ECONOMIC ASPECTS OF AQUACULTURE IN NORTH QUEENSLAND

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INTRODUCTION

Aquaculture in north Queensland is a relatively new industry. While pearl culture and crocodile farming were established by the 1980s, many aquacultural farms were started during that decade. Many species are being contemplated, researched or tested for commercial production. Most aquacultural output from north Queensland is produced in land based systems, with very limited use of sea cages. Prawns constitute the largest aquacultural output from north Queensland, and this region had 55 per cent of Australia's prawn farms in 1989-90 (Hardman, Treadwell and Maguire 1990). Also north Queensland accounts for virtually all barramundi cultured in Australia. Accordingly, the concentration in this paper is on prawns and barramundi.

The primary aim in this paper is to examine the factors that will contribute to the development of a viable aquacultural industry based on prawns and barramundi in north Queensland. This is undertaken using investment analysis of representative farm models to estimate likely future returns, the risk to those returns and effects of changes in key variables such as yield and prices.

INDUSTRY DEVELOPMENTS

The technologies being used in aquaculture in north Queensland are still developing and changes in farming methods have been occurring at a rapid pace. In prawn farming the major changes have been associated with increasing the stocking density. The major species of prawn farmed is the leader prawn (*Penaeus monodon*) although some production trials have been conducted in Queensland with the Australian tiger prawn (*Penaeus esculentus*) and *Penaeus japonicus*. The trend in growout has been toward higher stocking densities, with fewer farmers stocking below 25 prawns/m^2. While there have been major improvements in the performance of the main Australian commercial prawn feeds (Maguire 1990) there has been continuing reliance on imported feeds, particularly from Thailand and Taiwan. Although some farms are still experiencing feed conversion ratios in excess of 2:1, encouraging results in the range of 1.4–1.7:1 are being obtained (Gillespie 1991). It is likely that better survival rates and more appropriate feeding regimes as well as improved feeds have been the contributing factors. Improved survival rates have also contributed to higher yields being reported by at least some farmers (Gillespie 1991). The emphasis on aeration capacity has probably played a major role in these productivity improvements along with improved quality of post-larvae for stocking ponds.

In general farmers have avoided the high stocking densities (more than 40 prawns/m^2) that may have contributed to the decline of the Taiwanese industry. A notable development has been the initiation of some cage culture trials with prawns at Weipa. Overall the major dilemma has been the issue of the optimal number of crops a year. Given the trade-offs between prawn size and time period of growout, stocking rates, yields and the associated costs, many farmers in north Queensland consider that 3 crops in 2 years is appropriate. Although 2 crops a year are possible this would result in smaller, less valuable prawns at harvest. Alternatively, much lower stocking densities could be employed to achieve larger prawns from 2 crops a year.

Barramundi farming did not commence until 1986 when the first commercial farm and hatchery was established. Initially the supply of fertilised eggs was a constraint to industry growth but now this is changing and progress is being made on captive maturation. The hatchery phase has been considerably diversified, with extensive production of fingerlings in ponds being undertaken (Rimmer and Rutledge 1991). This new technology should substantially lower the cost of fingerlings. However, problems associated with optimum larval stage for nursery pond stocking and the associated issue of survival rates in nursery ponds have to be resolved to make extensive rearing of fingerlings reliable. A considerable amount of research is being undertaken particularly for the fingerling production phase due partly to the significance of barramundi in terms of releases for recreational fisheries.

The growout phase can be in sea cages, for which there is proven worldwide technology, or in freshwater ponds. The control of cannibalism is crucial to achieving reasonable survival rates. In freshwater ponds, the use of 8 m^3 cages has been developed for growout to harvest. This allows protection from predatory birds, closer monitoring of feed demand and separation of size groups to limit cannibalism. However, this cage size is unusually small for commercial fish farming and results in high labour requirements. A more recent development has been to use the 8 m^3 cages until the barramundi reach 150 mm long (after which cannibalism is much less of a problem) and thereafter the fish are allowed to range freely in the pond. It is worth noting that there is a wide range in feed conversion ratios reported for barramundi farming. Although leading farmers in north Queensland have indicated that ratios of 1.5:1 have been achieved, ratios of 2–2.5:1 have been reported to be more typical (Trendall and Fielder 1991). These compare with an average of 1.7:1 for Taiwanese farms and 0.9–1.2:1 for experimental work in Australia (Tucker, MacKinnon, Russell, O'Brien and Cazzola 1988).

MARKET OPPORTUNITIES

In marketing their output on the domestic market aquaculturists do have several advantages over the competition from wild fisheries and imports. Compared with wild fisheries, aquacultural output is more controllable and predictable in terms of timing, quantity, product form and quality. This is a distinct advantage in developing market outlets. The ability to plan the harvest in terms of time, quantity and quality (albeit with some risk) means aquaculturists can more easily market their product directly and enter into forward contracts. Indeed, as it is feasible to harvest prawns throughout the year it would be feasible for prawn farmers to develop a market for fresh prawns through supermarkets, which generally require supplies on a planned, consistent, year-round and standardised basis.

Compared with importers, Australian aquaculturists have an advantage in supplying fresh high quality products to the domestic market. However, this is not always the case and the proximity to transport networks should be considered in locating the farm. For example, one factor cited as a reason for the recent closure of the Comalco barramundi farm at Weipa was isolation from markets and the inability to supply fresh product. As a result of isolation the farm's output was in direct competition with imports of relatively cheaper cultured fish from Asia.

Since aquaculturists can control production characteristics to a large degree, they have the ability to take advantage of relative price differences between the various forms — fresh, live, frozen or cooked, large or small — to maximise profit. The ability to alter production characteristics, even within the period of a crop, to suit market fluctuations is obviously a factor which aquaculturists can use to their advantage. Altering production regimes has associated costs — thus it is necessary to have detailed market information to assess the benefits of supplying various product forms at differing times and of various specified qualities. For example, larger prawns generally fetch a higher price but to grow larger prawns farmers have the added costs associated with more feed, lower stocking densities and/or longer crop periods.

Developments in the Prawn Market

Due largely to the rapid growth of cultured prawns in Asia, prawn prices have fallen. Although production has stabilised in some countries, such as China (Rosenberry 1991), further increases in output are expected as other Asian producers expand production. Competition in prawn markets has intensified and there appears to be no likelihood of this situation easing during the medium term. With the prospect of further expansion of prawn farming in Asia, world prices are expected to continue to fall.

Australian farmed prawns are generally aimed at the domestic market; however, Australian producers are still exposed to world price trends. The Australian prawn market closely follows trends in the international market, as about half of Australia's production of prawns is exported and imports are of a similar magnitude (ABARE 1990a). However, domestic prices do fluctuate with seasonal variations in supplies of wild caught prawns. This provides perhaps the best opportunity for Australian prawn farmers — if they can time their harvest to take advantage of seasonal peaks in prices. In this respect producers in north Queensland have an advantage over southern producers. Whereas production in southern regions is restricted by seasons, the capability to produce throughout the year in north Queensland allows more flexibility in timing the harvest to coincide with peak prices.

Markets for Barramundi

Barramundi producers are also facing increasing competition from imported cultured product from Asia. Virtually all imports of cultured barramundi are frozen and prices have fallen over the past year to between $4.50/kg and $5/kg. However, the market for fresh plate size barramundi has not been subjected to the same degree of competition. In 1989-90 the average price for plate sized, gilled and gutted farmed barramundi was around $13/kg (Quinn, Barlow and Witney 1991). This price represented a fall of $1.60/kg from 1988. The likelihood of prices for fresh barramundi falling further depends not only on the supply of fresh cultured barramundi but on competing wild fisheries supplies and supplies of other substitute fish. Although wild fisheries are not expected to increase supply substantially in the long term future, increasing aquacultural production across Australia of fish, in addition to barramundi, would place downward pressure on fresh barramundi prices.

METHOD OF ANALYSIS

The Farm Model

In order to analyse the potential profitability of prawn and barramundi culture, farm models were constructed. These models were designed to represent the current situation. These were then modified to incorporate expected productivity improvements to represent the potential situation.

The representative farm model was defined in consultation with farmers in the industry, researchers and others involved with the industry. After defining the model farm in terms of size and technology, the key parameters were set from information supplied mainly by farmers and researchers. Ranges for the key parameters were used in the analysis to reflect the large degree of uncertainty and risk which is due principally to the early developmental phase of aquaculture. Given this framework, costs were determined from data supplied by farmers, researchers and suppliers of equipment and inputs. At this stage comments on the farm model parameters and costs were sought from industry and researchers and their comments were then incorporated in the revised model for analysis.

Average Cost of Production

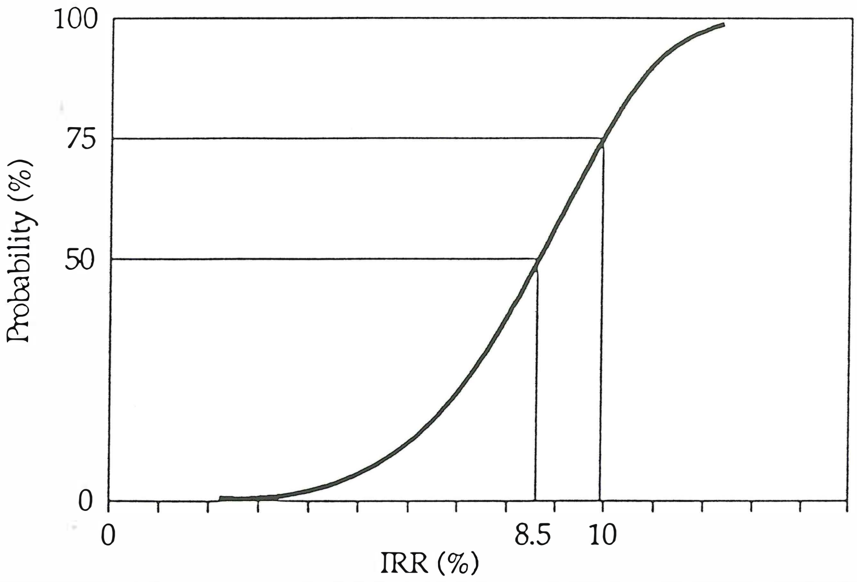
To allow for the fact that there is a delay between establishing a farm and first selling output and that purchases of capital equipment vary widely between years, the average cost of production was determined over the life of the project. Costs throughout the 20 year life of the project were discounted at 6 per cent a year, the long term interest rate net of inflation (ABARE 1990b). The average annual cost of production equals the annuity (or the amount required each year) which would equate to the total of the discounted costs over the 20 years.

Stochastic Investment Analysis

A relatively new industry such as aquaculture in Australia is subject to much uncertainty and risk. Consequently, a rate of return based only on the most likely estimates would not fully reflect the nature of returns to aquaculture. Sensitivity testing over the range of possible values for all the uncertain parameters would become unwieldy and difficult to interpret. The alternative approach used in this paper is stochastic investment analysis. This approach is based on the stochastic analysis of returns to new horticultural crops by Treadwell and Woffenden (1984) and was used in analysing the profitability of 6 ha prawn farms by Hardman, Treadwell and Maguire (1990).

The analysis used the estimated range for each uncertain parameter. For each simulation, a value (or a fluctuating time series) was randomly generated for each parameter from its specified distribution. Each such set of parameter values was used to calculate a specific stream of costs and returns, from which the internal rate of return (IRR) was derived. This procedure was repeated to generate a set of IRRs. These were then ranked and the cumulative probability function was calculated. This function gives the probability of the IRR being less than any particular level. For example, in figure 1 there is a 75 per cent chance that the IRR is less than 10 per cent, the level where the horizontal line from 75 per cent probability crosses the cumulative probability function. The point at which the horizontal line from 50 per cent probability meets the cumulative probability function is the mean IRR.

Figure 1: Cumulative probability of IRR



The advantage of this stochastic approach is that it not only produces the expected or mean IRR but also indicates the effect of uncertainty by providing a range of IRRs with their probability of occurrence. This procedure avoids the need for sensitivity testing of individual parameters, as the overall uncertainty is reflected in the probability distribution of the IRR. However, individual sensitivity tests can still be undertaken to show the specific effect of variation in a particular parameter.

The analysis was on a pre-tax basis, using private costs and revenue, and was conducted over 20 years, the estimated life of ponds. The analysis was based on the following assumptions.

- There is no correlation between prices, yields and costs, except for some specific costs such as marketing and processing costs which are dependent on prices and yields.
- Full production is possible from the first year that yields would occur.
- The farm is located on a suitable site with ready access to water.
- Although disasters that would cause extremely low yields or loss of a year's crop are allowed, no provision is made for loss of farm facilities.
- During the period of analysis, no technical changes are introduced that result in major changes in the relationship between costs and yields. This assumption is relaxed in sensitivity analyses on particular productivity improvements.

No allowance has been made for borrowing funds to establish and finance the farm. The IRR may then be interpreted as the highest interest rate that could be paid on borrowings while still covering costs. The IRR itself is that rate of interest that equates the discounted stream of benefits to the discounted stream of costs (or alternatively the rate of interest that results in a zero net present value). As risk is reflected in the resulting range of IRRs it is appropriate to compare those to a risk-free interest rate, rather than an average borrowing rate which would include a premium for risk. In general, an IRR range from this analysis of above 6 per cent, the long term interest rate net of inflation (ABARE 1990b), would indicate that the project was profitable if all assumptions held for the duration of the project.

FUTURE PROFITABILITY OF PRAWN FARMING

In July 1990 Hardman, Treadwell and Maguire (1990) presented an economic model of Australian prawn farming. Their analysis showed that profitability was very sensitive to the climate, prices, yields and the size of the farm. The north Queensland region was found to be a much more profitable area to grow *P. monodon* than the subtropical regions in southern Queensland and northern New South Wales. However, it appears that the underlying assumption of 2 crops of 25 g prawns a year is optimistic. In addition, as farmers gain experience in prawn farming there is a tendency for farm size to be increased above the 6 ha model used in analysis by Hardman et al. Accordingly, the following models are for a farm of 20 ponds of 1 ha, producing 3 crops every 2 years.

The Farm Model

To reflect some of the choices available to prawn growers, 3 variations to the model farm have been analysed. Generally larger prawns fetch higher prices. There are two main parameters a farmer may vary to achieve the desirable size. By varying the stocking density farmers may affect the size of the prawn harvested. Alternatively the length of the growout period could be altered to achieve the best size given market price relativities. In the following analysis 3 stocking densities were modelled to produce prawns of 3 differing average weights with the growout time set for 3 crops in 2 years. The relationship between stocking densities and prawn size at harvest accords with results obtained in model ponds in Australia (Allan, G., NSW Agriculture and Fisheries, personal communication, March 1991). It is recognised that optimal pond size could vary with stocking density, as it is easier to manage larger, less costly ponds at lower density. However, to facilitate direct comparisons between stocking densities, this factor has not been incorporated in the model.

As can be seen from table 1 the farmgate price has been varied for each model according to the size of prawn harvested. Farmgate prices have been used in the analysis as most prawn farmers in north Queensland sell prawns to processors or wholesalers at the farm and farmers do not directly pay marketing and transport costs. As prawn prices are expected to decline the analyses were performed with prices falling 1.5 per cent a year relative to costs.

Two sets of models were analysed. The first set was defined to reflect the current situation and was based on estimates of survival rates and feed conversion ratios from Hardman, Treadwell and Maguire (1990). The second set of models represents the potential situation and was based on improved feed conversion ratios, survival and yields as reported by Gillespie (1991). Average estimated costs for the 3 potential model farms are listed in tables 2 and 3. In the analysis costs were allowed to vary by 15 per cent around these averages. The average costs of production for the current models are higher due to higher feed conversion ratios and lower yields.

The Results

For the current situation models the mean IRRs are 15.4–17.5 per cent (table 4). By itself such average returns would appear to be viable. However, the results indicate there is at least a 25 per cent chance that returns could fall below 6 per cent. Hence prawn farming with current performance is not considered viable in the long term with falling prices. However, if farm performance were improved to the potential feed conversion ratios and yields shown in table 1, the results show prawn farming would be viable. Indeed for the simulated models for each

Table 1. Key characteristics of north Queensland prawn farm models

Item	Unit	Low	Medium	High
Total size of farm	ha	30	30	30
Number of ponds	no.	20	20	20
Area of ponds	ha	1	1	1
Number of crops/year		1.5	1.5	1.5
Stocking density	pl/m^2	15	25	35
Average prawn harvest size	g	34	30	27
Farm gate price – average	$/kg	10.10	9.50	9.05
– range	$/kg	8.1–12.1	7.5–11.5	7.05–11.05
Feed conversion ratio				
– Current average		1.8:1	2.0:1	2.2:1
– Potential average		1.5:1	1.7:1	1.8:1
Survival rate				
– Current average (range)	%	63(40–73)	60(39–70)	58(36–68)
– Potential average (range)	%	70(40–84)	67(39–80)	65(36–77)
Yield				
– Current average (range)	t/ha/crop	3.2(2.1–3.7)	4.5(2.9–5.25)	5.5(3.4–6.4)
– Potential average (range)	t/ha/crop	3.6(2.1–4.3)	5.0(2.9–6.0)	6.1(3.4–7.3)
Total farm production				
– Current average (range)	t/year	96(63–111)	135(87–158)	165(102–192)
– Potential average (range)	t/year	108(63–129)	150(87–180)	183(102–219)

Table 2. Annual costs for north Queensland prawn farm model – potential

Item	Low ($)	Medium ($)	High ($)
Post-lavae (a)	81 000	135 000	189 000
Feed (b)	243 000	382 500	494 100
Fertiliser	12 500	12 500	12 500
Electricity	60 000	73 000	80 000
Labour – permanent	105 000	105 000	105 000
– casual	25 000	34 000	42 000
– manager/owner	30 000	30 000	30 000
Repairs and maintenance	22 000	22 000	22 000
Miscellaneous	6 000	6 000	6 000
Administration	11 000	11 000	11 000
Total	559 200	811 000	991 600

(a) 1.8c each. (b) $1500/t.

Table 3: Capital costs for north Queensland prawn farm model

Capital item	Total value $	Scrap value (%)	Years of purchase
Land	180 000		0
Earthworks (ponds & channels)	400 000		0
Pump(s)	40 700	10	0,5,10,15
Motors(s)	40 700	10	0,5,10,15
Belts, pulleys, pump base etc.	6 700		0,3,6,9,12,15,18
Pumps shed, valves, filters	15 200	–	0
Pipes, gates, screens, boards	80 000	–	0
Electric power supply	200 000	–	0
Generator (standby)	20 000	10	0,10
Rotary hoe	5 000	10	0,10
Spike tooth harrows	2 000	10	0,10
Slasher	2 000	10	0,10
Bucket	5 000	10	0,10
Blade	1 500	10	0,10
Fertiliser spreader	2 500	10	0,10
Farm truck (2nd hand)	20 000	10	0,10
Tractor (2nd hand)	15 000	10	0,10
Motorbike	5 000	10	0,5,10,15
Blower pipe (feed)	1 000	–	0,3,6,9,12,15,18
Aeration Units (a)	110 000	10	0,5,10,15
Refrigeration plant, esky, bins, etc	22 000	10	1,11
Ice machine (2 t/day)	20 000	10	1,11
Prawn weighing scales	2 500	–	1,4,7,10,13,16,19
Harvest equipment (nets/cages)	4 000	–	1,4,7,10,13,16,19
Prawn handling area & equipment	10 000		1,11
Farm shed	25 000	–	0
Tools	10 000	–	0,5,10,15
Test kits	5 000	–	0,3,6,9,12,15,18
Boat (2nd hand)	2 500	10	0.10
Office equipment	5 000	–	0,5,10,15
Miscellaneous	5 000	–	0,5,10,15
Total	1 263 300		

(a) For 15 post-larvae/m^2 \$88 000, for 35 post-larvae/m^2 \$132 000.

Source: Based on Hardman, Treadwell and Maguire (1990).

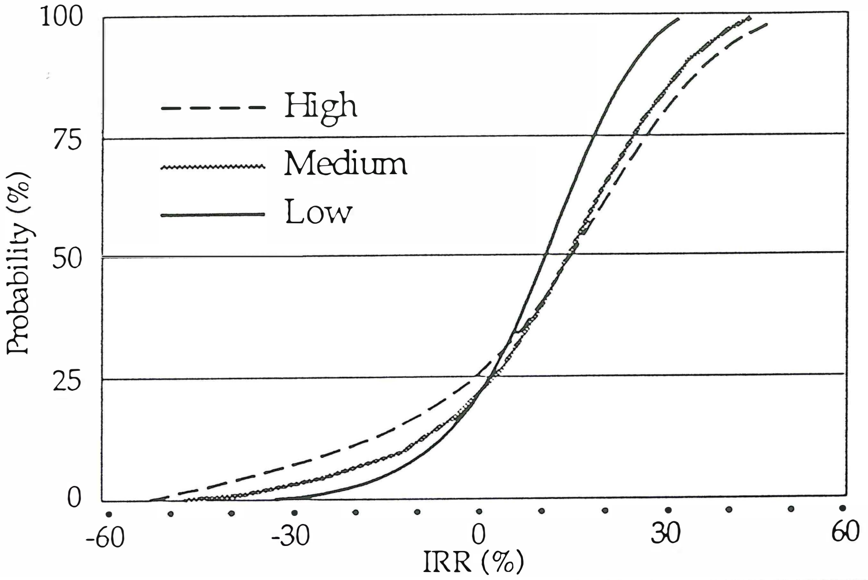
stocking rate there is a 75 per cent chance of returns exceeding 15 per cent. Although these results appear promising a few words of caution are necessary. These results would apply only for good management, on a suitable site, and in the absence of major disasters (such as cyclone damage to capital equipment).

Interestingly the average profit levels for the 3 stocking densities are quite similar (table 4). However, the risk, as reflected in the range of likely IRRs, rises with increasing stocking density (figure 2). These results are based on farmgate prices of $7.50/kg to $11.50/kg for 30 g prawns with a price premium (discount) of 15c/g for the other two models (see table 1). However, the price premium does vary during the year depending on relative supplies of the various sizes. Not surprisingly, if no such price differences were available, the highest stocking density is the most profitable. If a higher premium of 25c/g is obtained the lowest stocking density is most profitable. As the price premium varies during and between years it is unlikely that farmers could consistently receive higher than average price premiums for larger prawns or lower than average discounts for smaller prawns. Hence the high returns (average of around 40 per cent) would not be sustained in the long term. These results do indicate the sensitivity of returns to varying prices — hence the need for prawn farmers to assess their short term production decisions in view of their cost structures and likely prices, by size.

Table 4. Internal rates of return and cost of production for prawn farm

Farm model	Cost of production ($/kg)	Mean IRR (%)	IRR range 50% chance that IRR is: (%)
Low stocking density – 15 pl/m^2			
Current (15c/g price premium)	7.66	15.4	5.1 to 24.2
Potential (15c/g price premium)	6.66	27.5	16.0 to 37.7
– higher establishment costs	6.86	22.2	12.4 to 30.3
– no price premium	6.66	21.8	10.0 to 31.2
– 25c/g price premium	6.66	40.4	28.9 to 50.9
Medium stocking density – 25 pl/m^2			
Current	7.17	17.5	–0.1 to 29.9
Potential	6.30	31.1	15.5 to 45.0
– higher establishment costs	6.44	25.0	11.9 to 36.9
High stocking density – 35 pl/m^2			
Current (15c/g price discount)	7.15	17.2	–4.6 to 30.7
Potential (15c/g price discount)	6.17	33.9	17.3 to 48.5
– higher establishment costs	6.28	29.5	15.5 to 40.2
– no price discount	6.17	41.1	24.1 to 55.4
– 25c/g price discount	6.17	30.2	15.8 to 45.2

Figure 2: Prawn farm models Cumulative probability of IRR



Although costs were allowed to vary by 15 per cent in the analysis some costs could vary by even more than that. Establishment costs are site specific and vary markedly. For example, the cost of building a 1 ha pond could vary from $12 000/ha to $40 000/ha or even higher if difficult terrain and soils are encountered. Also, land and pump costs vary depending on the site. If the cost of earthworks were $40 000/ha and these other site specific costs were, on average, 15 per cent higher, the mean IRR would be reduced by about 5 percentage points. This result reinforces the need to investigate the site thoroughly, and estimate likely costs of establishment prior to commitments on the venture (whether prawns or any other species).

FUTURE PROFITABILITY OF BARRAMUNDI FARMING

The Farm Model

As farming methods for barramundi are evolving rapidly it is difficult to forecast future directions in management techniques and to define an indicative model farm. Consequently three farm models were constructed according to the techniques for growout — sea cages, cages in freshwater ponds and free ranging in freshwater ponds with nursery cages for fish up to 150 mm. In addition, sensitivity tests were performed for various improvements in productivity, such as improved feed conversion ratios, survival and supply of fingerlings.

The model farm size is for an initial stocking of 160 000 barramundi fingerlings with a pond area of 5 ha or 7 sea cages. To reflect the quite large range in yields, farm output has been allowed to vary between 28 800 and 64 000 gilled and gutted fish of between 450 and 500 g (table 5). It was assumed that all farm output was sold as fresh gilled and gutted plate sized fish for $12/kg delivered to the market, with a range of $10/kg to 15/kg

As can be seen from table 6 the largest operating cost for the model farm is feed. In the base models a feed conversion ratio of 2.25:1 was used. However, as indicated above ratios of

Table 5. Key characteristics of barramundi farm models

Item	Unit	Average	Range
Initial stocking of fingerlings	per farm	160 000	
Density at harvest	fish/ha	16 000	12 000–25 600
Fish size at harvest – liveweight	g	534	530–560
– gilled & gutted	g	475	450–500
Prices, delivered	$/kg	12	10–15
Feed conversion ratio		2.25	1.8–2.5
Survival rate	%	50	40–80 (sea 35–80)
Total farm output – gilled & gutted	t/y	38	34–68 (sea 25–68)

Table 6. Annual costs for barramundi farm model

	Freshwater ponds		
Item	Caged ($)	Free range ($)	Sea cages ($)
Fingerlings (a)	96 000	96 000	96 000
Feed	115 344	115 344	115 344
Electricity and fuel	13 000	13 000	12 000
Labour – permanent	46 000	26 000	46 000
– casual	12 500	0	12 500
– owner manager	30 000	30 000	30 000
Packaging	15 200	15 200	15 200
Marketing and freight	63 080	63 080	63 080
Repairs and maintenance	21 000	18 000	15 000
Licences, permits and rates	2 570	2 670	5 260
Administration	6 000	6 000	6 000
Miscellaneous	5 000	5 000	5 000
Total	425 794	390 294	421 384

(a) At 60c each.

1.7:1 could be achieved consistently. Due to this variation and the large component of feed in total costs, in the following analysis the effect of varying feed conversion ratios has been analysed. Also analysed was the effect of varying the cost of fingerlings, which is subject to much uncertainty as new technology is being introduced for rearing fingerlings. As a result the cost of fingerlings is expected to fall substantially to around 20c each (Trendall and Fielder 1991). However, in 1990 the cost of fingerlings was between 50c and $1 each, with an average of 60c. Labour is another large component of operating costs. The high labour component in producing barramundi results from the cannibalistic habit of the fish. Continual grading and care with feeding regimes are necessary to ensure a reasonable survival rate. Consequently, in the sensitivity tests with higher survival rates the labour input has been increased by 1–1.5 person years from the base model detailed in table 6. Details of capital costs are listed in table 7. In the analysis, costs were allowed to vary 15 per cent around these averages.

The Results

The results of the analysis indicate that with current technology and average performance using cages throughout the growout period in freshwater ponds is unviable, with the average cost of production of $13.42/kg being more than the average price (table 8). The results in table 8 indicate that sea cage culture would be more profitable than growout of fish in cages in freshwater ponds. By allowing the barramundi to range freely in the ponds after reaching 150 mm the estimated cost of production of $11.64/kg is lower than for the other 2 growout techniques. Although the simulated mean IRR is 20 per cent, there is a 27 per cent chance that returns could fall below 6 per cent. Thus, based on current technology and average performance, barramundi farming could not be considered viable. However, several developments are occurring which could dramatically alter this conclusion.

The viability of the sea cage model farm is higher than that for raising barramundi in cages in freshwater ponds. This result accords with the findings of Cann (1991) who compared the costs of producing barramundi by cage culture in ponds, lakes and the sea. However, returns to sea cage culture of barramundi are likely to be lower than free range barramundi in freshwater ponds. Also, the risk in sea cage culture is likely to be higher with less control over the environment and higher risk of loss to predators. In addition, likely initial charges for establishing aquacultural farms in the sea have not been established in Queensland and may vary widely depending on location especially in relation to National Parks. If a $50 000 initial charge were levied the average cost of production would increase by 5c/kg to $12.72/kg and the mean IRR would be slightly reduced to 13.0 per cent.

If extensive pond rearing of fingerlings does lead to the average price falling from 60c to 20c each the average cost of production would be about $1.70/kg lower. Similarly, if farmers could consistently achieve a feed conversion ratio of 1.7:1 the cost of production would be reduced by 75c/kg. As shown by the results in table 8, such variations in costs have a substantial effect on the profitability of barramundi farming. Improvements in survival rates also lead to markedly higher simulated IRRs. The average IRR for the farm model with free ranging fish increased by a half to 31 per cent with an average survival rate of 75 per cent For the sea cage model the effect of these increased survival rates was much more, with the average IRR doubling. Returns for the farm model using cages throughout the growout period in freshwater ponds also improved but are substantially lower than returns for the other growout techniques.

Table 7. Capital costs for barramundi farm models

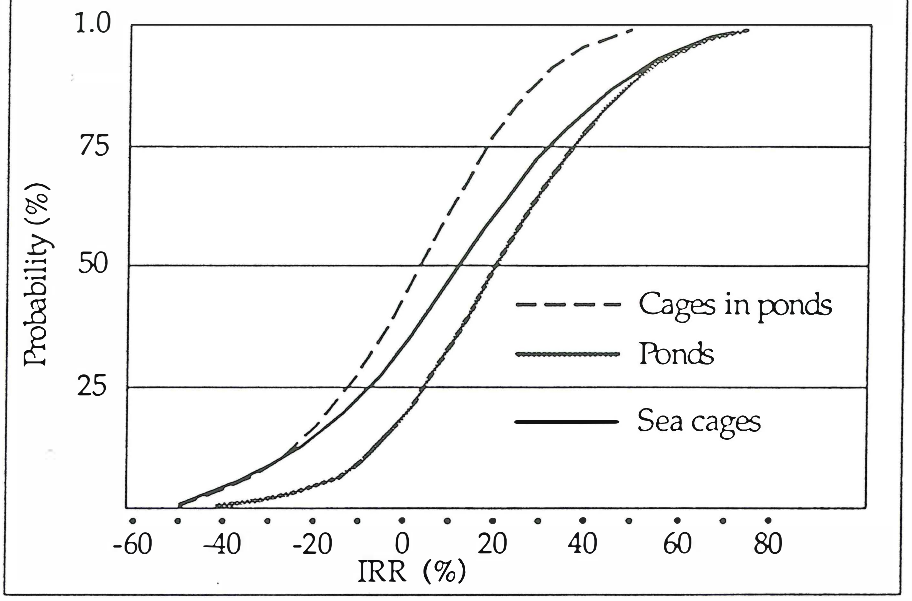
	Freshwater ponds				
Cost item	Caged (total cost) ($)	Free range (total cost) ($)	Sea cages (total cost) ($)	Scrap value (%)	Years of purchase (years)
Land	54 000	54 000	12 000		0
Earthworks	125 000	125 000			0
Electricity connection	20 000	20 000	20 000		0
Generator (standby)	8 000	8 000	8 000	10	0,10
Aeration pumps/aerators	25 000	22 000		10	0,5,10,15
Other pumps & motors	15 000	15 000		10	0,5,10,15
Piping	10 000	10 000			0,5,10,15
Cages – freshwater 8 m^3	125 000	10 000		5	0,5,10,15
Sea cages (incl. predator nets)			44 000	10	each 2–3
Nursery cages			30 000	10	every 3rd
Moorings & walkways	50 000	20 000	60 000	10	0,10
Jetty/pier			10 000		0
Storage barge			20 000	10	0
Boats	3 000	3 000	40 000	10	0,10
Crane			13 000		0
Safety and protective gear			2 000	10	0,5,10,15
Utility/truck	20 000	20 000	20 000	10	0,10
Backhoe	8 000	8 000		10	0,5,10,15
Motorbike	5 000	5 000		10	0,5,10,15
Mower	10 000	10 000		10	0,5,10,15
Feeding equipment	7 000	5 000	7 000	10	0,5,10,15
Testing equipment	3 000	3 000	3 000	–	each 3rd
Net & pond cleaning equipment	12 500	12 500	10 000	5	0,10
Harvesting equipment	2 000	2 000	2 000	–	1 & each 3rd after
Coolroom/freezer	15 000	15 000	15 000	10	1,11
Processing room	20 000	20 000	20 000		1
Processing equipment	5 000	5 000	5 000	10	1,6,11,16
Farm shed, incl. office	30 000	30 000	30 000		0
Miscellaneous	5 000	5 000	5 000		0,5,10,15
Total	577 500	427 500	376 000		

Table 8. Internal rates of return and cost of production for barramundi farm models

Farm model	Cost of production ($/kg)	Mean IRR (%)	IRR range 50% chance that IRR is: (%)
Freshwater ponds			
Cages for all growout	13.42	3.8	−12.2 to 17.5
– FCR 1.7:1	12.68	9.8	–4.2 to 23.6
– fingerlings at 20c	11.73	17.8	6.0 to 31.4
– price deflated 1.5% a year	13.42	-12.0	–37.1 to 14.7
– high survival rate (75%)	11.13	15.5	5.6 to 24.8
– high survival & falling prices	11.13	6.5	–36.8 to 17.3
Free ranging & nursery cages	11.64	19.6	4.7 to 36.8
– FCR 1.7:1	10.89	27.0	13.2 to 47.0
– fingerlings at 20c	9.95	35.8	22.8 to 50.8
– price deflated 1.5% a year	11.64	16.4	−19.6 to 34.2
– high survival rate (75%)	10.16	31.0	19.9 to 42.0
– high survival & falling prices	10.16	25.8	13.2 to 37.8
Cages in sea	12.67	13.6	–4.8 to 32.4
– FCR 1.7:1	11.92	16.5	–0.4 to 36.0
– fingerlings at 20c	10.98	27.8	12.0 to 47.0
– price deflated 1.5% a year	12.67	7.3	–25.1 to 25.5
– high survival rate (75%)	10.49	27.2	13.3 to 40.8
– high survival & falling prices	10.49	19.3	5.5 to 33.7
– with initial $50 000 charge	12.72	13.0	–4.4 to 31.2

There is a high degree of risk in barramundi farming as indicated by the range of IRRs (see figure 3). In addition, there is substantial uncertainty surrounding future market prices. Given the expected increase in cultured barramundi overseas and other finfish both in Australia and overseas, prices may well fall in the future. Also, to date supplies of fresh barramundi have been small and intermittent. Thus, if productivity improvements were achieved and returns improved as indicated in table 8 the supply of fresh barramundi would be likely to increase and consequently prices would be likely to fall. If prices declined continually by 1.5 per cent a year in relation to costs the average IRR with 75 per cent survival would fall to 25.8 per cent for the farm model with free ranging fish. Such a price decline resulted in the other two growout models being unviable, with a 25 per cent chance of returns falling below 6 per cent even with the higher survival rate. However, even these two techniques could be viable if both improved survival rates and lower fingerling costs are achieved. In all cases the estimated cost of production is above the price of imported frozen barramundi. This indicates the importance of maximising market returns, particularly by supplying high quality fresh fish rather than competing in the cheaper frozen fish market.

Figure 3: Barramundi farm models Cumulative probability of IRR



CONCLUSIONS

The results of the analyses indicate that prawn farming in north Queensland does have the potential to be profitable, even in the face of falling prices. But there are risks. Even for good managers on good sites the risks are substantial. The need to determine cost structures before commencing is evident. Also, the need to continually monitor market developments is crucial to the viability of the farm.

When growing barramundi entirely in cages in freshwater ponds, profitability of farming barramundi in north Queensland is not promising. However, the analysis shows that if barramundi are allowed to range freely in the ponds after reaching 150 mm profitability would improve substantially. So much so that this method is more profitable than raising barramundi in sea cages. However, as indicated by the range of IRRs, returns are very uncertain whichever technique of growout is employed. Given the high degree of risk and relatively low average rates of return barramundi farming has limited potential for expansion with current technology. But farming techniques for barramundi are changing rapidly. The two recent developments analysed certainly have increased expected profits significantly and have the potential to make barramundi farming viable. Recently, there have been many innovations adopted in the industry and further developments are likely in the future. In particular major labour saving techniques may be possible such as the successful modification of salmon graders or the feasibility of using larger sea cages. The potential for industry expansion could be further improved by such developments.

The results for the potential models presented in this paper are unlikely to be achieved by new farmers. These models are based on good management by experienced aquaculturists. Typically, there are teething problems encountered in establishing an aquacultural farm and, like any farming venture, husbandry skills need to be adapted to the particular circumstances. This is particularly true of barramundi farming as cannibalism can cause high mortalities unless due care is taken with setting appropriate stocking rates and feeding regimes.

The risk in returns is substantial for both prawn and barramundi farming in north Queensland. The risk facing new aquacultural industries could be expected to be even higher. If average returns are high this may compensate for very high risk. Given the high risks in aquaculture there could be high payoffs to research and extension which together can assist in reducing uncertainty and risk. The results presented in this paper imply more potential for expansion of prawn farming than barramundi farming with current technology and cost structures. However, there is possibly more scope for improving productivity in barramundi farming. Consequently, the potential average returns for prawns at around 25 per cent could be achieved with free range pond culture of barramundi even if only survival is improved.

Aquaculturists have more control over the timing, quantity and quality of supply and to realise this potential aquaculturists need to continually adjust production decisions to suit market conditions. For example, the results indicate the relative profitability of prawn farming for different stocking rates is quite sensitive to the level of price premiums paid for different sized prawns. Competition from imported cultured prawns and barramundi is likely to intensify in the future as world aquacultural output expands. However, Australian aquaculturists have an advantage in supplying fresh high quality products and supplying off-season to both wild fisheries and imported products. To capitalise on this advantage, aquaculturists need to pay particular attention to post-harvest handling and speed of distribution. This last factor may limit the expansion of aquaculture in north Queensland to regions with good transport links to major markets.

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Prospects for aquaculture

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■ *In the 1980s Australian aquaculture grew rapidly, but industry expansion is expected to slow in the 1990s.*
■ *There appear to be good prospects for expansion of aquaculture of several species, but sectors of aquaculture face some constraints.*
■ *Being a diverse industry, there are many and varied issues facing aquaculture. More coordinated efforts would facilitate the resolution of many industry constraints.*

The practice of farming aquatic animals is growing throughout the world. Between 1985 and 1988 the volume of world aquacultural production rose by 32 per cent to 14.6 Mt worth SUS22 500 million (FAO 1990). Asia is the world's largest supplier of aquacultural products, accounting for around 80 per cent of the total value of world production.

The Australian aquacultural industry also grew rapidly in the 1980s and the value of production reached S190 million in 1989-90 (table 1). This represented an increase in the four years to 1989-90 from only 7 per cent to 21 per cent of the value of production from the wild fisheries in Australia. Some of this recorded increase may be the result of better data collection since 1988-89 rather than actual increased production. Recently the growth in value appears to have slowed. The preliminary estimate of S218 million for the value of production in 1990-91 suggests an increase (net of inflation) of around 9 per cent in that year, compared with about 37 per cent a year over the four years to 1989-90.

Australian aquaculture has been dominated by the culture of pearl and edible oysters. This domination has declined, as indicated by the fall in the share of pearl and edible oysters in the total value of aquacultural production, from 76 per cent in 1988-89 to 66 per cent in 1990-91 (table 1). In the 1980s aquaculture in Australia became considerably more diversified. By 1991 about twenty species were being produced commercially, at least another eight species were at the pilot stage and many more species were under experimental development for aquaculture (table 2). Species being farmed in Australia include molluscs, crustaceans, finfish and reptiles. Both freshwater and saltwater species are in production from tropical regions in north Queensland to the southern tip of Tasmania. This diversity of species and regions is accompanied by a range of aquacultural systems of production — sea cages for finfish, racks or longlines for molluscs, and ponds filled with fresh, brackish or salt water for a variety of species.

Table 1: **Australian aquacultural production**

	1988-89		1989-90		1990-91 p	
	t	S'000	t	S'000	t	S'000
Pearls	na	64 500	na	96 500	na	112 500
Edible oysters	8 058	40 546	6 573	34 617	6 016	33 309
Mussels	660	1 322	747	1 669	706	1 699
Atlantic salmon	400	6 200	1 750	21 000	2 484	29 808
Trout – ocean	1 100	10 350	650	6 600	450	4 600
– freshwater	1 335	7 975	1 625	8 350	1 760	9 154
Barramundi	22	400	33	430	90	1 100
Native freshwater – fish	na	na	10	173	10	191
– fingerlings	na	na	na	2 715	na	2 722
Prawns	239	2 600	594	6 372	1 100	11 840
Freshwater crayfish	37	609	113	1 599	163	2 339
Crocodiles	na	773	na	1 364	na	1 906
Eels	na	na	271	1 692	273	1 700
Aquarium fish	na	na	na	828	na	882
Hatchery	na	na	na	2 660	na	2 443
Other	na	2 100	na	3 450	na	2 199
Total		137 375		190 0279		218 392

p Preliminary. na Not applicable or available.
Sources: State departments of agriculture and fisheries; Department of Primary Industries and Energy (personal communication).

Table 2: **Stage of development of aquacultural species**

Development stage	Species
Experimental	Lobsters, venerid clams, marine finfish (coral trout, flounder, mangrove jack, mullaway, schnapper, striped trumpeter, whitebait, whiting).
Pilot	Abalone, brine shrimp, dolphin fish, giant clams, machrobrachium, other native oysters, seaweed, tuna.
Commercial	Aquarium fish, barramundi, crocodiles, eels, freshwater crayfish, native freshwater finfish, micro-algae, mussels, prawns, salmon, trout, oysters (Pacific, pearl, ~~native flat~~ and Sydney rock).

The aim in this paper is to present an overview of the potential of aquaculture in Australia and to discuss some mechanisms open to industry and governments to facilitate the achievement of this potential. This paper is based on a major economic study of aquaculture which was undertaken in ABARE over the past two years. The results of this project are reported in more detail in Treadwell, McKelvie and Maguire (1991) and in an ABARE report to be released in 1992.

Market prospects

Demand for fisheries products on the world market is rising and it is expected to continue growing in the medium term. Although wild fisheries are not expected to supply this growth, increasing competition is likely from aquacultural products from other countries. For example, Japan is the largest importer of the world's fisheries products but Australian exports of aquacultural products to Japan would face strong competition, particularly from well established aquacultural industries in nearby Asia. Such competition is the main obstacle facing Australian exports to other Asian markets, although there may be some scope for exports of temperate species. High tariff barriers and high transport costs will limit Australian exports to European markets. Although the United States is a large fisheries product market it has a rapidly expanding local aquacultural industry.

Given the established nature of aquaculture in many other countries and the high transport costs facing Australian exporters it is unlikely that the majority of Australian aquacultural products will be price competitive on the world market, at least in the short term. For this reason exports are likely to be limited to high quality products with a high value to weight ratio and available during periods of low supply from competitors. One example, developed during the late 1980s, is exports of live prawns to Japan.

The domestic market offers the best prospects for Australian aquacultural products. During the past decade increasing health consciousness of consumers and rising incomes were the major factors leading to increased consumption of fisheries products. Recently market growth has slowed because of the downturn in economic activity. In the 1990s demand for fisheries products is likely to increase but at a slower rate than during the 1980s, mainly because of expected moderate increases in income as economic activity recovers over the medium term. During the next five years catches from Australian wild fisheries are not expected to rise because most wild fisheries are fully exploited. Therefore, market opportunities for many aquacultural products are expected to improve. Also, aquaculturists have a marketing advantage over wild fisheries suppliers because aquacultural production can be more easily controlled and predicted. Although there is strong competition from imports for some products, such as Asian farmed prawns and frozen barramundi, Australian aquaculturists do have an advantage in supplying fresh fisheries products to the local market. This advantage derives from Australia's distance from alternative supplies. There is an additional opportunity for Australian aquaculturists to supply fresh product during competitors' off seasons.

Potential of aquaculture in Australia

To determine potential and future directions of aquaculture individual species need to be assessed and ranked according to a set of criteria. The criteria used in this assessment necessarily encompass all aspects of aquaculture — the availability of stock, the biological suitability of species, availability of sites, cost structures, returns and market prospects. In assessing the species, particular attention was given to the major constraints in culturing the species and to areas where Australian aquaculturists may have an advantage over competitors in the markets. The overall assessment is designed to identify potential for development of an aquacultural industry based on that species. An above average rank is assigned to species for which aquacultural expansion is expected to exceed growth in economic activity. Species which rank poorly should not necessarily be viewed as being undesirable; there may be potential for some commercial production but the prospects for the establishment or expansion of an industry are considered to be low.

The species which appear to have the best prospects for industry expansion are Pacific oysters (particularly in Tasmania and South Australia) and, in northern Australia, redclaw and saltwater crocodiles (table 3). Each of these is considered to be able to generate good returns at low risk with few provisos. The main constraint on Pacific oysters will be the availability of good growth sites although adequate returns are possible from poorer sites. The realisation of growth

Table 3: **Potential of aquacultural species**

Potential	Species
Good	Pacific oysters, redclaw, saltwater crocodiles.
Above average	Aquarium fish, barramundi, brine shrimp, native freshwater finfish fingerlings, pearl oysters, prawns in tropics, scallops, seaweed, silver perch.
Average	Abalone, giant clams, golden perch, micro-algae, mussels, salmon, yabby.
Below average	Crabs, marron, Murray cod, Sydney rock and other native oysters, trout (freshwater), tuna.
Poor	Eels, catfish, freshwater crocodiles, machrobrachium, ocean trout, prawns in subtropics.
Experimental	Lobsters, marine finfish, venerid clams.

of the crocodile industry depends on the success of breeding programs to overcome the critical constraint on the availability of saltwater crocodile stock. For redclaw, potential hinges on the success of marketing efforts in developing market outlets.

Aquarium fish, brine shrimp and seaweed culture could also have good potential if operations were larger. A large operation would be necessary to develop export markets which require a reliable supply in large quantities of consistent quality. Although there is the potential to generate high average returns from growing barramundi and prawns in tropical areas, there is a high level of risk associated with returns from farming these species. The risk in barramundi farming arises from the low and variable survival rates of the fish. Returns to prawn farming are also variable because of the sensitivity to prices, which are volatile. Potential for both these species will be limited to the higher value domestic market because of fierce competition from Asian cultured product. Scallops have good market opportunities but expansion of scallop aquaculture could be hindered as production techniques have yet to be proven reliable and cost effective on a commercial scale. Growth of the pearl industry is expected to be slower than in recent years. This slowdown is expected as any substantial increase in Australian pearl production is likely to result in lower prices and there is also some constraint on the availability of oysters for culturing. Therefore, growth in the pearl industry is unlikely to exceed the rate of economic growth in the major markets.

There seems little potential for expansion in the aquaculture of eels, freshwater crocodiles, machrobrachium, prawns in subtropical areas or rainbow trout in ocean water because returns are relatively low with high risk. The culture of rainbow trout in freshwater has slightly better prospects than culturing the species in the sea, as the former has less risk and additional markets for eggs and fingerlings. Prospects for the Sydney rock oyster industry are below average unless improvements in sites and technology are achieved to raise profits and the image of the product is improved in markets. Native oysters, other than Sydney rock oysters, have little more potential for expansion principally because of slower growth compared with Pacific oysters. Development of crab growout technology is effectively being held back by lack of growout stock, but if this constraint were overcome culture of mud crabs could progress.

Although redclaw appears to have good prospects for growth the other freshwater crayfish species do not appear to be as suited to aquacultural production. Both marron and yabbies are slower growing than redclaw and also need to be stocked at lower densities. Consequently, the profitability of farming marron or yabbies is likely to be lower than that of redclaw. Yabby production is expected to increase more than marron principally because of supplies from extensive growout of yabbies in existing farm dams. Of the native freshwater finfish, silver perch appears to have the best prospects for growout to plate size. There is reasonable potential for some expansion of the fingerling market for all native freshwater finfish species.

The potential of other species is rated as average because expansion is being hindered to varying extents by one or two constraints. For example, although growth in the salmon farming industry has been rapid in the past five years, future substantial expansion is expected to be hindered by the prospect of much slower market growth, unavailability of further suitable inshore sites and costly production problems (which some trials have successfully overcome). Mussel culturing is also constrained by lack of market opportunities and production problems with only low yields being achieved. The lack of a cheap artificial feed is holding back growth of abalone farming. If this constraint were overcome expansion prospects would be good due to market opportunities. Whereas markets and a long growout period are problems for the giant clam industry, culture of other clams is only at an experimental stage.

Other than for the salmonids and barramundi, research on aquaculture of many of the marine finfish has only begun in recent years and is still in the experimental stage. The exception is dolphin fish which has been produced in pilot scale facilities and there are some moves to commercialise the growout of this species. Because research is still in the experimental stage, it is too early to determine which species will be able to be successfully mass bred, reared and marketed at a reasonable profit. Also, given the very long lead times experienced in developing some marine finfish aquacultural industries in other countries, commercial production of these species in Australia may not occur until next century.

Overall, there would appear to be potential for Australian aquaculture to continue expanding over the coming decade. At least some expansion will result from recent investments in the industry and expected improvements in farm productivity. The rate of growth will be largely determined by the success of marketing efforts to substitute aquacultural products on the domestic market and to develop profitable export markets. The phenomenal growth of aquaculture has recently slowed and it is unlikely that the very high rate of growth will be resumed from the much higher base. If, as expected, economic growth recovers during the coming five years this could add impetus to growth of aquaculture through increased market demand. Taking into account these factors and the assessed prospects for each species, the value of aquacultural production in Australia is likely to reach S300–350 million by 1995-96 (in 1990-91 dollars). This represents a growth rate (net of inflation) of 7–10 per cent a year over the five years, which is a little more than double that expected for the Australian economy, and contrasts markedly with wild fisheries supplies which are not likely to increase over this same period.

Major issues

For the industry to achieve the full potential indicated by the assessment of each species there are many issues which need to be resolved. The diversity of aquaculture has resulted in a wide range of issues and problems facing the industry. These include delays in licensing, obtaining finance, environmental conflicts and marketing the product. The problems currently confronting Australian aquaculture fall into four main categories — infrastructure, environment, marketing and research.

Some progress on the myriad of issues facing aquaculture has been made over recent years, particularly those concerned with infrastructure. For instance, supply of inputs, including suitable labour, is now more readily available and the licensing procedure is less protracted in some states. But more progress on the remaining problems is needed for the industry to reach its full potential. For example, licensing procedures could be shortened further if governments were convinced of the benefits in developing and coordinating policies between the relevant authorities and in publishing guidelines for industry.

Although some areas of research are receiving attention (such as biological research), other pressing needs such as extension services and research on market requirements and prospects have lagged behind industry requirements. Market research is particularly important for many species as potential expansion relies on identification and successful development of markets.

Little progress has been made on environmental issues. This is unfortunate as the availability of suitable sites may be a constraint on growth of some sections of aquaculture. The industry has not adequately drawn attention to or sought for a solution to the effects that pollution can have on production. This is a pressing need for the Sydney rock oyster industry. On the other hand, aquaculture can be a source of waste, which is recognised both within and outside the industry, but there have been few attempts to develop codes of practice in an attempt to minimise environmental impact.

The scope for environmental impact problems, and the potential for conflict with other users of water resources, varies with the type of aquacultural technology used. In the case of marine aquaculture (mariculture) the production process takes place within the public water resource. Here it is not possible to isolate the effects of the culturing activities from the marine environment, such as excessive feed or other nutrients. On the other hand, as land based aquacultural systems are physically isolated from the public water resource, there is more scope to avoid the effects of pollution on public water resources and on aquaculture itself. For instance, while the water used in aquacultural ponds and tanks is returned to the public waterway, the point of intake and discharge is easily identified and can be monitored. Mechanisms, such as settling ponds, can be employed to reduce the amount of pollutants entering or leaving the aquacultural system.

Role of government

The current work in developing a national aquacultural strategy, as well as strategies being developed for some states, shows the active interest governments have in aquaculture. Governments should focus their roles in terms of ensuring that aquacultural development has net benefits to Australia. To this end the role of governments should be concerned with the efficient working of markets to allocate resources.

In relation to aquaculture there are three areas in which government may need to intervene to improve the allocation of resources — non-paying users who cannot be excluded from the service (free-riders), the use of public resources (such as water) and external effects (for example the discharge of polluted pond water into waterways). Governments have in the past concentrated on research (to negate the free-rider problem) and licensing of projects to secure some control over the impact of the industry on the environment. Governments at all levels need to recognise that aquaculture is not fisheries or agriculture and growth of aquaculture will lead to problems unique to that industry. Such problems include the effects of discharge of pond water and sea cage culture on the marine environment and the effects of water quality on aquaculture. Resolution of these problems may require a different approach since aquaculture produces many of the same products as the fisheries industry but uses production processes more akin to agriculture.

There is potential for conflict between aquaculture and other users of water resources. Yet there have been few coordinated attempts to resolve these conflicts. In some states, aquacultural zones in public waterways have been defined and declared for use by aquaculture with exclusion of other conflicting uses. Such an approach has the potential benefits of reducing conflicts and time for approval of applications. The declaration of aquacultural zones (and conversely zones to exclude certain aquacultural activities) could assist in ensuring aquacultural development has net benefits overall, provided such zonings are based on an assessment of the net benefits from alternative uses and complete surveys. These surveys need to fully assess sites in regard to all potential uses, water flow, depth, nutrient supply and pollution issues. In addressing pollution issues associated with aquaculture it should be remembered that while aquaculture produces unwanted by-products itself, pollution can adversely affect aquacultural production.

The charging for water use and/or discharge by aquaculturists is in place in at least some states. In general, to ensure the nation's resources are employed in the most valued uses governments need to set charges consistent with costs and the distribution of benefits and combine these charges with transferable rights to a resource. Such charging policies need to be based on an objective assessment of the cost of provision of water and the cost to public water resources of the quality of water discharged, whether through pipes from land based facilities or through sea cages or other marine facilities. This should entail monitoring of water quality not only at the point of discharge to ensure that recommended quality standards are being met but also at the intake point or surrounding water areas as a warning to users of potential hazardous pollution.

Another aspect in which governments have a traditional role is in the provision of infrastructure. The needs of aquaculture certainly have to be assessed along with other industries and sectors of the economy to provide a basis for decisions by governments, at all levels, regarding the provision of services, such as education and transport networks. A continued role is envisaged for governments in research because of the public good aspect of some research. Also, it is desirable to avoid duplication of effort and free-riding, not only within aquaculture but across other similar industries such as the wild fisheries sector. The setting of priorities in aquacultural research needs to be assessed together with industry so that those research projects with potentially the highest net benefits are undertaken.

The way ahead

Arguably the most successful 'new' aquacultural industry has been salmon — it has grown from nothing in 1985 to be worth almost $30 million in 1990-91 and is now the largest of the new aquacultural industries. Although the industry has faced several previously unforseen problems (for example, weakening markets and biofouling of nets) significant progress in solving these problems has been achieved through industry research, promotion and product development. The salmon industry in Tasmania is characterised by a strong industry focus through Salmon Enterprises of Tasmania which has research and advisory roles in addition to providing the central hatchery for the industry. In contrast, many other industries have been characterised by individual endeavour and although there are many species and regional associations their roles are limited. Indeed, many aquaculturists in Australia have been secretive and not realised that in most cases their problem was common across the industry.

The implication is that an industrywide approach would be preferable for the resolution of common industry problems. This is not to say that it is unwise for individual aquaculturists to pursue their own approach. Such individual endeavour is necessary but more can be achieved if, on common problems, a more coordinated approach is taken. For example, individuals need to analyse their own particular circumstances but can benefit from using industrywide research results regarding general production techniques and market trends. As mentioned above research is often coordinated across an industry to negate the free-rider problem and in addition each individual often has not sufficient resources to undertake the necessary research. Consequently, an industrywide approach can reduce the overall cost of research and ensure that necessary research applicable across the industry is undertaken.

An industrywide approach can be beneficial in attempting to solve many issues. The question is how wide should the coordination be — across a species or across the whole of aquaculture. The answer will vary with the issue. Although spreading the costs of resolving an issue across the whole of aquaculture would be cheaper for each individual, it is imperative that all within the association (and hence paying the costs) can stand to benefit. Consequently, and because aquaculture is diverse, there are some issues which would be best addressed on a species basis.

A specieswide approach to developing codes of practice would be more sensible given the different technologies and species being produced. Because of the many different types of products any coordination of marketing efforts, such as coordinating large sales, promotion, distribution and handling practices, would be best undertaken on a species basis. Priorities for research and the requirements for infrastructure and services such as specialised training, inputs and processing, would also need to be initially assessed on a species basis. However, there is merit in coordinating any approach to government and other agencies and this could be better undertaken on an industrywide basis so as to avoid unnecessary duplication. This would assist in sorting out any conflicts between species. For example, although the site requirements may differ between aquacultural species and technologies, there is likely to be some overlap which could result in some conflict within aquaculture. Also, similar research would be required in determining site availability.

Resolution of issues in environment, licensing, taxation, finance, research priorities and funding would benefit all aquaculturists and could therefore be most efficiently undertaken by a larger industrywide organisation. Thus it is important that the many species–regional aquacultural associations work toward not only strengthening their own association but also forming an organisation which represents all aquacultural associations.

The final question is whether aquaculture should be associated with wild fisheries or agriculture. The advantage of the latter is the similarity in production processes. There are probably more benefits to be gained from association with wild fisheries — similar products are produced by both industries but also there are possibilities for mutual advantage. For example, biological research has benefits for both culturing and managing a fishery of the species. Some aquacultural industries and much of the experimental development depends on captured broodstock. Also, aquaculture could be a source of stock for reseeding or restocking programs for depleted wild fisheries.

Conclusion

Aquaculture in Australia has just been through a period of rapid expansion and its value of production reached an estimated $218 million in 1990-91. But there is some evidence that growth is slowing. In the medium term the industry will continue to grow because of recent investment in the industry, likely improvements in farm performance and expected economic recovery. By 1995-96 Australian aquaculture could be worth around $300–350 million (in 1990-91 dollars), which represents a real growth rate of 7–10 per cent a year. Much of this growth is likely to come from expansion in the farming of Pacific oysters, redclaw, saltwater crocodiles, pearls, aquarium fish, barramundi, brine shrimp, native freshwater fish, prawns, scallops and seaweed. The key to facilitating the achievement of the potential growth of aquaculture is in more coordinated efforts by industry and governments to resolve the major problems facing the industry.

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Markets and market development for aquaculture

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The culture of oysters was established in Australia in the 1800s, and the aquacultural industry was reasonably stable, and remained principally based on oysters, until the 1980s. In that decade aquaculture in Australia began growing rapidly, with many other species now being cultured using a variety of new techniques. More than 60 species, including salmonid, prawn, crayfish and crocodile species, are now being cultured on either a commercial, pilot or experimental scale throughout Australia. The techniques used in aquaculture vary according to the species cultivated, and range from cages, trays and baskets in the sea to earthen freshwater ponds. Provision for breeding of stock also varies between species, with some dependent on wild spawnings whereas others have captive breeding in ponds or specialised hatcheries.

Given increasing market demand and the existing investment in the industry, aquacultural production in Australia is expected to continue increasing at least over the medium term (Treadwell and McKelvie 1991). Continued expansion in the longer term depends not only on continuing market growth but also on the industry achieving a competitive basis. In this paper the focus is on the market opportunities for Australian aquaculture and how best to realise the potential for the industry through market development and research.

Industry situation

In 1989-90 the gross value of aquacultural production in Australia was an estimated $179 million, around three times as much as in 1985. Every state in Australia is involved in culturing at least one species on a commercial scale (table 1). Species farmed in each state are determined largely by climatic conditions. For example, in Tasmania temperate species such as salmon and trout are grown.

Table 1: Value of aquacultural production, 1989-90

	$'000	**Major species**
New South Wales	29 179	Oysters
Victoria	10 614	Rainbow trout, mussels
Queensland	8 616	Prawns, crocodiles
Western Australia	90 544	Pearls, freshwater crayfish
South Australia	652	Oysters
Tasmania	37 115	Salmonids, oysters
Northern Territory	2 000	Crocodiles
Australia	178 720	

Sources: State departments of agriculture and fisheries; Department of Primary Industries and Energy.

Western Australia has had a highly valued pearl oyster industry for many years. It was estimated that in 1989-90 the output of this industry was worth around $90 million, just over half of the total value of aquacultural production in Australia. Although pearl oysters account for almost all the value of aquacultural production in Western Australia, there are other species being commercially cultivated such as freshwater crayfish. Tasmania has the second highest value of aquacultural output, contributing just over 20 per cent to the total value of production in 1989-90. The value of Tasmania's industry has risen considerably over recent years. This increase is largely attributable to the recent development of the sea cage-based salmonid industry. In 1985 this industry had not achieved its first commercial harvest; in 1989-90 it produced 2 400 t of ocean-grown salmon and trout (table 2) with an estimated value of almost $28 million.

With the recent rapid growth in output and production of highly valued species, the value of aquacultural production has risen from around 9 per cent of the value of the wild catch in 1985-86 to almost 25 per cent in 1989-90 (figure 1).

Domestic market opportunities for aquacultural products

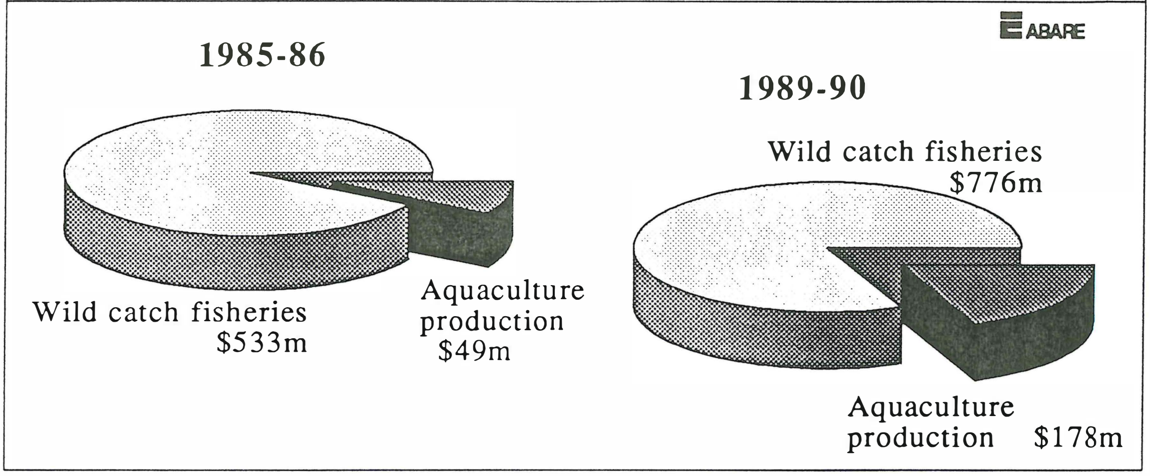
Aquaculture produces a diverse range of products aimed at a variety of markets, including the human food market, apparel and accessories (for pearls and crocodile skins), food additives and pharmaceuticals (seaweed, algae), and even the aquacultural industry itself (microalgae and fish feed). As most aquacultural products are supplied to the human food market, the focus in this paper is on that market — that is, the fish products market.

Table 2: Australian aquacultural production — selected species

	1985	1988-89	1989-90
	t	t	t
Edible oysters	7654	7430	6582
Mussels	154	686	714
Atlantic salmon	0	400	1750
Ocean trout	0	1100	650
Rainbow trout	974	1518	1631
Barramundi	2	22	33
Prawns	28	470	594
Freshwater crayfish	9	66	86

Sources: As for table 1.

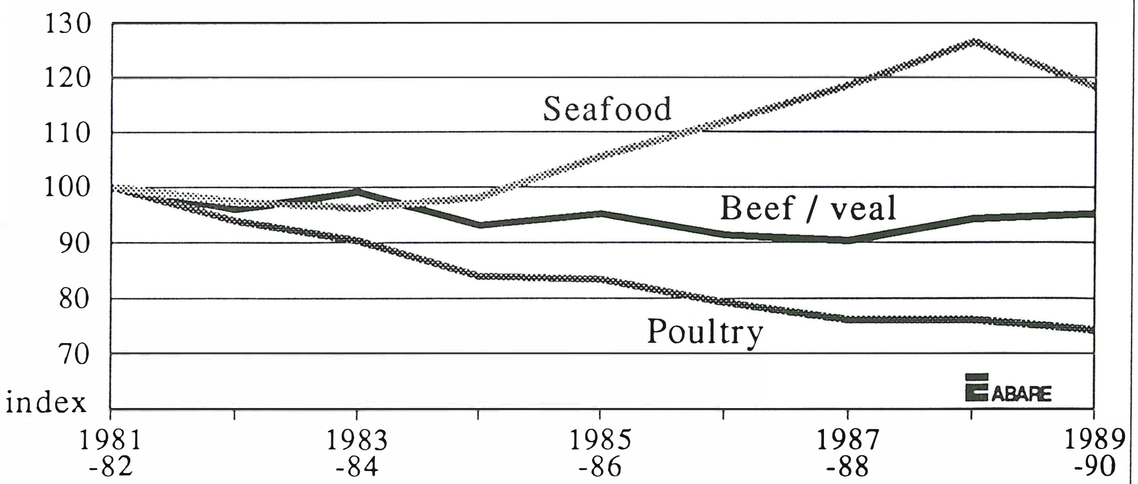
Figure 1: **Value of Australian fisheries production**



However, many points made in relation to products that go to the fish products market are also relevant to other aquacultural products. For example, as aquaculture is expanding worldwide in virtually all cultured species (and more species are likely to be cultured in the future) competition is likely to intensify in all aquacultural markets. Also, research and market development requirements are common across a range of products.

Past studies (Bockstael 1977; Pascoe, Geen and Smith 1987; Bjorndal 1990) have indicated that demand for fisheries products tends to be responsive to their price. That is, if the price of a product increases then the quantity of it demanded falls. During the 1980s (see figure 2) prices for fisheries products rose relative to inflation and to the prices for some major competing sources of dietary protein (Australian Bureau of Statistics 1991). Thus it is reasonable to expect that the consumption of fisheries products would have fallen over this

Figure 2: **Retail price changes, net of inflation**



period. In fact, consumption of fisheries products per person in Australia did not exhibit any consistent downward trend but fluctuated, rising to a peak in 1984-85, declining, and then rising above the previous peak in 1989-90 (table 3). (The fall in consumption of fisheries products by 13 per cent in 1982-83, when prices were falling, was due to canned salmon imports being recalled, not because of reduced demand.) Overall, apparent consumption per person of fisheries products (liveweight) in Australia increased from 15.1 kg a year in 1981-82 to 17.9 kg a year in 1989-90, an average annual increase of almost 3 per cent.

It is possible that greater consumer awareness of the health benefits perceived as inherent in fisheries products, and increased incomes, have prevented a decline in the consumption of fisheries products in the face of increasing prices. Generally, consumers have become more health conscious and are more concerned with the quality of the food they consume in regard to cholesterol, disease organisms, pollutants and chemical residues.

On the Australian market, competition with aquacultural products comes from wild fishery supplies, and a large component is supplied by imports. Since 1986-87 total imports of fisheries products to Australia have been around $400 million a year. On the domestic market Australian producers do have the advantage of some natural protection afforded by the distance from major producers, which increases the landed price of imports and reduces the ability of overseas producers to supply fresh product. Australian aquacultural products, if they can be price-competitive, have the opportunity to replace a proportion of imports.

Table 3: Apparent fish consumption per person in Australia

	All fish products	Fish	Crustaceans and molluscs
	kg	kg	kg
1981-82	15.05	12.02	3.01
1982-83	14.45	10.45	3.98
1983-84	16.91	13.31	3.57
1984-85	17.82	14.16	3.62
1985-86	16.94	13.61	3.32
1986-87	16.67	13.50	3.18
1987-88	16.90	13.83	3.09
1988-89	17.08	13.11	4.01
1989-90	17.87	13.95	3.92

Source: ABARE (1990).

Mussel imports, for example, have more than doubled in the past three years, from 381 t in 1987-88 to 828 t in 1989-90. This increase in imports is largely in response to reduced supplies from the Australian wild fishery and increased demand for fisheries products. In 1989-90 Australian mussel producers were selling mussels at the farm gate for $2.20/kg, whereas the wholesale price of imported mussels was almost $3/kg. The major reason for the difference in price is size — imported mussels are much larger than the domestically produced mussel. Marketing studies in Victoria have suggested that the taste of the Australian produced mussels is preferred to the imported product (Cox 1989). Thus, if Australian producers can expand production and market a reliable supply of a quality product of the size preferred by the domestic market, the opportunity exists to replace imports.

Australian producers may have the option of supplying the domestic market at times when alternative supplies are low. Prawn and barramundi farmers, for example, could time production to take advantage of the seasonal fluctuations in fresh supplies from the domestic wild catch and imports. However, as culture of both these species is expanding in Asia, strong competition from imports is likely to continue. Market demand is also seasonal, so that off-season supply may not always attract higher prices. The nature of demand and seasonal price fluctuations for the particular species need to be studied before commitments to off-season supply are undertaken.

Australian producers are developing farming techniques for several native species, such as freshwater crayfish, for which there is currently no commercial wild fishery or competing imported product. The growth of such industries will be dependent upon the success of marketing efforts in developing niche markets and substituting these new unique products for other foods, including other aquacultural and fisheries products.

The world market

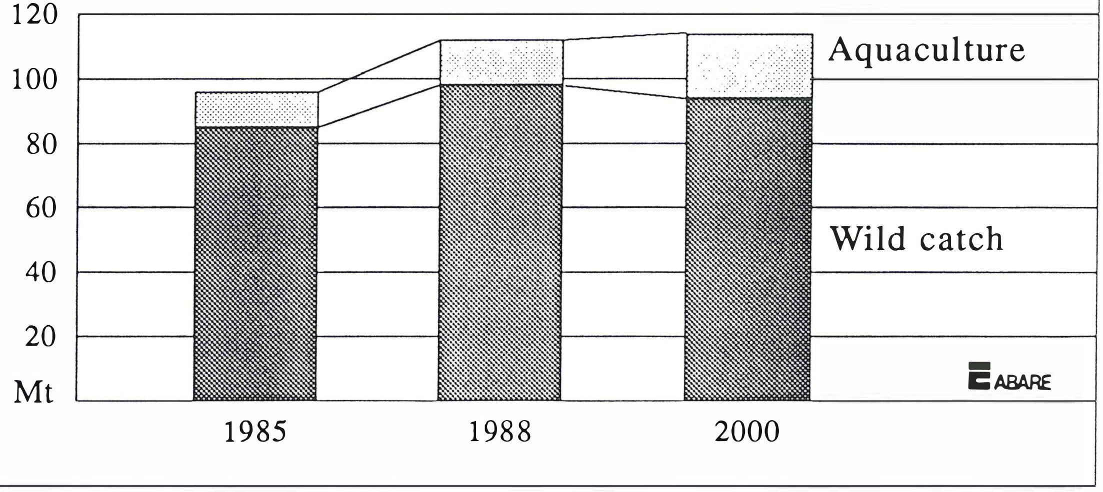
According to the United Nations Food and Agriculture Organization (FAO), annual world consumption of fisheries products per person increased by 9 per cent between 1978–80 and 1984–86, from 11.5 kg to 12.5 kg (FAO 1990b). As demand throughout the world has grown, increasing strain has been placed on the traditional sources of supply. The world catch of all species from the wild more than tripled between 1950 and 1970, but from 1970 to 1988 the increase slowed, rising only 39 per cent in the period (FAO 1990c). The FAO has projected that world production from wild fisheries in the year 2000 will amount to 94 Mt. On the other hand, current global trends indicate — assuming no real price change —

that demand could reach 114 Mt (Siegel 1989). The resulting shortfall of 20 Mt represents an opportunity for aquacultural production (see figure 3).

Although the world demand for fisheries products is expanding, total world aquacultural production is also growing. From 1985 to 1988 the value of world aquacultural production increased by 70 per cent, to about US$22 500 million (FAO 1990a). The largest production region is east Asia, with China and Japan accounting for more than 55 per cent of the total value of world aquacultural production in 1988.

Aquacultural industries are established near many of the major fisheries markets. For example, east Asia and the United States already have well established aquacultural industries. The opportunity for developing exports of Australian aquacultural products to the United States appears limited, due largely to the expanding local industry (Treadwell and McKelvie 1991). However, there is an opportunity for exporting temperate species to Asia, particularly to the newly industrialising countries which have strong growth in both income and seafood consumption (Treadwell and McKelvie 1991). There may be opportunities in the Japanese market for Australian aquacultural products, particularly for high value fresh or chilled products or for specialty products for particular market niches (Kingston, Battaglene, Smith and Beare 1991). However, Australian exports to Asia would face strong competition from local producers and from countries such as Norway and Canada which already have well established aquaculture industries. In meeting this competition, Australian suppliers can capitalise on advantages such as Australia's relatively clean environment and disease-free status. These factors have proved advantageous for Tasmania's salmon producers, who exported almost 1200 t to Japan in 1990-91 at premium

Figure 3: **World fisheries market: recent and projected**



prices (Julian Amos, Executive Officer Salmon Growers Association, personal communication, April 1991).

Overall, it appears that the world market for fish products is expanding. As the Australian industry is still in the developmental stage, it is unlikely that it will be price-competitive on the world market in the short term. Opportunities may exist to supply markets off season when prices are higher, or to supply high value markets, such as the European crayfish market.

In view of the established nature of aquaculture in many countries and the higher transport costs facing Australian exporters, the best potential for Australian aquacultural products is probably in Australia, at least in the short term. On the domestic market there is an opportunity for Australian aquaculturists to fill the gap in the market by supplying fresh product off-season. In addition, there is an increasing demand for high quality fish products due to rising incomes and the increasing health consciousness of consumers.

Developing the market

Successful marketing depends on knowing what consumers want and being able to present it in the appropriate form, at the right place and when it is most needed, in a reliable and consistent manner. The marketing process is quite complex, involving a number of specialised functions including promotion, presentation and packaging, transport, handling, storage and quality control. In addition, each aquacultural product has different characteristics (such as its seasonality, perishability, size and quality grade) which affect the marketing strategy that can be adopted. However, in comparison with wild fisheries, aquaculture has a distinct advantage in having more flexibility in choosing a marketing strategy, due mainly to the fact that its output is more controllable and predictable both in terms of timing and type of product.

Product supply

The first step in developing a market is to determine what consumers want — that is, the type of product and the likely prices and quantity. With such information producers are more likely to supply a product in a form which would attract higher demand and hence higher prices. Compared to wild fisheries, aquaculturists can control and predict their output with more certainty, in terms of timing, quantity, size and quality. Consequently, aquaculturists would be better able to enter into forward contracts than the wild fisheries suppliers. This is a distinct advantage in developing many market outlets. Being able to plan the harvest in terms of time, quantity and quality (although with some risk), aquaculturists can more easily market their product directly to restaurants and other market outlets. For those species for which year-round supplies are possible it would be feasible to establish a market for fresh product through supermarkets, which generally require supplies on a planned, consistent, year-round and standardised basis.

In the development of markets for a new small industry, coordination of sales across producers may in some cases be the only option. Buyers, particularly those for export markets, often demand consistent supplies of a quantity larger than can be met by an individual producer. Just as importantly, suppliers need to be careful not to develop the market more quickly than supply can respond. Although such premature market development may result in high prices in the very short term, these may well encourage competitors who could establish in the market and force out the original suppliers.

Distribution

Aquaculture producers have an opportunity to supply top quality fresh fisheries products — not marred by netting and other catching equipment or spoiled by the longer distribution times to which imports are often subjected. To capitalise on this potential advantage aquaculturists need to pay particular attention to post-harvest handling and quickness in distribution, and to developing appropriate distribution techniques.

Efficiency is just as imperative in distributing the product as in the production process. Due to the perishable nature of many of the higher valued aquacultural products, it is important that the distribution network is not prone to avoidable delays. There is an established marketing network for the wild fisheries which — it might be thought — the aquaculturists could link into and thereby avoid the costs of establishing new infrastructure. Whether, in any particular case, this existing network is appropriate depends mainly on the market that the aquaculturist wishes to supply and on the location of production in relation to the fish markets. In most cases the existing market infrastructure is inappropriate. Many aquaculturists are aiming at the high value and/or off-season markets for which the existing wholesale fish markets may not be as suitable as more direct marketing channels. Also, aquacultural producers are in many ways more akin to agriculturalists, and could benefit more from alternative marketing mechanisms such as forward contracts than from the existing fish auction marketing systems. If alternative distribution networks need to be established, a species-wide approach may result in lower costs per producer than separate attempts by individual suppliers.

Just as important as supplying the right product is getting it to the right market. Producers and selling agents require detailed market information — indicating not only average prices but also any price differences between markets and over time.

Time

The wild fisheries are becoming more controlled in regard to seasonal closures and allowable catch. Conversely, aquaculture could conceivably supply species at any time — within the limits set by breeding seasons, climatic conditions and hatchery technology. Hence, aquaculture may have the opportunity to produce when supplies from wild fisheries are low and prices are relatively higher. Not only do prices fluctuate throughout the year, but for some species sold in fresh form they tend to fluctuate during the week. Whereas wild fisheries are restricted by the variable wild supply, aquaculture has a captive supply base and has the capacity to supply on particular days.

Presentation

Packaging is an integral part of the marketing process in relation to promotion and presentation. It also makes an important contribution to marketing by minimising or avoiding damage and waste during transport, handling and storage, and reducing handling time and cost. The type of packaging required depends on factors such as the type of transport, time to destination, amount of handling, type of storage and rate of deterioration of the product. Unitisation of packaging across a species or industry (that is, standardising the units of size and weight) can generate benefits by reducing both packaging and distribution costs. The cost of packaging needs to be assessed against these benefits.

Quality

All of the above factors can assist greatly in successfully selling a product, but to secure a place in the market and to maximise returns suppliers need to ensure consistent quality and reliability. In the nature of aquaculture, it should be easier to ensure quality and reliability than in the wild fisheries. Aquacultural producers are able to ensure a lower variability in size within a harvest than fisheries operators. This confers a distinct quality advantage. In regard to how consistency of quality can be indicated to the buyer, producers have two main options. First, individual producers could use brand names to distinguish their products. The other option is a species-wide approach such as is employed by several primary production industries (for example meat and wool). This approach involves the use of species-wide grading standards together with industry logos. The success of this approach depends principally on the institution of a quality assurance scheme across the whole industry, as there can be substantial negative impacts if individuals are able to use the logo on product of lower quality than it implies.

Promotion

Small producers may find it difficult to promote their product effectively. Those producers who do advertise their product but do not differentiate it from that of others may find that they cannot prevent others from reaping the rewards. Promotion will generally offer the greatest benefits if the product is differentiated from competing products, whether imports or wild catch (Peterson 1991). For a small industry such as a sector of aquaculture, regional promotion campaigns with differentiated products may generate net benefits, as was achieved by the 'Health Fish Fest' in Sydney (Battaglene, Geen and Simmons 1991).

It may be possible for Australian aquacultural products to be distinguished on the basis of species native to Australia or by the use of brand names or logos. The use of industry logos would need to be linked to a quality control scheme, as mentioned above, to assure buyers of consistent quality. Reference to quality attributes such as Australia's relatively pollution-free environment, and disease-free status in relation to fish, could be advantageous in the marketing of Australian aquacultural products, given that consumers worldwide have generally become more health conscious.

Promotion, however, is more than merely advertising the availability of the product. To develop a market, it is necessary to inform consumers not just as to the availability of the product but also about its seasonality, selection and use, as well as creating an image for the product. Some aquacultural production is of species which have been largely unknown on the Australian market — for example, freshwater crayfish, mussels and, until recently, fresh salmon. Indeed, the salmon growers have recognised the need to develop their market by promoting the product to consumers through an industry-wide campaign. It is also important that consumers are able to distinguish products with desired features or grades so that once having tried a product the consumer is able to return and purchase it again. This is where quality control becomes important. There is little advantage in teaching consumers how to distinguish quality and features if, when they return to purchase the same product, the quality they obtain is different. It should be remembered that unless the product can be differentiated from substitutes there may be no benefit in promoting the product in any fashion.

Market research

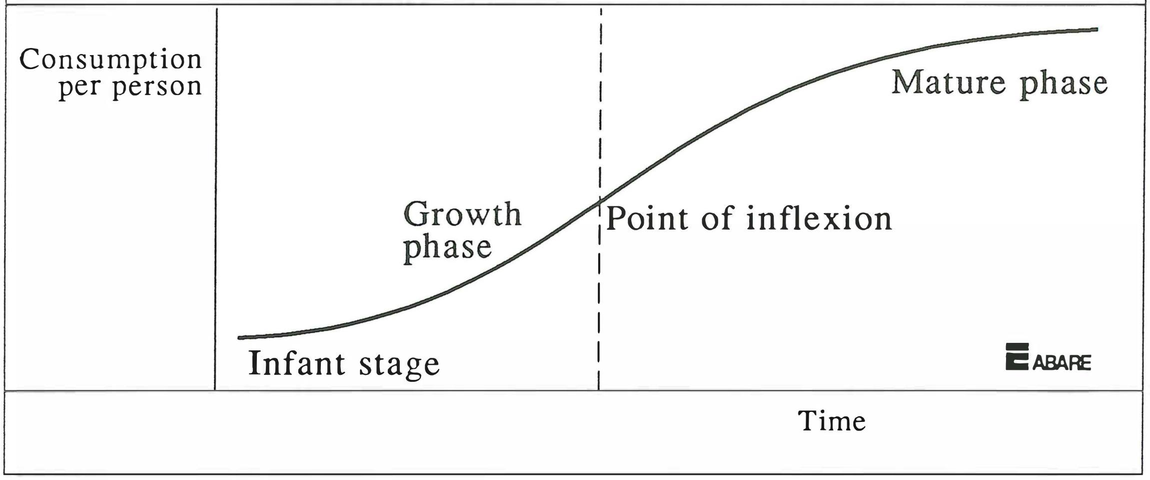
The basis for successful market development is good market information. Market research is an essential ingredient in marketing aquacultural products. The wants of consumers should be determined, both in terms of the type of product and likely prices and quantities. Ideally, this process should commence before establishing productive capacity. However, the need for such research is continual as producers can vary the timing, quantity, form and quality of the product. The payoff to market research may be higher for aquaculture than for wild fisheries, as the former has more control over quantity, quality and timing of output.

Market research can be divided into two components: market-wide research, and market intelligence — the identification of specific market openings for particular products. Market intelligence is the domain of individual producers, as the knowledge gained is directly related to supply decisions in competition with other producers. This is not the case with market-wide research, particularly if the results of the research may be available to people other than those who paid for the research. In this case a species-wide or industry-wide approach may prove to be less costly for individual producers, as its cost will be spread across all suppliers of the product. Indeed, market-wide research is undertaken on an industry- or species-wide basis in many of Australia's traditional primary production industries. ABARE and state departments of agriculture have provided such market research for these industries over a long period.

A major problem facing aquaculture is the prediction of future demand for the relatively new aquacultural products. In relation to species which have an established market through the wild catch and/or imports, there is already some market price and supply information available on a regular basis. Here, in determining future market opportunities, not only are likely future demand trends important but also the future prospects of competing suppliers, whether wild catch or imports.

Many Australian aquacultural products are relatively new to the Australian market. Products generally have a life cycle which is characterised by an initial development phase, then a period of rapid growth followed by slowing growth (see figure 4). Many aquacultural products are in the early infant stage or the rapid expansion phase of market development. A problem can arise, in that the high prices offered during the early growth phase can stimulate overinvestment and overproduction. The danger is these prices may be used to justify further large production increases, and if supply grows more rapidly than demand

Figure 4: **Logistic consumption pattern**



prices will fall. The price fall may be lessened by development of an export market or development of new product forms.

The costs of overproduction may be quite high due to the fixed nature and high cost of capital investment and establishment in many aquacultural industries. For example, the capital costs for a prawn farm can account for about a third to almost half of the total costs of production (Hardman, Treadwell and Maguire 1990). The likelihood of more profitable growth can be increased by realistic investment analyses and studies of the market situation and outlook, which can improve investors' knowledge and thereby decision making.

There are difficulties in applying the life cycle analysis of figure 4 to generate a projection of when the growth rate of consumption of a product per person will begin to taper off (the point of inflexion). Yet this levelling off is a critical stage of market development, with major implications for production and marketing decisions. This life cycle approach was used by Douglas (1984) in examining the potential for some new horticultural crops. In that study it was found that the life cycle model did in fact best fit the actual data of consumption of the horticultural products analysed. However, the long data series required would not be available for many aquacultural products. This deficiency could be overcome by use of data from overseas markets where the product has been available for a longer period, perhaps in conjunction with data on consumption of substitute products on the Australian market. For example, although freshwater crayfish is relatively new to the Australian market there are well established substitute products on the entree market, such as oysters and prawns. Nevertheless, forecasts of inflexion points derived from such analogous markets can only be approximate and uncertain. On the other hand, forecasts based on past growth alone cannot predict the point of inflexion, and will thus overestimate future growth. This problem becomes greater the longer the projection period. For short to medium term projection periods, a linear or log-linear approximation to the time path of growth may provide reasonable projections of future consumption. This problem serves to highlight the necessity for continual market research in order to minimise the risks and costs of overinvestment.

The role of research in market development is not confined to the provision of long term projections for investment planning. There is a need for continual shorter term research to determine market price trends, seasonal fluctuations in prices and supply, and demand for different product forms. With such information producers are better equipped to successfully develop the market by presenting their product in the most suitable form, at the right place and at the most opportune time to maximise market returns.

Finally, for such market-wide research to be truly successful the results need to be disseminated and adopted by industry. Extension services are an effective method of achieving this. Extension services have aided the successful adaptation of our traditional primary production industries throughout their history. For the traditional primary production industries such services are usually provided by the state departments of agriculture, but such services for aquaculture are in their infancy.

Concluding comments

Australian aquaculture has grown rapidly during the past decade but now faces strong competition from well established aquacultural producing countries as well as from the wild fisheries. In the long term further expansion of world aquaculture seems assured, with the expected increase in world seafood demand likely to exceed growth in traditional wild fisheries supplies. Whether Australian aquaculture will be part of that expansion is largely dependent on producers achieving a competitive production base and successful marketing of their products. At this stage Australia lags behind many countries in its development of the aquacultural industry.

There are market opportunities for Australian aquaculture, particularly on the domestic market. Here, local producers have an advantage in supplying fresh high quality products and in supplying in the off-season periods of both wild fisheries and imported products. Competition from imported aquacultural products is likely to intensify in the future as world aquacultural output expands. However, on the Australian market there is some natural protection afforded to local aquaculturists due to the distances from major producers. The other main opportunity is in the production of species unique to Australia, provided that niche markets can be successfully developed and the product is effectively differentiated from competing supplies. The general worldwide consumer trend toward greater health consciousness may well bestow an advantage on Australian aquaculture provided that Australia's 'clean' image is maintained.

The Australian aquacultural industry is sure to grow in the medium term, given existing investments, expected improvements in yields and increasing total demand. Further expansion of the industry in the long term is assured only if it can achieve a competitive basis and its products are successfully marketed. Successful market development for aquacultural products could be assisted by a species-wide approach to a number of marketing tasks, such as market-wide research, distribution, coordination of sales, packaging, promotion and quality control.

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Prospects for prawn farming in subtropical Australia

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There have been several recent developments in prawn farming in Australia which could result in much improved returns to prawn farming. In this paper the intention is to illustrate the effect of these developments on potential profitability of prawn aquaculture in subtropical Australia. This is undertaken using investment analysis of representative farm models to estimate likely future returns, the risk to those returns and effects of changes in major variables on those returns. The analytical model does not reflect the current industry average but rather what is feasible given good management. The results should be interpreted as an indication of the potential of the prawn farming industry in southern Queensland and northern New South Wales rather than what is being achieved now.

To reflect some of the choices available to prawn growers, three stocking rates producing different sized prawns were analysed. Larger prawns generally fetch higher prices but the price premium varies. The effects of changes in the price premium were analysed as well as the effect of a continual price fall. Also analysed were the effects on profit levels of changes in yields and establishment costs.

The results of the analysis indicate that prawn farming has limited potential for expansion in southern Queensland and northern New South Wales. Although the average expected return is above the long term rate of interest, net of inflation, there is substantial risk associated with that return. The results indicate the profitability of prawn farming is sensitive to the price received. This together with the prospect of future price falls will limit the potential of prawn farming in subtropical Australia. However, domestic prices do fluctuate with seasonal variations in supplies of wild caught prawns. This provides perhaps the best opportunity for Australian prawn farmers — if farmers are able to time their harvest to coincide with peak prices then profitability will be improved.

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Prawn farming in Australia became established in the 1980s despite a few unsuccessful prawn farms being constructed before 1980. The industry became established first in northern New South Wales with the construction of several farms stocked initially with school prawns (*Metapenaeus macleayi*) and later with leader prawns (*Penaeus monodon*). The latter is the main species stocked in prawn farms in Australia although some production trials have been conducted in Queensland with the Australian tiger prawn (*Penaeus esculentus*) and *Penaeus japonicus*. *Penaeus monodon* is also one of the two main species produced in Asia which is the largest prawn farming region in the world (Rosenberry 1991).

In this paper the intention is to illustrate the main economic factors which influence the profitability of prawn aquaculture in the subtropical prawn farming region of southern Queensland and northern New South Wales. This is undertaken using investment analysis of representative farm models to estimate likely future returns, the risk to those returns and effects of changes in major variables, such as price, on those returns. In the next section, likely future prices are determined by reviewing market opportunities for Australian prawn farmers.

Market opportunities for farmed prawns

Virtually all Australian farmed prawns are sold on the domestic market. Competition in this market comes from wild fishery supplies and imports. The Australian prawn market closely follows trends in the international market, as more than half of Australia's production of prawns are exported and imports are of a similar magnitude (ABARE 1990a).

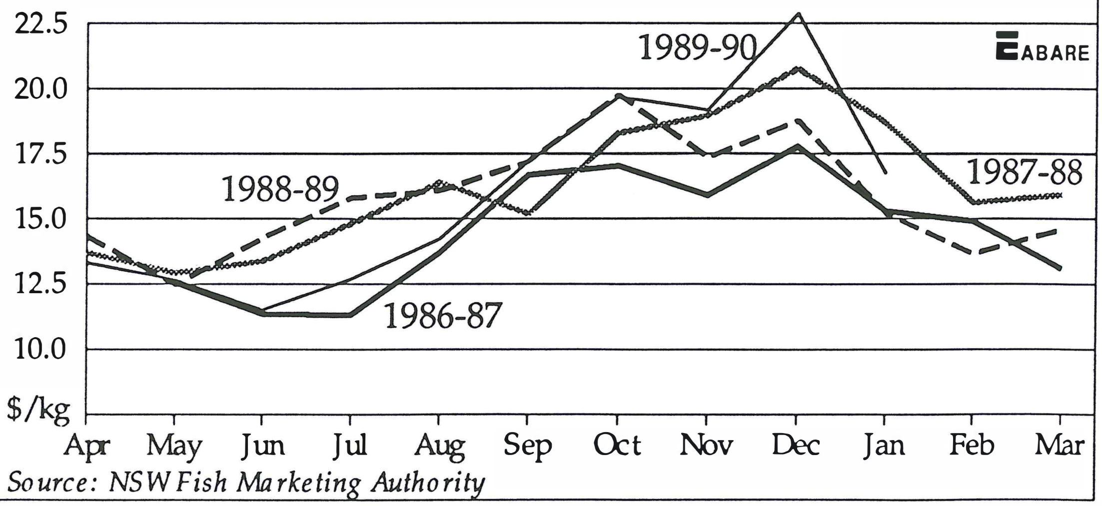
World prawn prices have fallen largely as a result of the rapid growth of cultured prawns in Asia. Although production has stabilised in some countries such as China (Rosenberry 1991) further increases in output are expected as other Asian producers expand production. Competition in prawn markets has intensified and as culture of prawns continues to expand in Asia strong competition for Australian produced prawns is likely to continue. With the prospect of further expansion of prawn farming in Asia further falls in world prices are expected.

On the domestic market Australian producers do have the advantage of some natural protection afforded by the distance from major producers which increases the landed price of imports and reduces the ability of overseas producers to supply fresh product. If Australian prawn products can be price competitive they have the opportunity to replace a proportion of imports.

In marketing their output on the domestic market prawn farmers do have several advantages over the competition from wild fisheries and imports. Compared with wild fisheries output aquacultural production is more controllable and predictable in terms of timing, quantity, product form and quality. This is a distinct advantage in developing and maintaining market outlets. The ability to plan the harvest in terms of time, quantity and quality (albeit with some risk) means that prawn farmers can more easily market their product directly and enter into forward contracts. In addition, domestic prices fluctuate with seasonal variations in supplies of wild caught prawns. As illustrated in figure 1, prices for large prawns reach a peak in December but fall quickly after Christmas down to a low in May–June. This provides perhaps the best opportunity for Australian prawn farmers to increase returns — if they can time their harvest to take advantage of seasonal peaks in prices. Although prawn farmers in subtropical regions are constrained by seasons, there is some flexibility in timing harvests. For example, an earlier harvest time in December could be achieved by lower stocking density to achieve faster growth, or the stocking density could be maintained with prawns being harvested at a smaller size. However, as shown in figure 2 the seasonality in prices for small prawns differs from that for large prawns as depicted in figure 1. Indeed it appears that peak prices for small prawns can usually be obtained in August and October as well as in December.

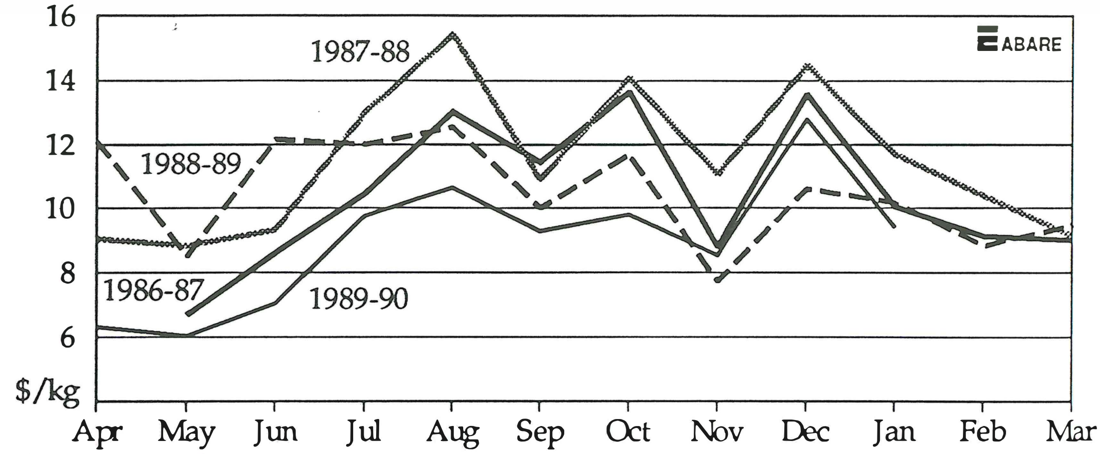
Since prawn farmers can control production characteristics to a large degree they have the ability to take advantage of relative price differences between the various forms — fresh, live, frozen or cooked, large or small — to maximise profit. The ability to alter production characteristics, even within the period of a crop, to suit market fluctuations is obviously a factor which aquaculturists can use to their advantage. Altering production regimes has

Figure 1: **Sydney prawn prices, large**



Source: NSW Fish Marketing Authority

Figure 2: Sydney prawn prices, small



Source: NSW Fish Marketing Authority

associated costs, thus it is necessary to have detailed market information to assess the benefits of supplying various product forms at differing times and of a specified quality. For example, larger prawns generally fetch a higher price but in producing larger prawns, farmers have the added costs associated with more feed, lower stocking densities and/or longer growout periods. Also, new markets are being investigated, such as the recent live export of *P. japonicus* to the Japanese market.

Compared with importers local prawn farmers have an advantage in supplying fresh high quality products. However, this may not always be possible and the proximity to transport networks should be considered in locating the farm. One further advantage that Australian cultured prawns may possess is a 'clean' image. It is possible that greater consumer awareness of the perceived health benefits inherent in fisheries products has prevented a decline in the consumption of fisheries products in the face of increasing prices (Treadwell and McKelvie 1991). Generally, consumers have become more health conscious and are more concerned with the quality of the food they consume in regard to cholesterol, disease, pollutants and chemical residues. Australia generally has a clean environment relative to many of the Asian prawn producers. If Australian prawn farmers can maintain this image, perhaps through developing a code of practice aimed at supplying a clean product to the market, it could assist in meeting the intensifying competition from imports, particularly from Asian farmed prawns.

Method of analysis

The farm model

In order to analyse the potential profitability of prawn culture, farm models were constructed. The models were designed to represent the current situation. These were then modified to incorporate expected productivity improvements to represent the potential situation.

The representative farm model was defined in consultation with farmers in the industry, researchers and others involved with the industry. After defining the model farm in terms of size and technology, the key parameters were set from information supplied mainly by farmers and researchers. Ranges for the key parameters were used in the analysis to reflect the large degree of uncertainty and risk which is due principally to the early developmental phase of prawn farming in Australia. Given this framework, costs were determined from data supplied by farmers, researchers and suppliers of inputs and equipment. At this stage the farm model parameters and costs were presented to industry representatives and researchers for review and their comments were incorporated in the revised model for analysis.

Average cost of production

To allow for the fact that there is a delay between establishing a farm and first selling output and that purchases of capital equipment vary widely between years, the average cost of production was determined over the life of the project. Costs throughout the twenty year life of the project were discounted at 6 per cent a year, the long term interest rate net of inflation (ABARE 1990b). The average annual cost of production equals the annuity (or the amount required each year) which would equate to the total of the discounted costs over the 20 years.

Stochastic investment analysis

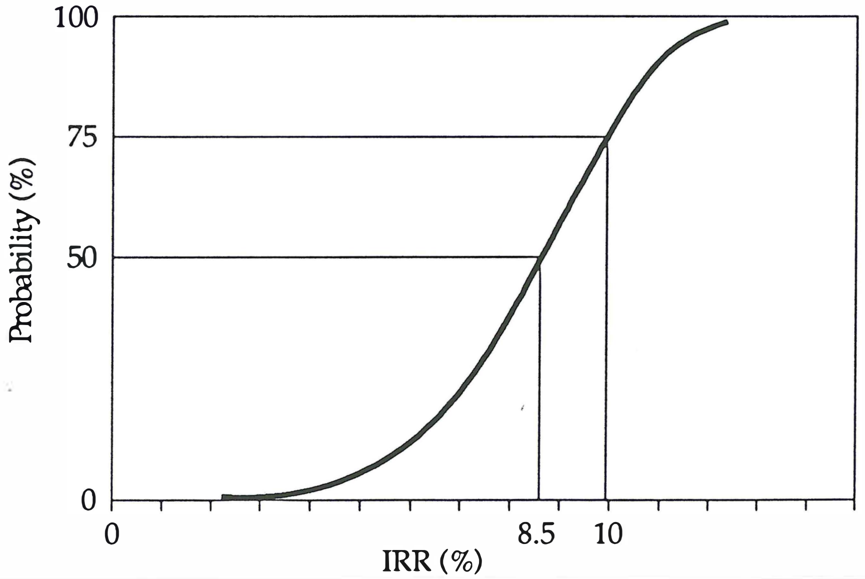
A relatively new industry such as prawn farming in Australia is subject to much uncertainty and risk. Consequently, a rate of return based only on the most likely estimates would not fully reflect the nature of returns to aquaculture. Sensitivity testing over the range of possible values for all the uncertain parameters would become unwieldy and difficult to interpret. The alternative approach used in this paper is stochastic investment analysis which was used in analysing the profitability of 6 ha prawn farms by Hardman, Treadwell and Maguire (1990).

The analysis used the estimated range for each uncertain parameter. For each simulation, a value (or a fluctuating time series) was randomly generated for each parameter from its specified distribution. Each such set of parameter values was used to calculate a specific stream of costs and returns, from which the internal rate of return (IRR) was derived. This procedure was repeated to generate a set of IRRs. These were then ranked and the cumulative probability function was calculated. This function gives the probability of the IRR being less than any particular level. For example, in figure 3 there is a 75 per cent chance that the IRR is less than the level where the horizontal line from 75 per cent probability crosses the cumulative probability function. The point at which the horizontal line from 50 per cent probability meets the cumulative probability function is the mean IRR.

The advantage of this stochastic approach is that it not only produces the expected or mean IRR but also indicates the effect of uncertainty by providing a range of IRRs with their probability of occurrence. This procedure avoids the need for sensitivity testing of individual parameters, as the overall uncertainty is reflected in the probability distribution of the IRR. However, individual sensitivity tests can still be undertaken to show the specific effect of variation in a particular parameter.

The analysis was on a pre-tax basis, using private costs and revenue, and was conducted over 20 years, the estimated life of ponds. The analysis was based on the following assumptions.

Figure 3: **Cumulative probability of IRR**



- There is no correlation between prices, yields and costs.
- Full production is possible from the first year that yields would occur.
- The farm is located on a suitable site with ready access to water.
- Although disasters such as those which would cause extremely low yields or loss of a year's crop are allowed for, no provision is made for loss of farm facilities.
- During the period of analysis, no technical changes are introduced which result in major changes in the relationship between costs and yields.

Finally, no allowance has been made for borrowing funds to establish and finance the farm. The IRR may then be interpreted as the highest interest rate that could be paid on borrowings whilst still covering costs. The IRR itself is that rate of interest which equates the discounted stream of benefits to the discounted stream of costs, (or alternatively the rate of interest which results in a zero net present value). As risk is reflected in the resulting range of IRRs it is appropriate to compare those with a riskfree interest rate, rather than an average borrowing rate which would include a premium for risk. In general, an IRR range from this analysis of above 6 per cent, the long term interest rate net of inflation (ABARE 1990b), would indicate the project would be profitable if all assumptions held for the duration of the project.

Costs of production and profitability

In July 1990 a paper on an economic model of Australian prawn farming was presented (Hardman et al. 1990). The analysis in that paper showed that profitability was very sensitive to the climate, prices, yields and farm size. The north Queensland region was found to be a much more profitable area to grow *P. monodon* than the subtropical regions in southern Queensland and northern New South Wales. Prawn farming techniques are still being developed for Australian conditions and there have been several recent developments in the industry that could result in much improved returns to prawn farming. The trend in growout has been toward higher stocking densities with fewer farmers stocking below 25 prawns/m^2. As farmers have gained experience survival rates of prawns have improved. Other productivity improvements reported by Gillespie (1991) are better feed conversion ratios. Although some farms are still experiencing feed conversion ratios in excess of 2:1, encouraging results in the range of 1.2–1.7:1 are being obtained. It is likely that better survival rates and more appropriate feeding regimes as well as improved feeds have been the contributing factors. In general farmers have avoided the high stocking densities (more than 40 prawns/m^2) that may have contributed to the decline of the Taiwanese industry.

The farm model

As farmers gain experience in prawn farming, there is a tendency for farm size to be increased above the six ha model used in the analysis by Hardman, Treadwell and Maguire (1990). Accordingly, the following models are for farms of 20 one ha ponds. In contrast to the model of Hardman et al., these farm models are based predominantly on southern Queensland rather than northern New South Wales. The former is becoming the major area for subtropical prawn farming in Australia with eleven of the fifteen subtropical farms being in Queensland. Consequently, these models include higher land costs and lower electricity connection than those used by Hardman et al.

costs

To reflect some of the choices available to prawn farmers, three variations to the model farm have been analysed. Generally larger prawns fetch higher prices. There are two main parameters a farmer may vary to achieve the desirable size. By varying the stocking density farmers may affect the size of the prawn harvested. Alternatively the length of the growout period could be altered to achieve the best size given market price relativities. In the following analysis three stocking densities were modelled to produce prawns of three average weights. The relationship between stocking density and prawn size at harvest accords with results obtained in model ponds in Australia. It is recognized that optimal pond size could vary with stocking density, as it is easier to manage larger, less costly ponds with lower density. However, to facilitate direct comparisons between stocking densities, this factor has not been incorporated into the following models.

As can be seen from table 1 the farm gate price has been varied for each model from an average of $9.80/kg for 30 g prawns, by 15c/g according to the size of prawn harvested. Farm gate (rather than market delivered) prices have been used in the analyses because most Australian prawn farmers tend to sell prawns to wholesalers or processors rather than market their product directly. As prawn prices are expected to decline the analyses were performed with prices falling 1.5 per cent a year relative to costs.

Two sets of models were analysed. The first set was defined to reflect the current situation and was based on estimates of survival rates and feed conversion ratios from Hardman, Treadwell and Maguire (1990). The second set of models represents the potential situation and was based on improved feed conversion ratios, survival and yields as reported by Gillespie (1991). Average estimated costs for the three potential model farms are listed in tables 2 and 3. In the analysis costs were allowed to vary by 15 per cent around these

Table 1 Key characteristics of subtropical prawn farm model

Item	Unit	Low	Medium	High
Total size of farm	ha	30	30	30
Number of ponds	no.	20	20	20
Area of ponds	ha	1	1	1
Number of crops/year		1	1	1
Stocking rate	no/m²	15	25	35
Average prawn harvest size	g	34	30	27
Farm gate price – average	$/kg	10.40	9.80	9.35
– range	$/kg	8.4–12.4	7.8–11.8	7.35–11.35
Feed conversion ratio				
– Current average		1.8:1	2.0:1	2.2:1
– Potential average		1.5:1	1.7:1	1.8:1
Survival rate				
– Current average (range)	%	63(40–73)	60(39–70)	58(36–68)
– Potential average (range)	%	70(40–84)	67(39–80)	65(36–77)
Yield				
– Current average (range)	t/ha/crop	3.2(2.1–3.7)	4.5(2.9–5.25)	5.5(3.4–6.4)
– Potential average (range)	t/ha/crop	3.6(2.1–4.3)	5.0(2.9–6.0)	6.1(3.4–7.3)
Total farm production				
– Current average (range)	t/year	64(42–74)	90(58–105)	110(68–128)
– Potential average (range)	t/year	72(42–86)	100(58–120)	122(68–146)

Table 2 Annual costs for subtropical prawn farm model

Item	Low	Medium	High
	$'000	$'000	$'000
Prawn fry (a)	54	90	126
Feed (b)	162	255	329
Fertiliser	8	8	8
Electricity	38	48	58
Labour – permanent	90	90	90
– casual	18	25	30
– manager/owner	30	30	30
Repairs and maintenance	22	22	22
Miscellaneous	6	6	6
Administration	11	11	11
Total	439	585	710

(a) 1.8c each. (b) $1 500/t.

Table 3 Capital costs for subtropical prawn farm model

Capital item	Total value	Scrap value	Years of purchase
	$	%	
Land	300 000		0
Earthworks (ponds & channels)	400 000		0
Pump(s)	40 700	10	0,5,10,15
Motors(s)	40 700	10	0,5,10,15
Belts, pulleys pump base etc	6 700		0,3,6,9,12,15,18
Pumps shed, valves, filters	15 200		0
Pipes, gates, screens, boards	80 000		0
Electric power supply	150 000		0
Generator (standby)	20 000	10	0,10
Rotary hoe	5 000	10	0,10
Spike tooth harrows	2 000	10	0,10
Slasher	2 000	10	0,10
Bucket	5 000	10	0,10
Blade	1 500	10	0,10
Fertiliser spreader	2 500	10	0,10
Farm truck (2nd hand)	20 000	10	0,10
Tractor (2nd hand)	15 000	10	0,10
Motorbike	5 000	5	0,5,10,15
Blower pipe (feed)	1 000		0,3,6,9,12,15,18
Aeration units (a)	110 000	10	0,5,10,15
Refrigeration plant, esky, bins, etc	22 000	10	1,11
Ice machine (2 t/day)	20 000	10	1,11
Prawn weighing scales	2 500		1,4,7,10,13,16,19
Harvest equipment (nets/cages)	4 000		1,4,7,10,13,16,19
Prawn handling area & equipment	10 000		1,11
Farm shed	25 000		0
Tools	10 000		0,5,10,15
Test kits	5 000		0,3,6,9,12,15,18
Boat (2nd hand)	2 500	10	0.10
Office equipment	5 000		0,5,10,15
Miscellaneous	5 000		0,5,10,15
Total	1 333 300		

(a)For 15 prawn fry/m^2 $88 000, for 35 prawn fry/m^2 $132 000.
Source: Based on Hardman, Treadwell and Maguire (1990).

Table 4 **Internal rates of return and cost of production for subtropical prawn farm**

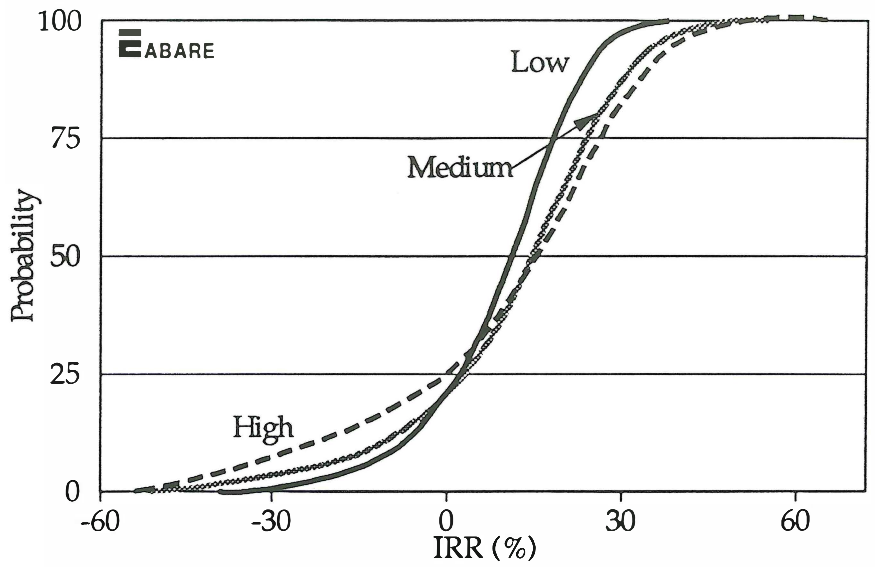
Farm model	**Cost of production**	**Mean IRR**	**50% chance that IRR is between:**
	$/kg	%	%
Low			
Current	9.11	1.6	–6.5–8.6
Potential	7.95	11.2	2.5–18.2
– survival rate up 10%	7.56	22.2	12.4–30.3
– no price premium	7.95	6.8	–3.0–14.4
– 35c/g price premium	7.95	16.4	7.6–23.3
Medium			
Current	8.18	5.1	–8.1–13.8
Potential	7.30	14.5	3.2–23.9
– survival rate up 10%	6.87	22.0	10.2–31.2
High			
Current	8.03	0.8	–21.8–12.3
Potential	6.96	15.5	0.1–26.4
– survival rate up 10%	6.55	21.1	7.0–32.8
– no price discount	6.96	18.9	5.7–29.3
– 35c/g price discount	6.96	8.2	–10.5–19.2

averages. The average costs of production for the current models are higher than for the corresponding potential model due to higher feed conversion ratios and lower yields.

The results

As shown by the results in table 4 the current situation farm models are not viable, with a high probability of receiving a return of less than 6 per cent. However, profitability is much improved through the productivity improvements encapsulated in the potential models. The average IRR for the potential models are reasonably close, lying between 11.2 and 15.5 per cent. The most profitable prawn farm model for subtropical Australia with a 15c/g price discount is one with a stocking density of 35 prawns/m^2. However, this model farm also has the highest risk.The risk, as reflected in the range of IRRs, rises with increasing stocking density (see figure 4). Indeed, although the average IRRs may appear reasonable, there is a 25 per cent chance of receiving an IRR of less than 3.2 per cent. These results are much lower than for similarly constructed models for north Queensland prawn farms with average

Figure 4: **Cumulative probability of IRR** Prawns

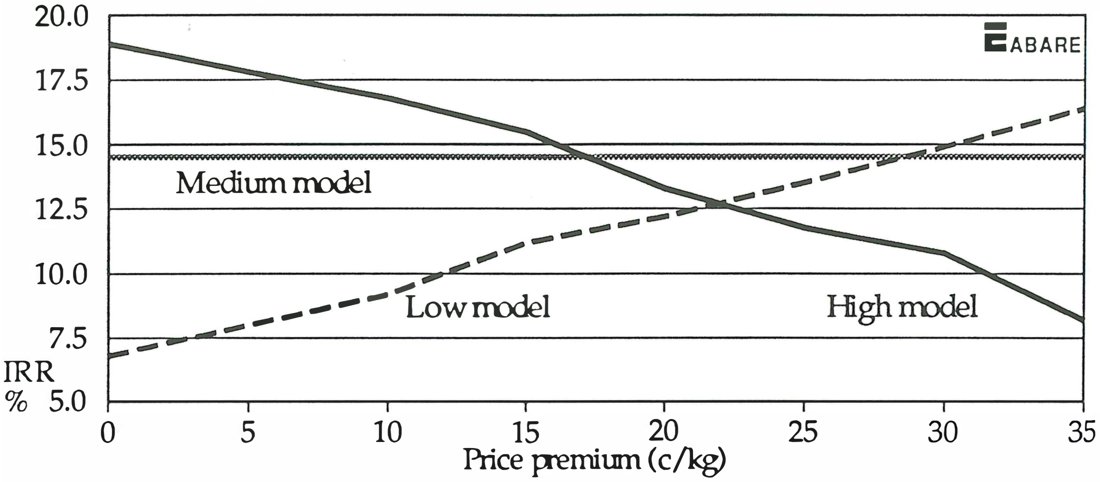


IRRs of around 30 per cent (Treadwell, Maguire and McKelvie 1991). This difference is due to faster growth and the possibility of three crops every two years in north Queensland compared with only one crop a year in subtropical regions.

While the potential situation farm models represent an improvement on current industry performance, some farmers believe survival rates could be increased a further 10 per cent. If such improvement in survival were achieved prawn farming in subtropical Australia could be considered viable in the long term with a 25 per cent chance of obtaining returns in excess of 7 per cent.

As mentioned above, these results are based on farm gate prices with a price premium (or discount) of 15c/g for the low and high models in relation to the prices for 30 g prawns in the medium model. However, the price premium available on the market varies depending on relative supplies of the various sizes. If a higher premium of 35c/g was obtained the lowest stocking density model would be most profitable whereas the rankings are reversed if no premium was obtained (figure 5). That is, the relative profitability of different stocking rates is sensitive to the price premium for prawn size. Farmers may vary the average size of the prawn harvested by means other than stocking rates, such as by changing feed regimes or altering the time period for growout. The sensitivity of prawn farming profits to prices indicates the need for prawn farmers to continually assess their production decisions in view of their cost structures and likely prices by size.

Figure 5: Effect of price premiums of average IRR



Conclusions

The results of the analysis indicate that prawn farming has limited potential for expansion in southern Queensland and northern New South Wales. Based on current average industry performance the results indicate that prawn farming in this subtropical region would not be viable in the long term with the prospect of further price falls. With feasible productivity improvements the simulated average expected return is above the long term rate of interest, net of inflation, but there is substantial risk associated with that return. Prawn farming would only appear to be viable in this subtropical region over the long term if identified productivity improvements with respect to feed, yields and high survival rates were all achieved consistently. Given the high risks in prawn farming there is potentially a high payoff to research and extension which together can assist in increasing returns and in reducing risk.

Compared with returns to similarly constructed models for north Queensland the subtropical region is at a distinct disadvantage. However, the southern region does have the advantage of proximity to major markets. This results in a transport cost advantage which was accounted for in the models by using a farm gate price of 30c/kg higher than that for north Queensland farms. In addition, proximity to markets could result in the southern prawn farmers being able to supply quickly very short term gaps in the market and thereby receive higher prices. The degree of advantage from this factor is dependent on the marketing skills of the individual farmers and was, therefore, not included in the analysis. Also, although competition from imported cultured prawns is likely to intensify in the future as world output of cultured prawns expands, both regions have an advantage in being able to supply fresh high quality products. To capitalise on this advantage aquaculturists need to pay particular attention to post-harvest handling and speed in distribution.

The results indicate that the profitability of prawn farming is quite sensitive to price. This, together with the prospect of future price falls, will limit the potential of prawn farming in subtropical Australia. However, prawn prices fluctuate throughout the year and this may be used to advantage. If farmers are able to time their harvest to coincide with peak prices then profitability will be improved substantially.

Finally, the results presented in this paper are unlikely to be achieved by new farmers. The models are based on good management by experienced aquaculturists. Typically, there are teething problems encountered in establishing a prawn farm and like any farming venture husbandry skills need to be adapted to the particular circumstances.

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THE ECONOMICS OF CROCODILE FARMING

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INTRODUCTION

Farming of crocodiles began in the late 1960s in Queensland, with farms being developed in Queensland, the Northern Territory and Western Australia. The industry is based on the production of skins and flesh from two native Australian species — the freshwater crocodile (*Crocodylus johnstoni*) and the saltwater crocodile (*Crocodylus porous*). However, the industry did not grow significantly until late 1986 when exports of crocodile skins were allowed. Since then the estimated value of the crocodile industry has grown from $0.9 million to around $1.5 million in 1989-90.

Production in the Northern Territory and Western Australia is based largely on the collection of eggs and hatchlings from the wild but is also supplemented by captive breeding. In contrast, production in Queensland relies totally on the success of captive breeding as the collection of eggs and hatchlings is prohibited. For the breeding programs, mature crocodiles can be specially bred for the purpose but more commonly 'problem' crocodiles are removed from the wild and used as farm breeding stock. However, the availability of such animals is limited. Farm raised breeding stock takes several years to mature. Also there are problems in matching couples, whether farm raised or wild crocodiles, for successful mating.These breeding problems have in part restricted the growth of the industry.

The aim in this paper is to determine the factors that will influence the long term future viability of the crocodile industry in northern Australia. The economic analysis is based on representative farm models, constructed with the help of industry and researchers. The analysis was designed to estimate the likely levels of returns to crocodile farming, the degree of risk associated with those returns as well as the effect on those returns of changes in major variables. First the markets for crocodile products are reviewed to determine likely future price trends.

MARKETS

There are three main products of crocodile farming in Australia other than tourism. The most highly valued product is the crocodile hide or skin. The other products are skulls and teeth, and crocodile meat.

Crocodile skins are sought by the producers of prestige leather goods such as shoes, handbags and wallets. On the international market saltwater crocodile skins command a premium price, whereas freshwater skins are considered of lower quality. In 1988 it was estimated that Australia supplied less than 1 per cent of the world supply of crocodilian skins (Webb 1988) thus the Australian industry can be described as a price taker. On the international market, Australian produced skins face competition from alligator and crocodile skins from other parts of the world such as Papua New Guinea, Africa, Asia and North America. The lower valued sector of the market is supplied largely by Caiman skins which are produced predominantly in South America.

The majority of first grade skins produced in Australia are exported green to Japan where they are processed and made into the finished product. Tanneries in Townsville, Perth and Darwin are currently experimenting with tanning crocodile skins. If these tanneries can succeed in producing first grade tanned product at a competitive price the value of Australia's crocodile industry would increase.

The preferred harvest and market size for saltwater crocodiles is around 1.5 m long while freshwater crocodiles, which are slower growing, are harvested at 1.2–1.3 m. On average crocodiles in captivity reach these sizes within 2–3 years but may take up to 5 years. The farmgate price for crocodile skins varies according to species, size and, of course, quality. First grade, green saltwater crocodile skins are the most preferred skin. The skin of the average saltwater crocodile culled at 1.5 m long measures 34–35 cm across the belly. In 1989-90 raw saltwater crocodile skins were selling for $10–12/cm across the belly at the farmgate (Webb and Manolis 1990). Freshwater crocodiles of the same length are smaller around the belly, 24–25cm, and in 1989-90 raw freshwater skins were selling for around $5–6/cm (Webb and Manolis 1990).

The supply of crocodile skins around the world is increasing rapidly (Goudie 1989). In 1989 Louisiana, which produces the majority of alligators in the United States, produced 67 000 farmed alligators and preliminary estimates suggest production from Louisiana's farms more than doubled in 1990, with nearly 150 000 hides being produced (US Department of Agriculture 1991). With increased supplies of skins available on the market it is likely that prices for skins may fall. Australia has the advantage though that the skin of the saltwater crocodile is considered the finest available, which suggests that the price premium for this product will be maintained. However, there is the possibility of increased supplies of freshwater crocodile skins from farms in Asia and Papua New Guinea. Prices for large skins (over 40 cm) are likely to be maintained as the majority of crocodilian skins produced from farms worldwide are of the smaller sizes (less than 40 cm).

The demand for crocodile leather is variable to say the least. The future for the market depends largely on whether the use of crocodile skins in the production of items such as shoes and handbags remains fashionable. In the short term, at least, the current trend toward products which use natural products provides bright market prospects for the industry. But fashions are unpredictable. Community concerns with respect to conservation and wildlife preservation also have an important impact on consumer demand for crocodile skins. To overcome or at least reduce the impact of this it is imperative that cultured crocodile products are labelled as such and the image of crocodile aquaculture being used to preserve wild populations could be stressed.

Apart from crocodilian skins from other countries, Australian skins also face competition on the international market from other reptile skins such as snake skins. Shark, emu and increasingly fish skins, in particular barramundi skins, also compete in the same market. Potential changes in fashion toward newer products such as fish skins combined with increased availability of these products, as well as crocodile products, may also put downward pressure on the prices for Australian crocodile skins on the international market.

Traditionally only the skin from the belly of the crocodile was used and the backstrap and flesh were discarded. Recently, however, small markets have developed for these so-called by-products of the crocodile skinning industry. New technology has enabled the tanning of backstraps for the production of leather goods such as belts, hat straps and key rings. The market for these leather goods is small in Australia at present, with most of the products being sold to overseas tourists. Small markets have also developed in association with the tourist trade for crocodile skulls and teeth. The sale of such products may increase the overall farmgate price of crocodiles. However, as development of these markets in Australia is relatively recent, the future of the markets is largely uncertain and perhaps in many cases limited by tourist activity.

A small niche market for crocodile flesh has also been developed over recent years as a part of the gourmet, speciality or novelty meats market. On this market, crocodile meat competes with gourmet meats such as water buffalo, kangaroo and venison. In 1989-90 the farmgate price for crocodile flesh from both saltwater and freshwater crocodiles was around $20/kg. It is unlikely that this price will be sustained in the long term as prices for substitute products are considerably lower — for example, venison currently retails for around $10/kg. On average a 1.5 m crocodile yields 7–10 kg of flesh of which only 1 per cent is reported to be fat. With today's health conscious consumer, crocodile flesh may prove to be popular as a substitute for other low fat meats, but this will depend largely on the price.

METHOD OF ANALYSIS

The Farm Model

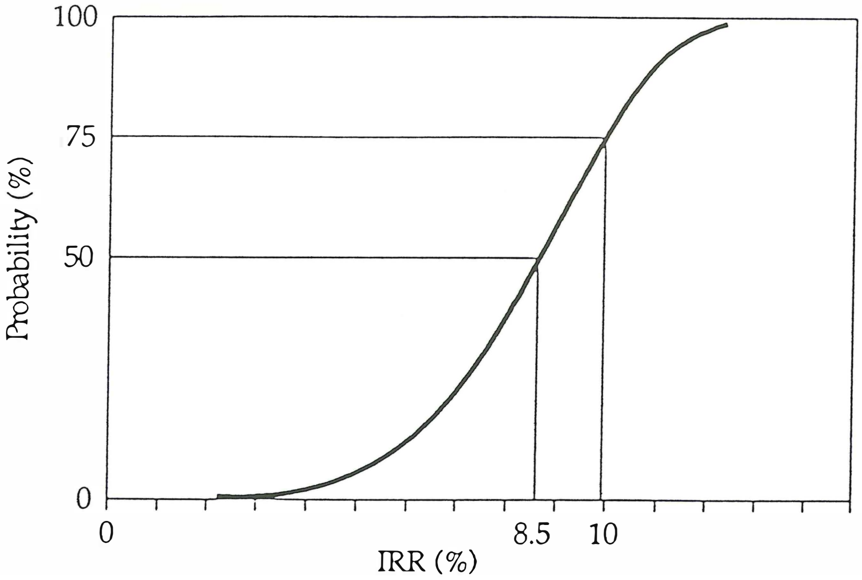
The representative farm models were defined in consultation with farmers in the industry, researchers and others involved with the industry. After defining the model farms in terms of size and technology, the key parameters were set from information supplied mainly by farmers and researchers. To allow for the uncertainty and risk inherent in aquaculture, ranges for the key parameters were allowed. Given this framework, costs were determined from data supplied by farmers, researchers and suppliers of equipment and inputs. At this stage comments on the farm model parameters and costs were sought from industry and researchers and their comments were then incorporated in the revised model for analysis.

Stochastic Investment Analysis

A relatively new industry such as aquaculture in Australia is subject to much uncertainty and risk. Consequently, a rate of return based only on the most likely estimates would not fully reflect the nature of returns to aquaculture. Sensitivity testing over the range of possible values for all the uncertain parameters would become unwieldy and difficult to interpret. The alternative approach used in this paper is stochastic investment analysis. This approach is based on the stochastic analysis of returns to new horticultural crops by Treadwell and Woffenden (1984).

The analysis used the estimated range for each uncertain parameter. For each simulation, a value (or a fluctuating time series) was randomly generated for each parameter from its specified distribution. Each such set of parameter values was used to calculate a specific stream of costs and returns, from which the internal rate of return (IRR) was derived. This procedure was repeated to generate a set of IRRs. These were then ranked and the cumulative probability

Figure 1: Cumulative probability of IRR



function was calculated. This function gives the probability of the IRR being less than any particular level. For example, in figure 1 there is a 75 per cent chance that the IRR is less than 10 per cent, the level where the horizontal line from 75 per cent probability crosses the cumulative probability function. Similarly, the point at which the horizontal line from 50 per cent probability meets the cumulative probability function gives the mean IRR.

The advantage of this stochastic approach is that it not only produces the expected or mean IRR but also indicates the effect of uncertainty by providing a range of IRRs with their probability of occurrence. This procedure avoids the need for sensitivity testing of individual parameters, because the overall uncertainty is reflected in the probability distribution of the IRR. However, individual sensitivity tests can still be undertaken to show the specific effect of variation in a particular parameter.

No allowance has been made for borrowing funds to establish and finance the farm. The IRR may then be interpreted as the highest interest rate that could be paid on borrowings while still covering costs. The IRR itself is that rate of interest which equates the discounted stream of benefits to the discounted stream of costs (or alternatively the rate of interest that results in a zero net present value). As risk is reflected in the resulting range of IRRs it is appropriate to compare those with a risk-free interest rate, rather than an average borrowing rate which would include a premium for risk. In general, an IRR range from this analysis of above 6 per cent, the long term interest rate net of inflation (ABARE 1990), would indicate the project would be profitable if all assumptions held for the duration of the project.

INVESTMENT ANALYSIS OF CROCODILE FARMING

Although some crocodile farms in Australia are associated with tourist facilities this analysis concentrates solely on the costs and returns to the sale of crocodile products from farming in the absence of tourist facilities. As the aim of the analysis is to indicate the potential of the crocodile industry in Australia the model was based on a well-managed farm on a suitable site with ready access to water. Although the range in possible farm production allowed for variations in survival rates and availability of hatchlings, no allowance was made for an unexpected disaster which would result in the total loss of farm stock. The analysis was on a pre-tax basis and was conducted over 20 years. Although the aim is to indicate potential it was assumed that no technical changes are introduced during the period of analysis due to a lack of information on the effects on costs and yields of such potential changes. It was assumed that there is no correlation between yields and prices. In one respect this assumption is true, as mentioned above Australian crocodile farmers are price takers and unable to affect prices. However, farmers could in practice delay harvest if prices declined for short periods. Also, prices were assumed not to change relative to costs. Given these assumptions, the results would reflect potential and may not represent the current industry average. The effects of these assumptions on IRRs were gauged by sensitivity tests. For example, there is some likelihood that prices may fall, and so an analysis was conducted with prices falling by 1 per cent relative to costs.

There are basically two types of crocodile farms in Australia — the first captively breeds stock for growout while the second buys in hatchlings. Hatchlings are available from either wild collections (in states where this is permitted) or from hatcheries and other farms. Both farm models are based on an average annual production of 1500 crocodiles (table 1). Farm production was allowed to vary about this average due to a range in survival rates and the constraint of breeding problems and the variability in supply of hatchlings based on wild supplies. Currently the majority of farms in operation throughout Australia produce approximately equal numbers of saltwater and freshwater crocodiles each year. Thus this 50:50 mix of species was used as the base case for each model. Survival rates for each species were assumed to be identical and the rates used are known to be achievable on well-managed farms but do not necessarily reflect the current industry average. The majority of animals grow to harvest size within 3 to 5 years. For the analysis it was assumed that the required number of mature breeders were purchased when establishing the farm and that the first hatchlings from

Table 1. Key characteristics of model farms

Item	Unit	Most likely outcome	Range
Yield	crocodiles/yr	1 500	1 278–1 600
Survival rate (hatchlings to harvest)	%	88	75–94
Time period for growout	year	3.5	2–5
Skin size at harvest			
– saltwater	cm		34–35
– freshwater	cm		24–25
Income			
– saltwater	$/crocodile	550	500–600
– freshwater	$/crocodile	250	220–280

the breeding stock would be available in the third year. However, in practice it may not be possible to purchase all breeders in the one year due to constraints on the availability of breeding stock. Indeed, the limited supply, particularly of saltwater crocodiles has been a constraint to industry growth in the past (Taplin 1989).

All costs were allowed to vary by 15 per cent around the averages listed in tables 2 and 3 to reflect uncertainty and variations in costs due to differing sites and the different number of hatchlings each year. The unit costs used to calculate annual running costs for each model were in general identical (table 2). However, the costs of permits to farm, move and kill crocodiles vary between states and permits to export crocodile products vary according to the origin of the product — $5 if the skin was obtained under an approved management program or $40 if obtained under a captive breeding program. For the analysis, fees applicable to farmers in the Northern Territory (the Northern Territory industry is largely dependent upon wild stocks) were used for the purchasing farm model. For the breeding farm model, permit fees applicable to Queensland farmers (where the industry does not depend on wild stocks) were used. In the base case annual permit fees for the purchasing farm model amount to $11 500, considerably more than the $1850 incurred by the breeding farm model.

Table 2. Annual running costs for model farms

Item	Breeding farm ($)	Purchasing farm (%)
Manager	30 000	30 000
Permanent hired labour	120 000	100 000
Casual labour	27 000	27 000
Feed	170 000	160 500
Hatchlings	0	46 750
Fuel	1 000	1 000
Electricity	30 000	25 000
Land rates	2 800	2 000
Permits	1 850	11 500
Repairs and maintenance	17 100	12 000
Administrative costs	5 000	5 000
Miscellaneous	4 000	4 000
Total	408 750	424 750

Feed is the largest component of operating costs, accounting for 42 per cent for the farm which breeds its own stock and 38 per cent for the farm which buys hatchlings (table 2). On average a crocodile culled at 1.5 m long will have consumed throughout its life a total of 120 kg of feed which costs about $1/kg. It is possible that feed costs could be reduced in the future with further refinements in diet. Labour is another major cost, representing around 40 per cent for both farm models. The major difference between the farm models, in terms of annual operating costs, is the purchase of hatchlings. Initially both will need to buy hatchlings for growout but from the third year of operation the breeding farm model will be relying on the success of its own captive breeding operation to provide stock for growout. For each year in the analysis it is assumed that each farm model begins with 1700 hatchlings. In practice it may not be possible to maintain this constant level of supply of hatchlings from the wild each year; however, to enable a comparison between the two models in the analysis it was necessary to assume the number of hatchlings supplied annually to each model as identical. Overall, running costs for the farm model which has breeding facilities are almost 4 per cent lower than those for the farm which annually buys hatchlings.

Table 3. Capital costs for farm models

Item	Breeding farm ($)	Purchasing farm ($)	Expected life (years)	Scrap value (%)
Land	84 000	60 000	–	100
Perimeter fencing	32 180	26 880	20	10
Office/storage shed	30 000	30 000	20	10
Electricity connection	40 000	40 000	–	–
Backup generator	15 000	15 000	10	10
Incubation/hatchling area	30 000	25 000	20	10
Incubators	18 000	0	10	10
Growout pens	180 000	180 000	10	–
Breeding pens	147 750	0	10	–
Breeders				
Saltwater				
– Females	10 200	0	–	–
– Males	25 500	0	–	–
Freshwater				
– Females	14 100	0	–	–
– Males	7 125	0	–	–
Settling ponds	20 000	20 000	20	–
Pen cleaning equipment	1 000	1 000	1	–
Harvesting equipment	2 000	2 000	5	–
Meat mincer (new)	5 000	5 000	10	10
Bandsaw (2nd hand)	1 500	1 500	5	10
Scales	1 000	1 000	5	10
Processing room & equipment	80 000	80 000	20	10
Freezer/cooler	20 000	20 000	10	10
Coolroom	10 000	10 000	10	10
Pumps (5 hp)	20 000	15 000	5	10
Utility/truck (1 t)	25 000	25 000	10	10
Coolbox	10 000	10 000	15	10
Tractor	10 000	10 000	10	10
Trailer	500	500	10	10
Motorbike (3–4 wheels)	6 000	6 000	5	10
Slasher	2 000	2 000	5	10
Miscellaneous tools	5 000	5 000	5	10
Total	852 855	590 880		

The construction of crocodile pens represents a major cost in establishing a crocodile farm (table 3). In the case of the model farm which buys hatchlings, 15 pens or enclosures are required at a cost of $12 000 each for growout of the purchased hatchlings. The farm model with breeding facilities will also require 15 growout pens but breeding enclosures will also need to be constructed. The number of breeding pens required depends on the number of each species produced. Saltwater crocodiles are best mated on a one to one basis whereas freshwater crocodiles are a communal species and more than one female can be mated with each male, without reductions in fertility levels. In the analysis a ratio of five freshwater females to every male has been used. On average, in good captive conditions, saltwater crocodiles can produce between 25 and 30 hatchlings each season whereas freshwater crocodiles produce 9–10 hatchlings. In the base case where production is equally split between freshwater and saltwater crocodiles, 53 breeding pens are required — 34 for saltwater crocodiles and 19 for the freshwater crocodiles. The total cost of pens on the breeding farm model is estimated at $327 750 or around 38 per cent of total capital costs (table 3). The capital requirements for the hatchling purchasing farm are considerably lower than those of the breeding farm model simply because the former does not require breeding facilities. Overall capital costs for the farm which buys hatchlings are 31 per cent lower than for the farm model which breeds its own stock.

RATES OF RETURN TO CROCODILE FARMING

An investment analysis for both farm models was conducted using the information outlined in the previous sections. In the base case where the production for each farm model is equally split between freshwater and saltwater crocodiles, the profitability of the breeding farm model is much lower, with an average IRR of 5.8 per cent, whereas the hatchling purchasing farm model has an average IRR of 9.0 per cent (table 4). When the average and range in IRRs are compared with the long term interest rate of 6 per cent a year it becomes apparent that the breeding farm model is unprofitable with current farm structures and without joint production with tourism, whereas the alternative model is viable. The risk in crocodile farming is much less than in culturing other aquacultural species in northern Australia (see figure 2 and Treadwell, Maguire and McKelvie 1991).

Figure 2: Cumulative probability of IRR

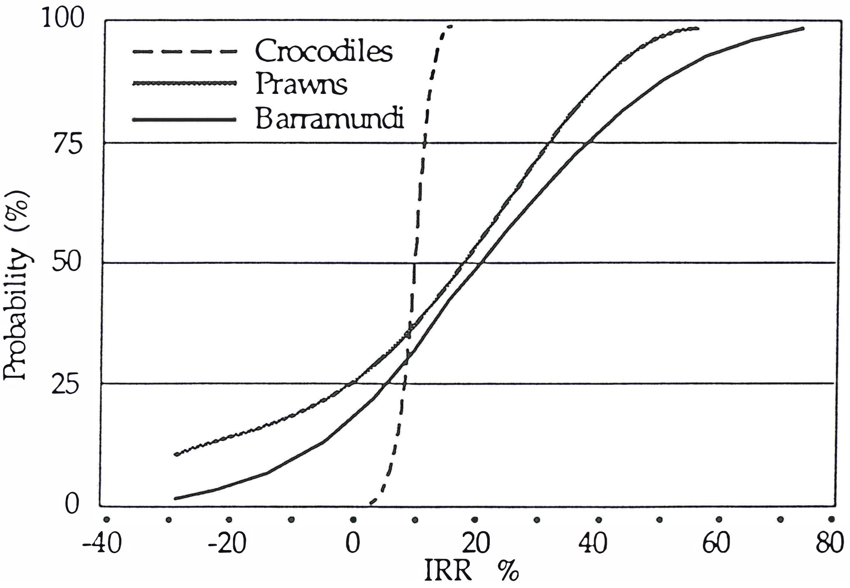


Table 4. Internal rates of return

Item	Mean IRR (%)	IRR range 50% chance that IRR is: (%)
Base model		
Breeding farm	5.8	4.2 to 7.1
Purchasing farm	9.0	7.1 to 10.5
Average growout time reduced to 2.5 years		
Breeding farm	10.9	9.0 to 12.4
Purchasing farm	15.8	13.4 to 17.8
Feed costs reduced by 10 %		
Breeding farm	6.7	5.5 to 8.0
Purchasing farm	10.2	8.5 to 11.7
100% freshwater		
Breeding farm	–23.4	–28.4 to –18.6
Purchasing farm	–31.4	–40.0 to –22.4
100% saltwater		
Breeding farm	16.7	15.4 to 17.8
Purchasing farm	21.6	20.1 to 23.0
60% saltwater		
Breeding farm	8.5	7 to 9.7
Purchasing farm	12.0	10.4 to 13.4
Prices deflated 1%		
Breeding farm	1.0	–1.0 to 2.7
Purchasing farm	2.8	0.2 to 5.1

As mentioned above there is some uncertainty about the maintenance of relative price levels in the future. If prices fell by 1 per cent a year in relation to costs crocodile farming would be unprofitable with current technology and the 50:50 species mix. However, such a price decline could be offset by productivity improvements, such as higher growth rates, lower feed costs and more concentration on the production of saltwater crocodiles. If feed costs could be reduced by 10 per cent, returns would be improved but not sufficiently to offset such a price fall.

On average the majority of crocodiles reach harvest size about 3.5 years after hatching, although some are culled at 2 years. An analysis was conducted to examine the likely effects on returns to farming if the average harvest age of the majority of crocodiles was reduced to 2.5 years, with a range of 1.5–3.5 years. The 50:50 mix of species was maintained. Under this regime the likely returns of both farm models increased substantially — almost double the base case. Increased growth rates may be achievable as the result of improved diets, more favourable temperatures or by selectively breeding stock. However, farms which rely on the collection of eggs and hatchlings from the wild are prevented from controlling the entire life cycle of the crocodiles. Selective breeding is not an easy process. Problems with obtaining adequate numbers of suitable mature crocodiles and successfully mating them are possibly the major constraints at present.

The value of fresh and saltwater crocodiles differs substantially — on average saltwater crocodiles are worth more than twice the value of freshwater crocodiles (table 1); however, they cost around the same to produce. Several analyses were performed using different mixes of the species. Not surprisingly, returns for farm models producing only saltwater crocodiles more than doubled in both cases. Conversely, farm models with production of freshwater crocodiles only earned negative returns. This raises the point why farmers are persisting with the farming of freshwater crocodiles. One reason may be the existence of economies of size together with the limited supply of saltwater crocodiles; however, insufficient data were available to determine whether this is the case.

CONCLUSIONS

Since exports of crocodile skins have been allowed the Australian crocodile industry has expanded to an estimated value of production of $1.5 million in 1989-90. Crocodile farms have been developed in Queensland, the Northern Territory and Western Australia. Currently most farms stock an equal number of saltwater and freshwater crocodiles, due mainly to constraints on the availability of saltwater crocodiles. The basis of farms' breeding programs varies between states, with the Northern Territory and Western Australia being principally dependent on collections of wild hatchlings or eggs, while captive breeding is used in Queensland. In terms of profitability, farms dependent on wild breeding stock earn higher returns than those using captive breeding techniques with current technology and if hatchlings and adequate numbers of suitable adult crocodiles are available for purchase prior to the farm's establishing its own breeding program

The results of the analysis of crocodile farm models using current technology indicate that although returns vary between farm type these returns are reasonably certain provided prices do not decline in relation to costs. Although the market outlook for crocodile skins is favourable, prices could fall if crocodile farming is expanded substantially in Australia and South-East Asia. If prices did decline by 1 per cent a year in relation to costs the analysis indicated that crocodile farming would be unprofitable with current technology and species mix. Further expansion of this industry in Australia will be constrained unless improvements in farm productivity can be achieved or a higher proportion of saltwater crocodiles are produced or joint production with tourism is pursued. As indicated by the analysis, productivity improvements, such as higher growth rates, could result in significant increases in likely returns. However, the profitability of crocodile farming would be improved far more if production were concentrated on producing saltwater crocodiles. If constraints on saltwater stock can be overcome, the results of this analysis indicate that crocodile farming has the potential to continue expanding in the future. The prospects for increasing saltwater stocks are much better for farms which undertake their own breeding, as farms relying on wild supplies may always be subject to limited supply of stock for growout. Thus, although the simulated results indicate that the farm model which breeds stock receives lower returns, future potential for the industry may be improved if captive breeding of saltwater crocodiles is pursued.

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