



# FINAL REPORT

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## *Part 1 - Summary Details*

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**Cotton CRC Project Number:** 4.06.02

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**Project Title: Evaluation of the potential for aquaculture on cotton farms – cage culture of silver perch**

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**Project Commencement Date:** 01/01/2007      **Project Completion Date:** 30/06/2009

**Cotton CRC Program:** The Product

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## ***Part 3 – Final Report Guide (due within 3 months on completion of project)***

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### ***Background***

1. Outline the background to the project.

Aquaculture is the fastest growing food-producing industry in the world, with growth of 8.8% per annum since 1970 (FAO 2007). This growth is expected to continue due to the rapidly increasing human population, increasing demand for seafood, and declining harvests from wild fisheries. In 2004, global aquaculture production was 59.4 million tonnes, but it is predicted that 70 million tonnes will be required from aquaculture to meet demands in 2020 (FAO 2007). Currently nearly half of world's fisheries production comes from aquaculture, and of this around half is freshwater finfish, mainly omnivorous species of catfish, tilapia and carp.

Aquaculture has great potential in Australia where wild fisheries resources are limited, many commercial fisheries are over-exploited, and around 70% of fish consumed is imported. Silver perch (*Bidyanus bidyanus*) is an Australian native freshwater fish that is endemic to the Murray-Darling River System. It is an omnivorous, warmwater species whose potential for aquaculture has long been recognised (Rowland 2009). Techniques for intensive pond culture of silver perch have been developed, and a small industry produces around 500 tonnes annually (Rowland and Bryant 1995; Rowland 2009). Although returns per volume of water are high (~ \$3,000/ML in pond culture), silver perch culture has not yet realised its potential as a large-scale, low-cost industry due to a number of factors including difficulties with pond management, losses to bird predation and infectious diseases particularly during winter, the relatively high costs of feeds, and the small scale of most farms (Rowland 2009). Preliminary research has indicated that silver perch perform well in cages (Rowland et al. 2004, 2006), and some of the largest aquaculture industries in Australia (southern bluefin tuna *Thunnus maccoyii*, Atlantic salmon *Salmo salar* and barramundi *Lates calcarifer*) are cage-based for at least part for their production (O'Sullivan and Savage 2009). Cage culture is increasingly being used for different species through-out the world, and has advantages such as ease of husbandry and management, and protection from bird predation (Beveridge 1996). Cages also enable the use of existing water bodies such as storages on cotton and other irrigation farms that are otherwise unsuitable for commercial aquaculture (Rowland and Allan 2006).

Water for irrigation is a substantial and recurring cost to cotton farmers, and freshwater aquaculture may offer an opportunity to add value and improve water-use efficiencies. Integration of fish farming could provide cotton farmers with an additional crop without an increase in water allocation, and the opportunity for greater financial return through "more crop per drop". The late Professor Peter Cullen, Wentworth Group of Scientists, stated that "*In the future smarter irrigation*

farmers will have a portfolio of crops”(ABC TV News, 3<sup>rd</sup> January 2008). In the USA, farming of channel catfish (*Ictalurus punctatus*) developed in the 1960s and 1970s as an alternative crop for cotton and grain growers in the southern states, particularly Mississippi and Alabama, and is now by far the largest aquaculture industry in that country in both tonnage and value (Hargreaves 2002).

In addition to benefits for cotton farmers, the involvement of the highly professional cotton industry could enable silver perch aquaculture to expand and realise its potential of becoming one of Australia’s largest fisheries.

A collaborative project between Industry & Investment NSW (I&I NSW, formerly NSW DPI), the University of New England (UNE) and the Cotton Catchment Communities Cooperative Research Centre (Cotton CRC) has evaluated the potential for cage culture of silver perch on cotton farms. The project aimed to: determine optimal cage culture conditions for silver perch; identify cotton farms and infrastructure with potential for fish culture; evaluate the feasibility and economics of silver perch cultured in cages using on-farm trials; determine appropriate fish culture strategies for use on cotton farms; and provide technical advice to farmers diversifying into fish farming (Rowland and Allan 2006).

## References

- Beveridge, M.C.M. (1996). *Cage Aquaculture*. Fishing News Books, Carlton.
- FAO (2007). *The State of the World Fisheries and Aquaculture 2006*. Food and Agricultural Organization of the United Nations, Rome.
- Hargreaves, J.A. (2002). Channel catfish farming in ponds: lessons from a mature industry. *Reviews in Fisheries Science* **10**(3 & 4), 499-528.
- O’Sullivan, D. and Savage, J. (2009). *Status of Australian Aquaculture in 2006/2007*. Austasia Aquaculture Trade Directory 2009. Turtle Press, Hobart.
- Rowland, S.J. (2009). Review of aquaculture research and development of the Australian freshwater fish silver perch, *Bidyanus bidyanus*. *Journal of the World Aquaculture Society* **40**(3), 291-324.
- Rowland, S.J. and Allan, G.L. (2006). Development of techniques and evaluation of the potential of cage culture of silver perch for cotton farms. In, *Proceedings of the 13<sup>th</sup> Australian Cotton Conference, August 8-10, 2006*. Australian Cotton Growers Research Association, Narrabri.
- Rowland, S.J., Allan, G.L., Hollis, M. and Pontifex, T. (2004). Production of silver perch (*Bidyanus bidyanus*) fingerlings at three stocking densities in cages and tanks. *Aquaculture* **229**, 193-202.
- Rowland, S.J. and Bryant, C. (1995) (Editors). *Silver Perch Culture: Proceedings of Silver Perch Aquaculture Workshops, Grafton and Narrandera, April 1994*. Austasia Aquaculture, Sandy Bay.
- Rowland, S.J., Mifsud, C., Nixon, M. and Boyd, P. (2006). Effects of stocking density on the performance of the Australian freshwater silver perch (*Bidyanus bidyanus*) in cages. *Aquaculture* **253**, 301-308.

2. List the project objectives and the extent to which these have been achieved.

### *Objectives*

- **Identify existing cotton farms, and farm infrastructure, including water storages, channels and water allocations with potential for aquaculture**

Over the course of the project, Dr Stuart Rowland visited cotton farms in the Moree, Narrabri/Wee Waa, Bourke, Hillston and Dalby areas to become familiar with farm layouts, cotton farming techniques and growing seasons, general farm operations, water supply and management, farm equipment, staffing, and general infrastructure. He was accompanied to some farms by Bernie McMullen (I&I NSW, Horticulture Industry Development Officer) who is familiar with irrigation farms and industries, and has been involved in the development of new industries in NSW.

Dr Rowland discussed the following subjects with farm owners/managers: Australian and World aquaculture; freshwater aquaculture and suitable species; principles of intensive aquaculture; fish husbandry; water quality; diseases and health management; fish farm management; product handling, marketing and promotion; and the potential for integration of aquaculture with cotton and other irrigation industries. He emphasised that fish farming is an intensive animal industry that requires substantial capital investment and technical knowledge.

Key observations made in relation to potential integration of aquaculture on cotton farms were:

- (i) the seasonal nature of cotton production and water-use;
- (ii) the limited availability or lack of water on some farms outside the cotton-growing season;
- (iii) the availability of high quality underground water on some farms, including water at constantly high temperatures (e.g. 20 – 24°C) ;
- (iv) the lack of technical knowledge of aquaculture amongst staff on cotton farms;
- (v) some farmers are interested in alternative and/or additional crops, including fish; and
- (vi) the potential for, and perception of chemical contamination of fish from pesticides and herbicides used on cotton farms.

Some cotton farms have potential for integration with aquaculture, while others range from marginally suitable to totally unsuitable. Characteristics that are essential for integration are:

- (i) permanent supply of water suitable for fish culture (ideally a combination of surface and underground water);
- (ii) water storage(s) available for fish culture (can be dams or channels that are > 2 m deep);
- (iii) 3-phase power for aerators and other equipment;
- (iv) buildings and infrastructure for quarantine/purging tanks, laboratory, offices, feed storage, equipment storage – all in close proximity to the fish culture site;

- (v) technically-trained staff with considerable experience in fish husbandry, health management, and the operation of aquaculture facilities and equipment;
- (vi) staff for fish culture activities (7 days/week);
- (vii) proximity to supply centres, transport routes and markets.

Farms in most cotton growing areas from Hillston in the south to Emerald in the north would have suitable water temperature regimes, and hence potential for the aquaculture of native freshwater fish. Growth of silver perch is temperature-dependent, with good growth at temperatures of 18° – 30°C. Growing seasons on farms in southern regions would be shorter and production periods longer than those in the north because of the relatively long, cold winters. Slow growth in the south may be off-set by: (i) the use of “warm” underground water; or (ii) the over-wintering strategy for fingerlings (see following).

#### ▪ **Identify optimal cage culture conditions for silver perch**

A series of experiments was carried out at I&I NSW’s Grafton Aquaculture Centre (GAC) over a period of 30 months (January 2007 – June 2009) to identify optimal cage culture conditions during different culture phases, with different-sized fish, and over the annual range of water temperatures.

This experimental phase was necessary to determine culture conditions that could be used in subsequent on-farm trials and economic evaluations. The experiments addressed key husbandry and production aspects of fish culture including stocking density, diets, cage design and production strategy. A new production strategy of over-wintering fingerlings at elevated temperatures in a tank-based, re-circulating aquaculture system (RAS) was evaluated in an attempt to overcome the potential problems of slow growth and losses to bird predation and infectious diseases, and limited water availability on some cotton farms in winter.

#### Research topics

1. Performance at different stocking densities during the fingerling, grow-out and over-wintering phases of production.
2. Performance of fingerling and large fish fed commercially-available diets.
3. Performance of fish in cages of different sizes and shapes.
4. New production strategy: over-wintering of fingerlings at elevated temperatures in a tank-based, re-circulating aquaculture system (RAS).
5. Development of methods of treating infectious diseases in cages.
6. Economic assessment of different farm and production scenarios.

The experimental phase of the project confirmed the suitability of floating cages for farming silver perch, particularly for fingerlings, and identified optimal culture conditions and a new production strategy (see details in following sections). Methods of disease treatment in cages were not developed due to a very low incidence of infectious diseases during the project. The economic assessment

highlighted potential advantages of cage culture and the use of RAS for over-wintering fingerlings.

- **Determine the feasibility and economics of silver perch cage culture on cotton farms**

Initially a 3-year project was proposed involving an experimental phase followed by an on-farm trial(s). The project was subsequently funded for 2 years (with additional funding for the PhD stipend only), restricting it to the experimental phase only. The on-farm trial could not be done due to the limited funds and time, the need to identify optimal culture conditions prior to any on-farm trial, and other factors including the on-going drought and limited/lack of water on cotton farms over the last three years.

During the course of the project, it also became apparent that there was a lack of infrastructure and equipment to facilitate fish culture on most cotton farms, and no technically-trained staff for the day-to-day, on-site fish husbandry and management. These short-comings could potentially derail an under-funded on-farm trial, and unrepresentative results could give misleading conclusions about the potential of cage culture.

It was considered that a separate project was needed to effectively evaluate the potential of cage culture under practical, commercial conditions on a cotton farm(s). A Preliminary Research Proposal "On-farm evaluation of the cage culture of silver perch" for a 2-year project (July 2009 - June 2011) was submitted to the Cotton Research and Development Corporation (CRDC), but the proposal was not progressed.

The commercial aquaculture software package *Perch Profit* was used to produce economic models simulating different farm and production scenarios (see following for details).

Cage culture provides performance and economic advantages over pond culture. Advantages are achieved through high survival, efficient feeding, and lower capital costs when established storages are used. Despite initial capital investment for construction and the operating costs of the RAS, over-wintering fingerlings at elevated temperatures significantly increases annual production and revenue.

- **Determine appropriate culture conditions and strategies to suit different cotton farming locations and infrastructures**

#### Stocking densities

Silver perch performed well in cages. Survival was very high (> 95%) in most treatments and experiments. Optimal stocking densities were identified (Table 1). The selection of optimal densities is a compromise between survival, growth, production and fish welfare. We identified problems with erosion of the caudal fin (i.e. tail fin) in silver perch over 300 g. Although there is good growth and high production rates at 200 - 400 fish/m<sup>3</sup>, there was a significantly higher proportion of

fish with damaged tails at these densities. There were very few fish with eroded caudal fins at 100 fish/m<sup>3</sup>, indicating this is an optimal density for fish welfare, at least for fish grown to around 600 g.

**Table 1.** Optimal stocking densities for silver perch during different culture phases and at different fish sizes.

Culture phase	Fish size (g)	Stocking density (fish/m <sup>3</sup> )	
		Cages	RAS
Fry to small fingerlings	2 – 20	1000	1000
Small to large fingerlings	20 – 50	500	1000
Large fingerlings	50 – 150	400	500
Grow-out	150 – 300	100	not recommended
Grow-out	300 – 600	100	not recommended

### Over-wintering in RAS

Survival of fingerlings in the RAS was high (96.4%). The fingerlings in the RAS also grew faster, were significantly larger (145.8 g v's 73.1 g), and had greater production rates compared to those reared in cages at ambient temperatures over winter. Our results demonstrate that a production strategy of over-wintering fingerlings at elevated temperatures can lead to the production of large fingerlings in spring. The use of this strategy could reduce or eliminate bird predation, reduce losses to diseases, shorten the overall culture period and potentially lead to increased profitability. Besides providing advantages of high survival and fast growth, the strategy would also be an advantage on farms with limited water in storages during winter. All or most of the fingerlings could be held in an RAS, which has a relatively low demand for water compared to large storages. Heating of water using mains electricity is a significant cost in winter, but costs could be reduced using underground water with elevated temperatures, insulated greenhouse facilities or other forms of power including solar, oil or gas for heating.

### Growth, production and feeding

Growth of fingerlings and larger fish in cages was similar to that in earthen ponds, production rates were high (to 50 kg/m<sup>3</sup> at a density of 100 fish/m<sup>3</sup>, and around 100 kg/m<sup>3</sup> at 400 fish/m<sup>3</sup>), and feed conversion ratios were 1.1 – 2.5. Silver perch feed well in cages, and costs of feeding (at current feed prices) were \$2.27/kg of fish for fingerlings and \$2.00/kg of fish for larger fish (> 100 g). Silver perch performed well on diets with a range of protein (35 – 45%), energy (14 – 17 MJ/kg) and lipid (5 – 10%) levels, and cost of feeding was primarily influenced by the purchase price of feeds from suppliers. Feeding can be based on restricted rations, satiation, or a combination of these strategies may be used.

### Production phases and grading

Our project confirmed the advantages of using distinct production phases for fingerlings and grow-out. Grading is an essential operation for fingerlings because it minimises size variation, reduces aggression between fish in different size cohorts, maximises survival and growth, and enables efficient management and feeding.

Cages facilitate grading, and there may be advantages in further dividing both the fingerling and grow-out phases as indicated in Table 1.

#### Methods of disease control

Infectious diseases of silver perch are well known, and control usually includes application of permitted chemicals such as formalin and copper directly to the whole pond. This method has some disadvantages including the high cost of formalin and the detrimental effects of both chemicals on some aquatic organisms. It was proposed to evaluate the use of “bags” to enclose each cage during chemical treatment, and to determine the effects of copper on a terrestrial crop (soybeans) during treatment. Unfortunately, this component of the project could not be completed due to a very low incidence of pathogens and infectious diseases. This was probably due to the high level of health management routinely undertaken at GAC (see Rowland et al. 2007 and Read et al. 2007).

#### Advantages of cage culture

Results of this project suggest that advantages of cage culture include:

- (i) ease of monitoring fish after stocking;
- (ii) fish are readily observed and changes in behaviour, colour and feeding activity can be seen;
- (iii) no/limited bird predation;
- (iv) efficient delivery of feed, and determination of satiation;
- (v) ease of sampling to determine size, growth, daily ration, and to monitor health;
- (vi) facilitates grading;
- (vii) crop is divided into discrete, manageable units;
- (viii) ease and efficiency of harvesting;
- (ix) adaptability for different storages and locations;
- (x) ease of movement, cleaning and storage of cages.

The results of our project, as well as experience from producing fish commercially under research conditions at GAC, suggest that 4 or 8 m<sup>3</sup> square or round cages would be suitable on small to medium-sized commercial farms (10 – 100 tonnes per year) because they are easily managed and safely handled by two persons. On farms producing over 100 tonnes, larger cages and increased mechanisation (e.g. for feeding, grading and harvesting) would be needed to enable efficient production.

#### Production strategies for farms

1. Purchase small fingerlings from a hatchery in summer; fingerling phase, over-winter fingerlings in cages and then grow-out in cages; total culture period 15 – 24 months depending on the water temperature regime in the farming region.
2. Purchase small fingerlings from hatchery in summer; over-winter fingerlings (20 – 50 g) in RAS; stock large fingerlings (> 100 g) in early spring for grow-out in cages; 12 – 18 months.
3. Combination of 1 and 2, i.e. using RAS to rear some, but not all fingerlings.

4. Purchase large fingerlings in early spring; grow-out phase only; 6 – 8 months – this strategy would suit farms with limited water during winter.
5. Hatchery production on-site, then fingerling and grow-out using above strategies; hatchery enables control of supply, quality and genetics of fingerlings.
6. Use Murray X Cataract cross to obtain advantage of faster growth of fry and fingerlings due to hybrid vigour.

▪ **Provide technical support to cotton farmers for the integration of aquaculture technology**

Technical support for the freshwater aquaculture industry in NSW and other states has been provided principally by staff at GAC since 1990. The research and extension staff at GAC are some of Australia's most highly experienced, and GAC is a model aquaculture facility. Technical publications on silver perch are available and some are listed in this report. Topics covered in these publications include; broodfish management and hatchery techniques, production of fingerlings and market-size fish, water quality monitoring and management, diseases and health management, fish husbandry, bird predation, off-flavours, and post-harvest management.

Specific publications on cage culture are planned, including a manual "*Techniques for the Cage Culture of Silver Perch*", but production depends on the availability of funds and appropriate staff in 2010 and 2011.

In early 2009, I&I NSW made a decision to phase-out aquaculture production research, including the silver perch work at GAC. The facility is currently being destocked and equipment will be mothballed from mid 2010. Consequently, there will only be limited extension of silver perch and freshwater aquaculture technology after this period. GAC will not be available as a model freshwater farm. I&I NSW staff at the Port Stephens Fisheries Institute will be able to provide potential farmers with published information on silver perch aquaculture, including cage culture, information on the approval process for commercial aquaculture in NSW and general information on aquaculture, including fish husbandry, feeds and feeding, water quality management and health management.

### ***Methods***

3. Detail the methodology and justify the methodology used. Include any discoveries in methods that may benefit other related research.

### **General**

The experimental phase of this project was carried out at GAC which is located near Grafton on the NSW North Coast. The climate is sub-tropical, and annual rainfall

around 1000 mm. The range of water temperatures in ponds at GAC is 10° - 30°C. GAC consists of 19 earthen ponds (0.1-0.3 ha surface area), 2 reservoirs (8.5 and 9 ML capacity), an effluent/settlement dam (43ML), a hatchery/office/laboratory complex, and a large workshop/storage shed and associated equipment such as pumps, aerators, a tractor and other vehicles. The main water supply is the Clarence River, and all effluent water is stored and settled in the effluent/settlement dam, and either re-used for fish culture or used for irrigation. Town-water is de-chlorinated and used for purging fish for market, and sometimes for quarantine.

Prior to stocking in each experiment, silver perch were quarantined for 7 – 14 days in 9000 L tanks and treated continuously with salt (NaCl) at 2-5 g/L to ensure they were free of ectoparasites, to prevent fungal infection and to reduce stress (Selosse and Rowland 1990; Mifsud and Rowland 2008). Fish were anaesthetised using 20 mg/L Benzocaine (ethyl-*p*-aminobenzoate), randomly selected, counted and stocked into cages. Treatments and replicates were randomly assigned to cages, usually with 3 – 5 replicate cages for each treatment.

Each experimental cage was made from knotless netting with a lead-line sewn onto the perimeter of the cage bottom, and had a submerged volume of 1 m<sup>3</sup>; except in cage-design experiments where larger cages and cages made of nylex were also used. The use of 1 m<sup>3</sup> cages enabled sufficient replication of treatments for statistical analyses. Cages had a stretched mesh size of 12 mm for fry and small fingerlings, 19 – 25 mm for large fingerlings, and 40 – 44 mm for the large fish. A 1 mm gauze apron extended 50 mm below the water surface to reduce the amount of food floating out of the cages during feeding. Netting (32 mm mesh) was stretched over each cage to prevent predation by birds. The cages were placed in floating pontoons attached to a fixed walkway in 0.32-ha earthen ponds (5 ML capacity) or to a floating pontoon in an earthen reservoir (8 ML capacity). The ponds were 2 m and the reservoir 3 m deep, and there was 1 – 2 m between the base of each cage and the bottom of the ponds/reservoir. In most experiments, a net (mesh 150 mm and 1.5 m deep) was extended around the cages to exclude birds. The ponds and reservoir were aerated using paddlewheel aerators for a least 11 h/day, including between 21:00 and 08:00 h. The aerators were positioned to ensure an even current flowed through each cage.

Fish husbandry, disease monitoring and health management followed Rowland and Bryant (1995), Rowland et al. (2007) and Read et al. (2007). Water quality variables of temperature, dissolved oxygen (DO), pH, total ammonia–nitrogen (TAN) and unionised ammonia–nitrogen (NH<sub>3</sub>–N) were routinely monitored at a depth of 0.5–1.0 m from the pond walkway adjacent to the cages, and water quality was managed following Rowland (1995).

Fry and fingerlings were fed a commercial fingerling diet containing 52% protein, 17MJ/kg energy and 12% lipid (Ridley Aqua-Feed Pty Ltd) and larger fish were fed a grow-out diet with 45% protein, 17MJ/kg energy and 10% lipid (Ridley Aqua-Feed Pty Ltd). Exceptions were diets used in the experiments to evaluate performance on commercially-available formulations (see Table 2). In all experiments, with the

exception of the diet and some RAS experiments, fish were fed a restricted ration following Rowland et al. (2005) for 5 or 6 days/week. This feeding strategy had been developed for silver perch in cages. Feeding to satiation was used in the diet and some RAS experiments.

In each experiment, fish were sampled routinely (usually each 30 days). Approximately 15-20 % of fish were randomly selected and removed from each cage, placed into a light anaesthetic bath (~ 20 mg/L benzocaine), weighed, counted and returned to the cage. The mean weight and biomass in each cage were estimated, and the daily ration adjusted accordingly.

At the termination of each experiment, all fish were harvested and weighed. The survival (%), final weight (g), specific growth rate ( $SGR = \ln \text{ final weight (g)} - \ln \text{ initial weight (g)} / \text{days} \times 100, \%/ \text{day}$ ), absolute growth rate ( $AGR = \text{ final mean weight (g)} - \text{ initial mean weight (g)} / \text{days, g/fish/day or g/day}$ ), production rate ( $\text{kg/m}^3$ ) and feed conversion ratio ( $FCR = \text{ weight of feed supplied (g)} / \text{ wet weight gain of fish (g)}$ ) were calculated for each cage and the mean calculated for each treatment. Fish in sub-samples of 10 – 20% from each cage were individually weighed (g) and measured (fork length, mm) to determine a coefficient of variation of weight (CV) and to calculate a condition factor ( $K = \text{ weight (g)} / \text{ length (mm)}^3 \times 10^5$ ). Statistical analyses used are detailed in the following sections. Where appropriate, variations in the methodology are given in the following sections for each experiment.

## References

- Mifsud, C. and Rowland, S.J. (2008). Use of salt to control ichthyophthiriosis and prevent saprolegniosis in silver perch, *Bidyanus bidyanus*. *Aquaculture Research* **39**, 1175-1180.
- Read, P., Landos, M., Rowland, S.J. and Mifsud, C. (2007). *Diagnosis, Treatment & Prevention of the Diseases of the Australian Freshwater Fish Silver Perch (Bidyanus bidyanus)*. NSW Department of Primary Industries, Orange.
- Rowland, S.J. (1995). Water quality in the intensive pond culture of silver perch. In, *Silver Perch Culture: Proceedings of Silver Perch Aquaculture Workshops, Grafton and Narrandera, April 1994*. (editors SJ Rowland and C Bryant), pp. 51-65. Austasia Aquaculture, Sandy Bay.
- Rowland, S.J., Allan, G.L., Mifsud, C., Nixon, M., Boyd, P. and Glendenning, D. (2005). Development of a feeding strategy for silver perch, *Bidyanus bidyanus* (Mitchell), based on restricted rations. *Aquaculture Research* **36**, 1429-1441.
- Rowland, S.J. and Bryant, C. (1995) (Editors). *Silver Perch Culture: Proceedings of Silver Perch Aquaculture Workshops, Grafton and Narrandera, April 1994*. Austasia Aquaculture, Sandy Bay.
- Rowland, S.J., Landos, M., Callinan, R.B., Allan, G.L., Read, P., Mifsud, C., Nixon, M., Boyd, P., and Tully, P. (2007). *Development of a Health Management Strategy for the Silver Perch Aquaculture Industry*. NSW Department of Primary Industries – Fisheries Final Report Series No. 93. NSW Department of Primary Industries, Cronulla.
- Selosse, P.M. and Rowland, S.J. (1990). Use of common salt to treat ichthyophthiriasis in Australian warmwater fishes. *The Progressive Fish-Culturist* **52**, 124-127.

## 1. Stocking density

A series of four experiments (detailed below) was carried out to determine the effects of stocking density on culture performance during different production phases and at different fish sizes.

## Data analyses

Data were tested for normal distribution and homogeneity of variance with Shapiro-Wilk and Levene's tests respectively. When variance was normally distributed and homogenous, one-way ANOVA with Tukey's post-hoc comparisons were used to determine significant differences between densities. Where data was normally distributed, with uneven variance between densities, individual unequal variance *t*-tests were used to test for differences of between means at each density. A partial correlation procedure tested the significance of length and weight as factors in the incidence of tail damage after accounting for stocking density.

### Experiment 1.1: fry – fingerlings (1-20g)

Silver perch fry (mean weight, 1.3g; range 1.0 – 3.2 g) were stocked into cages at densities of 500, 1000, 1500 or 2000 fish/m<sup>3</sup>, with four replicate cages for each density, and cultured for 120 days.

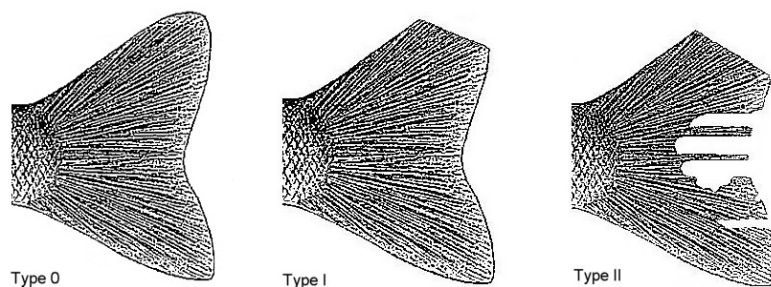
### Experiment 1.2: large fingerlings (18-150 g)

Fingerlings (mean weight, 23 g; range 18 – 27 g) were stocked at densities of 50, 100, 200, 400 or 500 fish/m<sup>3</sup>, with four replicate cages for each density. After 120 days, when pond water temperatures dropped below 20°C the experiment was terminated.

### Experiment 1.3: grow-out (162 – 366 g)

Silver perch (range initial mean weights, 162.0 – 224.1 g) were stocked at densities of 50, 100, 200 or 400 fish/m<sup>3</sup>, with three replicate cages for each density and cultured for 110 days. After harvest, each fish was anaesthetised, weighed and measured, and damage to the caudal fin was categorised as: type O – no damage; type I – erosion of upper tip of caudal fin; type II – erosion of upper tip, plus splitting and erosion of caudal edge (see Fig. 1).

**Figure 1.** Diagrammatic representation of damage and erosion of the caudal fin on silver perch in cages. Type O – no damage.



### Experiment 1.4: grow-out (316 – 587 g)

Silver perch (range initial mean weights, 316 – 317 g) were stocked at densities of 25, 50, 100 or 150 fish/m<sup>3</sup>, with five replicate cages for each density. During the first

month, there were mortalities in some cages stocked at the lowest density of 25 fish/m<sup>3</sup>, and fish were replaced in four of the replicate cages using spare fish that had a similar culture history; subsequently, no fish were replaced. After 210 days all fish were harvested, individually weighed and measured, and tail damage assessed as in the previous experiment.

## 2. Diets

### *General*

Two experiments were run concurrently in the same pond at GAC for 105 days from late-summer (February) to early autumn (May). Pond water temperatures during this period ranged from 21.2 to 29.4°C.

Diets were purchased from the different feed mills or feed suppliers approximately one month prior to the experiments, and stored in a dehumidified cool-room at 18°C. Each diet consisted of floating and sinking extruded pellets. Protein, energy and lipid levels for each diet were as given by the manufacturer or feed supplier (Table 2). Fish in both experiments were fed to satiation because of the known inverse relationship between the size of the daily ration and protein level in silver perch. The amount of feed put into each cage daily was recorded.

One hundred fingerlings from each cage in Experiment 1, and 30 fish from each cage in Experiment 2 were sampled monthly. Fish were anaesthetized, weighed, counted and returned to the cage. The mean weight and biomass were estimated for each cage and treatment. Normal distribution and homogeneity of data variance was confirmed with Shapiro-Wilk and Levene's tests respectively. One-way ANOVA with Tukey's HSD tests were used to determine if there were significant differences between the performance parameters of fish fed each diet. Differences between means were considered significant at  $P < 0.05$ .

**Table 2.** Commercial diets fed to silver perch in cages in Experiments 2.1 and 2.2. Protein, lipid and energy are minimum levels given by feed manufacturers and suppliers.

Diets and production phase	Pellet size (mm)	Days used	Protein (%)	Energy (MJ/kg)	Lipid (%)	Price of diet (\$/kg)
Fingerling A	1	0-35	54	20	19	7.80
	1.8	36-65	50	20.4	22	7.35
	2	66-105	50	20	23	2.71
B	1	0-35	52	17.1	12	2.82
	2	36-65	52	17.1	12	2.42
	3	66-105	52	17.1	12	2.28
C	1.4	0-35	35	14.4	10	2.08
	1.8	36-65	35	14.4	10	2.08
	2.2	66-105	35	14.4	10	1.86

Grow-out						
X	4.5	0-105	30	15.2	6	1.50
Y	4.5	0-105	35	14.4	10	1.75
Z	4.5	0-105	45	17.3	10	1.36

### *Experiment 2.1: fingerling phase*

Small fingerlings (weight range, 2.3 – 3.1 g) were stocked in cages at a density of 500 fish/m<sup>3</sup> and fed one of three commercial diets A, B or C (see Table 2) to satiation twice daily, 6 days/week. Feed was broadcast into cages by hand until satiation was reached, as determined by lack of feeding activity at the surface and mid-water in each cage. Fingerling diets consisted of a series of increasing pellet sizes, and for diet A, the protein and lipid contents also varied with pellet size (see Table 2). The size of pellets offered to fingerlings was adjusted following Rowland et al. (2005).

### *Experiment 2.2: grow-out phase*

Silver perch (mean weight, 88.4 g) were stocked into cages at a density of 100 fish/m<sup>3</sup> and fed one of three diets X, Y or Z (Table 2) to satiation twice daily, 6 days/week. Satiation was determined as for Experiment 2.1. Each diet consisted of a single pellet size and composition over the duration of the experiment.

## 3. Cage size and shape

### *General*

Two experiments were used to evaluate the performance of silver perch in cages of different sizes and shapes. In the cage-size experiment, fish (mean weight, 98 g) were stocked at 120 fish/m<sup>3</sup> into cages of volumes of 1 m<sup>3</sup>, 4 m<sup>3</sup> or 8 m<sup>3</sup> with three replicate cages for each volume; fish were cultured for 90 days. Cages were made of knotless netting as previously described.

In the cage-shape experiment, silver perch (mean weight, 147 g) were stocked at a density of 100 fish/m<sup>3</sup> into square or cylindrical cages of 1 m<sup>3</sup> volume, and cultured for 90 days. There were four replicate cages for each shape. To ensure consistent shapes, cages were constructed of 10 mm rigid plastic square mesh. Circular cages consisted of two PVC irrigation pipe (25 mm) joined as rings, attached to the top and bottom of rigid mesh with cable ties. The inner diameter of the cage was 1270 mm and depth was 910 mm. Square cages were assembled from 1120 x 910 mm and 1120 x 1120 mm wooden frames, constructed from 20 x 20 mm hardwood stakes. Each cage had a framed rigid mesh lid to exclude birds. A 1 mm gauze apron extended 50 mm below the surface to reduce the amount of food floating out of the cages during

feeding. Cages had polystyrene floats (200 mm diameter) cut in half and attached at four compass or corner points ensuring all cages had equal submerged depth of 800 mm.

Normal distribution and homogeneity of data variance was confirmed with Shapiro-Wilk and Levene's tests respectively. Differences among cage-size means were compared with one-way ANOVA. Cage-shape means were compared with t-tests, while individual fish weights were compared with nested ANOVA.

#### 4. New production strategy - over-wintering fingerlings in RAS

##### *RAS*

The RAS had a total water volume of 16000 L. There were 12 black, circular, fibreglass culture tanks, each of 1 m<sup>3</sup> capacity, with central drainage. Central standpipes (50 mm) allowed the removal of water and wastes, and prevented fish from escaping. Water entered the tanks through submerged manifolds at flow rates of 10 - 15 L/min. The tanks were subjected to a natural photo-period and were aerated continuously with diffused air, via air-stones centrally located in each tank. Effluent water from each rearing tank flowed into two, 500 L swirl separators where larger solids were removed. A 50 L drum filter then removed suspended solids greater than 80 µm prior to the water entering a 1000 L sump. A 60 L foam fractionator between the sump and the main water line removed fine and dissolved solids. Water was pumped to a mezzanine level via a UV sterilisation unit. An 11 kW heater-chiller unit was used to elevate water temperature during winter. The bio-filter consisted of a 1000 L tank with a rotating arm that sprayed water over 1 m<sup>3</sup> of "ovi-flow" bio-balls that had a specific surface area of 402 m<sup>2</sup> m<sup>-3</sup>. Water then flowed into a 2000 L header tank before returning to the rearing tanks by gravity. Salinity was maintained at 2-3 g/L NaCl to prevent nitrite poisoning. Total alkalinity and pH were maintained by the daily addition of 0.8 - 1.0 kg of sodium bi-carbonate. A 110 KVA generator provided back-up power to the RAS and other facilities at GAC.

##### *Experiment 4.1: over-wintering in cages and RAS*

Fingerlings (mean weight, 38 g) were stocked at a density of 200 fish/m<sup>3</sup> into either 1 m<sup>3</sup> cages in a pond or 1 m<sup>3</sup> tanks in the RAS and cultured for 125 days. There were 8 replicate cages and 8 tanks. Fifty fish from each cage or tank were sampled each month, weighed and the mean weights and biomasses estimated. Water quality variables including temperature were recorded twice daily, 5 days/week. After 125 days, when pond water temperatures rose above 20°C, fish were harvested from cages and the RAS, and the experiment terminated.

##### *Experiment 4.2: on-growing after winter*

Fingerlings (mean weight, 85 g) that had been over-wintered in cages were randomly selected and stocked into 1 m<sup>3</sup> cages (19 mm mesh) at a density of 100 fish/m<sup>3</sup>, and fish over-wintered in the RAS (mean weight, 165 g) were randomly selected and stocked into 1 m<sup>3</sup> cages (44 mm mesh) at a density of 100 fish/m<sup>3</sup>. There were six replicate cages for each treatment. Fingerlings that had been over-wintered in cages were fed the fingerling diet, until mean weights exceeded 100 g, after which the commercial grow-out diet previously described was used. Fingerlings over-wintered in the RAS remained on the commercial grow-out diet. Fish were sampled monthly, weighed, mean weights and biomasses estimated and the daily feed rations adjusted accordingly. Fish were harvested and the experiment terminated after 129 days.

#### *Experiment 4.3: stocking densities in RAS*

Silver perch fingerlings (11.8 g) were stocked into RAS tanks at densities of 500, 1000 or 1500 fish/m<sup>3</sup>, with three replicate tanks for each density. Fish were fed the fingerling diet to satiation three times each day (08:30, 12:30 and 16:30 h), 5 days/week. The water quality variables temperature and dissolved oxygen (DO) were recorded at 09:00 and 14:30 daily, 5 days/week. A random sample, equal to 10% of the assigned stocking density of fish from each tank, was weighed after 33 days and 66 days. All fish were harvested and the experiment terminated after 99 days.

### 5. Development of methods of treating infectious diseases in cages

In each experiment, two additional cages termed “canary” cages were placed adjacent to the experimental cages to provide fish for disease monitoring without disturbing experimental fish. Fish were sampled monthly from the canary cages or more frequently if fish displayed unusual signs such as decreased appetite and lethargy. In addition, spare fish that were held in cages for use in later experiments, including disease-management experiments, were sampled regularly and monitored for diseases. Disease monitoring and health management followed Rowland et al. (2007) and Read et al. (2007).

### 6. Economic assessment of different farm and production scenarios

The commercial aquaculture software package *Perch Profit* was used to produce farm models simulating different scenarios using the following: (i) data from the experimental phase of the project; (ii) published data on pond culture; (iii) known performance of silver perch on large commercial farms (> 10 ha and 100 tonnes capacity); and (iv) a published economic assessment of silver perch culture using an intra-specific cross (Guy et al. 2009 – see References). *Perch Profit* is a whole-farm economic decision tool based on quantitative cost-benefit analysis methods. It

operates over a 20-year time frame and utilises discounted cash flow analysis to assess cash inflows and outflows over time.

The different scenarios had a target annual production of 100 tonnes or more from 18 ha of water storage. Common assumptions across scenarios were feed type and cost, water use and exchange, power costs, labour costs, fuel, maintenance, packaging and marketing costs, licence fees and administrative costs, and land value. Revenue was based on current market prices for small silver perch (300 – 450 g) of \$11.90/kg. This is conservative because price is sensitive to fish size, and prices for medium, large and extra-large fish were up to \$18/kg through-out 2009.

The different scenarios were:

- (i) Ponds (A) – pond culture in purpose-built ponds with low survival (51% for fingerlings, and 55% for grow-out; similar rates have been reported on large commercial farms);
- (ii) Ponds (B) – pond culture in purpose-built ponds with high survival (80% fingerling phase, 90% grow-out phase; these rates have been achieved on small, well-managed farms);
- (iii) cage culture in established storages (95% fingerlings, 98% grow-out);
- (iv) cage culture in storages with fingerlings over-wintered at elevated temperatures in an RAS (98% survival).

## ***Results***

4. Detail and discuss the results for each objective including the statistical analysis of results.

### 1. Stocking density

#### *Experiment 1.1: fry – fingerlings*

Data on survival, initial and final mean weights, AGR, SGR, production rate, FCR and CV are presented in Table 3, and the growth of fingerlings is shown in Fig. 2. Survival was high (> 96%) in all cages and did not differ significantly between stocking densities. Density had significant effects on other performance parameters. The mean weight of fingerlings stocked at 500 fish/m<sup>3</sup> (15.4 g) was higher than the mean weight of fingerlings stocked at 1000 fish/m<sup>3</sup> (10.5 g), 1500 fish/m<sup>3</sup> (7.1 g) or 2000 fish/m<sup>3</sup> (4.3g). Growth rates were inversely proportional to stocking density, with differences in SGR between each density. The production rate in cages stocked at 500 fish/m<sup>3</sup> (7.7 kg/m<sup>3</sup>) was lower than for fingerlings stocked at 1000 (11.4 kg/m<sup>3</sup>) and 1500 fish/m<sup>3</sup> (10.4 kg/m<sup>3</sup>), but was not different to the rate for fingerlings stocked at 2000 fish/m<sup>3</sup> (9.0 kg/m<sup>3</sup>). FCR was not different between fingerlings stocked at 500 fish/m<sup>3</sup> (1.47) and 1000 fish/m<sup>3</sup> (1.61), but was lower than for fingerlings stocked at 1500 fish/m<sup>3</sup> (2.41) and 2000 fish/m<sup>3</sup> (3.68). The CV of

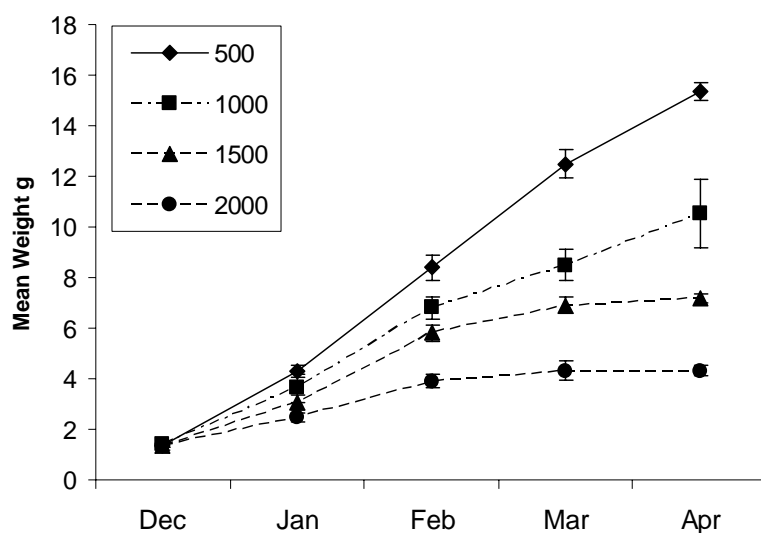
weight for fish stocked at 500 fish/m<sup>3</sup> was lower than for fingerlings stocked at 2000 fish/m<sup>3</sup>, but there were no differences in CV among other stocking densities.

These data suggest that a density of 1000 fish/m<sup>3</sup> is optimal for this culture phase, but that 500 fish/m<sup>3</sup> could be used to produce larger fingerlings.

**Table 3.** Survival, production rate, initial and final weights, absolute growth rate (AGR), specific growth rate (SGR), feed conversion ratio (FCR), and coefficient of weight variation (CV) of silver perch fingerlings (initial weight range, 1-3 g) cultured for 120 days at four stocking densities in 1 m<sup>3</sup> cages. Data are means ± SD of four replicates cages.

Stocking density (fish/m <sup>3</sup> )	500	1000	1500	2000
Survival (%)	97.3 ± 0.8	97.6 ± 1.0	96.8 ± 1.9	99.4 ± 0.1
Production rate (kg/m <sup>3</sup> )	7.70 ± 0.18	11.45 ± 1.09	10.36 ± 0.30	9.00 ± 0.54
Initial weight (g)	1.36 ± 0.04	1.39 ± 0.10	1.35 ± 0.05	1.38 ± 0.07
Final weight (g)	15.37 ± 0.36	10.53 ± 1.36	7.13 ± 0.32	4.30 ± 0.21
AGR (g/day)	0.12 ± 0.01	0.08 ± 0.02	0.05 ± 0.00	0.03 ± 0.00
SGR (%/day)	2.11 ± 0.04	1.74 ± 0.20	1.45 ± 0.07	0.99 ± 0.06
FCR	1.47 ± 0.11	1.61 ± 0.31	2.41 ± 0.11	3.68 ± 0.51
CV	0.09 ± 0.05	0.15 ± 0.08	0.17 ± 0.04	0.28 ± 0.08

**Figure 2.** Growth of silver perch fingerlings stocked in 1 m<sup>3</sup> cages at densities of 500, 1000, 1500 or 2000 fish/m<sup>3</sup> and cultured for 120 days. Data are means (± SD) of four replicate cages.



### Experiment 1.2: large fingerlings

Data on survival, initial and final mean weights, AGR, SGR, production rate, FCR and CV are presented in Table 4, and the growth of fish is shown in Fig. 3. Survival was high (> 92%) for all cages and did not differ significantly between stocking densities. The final weight, AGR and SGR of fish stocked at 500 fish/m<sup>3</sup> were

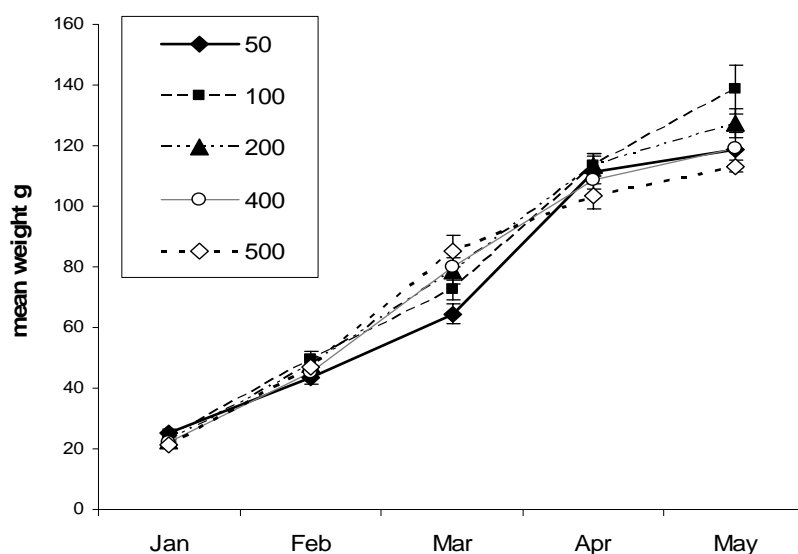
significantly lower than for fish stocked at 100 or 200 fish/m<sup>3</sup>. Mean weight, AGR and SGR of fish stocked at 50, 400 or 500 fish/m<sup>3</sup> were not significantly different. There was no significant difference in FCR between stocking densities. The CV of weight for cages stocked at 500 fish/m<sup>3</sup> was significantly higher than for other densities. There was no significant difference in condition factor (K) between fish cultured at different densities.

These data suggest that 400 fish/m<sup>3</sup> is the optimal density for the production of large fingerlings.

**Table 4.** Survival, production rate, initial and final weights, absolute growth rate (AGR), specific growth rate (SGR), feed conversion ratio (FCR) and coefficient of weight variation (CV) and condition (K) of silver perch fingerlings (initial weight range, 18 - 30 g) cultured for 120 days. Data are means±SD of four replicates cages. Within rows, data with different superscripts are significantly different ( $P<0.05$ ).

Stocking density (fish/m <sup>3</sup> )	50	100	200	400	500
Survival (%)	92.5 ± 5.7 <sup>a</sup>	99.0 ± 1.2 <sup>a</sup>	99.5 ± 0.6 <sup>a</sup>	94.5 ± 7.0 <sup>a</sup>	95.5 ± 1.9 <sup>a</sup>
Production rate (kg/m <sup>3</sup> )	5.33 ± 1.03 <sup>a</sup>	12.87 ± 1.40 <sup>b</sup>	20.78 ± 1.19 <sup>c</sup>	44.99 ± 3.13 <sup>d</sup>	49.04 ± 0.85 <sup>e</sup>
Initial weight (g)	23.8 ± 0.8 <sup>a</sup>	23.8 ± 2.4 <sup>a</sup>	23.3 ± 0.4 <sup>a</sup>	23.5 ± 1.0 <sup>a</sup>	22.7 ± 0.7 <sup>a</sup>
Final weight (g)	114.6 ± 15.1 <sup>ab</sup>	130.0 ± 5.2 <sup>a</sup>	128.3 ± 6.6 <sup>a</sup>	119.4 ± 10.0 <sup>ab</sup>	102.8 ± 1.5 <sup>b</sup>
AGR (g/day)	0.83 ± 0.14 <sup>ab</sup>	1.01 ± 0.12 <sup>a</sup>	0.95 ± 0.06 <sup>a</sup>	0.87 ± 0.09 <sup>ab</sup>	0.73 ± 0.01 <sup>b</sup>
SGR (%/day)	1.42 ± 0.14 <sup>ab</sup>	1.55 ± 0.03 <sup>a</sup>	1.55 ± 0.03 <sup>a</sup>	1.47 ± 0.09 <sup>ab</sup>	1.37 ± 0.01 <sup>b</sup>
FCR	2.19 ± 0.42 <sup>a</sup>	1.69 ± 0.14 <sup>a</sup>	1.73 ± 0.11 <sup>a</sup>	1.94 ± 0.20 <sup>a</sup>	2.16 ± 0.12 <sup>a</sup>
CV	0.45 ± 0.04 <sup>ab</sup>	0.44 ± 0.04 <sup>ab</sup>	0.41 ± 0.04 <sup>ab</sup>	0.40 ± 0.02 <sup>a</sup>	0.49 ± 0.05 <sup>b</sup>
K	0.133 ± 0.015 <sup>a</sup>	0.136 ± 0.014 <sup>a</sup>	0.134 ± 0.014 <sup>a</sup>	0.136 ± 0.013 <sup>a</sup>	0.130 ± 0.015 <sup>a</sup>

**Figure 3.** Growth of silver perch fingerlings stocked in 1 m<sup>3</sup> cages at densities of 50, 100, 200, 400 or 500 fish/m<sup>3</sup> and cultured for 120 days. Data are means± SD of four replicate cages.



### Experiment 1.3: grow-out

Data on survival, initial and final mean weights, AGR, SGR, production rate, FCR and CV are presented in Table 5. Survival was high ( $\geq 98.0\%$ ) and not significantly different between densities. There was no significant difference in the SGR between fish stocked at 100, 200 or 400 fish  $m^{-3}$ , and the SGR of fish stocked at 50 fish  $m^{-3}$  was significantly slower than for fish stocked at 100 fish  $m^{-3}$ . There was no significant difference in CV or K between stocking densities. Production rates increased with increasing stocking density, from 16.6 to 103.3 kg  $m^{-3}$  at densities of 50 and 400 fish  $m^{-3}$  respectively.

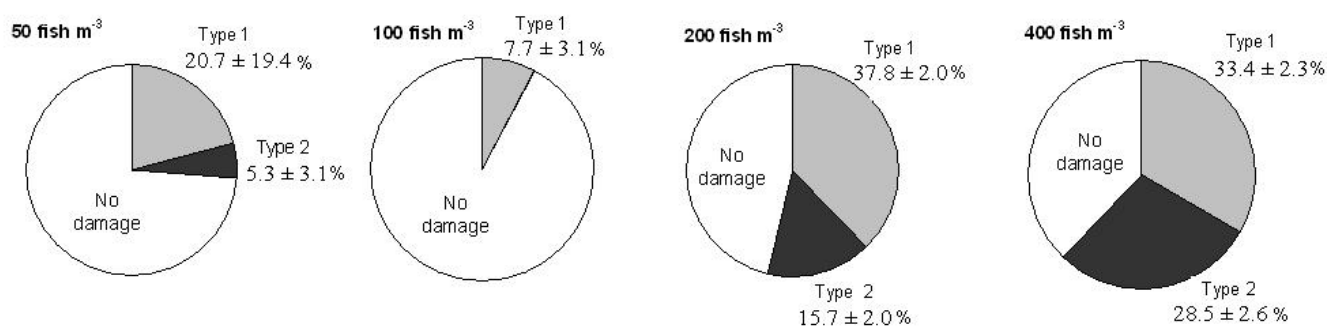
There were significant differences in the incidence of caudal fin damage between stocking densities (Fig. 3). Initial damage was usually to the upper node of the caudal fin (type I), and splitting was always associated with erosion of the upper node (type II). Fish stocked at 100 fish/ $m^3$  had the lowest incidence of fin damage (7.7%) and there was no type II damage in fish cultured at this stocking density. The incidences of caudal fin damage of 53.5% and 61.9% at 200 and 400 fish/ $m^3$  respectively, were significantly higher than 26.0% at 50 fish/ $m^3$ . There was an increasing incidence of type II damage at 200 and 400 fish/ $m^3$  (see Fig. 3).

Considering performance and fish welfare, the optimal stocking density for silver perch above 200 g is 100 fish/ $m^3$ .

**Table 5.** Survival, production rate, initial and final weights, absolute growth rate (AGR), specific growth rate (SGR), feed conversion ratio (FCR) and coefficient of weight variation (CV) of silver perch fingerlings stocked at 50, 100, 200 or 400 fish/ $m^3$  and cultured for 120 days in 1  $m^3$  cages. Data are means $\pm$ SD of three replicates cages. Within rows, data with different superscripts are significantly different ( $P < 0.05$ ).

Stocking density (fish/ $m^3$ )	50	100	200	400
Survival (%)	98.0 $\pm$ 2.0 <sup>a</sup>	98.7 $\pm$ 0.6 <sup>a</sup>	99.0 $\pm$ 0.9 <sup>a</sup>	98.5 $\pm$ 1.0 <sup>a</sup>
Production rate (kg/ $m^3$ )	16.55 $\pm$ 0.67 <sup>a</sup>	36.11 $\pm$ 1.94 <sup>b</sup>	62.51 $\pm$ 0.88 <sup>c</sup>	103.31 $\pm$ 2.41 <sup>d</sup>
Initial weight (g)	220.93 $\pm$ 1.24 <sup>a</sup>	224.07 $\pm$ 9.64 <sup>a</sup>	199.20 $\pm$ 4.68 <sup>b</sup>	161.95 $\pm$ 1.10 <sup>c</sup>
Final weight (g)	338.00 $\pm$ 9.56 <sup>ab</sup>	365.96 $\pm$ 8.53 <sup>a</sup>	315.76 $\pm$ 6.09 <sup>bc</sup>	262.20 $\pm$ 4.85 <sup>c</sup>
AGR (g/day)	1.17 $\pm$ 0.12 <sup>a</sup>	1.42 $\pm$ 0.09 <sup>b</sup>	1.16 $\pm$ 0.04 <sup>a</sup>	1.17 $\pm$ 0.06 <sup>a</sup>
SGR (%/day)	0.42 $\pm$ 0.03 <sup>a</sup>	0.49 $\pm$ 0.01 <sup>b</sup>	0.46 $\pm$ 0.02 <sup>ab</sup>	0.48 $\pm$ 0.02 <sup>ab</sup>
FCR	3.53 $\pm$ 0.40 <sup>a</sup>	2.87 $\pm$ 0.08 <sup>b</sup>	3.08 $\pm$ 0.19 <sup>ab</sup>	3.54 $\pm$ 0.26 <sup>ab</sup>
CV	0.22 $\pm$ 0.04 <sup>a</sup>	0.22 $\pm$ 0.03 <sup>a</sup>	0.23 $\pm$ 0.02 <sup>a</sup>	0.27 $\pm$ 0.03 <sup>a</sup>
K	0.142 $\pm$ 0.014 <sup>a</sup>	0.141 $\pm$ 0.014 <sup>a</sup>	0.139 $\pm$ 0.015 <sup>a</sup>	0.139 $\pm$ 0.014 <sup>a</sup>

**Figure 3.** Incidence of caudal fin damage in silver perch (> 160 g) cultured in 1 m<sup>3</sup> cages at stocking densities of 50, 100, 200 or 400 fish/m<sup>3</sup>. Data are means±SD of three replicate cages. See text for description of types of damage.



#### Experiment 1.4: grow-out

Data on survival, initial and final mean weights, AGR, SGR, production rate, FCR and CV are presented in Table 6. Survival of fish stocked at 25 fish m<sup>-3</sup> (79%) was significantly lower than those stocked at 50, 100 or 150 fish/m<sup>3</sup> (> 96%). The final survival rate of fish stocked at 25 fish/m<sup>3</sup> did not include the mortalities observed and replaced in the first month. Moribund fish, showing signs of aggravated damage (lesions on the caudal peduncle, pale colour and unresponsive behaviour) were later observed in three of the restocked cages. The SGR for fish stocked at 25 fish/m<sup>3</sup> was significantly slower than for fish stocked at 100 fish/m<sup>3</sup>, but not fish stocked at 50 or 150 fish/m<sup>3</sup>. FCR was significantly higher for fish stocked at 25 fish/m<sup>3</sup> as cages continued to receive the ration for 25 fish, but there was no other significant difference in FCR among stocking densities. There was no significant difference in CV or K among stocking densities. There were no significant differences in the incidence of type I tail damage between densities (9.8% ± 2.7% across all densities) and no type II tail damage was observed in this experiment.

Considering performance and welfare, a stocking density of 100 fish/m<sup>3</sup> is optimal for large silver perch (300 - 600 g).

**Table 6.** Survival, production rate, initial and final weights, absolute growth rate (AGR), specific growth rate (SGR), feed conversion ratio (FCR) and coefficient of weight variation (CV) of silver perch (> 300 g) cultured for 120 days at four stocking densities in 1 m<sup>3</sup> cages. Data are means±SD of five replicate cages. Within rows, data with different superscripts are significantly different ( $P<0.05$ ).

Stocking density (fish/m <sup>3</sup> )	25	50	100	150
Survival (%)	79.2 ± 15.8 <sup>a</sup>	98.8 ± 1.1 <sup>b</sup>	97.6 ± 0.5 <sup>b</sup>	98.3 ± 1.6 <sup>b</sup>
Production rate (kg/m <sup>3</sup> )	10.49 ± 2.63 <sup>a</sup>	27.85 ± 1.19 <sup>b</sup>	57.31 ± 2.57 <sup>c</sup>	81.95 ± 2.94 <sup>d</sup>
Initial weight (g)	315.7 ± 1.8 <sup>a</sup>	317.4 ± 1.4 <sup>a</sup>	316.1 ± 1.0 <sup>a</sup>	316.8 ± 0.7 <sup>a</sup>
Final weight (g)	525.8 ± 32.4 <sup>a</sup>	563.6 ± 21.5 <sup>ab</sup>	587.1 ± 23.2 <sup>b</sup>	556.1 ± 22.9 <sup>ab</sup>
AGR (g/day)	0.67 ± 0.39 <sup>a</sup>	1.14 ± 0.12 <sup>ab</sup>	1.22 ± 0.12 <sup>b</sup>	1.09 ± 0.09 <sup>ab</sup>
SGR (%/day)	0.17 ± 0.09 <sup>a</sup>	0.27 ± 0.02 <sup>ab</sup>	0.28 ± 0.02 <sup>b</sup>	0.26 ± 0.02 <sup>ab</sup>
FCR	6.02 ± 3.94 <sup>a</sup>	2.56 ± 0.23 <sup>b</sup>	2.39 ± 0.23 <sup>b</sup>	2.67 ± 0.24 <sup>b</sup>
CV	0.194 ± 0.056 <sup>a</sup>	0.146 ± 0.020 <sup>a</sup>	0.139 ± 0.011 <sup>a</sup>	0.157 ± 0.012 <sup>a</sup>
K	0.165 ± 0.013 <sup>a</sup>	0.163 ± 0.012 <sup>a</sup>	0.164 ± 0.012 <sup>a</sup>	0.161 ± 0.012 <sup>a</sup>

This series of experiments has identified optimal stocking densities for the cage culture of silver perch based on fish performance and fish welfare at different fish sizes and production phases.

## 2. Diets

### *Experiment 2.1: fingerling phase*

Data on survival, initial and final weights, SGR, production rate, FCR, CV, K and CF are presented in Table 7. Mean survival rates were high (> 99%) and did not differ significantly between diets. Although fingerlings fed diet A were significantly heavier and FCR significantly lower than fingerlings fed diet C, there were no significant differences in the SGR or production rate between fingerlings fed each diet. The CV of fingerlings fed diet C was significantly lower than the CVs for fingerlings fed diets A or B, and K of fish fed diet C was significantly higher than the condition of fish fed diets A or B. Fish fed diet C were observed to be plump, and brighter in appearance compared to fish fed other diets. The cost of feeding diet A (\$5.56/kg of fish) was significantly higher than feeding B (\$2.80/kg of fish), which in turn was significantly higher than feeding diet C (\$2.27/kg of fish). Diet C had the lowest purchase price (Table 2).

**Table 7.** Survival, initial and final weights, specific growth rate (SGR), production rate, feed conversion ratio (FCR), coefficient of variation of weight (CV), condition factor (K) and cost of feeding (CF) of silver perch fingerlings fed one of three commercial diets for 105 days in cages. Data are means  $\pm$  SD of four replicates cages. Within rows, data with different superscripts are significantly different ( $P < 0.05$ ).

	Diet A	Diet B	Diet C
Survival %	99.6 $\pm$ 0.5 <sup>a</sup>	99.5 $\pm$ 0.5 <sup>a</sup>	99.8 $\pm$ 0.5 <sup>a</sup>
Initial weight (g)	2.57 $\pm$ 0.09 <sup>a</sup>	2.40 $\pm$ 0.12 <sup>a</sup>	2.42 $\pm$ 0.17 <sup>a</sup>
Final weight (g)	47.1 $\pm$ 1.0 <sup>a</sup>	44.4 $\pm$ 1.5 <sup>ab</sup>	43.2 $\pm$ 2.7 <sup>b</sup>
SGR (%/day)	2.77 $\pm$ 0.02 <sup>a</sup>	2.78 $\pm$ 0.06 <sup>a</sup>	2.75 $\pm$ 0.04 <sup>a</sup>
Production rate (kg/m <sup>3</sup> )	23.49 $\pm$ 0.55 <sup>a</sup>	22.07 $\pm$ 0.83 <sup>a</sup>	21.56 $\pm$ 1.45 <sup>a</sup>
FCR	0.94 $\pm$ 0.03 <sup>a</sup>	1.12 $\pm$ 0.06 <sup>b</sup>	1.13 $\pm$ 0.03 <sup>b</sup>
CV	0.41 $\pm$ 0.02 <sup>a</sup>	0.42 $\pm$ 0.01 <sup>a</sup>	0.34 $\pm$ 0.01 <sup>b</sup>
K	0.158 $\pm$ 0.012 <sup>a</sup>	0.162 $\pm$ 0.012 <sup>a</sup>	0.173 $\pm$ 0.017 <sup>b</sup>
CF (\$/kg of fish)	5.56 $\pm$ 0.15 <sup>a</sup>	2.80 $\pm$ 0.16 <sup>b</sup>	2.27 $\pm$ 0.06 <sup>c</sup>

### *Experiment 2.2: grow-out phase*

Data on survival, initial and final weights, SGR, production rate, FCR, CV, K and CF are presented in Table 8. Mean survival rates were high ( $\geq 98\%$ ) and there was no significant difference in survival, final weight, SGR, production rate, CV or K

between fish fed each diet. The FCR of fish fed diet X (1.8) was significantly higher than for diet Z (1.5). The cost of feeding diet Z (\$2.00/kg of fish) was significantly lower than feeding diet Y (\$2.68/kg of fish) or diet X (\$2.61/kg of fish). Diet Z had the lowest purchase price (Table 2).

**Table 8.** Survival, initial and final weights, specific growth rate (SGR), production rate, feed conversion ratio (FCR), coefficient of variation of weight (CV), condition factor (K) and cost of feeding (CF) of silver perch fed one of three commercial diets for 105 days in cages. Data are means±SD of four replicates cages. Within rows, data with different superscripts are significantly different ( $P<0.05$ ).

	Diet X	Diet Y	Diet Z
Survival %	98.8 ± 0.6% <sup>a</sup>	98.0 ± 0.6% <sup>a</sup>	98.3 ± 1.4% <sup>a</sup>
Initial weight (g)	88.6 ± 4.3 <sup>a</sup>	86.9 ± 4.4 <sup>a</sup>	89.7 ± 7.0 <sup>a</sup>
Final weight (g)	168.7 ± 7.7 <sup>a</sup>	184.3 ± 16.1 <sup>a</sup>	188.6 ± 15.5 <sup>a</sup>
SGR (%/day)	0.61 ± 0.06 <sup>a</sup>	0.71 ± 0.07 <sup>a</sup>	0.71 ± 0.05 <sup>a</sup>
Production rate (kg/m <sup>3</sup> )	16.66 ± 0.71 <sup>a</sup>	18.07 ± 1.73 <sup>a</sup>	18.55 ± 1.87 <sup>a</sup>
FCR	1.79 ± 0.17 <sup>a</sup>	1.49 ± 0.17 <sup>ab</sup>	1.47 ± 0.12 <sup>b</sup>
CV	0.30 ± 0.01 <sup>a</sup>	0.27 ± 0.03 <sup>a</sup>	0.31 ± 0.03 <sup>a</sup>
K	0.146 ± 0.014 <sup>a</sup>	0.147 ± 0.023 <sup>a</sup>	0.157 ± 0.069 <sup>a</sup>
CF (\$/kg of fish)	2.68 ± 0.26 <sup>a</sup>	2.61 ± 0.31 <sup>a</sup>	2.00 ± 0.16 <sup>b</sup>

The similar performances of silver perch on diets with different protein, energy and lipid levels suggest the species is flexible in its dietary requirements, and that each diet met or exceeded the nutritional requirements of the species. Commercial diets with 35 – 45% protein, 14.4-17.3 MJ/kg energy and 10% lipid are suitable for silver perch in cages, and the cost-effectiveness of diets is primarily dependent on the purchase price from the feed suppliers.

The costs of feeding small fingerlings and larger fish in our study were \$2.27/kg of fish and \$2.00/kg of fish respectively. Small differences in feed prices can have a profound effect on the cost of production, particularly for grow-out diets which account for 60% or more of total feed used in a production cycle. Our results suggest that price should be a key factor when selecting diets for silver perch in cages.

### 3. Cage size and shape

Survival was high in both experiments and there was no significant difference in the survival of fish in cages of different sizes or shape.

Final weight, production rate, AGR and SGR were significantly higher, and FCR significantly lower for fish cultured in 4 m<sup>3</sup> cages compared to fish in 1 m<sup>3</sup> cages (Table 9). There was no significant difference in performance of fish cultured in 4 m<sup>3</sup> or 8 m<sup>3</sup> cages. There was no significant difference in CV or K among fish cultured in different-sized cages.

**Table 9.** Performance of silver perch stocked at a density of 120 fish/m<sup>3</sup> in cages with volumes of 1 m<sup>3</sup>, 4 m<sup>3</sup> or 8 m<sup>3</sup> and cultured for 90 days. Data are means±SD of four replicate cages. Within rows, data with different superscripts are significantly different ( $P<0.05$ )

Cage Volume (m <sup>3</sup> )	1	4	8
Survival (%)	100 ± 0	100 ± 0	99.7 ± 0.0
Production rate (kg/m <sup>3</sup> )	31.42 ± 1.87 <sup>a</sup>	36.34 ± 0.36 <sup>b</sup>	34.51 ± 0.71 <sup>b</sup>
Initial weight (g)	97.3 ± 1.3 <sup>a</sup>	99.7 ± 1.6 <sup>a</sup>	98.8 ± 0.8 <sup>a</sup>
Final weight (g)	261.8 ± 15.5 <sup>a</sup>	302.8 ± 3.0 <sup>b</sup>	287.6 ± 5.9 <sup>b</sup>
AGR (g/day)	1.83 ± 0.16 <sup>a</sup>	2.26 ± 0.04 <sup>b</sup>	2.10 ± 0.07 <sup>b</sup>
SGR (%/day)	1.10 ± 0.06 <sup>a</sup>	1.24 ± 0.02 <sup>b</sup>	1.19 ± 0.03 <sup>ab</sup>
FCR	1.76 ± 0.09 <sup>a</sup>	1.56 ± 0.03 <sup>b</sup>	1.63 ± 0.04 <sup>ab</sup>
CV	0.25 ± 0.03 <sup>a</sup>	0.24 ± 0.01 <sup>a</sup>	0.25 ± 0.02 <sup>a</sup>
K	0.169 ± 0.006 <sup>a</sup>	0.166 ± 0.002 <sup>a</sup>	0.168 ± 0.005 <sup>a</sup>

There was no significant difference in final weight, production rate, AGR, SGR, FCR, CV or K between fish cultured in square or round cages (Table 10).

**Table 10.** Performance of silver perch stocked at a density of 100 fish/m<sup>3</sup> into round or square 1 m<sup>3</sup> cages and cultured for 90 days. Data are means±SD of three replicate cages for each shape.

Cage shape	Round	Square
Survival (%)	98.3 ± 1.0	99.0 ± 0.0
Production rate (kg/m <sup>3</sup> )	31.75 ± 0.95	30.49 ± 1.23
Initial weight (g)	146.5 ± 0.6	147.0 ± 0.4
Final weight (g)	322.9 ± 7.0	307.7 ± 13.1
AGR (g/day)	1.96 ± 0.08	1.79 ± 0.14
SGR (%/day)	0.88 ± 0.02	0.82 ± 0.05
FCR	1.62 ± 0.07	1.71 ± 0.12
CV	0.16 ± 0.01	0.18 ± 0.01
K	0.176 ± 0.002	0.172 ± 0.004

While 1 m<sup>3</sup> cages were used in this project to enable appropriate statistical analyses under experimental conditions, results of this experiment suggest that larger cages of 4 or 8 m<sup>3</sup> would be suitable under commercial conditions on farms up to, say 100 tonnes production capacity. Cages of this size would suit this level of production because they could contain up to 200 and 400 kg of fish respectively, are easily managed, and easily handled by two people.

#### 4. New production strategy – over-wintering fingerlings in RAS

##### *Experiment 4.1: over-wintering in cages and RAS*

Survival of fingerlings over-wintered in cages (mean 76.8%) was significantly lower than survival in the RAS (96.4%) (Table 11). Growth of fish in the RAS and in cages is shown in Fig. 4. Differences in growth were evident by June. At the end of winter, the final weight, AGR, SGR and production rate of fish cultured in the RAS were all significantly higher or faster than fish over-wintered in cages. There was no significant difference in FCR between fish over-wintered RAS or in cages.

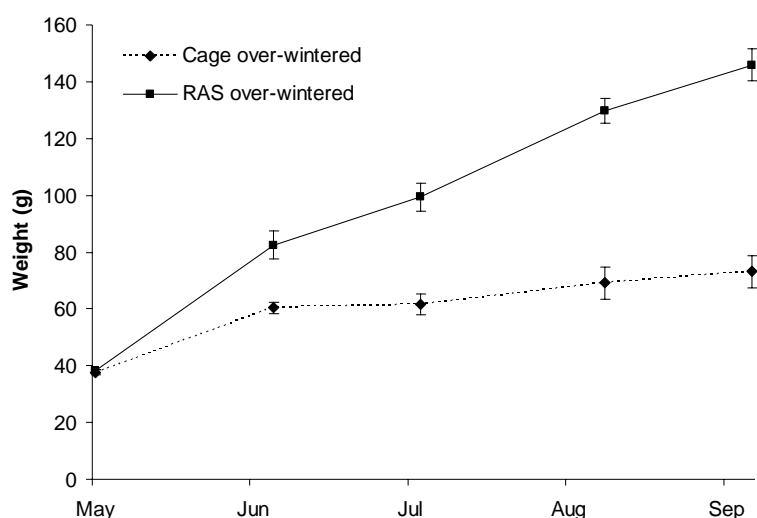
Pond water temperatures ranged from 10.7° to 21.0°C with a mean of 15.9°C, while water temperatures in the RAS ranged from 19.3° to 25.5°C with a mean of 22.8°C. Each day, one or more of five species of fish-eating birds (little black cormorant *Phalacrocorax sulcirostris*, black cormorant *P. carbo*, little pied cormorant *P. melanoleucos*, darter *Anhinga melanogaster*, and large egret *Ardea alba*) were observed in the pond containing cages. Moribund fingerlings showing signs of bird strike were observed in cages on five occasions.

It is likely stress associated with low water temperatures and the presence of predatory birds contributed to relatively poor survival in cages during winter. High survival and fast growth are clearly advantages of rearing silver perch fingerlings at elevated temperatures in the RAS during winter.

**Table 11.** Survival, initial and final weights, absolute growth rate (AGR), specific growth rate (SGR), feed conversion ratio (FCR), biomass increase and production rate of silver perch fingerlings over-wintered in cages under ambient water temperatures or in tanks in a recirculating aquaculture system (RAS) at elevated temperatures. Fish were stocked at a density of 200 fish/m<sup>3</sup>. Data are means± SD of six replicates cages or tanks. Within rows, data with different superscripts are significantly different ( $P<0.05$ ).

Parameter	Rearing facility	
	Cages	RAS
Survival %	76.8 ± 17.1 <sup>a</sup>	96.4 ± 1.5 <sup>b</sup>
Initial weight (g)	37.7 ± 1.0 <sup>a</sup>	38.1 ± 0.6 <sup>a</sup>
Final weight (g)	73.1 ± 5.7 <sup>a</sup>	145.8 ± 5.7 <sup>b</sup>
AGR (g/day)	0.28 ± 0.04 <sup>a</sup>	0.86 ± 0.04 <sup>b</sup>
SGR (%/day)	0.53 ± 0.06 <sup>a</sup>	1.07 ± 0.02 <sup>b</sup>
FCR	2.10 ± 0.31 <sup>a</sup>	2.23 ± 0.07 <sup>a</sup>
Biomass increase (kg)	3.59 ± 2.19 <sup>a</sup>	20.50 ± 0.99 <sup>b</sup>
Production rate (kg/m <sup>3</sup> )	11.13 ± 2.03 <sup>a</sup>	28.12 ± 1.04 <sup>b</sup>

**Figure 4.** Growth of silver perch fingerlings over-wintered in 1 m<sup>3</sup> cages at ambient water temperatures in an earthen pond or in 1 m<sup>3</sup> tanks at elevated temperatures in a recirculating aquaculture system (RAS). Fingerlings (mean weight, 38 g) were stocked at a density of 200 fish/m<sup>3</sup> in both cages and tanks. Data are means±SD of five replicate cages or tanks.



#### Experiment 4.2: on-growing after winter

At the commencement of the grow-out period, the mean weight of fish over-wintered in the RAS was 165.5 g, while the mean weight of cage over-wintered fish was 80.7 g (Table 12). After 129 days, there was no significant difference in survival between fish from the cages and the RAS. At harvest, the final weight, AGR, production rate and FCR of fish that had been originally over-wintered in the RAS were significantly higher than fish from the cages. The final mean weight of fish overwintered in the RAS was 426 g and above minimum market size of around 300 g, whereas the mean weight of fish over-wintered in cages was only 273 g.

**Table 12.** Survival, initial and final weights, absolute growth rate (AGR), specific growth rate (SGR), feed conversion ratio (FCR), biomass increase and production rate of silver perch stocked in 1 m<sup>3</sup> cages at a density of 100 fish/m<sup>3</sup> and reared for 129 days. Prior to stocking, the fingerlings had either been over-wintered in cages at ambient water temperatures or in tanks in a recirculating aquaculture system (RAS) at elevated temperatures. Data are means± SD of six replicate cages. Within rows, data with different superscripts are significantly different at ( $P < 0.05$ ).

Parameter	Facility used for over-wintering	
	Cages	RAS
Survival %	99.0 ± 2.0 <sup>a</sup>	98.2 ± 2.8 <sup>a</sup>
Initial weight (g)	80.7 ± 9.5 <sup>a</sup>	165.5 ± 2.8 <sup>b</sup>
Final weight (g)	272.9 ± 20.3 <sup>a</sup>	425.9 ± 12.8 <sup>b</sup>
AGR (g/day)	0.91 ± 0.06 <sup>a</sup>	1.23 ± 0.06 <sup>b</sup>
SGR (%/day)	0.59 ± 0.03 <sup>a</sup>	0.45 ± 0.02 <sup>b</sup>
FCR	2.39 ± 0.32 <sup>a</sup>	2.89 ± 0.02 <sup>a</sup>
Biomass increase (kg)	18.80 ± 2.88 <sup>a</sup>	26.43 ± 2.37 <sup>b</sup>

Production rate (kg/m <sup>3</sup> )	26.87 ± 4.83 <sup>a</sup>	42.99 ± 2.48 <sup>b</sup>
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#### Experiment 4.3: stocking densities in RAS

Mean survival ranged from 90.0 to 96.7% and was not affected by stocking density (Table 13). Growth of fish is shown in Fig. 5, and it was apparent after 66 days (July) that the growth of fish stocked at 1500 fish/m<sup>3</sup> was slower than at the other densities. Final weight, AGR and SGR were significantly higher and FCR significantly lower in fingerlings stocked at densities of 500 or 1000 fish/m<sup>3</sup> compared to those stocked at 1500 fish/m<sup>3</sup>. Production rates at densities of 1000 fish/m<sup>3</sup> and 1500 fish/m<sup>3</sup> were not significantly different and were significantly higher than at 500 fish/m<sup>3</sup>.

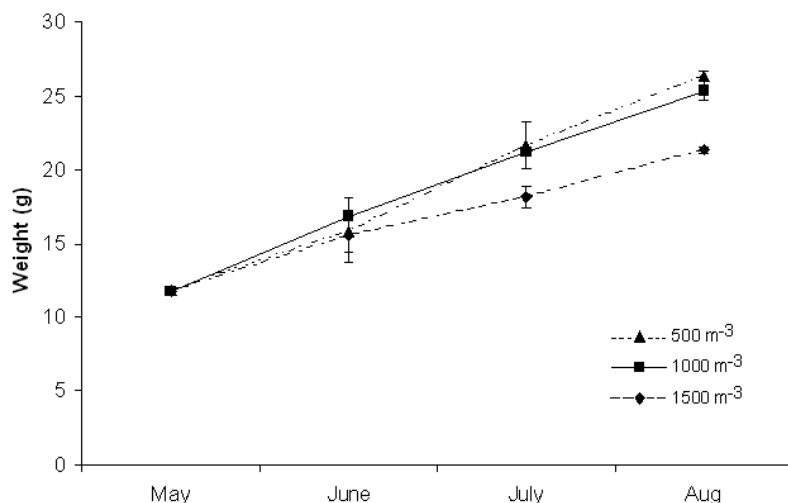
These data suggest that 1000 fish/m<sup>3</sup> is the optimal stocking density for fingerlings in the RAS.

Water temperatures in the RAS ranged from 17.3° to 25.1 °C with a mean of 22.8 °C. There was a trend towards decreasing DO (monitored two hours after feeding) over the duration of the experiment as both ambient temperatures and tank biomasses increased. The DO ranges and means at the different stocking densities were: 500 fish/m<sup>3</sup> 4.8 – 7.8 mg/L (mean 6.5 mg L<sup>-1</sup>); 1000 fish/m<sup>3</sup> 3.8 – 6.9 mg/L (5.3 mg/L); 1500 fish/m<sup>3</sup> 2.4 – 6.1 mg/L (4.3 mg/L). DO in the RAS header tank where there were no fish was 7.0 - 8.5 mg/L (7.9 mg/L).

**Table 13.** Survival, initial and final weights, absolute growth rate (AGR), specific growth rate (SGR), feed conversion ratio (FCR), biomass increase and production rate of silver perch fingerling stocked in 1 m<sup>3</sup> tanks in a recirculating aquaculture system at densities of 500, 1000 or 1500 fish/m<sup>3</sup>. Data are means ± SD of three replicate tanks. Within rows, data with different superscripts are significantly different at ( $P < 0.05$ ).

Parameter	Stocking density (fish/m <sup>3</sup> )		
	500	1000	1500
Survival (%)	90.0 ± 10.8 <sup>a</sup>	96.1 ± 1.6 <sup>a</sup>	96.7 ± 3.3 <sup>a</sup>
Initial weight (g)	11.85 ± 0.19 <sup>a</sup>	11.78 ± 0.07 <sup>a</sup>	11.67 ± 0.06 <sup>a</sup>
Final weight (g)	26.35 ± 0.31 <sup>a</sup>	25.36 ± 0.67 <sup>a</sup>	21.36 ± 0.23 <sup>b</sup>
AGR (g/day)	0.146 ± 0.003 <sup>a</sup>	0.137 ± 0.06 <sup>a</sup>	0.098 ± 0.002 <sup>b</sup>
SGR (%/day)	0.807 ± 0.014 <sup>a</sup>	0.774 ± 0.021 <sup>a</sup>	0.611 ± 0.006 <sup>b</sup>
FCR	1.93 ± 0.20 <sup>a</sup>	1.95 ± 0.07 <sup>a</sup>	2.42 ± 0.26 <sup>b</sup>
Biomass increase (kg)	5.94 ± 1.50 <sup>a</sup>	12.57 ± 0.28 <sup>b</sup>	13.49 ± 1.17 <sup>b</sup>
Production rate (kg/m <sup>3</sup> )	11.87 ± 1.55 <sup>a</sup>	24.36 ± 0.35 <sup>b</sup>	30.99 ± 1.25 <sup>b</sup>

**Figure 5.** Growth of silver perch fingerlings stocked at densities of 500, 1000 or 1500 fish/m<sup>3</sup> in 1 m<sup>3</sup> tanks in a recirculating aquaculture system and cultured for 99 days. Data are means± SD of three replicate tanks.



Our results demonstrate that over-wintering silver perch in an RAS can produce large fingerlings for grow-out in early spring. The optimal stocking density for fingerlings is 1000 fish/m<sup>3</sup>. This strategy could eliminate bird predation, reduce losses to diseases and shorten the overall culture period.

## 5. Development of methods of treating infectious diseases in cages

There was a very low incidence of pathogens and infectious diseases at GAC during the project. Some common pathogens such as the ciliate, *Trichodina* sp. and the gill fluke *Lepidotrema bidyana* were seen during routine monitoring, but neither pathogen reached epizootic levels requiring treatment. There was an outbreak of the disease Epizootic Ulcerative Syndrome (EUS) which is caused by the fungus *Aphanomyces invadans*; however, there is no known treatment for EUS and the disease rarely causes mortalities in large silver perch (Read et al. 2007). Consequently, there were no opportunities to evaluate different methods of disease control in cages.

The low incidence of pathogens and diseases was probably due to the high level of fish husbandry and health management routinely undertaken at GAC including screening of incoming water from the river, filtration of water used in tanks, quarantine procedures, use of anaesthetics and knotless nets for handling and grading fish, the maintenance of good water quality, and good nutrition (see Rowland et al. 2007).

## 6. Economic assessment of different farm and production scenarios

Outcomes of the economic modelling using *Perch Profit* are given in Table 14. Economic performance is very sensitive to survival rates, with significantly higher production costs and lower annual return and benefit-cost ratio when survival rates are 51 – 55% (Ponds A) compared to rates of 80 – 90% (Ponds B). In comparison to pond culture, the use of cages in storages increases production and revenue, lowers production costs, increases annual returns, and leads to higher internal rates of return and benefit-cost ratios. The benefit-cost ratios are higher and break-even production lower in cage culture compared to pond culture. The use of RAS to over-winter fingerlings significantly increases annual production, revenue and return due to higher survival and faster growth through winter. However, the costs of establishing and operating the RAS lead to higher production costs.

**Table 14.** Economic indicators for silver perch under different farm and production scenarios with a target annual production of 100 tonnes or more from 18 ha of storage. Ponds (A) - survival rates of 51% fingerlings, 55% grow-out; Ponds (B) survival rates 80% fingerlings, 90% grow-out; cages in storages 95% fingerlings, 98% grow-out; cages with RAS 98% fingerling and grow-out.

Economic indicator	Farm and production scenario			
	Ponds (A)	Ponds (B)	Cages in cotton storages	Cages with RAS
Annual: production (kg)	102,963	102,395	111,264	164,750
Gross revenue (\$)	1,227,324	1,220,544	1,326,267	1,963,820
Production cost (\$)	984,097	692,316	645,112	936,833
Revenue (\$/kg)	11.92	11.92	11.92	11.92
Internal rate of return (%)	19.12	34.04	57.32	54.82
Net present value (\$)	2,338,048	5,186,217	6,687,672	10,083,110
Annual return (\$)	243,228	528,228	681,154	1,026,987
Benefit-cost ratio	1.25	1.76	2.06	2.10
Break-even production (kg)	60,361	39,324	30,459	37,659

## *Outcomes*

5. Describe how the project's outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.

This research project demonstrated that the native freshwater fish silver perch can be successfully grown in floating cages. Cage culture is a flexible, adaptive form of aquaculture that facilitates the use of numerous water bodies such as irrigation storages and channels, sites that are generally impractical for intensive, commercial aquaculture. Some cotton farms have suitable water supplies and infrastructure for the integration of cage culture. Underground water supplies, particularly those with constant and relatively high water temperatures (e.g. ~ 23°C in the Hillston area of NSW) provide significant advantages of: (i) an abundant, regular supply of high quality water; (ii) water that is free of pathogens and pollutants; and (iii) temperature regimes that enable year-round growth of fish.

The project has established optimal culture conditions, and provided basic fish husbandry and farming techniques for the commercial production of silver perch in cages. Modelling highlighted that the following factors could deliver economic advantages: (i) higher survival and efficient feeding in cages compared to ponds; (ii) use of cages in established storages; (iii) higher survival and faster growth during winter at elevated temperatures in a tank-based, re-circulating aquaculture system; (iv) faster growth of cross-bred fingerlings (Murray River strain X Cataract Dam strain) through hybrid vigour (Guy et al. 2009).

The feasibility of actually integrating silver perch cage culture on cotton farms was not determined. Cage culture is an intensive animal industry that requires significant infrastructure, capital investment, and in particular, significant technical knowledge and input. It is suggested that a series of trials is needed to determine the feasibility and economic viability of integration. The trials need to account for the variation between individual cotton farms, and the different water supplies, temperature regimes, and climatic and environmental conditions on each farm and in each region. These could be objectives of a future project using on-farm trial(s) and the techniques developed in the current project.

The reduced duration of the project (3 to 2 years) and the subsequent lack of an on-farm component also prevented the achievement of other planned outcomes detailed in the original project application (transfer of technology; viable diversification for cotton farmers; significant addition to the value of irrigation water; increases in efficiency of water-use and environmental sustainability; increased production of silver perch; introduction of economies-of-scale to the silver perch industry; increased employment and wealth generation opportunities; a successful example of integration of aquaculture and agriculture).

6. Please describe any:-

a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.).

No findings leading to patents.

b) other information developed from research (eg discoveries in methodology, equipment design, etc.).

Suitable cage design (shape and size), construction materials, floatation methods and general management techniques were identified.

The new production strategy of over-wintering fingerlings is a significant advance, particularly for farms located in southern (e.g. the Riverina) or Tablelands areas where relatively long, cold winters restrict the growing seasons, subsequently extending production periods, increasing the risk of losses to infectious diseases and increasing production costs.

The good performance of silver perch fed different, commercially-available diets containing varying levels of protein, energy and lipids has application to all farmers, including those in the current pond-based industry because species-specific diets for silver perch are currently not available from feed mills or suppliers. Our project also quantified current feeding costs. This is an important component of commercial aquaculture because feed costs can constitute 20 – 40% of total production costs in silver perch culture.

c) required changes to the Intellectual Property register.

N/A

### ***Conclusion***

7. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?

This study demonstrated that silver perch is an excellent species for cage culture. Very high survival (> 95%) and good growth at high stocking densities lead to high production rates (around 50 kg/m<sup>3</sup>) with good fish health and welfare. Fish welfare

was identified as an important issue, and conditions to ensure good fish welfare were determined.

Modelling suggests that there are potentially significant economic advantages of farming silver perch in cages in cotton storages compared to the use of ponds. The results of the project, in combination with those from previous research, particularly in relation to fish husbandry, feeding, water quality, and diseases and health management, provide a sound foundation for successful cage culture of silver perch.

Cage culture of silver perch has potential for integration with cotton farming. Fish could be an additional crop that adds value to a farm and improves water-use efficiencies without requiring an increased water allocation – “more crop per drop”. Integration with freshwater aquaculture would be an environmentally-responsible diversification for established irrigation farms. However, farms must have suitable facilities and infrastructure for aquaculture, and farmers must be prepared to make a commitment to an intensive animal industry.

### *Extension Opportunities*

8. Detail a plan for the activities or other steps that may be taken:

(a) to further develop or to exploit the project technology.

The potential for integration of aquaculture with cotton and other irrigation industries requires further work including on-farm trials to determine the feasibility of integration, and the economic viability under practical farming conditions.

To further develop cage culture technology for use on cotton farms, the following steps are recommended:

- (i) produce a user-friendly, farmer-orientated manual with explicit advice on the cage culture of silver perch;
- (ii) select appropriate cotton farm(s) for practical, on-farm trials;
- (iii) run trials with daily, hands-on supervision by an applied aquaculture scientist/technician with experience in running large-scale trials or experiments;
- (iv) evaluate the performance of fish;
- (v) evaluate economic performance;
- (vi) analyse fish for organoleptic properties (smell, taste);
- (vii) evaluate chemical residues and other potential contaminants;
- (viii) review results and revise fish husbandry and management procedures, cage design, water quality management, farm operation and other factors where appropriate.

(b) for the future presentation and dissemination of the project outcomes.

The publications arising directly from the project are listed below, as well as relevant papers and reports from other concurrent projects at GAC with direct application to silver perch cage culture.

It is proposed to apply to the Cotton CRC/CRDC for funds to prepare and publish a silver perch cage culture manual after completion of the associated PhD in June 2010.

Talks will be presented at conferences in 2010, including Australasian Aquaculture 2010 in Hobart in May, and the 15<sup>th</sup> Annual Cotton Conference in August.

(c) future research.

Suggested future research topics are:

- (i) on-farm trials;
- (ii) aeration strategies for cage culture;
- (iii) cage design – effects of partial and complete cover;
- (iv) health management strategies for cage culture;
- (v) nutrients in fish effluent and possible advantages for terrestrial crops;
- (vi) toxicity of chemicals and residues of chemicals in cultured fish on cotton farms.

### ***Publications***

9. A. List the publications arising from the research project and/or a publication plan, including publications linked to the project and published in 2007 - 2009.

(NB: Where possible, please provide a copy of any publication/s)

Scientific journals (papers in review or published during the course of the project, as well as papers and reports from other concurrent projects at GAC with direct application to silver perch cage culture)

Foley, D.A., Rowland, S.J., Wilson, G.G., Winters, P., Nixon, M. and Mifsud, C. (in review). Performance of silver perch (*Bidyanus bidyanus*) fed commercially-available diets in cages.

Foley, D.A., Rowland, S.J., Wilson, G.G., Winters, P., Nixon, M. and Mifsud, C. (in review). Cage design for silver perch (*Bidyanus bidyanus*).

Foley, D.A., Rowland, S.J., Wilson, G.G., Winters, P., Nixon, M. and Mifsud, C. (in review). Effects of stocking density on the performance and welfare of silver perch (*Bidyanus bidyanus*) in cages.

Foley, D.A., Rowland, S.J., Wilson, G.G., Winters, P., Nixon, M. and Mifsud, C. (2009). New production strategy for silver perch (*Bidyanus bidyanus*); over-wintering fingerlings in a tank-based recirculating aquaculture system. *Aquaculture Research*, published on-line December 2009.

Guy, J.A., Jerry, D.R. and Rowland, S.J. (2009). Heterosis in fingerlings from a diallel cross between two wild strains of silver perch (*Bidyanus bidyanus*). *Aquaculture Research* **40**, 1291-1300.

- Guy, J.A., Johnston, B. and Cacho, O.J. (2009). Economic assessment of an intra-specific cross of silver perch (*Bidyanus bidyanus* Mitchell) for commercial farming. *Aquaculture Economics & Management* **13**, 328-343.
- Rowland, S.J. (2009). Review of the aquaculture research and development of the Australian freshwater fish silver perch, *Bidyanus bidyanus*. *Journal of the World Aquaculture Society* **40**(3), 291-324.
- Rowland, S.J., Mifsud, C., Nixon, M., Read, P. and Landos, M. (2009). Use of formalin and copper to control ichthyophthiriosis in the Australian freshwater fish silver perch (*Bidyanus bidyanus* Mitchell). *Aquaculture Research*, **40**, 44-54.
- Mifsud, C. and Rowland, S.J. (2008). Use of salt to control ichthyophthiriosis and prevent saprolegniosis in silver perch. *Aquaculture Research* **39**, 1175-1180.

#### Conference Abstracts and Proceedings

- Foley, D.A. (2009). The welfare of silver perch in cages. University of New England, Untamed Post-graduate Conference, National Marine Science Centre, Coffs Harbour, July 2009.
- Foley, D.A. (2009). Silver perch cage culture. Cotton Catchment Communities CRC Science Forum, Narrabri, August 2009.
- Foley, D.A., Rowland, S.J., Wilson, G., Boulton, A., Nixon, M., Winters, P. and Mifsud, C. (2008). Cage culture of silver perch *Bidyanus bidyanus* on cotton farms. Australasian Aquaculture International Conference and Trade Show, Brisbane, August 2008.
- Foley, D.A., Rowland, S.J. and Wilson, G.G. (2008). The cage culture of silver perch on cotton farms. Cotton Catchment Communities CRC Science Forum, Narrabri, August 2008
- Guy, J.A., Mifsud, C., Nixon, M., Winters, P., Foley, D. and Rowland, S.J. (2008). Strategies for improved growth in silver perch *Bidyanus bidyanus* – practical considerations for industry. Australasian Aquaculture International Conference and Trade Show, Brisbane, August 2008.
- Rowland, S.J. (2008) (Abstract). Review of aquaculture research and development of silver perch *Bidyanus bidyanus*. Australasian Aquaculture International Conference and Trade Show, Brisbane, August 2008.
- Foley, D.A. Rowland, S.J. and Wilson, G.G., (2007) The cage culture of silver perch on cotton farms University of New England, Untamed Post-graduate Conference, Coffs Harbour, July 2007.
- Foley, D.A. and Rowland, S.J. (2007). The cage culture of silver perch on cotton farms. Cotton Catchment Communities CRC Science Forum, Narrabri, Aug 2007.

#### Departmental and technical publications

- Read, P., Landos, M., Rowland S.J. and Mifsud, C. (2007). *Diagnosis, Treatment and Prevention of the Diseases of the Australian Freshwater Fish Silver Perch (Bidyanus bidyanus)*. NSW Department of Primary Industries, Orange.
- Rowland, S.J., Landos, M., Callinan, R.B., Allan, G.L., Read, P., Mifsud, C., Nixon, M., Boyd, P. and Tully, P. (2007). *Development of a Health Management Strategy for the Silver Perch Aquaculture Industry*. NSW Department of Primary Industries – Fisheries Final Report Series No. 93. NSW Department of Primary Industries, Cronulla.

B. Have you developed any online resources and what is the website address?

No.

## ***Part 4 – Final Report Executive Summary***

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Aquaculture is the fastest growing food-producing industry in the world, and currently contributes nearly 50% of total fisheries production. It has great potential in Australia because of our limited wild fisheries, over-exploitation of some fisheries, and importation of large quantities of fish. Freshwater fish contribute around half the global aquacultural production. The native freshwater fish silver perch (*Bidyanus bidyanus*) has significant potential, and R&D by the NSW Government has provided a technical basis for industry development. Although around 500 tonnes are produced annually in ponds, the industry has not realised its potential to date due to difficulties with pond management, slow growth and losses to bird predation and infectious diseases during winter, the high cost of feeding and the small scale of most farms. Cages are easy to manage, facilitate efficient feeding, and protect fish from birds. Cages also enable the use of water bodies such as storages on cotton farms that are otherwise unsuitable for commercial aquaculture. Water for irrigation is a substantial and recurring cost to cotton farmers, and freshwater aquaculture may offer an opportunity to add value to the water and improve water-use efficiencies.

This study demonstrated that silver perch is an excellent species for cage culture. High survival and good growth at high stocking densities lead to high production rates. Optimal stocking densities based on fish performance and welfare were identified for different production phases (e.g. 100 fish/m<sup>3</sup> for grow-out to > 500 g). Commercially-available diets with 30-45% protein and 10-17 MJ/kg energy were suitable, and the cost-effectiveness of feeding was determined principally by purchase price. A new strategy of over-wintering fingerlings at elevated temperatures in a tank-based recirculating aquaculture system (RAS) significantly improved survival and growth, and shortened the overall culture period.

Modelling suggested that there are significant economic advantages of farming silver perch in cages compared to pond culture, and that annual production and revenue would be enhanced with the use of RAS for over-wintering fingerlings. Farms in cotton growing areas from Hillston in the south to Emerald in the north would have suitable water temperature regimes for silver perch. Optimal growth occurs at 18° - 30°C, and shorter growing seasons in southern regions may be off-set by the use of “warm” underground water and/or over-wintering fingerlings in RAS or similar systems. The following are essential for the integration of fish culture on cotton farms: permanent supply of high quality, surface and/or underground water; water storages (> 2m deep) for fish culture; 3-phase power for aeration; buildings and infrastructure for quarantine and purging, laboratory and offices, storage of feed and equipment; staff with a high level of technical knowledge to manage all aspects of fish growth, production, health and welfare.

Cage culture of silver perch offers an opportunity to add value to irrigation water, and provide cotton farmers with “more crop per drop” without increasing water allocation. Although optimal conditions were identified, the feasibility and economic viability of integrating silver perch cage culture needs to be evaluated using trials under practical farming conditions on cotton farms, in different regions and over a number of years.

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