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The Australian mariculture industry : finfish, molluscs and crustaceans.

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Abstract — *Australia's interest in mariculture has been comparatively recent when compared with the developments in many other Pacific countries. Two exceptions are native oysters, cultivated for food since the late 1880's, and pearl oysters which have been cultured, particularly in the northern part of Australia, following the initial work of Saville-Kent.*

The additional organisms of current interest are penaeid prawns (shrimps), mud crabs, scallops, abalone, mussels, clams, brine shrimp, halophilic microalgae and several fish of temperate and tropical waters. Australian mariculture is also directed towards the production of fine chemicals and the replenishement of wild stocks.

Australia offers great opportunities for mariculture. Its coastal area is vast, a wide range of water temperature regimes is available and its coastal waters are of high quality.

Disadvantages include distance from major markets and consequent high shipping and labour costs, and a relatively inexperienced labour force.

This paper describes recent developments in mariculture in Australia and the progressive input of science to the art.

THE AUSTRALIAN SETTING, HISTORY AND GENERAL DEVELOPMENTS

Physiographic details of Australia's coast are given in figure 1.

Australia contrast with other countries in the Pacific by its latitudinal extent, its continental age and the consequent characteristics of the majority of its river systems.

Australian settlement by Europeans occured just over 200 years ago. The Aboriginal populations which have lived in Australia for more than 40,000 years do not appear to have practised extensive mariculture operations. However, evidence from southern Australia illustrates that aborigines were practising aquaculture in fresh water systems from about 4,000 years ago (Coutts *et al.*, 1978; Flood, 1983). There is no clear evidence that Aboriginal people used mariculture products in trade.

Commercial mariculture has developed in Australia only in the past 10 years. Apart from the efforts in oysters and to some extent mussels in Victoria, the greatest emphasis has been paid to penaeid prawns in the tropical regions and to Atlantic salmon and ocean trout cage culture in Tasmania.

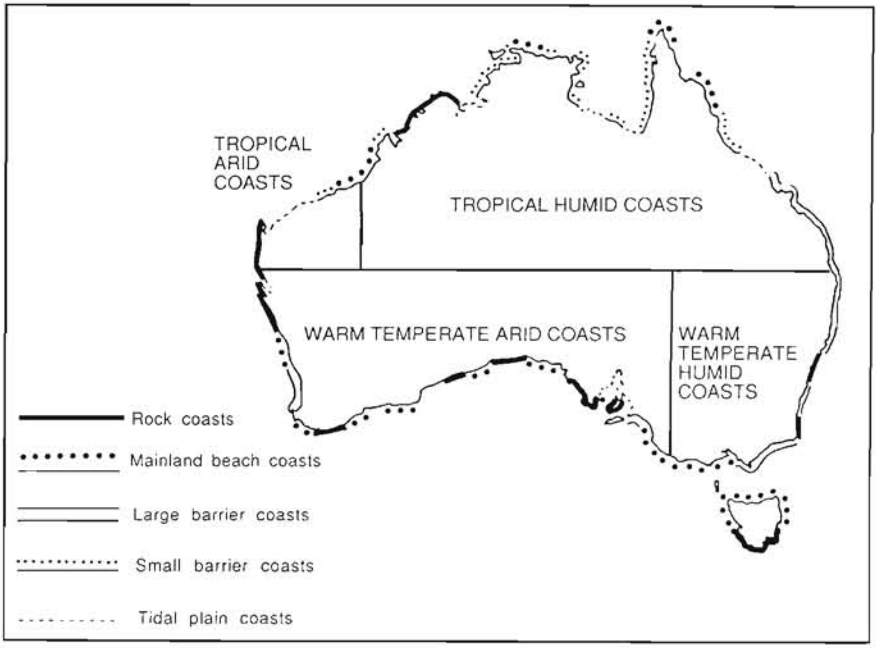

Fig. 1. — Coastal types of Australia based on Davies 1977

Penaeid prawn culture is now well established in the area from northern New South Wales and throughout Queensland as far north as Cooktown. Over more than 2,000 kilometres of coastline the principal pocket of activity are : northern New South Wale, Mackay, Townsville, Innisfail, Cairns, Port Douglas/Mossman, Cooktown and Darwin.

Oysters have been grown in Australia since the 1880's with the industry centred in New South Wales. In the past oyster farming concentrated on one principal species. *Saccostrea commercialis*, making the Sydney rock a regular treat in Australia. Recent developments have seen new methods of farming of different species of oysters.

The pearl oyster industry of northern Australia, particularly around Broome and Thursday Island, may not be regarded as a conventional mariculture industry but it was a very carefully managed resource.

During some 190 years Australians have neglected the potential of farming the sea whilst significantly modifying the land for agriculture. Australia now stands poised to redress this imbalance and impart significant effort to commercial mariculture. Education, training and research are the keys to ensure the success of the industry.

THE ADVANTAGES AND DISADVANTAGES OF AUSTRALIA FOR MARICULTURE DEVELOPMENT

a. Advantages

The country has a very wide range of coastal features and water temperature regimes suitable for different types of marine animals and plants.

Because of its relatively low population density most of Australia's coastline has very long stretches little influenced or unaffected by human pollutants.

Large areas of coastal land are avalaible at relatively low prices. This characteristic has been somewhat reduced over the past few years with significant tourist and residential developments which compete for areas of land suitable for mariculture.

In spite of some over-exploitation of commercial species most of Australia's naturally occuring marine animals and plants can still provide healthy broodstock, comparatively free of disease.

The law level of pollutants and generally high quality of Australian waters give the opportunity to produce mariculture products acceptable to the most discerning world markets.

Australia has regular reliable airlinks to major markets of Southeast Asia, Japan, Europe and the U.S.A.

Australia's stable political environment encourages major investment from overseas countries.

b. Disadvantages

Australia's disadvantages with regard to mariculture relate predominantly to the country's late entry into the field and its very high labour costs.

Although it does have airlinks to overseas markets, the distances involved are greater and the services fewer than for many competitor countries.

Fresh water supplies are limited and seasonal in many of the regions of Australia which would otherwise have ideal conditions for mariculture.

The high costs of wages and services in Australia require the development of methods which are not labour-intensive and which maximize efficiency.

A long term advantage, but a short term perceived disadvantage, is the concern of all Governments of the Australian Commonwealth for environmental quality and stability. The import of species from overseas is regulated strictly, requiring breeding through several generations has completely enclosed quarantined systems prior mariculture production. These regulations, **which are defended as absolutely essential,** increase initial costs but offer the prospects of long term sustainable disease-free productivity, and minimize the likelihood of infection of natural stocks.

INCENTIVE

Most states in Australia have given very few incentives to mariculture. This places the developing industry at a comparative disadvantage with many other countries (such as Taiwan) where signifiant taxation benefits apply during the first five to seven years of operation. In contrast, in many States of Australia license fees and the fees for discharge of water from mariculture ponds may be regarded as high for a new industry. There are some tax incentives for industries which wish to undertake research or to support research in mariculture. Perhaps the most attractive is a 150% tax saving on monies invested in approved research whether conducted within a company or contracted to a research institution.

ENVIRONMENTAL CONTROL

The Australian Government and the different State Governments have been very cautious in their attitudes towards the development of mariculture and its possible effects on the environment. Strict regulations control water quality and standards define the conditions under which different types of nutrient and sediment load from mariculture can be discharged into open waters. This is clear recognition that the growth of

Tab. 1. — Lists those species presently cultured in Australia as well as those thought to have future potential, adapted from Finney, A.J.F. and Garland, C.D. (unpublished data)

Commercial	Experimental (Pilot Scale)	Potential
	FINFISH	
Salmo salar	*Sillago ciliata*	*Plectropomus maculatus*
Salmo gairdneri	*Coryphaena hippurus*	*Ltjanus argentimaculatus*
Lates calcarifer	*Lutjanus johni*	*Epinephelus suillis*
	Epinephelus tauvina	*Epinephelus malabaricus*
		Acanthopagrus australis
		Chrysophys auratus
		Seriola lalandi
		Seriola hippos
		Argyrosomus hololepidatus
		Latris lineata
		Rhomboslea spp.
		Aquarium spp.
	MOLLUSCS	
Saccostrea commercialis	*Haliotis rubra*	
Crassostrea gigas	*Haliotis laevigata*	*Amusium balloti*
Ostrea angasi	*Tridacna gigas*	
Saccostrea echinata	*Pecten fumatus*	
Mytilus edulis planulatus		
	CRUSTACEA	
Penaeus monodon	*Penaeus esculentus*	*Panulirus cygnus*
Metapenaeus macleayi	Various others *Penaeus* spp.	
Artemia sp.	*Scylla serrata*	

many species under high density situations is likely be accompanied by the development of diseases and there is a major concern that any disease occuring under farming conditions must not be transmissed to the open waters where it may affect the very large commercial industry based on open-range harvesting.

Most States of Australia have pollution control commissions or environmental agencies which check very carefully on all types of coastal development. Most mariculture operations are developed either in coastal ponds where the waters are discharged back into the rivers or to the ocean, or in cages which are suspended at different depths either in channels, river mouths or in the open sea. Raft and rack culture techniques are preferred for commercial oysters production, loose-weave rope culture for mussels, and Scallops have been grown on plastic strips.

The selection of land for a proposed mariculture operation is very carefully screened. In some areas ponds are prohibited because of concern about aquaculture discharges into creeks or rivers which are believed to be important for convential commercial fisheries.

The levels of pollutants which are allowable in discharged waters are very carefully defined. An example is shown in Appendix 1 (State Pollution Control Commission N.S.W. 1988).

FINFISH

Atlantic Salmon and Ocean Trout

The sea cage culture of introduced Atlantic Salmon and ocean trout in Tasmania is undoubtedly the most successful Australian finfish farming activity. Production figures are given in Table 2.

Tab. 2. — Salmon and Trout production in Tasmania. Data from Purser (1988) and Purser J.

	Atlantic Salmon *Salmo salar* tonnes	Rainbow Trout *Salmo gairdneri* tonnes
1986/87	50	300
1987/88	250	1200
1988/89	500	1 200
1989/90	2 500	1 500

The higher market value of salmon (75 % greater than trout) makes this the preferred farm species as more smolt become available. Currently the production of smolt is controlled by Salmon Enterprises of Tasmania Pty Ltd (SALTAS); a joint venture between the Tasmania Government, a Norwegian aquaculture company and commercial growers. The company produces smolts in its freshwater hatchery in the upper Derwent Valley and has a monopoly on their production until 1995.

The hatchery production of rainbow trout comes from two commercial hatcheries which together are capable of supplying the anticipated demand.

In october 1987, the Tasmanian Government declared a moratorium on applications for more permits. This has now been further extended to allow an accurate assessment of the industry's development. There has been some local protest from recreational groups who claim that the farms are impeding protected waterways.

During the cage culture period the fish is entirely on a formulated diet. Food conversion rates (1.5-2) : 1 have been achieved using locally produced pellets. Nets are changed every 2-3 weeks as fouling is a problem. Predators such as seals have been reported from some areas.

Gjovik (1987) in his overview of salmon and trout farming lists the key factors responsible for the successful establishment of the industry in Tasmania as follows :

1. close to ideal climatic conditions and sites suitable for net pen culture,

2. the disease-free status of the fish stocks, maintained by Tasmania's isolation from any other stocks of salmonids,

3. the captive market provided by quarantine legislation,

4. government support, and early establishment of suitable legislation,

5. industry organization through the joint development company SALTAS,

6. early development of support industry (fish feed, equipment),

7. creation of infrastructural support (advice, research, fish pathology, etc).

Research priorities for this industry include : the development of triploid stock, feed cost reduction (i.e. need to reduce the dependence on fish meal), optimization of feeding rates and several disease problems (e.g. amoebic gill disease and *Streptococcal* infection) normally associated with fish being exposed to high water temperatures ($>20^{o}C$) for long periods (Maguire. G. and Munday, B. pers. comm.).

Lates calcarifer - **Barramundi**

The recent appearance of plate-sized (400-500 g) barramundi on the Australian market signals the emergence of a new tropical finfish mariculture industry for Australia. Sea Hatcheries Limited of Queensland produced 150,000 such fish using cage culture methods during 1988 and already forecast production of up to 600,000 during the 1989 season (Heasman 1988).

The Queensland Department of Primary Industries is also actively researching barramundi culture and Mr McKinnon of that Department will present an overview of recent advances during this workshop.

Coryphaena hippurus - **Dolphin Fish (mahimahi)**

Southern Sea Farms Ltd. of Western Australia have been actively engaged in research directed toward the commercial culture of mahimahi. Already broodstok conditioning and spawning techniques have been established and problem areas during the larval rearing process identified. The company list some of its recent achievements as including the development of live food enrichment techniques for mahimahi larval culture and the formulation of specific inert pelletized food suitable for weaning juveniles (Southern Sea Farms 1988). The hatchery at Yanchep. Western Australia, has already been upgraded and now has the capacity to supply enough juveniles to stock a 50 tonnes/annum grow-out farm. Grow-out trials are now in progress at a number of locations in Western Australia (Nel. S. pers. comm.).

OTHER FINFISH SPECIES

Although there are no other commercial mariculture ventures in Australia relying on finfish, other than those already mentioned, several other species are considered to have culture potential.

One of these, the summer whiting *Sillago ciliata*, has been reared in low densities at a commercial oyster hatchery in NSW. Researchers in Southern Queensland have also developed reliable sperm storage and spawning techniques for this species (Goodall, A. pers. comm). Similar work is about to be carried out on the yellow finned bream *Acanthopagrus australis*.

Further to the North Sea Hatcheries Limited have recently acquired broodstock of the estuary cods *Epinephelus tauvina*, *E. suillis* and *E. malabaricus*, the golden snapper *Lutjanus johni* and the mangrove jack L. *argentimaculatus* (Heasman, 1988a). Initial spawning work on E. *tauvina* and L. *johni* using techniques similar to those developed for L. *calcarifer* has proven successful (Heasman, 1988b). Spawning trials on the coral trout *Plectopomus maculatus* have been carried out by the Queensland Department of Primary Industries in Cairns (Rimmer, M. pers. comm.).

Southern Sea Farms of Western Australia intends to investigate the potential of the snapper *Crysophysis auratus*, yellowtail kingfish *Seriola lolandi*, the Western Australian jewfish *Glaucosoma hebraicum*, sampson fish *Seriola hiopps* and the mulloway *Argyrosomus hololepidotus*.

Garland (1988) has included the Tasmanian trumpeter *Latris lineata*, some aquarium spp. and the flounders *Rhomboslea* spp. as having potential.

MOLLUSCS

Saccostrea commercialis — Sydney rock oyster

Cultivation of the Sydney rock oyster is based in New South Wales and has an annual production value of A $ 35 million. Despite the impressive track record of this well established mariculture industry a recent decline in production has occured (Maguire *et al.*, 1988). Some of the factors contributing to this decline are : rising labour costs, disruption to conventional production methods (especially regulations to control the spread of *Crassostrea gigas*) declines in growth rates, disease problems (e.g. winter mortality in southern NSW and the QX haplosporidian parasite (*Marteilia sydneyi*) in northern NSW) and toxicity problems associated with the use of tributyltin antifouling paints.

The NSW industry is also under competition from *C. gigas*, both in terms of biological effects e.g. overcatch of faster growing *C. gigas* (Holliday and Nell, 1985; Nell, 1988), and marketing factors, especially the supply of cheaper *C. gigas* from Tasmania and New Zealand (Holliday *et al.*, 1988).

Following an extensive oyster research programme at the Brackish Water Fish Culture Centre in NSW methods such as subtidal culture and single seed production have been proposed to re-stimulate *S. commercialis* production within the industry.

Some of the advantages listed by those authors for subtidal culture over conventional methods include :

- quicker growth rates (Wisely *et al.*, 1979);
- utilization of deep water areas;
- increased production through expansion of growing areas and higher yields per unit water surface area;
- reduced production costs (Green, unpublished report, 1983)
- reduced risk from heat kill during intertidal exposure (Poter and Hill 1982);
- the ability to work the crop regardless of tidal influences.

Holliday *et al.* (1988) state that the main advantage of single seed culture over conventional methods is the virtual elimination of the laborious task of culling oysters. The single seed spat are also more uniform in shape and this allows the use of grading and packaging machines which are used widely overseas to reduce production costs. Single seed culture in hatcheries potentially allows the genetic selection and improvement of faster growing or triploid oysters (Mason, 1986; Griffiths *et al.*, 1988).

Crassostrea gigas — Pacific oyster

The Pacific oyster is a fast growing introduced species now widely cultured in Tasmania. In 1988, 1,5 million dozen oysters valued at A$4 million were produced in this state (Crawford, C. pers. comm.). Three large hatcheries are presently supplying growers with spat. Suitable sites for culture have also been identified in South Australia (Grove Jones, 1988). The culture of this species is banned in Victoria, and in NSW regional boundaries have been imposed to limit the transfer of oysters between river systems in an attempt to control the natural spread of *C. gigas* populations.

Ostrea angasi — Flat oyster

Research into hatchery production, nursery techniques, growth and meat yields of the flat oyster by the Victorian Marine Science Laboratories has demontrated that a commercial crop can be grown within two years (Hickman *et al.* 1988; O'Meley 1988). In response Government has approved 21 hectares of lease site and the pilot scale hatchery is to be upgraded to enable the production of 5 million seed by 1988/89 (Kirner, 1988).

Crassostrea echinata — Tropical blacklip oyster

The tropical blacklip oyster *C. echinata* is cultivated on a small scale in north Queensland.

Pinctada maxima — Pearl oyster

The development of culture techniques to produce hatchery reared pearl oyster spat for pearl culture is well underway in Western Australia. This research is regarded as vital to ensure the long term viability of the industry in that State, worth A$55 million annually.

Each year 450,000 shells are collected in Western Australian waters by the 13 licensed pearling companies and transferred to their lease sites for culture (Scoones, 1988). During the early 1980's high mortalities from *Vibrio* infections during these transfers were of paramount concern. Handling methods were later improved after the infections were linked to :

— cold water temperatures during the transfer period,

— crowding of oysters during transport,

— inadequate water circulation in carrier tanks (Pass, 1988).

Attempts to collect wild spat for reseeding purposes have been largely unsuccessful as there are several spawning peaks during the season with no specific periodicity (O'Sullivan and Munro, 1987).

The current hatchery programme in Broome, WA relies on local broodstock, the transport of which to southern research centres often hindered previous rearing experimentation. Larvae are now reared to the settlement stage in 2-3 weeks then ongrown for a further 12-15 months to a size suitable for nucleus implantation (Dybdahl *et al.*, 1988).

The Queensland pearl culture industry had 16 farm licences in 1988 (Curtis, 1988). One operation at the Escape River includes a small hatchery which has successfullly produced spat but is suffering significant juvenile mortalities.

Declining shell production in some of the traditional grounds around the Torres Strait is also of concern to the Queensland industry (Colgan, 1988).

Mytilus edulis planulatus — Blue Mussel

Production of the blue mussel *Mytilus edulis planulatus* in Port Phillip Bay, Victoria has increased from 30 tonnes in 1984/85 (O'Sullivan, 1987) to over 1,000 tonnes in 1988 (Hickman *et al.*, 1988). This increase has been due largely to research into the culture of this species at the Marine Science Laboratories at Queenscliff, Victoria.

Mussels are rope cultured and breeding studies have indicated that the industry could rely on the collection of wild spat during their spring settlement. Prior immersion of mussel ropes for two months to allow a dense growth of filamentous hydroids increased spat catches. An optimum spat density of 250/m of rope was determined and found to produce 30 % more meat/mussel than those grown at 750/m of rope (Hickman *et al*,. 1988).

Haliotis ruber, Haliotis laevigata — Abalone

Abalone are a high priced shell fish with annual production from the wild fishery in excess of A $ 100 million. Abalone culture in Australia is underdeveloped and untried on a commercial scale (McShane, 1988a). Successful culture techniques have been developed overseas (e.g. Japan, China and the USA) and are now being tested on Australian native species. *Haliotis ruber* and H. laevigata appear to have the greatest potential (McShane, 1988b).

By far the largest commercial investment today is that of Tasmanian Univalve Pty. Ltd. who, together with a joint venture Japanese partner, have begun to establish a A $ 5 million land based farm on the east coast of Tasmania. At full capacity they plan to export 1,000,000 abalone annually (McShane, 1988c).

McShane (1988b) predicts a bright future for abalone culture in Australia and has indicated that :

— land based culture to a marketable size of 6-8 cm shell length is preferable.

— a suitable artificial food needs to be developed because the natural harvesting of their preferred food (red seaweeds) is not practicable on a large scale.

— developments in selective breeding, including hybridization, should provide a mean of tailoring the cultured product to meet market demand.

Tridacna gigas — Giant Clams

The largest and fastest growing of the giant clams (*T. gigas)* is now considered to have commercial mariculture potential. Research into this species by a team from the James Cook University of North Queensland commenced in Australia in 1985 as part of an international collaborative project funded by the Australian Centre for International Agricultural Research. Additional funding to assess the potential of clam mariculture in northern Australia was provided by the Fishing Industry Research Trust Account (FIRTA) (Lucas, 1988).

The culture of *T. gigas* can be divided into five phases (Crawford, Lucas and Munro, 1987).

1. **Spawning** : Recent advances have included the development of gonad biopsy techniques and the use of serotonin to induce spawnings (Braley, 1985; Crawford *et al*,. 1986).

2. **Hatchery Phase** : During this phase the free swimming veliger larvae are fed unicellular algae (*Pavlova salina, Isochrysis galbana* and *Tetraselmis chuii*) at concentrations of 10,000 to 20,000 cells per ml (Barker, J. pers. comm.). It is envisaged that a microencapsulated diet will be formulated for this phase (Southgate, 1988).

3. **Nursery** : Late stage pediveliger larvae are transferred to raceway systems and soon after settlement are inoculated with zooxanthellae. This essential symbiont is either cultured or extracted from the mantle tissue of other clams (Crawford *et al.*, 1986). High mortalities post-metamor-

phosis and the fouling of juvenile clams by benthic algae are the main problems during the phase.

4. **Open Nursery Phase** : The juvenile clams of >20 mm are then reared for 1-2 years in mesh cages to exclude predators. During this stage maximum growth and high survival were obtained in the interdinal zone when compared with subtidal cultures, especially when cages were located on protected fringing reefs (Lucas, 1988).

5. **Grow Out Phase** : *T. gigas* of two years and older are about 200 mm in shell length and have virtually no predators. They are grown on the intertidal zone without protection (Lucas, 1988).

James Cook University is now seeking a joint venture partner to translate the experimental results into commercial production. The identification of appropriate markets will be critical to this development. Preliminary trials have indicated that meat from 2-3 years old clams is potentially a high priced « sashimi » suitable for Japanese cuisine (Cowan, 1988).

Two commercial clam growers are in operation in Australia although only small numbers of juvenile have been produced so far.

Pecten fumatus — Scallops

In 1987 the Tasmanian Government signed a Memorandum of Agreement with the Overseas Fisheries Co-operation Foundation of Japan for three years project to examine the potential for scallop cultivation — both reseeding and hanging cage culture — in Tasmania (Crawford, 1987).

Already the results from this project indicate that overseas scallop growing technology can be readily applied to one of the Tasmanian species, *Pecten fumatus*. Under culture conditions this species exhibited excellent growth rates, much higher than those reported from the wild (Friend. R. pers. comm.).

The major problem facing researchers is the limited availability of spat. Attempts to capture wild spat have been largely unsuccessful due to a low density of natural broodstock. Efforts to increase this density by maintaining scallops in hanging cage cultures may increase future spat catches in localized areas. Hanging cage culture is preferred to reseeding at this stage because of limited spat availability and the higher mortality rate associated with reseeding (Friend. R. pers. comm.).

Limited availability of natural spat has prompted further hatchery research. Two commercial oyster hatcheries were recently contracted to supply spat for this research but few were produced.

The economics of culturing this species have yet to be demonstrated.

Trochus niloticus — Trochus Shell

There is presently some interest in the reseeding of depleted trochus stocks, particularly in the Torres Strait region. This has been prompted by the high value of trochus shell : currently A $ 4.000/tonne.Trochus eggs are lecithotropic (the developing larvae feed on their yolk reserves) which makes the larvae easy to rear to settlement stage. Nash (1988) obtained almost 100 % survival in some experimental trials, however, considerable mortalities occured after settlement, due to predation. He considers that until geographic areas of the low juvenile mortality are identified, reseeding programmes would not be successful.

CRUTACEANS

Penaeid Prawns

The pond rearing of penaeid prawns, although very much a new industry in Australia, has developed rapidly during the last few years. Development has been concentrated primarily in Queensland and northern NSW. Farms have also been constructed in the Northern Territory and certain areas in north western Western Australia have been identified as having future potential.

Today 200 ha of ponds have been constructed in NSW with another 300 ha being approved (Maguire and Allan 1988; Maguire *et al.*, 1988). Pondage area in Queensland is about 180 ha (20 farms) (Curtis, 1988). However, recent developments in the Cardwell area will increase this total. Farms range in size from 1 ha to >50 ha and are owned largely by cane farmers diversifying their activities or investment companies (Robertson 1988). The average size of newly constructed ponds is c. 1 ha.

Production estimates for Queensland and NSW during the 1987/88 summer season were 200 tonnes and >40 tonnes respectively (Curtis, 1988; Maguire, 1988). These figures are misleading as a significant number of grow-out ponds were not stocked effectively. Yields of around 3T/ha per crop have been the highest achieved so far but these are expected to increase during the 1988/89 harvest. One particular farmer in southern Queensland is confidently predicting a summer crop in excess of 7T/ha from certain ponds (Moreton Bay Prawn Farms pers. comm.).

Penaeus monodon is the main species cultured. However, the industry is actively investigating alternative species especially *P. esculentus*. Small quantities of *Metapenaeus macleayi* are grown in NSW where the capture of wild juvenile seed is currently allowed. Trial crops of *P. plebejus*, *P. merguiensis* and *P. semisulcatus* have also been produced.

Twelve hatcheries are now producing postlarvae for stocking ponds. These range from small backyard operation to larger complexes with production capacities in excess of 3 million postlarvae/month (these numbers are rarely achieved).

Pond management techniques are continually improving but the lack of a regular supply of healthy robust postlarvae is the biggest single constraint to the development of the industry. Irregular supply, low numbers and variable larval quality have meant that farmers are faced with poor initial stockings.

Intermittent hatchery production often results from the irregular supply of wild caught broodstock. To overcome this dependence, several maturation units are in operation. However, this industry generally questions the quality of the larvae from these units.

Disease problems, usually associated with poor water quality or inadequate nutrition have arisen, often during the hatchery phase.

Drs Lester and Owens will present results of their research on these diseases during this workshop.

In an attempt to overcome of the constraints imposed by temperature regimes upon grow-out a number of farmers are presently trailing heated nursery systems in an attempt to "head start" prawns held through the winter for a spring stocking. Apart from some obvious advantages, especially in assessing postlarval feeding and mortality, these systems will be necessary in the southern farming region if two crops/year are to be achieved.

Another top priority is to produce local feeds comparable in quality to the Taiwanese pellets on which the industry currently relies (Maguire *et al.*, 1988). Several companies are actively involved and trials are being conducted.

Research will play a critical role in the future development of this industry. Maguire (1988) summarizes some of the projects already in progress.

Scylla serrata — Mud crab

Although seven licences have been granted in Queensland for the production of mud crabs (Curtis, 1988), no commercial industry exists for the culturing of this species in Australia. The establishment of the industry awaits the development of sound larval rearing techniques as the collection of wild seed stock is illegal in this country. This contrasts with the Asian situation where seed used are taken from the wild.

Preliminary hatchery research by the Queensland Department of Primary Industries (DPI) at Deception Bay has identified the moult from zoea 5 to megalopa 1 as a particularly critical period which usually results in high mortalities. Inadequate larval nutrition is suspected as the cause. The DPI researchers have been successful in reducing mortalities associated with the first three days following hatching from >90 % to <50 % and have also produced 1st stage (CI) crabs (Potter, M. pers. comm.).

Low larval survival to the CI crab stage (1-2 %) has also been experienced by a private company, Sea Hatcheries Ltd. They also consider it important to identify the essential nutrients during the rate larval stages as a guide towards the development of a synthetic larval food. This is necessary to streamline production by reducing dependence on live foods (Fielder. S. pers. comm.).

Artemia sp — Brine Shrimp

Although the demand for brine shrimp products is escalating because of the recent increases in finfish and crustacean larviculture there are currently no commercial quantities of Australian produced cysts on the market. In Western Australia, where large tracts of land appear suitable, there is interest by several companies.

A small pilot scale farm has been recently established on a salt pan area near Townsville, Queensland. Presently the owners are still assessing the viability of producing either cysts or live *Artemia* products. In Victoria, a private company, Victorian Brine Shrimp Growers, produces up to 40 kgs of live adult brine shrimp per week using intensive culture methods. These are marketed in pet shops throughout Australia as live or fresh frozen products (O'Sullivan, 1988).

Paulirus cygnus — Western rock lobster

Given the value of the Australian rock lobster catch (A$220 million in 86/87° it comes as no surprise to learn that there is tremendous enthusiasm to develop commercial mariculture for this crustacean. Culture difficulties are immediately apparent because of its long oceanic larval phases of 9-11 months (Phillips, 1985).

One suggestion was to collect wild puerulus larvae (the final planktonic stage) and grow these to a marketable size. However, this would invariably lead to conflict with established fishermen (Phillips, 1988).

CSIRO in Western Australia is investigating *Panulirus cygnus* and consider that the fundamental step required is to rear this species through all of its larval stages in the laboratory. This group is presently seeking a commercial partner to undertake a research programme aimed at developing a technological base to establish a mariculture industry for this species in Australia.

ECONOMIC ASPECTS

Initially, effort in the mariculture industry has concentrated on production but very careful economic analysis of the viability of each specific production is required.

Ruello (1986), commenting upon the fresh water species *Macrobrachium rosenbergii*, stressed the importance of analysis market potential and identifying the most likely receivers of production well before production actually starts.

For prawn mariculture in Australia, very careful product analyses have been conducted, and it is clear that a well managed penaeid prawn farm can yield a very high economic return. Tisdell (1987) analysed the potential of giant clam farming in Australian waters, and concluded that further market analysis was essential, particularly for the mantle meat, and for a wider market for adductor muscle.

THE EXTENT OF SUPPORT THROUGH EDUCATION PROGRAMMES

Weir and Garland (1988) estimated that the total farm gate value of mariculture products in Australia for the financial year 1987/88 was A$105.17 million. The principal species were molluscs, crustaceans, fish, macro-algae; molluscs, crustaceans and fish accounting approximately A $ 102 million. By contrast the current value of the wild fishery of Australia was estimated at A $ 720 million per annum in the same fiscal year.

The authors estimate that the mariculture industry income of Australia will increase at approximately 33 % in the financial year 1988/89 and by a further 43.5 % above that level in 1989/90. Their analysis reveals that Queensland is the principal State as far as crustacean mariculture is concerned, New South Wales the principal State for molluscs mariculture and that fish mariculture is concentrated in Tasmania.

ROLE OF RESEARCH

If Australia is to compete successfully in the international markets for marine products based on mariculture it will have to develop effective and efficient intensive methods of culture because our wage structure will not allow us to compete using methods of production which are labour-intensive.

Many of the techniques originally used in Australia for prawn mariculture were imported from overseas countries, notably Taiwan. While these procedures are very effective in their countries of origin they are sometimes unsuited to Australian conditions and prospectively are not competitive in international export markets or even in local markets. Territorial agriculture in Australia is competitive internationally largely through improved stock performance by adapting existing breeds to Australian conditions. As yet there have been no such developments in the mariculture industry and genetic research directed to the improvement of stock performance and productivity should be a major research emphasis in Australia.

Several institutions in Australia are now involved in mariculture research or have initiated plans to undertake such research.

One of the Commonwealth authorities, the Australian Institute of Marine Science (AIMS), has begun research into the genetics of prawns relative to mariculture. We believe that this is the most important fundamental research that should be undertaken for the prawn industry. Additional research must be undertaken towards better understanding the life cycle and improving survival, particularly at the larval stages. Such understanding is fundamental to further genetic studies.

Our research will also cover a careful analysis of hatchery water conditions because AIMS technical support is excellent in this area.

Research in nutrition in general and in food supplies is not being emphasized within our institutions, but we are anxious to collaborate with institutions and companies on this and other aspects of research.

COLLABORATION AND COMMUNICATION

It is our firm belief that communication among research organisations and between research organisations and growers is essential to the success of the mariculture industry.

CSIRO. which is Australia's largest research organisation has only limited research activity associated with prawn mariculture at this stage. However, it does have extensive research facilities at the Cleveland Laboratories in Brisbane and at the Fisheries Laboratories located in

Hobart and in Western Australia. One of the key features of the CSIRO Laboratories in Hobart is their algal culture collection which has been the basis for the supply of algal foods for hatcheries in Australia as the mariculture industry develops.

The different State Government Departments have been involved in research into those species which are of most interest to their local production. In Tasmania the emphasis has concentrated on salmon, scallops and oysters. In Victoria research has concentrated on mussels and oysters, and in New South Wales on oysters, prawns and certain species of fish. The Queensland Government has recently constructed a research facility at Bribie Island near Moreton Bay and has been particularly active in barramundi farming in its north Queensland operations near Cairns.

The Northern Territory has stimulated investors to develop prawn farming in the Territory. That Government has a small support operation and has supported the industry without directly undertaking research.

South Australia, early involved in a joint venture with I.C.I. in oyster mariculture (particularly in development of hatchery techniques), has completed a new research facility without as yet making public the particular species on which research will concentrate.

In Western Australia the principal emphasis has been on the halophilic microalga *Dunaliella salina* and also on the brine shrimp *Artemia salina.* These activities have been largely conducted by commercial operations with a backup service provided by the State. That State has commited its efforts to better understanding its lucrative crayfish open water fishery.

During the last two to three years most universities of Australia have been giving attention for the first time to research supporting mariculture and aquaculture in general. This has been stimulated by the availability of special grants through the Fishing Industry Research Development Committee. In North Queensland, James Cook University of North Queensland is very active in research on giant clam mariculture and has coordinated a major ACIAR project over the last four years. The university also has a smaller research activity in prawn farming, particularly looking at aspects of desease and nutritional requirements in microalgal food sources.

The University of Queensland is also involved in crustacean research, but with an emphasis on the freshwater species. However, that University has indicated clearly that it wishes to be more involved in general mariculture farming.

EDUCATION

Mariculture, a relative new industry in Australia, is presently faced with a shortage of skilled personnal. The future long term success of the industry depends on training technicians and researchers well versed in aquacultural methods. Several institutions already have included aquacultural components in existing science courses. Specialist courses (undergraduate and postgraduate) are offered by the Tasmanian State Institute of Technology (since 1983) which has been identified by the Federal Government as Australia's key centre for teaching and research in aquaculture (Forteath, 1988).

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