Increasing Water Use Efficiency through Integrated Agri-Aquaculture

Peter Rawlinson (Fisheries Division)
Department of Natural Resources and Environment, Victoria, Australia

ABSTRACT
This paper investigates the integration between freshwater cage culture and irrigated agricultural activity in order to determine the relative benefits and investment requirements of installing small, medium and large scale fish farm operations into traditional farms. Through providing a growing medium for finfish, water can be used for the purpose of aquaculture prior to its customary irrigation use. In doing so extra nutrients in the form of organic metabolic wastes are also capable of being introduced to the farm in the form of fertiliser and contributing to cost reductions. The paper concludes that cage culture integration supplements the traditional gross margins expected from traditional agriculture and that capital payback is less than 5 years.

Keywords: Agri-aquaculture, aquaculture economics, caged fish culture.

1. INTRODUCTION

This paper builds on research carried out for the Rural Industries Research and Development Corporation (RIRDC) on Integrated Agri-Aquaculture Systems (Gooley,G.J.,2001). The RIRDC research investigated the impact of integrating small to medium sized aquaculture systems (intensive and extensive) to traditional irrigated agriculture (including dairy, horticulture (stonefruit and vegetables), viticulture, rice and cotton).

This paper extends the analysis by adopting a more sophisticated harvesting strategy in terms of discreet product ranges (500 – 700g). Since the RIRDC investigations there have also been changes in major variables including product sale price and feed costs. Further investigations are also being carried out by the Marine and Freshwater Resources Institute over the next 3 years which will construct model farms in order to obtain optimum operating specifications (see Appendix A for more information regarding this project).

2. IRRIGATED AGRICULTURE IN AUSTRALIA

2.1 Irrigated Water Use

Efficient water use is becoming increasingly important for irrigated industries within Australia. Limited availability of water, rising costs and environmental issues such as salinity, nutrient runoff, and erosion has led to this notion of improving water-use efficiency. In the past some irrigation industries have been able to better use their water resource more effectively than others by adopting more efficient processes, subsequently realising more profitable returns per megalitre (ML) used. A large proportion of sectors however have been unable to effectively gain more for their megalitre.

Irrigated agriculture (gross value $7.25 billion) is the largest net user of water, totalling 15.5 million megalitres or 70% of net water use in Australia. During the period 1993/94 to 1996/97 total net water consumption has risen by 19%. A large proportion (over 95%) of this is accounted for by the agriculture sector. Irrigated pastures covered the largest area of irrigated land, accounting for approximately 935,000 hectares or 45% of all irrigated lands. The major component of this is for livestock, pasture and grains with 46% of the water used self extracted (Australian Bureau of Statistics, 2000).

Of the six sectors under study in the proceeding analysis (dairy, horticulture – vegs & fruit, rice, cotton and viticulture) the rice sector consumes the most water per hectare (10.8 megalitres) with each average farm consuming over 3,000 megalitres per year. The viticulture sector consumes the next highest water but the farm sizes are considerably smaller so overall average farm consumption is much less. Table 2 below outlines the consumption of water by the average farm.

Agricultural Sector	Land use (ha) irrigated	Water Use (ML)	ML per ha	Average farm area (ha)	ML Per farm
Dairy [1]	241,650	1,884,870	7.8	75	585
Horticulture (Veg) [3]	88,782	634,913	7.2	10	72
Horticulture (Fruit) [2]	82,316	703,878	8.5	10	85
Rice [2]	152,367	1,643,306	10.8	300	3,240
Cotton [2]	314,957	1,840,624	5.8	400	2,320
Viticulture [2]	70,248	648,574	9.2	18	167

Table 1: Land and Water Use by Sector

Notes:

1. Armstrong et al (1998).
2. ABS Water Account (4610.0), p. 15, Table 1.13, 1993-94 to 1996-97)
3. NSW Dept. of Agriculture (www.agric.nsw.gov.au)

2.2 Sectoral Gross Margins

Gross Margins (GM) are defined as the gross income derived from farming enterprise minus the variable costs (those costs that are dependent on the output or size of the farm). Usually the margin is expressed in relation to the most limiting resource (eg. land area or h.a. and water or megalitres).

Agricultural Sector	Gross margin Per ha ($)	Gross margin Per ML ($)
Dairy	1,435	184
Horticulture (Veg) [1]	3,825	630
Horticulture (Fruit) [2]	13,237	1,927
Rice [3]	1,192	92
Cotton [3]	1,738	238
Viticulture [4]	14,010	2,802

Table 2: Gross margins by Agricultural Sector

Notes:

1. Horticultural gross margins from NSW Agriculture (averaged from Tomatoes, Potatoes, Capsicum, Carrots, Onions, Asparagus, Broccoli and Zucchini)
2. Downs,A. (1999), (Loddon / Murray region). Stone fruit
3. NSW Dept. of Agriculture
4. Downs,A. (1999), (Loddon / Murray region).

3 INTEGRATED AGRI-AQUACULTURE SYSTEMS (IAAS) IN AUSTRALIA

3.1 Advantages of IAAS

Integrated agri-aquaculture systems (IAAS) are farming systems which commercially link aquaculture to irrigated farming systems under a common business farming management objective. The objective of this linkage is to optimise the economic and environmentally sustainable use of existing energy, resources and infrastructure (Gooley G.J. 2000)

The advantages of IAAS over conventional farming systems include:

- Increases in farm productivity without any net increase in water consumption.
- Farm diversification into higher valued crops, including aquatic species.
- Re-use of otherwise wasted on farm resources (capture and re-use of nutrients and energy).
- Reduction of net environmental impacts on semi-intensive farming practices.
- Net economic benefits by offsetting existing farm capital and operating expenses.

There are several ways that aquaculture can be integrated into the irrigated farming systems (Gooley G.J. 2000) These include:

(i) use of irrigation and nutrient rich waste water, first for aquaculture production (cages) and secondly for conventional irrigation use on land-based crops and pastures

(ii) concurrent/simultaneous use of water for aquaculture and crops.

(iii) aquaculture use of water subsequently used for hydroponics (aquaponics)
(iv) aquaculture use of shallow saline ground water, increasingly associated with irrigation areas, which is pumped and stored for evaporation or other forms of disposal

3.2 Extensive Cage Culture in Irrigation Ponds

This investigation will concentrate on the first type of integrated use, that is, IAAS scenarios that use ponded irrigated water to first grow fish and then irrigate with nutrient added (fish and feed waste) water. Three scales of production will be investigated: 1 hectare (14 tonnes), 2 hectare (28 tonnes) and 5 hectare (70 tonnes). These scenarios will possible result in a savings to the whole farm system in terms of fertiliser savings. These savings will be estimated and added to the IAAS margin impact.

Cage culture operation in south-eastern Australia would typically be undertaken on a seasonal basis to coincide with the irrigation season within the warmer months of the year. Accordingly the growout season would be limited to about 7 months (October to April) under suitable ambient water temperatures, thus dictating the need for use of advanced sized seedstock (150g).

In this analysis the ponds are assumed to already exist for irrigation purposes, and therefore require no extra capital costs other than three phase power to operate mechanical aerators. As for the intensive system analysis, each of the cage culture systems will have no extra labour or water costs imposed as these are considered already part of the irrigation farm enterprise.

The development of extensive cage culture systems by utilising existing irrigation infrastructure (water body and pumping equipment) has the benefit of lowering capital set-up costs. Advantages of such systems are that they are versatile facilities, which can be adapted to most locations where suitable water supplies exist. Minimal capital outlay and technology are required with the size of the operation being easily changed.

Threats of predation from birds are lowered by cage culture, monitoring is made more manageable, feed is also utilised more efficiently and harvesting made easier. Perhaps the greatest benefit from cage culture is they ensure the final product is handled as little as possible.

3.3 Scenario Parameters

Growout cages within the system are 20m^3 capacity, with a maximum growout stocking density of 20 kg/m^3. Cages are anchored to, and accessed *via* a floating walkway. The ponds are assumed to already exist and require no extra capital costs. Each of the systems will have no extra labour costs imposed or water costs as these are considered already part of the farm enterprise. The Marine and Freshwater Institute (MAFRI is the State Fisheries Agency : Fisheries Division, Department of Natural Resources and Environment) is currently investigation the dynamics of farm diversification. The study will set up model farms in order to ascertain optimal operating procedures. See Appendix A for more detail.

All systems are supplied with supplementary mechanical aeration, with fish husbandry (feeding, monitoring, harvesting, processing *etc.*) undertaken by existing farm staff or purchaser of fish. The analyses for each of the three systems make the following additional capital and operational/variable costing assumptions:

- Growout cage (20 m^3 capacity) costs @ $2,000 each.
- Cages occupy max. 5% of surface water area (*i.e.* 25 cages/ha) and there is a min. 7.5% daily water exchange through the cages; discharged water from the pond is used for irrigation of crops/pasture. (1 hectare @ 20M/L @ 1.5M/L per day is equivalent to 534 M/L per year).
- Capital cost of putting in 3 phase power to ponds @ nominal $10,000.
- Mechanical aerator costs @ $750 each with 4 units/ha (or $3,000/ha total cost).
- Growout stocking density @ 20 kg/m^3 (final maximum density of cages prior to harvest).
- Cost of advanced (fully weaned) seedstock @ $2.50/150g stocker. (approximately 50% of total costs)
- Grow out period 7 months (stocking in October and harvesting throughout period), with final weight of fish @ 350g and 500g.
- Mortality of 1%/month over growout period.
- Feed costs @ $1.50 per kilo (typically over 35% of total variable costs).

- Operational cost of aeration (electricity) @ $24/day/ha (continuously operational); approximate total cost of $6,000/ha/annum.
- Cost of pumping (electricity) $600/ha/annum.
- Stock insurance @ 4% of turnover/annum.
- Repairs and maintenance @ nominal $1,000/ha/annum.
- Fees and licence charges @ nominal $2,000 per year.
- Farm gate sale price of fish (whole) @ $12.00/kg.

3.4 Fish Stocking and Forward Selling

The species that will be used to construct scenarios for these two aquaculture systems will be Murray Cod (*Maccullochelli peelli peelli*) which is becoming a premium species for aquaculture in Australia, especially Victoria. In 2001 trials were carried out by the Marine and Freshwater Resources Institute (MAFRI) which indicated that stocking densities of over 40 k/g per cubic metre could be obtained with little mortality and a grow out period to plate size (350g – 500g) in 7 months from an intial stocking size of 150 grams. Growth curves have been constructed from these trials growth studies carried out by the Marine and Freshwater Resources Institute (MAFRI) This was despite previously held views that the species were territorial and aggressive and therefore unsuitable to high density stocking. (Ingram,B. 2000).

Fish growth is done over the summer months from October to April. Fish are stocked at 150 grams and grow through to product size between 350gram and 500gram and sold chilled to contractor who collects product from farm gate. Harvesting is carried out in November, December, February and April. Fish are again restocked in October.

The capacity to co-operate whereby the seller of the stockers also buys back the final product at a predetermined price (forward selling) has the benefit of that the stockers have been age graded and that only the fast growers are made available to the IAAS farm. The farm is stocked with two growth cohorts 25% of the fastest growers and 75% of the average growers. The fast growers reach their maximum product targets in 3 months while the average growers reach their maximum product target in 7 months.

4. FISH PRODUCTION GROSS MARGINS

4.1 Introduction

The gross margins generated by the production of fish will be examined using the software package *AQUAFARMER*™ to analyse each of the production scenarios outlined above. Each scenario assumes no additional labour costs. The capacity of each of the scenarios to support extra labour costs can be gauged from the annual earnings generated (defined as Earnings before Interest, Tax and Depreciation or EBITD).

The IRR is calculated on three risk scenarios. Risk scenarios 1 and 2 show a learning curve in the first years and a one in ten stock loss of 50% due to disease or other natural disaster. The risk scenarios are as follows:

- **Risk 0**: Optimum harvest with no risk (any stock loss is insured)
- **Risk 1**: 75% production in year 1, 85% in year 2
- **Risk 2**: 60% production in year 1, 75% in year 2 and 85% production in year 3.

Table 4 below details the estimated annual production capacity and associated capital costs and IRRs for each system and risk scenario being evaluated. Gross margins in absolute terms, as well as in terms of a ratio of water (ML) used, are summarised in Tables 5 and 6 respectively for each of the specified production scenarios at zero risk (R0).

Pond Area	Annual Production	Capital Costs [1]	No. of Cages	IRR (%) R0/R1/R2
1 hectare	14 tonnes	140,000	25	21/13/5
2 hectare	28 tonnes	270,000	50	21/12/3
5 hectare	70 tonnes	650,000	125	28/18/11

Table 3: Capital costs and IRR.

Notes:
1. Includes purchase of fingerlings in Year 0 (1 ha = $73,000; 2 ha = $150,000; 5 ha = $375,000).

Pond Area	Revenue	Variable costs [1]	Gross Margin	EBITD	Capital Payback (Y)
1 hectare	162,000	137,000	25,000	22,000	4
2 hectare	334,000	279,000	55,000	39,000	4
5 hectare	836,000	702,000	134,000	128,000	3

Table 4: Summary of Gross Margins and EBITD for selected cage/pond systems at zero risk (R0).

Notes:
1.Includes aeration costs (electricity), maintenance, stock insurance, feed, juveniles for following year, pumping costs.

Pond Area	M/L per year	GM Per M/L
1 hectare	534	$47
2 hectare	1,068	$51
5 hectare	2,670	$50

Table 5: Summary of Gross Margins/ML for selected cage/pond systems at zero risk (R0).

5. FISH EFFLUENT AND FERTILISER SUPPLEMENTATION

The nutrient by-product of fish production as part of an IAAS enterprise provides benefits for farmers through reduced fertiliser applications on crops and pasture. In the following model, quantities of phosphorous present in the effluent of respective production regimes are estimated along with their impact on farm fertiliser budgets for various irrigated agricultural sectors suitable for IAAS application.

In a cage culture system the storage pond is assumed to exchange on average 1.5 ML/day/ha of pond surface area during any one irrigation season/fish growout period. This water exchange is assumed to be for routine, operational irrigation purposes in the first instance. However it is also necessary to ensure adequate fish waste removal and maintenance of water quality for cage culture fish production in the pond. A nominal economic value of Ph is estimated at $2/kg (current approximate retail value), and it is assumed that the aquaculture effluent is used for irrigation purposes and can achieve a cost offset against the existing variable farm costs of inorganic fertiliser application.

Estimates of quantity and value of Ph discharged to the pond and subsequently made available for irrigation purposes to offset existing on-farm fertiliser application costs are summarised for each production scenario in Table 7 at zero risk (R0). Using a simple mass balance model, approximately 31.2 kilograms of Ph per tonne fish produced per year is produced in waste water(Gooley *et al.* 2001b).

Annual Production	Kg of P in Effluent	$ Value of P in effluent
14 tonnes (1 ha)	436	872
28 tonnes (2 ha)	874	1,748
70 tonnes (5 ha)	2,184	4,368

Table 6: Effluent P production of cage culture systems.

6. VIABILITY OF "WHOLE FARM" IAAS OPERATION

In all cases GMs on a per ML basis are much higher than for irrigated agriculture sectors, suggesting that intensive aquaculture use can provide an increased economic return for the same amount of water use when compared with irrigated agriculture.

On a stand-alone basis, IRRs for the three IAAS options in the present study are commercially viable at nil risk and second risk levels. The 5 hectare operation is viable at all risk levels. The average GM per M/L for each of the farms investigated is in the order of $48.00. The relationship between the gross margins of traditional farming practices and fish farming can be seen in table 7.

Agricultural Sector	Gross margin Per ML Ag. ($)	Gross margin Per ML Fish as % of Ag.
Rice	92	52.2
Dairy	184	26.1
Cotton	238	20.2
Horticulture (Veg)	630	7.6
Horticulture (Fruit)	1,927	2.5
Viticulture	2,802	1.7

Table 7: Comparison of Gross Margins per M/L

However when the economic benefits of water and nutrient (Ph) re-use are factored into the GM analysis on a 'whole-of-farm' basis, the results provide another perspective on the economic viability of IAAS application.

The increase in economic benefits of IAAS to irrigated agriculture on a water consumption basis are in part directly proportional to the amount of water used by agriculture, and what percentage can be used by the aquaculture operation first. Taking the average M/L per agricultural farm type as an indication of the amount of water used (see table 2) then the 1 hectare fish farm integration is best suited to the dairy sector, while the 5 hectare integration is best suited to the rice and cotton sectors. The horticulture and viticulture sectors would have to be larger than the average to take advantage of the benefits of a 1 hectare integration, or they could downscale the integration to fit their water usage.

Tables 8 and 9 show the outcome on "whole of farm" gross margins as the combined affects of increased cashflow and savings increase the overall return to the average farm.

Annual Production	Gross Margin (Fish)	Extra Revenue (Fertiliser)	Total Gross Margin
1 hectare	$25,000	$872	$25,872
2 hectare	$55,000	$1,748	$56,748
5 hectare	$134,000	$4,368	$138,368

Table 8: Gross Margins with fertiliser savings (F) for semi-intensive, cage-based pond IAAS.

Principle Activity	Gross Margin [1]	1 ha % increase	2 ha % increase	5 ha % increase
Dairy	$107,600	24	53	128
Hort.(V)	$45,400	57	125	304
Hort.(F)	$163,800	16	35	84
Rice	$298,000	7	19	46
Cotton	$552,000	5	10	25
Viticulture	$468,000	6	12	30

Table 9: Increase in 'Whole-of-Farm' Gross Margins due to semi-intensive, cage-based pond IAAS.

Notes:
1. Gross margin per average farm (principal activity).

7. CONCLUSIONS

On a conceptual basis this analysis shows that opportunities exist for the Australian irrigated agriculture industry to integrate various forms of aquaculture systems onto existing farms in order to increase profitability. Such benefits are best evaluated on a 'whole-of-farm basis which factors in not only increased revenue from fish production, but also synergies with other aspects of farm enterprise, *viz*. multiple water use and nutrient/waste re-use. Indeed, the integration of aquaculture with irrigated farming needs to be viewed essentially as diversification of the farm business into another relatively high value crop, for which there are inherent operational efficiencies and associated cost savings.

The specific economic merits of one aquaculture system or species over another will also depend on the inherent characteristics of the different systems and species and the suitability of each to conform with the specific objectives and targets of the broader business plan, such as:

- Length of grow out time to market size,
- Seedstock costs,
- Stocking density,
- Efficiency of feed conversion,
- Survival rates, and
- Market price/demand.

Cost-effective options for integration of aquaculture include the use of intensive and semi-intensive production systems of the type evaluated in this paper, although other system designs also exist and are likely to be equally feasible in certain circumstances. Furthermore, although Murray cod is used in this paper for demonstration purposes, many other species are considered suitable for IAAS production. Indeed, in many cases the profitability of various IAAS system and species combinations, other than those described in this paper, is likely to exceed the financial projections made here.

A 1 hectare fish farm integration (14 tonnes) is suitable for the average Dairy farm and larger than average Horticulture and Viticulture. The 2 hectare (28 tonnes) and 5 hectare (70 tonnes) integrations are best suited for Cotton and Rice ventures.

All integrations deliver between $47 to $51 extra gross margin per M/L to the farm which represents up to 52% of principle farm gross margin return (eg Rice)

Ultimately the choice of IAAS design (and species) will vary from farm to farm, depending on key criteria such as ambient climatic conditions, water supply, availability of suitable infrastructure, market demand, availability of human resources and associated skills, acceptable risk and preferred revenue targets, and compatibility with existing farm operations/business. These criteria vary little from stand-alone aquaculture suitability criteria. As always therefore, aquaculture investors, be they IAAS compliant or otherwise, need to undertake appropriate financial due diligence as a necessary precursor to preparation of a comprehensive business plan prior to committing themselves.

Profitable IAAS investment in Australia is ultimately about making correct business decisions at the 'whole-of-farm' level to address the triple bottom line imperatives for Australian irrigated agribusiness of social, economic and environmental sustainability.

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Appendix A

Ecologically Sustainable Agriculture Through Aquaculture Integration

Project No. 05108
Ecologically Sustainable Agriculture Initiative
Department of Natural Resources and Environment.

1. Background

Aquaculture is often overlooked as an option when farmers are considering diversification as the industry is still relatively small in Victoria and farmers often have no direct experience of the systems and species options available. There are many similarities between agriculture and aquaculture systems, both relying on basic inputs such as land, water, nutrients and sometimes sunlight to produce marketable commodities. These similarities can be exploited to increase the efficiency of resource use by linking the two systems so that the outputs of one system can be used as an input to the other. The linking of agriculture and aquaculture is formally known as Integrated Agri-Aquaculture Systems (IAAS).

IAAS have developed in various forms in other parts of the world, notably Israel and Asia. Israeli models of IAAS are based on the need to obtain maximum economic return from very limited water resources whereas the Asian experience is driven by the need to utilise all available land, water and nutrient resources for subsistence. The key driver behind IAAS in Victoria and Australia is the more efficient and sustainable utilisation of water and other natural resources in irrigated farming systems.

The aquaculture program at the Marine and Freshwater Resources Institute has been involved in R&D into IAAS for a number of years. This work has been funded by a number of different sponsors including Fisheries Victoria (Department of Natural Resources and Environment - DNRE), Rural Industries Research and Development Corporation (RIRDC), Murray-Darling Basin Commission (MDBC), Australian Centre for International Agricultural Research (ACIAR) and more recently the Agriculture Division of DNRE. The research has shown that various IAAS models are technically feasible under Australian conditions, specifically:

- Multiple water use in existing irrigated farm enterprises (in dams, ponds, tanks or channels);
- Value-adding otherwise unproductive resources e.g. inland saline water.
- Utilisation of aquaculture wastewaters for hydroponics, or “Aquaponics”.

Environmental benefits of IAAS are site specific, depending on the model adopted, but include the re-use of otherwise wasted resources (water, nutrients, energy), rehabilitation of unproductive land (e.g. inland saline aquaculture), and improvements in on-farm bio-diversity through the re-introduction of ponds onto farms. Although the technical feasibility of the concept of IAAS has been demonstrated through the R&D that has been carried out to-date there is a clear need to prove the concept at a commercial scale. This will allow actual efficiencies in water, nutrient and infrastructure use to be documented and the environmental and socio-economic benefits quantified.

2. Project Objective

The objective of this project, funded by the Ecologically Sustainable Agriculture Initiative (ESAI) of the Department of Natural Resources and Environment (DNRE) is to develop, promote and coordinate commercial-scale IAAS practice within Victoria in order to enhance water re-use and recycling in agricultural systems. The project will run from February 2002 to June 2005 and aims to extend and ultimately commercialise the concept of IAAS through co-investment with industry.

The project will initially aim to increase awareness within the farming community of aquaculture as a viable and sustainable farm diversification option. It will facilitate access of the farming community to information on IAAS through DNRE extension services. The project will also aim to evaluate the opportunity presented to Victorian agriculture through IAAS at a commercial scale by facilitating the establishment of one or more case study/demonstration sites. These demonstration sites will be monitored to quantify environmental benefits of IAAS, particularly in the area of natural resource utilisation

3. Project Timelines/Milestones

This is a four-year project commencing in February 2002. A sector analysis will be conducted in 2002 to identify constraints to farmers diversifying into aquaculture as well as training and skill requirements. An Expression of Interest process will be run during 2002 to identify potential industry co-investors to develop demonstration sites. It is hoped that the demonstration sites will be commissioned by June 2003 and fully operational by December 2003. The demonstration sites will be monitored until May 2005 to evaluate environmental and economic benefits of IAAS.

4. Project Outcomes

The major outcomes of this project will be:

- Establishment of one or more commercial case study/demonstration sites designed and managed according to best practice models. These case study sites will be funded by industry co-investment, with Government investment in the form of technical support and R&D.
- A fully documented assessment of the environmental and socio-economic cost-benefits of IAAS development at the case study/demonstration sites. Monitoring of water, nutrient and salinity will be undertaken at each site to evaluate key environmental performance indicators for IAAS.
- Development of an industry development strategy so that the environmental and productivity benefits of IAAS can be adopted by others in Victorian agriculture.