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Recirculation Prawn Farming Project

Final Report



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MARINE RESEARCH



Natural Heritage Trust
Coast and Clean Seas
Project Number 717511

Report by
C. H. Robertson
M. A. Burford
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The Department of Primary Industries seeks a better quality of life for all Queenslanders—a quality of life supported by innovative world-class food and fibre industries, by responsible and ecologically sustainable use of natural resources and by capable and self-reliant rural communities.

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This publication is designed to offer information on recirculation technologies to aquaculturists and related stakeholders for further improvement in sustainable prawn farming practices.

While every care has been taken in preparing this publication, the State of Queensland accepts no responsibility for decisions or actions taken as a result of any data, information, statement or advice, expressed or implied, contained in this report.

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Chris Stafford was the project biologist for this study and played a key role in the planning and conductance of the field and laboratory work for the overall project as well as in the completion of this report. Chris was instrumental in maximising the collaboration between the research team and the farm management staff through both his friendly nature and his persistence to achieve the objectives of the task. His efforts have provided the core of a complex and challenging project.

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EXECUTIVE SUMMARY

Experimental design and commercial application

The research project was conducted on a commercial prawn farm to investigate a comparison of recirculation and flow through ponds systems, in aspects of production as well as nutrient dynamics and microbial ecology. Three growout ponds in the recirculation system supplied effluent to a common treatment pond, and water was recycled after settlement and bioremediation treatment, back to the growout ponds. Three adjacent growout ponds operated using flow-through methods were essentially the same design as the growout ponds in the recirculation system, except that pond effluent was not recycled but drained into a drain canal for eventual release at a licensed discharge point.

In order to achieve statistically valid comparisons of both production results and water quality data, all of the six growout ponds in the trial were stocked within one week at the same density of 40 post larva/m² and as alternate pairs. Pond management methods and harvesting techniques used were the same for both recirculation and flow through pond systems.

Production outcomes

No effluent water was discharged from the recirculation pond system during the period of monitoring for water quality and production. For two of the experimental ponds (one recirculation and one flow through) this was the entire crop duration (130 days) because they were harvested the next day.

Estimated production was higher for the recirculation ponds (5207.4 kg/hectare) than for the flow through system (4,305.1 kg/hectare). The estimated survival, mean body weight, feed consumption and yields were all higher in the recirculation ponds.

The trial comparison of recirculation ponds with conventional flow through ponds have demonstrated that commercial scale prawn production can be achieved in recirculating systems with no discharge of effluent during a crop, using conventional pond management methods.

Nutrients and water quality results

The proportion of nitrogen in the water column was higher in the flow-through ponds compared with the recirculation ponds. Mean salinity over the entire crop was higher in the recirculation production ponds than the flow through ponds, while deposition of sludge was significantly higher in the recirculation system. The eventual fate of nitrogen in the recirculation ponds by the end of the crops was predominantly in the sediment and was higher than in the flow-through ponds. In the recirculation ponds the loss of nitrogen due to denitrification was close to double that in the flow-through ponds.

1 INTRODUCTION AND BACKGROUND

1.1 The Recirculation Prawn Farming Project

The purpose of the Recirculation Prawn Farming Project was to establish and trial a commercial scale recirculation prawn farm system, as a demonstration of the potential effectiveness of such technology in improving the environmental performance of prawn farming practices. The project included the comparison of water quality data and production results in a recirculation system with that of an adjacent conventional flow-through pond system.

The project was jointly funded by the Coast and Clean Seas Program in the Natural Heritage Trust, and by Queensland Department of Primary Industries. Pacific Blue Technologies Pty Ltd were industry collaborators in the project, while CSIRO were partners in the research team.

1.2 The Australian prawn farming industry

Prawn farming in Australia is now a substantial seafood farming industry that has created significant economic development in regional Australia. It has progressed from early pioneering trials in the early 1980's to an established commercial industry that continues to expand in various regions of the tropical coast. In 2000-2001 the production of Queensland farmed prawn was 2525 tonnes, valued at \$44.6 million (Lobegeiger 2002), representing approximately 21% of total prawn production in Queensland. Prawn farm production for the 2001-2002 season was expected to reach 3500 tonnes with a value of more than \$70 million (APFA 2002b). Approximately 600 hectares of ponds are currently in production in farms in NSW, QLD, NT and Western Australia, with more than 80% distributed along the east coast of Queensland.

The majority of Australian prawn farming production is of the black tiger or leader prawn, *Penaeus monodon*, while commercial production of the banana prawn *P. merguensis* and the kuruma prawn *P. japonicus* has also increased in recent years in Queensland. Other species such as *P. esculentus* and *Metapenaeus macleayi* have been farmed at various times in NSW and in Queensland.

In most other countries penaeid prawns are termed shrimp. The Australian prawn farming industry is relatively small, in comparison to many other shrimp farming countries in South East Asia and South America. Thailand is considered the largest shrimp farming country, with farms producing more than 200 000 tonnes of *P.monodon* per annum, while shrimp farming industries in the Americas produce more than 115 000 tonnes of *P. vannamei*, *P. stylirostris* and other species (Rosenberry 2000).

The prawn farming techniques now used in Australia were developed mostly from the intensive methods established in South East Asia, where farming of *P.monodon* developed so successfully in the 1970s. Significant research and development in the Australian industry has now provided further advances in nutrition, health, water quality and environmental management.

Australian prawn farming essentially started in the early 1980s in northern NSW with the pond farming of juvenile school prawns, *M. macleayi*, collected by trawlers in the Clarence River. Success in this low-risk method of pond farming and the development of hatchery technology for the faster growing *P. monodon* led to intensification of production and the development of farms in the more tropical areas of Queensland.

Australian prawn farms typically now have one-hectare earthen ponds that are stocked intensively at 20–45 prawns/m² and produce 3–8 tonnes per hectare per crop. High-protein pelleted feeds are used to increase growth rates and may be distributed three to five times per day by vehicle-mounted blowers. The ponds are aerated and may require regular water exchange by floodlifter pumps to help maintain water quality. Hatchery production of *P. monodon* is constrained at various times each year by significant shortages of broodstock from the wild fishery, and captive breeding programs are yet to provide regular commercial supplies of post larvae. On the other hand, farming of *P. merguensis*, *P. japonicus* and *P. esculentus* is not constrained by wild broodstock shortages, and closed life cycle breeding techniques are now well established. However, these species can have slower growth rates and more specific pond management requirements.

1.3 Background research and development

Various studies in Australia and overseas have shown that the use of high protein feeds in intensive prawn farming methods are inherently inefficient in terms of assimilation of protein nitrogen to prawn biomass. In typical *P. monodon* farming systems, approximately 70–75% of total nitrogen in the feed can be lost to the environment with only 25–30 % incorporated as prawn biomass (Funge-Smith and Briggs 1998, Teichert-Coddington 1999, Jackson et al. 2003). This represents a major loss in economic efficiency when it is considered that feed is usually the highest operational cost in a prawn farming enterprise.

Prawns have a requirement for high levels of protein in the feed, not only for growth but also because of a dependency on the metabolism of proteins for energy (Conklin et al 1983). From such metabolism, prawns excrete ammonium into the water column, primarily through their gills. Any excess feed unconsumed by the prawns can breakdown and release nutrients into the water column. Overfeeding can result in reduced feed digestion and increased faeces production. Despite steam pelleting technology and the use of binders, a significant proportion of feed nutrient can also leach out and dissolve in the water column if the pellets are not consumed within a short time. The dissolved inorganic nutrients effectively become a fertiliser in the pond and promote further algal blooms, leading to the eventual deposition of dead algal cells on the pond floor. Subsequent microbial decomposition of the organic matter or sludge resulting from excess feed, faeces, dead algae and other material can contribute to the accumulation of toxic compounds such as ammonia and hydrogen sulphide in the pond system (Burford & Longmore, 2001).

With such losses in the feeding process, the potential for diminished water quality may lead pond managers to exchange water in the ponds in order to flush accumulated nutrients and algal material. The volume of water exchanged, usually expressed as a percentage of the pond volume added per day (%/day), can increase during the crop as the amount of feed added per day increases, and at times may exceed 30%/day for individual ponds. However, typical daily averages across an entire farm are typically around 2–5 %/day.

Concern about the potential for downstream environmental impacts from pond effluent released from prawn farms has led to considerable research in Australia on the composition,

origin and treatment of prawn farm effluent (Preston et al 2000). These studies have provided significant outcomes to industry including data and information on the use of settlement ponds in effluent treatment. The Australian prawn farming industry has since capitalised on such research and a considerable number of farms have installed settlement ponds and or drain systems in farms, valued at more than \$15million (APFA 2002a). Some prawn farming companies in various parts of Australia have retrofitted ponds or constructed new farms that can be operated as partial recirculating systems. It is apparent that each of these systems has been established to provide improved discharge water quality and improve environmental performance.

1.4 Prawn farming environmental regulations.

Rigorous environmental regulations for prawn farming in Queensland are now established at both the State and Federal level. The Queensland Environmental Protection Authority (EPA) administers the regulation of aquaculture effluent discharge to state waters under the mechanisms of the Environmental Protection Act (1997). Assessments of potential impact are made against criteria provided in the ANZECC Water Quality Guidelines.

In 2000, the Great Barrier Reef Marine Park Authority (GBRMPA) introduced federal enacted legislation (Great Barrier Reef Marine Park (Aquaculture) Regulations 2000) to regulate aquaculture operations in or adjacent to the Marine Park. Also in 2000, the Federal government through Environment Australia enacted the Environmental Protection, Biodiversity and Conservation Act 1999 (EPBC) legislation that enabled the regulation of activities such as aquaculture where they may be considered significant to World Heritage Areas.

1.5 Recirculation technologies established overseas

In other countries the technology of recirculation shrimp farming has progressed in various forms for different reasons (Robertson 2001). The most common reason for recirculation systems in most other shrimp farming countries such as Thailand, is the need to minimise the risk of on-farm infection by serious diseases such as White Spot Syndrome Virus. A recirculating farm may achieve improved biosecurity by increasing the degree of isolation of farm stock from the adjacent estuary that may carry disease vectors. Shortage of land, or the high cost of land or pumping of water is another reason for recirculating systems, for example in Israel. Some recirculation shrimp farms have been established to achieve higher environmental performance by significantly reducing effluent nutrient loads, and new recirculation technology suggests that some economic benefits can also be gained. This may be from the recycling of nutrients back into the pond food chain, or the potential to produce another crop from the treatment of recirculated effluent (bioremediation).

1.6 Objectives of this study

By implication recirculation systems offer potential for a reduction in the volume of prawn pond effluent and a reduction in the nutrient loading discharged from a farm to the environment. As with any closed loop aquaculture system, recirculation prawn farms require treatment systems that can capture suspended solids and nutrients such as nitrogen from the recycled water to minimise the potential for degraded water quality in the growout pond system. Avoiding ammonia toxicity and reduction in total phosphorus and suspended solids are also important in maintaining water quality for prawn production. The effectiveness of

treatment systems in reducing nutrient load in the effluent train will therefore determine the overall carrying capacity of a recirculation system.

This study reports on the design and operation and water quality management of a recirculation prawn farm system that operated without discharge of effluent during the crop until when harvesting was commenced. The objectives of the study were to:

- Harvest crops of prawns from typical prawn farm ponds, without discharge of effluent water to the environment, under normal commercial conditions and with a profitable yield
- Show that prawn ponds can be managed as closed systems (as compared to up to 30 % exchange per day) by recycling of the nutrients in a natural assimilative process
- Investigate potential for off-flavour in prawns cultured in zero discharge systems
- Provide demonstration of the results to the prawn farming industry and the community, with the aim of improving the understanding and management of such a new innovative technique, and showing that it is economically viable
- Investigate nutrient dynamics and microbial ecology in recirculation pond systems to potentially improve yields.

2. PROJECT DESIGN AND SITE DESCRIPTION

2.1 Prawn farm site - Ponderosa Prawn Farm

The project site was situated at Ponderosa Prawn Farm, located approximately 10 kilometres from the city of Cairns (Figure 2.1). The prawn farm consists of 17 production ponds with an intake storage reservoir and a settlement pond. The growout ponds are approximately one hectare in size, with side drain monk outlets and an aquaduct water delivery system from the reservoir. The farm is operated as an intensive prawn farm with large water exchange capacity, electric aeration systems and ponds designed for drain harvest and with plastic lined walls to minimise bank erosion.

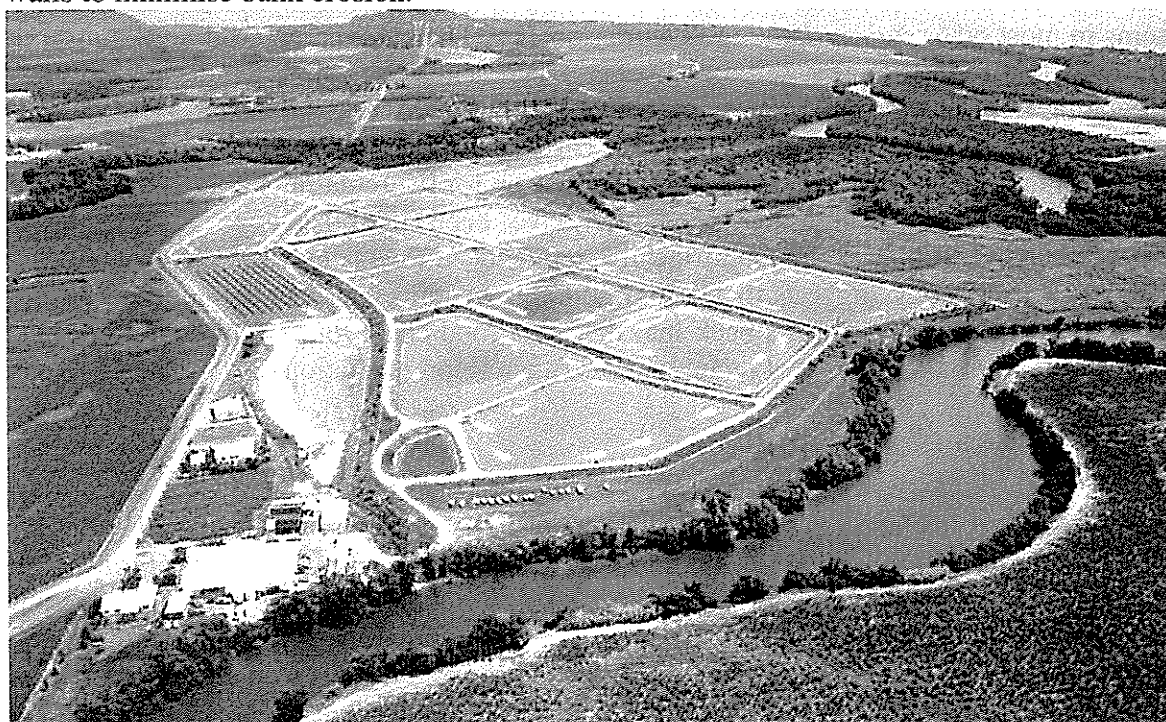


Figure 2.1 Ponderosa Prawn Farm, Cairns

The farm is typical of most other prawn farms established in the Queensland industry, established on coastal clay soils adjacent to an estuary system. This farm is subject to seasonal fluctuations in intake water quality with potential for wet season rains to reduce salinity and exacerbate agricultural runoff. Intake water is sourced from a tributary of Thomatis Creek which is a branch of the Barron River. All of the growout ponds can be drained through the settlement pond before release to the estuary at an EPA licensed discharge point in the upstream area of Thomatis Creek.

Ponderosa Prawn Farm is located in the wet tropics region of north Queensland. Mean annual rainfall is 2028 mm and the highest mean daily maximum and lowest mean daily minimum temperatures are 31.4 and 17.0°C respectively.

2.2 Description of the Prawn Farm Recirculation System

2.2.1 POND SYSTEM

The Recirculation Prawn Farming Project was conducted at the Ponderosa Prawn Farm site in seven existing ponds used for growout and treatment. Plumbing and structural modifications to four of these ponds enabled the establishment of a pilot recirculation system that could be compared simultaneously with three other ponds managed using conventional flow-through methods.

Three growout ponds in the recirculation system supplied effluent to a common treatment pond, and water was recycled after settlement and bioremediation treatment, back to the growout ponds. Three adjacent growout ponds operated using flow-through methods were essentially the same design as the growout ponds in the recirculation system, except that pond effluent was not recycled but drained into a drain canal for eventual release from the farm at the EPA licensed discharge point (Figure 2.2).

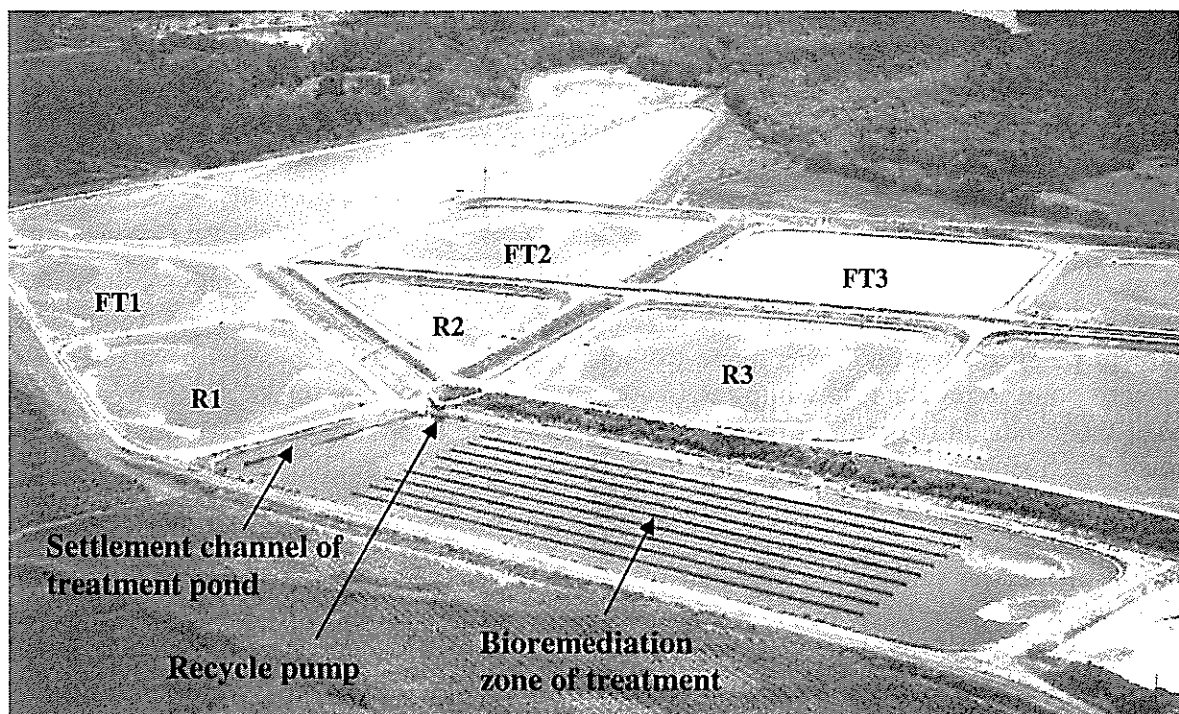


Figure 2.2 Flow through ponds (FT), recirculation ponds (R) and treatment pond used in the Recirculation Prawn Farming Project.

2.2.2 PRODUCTION AND TREATMENT AREA

The ponds included in the Recirculation Prawn Farming Project had a range of production areas that enabled a comparison of pond management and water quality results in a commercial scale system (Table 2.1).

Table 2.1 Pondage areas in Recirculation Prawn Farming Project ponds at Ponderosa Prawn Farm

	<i>Individual pond sizes (ha)</i>	<i>Total pond area (ha)</i>
Recirculation System		
growout ponds	0.70, 0.31, 1.00	2.01
treatment pond	1.30	1.30
total recirculation system		3.31
Flow-through System		
growout ponds	0.7, 1.0, 1.0	2.70

The growout to treatment ratio in the recirculation pond system is therefore :

$$2.01 \div 1.30 = 1.55$$

or expressed as the % treatment area (in relation to total growout area) is :

$$1.30 \times 100/2.01 = 64.7 \%$$

2.2.3 MODIFICATIONS TO ESTABLISH RECIRCULATION SYSTEM

Each of the seven ponds were already established with inlet water delivery pipes from an aqueduct, outlet drains through concrete monks, aeration systems and parallel monofilament bird deterrent wire. The modifications required to establish the recirculation system using four of the existing ponds can be described in four categories :

- Siphons and transfer pipes
- Treatment pond – settlement channel area
- Treatment pond – bioremediation area
- Recycle pump

2.2.3.1 Siphons and transfer pipes

Due to higher embankments and differences in pond heights, a double siphon system was established in two of the growout ponds in the recirculation system to drain pond water to the treatment pond. Each siphon was made from 150mm diameter PVC pipe with valves at the discharge point to regulate flow into the treatment pond. The siphon intake points were at the side of the ponds, in the path of paddlewheel aerators and approximately 750 mm below the surface. Each siphon was screened with 10mm mesh screens and could be started by capping both ends and filling with a mobile 50mm pump.

A series of transfer pipes were installed on the third growout pond, adjacent to and at the same level as the treatment pond. A total of six 150mm diameter PVC pipes buried in the embankment enabled the drainage of pond water into the treatment pond when water levels were high. The intake points of each transfer pipe were at the side of the ponds near the outlet monk, in the path of paddlewheel aerators and approximately 250-750 mm below the surface.

Each transfer pipe was screened with 10mm mesh screens and could be started by removing caps at the outlet end.

2.2.3.2 Treatment pond – settlement channel area

The treatment pond for the recirculation system was divided into a settlement channel area and a bioremediation (biological treatment) area, using partitions made from HDPE plastic film. The settlement channel area was 70 x 15 metres (0.105 hectare) and 2 metres deep at the eastern end where the siphons delivered effluent from the growout ponds (Figure 2.3). Pond effluent passed through the settlement channel area and discharged into the bioremediation area of the pond through a shallow overflow gate in the plastic partition at the western end. No aeration was installed in the settlement channel area.

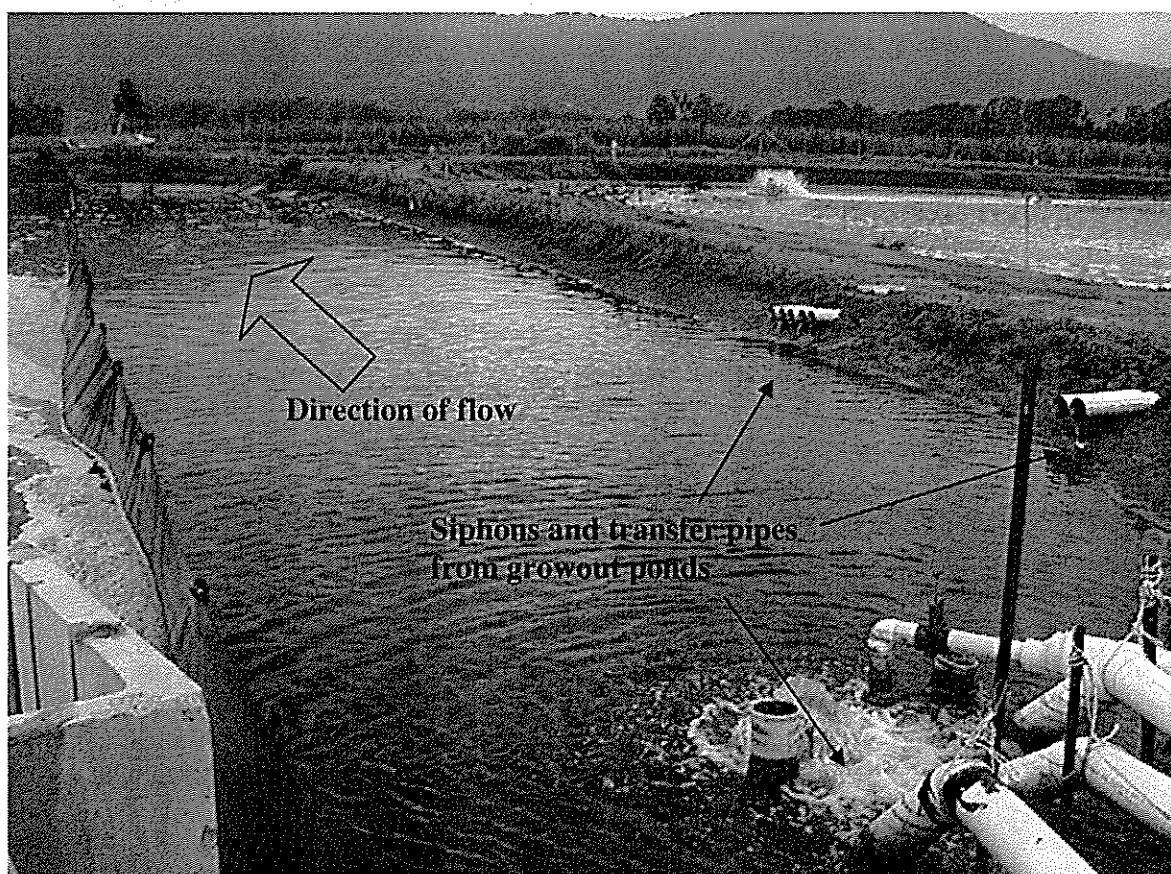


Figure 2.3 Settlement channel of treatment pond

2.2.3.3 Treatment pond – bioremediation area

The bioremediation area of the treatment pond was 170 metres long by 70 metres wide (1.190 hectare) and included a central partition made from HDPE plastic film and a total of 600 metres of submerged shade cloth fencelines (total submerged surface area = 900 m²). Aerators and water movers in the bioremediation area provided aeration and created a slow current revolving around the central plastic partition (Figure 2.4). The shade cloth fences were installed to provide surface area for fouling organisms to assist bioremediation processes in the pond.



Figure 2.4 Overflow gate and bioremediation zone of treatment pond, showing direction of water flow.

2.2.3.4 Recycle pump

A diesel powered 12" floodlifter pump was installed at the corner of the bioremediation area of the treatment pond (beside the outlet monk) to pump recycled water back to the growout ponds through 12" PVC pipe and fluming.



Figure 2.5 Recycled water entering a recirculation growout pond.

2.2.4 WATER EXCHANGE CAPACITIES

The plumbing modifications in the recirculation system were installed to provide water exchange in each of the recirculation ponds (using recycled water) with a capacity equivalent to that in the existing flow-through ponds (using inlet water from the estuary). Typical daily water exchanges involved firstly draining pond water levels by siphons and/or transfer pipes, and then refilling the recirculation ponds with water from the treatment pond via the recycle pump.

2.2.5 POND MANAGEMENT AND WATER CONSUMPTION

The three flow-through growout ponds were managed according to existing farm practices, and received water exchanges when required during the crop with water sourced from the estuary. Pond effluent released during water exchanges from these ponds was eventually discharged from the farm at the EPA licensed discharge point. Effects of evaporation required additional estuary water to be added to the system to maintain pond levels.

The three recirculation ponds were also managed according to existing farm practices, except that all water exchanges were made with water recycled from the treatment pond (after the initial fill using estuary water) until the end of the water quality sampling program. Effects of evaporation required additional estuary water to be added to the recirculation system to maintain pond levels.

2.3 Experimental design

The aim of the Recirculation Prawn Farming Project was to compare the productivity and water quality processes in a pilot recirculation pond system with that of a conventional flow-through pond system. This ranged from broad comparisons of prawn yields and survivals to the detailed analysis of differences in nutrient processes between the two systems.

2.3.1 UNIFORM STOCKING DENSITY AND SINGLE HATCHERY SUPPLY

In order to achieve statistically valid comparisons of both production results and water quality data, all of the six growout ponds in the trial were stocked at the same density of 40 post larva/m² during the period 7th to 11th August 2001. Due to the constraints of unpredictable hatchery supply, the ponds were stocked as alternate pairs where one hatchery batch was used to stock one recirculation pond and one flow-through pond on the same day. Three batches were sourced from the same hatchery to stock all six ponds. No prawns or fish were stocked in the treatment pond of the recirculation system.

2.3.2 STANDARDISED POND MANAGEMENT METHODS

Pond management methods for the recirculation ponds were essentially the same as used in the conventional flow-through ponds, except that water was recycled from the treatment pond and not sourced from the estuary. Farm staff carried out the stocking of ponds, feeding, water quality and prawn health monitoring, and the harvesting of the crop in a similar fashion for all the ponds included in the trial.

3.0 POND MANAGEMENT AND PRODUCTION PERFORMANCE – COMPARISON BETWEEN THE RECIRCULATION AND FLOW-THROUGH SYSTEMS

3.1 Introduction

Profitable and productive prawn farming methods are based on good water quality management and the use of high quality feeds to achieve high survival and growth. However, the poor conversion of protein nitrogen in the feeds to prawn biomass is now known to contribute to considerable leaching of excess nutrients to the pond environment (Burford & Williams 2001). Good pond management methods may therefore include flushing to reduce the loading of nutrients and the algae that thrive from them, especially when the crop is reaching harvest size and daily inputs of feed are high.

Given that the conventional prawn farming method depends on various management procedures to minimise nutrient accumulation, it would be expected to be more difficult to maintain good water quality in recirculation ponds stocked at similar production levels. The main management concerns in operating recirculating ponds would be the potential for nutrient accumulation, particularly ammonia which, in high concentrations, can be toxic (Robertson 2001). This may lead to unstable algae blooms that can cause pH fluctuations and dissolved oxygen dips, creating stress on the prawns and potentially causing slow growth rates and or disease problems. The risks of disease outbreaks is also expected to be higher in recirculation pond systems because the recycling of water could lead to further infection in other prawns in the same or other ponds. Each of these issues need to be addressed if recirculation prawn farming methods are to be commercially successful.

Previous research in minimal water exchange methods for prawn farming (Robertson and Stafford 1997) has also highlighted the potential for taste problems in prawns harvested from closed pond systems. Causative factors may include the effects of blue green algae, excessive accumulation of sludge in the pond or the potential effects of lower water quality stresses created in recirculation methods.

While it is important to consider the potential for recirculation prawn farming methods to improve industry practices and assist the industry in meeting environmental requirements, uptake of the technology will mostly depend on the demonstration of commercial viability within the context of existing industry standards. Questions of practical application of the technology to large scale farming systems will need to be answered, as well as the potential issues of lower productivity and/or disease problems. Commercial scale demonstration of recirculation methods should also identify any management risks or problems that would make the technology any less viable than the conventional prawn farming methods.

The objectives of the study described in this section were to show by using a commercial scale demonstration that recirculation prawn farming methods could be applied at a commercial scale in the Australian prawn farming industry, using established pond management methods. By comparing the management and production results of recirculation ponds with the conventional flow-through ponds, the aims of the study also included identification of any pond management issues that could occur in recirculation systems.

3.2 Methods

The six production ponds and the treatment pond in the study were stocked with prawns and then monitored weekly for production and water quality parameters for a period of 131 days, until 18/12/01 when 2 of the 6 ponds were harvested (Table 3.1). At this time, water recirculation ceased. The four remaining ponds were retained and harvested over the following weeks. Therefore the harvest data for these four ponds is not comparable with the two ponds harvested on the 18/12/01. For this reason, statistical comparisons could not be made between the recirculation and flow-through pond systems. In order to make comparisons, it was necessary to estimate the survival, individual weights and various production parameters for the prawns in four of the six ponds on 18/12/01 assuming that prawn growth and survival did not change dramatically after this date.

Pond stocking

All six production ponds used in the trial were stocked in August 2001 for the dry season crop. The ponds were stocked in alternate pairs, one a recirculation and one a flow-through pond, at densities of 40 prawns/m². Pond pairs were stocked on the same day and all the ponds were stocked within 5 days (Table 3.1). The same batch of post larvae was used to stock each pair of ponds.

Table 3.1 Stocking and harvesting dates for the recirculation and flow-through ponds; pond pairs were stocked on the same days with the same hatchery batch of post larva. (R = recirculation pond, FT = flow-through pond).

<i>Pond</i>	<i>Stocking Date</i>	<i>Harvest Date</i>	<i>Crop duration (days)</i>
R1	09/08/2001	21/12/2001	134
FT1	09/08/2001	13/12/2001	126
R2	11/08/2001	23/01/2002	167
FT2	11/08/2001	4/02/2002	179
R3	07/08/2001	21/01/2002	165
FT3	07/08/2001	2/02/2002	177

Water exchange

Water exchange in the recirculation and flow through ponds was estimated during the crop by the number of monk outlet boards removed to enable a water exchange to occur.

Survival

Data on survival at the time of harvest was used despite the fact that the experiment was concluded on 18/12/01 prior to harvesting. Therefore survival values are likely to be under-estimates for ponds R2, R3, FT2 and DT3.

Mean body weight

The mean body weight was estimated at the end of the monitoring period using

$$\text{Mean body weight (g)} = [(\text{feed used (g)} / \text{final FCR}) / (\text{survival/no. stocked})]$$

Production per hectare

The prawn production or yield per unit of growout area was determined using

$$\text{Yield (kg/ha/crop)} = (\text{feed used (kg)} / \text{final FCR}) / \text{growout pond size (ha)}$$

For the purposes of comparison, the production per hectare for both the recirculation and flow through pond systems was determined with growout areas only, i.e. the treatment pond area for the recirculation ponds was not included in the calculation.

Feed consumption

The feed used during the monitoring period (up to 18/12/01) for each pond was converted to feed consumption/hectare by dividing total feed per pond by pond size.

Water use efficiency

The volume of water discharged from the pond system per unit of production was estimated by:

$$\text{Water use efficiency (m}^3\text{/kg)} = \text{volume of water discharged/kg prawns}$$

For the flow through ponds, the volume of water discharged is the cumulative amount of water exchanged in the ponds and discharged from the farm during the crop plus the pond volume discharged for the final drain harvest, whereas for the recirculation ponds it is only the pond volume of water discharged from the farm for the final drain harvest (because no discharge of effluent occurred during the crop).

3.3 Results

No water was discharged from the recirculation pond system during the monitoring period from 7/8/01 to 18/12/01. For two of the experimental ponds (one recirculation and one flow through) this was the entire crop duration (130 days) because they were harvested the next day.

Production per hectare

Estimated production during the monitoring period was higher for the recirculation ponds (5207.4 kg/hectare) than for the flow through system (4,305.1 kg/hectare). The estimated survival, mean body weight, feed consumption and yields were all higher in the recirculation ponds (Table 3.2).

Water use efficiency

While more water was exchanged within the recirculation system (86,775 m³ compared with 61,695 m³ in the flow-through ponds), less water was discharged to the environment per kilogram of prawn produced in the recirculation ponds, compared to the flow-through system (2.9 m³/kg compared to 14.8 m³/kg of prawn yield) (Table 3.2). The volume of water discharged per kilogram of prawn produced in the recirculation system is based on one pond volume only, when it is discharged from the farm as a result of the harvest (with no discharge during the crop).

Table 3.2 Comparison of mean (\pm SE) production parameters for *P. monodon* in the recirculation and flow-through systems from the period 7/8/01 to 18/12/01. *Production was measured in one recirculation pond and one flow-through pond and estimated for the remaining ponds from FCR.

<i>Parameter</i>	<i>Recirculation</i>	<i>S.D.</i>	<i>Flow through</i>	<i>S.D.</i>
Mean pond size (ha)	0.67	± 0.2	0.91	± 0.1
Mean pond depth (m)	1.5		1.5	
Stocking density (prawn/m ²)	40		40	
Survival (%)	91.7	± 5.4	79.8	± 6.4
Mean weight (g)	14.0	± 0.7	13.5	± 1.5
Growth rate (g/week)	0.8		0.7	
Production (kg/ha/crop)	5207*	± 295	4,305*	± 525
Food fed (kg/ha/crop)	8,145	± 443	7275	± 150
Feed Conversion Ratio	1.6	± 0.2	1.7	± 0.2
Culture period (days)	131	± 1	129	± 2
Water exchange (m ³ /ha/crop)	86,775	$\pm 15,943$	61,695	± 404
Water use efficiency (m ³ /kg prawn)	2.9	± 0.2	14.8	± 1.9

3.4 Discussion

The trial comparison of recirculation ponds with conventional flow through ponds have demonstrated that commercial scale prawn production can be achieved in recirculating systems with no discharge of effluent during a crop, using conventional pond management methods and treatment systems similar to those recently established in Queensland prawn farms, and at yields on par with industry averages (Lobegeiger 2002).

However a range of operational problems encountered during the trial, and the existing limitations on the carrying capacity of recirculation ponds created by problems of nutrient build-up, indicate that considerable more improvements are required before the technology can be adopted as mainstream industry practice. The processes leading to the potential for nutrient build-up in the recirculation system are discussed in detail in Chapter 4, while this chapter examines the management of production and water quality in the recirculation system.

3.4.1 POND MANAGEMENT - HIGHER YIELDS, SMALL PRAWN SIZE

The recirculation and flow-through ponds in the trial were not all harvested immediately at the end of the monitoring program. One recirculation pond and one flow-through pond were harvested immediately after, while the others were not completely harvested until February. While the estimated average prawn sizes at the end of the monitoring program were smaller than typical market size and growth rates were lower, the estimated yields of 5,207 kg/ha/crop in the recirculation ponds show that commercial production was achieved. Average yields in the Queensland prawn farming industry in 2000/2001 were 3,406 kg/ha/crop, with an average stocking density of 35 post larva/m² (Lobegeiger 2002). In this study, the recirculation ponds were stocked at 40 post larva/m² and showed a yield higher than industry average and also a greater yield than that in the flow-through ponds.

However whilst the yields in these trials were similar, the average body weights in the recirculation ponds at harvest were lower and survival rates were higher than in typical industry ponds. The high survival is clearly a positive outcome and is typical for most crops on the collaborating farm. The tendency to harvest early at a smaller size to meet market demands is also typical for the farm but creates some additional unresolved questions for this study.

While the recirculating pond system was successful in achieving yields of over 5 tonnes per hectare in the growout ponds at peak capacity, the results do not show how the treatment and bioremediation system would have catered for higher biomass loadings if the prawn size was taken to 25g or more before harvesting was commenced. Biomass loadings of 7-9 tonnes per hectare would be expected to cause significant pond management issues (unstable blooms, low dissolved oxygen etc) that may not be sustainable for the recirculation system used in this study. Further bioremediation improvements are required for more effective removal of nutrient loads from the recirculation system if higher yields are to be achieved.

The terms of this study did not include any explanations of yield differences between the two systems, but the results present other questions about possible benefits in the use of recirculated water for pond exchanges. These may include improved stability or consistency of relevant water quality parameters in the recirculation ponds compared to more significant fluctuations that may occur in flow-through ponds receiving new water directly from an estuary intake source. Such considerations correlate with an industry trend in pond management to minimise stress to the prawns by adopting more gradual or continuous water exchanges compared to large sudden exchanges with new water, and the use of recirculated water to 'seed' a stable bloom as part of pond preparation (Dick 2002).

3.4.2 POND MANAGEMENT PROBLEMS IN THE RECIRCULATION SYSTEM

While the pond management requirements for the recirculation ponds were essentially the same as for the flow-through ponds, a range of operational issues required additional attention to minimise risks in water quality and prawn health management. Most of these potential problems were resolved through either infrastructure changes or with changes in management processes.

The recirculation system including the treatment pond required additional aeration capacity to maintain appropriate oxygen levels and assist in the amelioration of water quality. During the course of the crop it became apparent from weekly collation and review of the monitoring program data that the potential for nitrogen accumulation in the recirculation system may lead to ammonia and nitrate toxicities, or serious diurnal fluctuations in pH and/or dissolved oxygen from the collapse of algae blooms. Indeed such events did occur at various times towards the end of the crop, but were mostly predicted and effectively controlled through the addition or change of placement of aerators, short term changes in feeding rates, or increased water exchange from the treatment pond. It is also worth noting that similar pond management problems occurred during the crop in the flow-through ponds.

A series of structural improvements were made to the plumbing and aeration systems in the recirculation ponds during the course of the crops. The siphons and transfer pipes initially installed to deliver pond water to the treatment pond were found to have inadequate flow rates and were doubled in capacity so that a daily exchange of more than 5% could be achieved. The return fluming from the diesel pump to the growout ponds was upgraded with additional pipes and fittings to enable an easier operation and greater daily capacity from the pump. Additional aeration was installed in the recirculation ponds and bioremediation area of the treatment pond to improve both oxygenation and water currents, so that by the end of the crops the total aeration capacity in the recirculation ponds was 18.9 horsepower/hectare (HP/ha) compared with 14.4 HP/ha in the flow through ponds.

3.4.3 WATER EXCHANGE RATE DIFFERENCES

The water exchange rate is the amount of water flushed through a pond on a daily basis, and is expressed as a percentage of the total pond volume. Water exchange in the recirculation ponds

was with recycled water from the treatment pond, whereas in the flow through ponds water was sourced from the estuary. Daily water exchanges in the recirculation system using recycled water would therefore not result in discharge from the farm, whereas flow through pond water exchanges can contribute to the daily effluent loading allowable under the EPA license conditions.

On an average % daily exchange basis over the course of the whole crop, the recirculation ponds received more water exchanges through internal recirculation than what the flow-through ponds received through external exchanges from the estuary. Other than the initial fill water and water added from the estuary to account for evaporative losses, all of the water exchanged in the recirculation ponds was recycled from the treatment pond. Whilst the flow-through ponds were managed according to the established farm methods and received water exchanges from the estuary as required for conventional flow-through ponds, the recirculation ponds were purposefully provided with more water exchanges to pre-empt potential water quality problems. If such recirculation prawn farming systems are to be improved as commercial ventures, it is apparent that an increase in the daily exchange rate may benefit pond water quality, contrary to the industry trend in flow-through ponds to minimise daily exchanges.

3.4.4 WATER USE EFFICIENCIES

The calculations for the water volumes discharged to the estuary during the entire crop per kilogram of prawn produced, highlight the potential differences in environmental performance between the recirculation and flow-through prawn farming systems. A comparison of the water use efficiency in the flow through ponds of 14.8 m³/kg of prawn yielded, with the recirculation ponds rate of 2.9 m³/kg, represents a significant reduction in the volume of effluent that could be discharged from a farm overall. However in this instance, enhanced nutrient concentrations in the recirculation pond water at the end of the crop (see Chapter 4) indicate that further treatment would be required downstream before its release to the estuary at the time of harvest. The volumes of effluent discharged would be effectively further reduced in recirculation pond systems if the pond water was retained on-farm after each harvest for re-use in subsequent crops, instead of discharge to the estuary.

3.5 Taste sensory evaluation - Executive Summary

Prawns harvested from the flow through and recirculation ponds were used to evaluate any taste differences in product from the two pond systems. A summary of the report is provided below while the full report is provided in Appendix 7.2.

A triangle test was completed to establish whether a perceptible taste difference exists (at the 5% level of significance) between prawns from recirculated and flow-through (control) ponds. Twenty-one panellists from the Centre for Food Technology completed the test on 17 December 2001. No significant difference (P=0.125) was found between the prawns from the recirculated and flow-through (control) ponds.

4. NUTRIENT BUDGETS, WATER QUALITY AND SLUDGE MANAGEMENT - COMPARISON BETWEEN RECIRCULATION AND FLOW-THROUGH SYSTEMS

4.1. Introduction

Recirculation or closed system prawn farming systems often show some deterioration in water quality as the crop matures (Samocha *et al.* 2002, Burford *et al.* in press). These systems may require more infrastructure (eg. aerators) and additional pond management considerations to achieve production similar to or greater than the conventional flow through systems. The conventional systems are based on diluting pond water with new water from an external source, whereas recirculation systems rely on an internalised water quality management system.

The recirculation system at Ponderosa prawn farm is reliant on a large treatment pond that was designed to facilitate settlement of solids as well as microbial processing of nutrients, to provide optimal water quality for exchange in the growout ponds. This made greater economic demands on the prawn farming enterprise including the cost of additional land for treatment area, and aeration and water exchange equipment. Such infrastructure is required to reduce the concentrations of particulate matter, eg. particulate nitrogen (PN), total suspended solids (TSS), sediment, chlorophyll, detritus, and dissolved nutrients (eg nitrogen and phosphorus), before it is used for recirculation. A majority of the sludge waste that accumulates in production ponds is inorganic sediment scoured from the pond itself (Smith 1996, Burford *et al.* 1998). The organic fraction originates from faeces, excessive feed input, dead algae cells and to a lesser extent fertiliser and pre-existing levels in soil and intake water. The effects of remineralisation of the organic fraction in the sludge can in turn release significant quantities of inorganic nitrogen in the form of ammonium back into the water column (Burford & Longmore 2001). Reducing these wastes to avoid excessive nitrogen accumulation is the challenge for recirculation system management.

Different management techniques have been employed to improve waste reduction in prawn aquaculture, including settlement ponds and increased aeration to enhance removal of nitrogen via ammonia volatilisation. Water exchange is vital in the growout ponds to reduce dissolved nutrients, suspended solids, plankton and debris but may remove only a small proportion of solids. Centre drains have been considered effective in removing sludge from ponds during a crop (McIntosh *et al.* 1999), but were not considered cost effective in the Ponderosa prawn farm trial. The use of central drains also requires further infrastructure to process the sludge. Other management techniques include changes in feed inputs, low protein feeds or lowering ration size, and lining ponds (Burford *et al.* 2001).

This chapter compares water quality and nutrient budgets between the flow-through and recirculation ponds for the duration of the monitoring period. Pond management and environmental performance issues are discussed.

4.2 Methods

4.2.1 SAMPLE COLLECTION AND STORAGE

Farm staff monitored temperature, pH, dissolved oxygen (DO) and water turbidity (secchi disk depth) twice daily at approximately 6:30am and 6:00 pm for the duration of the study. A YSI meter was used for DO and temperature, a Hanna meter for pH, and a standardised black/white secchi disk for turbidity. Salinity was measured weekly using a WTW salinity meter. All meters used for recording physical parameters were calibrated before use and serviced according to manufacturers' recommendations.

Water samples for the determination of nutrients were collected weekly throughout the crop (130 days) and daily during an intensive week late in the crop (21.11.01 to 24.11.01). For the weekly analyses, samples were collected in duplicate from the same location in all of the test ponds (3 recirculation ponds, the treatment pond and 3 flow-through ponds) using clean 10 L buckets, on each Tuesday commencing at 8 am. Samples were processed in a laboratory as soon as possible, usually within 1 h of collection. A subsample of 20 ml of unfiltered water was taken and frozen for TN and TP analyses. Further 20ml subsamples for ammonia (NH_4), nitrite (NO_2), nitrate (NO_3) and free reactive phosphorus (FRP) analyses, were filtered through a GF-F filter in line with a 0.45 μm cellulose acetate filter. Samples were frozen until analysed.

Duplicate samples for total suspended solids (TSS) and chlorophyll *a* (Chla) were collected weekly throughout the crop (130 days) and daily during an intensive week late in the crop (21/11/01 to 24/11/01) from all 7 ponds (3 recirculation production ponds, one treatment pond and 3 flow-through ponds). Clean 10L buckets were used on the same day each week and time in the morning. Samples were processed as soon as possible, usually within an hour of collection, in a water quality laboratory. Salinity was measured weekly to validate farm data.

4.2.2 ANALYSIS METHODS

Total & Dissolved Nitrogen and Phosphorus - water samples were analysed using a simultaneous persulphate digestion method (APHA, 1995), and analysed by standard methods 4500-P E (APHA, 1995). A 5ml sample and 2.5ml of digestion reagent were used for an initial 45 min digest and a second digest for 30min at 120⁰C, following shaking to dissolve a precipitate. Following the simultaneous digestion of TN and TP, subsequent analysis of the respective digestion products (nitrate and reactive phosphorus) was undertaken using standard method 4500 - NO_3 E (APHA, 1995) for nitrate and standard method 4500-P E (APHA, 1995) for reactive PO_4 -P.

Ammonia - ammonia nitrogen was determined using the Hach Salicylate Method 10023 (low range, 0 to 2.500 mg/L NH_3 -N) on a DR 4000 spectrophotometer.

Nitrate and nitrite - total oxides of nitrogen were determined using a variation of the standard cadmium reduction method 4500- NO_3 -E (APHA,1995). In place of a cadmium column, spongy cadmium was used in the reduction step (Jones 1983).

Free Reactive Phosphate (FRP) - Reactive PO_4 -P analysis were performed by the standard method 4500-PE ascorbic acid method. (APHA, 1995).

Chlorophyll and Total Suspended Solids - Known volumes of water were filtered through pre-weighed glass fibre GF-F filters for chlorophyll and TSS determinations. In the case of TSS, preweighed filters were dried at 60°C then weighed. For determination of the volatile fraction, filters were ashed at 550°C and weighed. Chlorophyll was extracted from filters in 100% acetone by sonicating for 1 min on ice. A subsample was diluted with water to give 90% acetone. Samples were read spectrophotometrically to determine chlorophyll *a* concentrations (Jeffrey & Welshmeyer 1997).

4.2.3 METHODS OF DETERMINING SLUDGE VOLUME

Sludge in prawn ponds is typically concentrated in the inner regions of the pond due to the action of the aerators. Quantities of particulate matter deposited as sludge during the crop were estimated in the growout ponds and the treatment pond by measuring sludge depth in each pond. Sludge volume was quantified on two separate occasions during the crop in all seven ponds. The first sampling event was in the middle of the growth crop and the second occasion was at the end of the crop. Sludge profiles were determined in all seven ponds using the method described by Burford and Longmore (2001). Sludge depths were recorded at 1 m intervals for two transects run 90° to one another across each pond. Sludge area and volumes were calculated, and the outer regions were determined by subtracting the sludge zone from the total pond area.

A total of six sediment cores (30 mm deep, 30 mm diameter) were taken in both the sludge and sediment regions of each pond. Cores were bagged separately for each zone, mixed thoroughly and divided into three sub-samples for wet wt/dry wt, pore-water and CNP analyses. Wet wt/dry wt were determined by weighing samples before drying at 60°C for 24hrs, then reweighing. For porewater analyses, samples were centrifuged at 8000 rpm for 5 min, then filtered through GF/F glass fibre filters. The filtrate was analysed for ammonia-N, nitrite-N and nitrate-N.

Sediment and sludge samples for nitrogen, phosphorus and carbon concentrations were frozen until analysed. N and P were calculated using a Kjeldahl digestion mix then analysed using a segmented flow auto analyser. Organic carbon (C) were calculated using a LECO Induction Furnace method. Carbon was heated in the presence of oxygen to liberate CO₂ (carbon oxidised to produce CO₂). Carbon dioxide was then detected by a WR12, LECO Thermal Conductivity Detector.

The volume of sediment and sludge was converted into wet weight by the following calculations: sludge: 35 cm³ = 42.9 g ww, and sediment: 31 cm³ = 52.9 g ww. This, coupled with the total volume estimates for the ponds, was used to calculate the total amount of nitrogen, phosphorus and carbon in the sludge.

4.2.4 METHODS – NITROGEN AND PHOSPHORUS BUDGETS

Budgets were constructed for nitrogen and phosphorus inputs and destinations in the recirculation ponds and the flow-through ponds, summed over the entire crop. Input sources include feed, intake water, fertiliser and sediment remaining in a pond from previous crops. Destinations include prawn biomass, sediment within the pond, water discharged from the pond and atmospheric losses, for example through denitrification and volatilisation.

N and P addition was calculated from feed quantities assuming 6.9% N, 1.5% P (as a proportion of pellet wt, including 9% water: unpublished data, D. Smith and M. Barclay, CSIRO). Intake water N and P was calculated from laboratory analyses of intake water, where concentration was multiplied by volume to determine the load in kilograms of N and P

imported. Fertiliser N and P addition was calculated assuming DAP: 18% N and 48% P, NaNO₃: 16% N, KNO₃: 13% N, Urea: 45% N, Dynamic Lifter: 1.2% N and 1.3% P. Nitrogen and phosphorus concentrations in the sediment were determined as described in Section 4.2.3

The N and P content of harvested prawns was calculated assuming 2.9% N and 0.34% P (as proportion of wet wt, including 74% water: unpublished data, D. Smith and M. Barclay, CSIRO). Total water N and P was measured as described in Section 4.2.2. Nitrogen lost from the system via denitrification was measured using the nitrogen gas/argon method (Kana *et al.* 1994), where replicate cores were collected from one recirculation pond, one flow through pond and the treatment pond.

N and P lost as leakage from outlet points in ponds were calculated from the estimated volumes of water lost multiplied by TN and TP determined in samples collected from the leaked water. Estimates of TN in the fouling organisms on the shade cloth panels (150x300mm) attached to shade cloth fences in the treatment pond were made 105 days after stocking. An area of 100 x 100 mm was sampled on each of eight panels. The material on the screens were scraped off, filtered into preweighed glass fibre filters, weighed, dried at 105°C for 24 h, then reweighed. The filters were analysed for carbon and nitrogen content using a CHN analyser.

4.3 Results

4.3.1 PHYSICAL PARAMETERS

There was no significant difference in water temperatures and pH between the treatment, recirculation and flow-through ponds over the crop period (Figures 4.1 and 4.2). Mean DO levels in the morning were lowest ($P < 0.05$) in the treatment pond, followed by the recirculation ponds, while the levels in the flow-through ponds were marginally higher. Afternoon DO levels were highest in the treatment pond ($P < 0.05$), followed by the flow-through ponds, then the recirculation ponds. Both pond systems showed a general lowering of DO levels towards the end of the crop (Table 4.1, Figure 4.3).

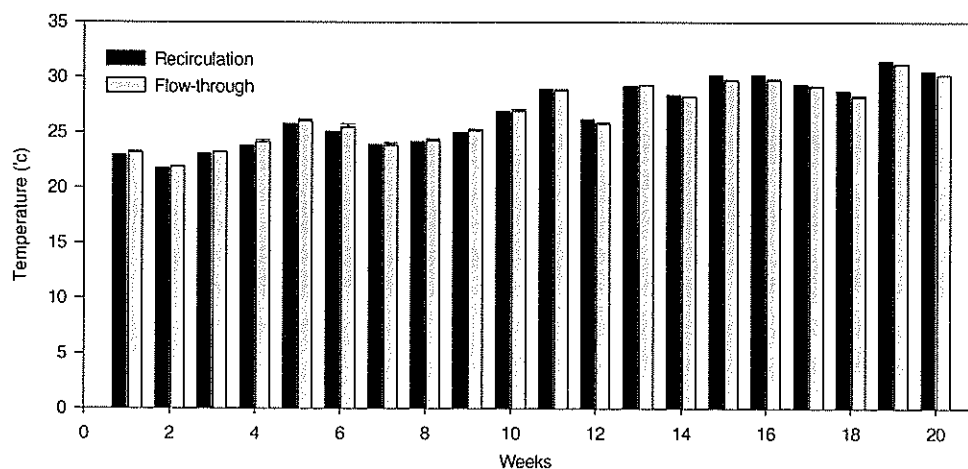


Figure 4.1 Weekly mean (+/-SD) temperature (°C) reading during the monitoring period for the recirculation and flow-through systems

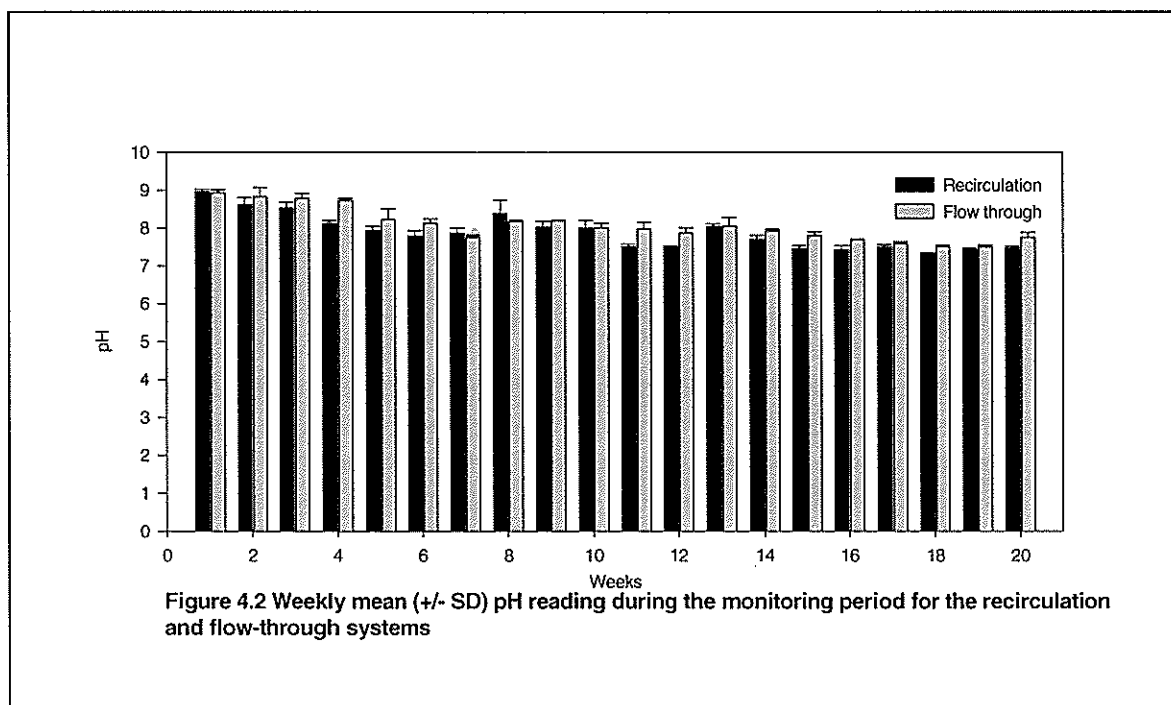


Table 4.1 Physical parameters for the treatment pond and the recirculation and flow-through ponds (mean over the duration of the monitoring period \pm SE, * denotes $P < 0.05$).

Parameter	Treatment Pond	Recirculation Ponds	Flow through ponds
Temperature ($^{\circ}$ C)	27.4 \pm 0.68	26.7 \pm 0.38	26.7 \pm 0.35
Salinity ($^{\circ}$ / $_{00}$)	26.2 \pm 0.72*	27.4 \pm 0.22*	24.6 \pm 0.24*
pH	8.0 \pm 0.06	7.9 \pm 0.0	8.1 \pm 0.06
Dissolved Oxygen : AM (mg/L)	3.7 \pm 0.24*	4.8 \pm 0.10*	4.9 \pm 0.08*
Dissolved Oxygen : PM (mg/L)	7.9 \pm 0.35*	7.1 \pm 0.14*	7.5 \pm 0.19*

In contrast, mean salinity over the entire crop was higher in the recirculation production ponds than the treatment pond (27.4 ppt and 26.2 ppt respectively, $P < 0.05$), which in turn was higher than the flow-through ponds (Table 4.1). Salinity in the recirculation ponds increased over time, due to the effects of evaporation and no input of low salinity water from external sources, whereas the salinity decreased in the flow through ponds through regular water exchanges (Figure 4.4).

The mean secchi disc reading was significantly lower in the recirculation ponds than the flow through ponds (24.9 \pm 1.41 cm compared to 32.8 \pm 1.86 cm, Table 4.2). Secchi values decreased in both systems towards the end of the season (Figure 4.5). Consistent with the changes in secchi readings, TSS and chlorophyll *a* concentrations increased over the season in both pond systems (Figure 4.6, Figure 4.7). There were, however differences between the two systems. The flow through system had higher TSS concentrations while the recirculation system had higher chlorophyll *a* concentrations (Table 4.2).

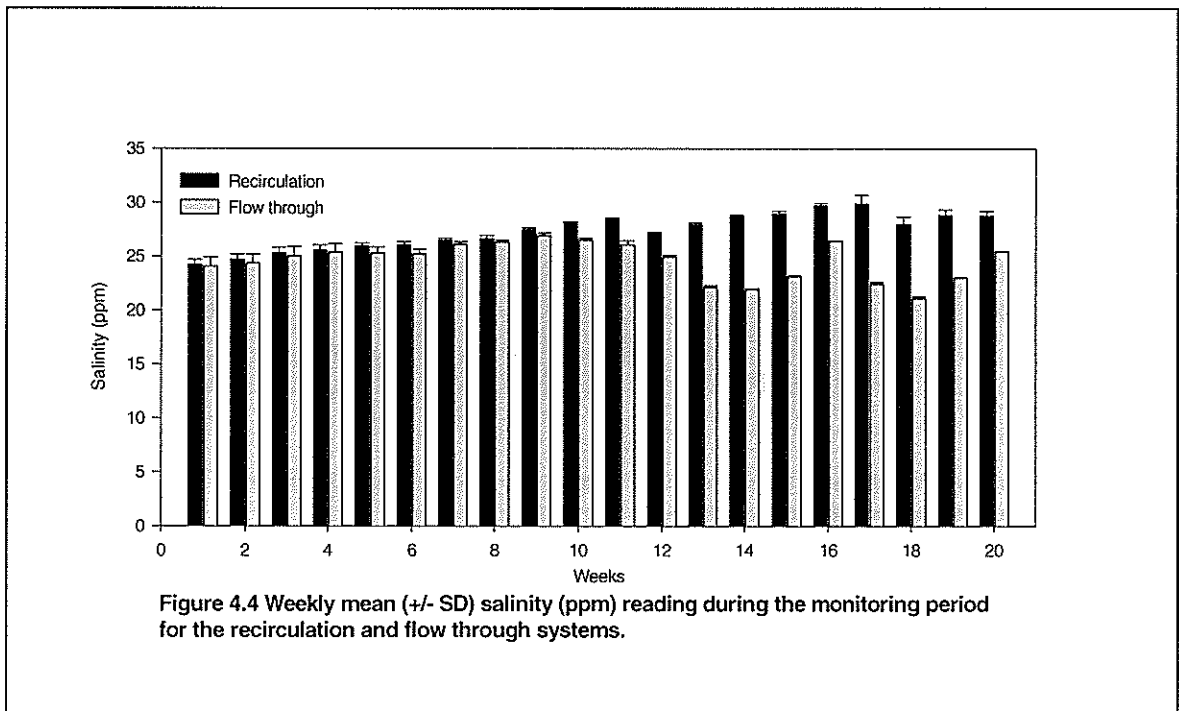
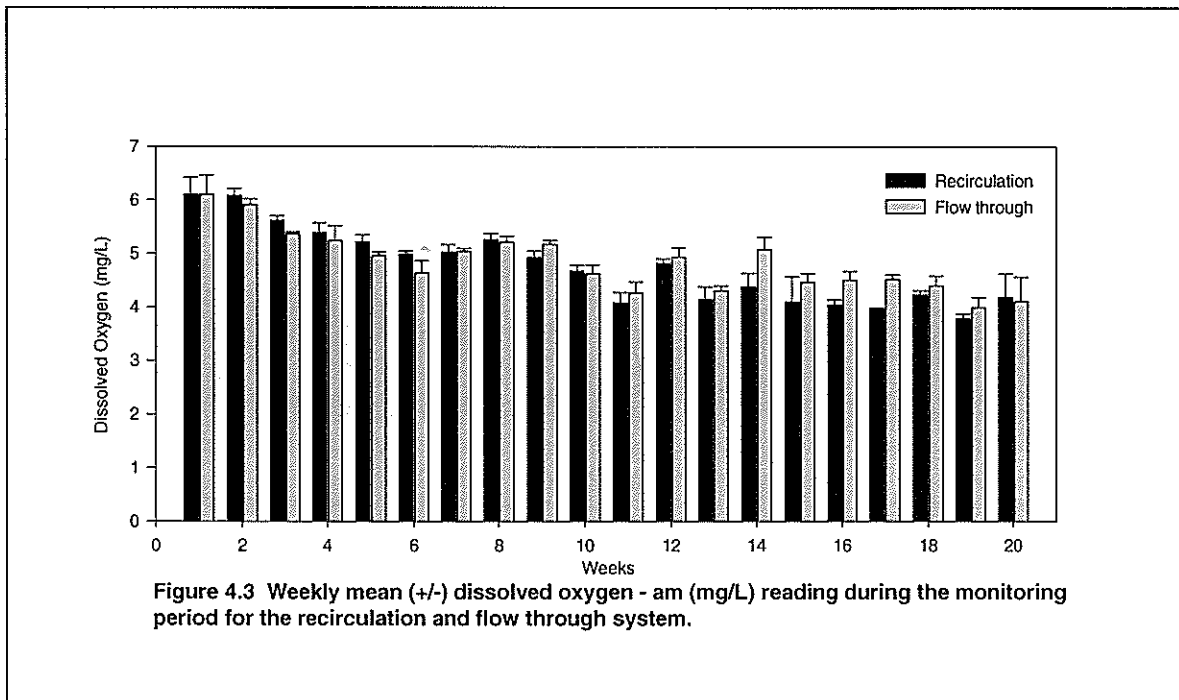
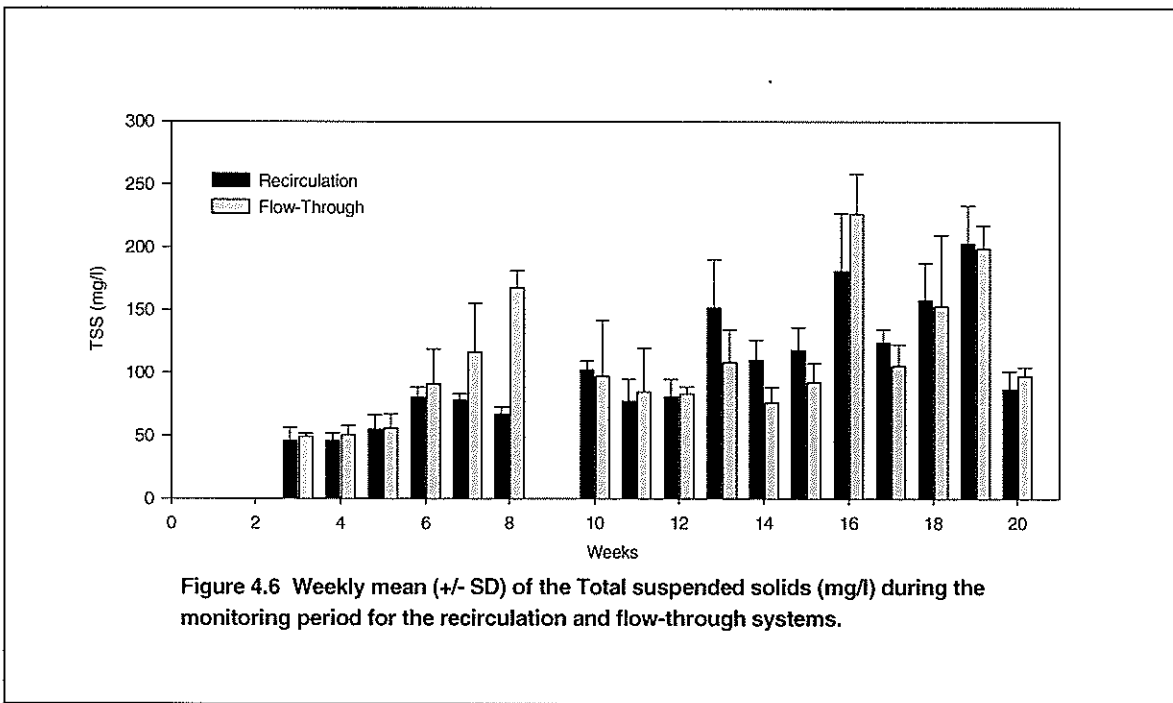
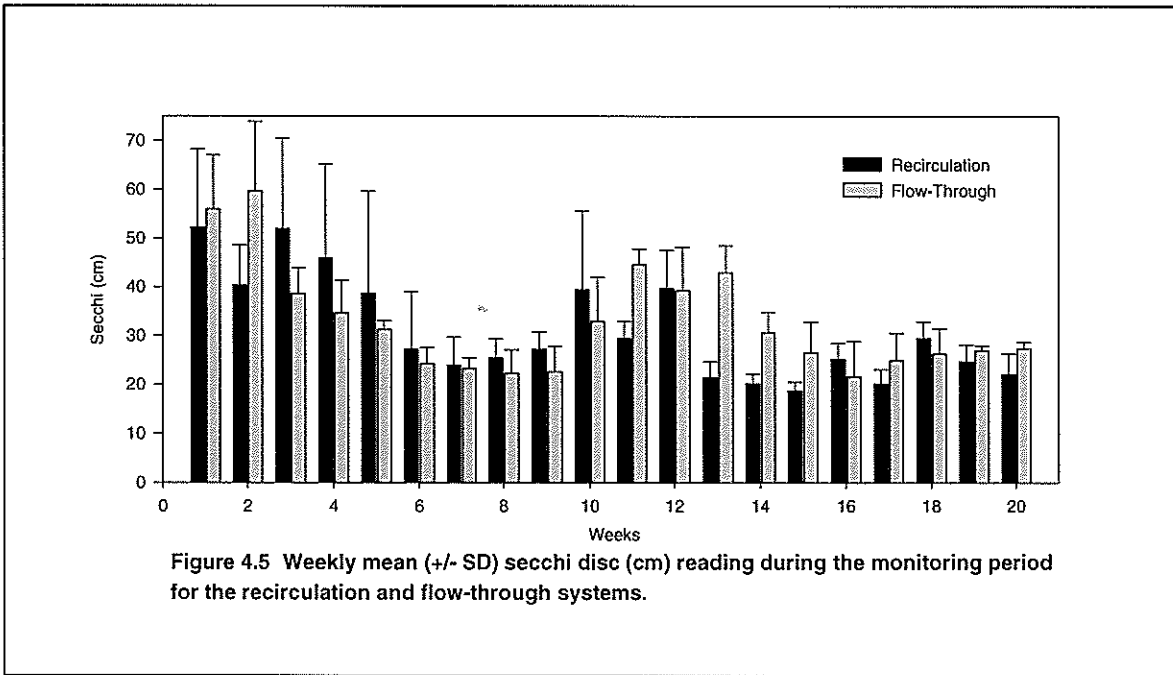
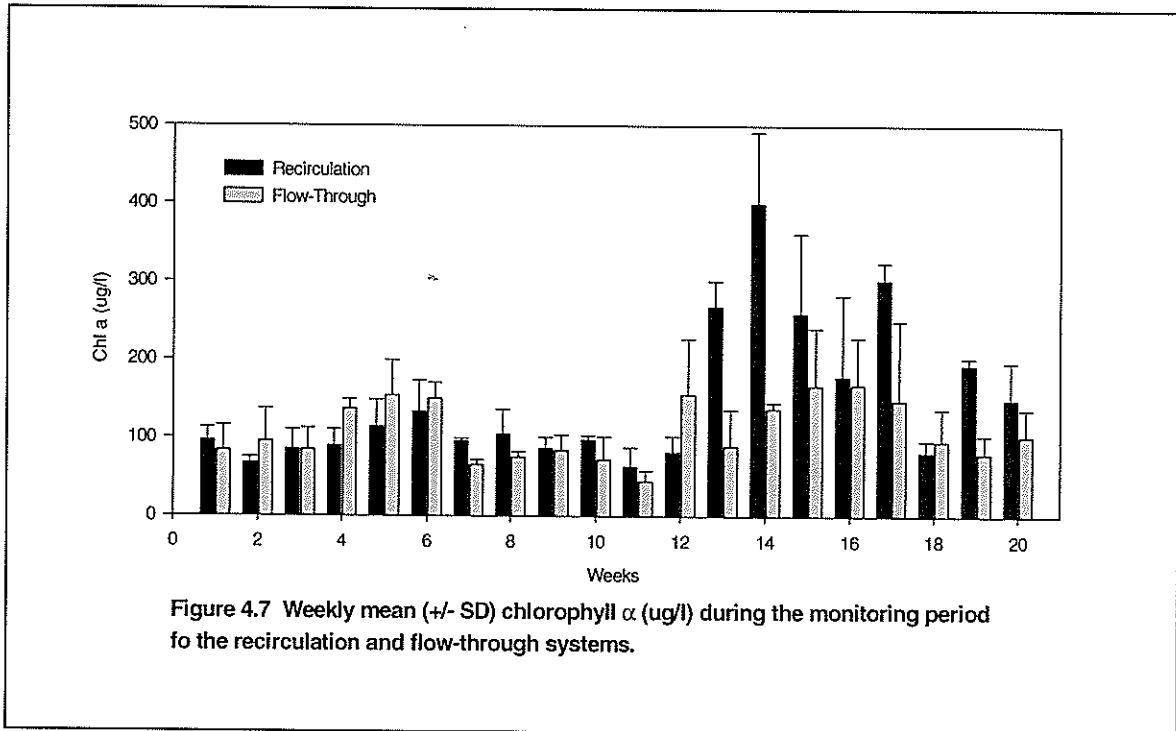


Table 4.2 Comparison of turbidity parameters for the treatment, recirculation and flow through pond systems (mean over the duration of the monitoring period, * denotes $P < 0.05$)

Parameter	Treatment Pond	Recirculation Ponds	Flow through Ponds
Secchi depth (cm)	50.7 ± 6.97*	24.9 ± 1.41*	32.8 ± 1.86*
TSS (mg/L)	69.7 ± 8.02	104.1 ± 7.59	109.7 ± 8.82
Non-volatile (mg/L)	33.3 ± 4.03	70.0 ± 5.31	62.3 ± 6.01
Volatile (mg/L)	41.6 ± 5.31	43.3 ± 3.38	35.0 ± 2.76
Chlorophyll a (µg/L)	69.9 ± 16.34	148.6 ± 14.51	109.5 ± 9.52

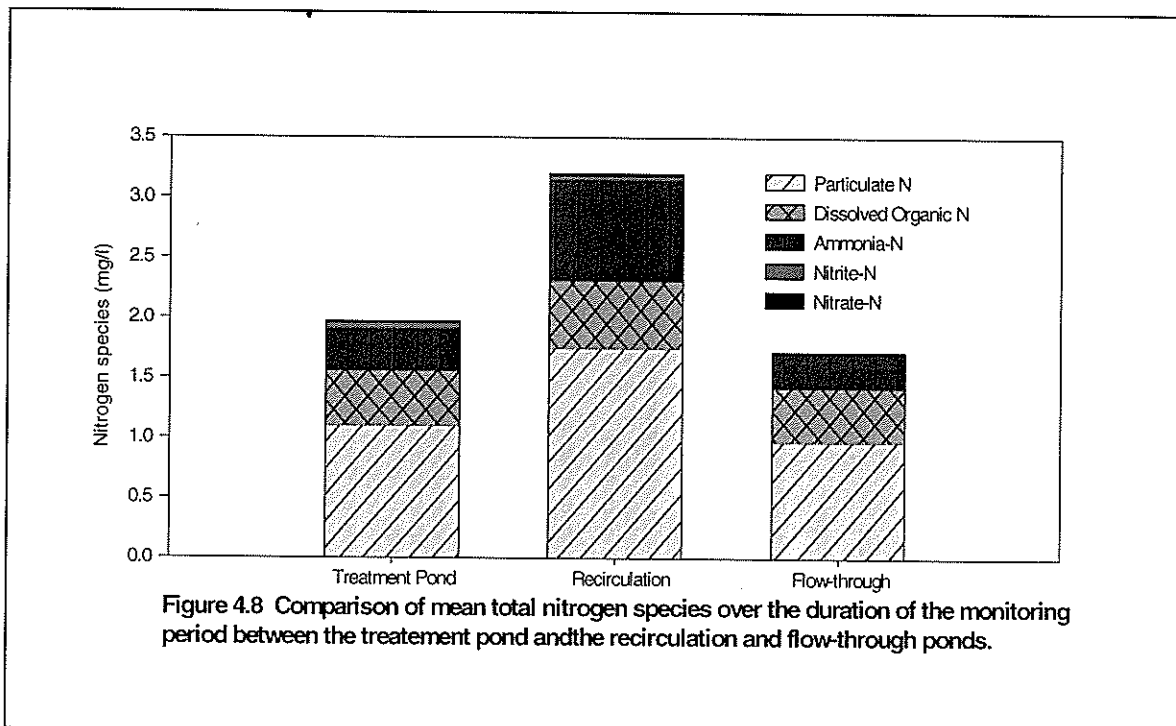


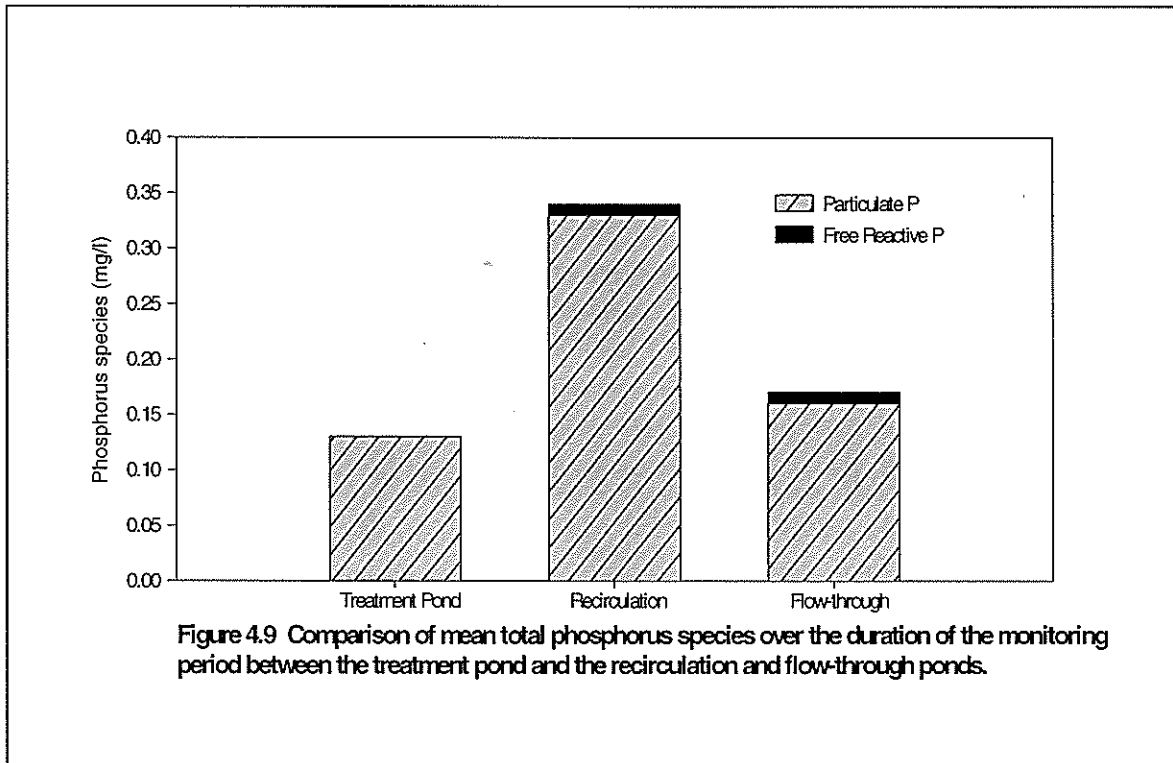
The proportions of the inorganic and organic (volatile) TSS were different between the pond systems. The non-volatile (inorganic) proportion in the recirculation system averaged 70 mg/l compared with 62 mg/l for the flow through system (Table 4.2). The volatile fraction, or organic component averaged 43 mg/l for the recirculation ponds which was not statistically different from the flow through ponds (37 mg/l).



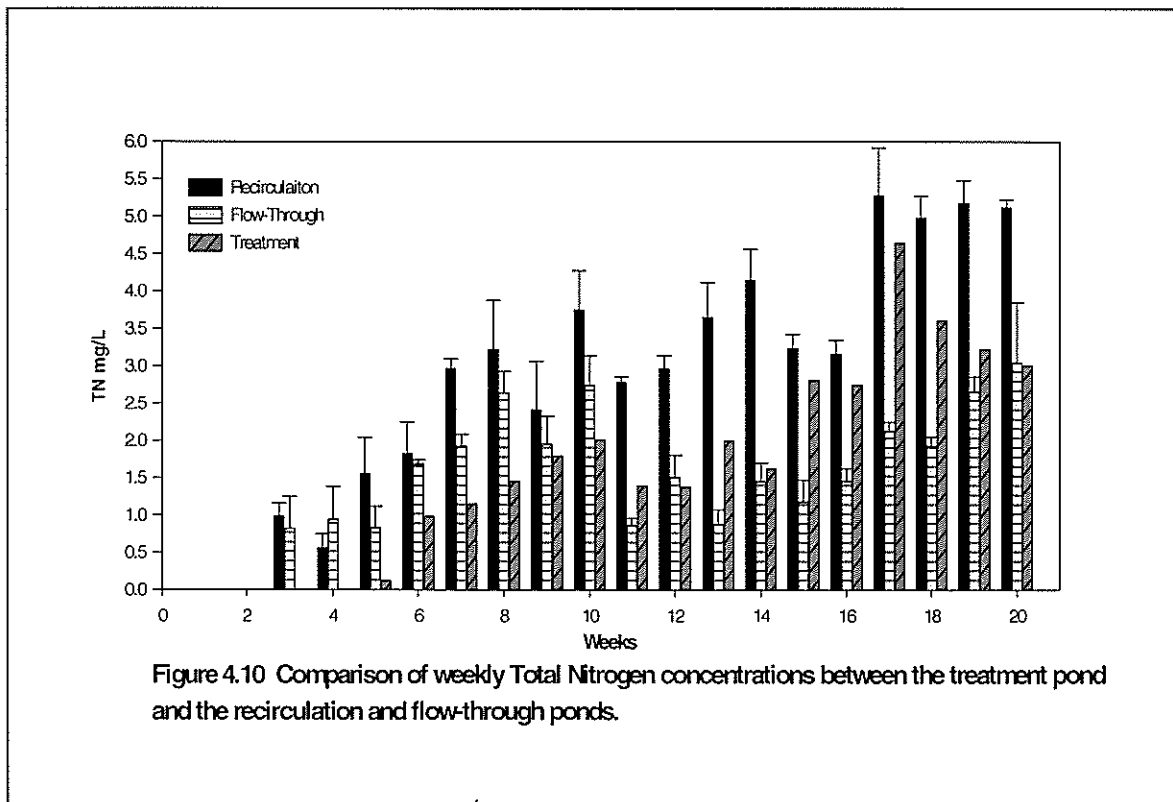
4.3.2 NITROGEN AND PHOSPHORUS CONCENTRATIONS

Both nitrogen and phosphorus species were statistically higher in the water column of the recirculation ponds than both the treatment pond and the flow-through ponds (Figures 4.8 and 4.9, Table 4.3). Overall total nitrogen (TN) increased during the crop in the recirculation ponds whereas in the flow through ponds it reached a maximum by week 10 then fluctuated around this level (Figure 4.10).





Most of the mean nitrogen in the water column was particulate nitrogen (55%). Ammonia was the major component of the mean dissolved inorganic nitrogen (DIN) pool in all systems (95%). In the recirculation ponds, the proportion of mean DIN was 28% compared with 17% in the flow-through ponds but the differences were not statistically significant. The proportion of mean dissolved organic nitrogen (DON) was significantly higher in the flow through ponds (28%) than the treatment pond or recirculation ponds (Table 4.3).



Total phosphorus (TP) in the water column showed a small increase during the crop in the recirculation ponds whereas in the flow through ponds it was maintained at lower levels through water exchange (Figure 4.11). TN/TP ratios for the three systems were 16:1, 9.7:1 and 10.5:1 (w/v) for the treatment pond, recirculation and flow-through systems respectively. Free reactive phosphorus (FRP) levels were low in all systems and contributed little to the TP (3%) (Figure 4.11).

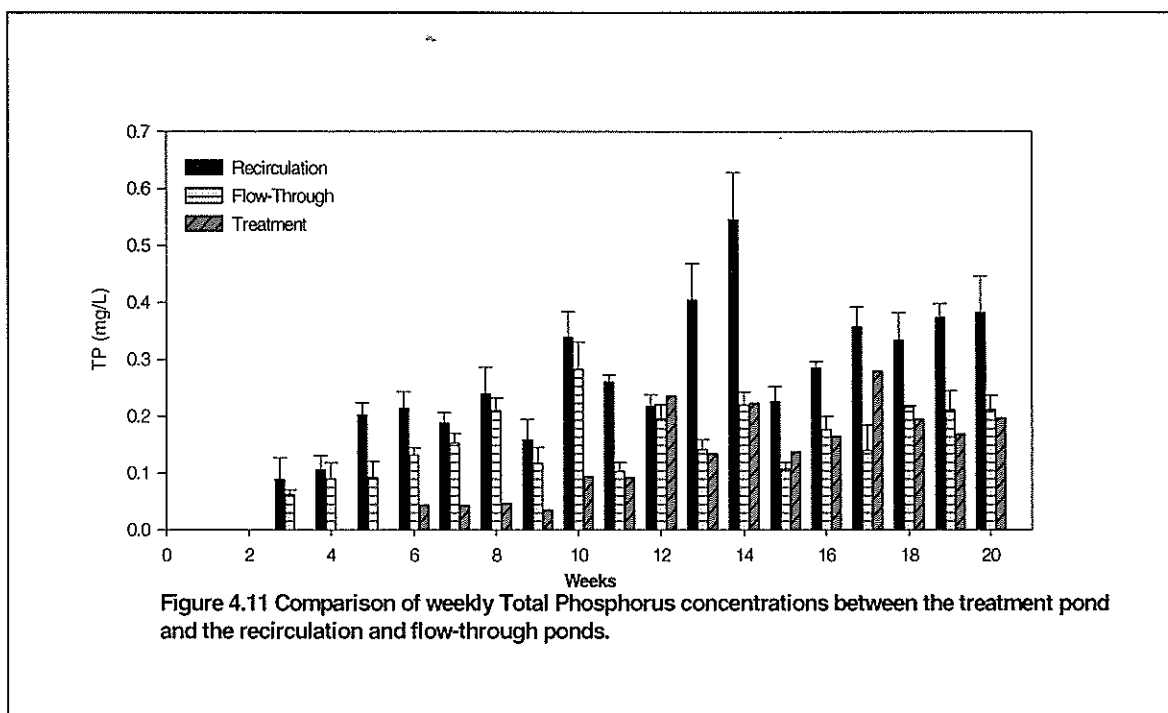


Table 4.3 Comparison of Nitrogen and Phosphorus species for the treatment pond and the two operating systems, Recirculation and Flow-through (mean over the duration of the monitoring period \pm SE, * denotes $P < 0.05$).

Parameter	Treatment Pond	Recirculation Ponds	Flow Through Ponds
TN	2.12 \pm 0.29*	3.21 \pm 0.20*	1.68 \pm 0.11*
DON	0.46 \pm 0.08*	0.56 \pm 0.05*	0.45 \pm 0.06*
PN	1.10 \pm 0.19*	1.75 \pm 0.14*	0.97 \pm 0.09*
DIN	0.27 \pm 0.10	0.90 \pm 0.17	0.29 \pm 0.07
NH ₄	0.25 \pm 0.10	0.84 \pm 0.17	0.27 \pm 0.07
NO ₂	0.05 \pm 0.02	0.03 \pm 0.01	0.012 \pm 0.004
NO ₃	0.01 \pm 0.004	0.02 \pm 0.01	0.019 \pm 0.01
TP	0.13 \pm 0.02*	0.33 \pm 0.05*	0.16 \pm 0.01*
FRP	0.003 \pm 0.001	0.010 \pm 0.001	0.007 \pm 0.002

The quantities of water column TN discharged from the flow through, recirculation and treatment ponds were estimated, based on the concentrations of TN in the recirculation system on the last monitoring day (assuming that the treatment pond and recirculation ponds were drain harvested on that day) compared with the cumulative quantity of TN discharges over the growth season in the flow through ponds. The total amounts of TN discharged from the flow through ponds were higher than that for the recirculation ponds on a per hectare basis (Table 4.4).

Table 4.4 Results of water column TN discharged from the treatment, recirculation and flow through ponds. R = recirculation pond, Tr = treatment pond, FT = flow-through pond

<i>Pond</i>	<i>Culture Period</i>	<i>Kg Water TN</i>	<i>Kg/ha</i>	<i>Mean</i>
R1	131	55.68	79.54	Recirculation system = 69.41 kgTN/ha
R2	133	76.70	76.70	
R3	129	22.90	76.33	
Tr		58.62	45.09	
FT1	126	78.71	112.44	Flow through ponds = 120.73 kgTN/ha
FT2	133	137.32	137.32	
FT3	129	112.79	112.79	

4.3.3 SLUDGE DEPOSITION RATES

There was little visual evidence of sedimentation in the sedimentation canal of the treatment pond. Most sludge deposition occurred in the recirculation growout ponds rather than in the sedimentation canal. It is assumed that this was mostly due to the low suction pressure of the drainage siphons that were located at the edge of the ponds, effectively allowing most of the sediments to migrate towards the centre of the ponds with the circulating effects of aerators.

In a comparison between the recirculation system and the flow through ponds, deposition of sludge was significantly higher in the recirculation system (Table 4.5). This is not surprising given that the flow through ponds were regularly flushed to reduce the loadings of TSS as well as nutrients, whereas the recirculation ponds were operated as a closed system and therefore accumulated particulate matter during the crop.

Table 4.5 Dry weight (tonnes/hectare) of the sludge pile (inner zone) accumulated in the recirculation and flow through ponds by the end of the crop

<i>Ponds</i>	<i>Dry weight (t/ha)</i>	<i>S.D.</i>
Recirculation ponds	96.88	+/- 9.72
Flow through ponds	47.38	+/- 12.74

4.3.4 NITROGEN BUDGET

Total nitrogen input quantities were higher in the flow through ponds (1351 kg of TN vs 1121 kg TN in the recirculation ponds). Nitrogen inputs and final destinations were determined for the recirculation ponds and the flow-through ponds (Figures 4.12, 4.13, 4.14 and 4.15). The main input contribution for both systems was feed, 92% and 88% respectively for the recirculation and flow-through ponds. Other inputs included fertiliser 6.8% and 9%, intake water 1% and 3% respectively for the recirculation and flow-through ponds.

The fate of nitrogen was predominantly in the sediment (45% of total) in the recirculation ponds. This was higher than in the flow-through ponds (34%). The proportion of nitrogen in the water column was higher in the flow-through ponds (30%) compared with the recirculation ponds (17%). Nitrogen retained in prawn biomass varied to a smaller degree between the systems; 28% and 24% respectively in the flow-through and recirculation ponds. In the recirculation ponds the loss of nitrogen due to denitrification was close to double that in the flow-through ponds (12% vs 7%), although almost all of the denitrification activity was in the treatment pond, not in the growout ponds. It should be noted that denitrification was only measured once late in the growth season. The rate of volatilisation of NH_4 as nitrogen loss was not measured from either pond systems, but included in the estimate of 'Other' destinations by

subtracting all determined destinations from total inputs. Benthic biota inhabiting the 2688m² of artificial substrate ('panel') in the treatment pond retained 1%, or 17.5kg of nitrogen (Table 4.6).

Figure 4.12 Nitrogen inputs for recirculation ponds

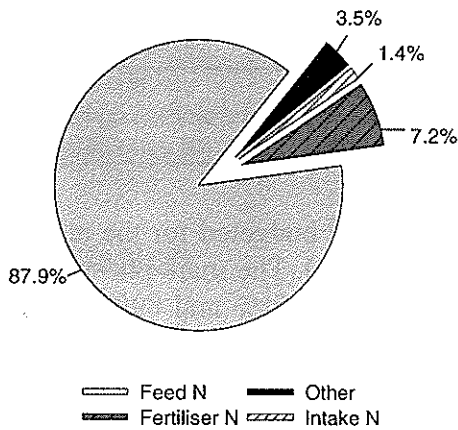


Figure 4.13 Nitrogen destinations for recirculation ponds.

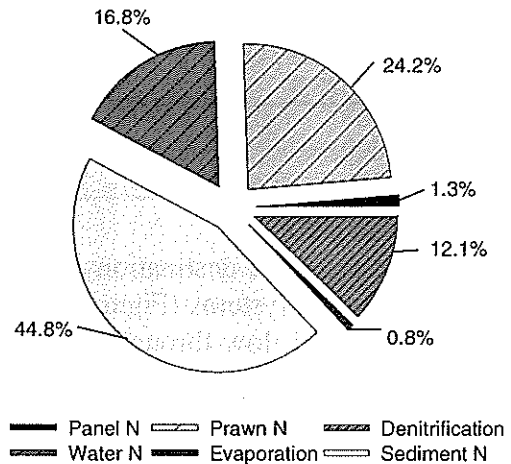


Figure 4.14 Nitrogen inputs for flow-through ponds.

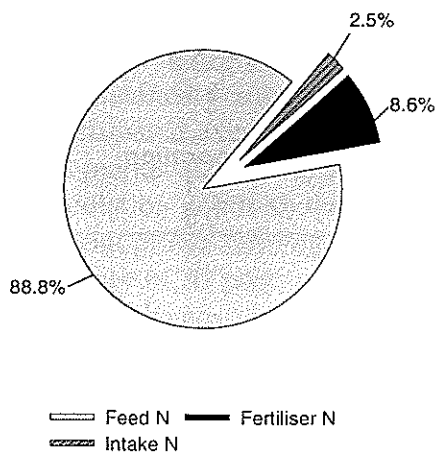


Figure 4.15 Nitrogen destinations for flow-through ponds.

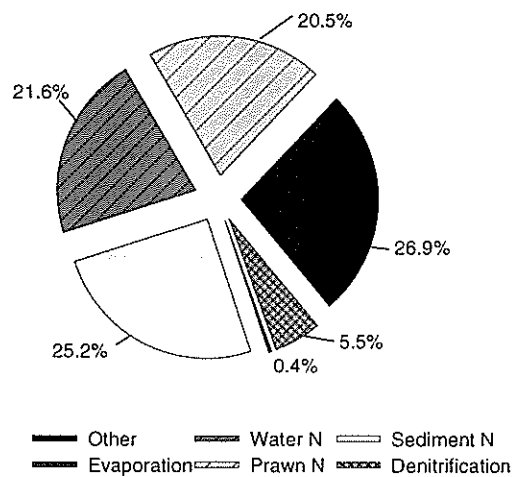


Table 4.6 Nitrogen budget: Nitrogen inputs and final destinations (kg) for the entire crop for the recirculation and flow-through pond systems (Panel denotes nitrogen quantities in benthic biota in the treatment pond).

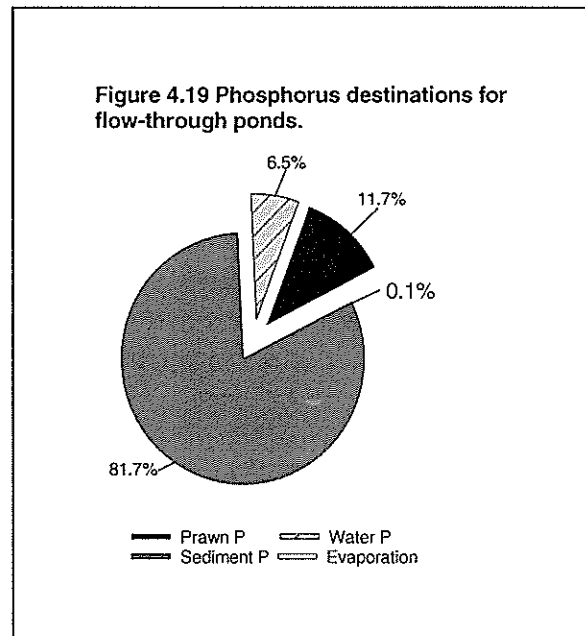
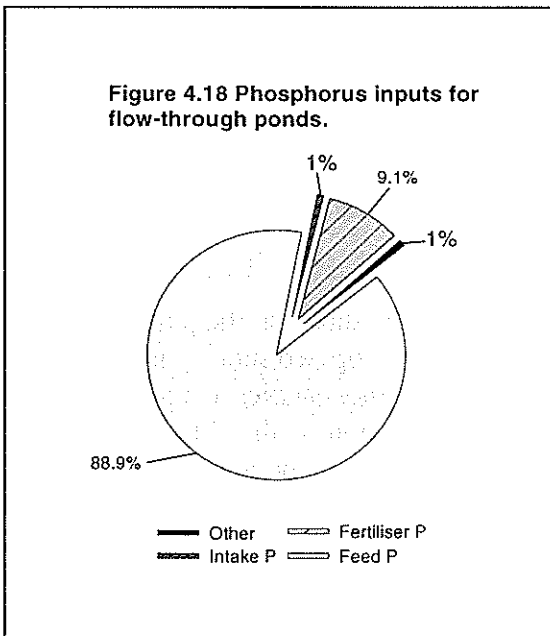
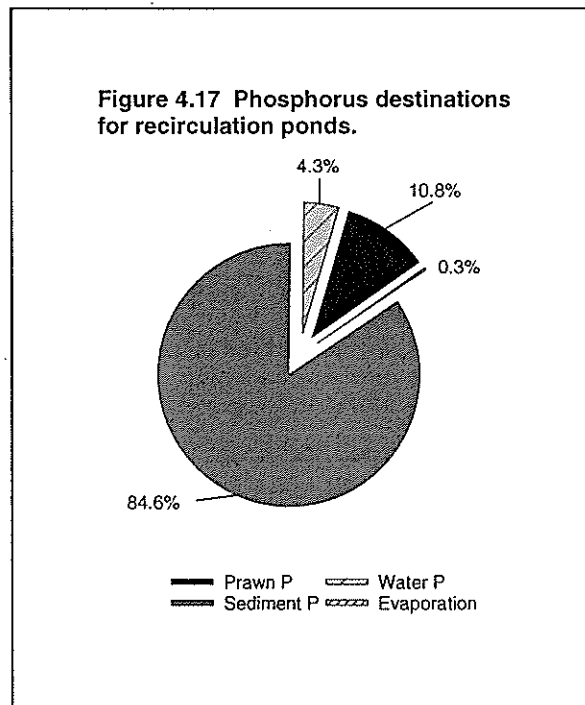
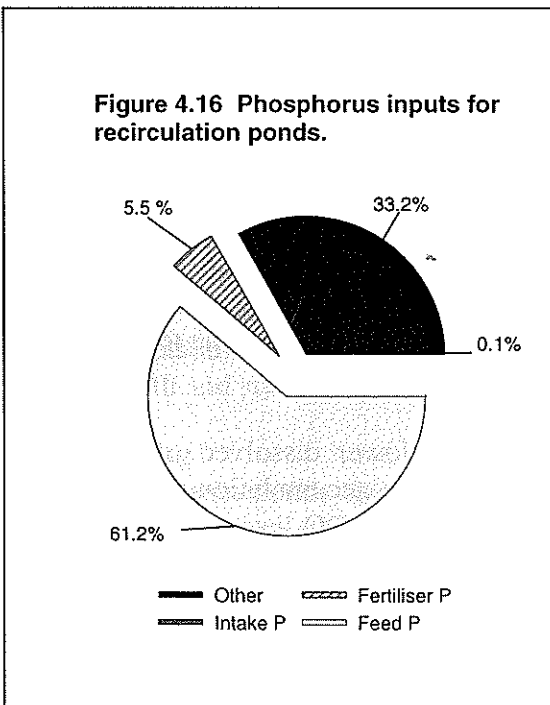
<i>Inputs</i>								<i>Total</i>
	<i>Feed</i>	<i>Fertiliser</i>	<i>Intake</i>	<i>Other</i>				
Recirculation	1120.6	91.9	17.2	45.0				1274.7
Flow through	1351.2	131.2	38.1					1520.5
<i>Destinations</i>								
	<i>Prawn</i>	<i>Water</i>	<i>Sediment</i>	<i>Evaporation</i>	<i>Denitri- fication</i>	<i>Panel</i>	<i>Other</i>	
Recirculation	308.6	213.9	570.9	10.0	153.8	17.5		1274.7
Flow through	311.2	328.8	382.7	5.1	84.0		408.8	1520.5

4.3.5 PHOSPHORUS BUDGET

Phosphorus inputs and final destinations were determined and budgeted for the recirculation and flow-through ponds systems (Figures 4.16, 4.17, 4.18, 4.19). The main phosphorus input for the recirculation and flow-through ponds systems was feed (61% and 89% respectively, Table 4.7). The predominant fate of phosphorus for both systems was entrapment in the pond sediments, where surprisingly, a higher percentage of TP was present in the flow-through pond sediments (82% compared to 72% in the recirculation ponds). Again surprisingly, a higher percentage of TP was lost in the discharge water in the recirculation ponds (19%) compared to that in the flow-through ponds (7%). Phosphorus retained in prawn biomass varied little between the two systems (9% and 11% for the recirculation and flow-through ponds systems respectively). Less than 1% of total P inputs was estimated to be lost through leakage from both systems.

Table 4.7 Phosphorus budget: Phosphorus inputs and final destinations (kg) for the entire crop in the recirculation and flow-through pond systems.

<i>Inputs</i>					
	<i>Feed</i>	<i>Fertiliser</i>	<i>Intake</i>	<i>Other</i>	<i>Total</i>
Recirculation	243.6	21.9	0.4	132.3	398.2
Flow through	293.7	30.9	2.5	3.1	330.2
<i>Destinations</i>					
	<i>Prawn</i>	<i>Water</i>	<i>Sediment</i>	<i>Evaporation</i>	
Recirculation	36.2	76.1	284.9	1.1	398.2
Flow through	38.6	21.4	269.8	0.5	330.3



4.4. Discussion

4.4.1 WATER QUALITY

The trial was conducted during the dry season from August to December 2001. The weather was characterised by rainfall during the first weeks of pond stocking and infrequent and intermittent showers through the remainder of the crop. Evaporation generally increased over the crop and was higher than the rainfall during the trial.

Salinity levels increased in the recirculation system during the monitoring period due to increasing effects of evaporation (mean daily evaporation 5.35 mm), whereas the flow

through pond salinities decreased due to regular external water exchanges. Rising salinity levels in the recirculation system were also buffered by occasional rainfall (mean daily rainfall 4.43 mm) along with pumping of brackish water of variable salinity for top-up of the growout ponds. Salinity levels remained within optimal ranges for *P.monodon* growth (18 to 28ppt) in both systems and growth rates were not markedly different.

While this study was conducted in the Wet Tropics region of north Queensland and did not encounter any effects of high salinity on prawn growth rates, some prawn farmers located in the arid dry tropics consider that recirculation pond systems will be difficult to maintain at optimum salinity regimes without brackish or freshwater supplies. In some areas of northern Australia where evaporation is high and freshwater sources are unavailable, the technology of water recirculation may not be viable.

As the crops matured, the recirculation pond system had lower dissolved oxygen (DO) concentrations in the mornings probably due to elevated waste accumulation and microbial activity. At the start of the project an arbitrarily agreed minimum DO limit of 4mg/l was set for pond managers to maintain an optimum water quality range. Morning DO concentrations were below this level on several occasions in the later stages of the crop and required adjustments to aeration, water exchange rates or feeding rates to get the DO back to above 4 mg/L. Similar incidents occurred in the flow through ponds at various times but were usually remedied by increased water exchange or additional aeration.

The incidents of low DO in the recirculation system suggest that it may be overloaded with high biomass of prawn crop, or that the feeding rate or rate of daily nitrogen input was exceeding the bioremediation capacity of the treatment system. The pond management changes used to remedy these situations suggest that provisions need to be made in recirculation pond systems (eg. additional aeration capacity is available) to optimise feed utilisation and prawn biomass, thereby maximising prawn growth rates.

4.4.2 NITROGEN AND PHOSPHORUS CONCENTRATIONS

Nitrogen and phosphorus inputs to the ponds are principally through the application of formulated feeds, with a lesser input from fertiliser, previous crop sediment concentrations and intake water (see section 4.2). This is consistent with other studies (Funge-Smith & Briggs 1998, Martin et al. 1998, Jackson et al. 2003). In addition to the direct inputs, the concentration of the various species of nitrogen and phosphorus in the pond environment will vary over time as a result of microbial processes such as ammonification, uptake of ammonia by phytoplankton, denitrification and mineralisation, as well as the physical processes such as the settlement of solids. The overall differences in nitrogen and phosphorus concentrations in the water column between the two systems is mostly related to the effectiveness of these processes to capture or remove nutrients from the system

Total nitrogen concentrations generally increased during the crop in the recirculation ponds (compared to the flow through system), clearly due to the rate of waste accumulation exceeding the rate of removal. By the end of the crop total nitrogen levels were more than twice that occurring in the flow through ponds. Removal of accumulated wastes from the flow through ponds was mostly achieved with exchange of water to flush ponds and maintain optimal culture conditions, whereas in the closed system these wastes were mostly retained in the ponds and a treatment system was required to capture and remove them from the system.

It is apparent that the processes of phytoplankton growth (nitrogen uptake) and microbial breakdown of the resulting organic material (nitrogen release) have worked in tandem to

exacerbate the overall level of TN in the recirculation system. The dominant form of nitrogen in the water column of both systems was in particulate nitrogen form, mostly bacteria, phytoplankton, zooplankton as well as detritus. The levels of DIN were also higher in the recirculation system, where high ammonium levels made the greatest contribution, most likely as a result of poor treatment efficiency to capture accumulated nitrogen. This may have been caused by increased rates of remineralisation in the higher loadings of sludge (see section 4.2) including ammonia production, which, in high concentrations can affect prawn health (Burford & Longmore 2001). Higher chlorophyll levels in the recirculation ponds suggest a greater biomass of phytoplankton in these ponds. Given that 60 to 80% of particulate nitrogen can be in the form of phytoplankton (Jackson et al. 2003) the combination of the continual die-off of algae and recycling of pond waters will also lead to the increased accumulation of TN, particularly if the organic sludge component remains in the ponds.

Apart from small regular fertiliser applications to establish an algal bloom at the start of the growout period, nitrite and nitrate concentrations were undetectable until 90 days after stocking. This suggests that nitrification (bacterial conversion of NH_4 to NO_2/NO_3) was a minor process in the water column.

The low levels of denitrification in the growout ponds suggest that it was not an effective N removal mechanism. It is assumed that rates of denitrification were low primarily because there was insufficient nitrate. In addition, it was considered that the levels of anoxia in the sediments were actually too high to promote denitrification (Burford & Longmore 2001). The treatment pond used in the study was not established to specifically to encourage denitrification so it is assumed that rates could be enhanced with further bioremediation investigations.

The majority of total phosphorus in the water column was in the particulate form, most likely bound up in plankton and detritus, as well as sorbed to inorganic particles. Previous studies have shown that much of the P in prawn ponds is bound to the sediment (Ritvo et al. 2002). FRP concentrations were much lower probably because it can be rapidly taken up by living organisms or rapidly sorbed to the surface of water-borne silt and sediment. Levels of TP were twice as high in the recirculation ponds, which had higher loads of suspended solids and dense phytoplankton blooms, while TP levels were lowest in the treatment pond where settlement processes removed the greater proportion of solids.

4.4.3 ENVIRONMENTAL PERFORMANCE IN KG TN/HA/DAY

The greater quantities of TN discharged from the flow-through ponds compared to the recirculation ponds is to be expected given that water was discharged regularly from these ponds throughout the growth season. However, the TN concentrations discharged from the recirculation ponds at harvest was higher than in the flow through ponds. This is not surprising given the accumulation of nutrients within the recirculation system. This may be of concern in meeting environmental license requirements as both loads and concentrations of nutrients are assessed. It is also apparent that while the treatment system removed some nitrogen and phosphorus, it was relatively inefficient. While the TN concentrations for both pond systems were within the required EPA requirements at the final point of discharge (after passing through a common settlement pond), the significant difference between TN discharge rates over the course of the crop highlight the potential for improvements in environmental performance with recirculating pond systems.

Nitrogen discharge loads, on a kgTN/ha/day basis for the two systems were compared over the crop duration period of 130 days, (despite the recirculation ponds not discharging effluent

until the final day). Overall the recirculation ponds had a much lower mean discharge rate (0.53 kg TN/ha/day) than the flow-through ponds (0.92 kgTN/ha/day). While these estimates of averages are based on only one discharge event, they do illustrate the improvements in environmental performance that can be provided with recirculation methods. Similar to the results for water use efficiency, the loadings of nitrogen discharged overall can be significantly lower if water is recycled during the crop. The future challenge in improving the technology of recirculation pond systems will include the capability to re-use pond water for further crops. This has the potential to further improve environmental performance.

4.4.4 SLUDGE REMOVAL AS A MANAGEMENT OPTION

Prawn ponds are dynamic ecosystems with planktonic populations that rapidly absorb dissolved nitrogen, such as ammonium, into cellular growth (Burford & Glibert 1999). The blooms and crashes of algal and bacteria populations provide a constant rain of particulate nitrogen which settles on the pond floor. The aerator currents sweep much of it to the inner zone of the pond and bury it in an anoxic sludge layer where it may act as a significant reservoir of excess nitrogen. Remineralisation processes in the sludge result in the release of large amounts of ammonium back into the water column (Burford & Longmore 2001).

In our study, ammonium was one of the dominant components of the dissolved nitrogen fraction in both the flow-through and recirculation systems, and was higher in the recirculation system, especially the production ponds. Due to the action of aeration, two distinct zones were formed, a well oxygenated swept outer zone and an inner zone of accumulated sediment and organic wastes commonly characterised by anoxic sediments of high pore water ammonium (>50ppm). The insufficient water exchange provided by the siphons in the recirculation ponds as well as ineffective sludge removal from the production ponds resulted in large inner sludge zones.

Each of the prawn production ponds in the trial were managed according to existing farm practices, with aerators set up to concentrate any sediments and organic sludge in the central area of the pond. The siphons that were installed for the recirculation ponds to drain water to the treatment pond were not effective in capturing any significant quantities of sludge and shift it to the sedimentation canal.

Despite the poor efficiency of the sedimentation process, deposition of sludge was found to be significantly higher in the recirculation system than the flow through ponds, essentially because flushing by water exchange in the flow through ponds had reduced the quantities of particulate matter retained during the crop. The higher degree of sedimentation in a recirculation system combined with the finding that the sludge deposited in recirculation ponds carries a greater concentration of nitrogen, indicates that future management techniques should include sludge removal during the crop to avoid remineralisation problems and excessive nutrient accumulation. This is similar to findings in conventional flow through ponds investigated in other farms in Australia (Burford et al. 2001).

Further investigations are required to determine the appropriate methods for removing sludge from a recirculating system during a crop. Dredging of sludge may be most effective if done by a pump system from the sedimentation area, or alternatively from the growout ponds by way of a central drain or pump system. Both would require structural changes to the pond systems to maximise the efficiency of removing significant quantities of sludge without causing water quality problems by the disturbance of silt in the water column.

4.4.5 NITROGEN REMOVAL – BIOREMEDIATION OPTIONS

A relatively small amount of feed protein nitrogen (approximately 20%) is incorporated into prawn biomass. This is consistent with the findings of other nitrogen budget studies (Funge-Smith & Briggs 1996, Martin et al. 1998, Jackson et al. 2003). The remaining 80% was wasted, and in the case of the flow through ponds, a significant proportion of nitrogen wastes are in the water discharged from the ponds. In the recirculation ponds on the other hand much of the nitrogen was buried in the sludge with a smaller proportion remaining in the water column. This 80% loss of nutrients from feed inputs can be a concern to prawn farmers financially as well as environmentally because it represents low business efficiency and potentially high nutrient discharge loads.

It is apparent that the accumulation of TN in the recirculation system exceeded the ability of the system to process and remove nutrients from the water column. An effective removal mechanism is required to gain a net reduction in the overall nutrient load in the water column. While the data suggests that the treatment system in the recirculation ponds was effective in minimising the accumulation of nitrogen, it is apparent that this occurred as a result of the increased deposition of sludge. This again highlights a strong justification for sludge removal during the crop, to improve overall water quality and minimise the potential for nitrogen accumulation in the sludge and the recirculation system overall.

Future investigations to improve the efficiency and environmental performance of recirculation ponds and associated treatment systems could therefore include the capacity to capture or bioremediate excess nitrogen through the culture of other species, and/or the capacity to remove nitrogen in solids waste from the production ponds through sedimentation (as discussed above in 4.4.4).

Clearly further study is required to evaluate the effectiveness of bioremediation species in Australian pond aquaculture. Palmer et al. (2002) investigated the use of banana prawns as a bioremediation species in the treatment of effluent from Queensland prawn farms but did not detect significant changes in discharge water quality. Jones and Preston (1999) found that on a pilot scale, oysters (*Saccostrea commercialis*) could significantly reduce suspended solids, total nitrogen, total phosphorus, chlorophyll-*a* and total bacteria in prawn pond effluent water, however commercial scale application and marketability of oysters from bioremediation is yet to be evaluated. In overseas countries various investigations have evaluated the bioremediation of aquaculture effluent with macroalgae, bivalves and finfish with varying results (Chandrkrachang *et al.* 1991, Endander and Hasselstrom 1994, Shpigel *et al.* 1993, Winarno 1995).

5. CONCLUSIONS

The results of this project confirm that full recirculation prawn farming methods can be achieved at a commercial scale in the Australian prawn farming industry. In a trial where a pond based recirculation system enabled the regular recycling of water from conventional grow-out ponds, it was shown that a crop could be grown and harvested without discharge of any effluent during the crop, and that the yields and product quality (taste) were essentially the same as that from flow-through ponds. However final prawn weights and growth rates were lower in both the recirculation and growout ponds than typically seen in Australian farms. In the case of the harvest weight, this was a management decision by the farm. The project also showed that the pond management methods (feeding, stocking, harvesting) used

in flow-through ponds could also be used in the same way in the recirculation ponds, although aeration requirements were higher per unit of production.

No discharge of effluent during the crop resulted in a significant improvement in the efficiency of water use per kilogram of prawn harvested, essentially because of the recycling of pond water compared to regular external water exchange in flow through ponds. It was also calculated that the environmental performance of the recirculation system, expressed as kilograms of total nitrogen released per kilogram of prawn harvested and averaged over the course of the crop, was better than the comparative flow-through ponds.

While these results show that recirculation may be feasible in existing or new prawn farms, there are some limitations in the current technology that require further investigation before it can be adopted on a broader scale in the Australian prawn farming industry. An assessment of the economic comparison between recirculation and flow through ponds is required to clarify the outstanding questions of viability against existing conventional methods. For example this study investigated the management of a recirculation system with a treatment area that was 67% of the growout area, considerably higher than that established in the existing industry or required in the approvals process for any new prawn farms. Similarly the development of more efficient treatment processes may decrease the area of pondage and/or capital costs required to enable recirculation methods. The potential for evaporation to cause high salinities in recirculation ponds located in the arid tropics (most of northern Australia's coastline) remains a constraint to the use of recirculation technology for many prawn farms, although it is apparent that some arid zone farms have already trailed partial recirculation.

Prawn farmers wishing to consider incorporation of recirculation technology in existing or new farms need to consider a range of implications stemming from the project outcomes. A significant conclusion that can be made from the outcomes of the project is that the design and management of pond-based recirculation prawn farm systems requires an emphasis on nutrient capture and removal in the treatment and/or bioremediation systems, to enhance the water quality in the ponds and to ensure that crops can be farmed successfully under full or partial recirculation.

The accumulation of nitrogen in the recirculation ponds, both in particulate form and in the inorganic form as ammonium, can significantly impact on water quality management of the ponds and health of the prawns and will be a constraint to any further increases in productivity. For example the higher degree of sedimentation in a recirculation system combined with the finding that the sludge deposited in recirculation ponds carries a greater concentration of nitrogen, indicates that future management techniques should include sludge removal to avoid remineralisation problems and excessive nutrient accumulation. The sludge would need to be removed during the crop and extracted from the pond entirely to reduce the overall nutrient loading in the water column. Increased aeration capacity and increased water exchange within the recirculation ponds (i.e. recycling rate) will be important management changes to consider.

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7. APPENDICES

7.1. Abbreviations

APFA	Australian Prawn Farmers Association
ANZECC	Australia and New Zealand
CSIRO	Commonwealth Scientific and Industry Research Organisation
Chl a	chlorophyll a
EPA	Environmental Protection Authority (Queensland)
DIN	dissolved inorganic nitrogen
DO	dissolved oxygen
DON	dissolved organic nitrogen
FCR	feed conversion ratio
FRP	free reactive phosphorus
GBRMPA	Great Barrier Reef Marine Park Authority
PN	particulate nitrogen
ppt	parts per thousand
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
NO ₃	nitrate
NO ₂	nitrite
NH ₄	ammonia
FRP	filterable reactive phosphorus

7.2 Prawn Taste Sensory Evaluation Report

CENTRE FOR FOOD TECHNOLOGY

Difference testing of prawns from recirculated and flow-through ponds

Prepared by
Sensory and Consumer Science Unit
December 2001

Commissioned by:
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Executive Summary

A triangle test was completed to establish whether a perceptible difference exists (at the 5% level of significance) between prawns from recirculated and flow-through (control) ponds. Twenty-one panellists from the Centre for Food Technology completed the test on 17 December 2001. No significant difference ($P=0.125$) was found between the prawns from the recirculated and flow-through (control) ponds.

Aim

- To establish whether a difference exists between prawns from recirculated and flow-through (control) ponds
- To collect comments regarding the nature of any differences.

Methodology

Panellists

Twenty-one panellists were recruited from the staff of the Centre for Food Technology (CFT) who were consumers of prawns and available at the testing time.

Samples

The samples were collected from Australian Air Express, Brisbane Airport at approximately 10.00am on 17 December 2001. At this time, the prawns ranged in temperature between 11-12°C (at the side and top of container) and 6°C (at the bottom). They were transported directly to CFT where they were stored at 7°C until sample preparation commenced.

The samples were:

1. Recirculated pond prawns – from ponds 1, 9 and 10
2. Flow-through (control) pond prawns – from ponds 2, 4 and 5

Approximately 1kg of each of the samples were sent in individual plastic bags labelled with the pond number. According to the label on the polystyrene container in which the prawns were transported, the prawns were Australian Black Tiger prawns that were fresh, cooked and size 21/30.

Sample preparation and triangle test procedure

Ninety minutes prior to the commencement of the triangle test, 15 prawns were randomly selected from each of the three bags corresponding to the recirculated or flow-through (control) prawn samples. The 15 prawns from each of the three ponds for each treatment were then combined to form a composite sample of 45 prawns. The 45 prawns for each sample were then all peeled by the same person. Where the head and body of the prawn had been torn apart, this was cut cleanly with a sharp knife to ensure sample consistency. All samples were refrigerated at 7°C as much as possible during sample preparation.

Ten minutes prior to the start to the session, the prawns were placed into individual round opaque plastic cups that were labelled with 3-digit random codes. These were then positioned in a balanced presentation order according to the experimental design, covered with cling film and retained at 7°C.

The triangle test was completed on 17 December 2001 between 3.00 and 3.30pm. The triangle test was completed according to the Australian Standard (AS 2542.2.2). The panellists were seated in individual booths illuminated with white light (daylight equivalent). The temperature in the booths was approximately 24°C. Each panellist received the three test samples presented on a white tray with a glass. Purified water was freely available for palate cleansing between samples. The serving temperature of the samples was 10°C. Care was taken to ensure that the samples were not retained outside of the 7°C fridge for extended periods of time.

The results were collected directly into a computerised system (Compusense ®, ver 4.0) and panellists could add comments regarding any of the samples. Panellists were not provided with feedback as to whether they had chosen the correct sample or not.

Results and Discussion

Table 1 Triangle test results for prawns from recirculated and flow-through ponds

Number of correct responses	10
Total number of tests completed	21
Significance level	NS (P=0.125)

NS Not significant (P>0.05)

Table 2 Comments made by panellists who correctly identified the different sample

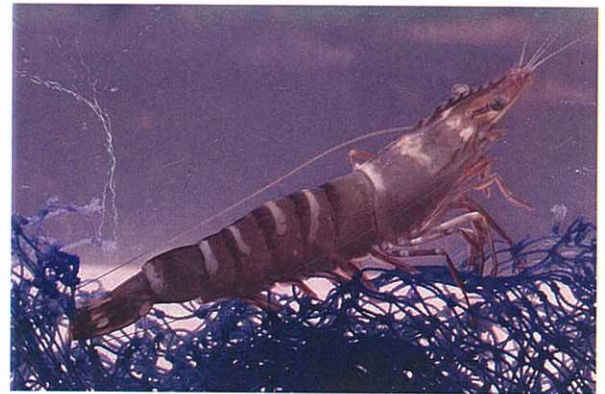
Sample	Comments
RECIRCULATED PONDS (558, 915)	<p>less salty, sweeter, slightly softer in texture - the sweetness seems artificial</p> <p>not much flavour</p> <p>stronger taste</p> <p>not sweet and very little flavour</p> <p>tasted a bit bland compared to 426 and 387</p> <p>they all tasted very similar but this one seemed to have less taste than the other 2</p>
Flow-through ponds (Control; 387, 426)	<p>this sample is much sweeter than the other two</p> <p>juicier and stronger, sweeter flavour</p> <p>it was more salty than the other 2</p> <p>tasted good and full-flavoured</p> <p>seemed saltier</p> <p>tasted good and full-flavoured</p> <p>less taste (more bland)</p> <p>taste crunchy and not as chewy as the other 2</p>

Tables 1 and 2 present the results of the triangle test for the recirculated and flow-through (control) pond prawns. Ten panellists out of the 21 panellists that completed the test correctly identified the different sample. This result

indicates that no significant difference ($P > 0.05$) was found between the recirculated and flow-through (control) pond prawns. With a P value of 0.125, this is close to the 10% level of significance.

However, from the statistical tables it is usual to quote either 5% or 1% as the level of significance. This is our safety margin, meaning if you repeated the same test 100 times, then 5 times or 1 time out of 100 you would get a different answer. It is interesting to note that if 12 panellists out of 21 had correctly identified the different sample, then this result would have been significant at the 5% level of significance.

Comments made by the panellists who correctly identified the different sample were collated. The comments do not conclusively indicate where the samples may have differed. However, four comments were made about the recirculated pond prawns regarding the perception of "not much flavour", "very little flavour", "tasted a bit bland" and "less taste". Only one panellist indicated that the sample had "stronger taste". For the flow-through (control) pond prawns, two panellists made comments indicating that the sample was sweeter and two panellists commented that the samples were saltier. For the recirculation pond prawns, comments were also made regarding differences in saltiness and sweetness but were not consistent or a comment was only made by one panellist. Texture related comments were made for both samples.



Queensland Government
Department of Primary Industries