MANAGING ENVIRONMENTAL IMPACTS FROM INLAND SALINE AQUACULTURE

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ABSTRACT

Aquaculture using saline groundwater may provide a productive use for salt-affected land that can no longer support traditional agricultural enterprises, and may also be used to defray part of the cost of existing surface and subsurface water management systems. Aquaculture may also, however, have its own environmental impacts, and these must be managed if an inland saline aquaculture industry is to develop. We surveyed farmers and resource managers, and monitored water quality parameters from different culture systems, to determine potential environmental impacts from the culture of rainbow trout on salt-affected farms in Western Australia. Four types of culture units have been used to grow trout: farm dams (66% of total units), constructed ponds (18%), natural lakes (9%) and tanks (7%). Comparison of water flow characteristics among these different culture units showed that they are likely to produce similar environmental impacts. Potential environmental impacts from inland trout farming are: changes in water quality within the production system, due to the accumulation of nutrients or other chemicals; discharges of nutrients and other chemicals into natural waterways; the impact of fish on aquatic communities in the production system; escape of fish into natural waterways; clearing of vegetation; use of groundwater; disposal of groundwater. The regulation of environmental impacts in inland saline aquaculture is complicated by the number of different government agencies involved and by the small scale of the industry. This suggests that economic instruments, facilitated by the voluntary development and application of an environmental management system, might be a better management tool than regulation. We use a model of nutrient cycling in inland trout farms to demonstrate the benefits to farmers of managing nutrient wastes. Demonstrating the benefits of managing other environmental impacts requires further research to quantify the marketing advantages of an environmental management system.

THE ROLE OF AQUACULTURE IN MANAGING SECONDARY SALINISATION

Secondary salinisation, caused by rising water tables as a consequence of irrigation or land clearing, is a major problem throughout the arid and semi-arid regions of the world. In Western Australia, where dryland (rather than irrigation) salinity is most evident, management strategies fall into three categories (Pannell 2001):

- Limiting groundwater recharge through planting deep-rooted perennial plants, and protecting remnant native vegetation (avoiding further salinisation).
- Preventing groundwater discharge through engineering solutions, such as pumps and drains (repairing existing salinisation).
- Developing new productive uses for salinised land (living with salinisation).

Aquaculture in pumped or intercepted saline groundwater is receiving increasing attention in Australia and other parts of the world (Forsberg *et al.* 1996; Samocha *et al.* 1998; Smith and

Barlow 1999). The importance of inland saline aquaculture is that it may not only provide a productive use for salinised land that can no longer support traditional agricultural enterprises, but it is also capable of being integrated into surface and subsurface engineering solutions, thereby defraying at least part of the cost of such schemes.

The long-term outlook for aquaculture products is bright. Aquaculture has been the world's fastest growing food production system for the past decade, with an average compound growth rate of 9.6% per year since 1984, compared with a growth of 3.1% for terrestrial livestock meat production and 1.6% for capture fisheries production (Tacon 1998). Australia has mirrored this global trend. Since 1985, the gross value of aquaculture production in Australia has grown from $49m to around $400m, with a current annual growth rate of about 30% (Brown *et al.* 1997). This spectacular growth has been fuelled by an increasing demand for seafood and a levelling of production from capture fisheries throughout the world.

While the productive use of saline groundwater has been regarded as an important component of an integrated, holistic approach to salinity management (State Salinity Council 2000), aquaculture may have its own environmental impacts. These impacts need to be considered in any long-term strategy for industry development. The competitive advantage for Australian aquaculture lies in our ability to supply quality products by avoiding the disease problems and environmental management issues that have plagued farmers in other parts of the world (Doupé *et al.* 1999). This means careful site selection, proper resource management, and systems for disease prevention and control. In this paper, we examine the management of potential environmental impacts from inland saline aquaculture, using as an example the production of rainbow trout, *Oncorhynchus mykiss* (Walbaum), in the wheatbelt of Western Australia.

TROUT PRODUCTION FROM INLAND SALINE WATER

In 1997, the Western Australian Departments of Fisheries and Agriculture initiated a joint project to assess the feasibility of using inland saline water for aquaculture. Rainbow trout were chosen as a trial aquaculture species because of their market acceptance, ready availability, production history and tolerance of a wide range of salinities. Like all salmonids, rainbow trout prefer water temperatures below 20°C, although Western Australian strains appear to be more resistant to higher temperatures (Morrissy 1973). There is evidence that growth and survival of trout in warmer waters is improved at higher salinities (Tatum 1976; Teskeredzic *et al.* 1989).

After surveying resources on 5 test farms in 1997, trout were successfully grown out over winter on 6 farms in 1998. In 1999, 2000 and 2001 a large number of farmers purchased trout for trials to determine production capabilities under a wide range of conditions, and to provide a preliminary assessment of product quality and consumer acceptance. It was found that over a wide area of the wheatbelt, fish stocked in May-June at about 50g could reach weights of up to 350-500g by October-November, although there was great variability in growth rates. Preliminary market testing of different types of product (fresh whole fish, frozen fillets, smoked fillets and canned fillets) produced encouraging responses from consumers. As a consequence, a producers' cooperative (Western Inland Fisheries Co-operative Ltd.) and a strategic alliance of producers and processors (Saltwater Trout Alliance Inc.) were formed to progress industry development, and a number of studies have been commissioned to assess the market potential and financial feasibility of an inland saltwater trout industry (Robinson 2000, Anon. 2002).

To determine the variety of production systems used to farm trout in the wheatbelt, we surveyed farmers from 113 properties, who had stocked rainbow trout between 1999 and 2001. Seventy six responses were received. Approximately 50,000 rainbow trout have been stocked on farms from Moora in the north to Albany in the south and Esperance in the east of Western Australia. The 168 separate culture units used by respondents (mean of 2.2 units per property) to stock trout can be grouped into four categories: existing farm dams, constructed initially for watering livestock (66%); ponds constructed specifically for fish production (18%); natural, seasonal salt lakes (9%); and tanks (7%). Lakes constitute a typical extensive production system, with a very low mean stocking density (0.04 fish/m^3) and no supplementary feeding, the fish being totally reliant on natural feed available within the lakes. Mean stocking density was higher in dams and ponds (0.22 fish/m^3), and 33% of these units were provided with supplementary feed in the form of trout pellets. Tanks are more of an intensive production system, with a mean stocking density of 0.41 fish/m^3, and trout pellets the only source of feed.

Despite their differences in physical structure, biomass and feeding practices, the four different categories of culture units had many similarities in their water flow characteristics. All of the units received water from both surface flows and groundwater interception, with surface flows providing the predominant water source in 76% of dams, 52% of ponds, 73% of lakes and 62% of tanks. While some lakes, dams and ponds could be regarded as static systems, with minimal inflow and outflow, many were fed by saline streams and are more appropriately regarded as partial flow-through systems. All tanks pumped and re-used treated water, but they also undertook regular partial or complete water exchanges, and so could also be regarded as partial flow-through systems.

POTENTIAL ENVIRONMENTAL IMPACTS FROM INLAND TROUT PRODUCTION

Natural ecosystems provide services that are essential for the health and economic well being of human communities; principal among these ecosystem services are the supply of natural resources and the assimilation of waste products. Aquaculture production systems can therefore potentially impact upon the environment through the consumption of resources, such as land, water, seedstock and feed, and through the production of wastes, such as uneaten and excreted nutrients, chemicals, pathogens and feral fish. These impacts can occur both internally (i.e. within the production system) and externally (outside the production system).

From our questionnaire survey of farmers who had stocked rainbow trout, we obtained information on the use of pesticides, fertilisers and other chemicals near fish culture units, the access of livestock to culture units, the extent of vegetation clearing, outflow protection measures and fish escapes. From this information, we were able to identify the potential environmental impacts listed in Table 1. We used responses from the questionnaire survey of farmers, and from a focus group interview with resource managers from government agencies in Western Australia, to determine the relative importance of these potential environmental impacts. Among farmers, the most highly ranked impacts were the internal effects of nutrients and other chemicals in the culture system, while among resource managers the most highly ranked impacts where the external effects of nutrients entering the receiving system and trout in lakes consuming natural feed.

Table 1: Potential environmental impacts from inland saline aquaculture of rainbow trout in Western Australia.

Environmental impact	Description of impact	Extent
Resource consumption		
Displacement of vegetation	The construction of culture systems may require the clearing of natural vegetation. .	External
Use of water	Abstraction of surface or groundwater may cause loss or fragmentation of habitat for aquatic communities.	External
Consumption of natural feed	The saline water fauna of Western Australia contains a number of endemic species. Where the culture system is a naturally occurring lake, cultured fish may have ecological effects upon aquatic communities through predation.	Internal
Consumption of artificial feed	Commercial salmonid diets are based on up to 50% fishmeal, and it is estimated that 5t of fish are required per 1t of fishmeal. Any contribution to the global demand for fishmeal also contributes to the global decline in ocean fisheries, the source of fishmeal.	External
Waste production		
Nutrients in culture system	Nutrients are principally nitrogen and phosphorous derived from uneaten feed, undigested solids and excretion. This may lead to eutrophication, with harmful effects on cultured fish or other organisms in the system.	Internal
Nutrients in receiving system	Nutrients that are discharged as effluent from the culture system to natural waterways may have harmful effects on aquatic communities.	External
Other chemicals in the culture system	Chemicals used in other farming activities, such as herbicides or pesticides, may enter the culture system and have harmful effects on fish or other organisms in the system.	Internal
Other chemicals in receiving system	Chemicals from fish culture or other farming activities that are discharged as effluent from the culture system to natural waterways may have harmful effects on aquatic communities.	External
Fish in receiving system	Fish that escape from culture systems into natural waterways may have harmful ecological effects upon existing aquatic communities through predation, competition, habitat disruption or as vectors for parasites or diseases.	External
Disposal of saline water	Saline groundwater may be discharged from culture systems into natural waterways, thereby increasing salinity.	External

MANAGING ENVIRONMENTAL IMPACTS

The management of environmental impacts in aquaculture has traditionally occurred through the use of regulatory instruments, such as licensing. In Western Australia, licensing and assessment policies for inland aquaculture are complicated by the involvement of many different government agencies and their restriction to commercial-scale production (Doupé *et al.* 1999). Inland saline aquaculture operations typically start out as small ventures, integrated into existing farm enterprises, and therefore largely outside the scope of current government regulations.

It may be more appropriate for the environmental impacts of inland saline aquaculture in Western Australia to be managed through the use of economic instruments, which encourage farmers to consider the societal costs of their production. This may be best achieved by the voluntary development of an environmental management system by the industry. Environmental management systems are being increasingly adopted by aquaculture industries to meet legal obligations and consumer aspirations for sustainable resource use. Environmental management systems require the development of environmental quality objectives, the formulation of environmental quality standards to meet the objectives, the adoption of best management practices to comply with the standards, a system of monitoring to ensure compliance and a means of correction for non-compliance (Boyd and Schmittou 1999; Fernandes *et al*. 2001).

From the point of view of the farmer, environmental impacts are external costs, and the incentive to manage impacts through the development of an environmental management system should be positively related to the extent that they can be internalised. In our study, this is seen most clearly in the link between the internal and external effects of nutrients from trout farming. Farmers were most concerned about the impact of nutrient wastes on the water quality of their culture system, presumably because this will directly affect profitability through reduced fish production. This represents an internalisation of the impact of most concern to resource managers, which was the effect of nutrient wastes flowing to the external environment. Economic incentives for farmers to improve feed quality, reduce feed wastage and control nutrients from other sources (such as fertilisers and livestock excrement) should lead to a reduction of the impact on both internal and external environments. Demonstrating the economic advantages of managing nutrient wastes is complicated, however, by the small scale of the industry, by the diverse range of production systems being used, and by the wide geographical area over which production is occurring. We believe that mathematical modelling of the impacts from nutrient wastes can help to overcome some of these complications and assist in the development of an environmental management system.

MODELLING IMPACTS FROM NUTRIENT WASTES

Using a mechanistic modelling approach, we produced a simulation model of the inputs, nutrient cycling and outputs that can be applied to inland trout farming in Western Australia. The model was developed according to the critical processes that affect nutrient cycling within five major sectors of an aquaculture system: inflow, fish, water column, water-sediment interface, and outflow (Figure 1). The model was designed using mass balance methods and processes described in previous studies (e.g. Kraft 1992; Chapelle 1995; van Rijn 1996; Hargreaves 1997, 1998; Sanz Rus *et al.* 2000; Lefebvre *et al.* 2001; Montoya *et al.* 2002), and calibrated using preliminary data from an on-going study of water quality parameters in different trout farming systems in the Western Australian wheatbelt.

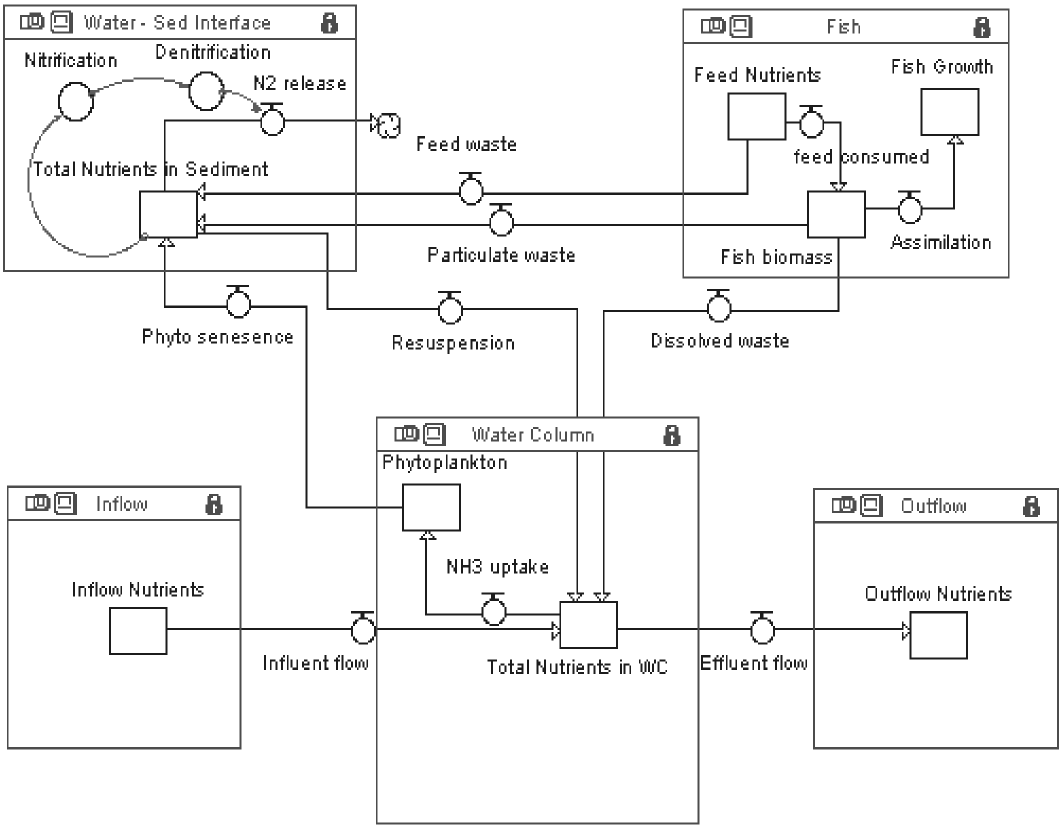

Figure 1. Schematic outline of model of nutrient cycling in inland trout aquaculture, showing critical processes affecting nutrient balance in five major sectors of an aquaculture system.

The main measurable sources of nutrients to the system are determined from the inflow water, the addition of fish and formulated feeding. Bioenergetics modelling calculates the retention and excretion of nutrients by the culture animals. The model predicts the extent to which nutrients are retained within the culture unit, in either the water column or the sediment. It also predicts the extent to which nutrients are lost from the system in the outflow, or retained by the fish as growth. The comparison of inflow and outflow loads provides an estimate of the management intervention required to prevent downstream environmental impacts. The comparison of inflow, water column and sediment loads can be used to predict the productive lifespan of the system at current management of nutrient assimilation.

A simple summary, using preliminary data from a flow though cage system, demonstrates the potential for nutrient retention within a culture unit. For 10,000 fingerlings stocked at an average weight of 100 g to achieve 300 g growth, assuming constant growth rate over a 240 day grow-out season, each individual must grow 1.25 g per day. To achieve this growth rate, the fish are fed 15 kg of commercial pellets per day with 5% nitrogen (N) constitution at a feed conversion ratio of

1.2. According to model predictions, 180 kg of feed N are added to the culture unit during the grow-out phase, 90 kg N of which is incorporated into fish biomass, with the remaining 90 kg N released as waste. Initial estimates from the model indicate that the nutrient load to the system from inflow water is approximately 310 *u*g N/l at 45000 kilolitres/yr, or 14 kg N/yr. The outflow is estimated to release approximately 36 kg N/yr, a net downstream load increase of 22 kg N. Concurrently, the system is retaining a further 68 kg N/yr, locked up in the water column - sediment nutrient cycle. This represents an approximate concentration increase of 300 mg/l/yr that requires assimilation by the system or treatment via incorporation of waste management.

MANAGING OTHER ENVIRONMENTAL IMPACTS

We believe that our model of nutrient cycling in inland trout aquaculture systems can assist in the formulation of environmental quality objectives and standards to minimise the environmental impact of nutrient effluent, by clarifying the links between water quality, production efficiency and nutrient outflow. However, other potential external environmental impacts, such as increasing demand for fishmeal and discharging saline groundwater (Table 1), are not so readily internalised as water quality, because they do not have any short- term impacts on profitability. The challenge is to demonstrate to producers that external environmental impacts do influence either costs of production or returns received from aquaculture products.

Clearly, there are societal costs to external environmental impacts. It may be possible to factor these societal costs into costs of production through economic incentives or disincentives, but this requires a reasonably precise valuation of the environmental goods and services that are affected (Muir *et al.* 1999). An alternative (or complementary) strategy is to attempt to obtain a marketing advantage from environmental management, by presenting the positive environmental attributes of the product (Young *et al.* 1999). While this sounds good in theory, in practice the advantages need to be identified and tested through market research before they will provide an economic incentive for farmers to spend money in mitigating external environmental impacts. This is the next challenge in the development of an environmental management system for inland trout farming in Western Australia.

ACKNOWLEDGEMENTS

Our work in the environmental management of inland saline aquaculture is supported by the Rural Industries Research and Development Corporation, and the Saltwater Trout Alliance Inc.

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