if farmers would adopt the use of formulated feeds. However, it may be possible to predict the trend based on current prices for commercial crabs (2–3 crabs/kg). At present, the price is about 80–120 million VND/t (AU$6730–10,098) for mature females and 50–70 million VND/t for males. Therefore, in order to guarantee a profit, farmers can use formulated feeds only when crab production reaches 1.5 t/ha.

Research on optimal crab nutrition and the development of suitable, cost-effective formulated feeds is essential for the continued growth of the industry.

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8. Effect of Salinity and Food Types on the Development of Fertilised Eggs and Zoea Larvae of Mud Crab (*Scylla paramamosain*)

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Abstract

A culture model of one shrimp crop and one crab crop per year was applied and has succeeded well in Vietnam. Currently, crab seeds supplied for a thousand hectares of crab culture are based on natural resources, but problems with supply of wild seed crabs has meant that only 10–20% of the demand has been met. This paper briefly reviews the research findings of two projects: Artificial mud crab seed production (Go VN); and the 'Leading Centres for mud crab aquaculture' project (ACIAR, FIS/1999/076). Survival rate of larvae from zoea to first crab stage reached 10–15%. At present, Vietnam has three crab hatcheries and one of them can produce 0.5–1 million crab seed per year.

Introduction

Vietnam has large potential for mud crab production. In the last few years, there was high consumption demand of this species both in domestic and export markets. Therefore, mud crab culture was developed in many coastal provinces as well as wild crab fisheries. A culture model of one shrimp crop and one crab crop a year was applied, which created high economic value and reduced shrimp diseases. However, shortages in availability of wild seed crabs need to be addressed through development of hatchery technology. This research aims to assist the development of this technology. This work will also affect the wild resource of this species.

A series of three studies was carried out by the mud crab research group at the Research Institute for Aquaculture No III (RIA No. 3), Nha Trang, Vietnam. These studies have determined maximum suitable habitat and also food and feeding during larva rearing from zoae to first crab. These findings have been applied to production of mud crab seed in Vietnam's hatcheries. This paper briefly reviews the results of these studies.

Material and Methods

1. Effects of salinity on embryo performance and larval stages.

   A series of experiments was carried out at salinity levels ranging from 10‰ to 35‰. The aim of the experiments was to identify the lethal and optimal salinity levels to maximise survival and reduce the period between moults.

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2. Effects of food types on survival rate and moult time of larval stages.

   A series of experiments using different food types was carried out: Type 1: *Artemia*; Type 2: Algae, *Artemia* and *Brachionus;* Type 3: Algae, *Artemia, Brachionus*; and Ls (Lansy); Type 4: Algae, *Brachionus*, and Ls; and Type 5: *Artemia* and *Brachionus*.

   The aim of the experiments was to identify the optimal food type in order to increase the survival rate and to reduce the moult time of larvae.

3. Experimental materials

   - 10 litre aquariums
   - 100 and 650 litre composite tanks
   - Concrete tanks (20,000 L)
   - Three replicate tanks were used for each treatment.

4. Data analysis

   All data were analysed using Excel software (Mean, SD).

Results and Discussion

1. Salinity threshold of the last embryo stage

Identification of the salinity threshold of the early embryo stage is difficult and complicated, and we could not distinguish dead from live embryos. Therefore, the last embryo stage (two days before hatching) was chosen for the experiment. In the last embryo stage, the heart is continuously active, so it is easy to observe under the microscope.

Table 1: Salinity threshold of the last embryo stage

Time (hrs)	Death rate (%)							
	1‰	5‰	10‰	15‰	20‰	35‰	40‰	45‰
5	100	30.7	0	0	0	20.0	100	100
10		71.0	17.3	8.7	5.7	6.3		
15		100	32.3	25.3	7.7	8.3		
20			85.0	65.7	27.3	11.3		
24			92.3	88.0	56.7	15.0		

Based on the lethal method (LC_{50}), the lowest and highest salinity threshold for the embryo stage was 16.29‰ and 37.01‰, respectively.

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2. Effects of salinity on embryo performance

Mud crabs are crustaceans and hold eggs until hatching. After spawning, the females can move to a habitat with suitable conditions for developing their embryos and larvae. Studies on the effects of salinity on embryo performance are necessary to determine the optimal salinity level for artificial production.

Table 2: Effects of salinity on embryo death rate

Time (Day)	Mean mortality rate (%)				
	15‰	20‰	25‰	30‰	35‰
4	12.3 ± 2.2	10.3 ± 7.2	13.2 ± 1.5	8.1 ± 0.4	10.8 ± 1.5
8	31.4 ± 2.6	25.3 ± 2.2	18.1 ± 0.3	14.0 ±1.1	18.1 ± 0.4
12	81.3 ± 10.4	65.8 ± 3.1	21.2 ± 1.0	17.2 ± 0.2	21.5 ± 0.9

Note: Time for hatching

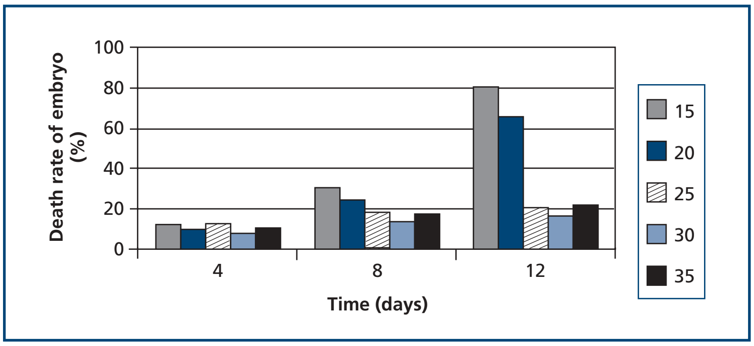

Figure 1: Relationship between death rate and salinity.
Distribution of data in salinity levels of Table 2 showed that: There were significant differences in mortality rates among salinity levels from the 8th to 12th day. The salinity levels of 15‰; 20‰; 25‰ are not suitable for embryo development. Optimal salinity levels for developing embryos range between 30‰ to 35‰.

3. Effects of salinity on survival rate and moult of zoea larvae

Adult mud crabs can live and grow well in a wide range of salinities (from 5‰ to 35‰). When crabs reach maturity, they migrate to areas of suitable salinity for spawning and with an abundance of phytoplankton and zooplankton.

Identifying the relationship between salinity and survival rate of larvae is necessary to determine an optimal salinity for artificial production. Based on the results of the effects of salinity on growing embryos and the lethal threshold for larvae, we set up experiments at salinities ranging from 20‰ to 35‰.

Table 3: Effects of salinity on survival rate of zoea larvae

Salinity (‰)	Survival rate of larval stages (%)					
	Z1	Z2	Z3	Z4	Z5	Megalopa
20	100	23.5 ± 13.4	0.4 ± 1.26	0.0	0.0	0.0
25	100	35.9 ± 10.9	7.5 ± 6.15	1.8 ± 2.9	0.0	0.0
30	100	64.7 ± 11.7	51.5 ± 20.6	36.2 ± 29.0	23.3 ± 10.0	13.9 ± 7.9
35	100	60.6 ± 14.5	33.7 ± 19.31	4.1 ± 10.7	4.2 ± 3.7	0.0

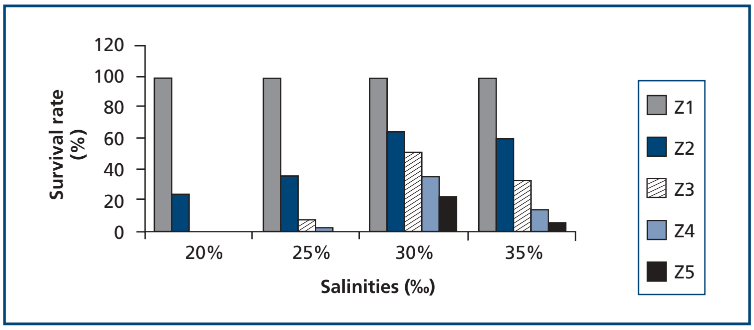

Figure 2: Relationship between salinity and survival rate of zoea larvae

At a salinity of 30‰, the survival rate gradually declined as larvae progressed from second stage zoea to megalopa, there were 64.6% (Z2), 51.5% (Z3), 36.2%, (Z4), 23.3% (Z5), and 13.9% (megalopa), respectively. The salinity of 30‰ is good for developing zoea larval stages.

Salinity not only affects survival rate, but also the moult and metamorphosis time of larvae. Research findings on moult time are shown in Table 4.

Table 4: Effects of salinity on moult time of zoea larvae

Zoea stages	Relationship between salinity (‰) and metamorphic time (day)			
	20‰	25‰	30‰	35‰
1st zoea (Z1)	6 days	5.3 days	5.0 days	6.0 days
2nd zoea (Z2)	5.3	4.3	4.0	5.0
3rd zoea (Z3)	Couldn't change to Z4	4.0	3.6	6.0
4th zoea (Z4)		Couldn't change to Z5	3.0	6.0
5th zoea (Z5)			5.0	Couldn't change to megalopa

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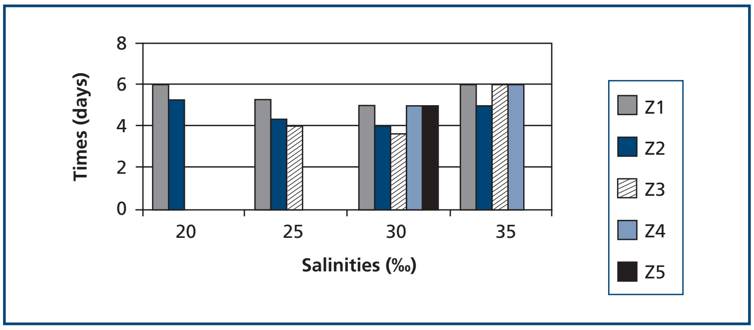

Figure 3: The relationship between salinity and metamorphic time.
At the salinity of 30‰, duration between (two) moults was shortest (from 3 to 5 days), and survival rate was highest 23.3% (at Z5 stage).

4. Effects of food types on survival rate of zoea larvae

The research findings on food types are shown in Table 5.

Table 5: Effects of food types on survival rate of zoea larvae

Food types	Percentage of survival rate in each larval stage (%)					
	Z1	Z2	Z3	Z4	Z5	Megalopae
A	100	44.0 ± 6.4	27.9 ± 7.3	19.2 ± 8.4	12.6 ±7.5	7.9 ± 4.9
B	100	62.6 ± 23.5	19.0 ± 20.3	0.8 ± 2.5	0	0
AB	100	69.7 ± 13.1	48.4 ± 6.4	33.0 ± 13.4	20.1 ± 8.8	12.9 ± 6.1
ABP	100	72.9 ± 11.9	51.1 ± 5.4	38.1 ± 2.7	25.2 ± 6.7	16.1 ± 6.2

Notes: Food A: *Artemia*; Food B: *Brachionus*; Food AB: *Artemia* and *Brachionus* Food ABP: *Artemia*, *Brachionus*, Phytoplankton (Chaetoceros, Platidomonas, *Nanochlolropsis* and *Chlorella*). Salinity for all experiments was set at 30‰.

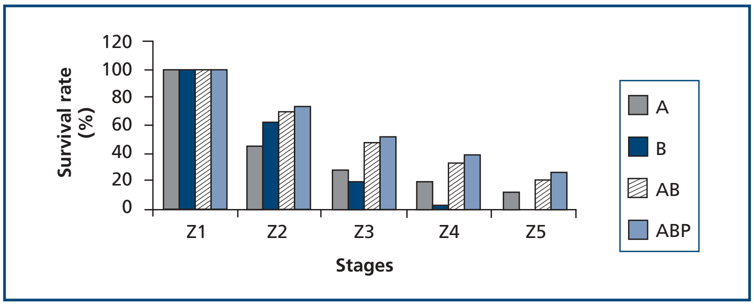

Figure 4: Relationship between food types and survival rate of zoea larvae

At the same larval stage, the feeding regime affected the survival rate. Survival rates of the second zoea stage, fed with *Brachionus* and *Artemia,* were 62.7% and 43.9% respectively. For the late zoea stages continuously fed with *Brachionus*, the survival rates were 18.9% (Z3), 0.8% (Z4), and 0% (Z5). When late zoea stages were continuously fed with *Artemia*, the survival rates were 27.8% (Z3), 19% (Z4), 12.6% (Z5), and 7.8% (meglopa). These results indicate that *Brachionus* is only suitable for the first and second zoea larval stages.

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Food types not only affect survival rate, but also the growth of larvae (i.e. moult times) (see Table 6).

Table 6: Effects of food types on moult time of zoea larvae

Moulting time in each stage (day)	Food types			
	A	B	AB	ABP
1st zoea (Z1)	6.00 ± 0.00	6.0 ± 0.0	5.7 ± 0.58	5.5 ± 0.58
2nd zoea (Z2)	4.30 ± 0.58	10.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0
3rd zoea (Z3)	4.30 ± 0.58		3.2 ± 0.0	3.5 ± 0.0
4th zoea (Z4)	5.0 ± 0.0		3.5 ± 0.0	3.0 ± 0.0
5th zoea (Z5)	5.0 ± 0.0		5.0 ± 0.0	5.0 ± 0.0

Conclusions

From the research results described above, we conclude that optimal salinity levels for developing embryo range from 30‰ to 35‰. Salinity of 30‰ is good for the development of zoea larval stages. In terms of food, a single type of food is not suitable for larvae so different ingredients should be combined. *Brachionus* is the most suitable for the first zoea and early second zoea larval stages. Nauplius of *Artemia* is suitable for early second to fifth zoea stages. The rich nutrition of *Artemia* is suitable for early fourth to late fifth zoea stages. Algae can feed all zoea stages.

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9. Mud Crab Hatchery and Grow-out Status in the Philippines

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Introduction

Interest in mud crab aquaculture is increasing throughout the Philippines because of its demand both in local and export markets. Mud crab culture started as low-density polyculture with fish or shrimp using wild crab juveniles and developed to monoculture in ponds and cages. Recently, an integrated mangrove-crab culture system has been practiced. Mud crab species commonly cultured are *Scylla serrata*, *S. tranquebarica*, and *S. olivacea.*

The yearly increase in production from 1996 to 2000 (Table 1) may indicate a corresponding increase in the seed collection activity due to greater demand of seeds for stocking. According to many gatherers in the country, there has been a declining volume of all size-classes, from juveniles to adult crabs, gathered from the wild over the last decade. Hence, the development of a commercially viable hatchery technology can play an important role in promoting sustainable crab aquaculture and fisheries management.

Table 1: Production of marketable size mud crab from brackish water ponds (BAS 1996–2000)

Year	Mud crab (mt)
1996	2,440
1997	3,710
1998	3,996
1999	4,215
2000	4,495

Hatchery

Studies on seed production of mud crab started in 1977 at the Southeast Asian Fisheries Development Center (SEAFDEC/AQD) but were discontinued shortly after to give way to higher priority species. Studies were resumed in 1997 during a three-year collaboration with Australian research institutions under the Australian Centre for International Agricultural Research (ACIAR). This collaboration paved the way to the development of seed production techniques in the country. Since then mud crab seed production has been a continuous research activity at SEAFDEC/AQD. The first training course on mud crab seed production was offered by SEAFDEC/AQD in October 2001 due to increasing interest. To date, three training courses have been offered to both local and foreign participants. Five local participants of these training courses have been conducting trial runs on larval crab rearing in their respective shrimp hatcheries, while one has just started operation on a commercial scale. Another participant is constructing a hatchery.

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The Western Samar Agricultural Resources Development Programme (WESAMAR) established the multi-species hatchery in western, Samar in April 1999. Mud crab was one of the species cultured. SEAFDEC/AQD provided the technical support. The project was funded by the European Union and implemented by the Department of Agriculture. The project intends to address the declining stock in the natural habitat due to unregulated and intensive gathering of mud crabs and other marine fishes. Four production runs were conducted with survival rates of 1.55–8% from zoea to megalopa and 40–70% from megalopa to juvenile stage.

Hatchery-reared crab juveniles produced in SEAFDEC/AQD since 1998 were grown by farmers in ponds and pens in various areas of Panay Island, Guimaras, Negros, and Davao. Hatchery-reared juveniles are easily acceptable to crab growers because of the advantages such as certainty of identification in smaller juveniles, uniformity in size and availability throughout the year. Growth performance is also similar to those from the wild-sourced juveniles.

The acceptability of a new technology like a mud crab hatchery depends on its profitability. The technology starts with the sourcing of females as broodstock and ends with the production of juveniles. Mature females sourced directly from ponds or buying stations are normally disinfected with 150 ppm formalin for 30 minutes prior to stocking in tanks. Females spawn within 1–5 weeks depending on the stage of ovarian maturity upon sourcing.

Unprocessed feeds for broodstock include mussels, squid, fish, or polychaetes given at 10–15% of the biomass daily. Formulated diets at 2–3% of the biomass are also given in combination with unprocessed feeds. The reproductive performance of broodstock is better in females fed on a combination of natural food and artificial diet than on artificial or natural food alone. Formulated feed is presented in cube form. Each feed is given separately to avoid selective feeding on preferred feeds. Feeding is adjusted based on consumption. Studies are being undertaken to improve the existing broodstock diet that was modified from shrimp formulated feed.

Newly hatched zoeae are immediately stocked in larval tanks at 50–80 ind./l. Water for holding the broodstock and larvae are chlorinated with calcium hypochlorite and neutralized with sodium thiosulfate. About 30% of water is replaced daily on day 2–3 and up to 80% as the larvae grow bigger.

The rotifer, *Brachionus*, is commonly fed to larvae because they are easier to propagate in the hatchery than other live food. The density of rotifers maintained in the larval tank is 10–15 ind./ml. Newly hatched *Artemia* are given to late zoea 2 and larger larvae at 0.5–3 individuals/ml. Because it provides bigger particle size and more meat per bite, 5–7 day old *Artemia* are fed to zoea 5 and megalopa. Rotifers eat a wide variety of phytoplankton but *Nannochlorum* sp. (formerly identified as *Chlorella virginica)*, is more commonly used in the hatchery. In the absence of an artificial larval crab diet, commercially available feeds formulated for shrimps are fed to crab larvae, particularly when there is a collapse in the *Brachionus* culture. Complex food types like formulated feeds may be suitable starting zoea 2 based on the ontogenic transformations in the proventriculus and mandibles of *S. serrata* larvae. Formulated feeds can reduce the rotifer requirement and consequently cut production costs.

In an attempt to find cheaper, natural food than *Artemia*, oyster larvae and copepods have been tested for zoeae, and free-living nematodes (*Panagrellus redivivus*) for megalopa and early crab stages. Fish, mussel or small shrimp are the major food items given to the early crab stages. The amount and size of feeds are adjusted based on consumption and size of the crab.

Research activities on larval nutrition are geared towards the improvement of physical characteristics of formulated diets and improvement of the diet by supplementation of specific nutrients. Likewise, the characterization and quantification of digestive enzymes, and energy requirements (elemental C, H, and N) at various developmental stages are being undertaken.

Using several tanks to rear megalopae up to juveniles at low density is not cost-effective because tanks are better used for rearing the zoeae. Therefore, a protocol to rear the megalopae in net cages set in brackishwater ponds was developed and has since been integrated in grow-out ponds.

A new integrated hatchery-nursery complex where the final product is the crab juvenile has a return of investment (ROI) of 56.05% and payback period of 1.4 years. If the hatchery is rented, the business will have a payback period of 0.8 years. The use of existing shrimp hatcheries that have been left idle could reduce the initial capital assets of a mud crab hatchery operator.

Grow-out

Mud crabs have been grown in four culture systems namely: monoculture, polyculture with fish and/or shrimp, integrated mangrove-crab culture, and fattening.

Mud crabs with mean body weight ranging from 5–30 g are cultured in ponds and pens in mangroves at 5,000–15,000 ind./ha for over 4–6 months. Mud crab juveniles at 5,000–10,000 ind./ha are grown with milkfish fingerlings at 500–2,500 ind/ha or shrimp at 10,000–20,000 ind./ha in ponds. A combination of three species is also practiced at a lower stocking density. In some cases, seaweeds (*Gracilaria*) are grown with crabs. Fences made of bamboo or polyethylene netting are installed to prevent the escape of the stock. Marketable, thin crabs are fattened in ponds, cages or pens for 15–30 days to gain more weight and develop gonad. In cages, the crabs are held individually in each compartment.

Feed is the most expensive item in the culture of mud crab, as it constitutes 40–50% of the total cost of production. The major food items for mud crabs are fish of various species, golden snails (*Pomacea canaliculata)*, telescope snails (*Telescopium telescopium*), small bivalves (*Potamocorbula* sp.), mussel, animal hides and entrails, and kitchen leftovers. Farmers prefer fish as feed for mud crabs because it is easy to prepare and no parts are wasted. When fish and other shellfish are not available, the crabs are fed animal entrails and kitchen leftovers that can reduce operational costs and recycle low value items. Feeds are provided daily at 5–10% of the total biomass. Feeding frequency varies from 1–2 times daily or every other day depending on the availability of feeds. A cold storage equipment to keep raw unprocessed feed requires electricity to operate; the use of a low-cost, formulated diet can reduce this expense.

A recent study showed that nutrients in feedstuffs of animal and plant origin were digested well by *S. serrata*. The digestibility of lipid in protein-rich animal feedstuffs was low compared to carbohydrate-rich plant feedstuffs. This study indicates that plant feedstuffs can be utilized as the major source of nutrients for cheaper and effective diet. *S. serrata* grows well when fed diets containing 32–42% dietary protein with 6% or 12% lipid at dietary energy ranging from 14.7–17.6 MJ/kJ. Another study showed that the survival, growth and economic viability of using a diet with or without vitamin and mineral supplements for grow-out culture were comparable.

Selective harvesting is normally practiced partly due to multiple sizes of crabs in ponds. Mud crab culture in ponds can give an ROI of 49–66% and a payback period of 1.2–2 years. Pens have an ROI of 60% and 1.4 year payback period. Fattening can give an ROI of 121% and a payback period of 0.64 years. Small-scale enterprises dominate the crab industry.

Local prices depend on season, size and gonad maturity. Processing of mud crabs is not extensively practiced in the Philippines because consumers prefer live crabs. Processing is done mainly for export due to difficulty in shipping live crabs.

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Constraints

Mud crab hatcheries are slowly emerging in the country. Low survival from larval to juvenile stages, maintenance of large-scale production of natural food, and a longer culture period compared to *P. monodon* hinder commercial production and adoption by the private sector. Bacterial and fungal infection, cannibalism at all stages, and limited knowledge on the nutritional requirements of larvae contribute to the low survival rate. The hatchery technology is continuously being refined to ensure economic viability.

Although mud crab farming has been practiced for several decades in the Philippines, information on the nutrient requirements of crabs is still limited. As the industry tries to expand, availability of fish by-catch and other unprocessed feeds becomes a problem. The use of fish and mussels is discouraged as these are also widely used as human food. The development of low cost, practical diets must be prioritized. Because crabs handle the feeds using claws, a good binder to keep the feed intact has to be determined. Feeding practices must be managed towards optimizing feed utilization to prevent pollution of the culture environment.

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10. Nutrition of the Mud Crab, *Scylla serrata* (Forskal)

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Introduction

Decapod crustaceans in aquaculture include penaeid prawns (shrimp), freshwater prawns and freshwater crayfish, true lobsters, spiny lobsters and crabs. Within and between these groups there are great differences in feeding preferences, as is seen in farmed mammals and fish. Some species (e.g. crawfish and crayfish) are mainly herbivorous, others (e.g. freshwater prawns) are omnivorous opportunists, others (e.g. mud crabs) are predatory but occasional scavengers, and some are very predatory (e.g. mantis shrimps). We should expect, again as seen in farmed mammals and fish, that there will be differences in nutritional requirements and acceptable feed components when we compare these diverse groups. Also, studies on nutritional requirements and dietary needs of other crustaceans may not necessarily be extrapolated to mud crabs.

While mud crabs have been farmed for many years in tropical Asian countries, it has only been as a secondary crop until recently, and traditionally they were fed on trash fish (small by-catch). With the trend to monoculture and increased stocking densities, and much greater competition for the trash fish resource, diet development has become more important. Compared with the traditional feed, pelleted feeds have much better storage qualities and, with appropriate knowledge, can be prepared by selection from a much wider range of ingredients. This allows considerable economies in feed manufacture as market prices of ingredients fluctuate, and the ability to prepare feeds in large quantities gives economies of scale to the industry. However, the nutritional needs of mud crabs, and acceptable feed components for pelleted feeds, have been researched only to a small extent.

Crustacean nutrition

Studies on other crustaceans have revealed some knowledge that may be of use in designing approaches to studying mud crabs. For example, the presence of endogenous cellulases has been detected in several species. High levels are expressed in *Cherax quadricarinatus* (Xue *et al.* 1999) and the cellulase gene has been shown to be present in the genome of the animal (Byrne *et al.* 1999). In *Macrobrachium rosenbergii,* the level of enzyme in gastric fluid is related to the level of cellulose in the feed, and cellulose has an apparent digestibility of 84% in that species (Gonzalez Pena *et al.* 2002). The metabolic significance of the cellulase is not yet clear. It may be that the animals partially digest the cellulose (cell walls) in order to more efficiently digest the cell contents, or they may fully digest it and derive metabolic energy from it. Work is in progress to investigate this point, and it is of interest that we have found that mud crabs do produce cellulase in their digestive systems.

There is considerable knowledge of the nutritional and feeding requirements of the penaeids, but much less is known regarding those of the other groups. Within the penaeids, *Penaeus japonicus* feeds have higher protein levels, and are made from a much more limited range of more expensive ingredients, than feeds for other *Penaeus* species (e.g. *P. monodon, P. indicus, P. vannami* and *P. stylirostris*). The reason for this has been the need to give the farmed product a flavour acceptable to the buyers in Japan, thus capturing the very high prices paid for *kuruma* prawns. This means that *P. japonicus* feeds are expensive, and thus uneconomic when used to grow other species of penaeids.

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The other penaeids have generally similar requirements. We know that they require the same essential amino acids as other animals, and that often lysine becomes limiting when plant-based protein sources are used to supply dietary protein. They will otherwise tolerate a variety of both animal and plant based protein sources in their diets, which can be combined to supply the total protein requirement. They appear to utilise dietary starch very well as an energy source, but there has been little work on utilisation of other carbohydrates. The reason for this is lack of economic need: feed grade grains are plentiful and can be used to supply plenty of cheap starch and a little protein as well, so alternatives to starch are not really needed and have not been investigated. However, if feed ingredients from plant sources become more important, the utilisation of non-starch polysaccharides will become an important aspect of feed efficiency.

The lipid requirements of *P. monodon* have been investigated in detail (Glencross *et al.* 2002a, 2002b). Like all crustaceans investigated to date, this species has a dietary requirement for cholesterol. In regard to triacylglycerols in the diet, there are two major factors that influence the dietary lipid requirement. The first factor is that the digestibility of lipid is strongly influenced by the level of lipid in the diet, and also by fatty acid composition. Levels over 100 g/kg (10%) significantly reduce digestibility, while the low levels of essential fatty acids reduced digestibility at levels of 45 and 75 g/kg. The second factor is that the essential fatty acid requirement, as measured by growth response, is a function of the level of lipid in the diet.

Another aspect of crustacean nutrition that has received attention is broodstock nutrition. Improved egg quality and larval survival have been shown to be associated with better nutrition of the broodstock females in several species. In particular, good quality protein and essential fatty acids appear to be factors in good nutrition of broodstock.

Mud crab nutrition

Recently, several reports have appeared in the literature that focuses on nutrition of mud crabs. Sheen and Wu (1999) investigated the effect of dietary lipid levels on growth of juvenile crabs. Using a mix of cod liver oil and corn oil, they determined that dietary levels of between 5.3 and 13.8% appear to meet the needs of the crabs. Interestingly, the upper level found was the highest tested, and showed no reduction in growth compared to that in *P. monodon* found by Glencross *et al.* (2002b). It is quite possible that mud crabs can tolerate, or actually require, a higher level of dietary lipid than does *P. monodon*. The cholesterol requirement of mud crabs was studied by Sheen (2000), by following growth, moult frequency and survival on diets with varying cholesterol levels. It was found that crabs on diets without added cholesterol had low weight gain, and the lowest moulting frequency and survival of all treatments. Dietary cholesterol levels over 1.12% had an adverse effect on growth. The optimal dietary level of cholesterol was determined to be 0.51% (5.1 g/kg).

The relationship between protein and lipid was investigated in a factorial design (3 protein levels × 2 lipid levels) experiment by Catacutan (2002), measuring growth and body composition responses to the diets. The conclusions were that the crabs grew well on diets containing 32 or 40% protein and 6 or 12% lipid, at dietary energies from 14.7 to 17.6 MJ/kg. Diets with high P/E ratios (31.1 mg protein/kJ) or high dietary energy (18.7 MJ/kg) were not well utilised by the crabs. Millamena and Quinitio (2000) investigated the effects of diet on reproductive performance of female mud crabs. Using three dietary treatments, a natural diet (meat from squid, mussel and fish), a formulated artificial diet, and a 50:50 mixture of the two, they concluded that a mixture of the two diets gave the best results overall in terms of fecundity, egg hatchability and larval survival.

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A study on digestibility of nutrients in feed components of mud crab diets has recently appeared (Catacutan *et al*. 2003) and shows some very encouraging findings. Using 30% inclusion levels in a reference diet, these workers measured the apparent digestibility coefficients (ADC) of some animal products including fish meal, squid meal, *Acetes* sp. and meat and bone meal; and some plant products including soybean meal, corn meal, wheat flour, rice bran and copra meal. The diets thus varied in composition: 34–54% protein, 4.8–10.8 fat, 2.1–4.3% fibre, 18.7–42.5 nitrogen free extract (NFE) and 0.6–22.0% ash. The digestibility of feeds found in the study indicates that mud crabs can digest a wide range of nutrients.

ADC of dry matter was between 88.3 and 93.6%, except for meat and bone meal (85.2%) that has a high (34% by weight) ash content. In all cases, protein digestibility was high, between 94.3% (copra meal) and 97.6% (squid meal). Fat digestibility was more variable, and generally higher in the diets that contained plant products. Ash ADC ranged from 64.4% (meat and bone meal) to 82.2% (squid meal). The encouraging aspects of the work come from the ADCs found for fibre and NFE. Fibre digestibility in all the plant feedstuffs was very high in the range from 94.4% to 96.1%. This may indicate that the crabs have some capacity to digest fibre, either by metabolising it as energy source, or breaking down plant cellular structures to liberate the cell contents for better digestion. Similarly, the high levels of NFE digestibility in the diets containing plant feedstuffs encourage the notion that the crabs can efficiently use starch and perhaps other carbohydrate material. These diets contained 31.3 to 42.5% by weight NFE, with digestibility ranging from 91.6% to 95.8%.

Conclusion

Recent work on mud crabs have shown results that can be regarded as very encouraging in terms of diet development. While mud crabs will grow well on *kuruma* prawn feeds, it is almost certain that *kuruma* feeds will not be viable as mud crab feeds in the long term. It seems that they can tolerate higher levels of dietary fat than penaeids can, enabling higher energy feeds and more rapid growth. It is also clear that mud crabs will grow on formulated pelleted feeds, and on feeds that contain plant feedstuffs. There are very encouraging signs that they can make good use of dietary starch and probably dietary fibre. Anecdotal evidence from Southeast Asia is that farms cannot get their feeds easily or economically so they are closing, resulting in decreased demand for seed crabs from the hatcheries, which are also forced to close. Development of cost effective diets prepared from largely local ingredients will have a strong positive impact on the industry.

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11. Status of Grow-out Feeds and Feeding Practice in Queensland

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Current feeds and feeding practice used in the pond grow-out of both mud crabs and blue swimmer crabs are largely derived from marine prawn culture. Prawn feeds, sourced locally and internationally, are predominately used with multiple feeding times throughout the day.

A recent pilot grow-out of mud crabs conducted on a north Queensland prawn farm in 2000 trialled the use of alternative feeds: crocodile pellets, a moist, large pellet containing blood meal and chicken waste, did not prove effective; but cooked waste prawns from the farm were successfully used to supplement the diet when available.

Currently blue swimmer crab grow-out in both ponds and cellular systems utilises prawn pellets almost exclusively. This is largely because they are: readily available in various size grades; easy to store and distribute; and achieve acceptable growth rates. Experimental comparisons of prawn diets at BIARC has shown that high growth rates are achieved with some feed brands during early crab stages

While detailed experimental data on the performance of prawn feeds in crab aquaculture is not yet available the following observations of its practical application have been made:

- high loss of small particulate matter
- low attractability (contributing to cannibalism)
- largest pellet too small for later grow-out stages
- possible change in diet preference during grow-out period.

Another practical issue that currently affects the use of prawn feeds in crab ponds is the estimation of optimal feed quantities. The *in situ* assessment of feed consumed by using feed trays, as used in prawn culture, is not successful in providing an indication of feeding rate by the crabs. At BIARC we have used direct observation of the pond bottom, when the algae bloom permits, to assess the amount of feed consumed. Typically however an estimate of the crab biomass is made from average weight derived from sample measurements and an approximation of the population size based on a predicted level of stock losses over time.

Typically BIARC feeds at a rate of 4 to 2% of estimated biomass with the rate decreasing from 10 g crabs to final harvest.

The food conversion ratio of blue swimmer crab grow-out at BIARC is around two, but it is clear that in the ponds a considerable amount of crab is consumed, supplementing the prawn feed supplied.

In the intensive, recirculating, cellular systems being used for both grow-out and shedding, the quality of the feed is more critical as there is no supplementary source of nutrition for the crabs. Diet work with early crab stages held individually at BIARC has indicated improved growth when high quality *kuruma* prawn feeds are used. Therefore these same diets are applied to the cellular

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systems with the expectation that they provide a more complete and balanced nutritional profile. Additionally, the efficiency of the diet, or the quantity of waste derived directly from the diet, is critical as excess waste can easily cause pollution problems. In these systems however, through direct observation either manually or automatically through the use of image analysis, it is relatively easy to accurately assess the quantity of food to supply to minimise uneaten food. Our commercial project partners have designed these systems and one has commenced operation.

A major issue requiring further investigation is the interaction between feeding and cannibalism. A better understanding of this interaction will potentially influence culture management and feeding practices. The key lies in a better understanding of crab behaviour and the triggers for observed behaviours. BIARC has initiated some studies investigating the behavioural aspect of cannibalism using closed circuit video monitoring.

A stock enhancement program to improve overall grow-out performance may ultimately influence the feeds used. A selection program under development at BIARC proposes a program to select the fastest growing crabs with the highest population survival under typical grow-out conditions. This will inherently select for stock that perform best with the standard food that is used, potentially going some-way to customising the crab for the feed rather than vice-versa.

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12. Workshop Group Tasks and Outputs

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Introduction

On the second day of the workshop, delegates were split into three groups and asked to identify constraints to: hatchery, nursery and grow-out production; list the key priorities; and recommend research strategies/activities for each priority.

Summary of working group outputs

Hatchery production

1. In terms of survival, price and production, what is needed from hatchery production?

(a) Survival

Zoea to megalopa, 10–20% is acceptable. Very good results for mud crabs are 40%; and for blue crabs are 80%. Megalopa to crablet 4–5 need 30–60% survival.

(b) Target price AU$/piece

	Philippines	Australia	Indonesia
Megsalopa	0.1	0.25	
1.5–2 g	0.25	0.2–0.5	
5 g (C3)		0.2	0.05
10 g	0.25		

(c) When/how often?

Year round production should be possible in the tropics. Seasonal deterioration in egg quality may occur in cooler climates
Mud crabs – 6 week cycle = 7–8 times/year
Blue crabs – 4 week cycle = 10–11 times/year

2. What are the best species?

Philippines	Australia	Indonesia
S. serrata	*S. serrata*	*S. paramamosain*
P. pelagicus	*P. pelagicus*	*P. pelagicus*

3. What are the constraints to hatchery practice?

(a) Water quality is still a problem at all sites and water treatment, e.g. ozone, carbon filtration, protein fractionation and removal, and better biofiltration require systematic evaluation.

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(b) Bacterial problems still require antibiotic intervention. Finding ways to eliminate or reduce antibiotic use, e.g. through better water treatment, improved hygiene or probiotic use, requires systematic investigation.

(c) Live food is still a major constraint. The cultures are difficult/expensive to maintain and live food is a disease vector. Research to eliminate live food for all or some stages is needed.

(d) Mortality at moulting is a problem. The inability to moult may be due to nutritional deficiencies and requires investigation.

(e) Nutritional adequacy of feed is unknown. Nutritionally optimal feeding regimes need to be developed (see (d) above).

(f) Transfer of technology has been excellent (under Leading Centres project) but will need to be maintained and expanded as new technology is developed.

Nursery

How?

There is a general consensus that mud crabs and blue swimmers can be easily reared in hapa nets to crab 5 (C5) at which size they are easily harvested and can be transported well.

Survival?

Survial of 50% is considered acceptable. Cannibalism is a problem and especially with variable size animals. Parasite problems have been reported in Indonesia with crabs in ponds.

Feed?

Existing prawn feeds are satisfactory for nursery size crabs but should do better with customised food – must eliminate trash fish from equation.

Grow-out

Similar constraints to grow-out development apply to mud crabs and blue swimmers.

(a) Replacement diets for trash fish needed in Southeast Asia. Existing high quality feed for *Penaeus japonicus* is effective, but prohibitive economically and physically: it is too small and the wrong texture.

(b) Diseases not a problem yet but will be in future.

(c) Regular harvesting to remove larger most aggressive animals difficult logistically and too expensive, especially in Australia.

(d) Moult synchrony a key priority.

(e) Possibility of selective breeding for 'increased survival' (reduced aggression).

(f) Better techniques for harvesting, especially with a view to reducing labour (particularly in Australia).

(g) High densities during transportation lead to significant limb loss and sometimes death.

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Shedding operations for soft-shell production

In Australia, an example of an intensive system is as follows:

	Mud crabs	Soft-shelled sand crabs
t/ha/crop	60	20
Crab/m^2	12	25
Survival	98%	95%
Growth (crops)	2/year	4/year
Size	450 mm	80 mm

The highest priority is establishing a regular supply of the correct size juveniles. Feed issues also exist, including feed management and conversion efficiency (i.e. the economics of feeding). Market oversupply and marketing are also likely constraints.

Postscript

During a visit to India, Peter Mather reported that a company was manufacturing and selling a formulated crab diet, which was apparently effective. No details on formulation, production rates or feed conversion ratios were available, but it augurs well for potential development and use of formulated feeds.

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Appendices

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Angus Cameron	Watermark Industries	P.O. Box 1254 Eagle Farm Qld 4009	07 3260 2411 0412 868 445	07 3260 2422	watermarkseafoods@bigpond.com	Principal of recently built close-circuit blue swimmer production company
Ross Meaclem		P.O. Box 426 Hervey Bay Qld 4655	07 4124 2771 0428 731 375		bluefins@optusnet.com.au	Principal of sea slug production company branching into crab production
Noel Herbst	Gold Coast Marine Hatcheries P/L	Marks Road, Woongoolba Qld 4207	07 5546 1361 0418 453 281	07 5546 7492	gcmh@ion.com.au	Principal of prawn production company branching into soft shell crab production
Shiu Quan Hung (Quan)	Tropical Mariculture	P.O. Box 289N North Cairns Qld 4870	07 4056 8198 0410 568 298		tropicalmariculture@bigpond.com	Principal of prawn hatchery also able to produce mud crablets
Bill & Vance Painter	Aquacrab	Suite 23 36-38 East Street Five Dock NSW 2046	02 9713 6777	02 9713 6999	austec@tpg.com.au	Principal of company developing site for mud crab aquaculture facility at Bowen

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13.1 Crab Aquaculture Contacts *(continued)*

Name	Institute	Address	Phone	Fax	Email	Comments
Chaoshu Zeng	James Cook University				chaoshu.zeng@jcu.edu.au	
Sam Gordon, Nick Moore, Mal Smith, Rob Scott	Seafarm	Bruce Hwy Cardwell Qld 4849	07 4066 8084	07 4066 8990	sgordon@toga.com.au; msmith@znet.net.au;	Prawn producing company with some recent involvement with crab production
Dos O'Sullivan	Austasia Aquaculture	PO Box 658 Rosny Tas 7018	08 8355 0277	08 8355 0288	dosaqua@bigpond.com	Principal of aquaculture publishing/consultancy company
Indonesia						
Ms Iin Djunaidah	Brackish Water Aquaculture Development Centre	P.O. Box 1 Jepara Central Java Indonesia	0291 591 724	0291 591 724	iinsd@telkom.net	Researcher in current ACIAR extension project
Johannes Hutabarat	Aquaculture Dept. Faculty of Fisheries & Marine Sciences	Diponogoro Uni Semarang Central Java Indonesia	024 8411 562	024 8446 865	jhutabarat@usa.net	ACIAR extension project
Ketut Sugama	Director (Aquaculture Research) Agency for Marine Affairs & Fisheries Research	Jl K.S. Tubun Petamburan VI Jakarta 10260 Indonesia	021 570 9162	021 570 9159	sugama@indosat.net.id	ACIAR collaborator
Adi Hanafi	Research Station for Coastal Fisheries	P.O. Box 140 Singaraja 81101 Gondol Bali Indonesia	362 92278	362 92272	ahanaf2001@yahoo.com	ACIAR collaborator
Philippines						
Emelia Quinitio	Aquaculture Nutrition Dept. SEAFDEC	5021 Iloilo Philippines	33 335 1009	33 336 2937	etquinit@aqd.seafdec.org.ph	ACIAR collaborator
Romeo Fortes			33 329 6638	9174 232 793	fortesrd@iloilo.I-next.net	Ex-collaborator ACIAR collaborator
Carlos G Co		P.O. Box 608 Sebu City 2000		32 255 2426	ofc@I-sebu.com.ph	
Vietnam						
Nguyen Co Thach	RIA No. 3	33 Dang Tat, Nha Trang, Vietnam	84 58 831136	84 58 831 846	thachria3@dng.vnn.vn	ACIAR collaborator
Truong Trong Nhia	Institute for Marine Aquaculture & Fisheries Can Tho University	3/2 Street Can Tho City Vietnam		84 71 830 247	ima@hcm.vnn.nv	
Japan						
Katsuyuki Hamasaki	Japan Sea-Farming Association, Yaeyama Stn	Ishigaki, Okinawa 907 0451			Katsuyuki-hamasaki@jasfa.or.jp	

13.1 Crab Aquaculture Contacts *(continued)*

Name	Institute	Address	Phone	Fax	Email	Comments
USA						
Yoni Zohar	Director, Center of Marine Biotechnology, University of Maryland				zohar@umbi.umb.edu	
UK						
Lewis Levay					l.levay@bangor.ac.uk	Runs EU program in collaboration with Philippines & Indonesia
Belgium						
Jerome Davis	Laboratory of Aquaculture & Artemia Reference Centre, Ghent University	Rozier 44, 9000 Ghent, Belgium	32 9 2643 754	32 9 2644 193	Jerome.davis@rug.ac.be	Cooperative South African/Belgium mud crab aquaculture project
Malaysia						
	Sepang Today Aquaculture Centre				http://www.todayaqua.com/	
Mohd Salleh Kamarudin	Dept. of Agrotechnology, Faculty of Agriculture, University of Putra Malaysia	43400 UPM Serdand, Selangor, Malaysia			msalleh@agri.upm.edu.my	
Denmark						
Don Macintosh	Dept. of Genetics & Ecology, Institute of Biological Science, University of Aarhus	Bld 540, Ny Munkegade, 8000 Aarhus Denmark	45 8942 3302	45 8942 3350	don.macintosh@biology.lau.dk	Center for Tropical Ecosystem Research = CenTER
Thailand						
Ratchada Kaonuna	Ranong Coastal Aquaculture Station	66/10 Judsanpatana Road, Bang-Rin, Muang, Ranon Province, Thailand		66 7784 0224		

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13.2 Thailand Department of Fisheries Crab Research Projects (Provided by Thai Department of Fisheries)

Projects	Researchers	Center/Station
Year: 2002		
Diseases in mud crab (*Scylla* spp.)	Ms Thitiporn Laoprasert	Aquatic Animal Health Research Institute
Mud crab culture system in earthen pond using water recycled with biological treatment	Mrs Rachada Kaonoona; Ms Adchoree Muchimpapiro	Suratthani CFR & DC
Effect of formalin and povidone iodine on crab larvae	Mr Somboon Laoprarert; Mr Vittya Havanont	Ranong CRF & DC
Rearing blue swimming crab (*Portunus pelagicus*) larvae in fiber tanks by providing different shelter	Miss Varin Tanasomwan	Samutsakorn CFR & DC
Experiment on rearing young blue swimming crab (*Portunus pelagicus*) in different ground base of pond	Mr Vutti Kuptacatin	Ranon CFR & DC
Nursing of young crab (*Scylla* spp.) at various salinities	Mr Vitaya Havannost; Mr Suprab Pripanopong	Ranong CFR & DC
Nursing of mud crab larva from zoea to megalopa with 3 different foods	Mr Surachart Chawepack	Chanthaburi CFR & DC
Culture of small mud crab *Scylla serrata* (Forskal) in plastic baskets	Miss Titima Thangaripong; Mr Wiwat Singthawesak	Chanthaburi CFR & DC
Nursing of mud crab *Scylla serrata* zoea at different stocking densities	Mr Chockchai Yosyingbumlue; Mrs Bung-orn Srimukda	Chanthaburi CFR & DC
Comparative study on 3 kinds of nursing for mud crab *Scylla serrata* (Forskal) megalopa	Mr Chockchai Yosyingbumlue; Mrs Bung-orn Srimukda	Chanthaburi CFR & DC
Larval rearing of mud crab *Scylla serrata* (Forskal) in a closed chamber with different circulation	Ms Wiwat Singthawemk	Chanthaburi CFR & DC
Biological study of mangrove crab *Sesarma mederi* around the upper Gulf of Thailand	Mr Boonchai Chianpeecha; Miss Atthayawadi Duangngrn; Mr Wuthichai Thonglum	Samutsakorn CFR & DC
Breeding and larval rearing crab *Sesarma mederi* in different salinities	Miss Atthaya Dvang-gern; Mr Boonchai Chiumpeicha	Samutsakorn CFR & DC
Raising of gravid female mud crab *Scylla serrata* in concrete tanks	Mr Wiwat Singthawesak	Chanthaburi CFR & DC
Recruitment fisheries production of mud crab, *Scylla serrata* (Forskal) for natural coastal areas around Kung Kraben Bay & Adjacent area, Chanthaburi Province	Mr Dusit Tanvilai; Ms Jarupa Sengeed	Rayong Marine Fisheries R&D Center
Year: 2003		
Mud crab *Scylla serrata* (Forskal) production increment in Phang-nga Bay, Phang-nga Province	Mr Khanchai Yoodee; Mr Wirot Kongasa; Mr Rojanaroot Roongruang; Mr Somsak Sirriraksa; Mrs Sujit Siriraksa	Phang-Nga Marine Fisheries R&D Center
An experiment on artificial feed for berried female mud crab producing	Mrs Rachada Kaonoona; Ms Adchoree Muchimpapiro	Suratthani CFR & DC
Optimum salinity on larval development of mud crab (*Scylla serrata*)	Mrs Aporn Teppanich; Mr Meechai Keawsrithong	Trang CFR & DC
Using different type of substratum and shelters on rearing megalopa stage of mud crab, *Scylla serrata*	Mr Chockchai Yosyingbumlue; Mrs Bung-orn Srimukda	Chanthaburi CFR & D
Culture of small mud crab *Scylla serrata* (Forskal) with artificial feed at different protein levels	Miss Titima Thangaripong; Mrs Tidaporn Chaweepark; Miss Sudarst Bowonrapakijkul	Chanthaburi CFR & DC
Nursing of mud crab larvae from zoea to crab stage at different water transparencies	Mr Surachart Chawepack	Chanthaburi CFR & DC
Study on bacterial flora in mud crab (*Scylla* sp.)	Mrs Titiporn Laoprasert	Ranong CFR & DC

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13.2 Thailand Department of Fisheries Crab Research Projects (Provided by Thai Department of Fisheries) ***(continued)***

Projects	Researchers	Center/Station
Recruitment fisheries production of mud crab, Kung-Kraben Bay and adjacent area, Chanthaburi	Mr Dusit Tunvilai; Mrs Jarupa Seng-iea	Rayong Marine Fisheries R&D Center
Experiment on soft shell mud crab (*Scylla* spp.) shelf culture	Mr Vitaya Havanont; Mr Suprab Pripanopong	Ranong CFR & DC
Experiment on nursing of swimming crab (*Portunus pelagicus* Linneaus) with various food	Mrs Aporn Teppanich; Miss Napsrat Prapaiwong; Mr Meechai Keawsrithong	Trang CFR & DC
Factors effecting survival rate of juvenile blue swimming crab (*Portunus pelagicus* Linneaus) in earthen nursing pond	Dr Varin Thnasomwong; Mr Suttichai Rittitum; Mr Jiramuwat Choopet	Samutsakorn CFR & DC
Biological study of mangrove crab *Sesarma mederi* with a variety of food around the upper Gulf of Thailand	Mr Boonchai Chianpeecha; Miss Atthayawadi Duangngrn; Mr Wuthichai Thonglum	Samutsakorn CFR & DC
Culture of young mangrove crab *Sesarma mederi* with live and formulated feeds	Mr Boonchai Chiampreecha; Miss Atthayawadi Iuangngern; Mr Wutthichai Thonglum	Samutsakorn CFR & DC
Effect of stocking densities on larval rearing of mangrove crab *Sesarma mederi* H. Milne-Edwards	Mr Wiwat Singthawesak	Chanthaburi CFR & DC
Effect of salinities on larval rearing of mangrove crab *Sesarm mederi* H. Milne-Edwards	Mr Wiwat Singthawesak	Chanthaburi CFR & DC

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