POLLUTION CONTROL POLICIES FOR AUSTRALIAN PRAWN FARMS

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Abstract

The environmental consequences of shrimp farming in Asia have caused widespread public concern. One of the main environmental impacts is the high nutrient load that is discharged from ponds, as part of the management routine aimed at maintaining pond water quality. In Australia, where there is a high level of community awareness of the problems associated with eutrophication, the Environmental Protection Agencies are faced with the difficult task of determining effluent control policies for the emerging prawn industry.

According to the standard environmental economic arguments relating to the design of pollution control instruments, the choice of the best policy instrument depends upon the nature of the pollution problem, the costs of abatement, and the transactions costs associated with administering the policy. Thus, in order to assess the appropriateness of alternative pollution control instruments it is necessary to examine the nature of the pollution problem, the technologies available for abatement, the accuracy and cost of monitoring and enforcement.

These practical aspects are examined from the perspective of the intensive prawn aquaculture industry. While there is insufficient data to conduct an empirical analysis of the relative effectiveness of alternative control measures, some of the key issues that need to be considered in designing such policies are highlighted. Because monitoring costs are significant, both direct and indirect (input based) controls are considered. In the context of this discussion, new legislation developed by NSW Environmental Protection Agency, which may soon be applied to the prawn farming industry, is examined.

Introduction

The rapid expansion of shrimp farming in Asian countries over the 1980's and 90's has led to enormous environmental problems (Phillips et al 1993, Primavera 1991, Primavera 1998). These include nutrient and sediment loads in waterways, as well as chemical pollution; salinisation of water supplies; concern over the potential infection of native stocks; and the destruction of mangroves. The external impacts of environmental pollution have affected local communities relying on water, mangroves and local fisheries (Primavera 1996) and have also impacted on the productivity of neighboring rice farmers through soil salinisation (eg. Phillips et al 1993, Tran 1996). The costs of environmental degradation have also been felt within the industry- it has been argued that the high level of pollution in water discharged from shrimp farms has contributed to the collapse of the industry in Taiwan and China (Phillips et al 1993). Concern over the social costs of shrimp farming led to the Indian Supreme Court ruling against shrimp farming, that included shutting down operations of a 100,000 ha region of shrimp farms, and banning of shrimp farming in sensitive areas (Hagler 1997). This ruling was made on the basis of a cost benefit analysis that found the social costs of shrimp farming were up to 4 times the benefit (Primavera 1998).

The Australian prawn farming industry has developed in the wake of the experience in Asia, and during a period of increasing community awareness of environmental issues (Preston et al 1996). The sites suitable for prawn farming in Australia are located in areas where environmental values are particularly high. For example, it has developed along the Queensland coast adjacent to the unique and environmentally sensitive Great Barrier Reef. It has also developed around the highly populated regions of SE Queensland and NE New South Wales. The high value placed on environment quality in these areas, together with poor environmental performance of shrimp farming in other parts of the world, mean that the shrimp farming sector in Australia has developed under very close scrutiny of environmental regulators.

An issue that is of major concern for the Australian industry is the pollution caused by the discharge of nutrients and sediment from shrimp farms. The main source of nutrients in discharge water of shrimp farms is from unassimilated food. For example, Funge-Smith et al (1998) found that only 18% of nitrogen contained in shrimp feed is harvested as shrimp biomass. Poor feed conversion by shrimp results in very high levels of nitrogen waste when shrimp are farmed intensively. For example, gross[1] nitrogen effluent loads of 410 kg per ha were attributed to prawn farm run off in the Logan river (SE Queensland) in 1997. This compares to nitrogen effluent loads of 40kg per ha for cane farms.

The regulation and control of shrimp farm effluent in Queensland and NSW is undertaken by the State Environmental Protection agencies. In NSW, farmers operate under licenses which have limits on effluent concentrations, but not on (cumulative) effluent loads, although the introduction of load based licenses is on the reform agenda

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[1] Net nitrogen loads added during the production phase are lower, because the intake water is likely to have a significant nitrogen load.

for NSW (EPA 1998). In Queensland, the state EPA operates under the Environmental Protection Act (1994) and farmers are issued licenses that are conditional upon environmental performance. However, these environmental performance standards are not clearly defined and are currently undergoing review. For example, a recent policy announcement on environmental targets for the Logan River indicated that current loads from prawn farms were to be reduced by 80% by the year 2001. This target was based upon bringing the industry's effluent load back to an historical benchmark of 5 years prior[2]. Attainment of such dramatic reductions in effluent from shrimp farms could impose large costs on the industry, and it is important to consider the least cost method of pollution control, as well as the equity implications of alternative control instruments.

The outline of the paper is as follows. First, a brief summary of the economics of pollution control is given. The subsequent section describes the nature of the prawn farm pollution problem. The main part of the paper involves an outline of the current and potential future technologies for effluent abatement, and a discussion of the incentives and regulatory controls that might be considered to encourage a reduction in pollution in waterways where prawn farms operate.

Policy options for pollution control

There is a strong economic argument for intervention in pollution problems, because of the market failure problems associated with environmental goods and services. In the absence of intervention, firms ignore the external costs associated with the damage caused by their effluent when making production decisions. Intervention in pollution problems is therefore warranted in order to reduce pollution back to the socially optimal level, where the marginal costs of abatement are equated with the marginal cost of pollution damage. Most of the literature on the economics of pollution control has recognized the difficulty in determining the optimal level of pollution, and has focused instead on examining the efficiency and effectiveness of alternative policies aimed at achieving certain pollution targets. Many authors have reviewed these works (eg. Fisher 1976, Segersen 1990, Cropper and Oates 1992) and some of the main points are summarized here.

Pollution control instruments are usually categorized as being either price based incentives or quantity based regulations. They can be further classified as being direct (on effluent) or indirect, on the inputs or output of the production of which pollution is a by-product. Debate about the appropriate mechanism for pollution control has focused on the economic efficiency of alternative control instruments, and the trade off between efficiency and other considerations, such as equity, accuracy, ease of administration and political acceptability. There has been increasing attention in recent years to the problems of enforcement of pollution and the recognition of transactions costs associated with alternative control instruments.

Most of the analysis of direct controls on effluent has been applied to industries in which point source pollution occurs. Generally, it has been argued that incentive schemes are

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[2] The expansion in effluent load over the last 5 years was due to industry area expansion.

more efficient in achieving the least cost method of pollution reduction, and the benefits of using incentive schemes are large when there are significant differences in the cost of abatement between firms. Direct incentives can be in the form of taxes or subsidies on effluent. Taxes are often seen as being politically difficult, because they impose a heavy financial burden on the polluter. However, subsidies can be inefficient in a long run as they can discourage exit and encourage entry of additional polluting firms.

In contrast, quantity based schemes achieve the same level of pollution reduction at a higher total cost, because no account is made for differences in abatement costs between firms. However, as long as there is uncertainty about the cost of abatement (and hence the appropriate tax), the reliability of meeting environmental standards is greater with a quantity based scheme. There are longer term efficiency costs associated with quantity based schemes, as the firm is given the right to pollute (at zero cost) up to the pollution standard. This implies that there are no incentives to invest in cleaner technologies and reduce the level of pollution below the standard in the longer run. Standards tend to be administratively easier and impose relatively lower financial burden on the polluter, hence are usually more acceptable politically.

A popular favourite amongst economists is the use of tradable (quantity based) pollution permits, which provide all the price incentives of the tax method, without the politically difficult financial burden on incumbent polluters. At the same time, they allow dynamic flexibility in that firms have a financial incentive to adopt cleaner technologies and sell their pollution rights, to new or existing firms. In addition, the regulator can enter the market and buy back pollution permits if they wish to reduce the total level of pollution over time. The monitoring requirements are similar to those of pollution standards.

There has been a great deal of attention paid to the problems of monitoring and enforcing pollution policies in recent years. In the case of point source pollution, the focus has been on the problem of asymmetric information between the polluter and the regulator (eg. Swierbinksi 1994). Much of the work on agricultural-sourced pollution recognizes the importance of monitoring and enforcement problems at the outset, because in the case of non-point source pollution, it is technically impossible or prohibitively costly to monitor the pollution output of an individual firm.

Griffin and Bromley (1982) introduced the concept of a pollution production function, that relates inputs/management practices to the production of pollution. They argue that as long as this "production function" can be defined, then it is possible to develop indirect pollution control measures using either incentives or standards on management practices. They present a model (based on perfect knowledge of the pollution production function) that illustrates that a pollution goal can be met efficiently by any of 4 possible regulatory instruments (direct taxes and standards, indirect taxes and standards). However, they show that the number of regulatory instruments vary in each case. If there are N firms and the pollution production function has J inputs, then the number of regulatory instruments required for efficient control are 1 for direct taxes, N for direct effluent control, NxJ for indirect input taxes, and NxJ for indirect regulations.

One of the main problems with the indirect method is the large number of instruments required to achieve efficient control (except in the case where there are no firm specific factors in the pollution production function). The information and administration costs of such detailed policies are high, and may be impractical in some cases (for example, differential taxes will be negated through arbitrage). Once the problems of administering different policies are considered, it is recognized that it is difficult to draw generalities about the "optimality" of any particular pollution control instrument. Rather, the efficiency of alternative policies will be dependent on the case specific transaction costs associated with each policy (Smith and Tomasi 1995). There will be a trade off between the efficiency costs associated with using uniform regulations and the transaction costs associated with administering an "optimal" set of instruments. Helfand and House (1995) present a case study where the efficiency costs uniform taxes or standards are relatively low, but argue that higher degree of heterogeneity between firms will increase the efficiency costs of second-best uniform policies.

In summary, the environmental economics literature provides some general guidelines for examining policies for pollution control. It recognizes that the appropriate methods are case specific and depend on factors such as the differences in costs of abatement between firms (which makes efficiency of pollution clean up an issue) and the costs of monitoring (which makes enforcement of direct controls an issue). If indirect control measures are used as an alternative to direct controls, then the efficiency and administrative costs of such measures depend on the number of management options associated with pollution abatement, and how firm specific factors affect the "pollution production function". Thus, it is necessary that issues regarding the design of pollution control for prawn farms should be considered in the context of the technical options for pollution abatement. In the next section, the nature of shrimp farm pollution and the options available for abating pollution are discussed.

The nature of shrimp farm pollution and abatement technologies

The pollution problem

When shrimp are farmed intensively, water quality in the pond is a crucial management factor. The high feeding rates associated with intensive production, combined with the poor feed utilisation of shrimp, mean that there is a large build up of toxic ammonia in the pond secreted from shrimp. In addition, unassimilated food stimulates biological activity in the pond, increasing the oxygen demand in the system. To reduce toxic ammonia and to reduce biological oxygen demand in these situations, ponds are generally flushed with water from outside and water is discharged into the environment. The nutrients released through routine water exchange, and the high level of nutrients contained in pond sludge that is released after harvest, both contribute to high nutrient loads in effluent from prawn farms.

Scientific evidence of poor feed utilisation by shrimp has been illustrated by the development of nutrient budgets, that determine the source and fate of N and P in the pond system. For example, Funge-Smith et al (1998) have estimated nitrogen and phosphorus budgets for intensive shrimp farmers in Thailand, and found that the percentage of pond nitrogen released into the effluent channel was around 27%, with other main sinks being sediment removal (24%) and volatilization (30%) and shrimp harvest 18%. The principle sources of N was feed, which accounted for 78%. The estimated loads of N and P in these shrimp ponds, and associated effluent, are illustrated in Figure 1.

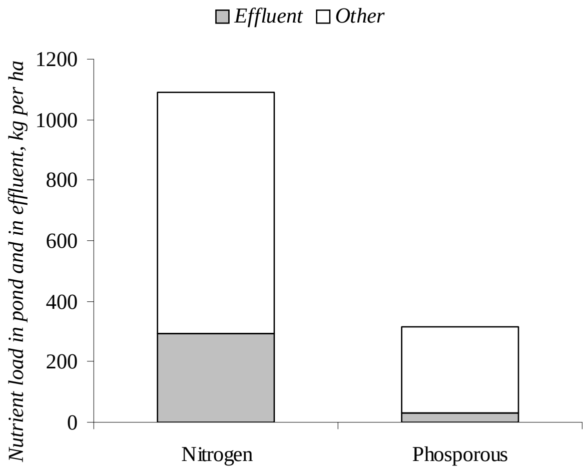

Figure 1: Estimated N and P in pond environment and in effluent

The external cost of prawn farm effluent
Two of the main physical effects of prawn farm effluent are the eutrophication of receiving waters and the impact of organic particulate matter on local ecosystems (Samocha 1996). The impact of shrimp farm effluent depends not only on the mass effluent load and its components but also on the assimilative capacity of the receiving environment (Phillips et al 1993). For example, when the point of discharge of effluent is a tidal creek, the benthic biota of the creek can assimilate some of the nutrients. The capacity of any waterway to assimilate nutrients is partly a congestion problem. In remote areas where there is little other activity causing nutrient run off, the marginal physical damage of effluent from a prawn farm will be lower than in waterways that have a high base load of nutrient from other sources.

The social cost of high nutrient loads is also dependent upon the downstream uses of water. In the case of water bodies in which Australian prawn farms operate, the downstream values include the recreational, environmental and commercial value of estuarine and adjacent coastal ecosystems, and in many cases these values are high. For example, farms are located in the densely populated areas of South East Queensland and Northern NSW, where the recreational and commercial values of clean waterways are high. Other farms have developed along the northern coast of Queensland, adjacent to the Great Barrier Reef Marine Park, where the potential cost of damage from eutrophic loads is high. In contrast, there are other sites where the potential social cost of effluent may be relatively low. These include sites where the physical damage from effluent is lower, and sites where the cost of any damage is relatively low.

Technical options for reducing effluent

There are a range of strategies for reducing effluent discharge from shrimp ponds. One way is to reduce production, either by reducing stocking density or by taking ponds about of production. However, less drastic abatement options are also available, which include technologies aimed at reducing waste per tonne of prawn produced, and those that focus on cleaning up the waste on the farm, through the use of effluent treatment ponds.

<u>1. Reduced output of waste per prawn</u>

The technical efficiency of feeding is measured by the feed conversion ratio. This ratio compares the dry weight of feed required to produce a mass unit of shrimp (measured in wet weight). The feed conversion ratio observed in intensive shrimp farms in Australia is typically around 2. This low level of technical efficiency is attributed to a number of factors.

First, there is considerable feed wastage. Primavera (1994) estimated that only 85% of feed given to shrimp is actually consumed by them. While this feed wastage can be managed to some extent by improved feed management, some is wasted during feeding as the prawns break up the feed pellets with their claws. Jory (1995) discusses some of the practices that can reduce feed wastage, which include the use of feeding trays to monitor appetite, and more frequent feeding times. Most farmers in Australia have adopted feeding trays to improve management of feeding (Preston 1998 personal communication)

It is apparent that the degree of control that a farmer has over feed wastage and feed conversion efficiency is relatively low. Appetite and growth are affected by pond conditions, which are highly volatile even between ponds on a single farm. The difficulty in managing the pond environment can be illustrated by a recent cross-sectional study of feed conversion efficiency on an Australian farm (having about 20 ponds). On this farm[3], the average feed conversion ratio was about 2, but ranged between 1.6 and 2.6.

Since feed is an important component of shrimp production costs, it would appear that a farm manager would have a strong incentive to adopt careful feed management practices in order to improve feed conversion ratios. For example, the savings achieved from reducing FCRs over the range of 2.5 to 1 are shown in Figure 2, where savings are express in dollars per ha and plotted against the associated net effluent loads per ha[4]. Based on these figures, it would seem that environmental management and farm management goals are not conflict with one another. For example, for an intensive farm producing 10t per ha of shrimp, a saving in feed costs of $25,000 per ha would be

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[3] Acknowledgement is given to the Co-operative Research Centre for Aquaculture for access to raw data from this study, used to calculate FCR shown here.

[4] These data were based on feed costs of $1500 per tonne, a N content of 7% of dry weight of feed, and Briggs et als estimate of 27% of pond N in effluent.

achieved by reducing the FCR from 2.5 to 1. At the same time, there would be beneficial reductions in effluent load of the order of several hundred kg N per ha.

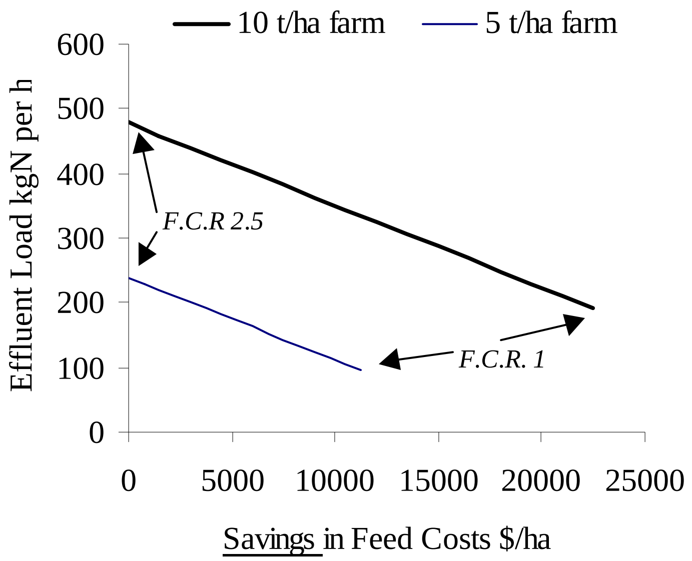

Figure 2: The benefits of reducing feed conversion ratios.

A second factor affecting the feed conversion ratio is the efficiency with which ingested feed in converted to harvested biomass. Of the feed that is actually consumed by the shrimp, 56% is used in metabolic processes (including molting), and 23% is excreted as fecal matter. Only 20% is harvested as biomass. Research on improved diet formulations may result in more nutritious feeds that may reduce feed conversion ratios in the longer term.

Thus, while it is possible that improvements to feed efficiency will be achieved in the longer term, with the development of improved diet formulations and more sophisticated feed management techniques, there may not be much scope for improved feed efficiency given current technology. Given the strong private incentives for improved feed management, it is likely that most of the existing potential for reduction in feed wastage have already been explored and adopted by farmers. This has important implications for the effectiveness of a feed tax in the short term.

2. On-Farm Treatment of Waste

The use of settlement ponds, that allow particulate nitrogen and phosphorous and suspended solids to settle out of the pond water is a relatively simple technique for improving the quality of water before discharging from the farm, or as part of a low water exchange (recirculating) system. Biotreatment using naturally occurring plants may improve water quality further, by removing dissolved nutrients. There is very little evidence on the effectiveness of such treatments in the Australian context, although on farm trials have begun in Queensland. Preliminary observations made by scientists at the CSIRO Division of Marine Research suggest that these treatment ponds may be effective in removing about 20-25% of the nutrients suspended in the water column (C. Jackson, personal communication 1998). Using data from these trials, an analysis of the cost-effectiveness of such effluent treatment ponds was conducted, over a range of assumptions about the effectiveness and cost of treatment ponds[5], including the opportunity cost of pond space. In the analysis, it was assumed that land on the farm was scarce and that effluent ponds could only be created by giving up pond space. Thus there are two effects on nitrogen output- the reduction in the production of nitrogen waste through reduced pond area, and the removal of nitrogen in the effluent treatment process. Under these assumptions, the main cost is the opportunity cost of pond space. The cost of nitrogen reduction was estimated to range between $26 and $61 per kg N for the range of parameter estimates examined.

Table 1: Analysis of the possible cost of effluent treatment ponds

Assumptions	Base assumptions	Sensitivity Analysis					
Pond Size ha	0.5						
N Removal kg/ha/day	3.5	2	5				
Yield tonnes per ha	6.51						
FCR	2						
Gross Margin $/kg	$4.42			$2.02	$6.52		
Effluent Pond Cost $ per pond	$4,600					$0	$10,000
N removed in treatment pond kg	263	150	375	263	263	263	263
N reduction from pond conversion kg	422	310	535	422	422	422	422
Total Reduction in N kg per pond							
Opportunity Cost of Lost Production	$14,393	$14,393	$14,393	$6,581	$21,229	$14,393	$14,393
Total Cost of Effluent Pond	$18,993	$18,993	$18,993	$11,181	$25,829	$14,393	$24,393
Average Cost $ per kg of N removed	$45.00	$61.36	$35.53	$26.49	$61.20	$34.10	$57.80

Clearly, the technology for effluent treatment is at an early stage of development, and it is possible that in the longer term, more cost effective methods will be available. Moreover, there are private benefits associated with the development of "closed system" aquaculture ponds, which include greater control over pond water quality, and greater production stability. In fact, there has been a strong interest in closed system or low water exchange systems in Thailand, in the interests of reducing the risk of introducing pathogens (from neighbouring shrimp farms) into the farm. Further development of biological treatment methods may also lead to commercial crops being introduced for nutrient clean up, thus reducing the opportunity cost of land associated with effluent ponds. A number of

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[5] The base case parameter for effluent treatment costs was based on a cost of $2000 per pond for capital, and $2600 for electricity and harvesting costs, based on estimated physical requirements.

potentially commercial biological treatments have been suggested, including seaweeds (Gavine et al 1994), molluscs and detritus eating fish (Lin 1995). In Australia, trials have begun on the use of oysters as bio-filters for shrimp farms (Jones and Preston 1996).

3. Reduced farming intensity

Further reduction in nutrient effluent beyond that achieved through effluent ponds can probably only be achieved through reduced production. This could occur through reduced stocking density or by taking some ponds out of production. The optimal strategy would require a consideration of the overhead costs of running extra ponds (for example, pond preparation, electricity costs, labour cost) and the possible benefits of reduced stocking density. These benefits include reduced pressure on pond ecosystem and resulting reduced risk of disease, as well as a possible increase in harvest size associated with reduced stocking density. For example, Jackson et al examined growth rates from a Monodon farm in northern Australia, and found a significant relationship between harvest weight and the number of shrimp harvested, which they attributed to the effect of density[6]. The benefit of larger shrimp is that they fetch a market premium (on price per kilogram of shrimp). Recent data from Japanese market suggests that there is a price premium of about 20c per kilogram, for each extra gram that an individual shrimp weighs. However, without more detailed data it is not possible to undertake a comprehensive evaluation of reduced density vs reduced area, as means of reducing production.

The opportunity cost of reducing the area of production, as a means of reducing effluent output, are shown in Table 2 for a range of assumptions. These costs are expressed in terms of the reduction in nitrogen effluent, for the purposes of illustration. However, the multi-pollutant nature of prawn farm effluent means that care should be taken in comparing this estimate against the "social cost of nitrogen pollution". This is because the reduced production will provide additional benefits of reduced phosphorous and sediment loads.

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[6] They modelled the survival rate in the growth curve, but suggested that the impact was due to density

Table 2. Cost of reducing N pollution through reducing pond area (per ha)

Gross Margin	Percent of pond N released to environment	Nitrogen Effluent[1] kgN	Production Opportunity Cost	Short Term[2] Cost $/kgN	Long Term[3] Cost $/kgN
4	27	319	$26,000	*81.61*	*48.40*
2	27	319	$13,000	40.80	7.60
6	27	319	$39,000	122.41	89.21
2	32	378	$13,000	34.43	6.41
4	32	378	$26,000	68.86	40.84
6	32	378	$39,000	103.28	75.27
2	22	260	$13,000	50.08	9.33
4	22	260	$26,000	100.15	59.41
6	22	260	$39,000	150.23	109.48

Notes
1. Based on Funge Smith's nutrient budget, where feed comprises 78% of N in, and 27% of N is released to environment. FCR of 2 is assumed.
2. Based on gross margin
3. Including an annualized capital cost.

4. Importance of farm and site characteristics in affecting the effluent abatement costs

An important factor affecting the efficiency costs and transactions costs of alternative pollution control instruments is the degree of heterogeneity between firms. In this section, some of the factors that may influence the cost of abatement between firms, hence cost associated with applying "uniform" regulatory measures, are considered. A summary of the farm and site characteristics that may influence abatement costs is provided in Table 3.

The cost of investing in effluent ponds is depends upon the opportunity cost of pond space. In the analysis presented in the above section, it was assumed that land is scarce, and the opportunity cost of land is the cost of foregoing production of an existing pond. The opportunity cost of pond space depends upon the profitability of the farm. It is more efficient to encourage the least profitable farms to invest in clean up, because these farms have a lower opportunity cost. Some farmers may perceive the opportunity cost of land to be lower than the cost of pond space. For example, they may be able to purchase adjacent land at a lower cost, or they may have available space for developing effluent ponds on their existing farm. While it is arguable whether the opportunity cost of this land should be valued at a price less than the profitability of prawn production, there may be some circumstances - for example, individual preferences concerning manageable size of the farm, where a lower evaluation is appropriate. At the extreme, if the opportunity cost of land were zero, the cost of developing effluent ponds to clean pollution would be considerably lower (at around $18 per kg N).

The cost of reducing effluent through output restriction will depend on the profitability of the farm and the feed conversion ratio. For example, highly profitable farms with low feed conversion ratios would have relatively higher costs associated with reducing prawn output. In addition, the reduction in effluent achieved from output reduction will depend on the effluent characteristics of the farm, such as whether there is natural assimilative capacity in the effluent channel, and whether the farm has invested in effluent treatment costs.

Table 3: Factors affecting the cost of abatement between firms

A. Options for reducing nutrient discharge from the farm

		Site or farm level characteristics affecting cost	
Option	*Cost Components*	*Management*	*Physical*
Effluent Pond	Opportunity Cost per ha	Feed Conversion Ratio Yield Species Other production costs	Farm Layout (available space for effluent ponds)
	Water Pumping Costs	Production intensity	Farm layout
Reduced output of shrimp	Opportunity cost per tonne shrimp	FCR Yield Other production costs Species	
	Nitrogen output per tonne shrimp	FCR	
Improved FCR[1]	More expensive feed Capital or labour costs of increased feed monitoring	Feeding technology	

B. Site specific factors affecting the social cost of nutrient discharged from ponds

Site Factors	*Effect on social cost*
Effluent Discharge Channel	Assimilation may occur before release to main waterway
Assimilative Capacity of Receiving Environment	Will affect physical damage from effluent
Downstream uses of water	Social evaluation of damage cost

Notes 1. May only be possible in the longer term

5. Other options for reducing nutrient load in waterways in which prawn farms operate

Another major type of agricultural land use in many catchments where prawn farms operate is sugar cane production, which produces effluent loads of around 40kg N/ha (Johnstone Catchment study). The total area of production of sugar cane in Queensland alone is around 0.5 million hectares, implying a total level of pollution of around 20,000 tonnes of nitrogen. In Logan River catchment, where around 110ha hectares of prawn farms are situated (producing around 45t of nitrogen effluent), the assigned area of cane production is around 6000 per ha. This implies that the total annual nitrogen load from cane farms is around 240 tonnes. While there are likely to be management practices that reduce nitrogen run off from a cane farm at lower cost, the maximum cost of reducing effluent from a cane farm is to take the land out of production. The gross margin on sugar cane land is around \$327/ha[7], which implies an opportunity cost of \$8 per kg of N abated.

6. Monitoring and compliance costs

The effectiveness of direct pollution control strategies depends upon the ability of regulators to enforce pollution regulations. Generally, the approach taken in monitoring aquaculture effluent, by the Environmental Protection Agencies in Australia and overseas, is to monitor effluent concentrations in the farms effluent, using infrequent (say monthly) sampling. In addition, water volumes are monitored and this data is used to provide an estimate of the load per farm. However, recent experimental evidence suggests that there is a high degree of volatility of nutrient concentrations in effluent from prawn farms. For example, results of intensive monitoring at a field site in north Queensland indicated that mean concentration of total in N water had a coefficient of variation of 40% within estimates taken over one week (C. Jackson personal communication). In addition, estimates varied significantly at different times of the season. Under such volatility, the estimates of effluent loads based "spot sampling" of effluent concentrations will be highly inaccurate.

Whilst the accuracy of monitoring effluent could be improved by more frequent sampling, the volatile nature of nutrient concentrations implies that very intensive sampling may be necessary in order to provide an accurate measure of effluent load from a farm. Given the high cost of collecting and analyzing samples[8], it may not be cost effective to adopt effluent monitoring as a routine compliance measure, given the legal difficulties in enforcing effluent regulations with inaccurate load estimates.

Conventional economic wisdom and the prawn pollution problem

. Prawn farms operate in a multi-polluter environment in which monitoring costs are high, abatement technologies are very costly (given current knowledge), and the farmers ability to control one of the major inputs affecting pollution (ie. control feed conversion efficiency) is limited by a complex and highly volatile pond ecosystem. Further, there

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[7] Based on costs and returns reported in Danzi et al 1997

[8] For example, the Queensland Government Health Laboratories standard fee is \$40 per sample for N and P analysis.

may be considerable spatial differences in the costs and benefits associated with pollution clean up within one jurisdiction (ie. the State Environmental Protection Agencies). The practical issues associated with prawn farm pollution result in one clear conclusion: that the efficiency and effectiveness of alternative policies, after transactions costs are considered, is an empirical matter.

Uniform or "efficient" regulations?

Differences in the water environment downstream from prawn farms imply that there may be large differences in the social cost of prawn farm effluent in different locations. This implies that the adoption of uniform statewide regulations on prawn farm effluent will be an inefficient control strategy, curtailing effluent from farms located in areas where the downstream impact is relatively low at the same rate as farms with relatively high downstream impact. Fortunately, the increasing trend towards catchment based management approach to river quality should ensure that the problem of spatial location will be dealt with in a non-uniform manner. In the longer term, appropriate selection and zoning of areas suitable for aquaculture development[9] will help to reduce the problem of prawn farm effluent by separating the victims from the polluters.

Within a given catchment area, there may also be site specific characteristics that affect the cost of abatement, and imply that uniform treatment of polluters may involve efficiency costs. The cost of abatement will depend upon many factors including the relative profitability of the farming operation, the feed conversion ratio, the availability of adjacent low cost land for the development of treatment ponds and the physical layout of the land. All of these factors imply that uniform effluent limits (say, based upon a load limit per pond area) will be inefficient compared to a uniform tax on effluent. Similarly, differences in the cost of establishing treatment facilities, and differences in types of abatement technology will imply that uniform regulation of management practices will be inefficient. Some of these issues will be discuss in the context of individual policies below.

Possible regulatory instruments

Load Limits and the New South Wales legislation

Currently, prawn farms do not operate under formal load limits. In New South Wales this is soon to change, when load based licensing regulations are applied to aquaculture facilities[10]. This will involve setting load limits based on existing loads, with the aim of preventing further increases in pollution. While it may be more politically acceptable to introduce pollution limits based on current loads, there are both efficiency and equity issues associated with such policies. First, those firms who have already made investments in effluent treatment ponds will be penalized , as their scope for future expansion will be less than the "dirty firms", who can invest in treatment ponds in order to expand production (within their effluent load limit). Second, load based policies do not

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[9] The use of GIS determining appropriate development sites for future prawn farm development has been proposed as a means of managing pollution problems in the longer term (Preston et al 1997).

[10] At this stage, it is expected to be applied by the end of 1999.

encourage the adoption of cleaner technologies, except for purposes of such expansion. While the NSW legislation proposed to also "tax" firms based on loads emitted, in order to encourage clean up below the "load limit", it is unlikely that the tax proposed for aquaculture will provide sufficient incentive.

Taxes

If taxes are to be effective in encouraging clean up, they need to be as high as the marginal cost of abatement, otherwise the firm would be better off polluting and paying the tax. There is little scope for an effluent tax to improve feed management (hence feed conversion efficiency) since the incentives for efficient feed management are already very high. Thus, since effluent treatment ponds are likely to be the cheapest form of clean up in the short term, the tax required to encourage clean up would need to be in the order of $45 per kg of nitrogen, based on the evidence available on the cost and effectiveness of treatment ponds. In contrast, the proposed load fee for nitrogen in NSW is around $1.60 to 3.20 per kg N.

More accurately, since there is also proposed a phosphorous tax (at $6.20 per kgP) the total tax paid on a 1 ha pond producing around 6.5 tonnes per ha would be between $500 and $1000 per ha for nitrogen and $220 per ha for phosphorous. This is unlikely to provide sufficient incentive to invest in an effluent pond (around $38,000 per ha if conversion from pond space is necessary). Thus, the proposed license fee is unlikely to make any difference to nitrogen loads from prawn farms, except for perhaps in isolated cases where farmers have access to land with no perceived opportunity cost.

The usual problems associated with taxing effluent apply to the prawn farm pollution problem. First, there is the political difficulty in setting such high taxes. If a tax of $45 per kgN were applied it could cost a 20ha farmer around $300,000 in tax. Further, the difficulties in monitoring effluent imply that a direct tax may be infeasible, particularly when the estimated effluent load involves such large financial consequences. Regulators would end up with considerable legal problems in trying to enforce the tax.

Tradable Permits

If effluent permits were tradable, the efficiency costs associated with the use of quantity based regulations could be mitigated. However, the effectiveness of a tradable permits market can be undermined when there are a limited number of traders, which will be the case in many locations where prawn farms operate. Thus it is not clear how effective a tradable permits scheme would be in some locations. However, the use of tradable permits within the prawn industry would provide a useful mechanism for entry and exit from the industry.

Another necessary condition for an effective permit market is the ability to monitor and enforce effluent controls, which may be difficult in the case of prawn farms. Further, given the large difference between the cost of nitrogen abatement between cane and prawn farms, it appears that the main efficiency gains associated with an effluent trading scheme would be achieved by inter-industry trade. However, the practical difficulties in administering trade between point and non-point source pollution may be prohibitive.

Indirect controls

The high costs of monitoring and enforcement may mean that indirect policies regulating farm management practices are a more practical alternative.

Input taxes

A tax on inputs to production has been proposed as a means of reducing the production of effluent. For example, a tax of feed is analogous to the fertiliser tax that has been proposed for agricultural sourced pollution (eg. Segerson 1995). A tax on shrimp feed would provide an incentive for farmers to reduce FCR and thus reduce effluent output. It would impose a heavier burden (and greater incentive) on farms with high FCR's. However, as noted previously, the effectiveness of a feed tax may be limited in the short run, because it is likely that all practical possibilities for achieving improved FCR's have probably been exhausted, given the strong private incentive.

Other incentive based policies could include a tax on shrimp seed stock to discourage stocking rate (Thongrak 1997) or subsidies on investment in effluent treatment ponds. The shrimp seedstock tax would not discriminate between producing adopting cleaner technologies so would be less desirable than a feed tax, which directly targets one of the main methods of reducing effluent. A subsidy on effluent ponds would provide an increased incentive to establish recirculating systems.

Compulsory effluent treatment ponds

To the extent that the opportunities for reducing FCRs may be limited in the short run, then the most cost effective way of cleaning up pollution is to invest in effluent ponds. Direct regulation on the required area of effluent treatment per area of growout pond might be one means that is used to achieve this target. However, the usual problems associated with regulations will apply to direct controls on effluent pond area. These are that they do not account for other factors affecting effluent output, which include feed conversion ratios, total production and site location. The optimal number of effluent ponds required to achieve the same level of production in nutrient load will vary between farms, and will require case-by-case environmental control measures.

Maximum feed conversion ratios

Just as the feed tax is a proxy for an effluent tax, a limit on feed conversion ratios could be used as a proxy for an effluent quantity standard. Compliance could be monitored using accounting records of sales and input purchases. However, the difficulty farmers have in controlling or reducing FCR would mean that a strict FCR limit is not likely to achieve a reduction in pollution in the short term. However, it may be socially efficient to penalise farms with high FCR's and encourage their exit from the industry, if the managers cannot meet required feed efficiency.

Output quotas

One means of reducing the total pollution load from prawn farms is to apply output quotas on shrimp. This policy would have efficiency implications because of the variation between the opportunity cost of prawn production between farms (difference in profitability) and due to between-farm differences in the quantity of nutrient load produced per tonne of prawn. While the efficiency costs associated with such between-farm differences could be reduced by allowing tradable shrimp production quotas, more serious problems exist with an output quota. These are that output restriction is the most expensive form of pollution abatement, and that quotas would not provide any incentive for investment in effluent ponds.

In the longer run, the social costs of restricting prawn production (by limiting growth of prawn farm area) may be high. Restriction of farm area (by stringent licensing approval procedures) is, by proxy, the current means of managing prawn farm effluent. However, consideration of the cost of foregone shrimp production (even after the capital costs of investment are accounted for) imply that the cost of this type of pollution control is around \$48 per kgN (per annum). Given the high opportunity cost associated with restricting shrimp farming, consideration should be given to the costs of other methods of achieving a reduction in nutrient loads, for example, through strict environmental requirements for new prawn farms, and through management of other sources of pollution. It is possible that the current limits to prawn farm growth are not the most socially efficient method of reducing nutrient loads in associated waterways.

Combining indirect policies

The main danger with using indirect instruments is that the use of a single instrument will provide distorted signals to farmers, as long as more than one input enters into the "pollution production function". The problem of policy bias could be overcome by using a combination of instruments. For example, the policies could be jointly targeted at increasing adoption of effluent ponds in the short term, and at reducing feed conversion ratios over the longer term. However, since farm specific factors enter into the pollution production function, an "efficient" policy[11] would require that regulations or incentives are farm specific.

Longer term issues

When the prawn farming industry began in Australia, little was known about effluent abatement. The technology available for abatement is still in its infancy now, and the large research effort both in Australia and overseas indicates that technological improvements are likely over the medium and long term. The likelihood of technical change means that dynamic efficiency issues may be important. For example, forced investment in existing technology may have a long term cost if technological advance led to another highly effective means of effluent treatment that superseded existing technology. Therefore it is important to consider flexibility in the short term. One means of achieving flexibility is to allow the farm to make the inter-temporal investment choices (by using direct rather than indirect policies). Alternatively, if indirect policies, such as forced effluent pond development are used, it is important to consider long run flexibility.

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[11] Efficient in the sense of least cost clean up, ignoring transactions costs.

For example, if farms were forced to invest in effluent ponds in a set pond area to effluent area ratio, then new feeding technology became available which reduced waste production per prawn, the total level of effluent load would be lower than the target, at the expense of the farmer. In contrast, if productive ponds and effluent ponds were readily substitutable (for example, simply using some established ponds as temporary settlement ponds), then the required area of settlement ponds could be revised over time, subject to FCR performance of the farm.

Conclusions

The simple pollution control instruments discussed in a standard environmental economics text have little relevance to a complex pollution problem such as that faced in the prawn farming industry. It is impossible to judge, from the basis of simple conceptual models, which pollution control policy would result in the most efficient clean up. Empirical issues abound.

Some of the most important issues that need to be considered in the context of the prawn industry include the cost of efficient (enforceable) monitoring of direct effluent controls, and the costs of administering case-by-case policies. The question of uniform vs. targeted pollution controls can only be answered by considering the importance of farm specific factors on the production of effluent.

The economic cost associated with targeting new, point source polluting industries, at the expense of incumbent diffuse source industries, should be considered carefully. While it may be easier to target point source pollution, and while it may be politically difficult to impose strict control over long-established industries, the efficiency costs of such biased policies could be high. In the case of the emerging prawn farming industry, which is competing for "waste disposal" with the long established cane farming industry, this appears to be very important. The absence of an institutional framework for "buying out" pollution rights from incumbent industries has high opportunity costs.

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Appendix: Budgets and Other Parameter Assumptions Used in Analysis

Table A.1: Budget for a 20ha *Penaeus Monodon* (Black Tiger Prawn) Farm

Technical parameters		*Cost and Price Parameters*	
Pond Area ha	20	Feed Cost $/t	1500
Harvest Yield t/ha	6.51	PL price $/PL	0.017
Feed Conversion Ratio	2	Fertiliser and Chemicals $/ha	370
Stocking density PL per m^2	35	Casual Labour Costs $/kg	1
Growout time days	150	Electricity cost $/kwh	0.04
Survival %	60	Freight and packing $/kg	0.67
Harvest Weight g	31	Seasonal Other Costs $/ha	5980
Land Value (unimproved) $	12,000	Annual Other Costs $/ha	1620
Pond Depth m	1.5	Permanent Labour Cost $/farm	40000
Water Exchange %	20	Plant Interest and Depreciation $/ha/yr	8000
Pond volume ML	33	Earthworks $/ha/yr	1280
Aerator Capacity kw per ha	4	Land Purchase $/ha/yr	1315
Pumping rate kwh/ML	29	Total Capital Costs $/ha/yr	10595
Perm. Labour Req. persons	2	Overdraft Rate	0.08

	Costs per kg		Total Costs $'000 per farm	
Crops per year	1	2	1	2
Production kg	130200	260400		
Annual Capital	$1.63	$0.81	212	212
Fixed Operating	$1.78	$1.18	232	308
Seed	$0.91	$0.91	119	238
Feed	$3.00	$3.00	391	781
Fertiliser and Chemicals	$0.06	$0.06	7	15
Electricity	$0.89	$0.89	116	232
Casual Labour	$1.00	$1.00	130	260
Freight	$0.67	$0.67	87	174
Operating Interest	$0.67	$0.52	87	136
Operating Costs	$8.98	$8.24	1169	2145
Total Costs	$10.61	$9.05	1381	2357
Farm Gate Price $/kg	GROSS MARGIN		NET CASH INCOME	
$11	$2.02	$2.76	263	527
$13.4	$4.42	$5.16	576	1,151
$15.5	$6.52	$7.26	849	1,698
Farm Gate Price $/kg			FARM BUSINESS PROFIT*	
$11			51	315
$13.4			*364*	*940*
$15.5			637	1,486

* Net cash income less capital cost.