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COMMENTARY

The economics of the adoption of BMPs: the case of mariculture water management

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Abstract

How shrimp mariculture interacts with the natural environment is a topic receiving growing attention from industry members and environmental organizations. The farms' use of water, and subsequent discharge problems, represent important inter- and intra-industry externalities. The non-point source nature of the pollution problem suggests direct effluent regulation is unfeasible, and voluntary adoption of best management practices is the current approach favored by the industry and international organizations. This paper provides an in-depth analysis of one such management practice, reduced water exchange. Significant reductions in pond pumping diesel costs, alongside possible reductions in pond productivity and shrimp size, are expected from this technique. Social benefits could follow from the reduction of nitrogen and other effluent loadings. But adoption problems are expected due to the current inability to value longer-term private and social benefits of the practice and the risk-creating nature of the technique. Voluntary compliance with sustainable practices could be enhanced by complementary policy tools and a role of governments in coastal zone management. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Non-point source pollution; Best management practices; Shrimp aquaculture; Water exchange

1. Introduction

The effect of animal agriculture on water pollution is a growing concern for policymakers in the US and developing countries alike. Aquaculture is an often-ignored animal industry that can produce large volumes of effluents to surface waters. While aquaculture currently supplies about 12% of all marine fisheries products, farmed shrimp (mariculture) represents over 25% of the total crustacean supply (FAO, 1998). The industry provides large export revenues and some employment opportunities for many developing countries. However, industrial expansion has been associated with mangrove deforestation, larva by-catch overfishing, and estuarine water pollution (Bailey, 1988; ISAnet, 1998; Stanley, 1998).

The tenuous link between individual farm practices and ambient water quality makes maricul-

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ture water use a difficult non-point source pollution problem. Wastewater from mariculture comes from a large number of farms over a large area, at irregular times and levels. The voluntary adoption of 'win-win' best management practices is a common strategy for such non-point problems. Indeed, producer associations, such as the Global Aquaculture Alliance, are developing best management practices (BMPs) through codes of conduct and eco-labelling efforts (Boyd, 1999; GAA, 1999).

However, discussions with farm operators suggest several concerns about changing management techniques. Perceived fixed costs and production uncertainties are real obstacles to BMP adoption. There is a growing awareness of the need to integrate regulatory policy with the voluntary adoption of green technologies in the US (Segerson and Miceli, 1998). This paper concludes such integration should also apply to natural resource sectors such as mariculture.

2. Water use and mariculture enterprises

Farm-raised shrimp production in developing countries involves the stocking and pond grow-out of wild or laboratory seed to mature shrimp for harvest. During the 4-month production cycle, feeds, some fertilizers, therapeutants, pesticides, and pumped water are continuously added to the pond as the animals are fattened to around 20 g each. Stocking and feeding rates determine whether the operation is classified as extensive, semi-intensive or intensive shrimp farming.[1] Upon reaching the desired weight, the animals are harvested, deheaded and occasionally devined, and packed for export.

Mariculture requires a high volume of brackish water. A recent study by the Environmental Defense Fund estimates that intensively-farmed shrimp require 29 000–43 000 m^3 per ton of fish produced in aerated systems (Phillips et al., 1991, cited in Goldburg and Triplett, 1997). Semi-intensive operations use less water at an estimated 11 000–21 430 m^3 per ton of shrimp produced (Chien et al., 1988 cited in Phillips et al., 1993). Even with these lower bounds mariculture operations use more water to produce a metric ton of meat than other animal operations (Goldburg and Triplett, 1997). Shrimp farming also has been labeled an ecologically unsustainable 'throughput' system since it is so energy-intensive and concentrates pollutants (Folke et al., 1994; Larson et al., 1994). Pumped sea or estuarine water is an important free input used in mariculture, and the electricity or diesel-driven pumping process is the most energy-intensive part of production (Odum and Arding, 1991).

Semi-intensive mariculture operations need water for pond filling, routine exchange, and replacement for evaporation and percolation. Daily water exchange — flushing out and refilling a percent volume of pond water — is necessary to manage several environmental parameters, most notably phytoplankton as a source of pond dissolved oxygen levels (Boyd, 1982). Fish living in waters with low dissolved oxygen become stressed and eventually die. Tidal flows, wind power, or mechanical aeration can increase dissolved oxygen levels. Irregular electricity and expensive blower machines mean water exchange often substitutes for aeration in developing countries.

Fig. 1 displays these factors affecting a farm manager's decision around water use and exchange rates. The specific relationship between water use, pond yields, and marginal profits remains unclear, but most farmers feel that catastrophic losses are possible if poor water management pushes pond parameters below a critical minimum. Feed and other input practices (as well as the hydrology of the farm site and soils) affect effluent quality, while water use levels affect effluent quantity and the concentration of pollutants.

Shrimp pond effluents come from untreated discharges of excessive precipitation, discharges from routine water exchange to dilute pond nutrients, and discharges when the pond is drained

[1] Extensive operations have a low (population) density of animal stocking over a large area, with little supplementary feeding and environmental management. In contrast, intensive systems require stocking ponds at a higher density with controlled feeding and higher investment costs.

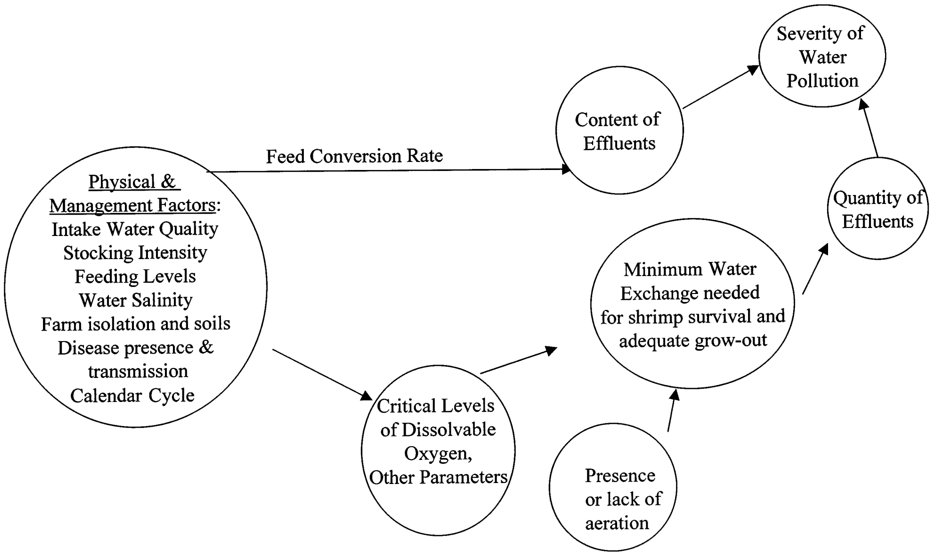

Fig. 1. Mariculture water use and pollution flow.

(Hopkins et al., 1995). To date there is no active market for pond waste products, so unused feeds and chemicals end up as effluents in public waterways. The wastewater may contain suspended solids, dissolved and particulate inorganic and organic nutrients, and high biochemical oxygen demand (BOD) (Hopkins et al., 1996; Browdy et al., 1997). Waste production is not constant over time as levels increase in the last quarter of the water discharge in pond draining (Boyd and Musig, 1992).

Estimates of total waste production vary widely. Boyd and Teichert-Coddington (1995) determine effluent loadings on semi-intensive Honduran shrimp operations are approximately 849 kg of carbon, 35 kg of nitrogen and 12 kg of phosphorus for 1000 kg of live shrimp produced. Higher loadings of 455 kg of nitrogen, 238 kg of phosphorus and 196 000 kg of total suspended solids per hectare have been observed even in low-density operations in Asia (Dierberg and Kiattisimkul, 1996). The common implications of these loadings include:

1. hypernutrification and eutrophication of adjacent estuaries with pond effluents,
2. impingement and destruction of estuarine biota through pumping,
3. increased sedimentation due to organic matter, and
4. reduced dissolved oxygen in receiving waters (Phillips et al., 1993; Hopkins and Sandifer, 1996).[2]

Mariculture water use most likely creates inter- and intra-industry social costs. Downstream artisanal fishing operations could be compromised. And neighboring mariculture operations are susceptible to pollution damage since a farm using poor incoming waters could have problems with algae blooms and depleted oxygen. The risk of disease transfer across farms increases; indeed, disease problems have caused farm bankruptcies in several Asian countries. The human health impacts of this water pollution are seldom mentioned. However, Seim et al. (1997) postulate that aquaculture's high water use may extend the distribution of snail habitat and possibly diseases such as schistosomiasis. Human consumers of fish products may be indirectly affected by chemical residues derived from pond waste. Lastly, un-

[2] Although this paper focuses on wastewater management, another aspect of water quality — seepage of brackish water from the culture pounds into groundwater supplies and increases in salinity levels — has been noted in Asia (Flaherty and Karnjanakesorn, 1995).

sightly and foul-smelling estuary water may reduce the enjoyment of potential recreational users of an estuary.

This typical externality problem around water use is described in Fig. 2. Mariculturalists face upward-sloping private (marginal) cost curves as (fuel and other) costs rise with increasing water exchange. The (private) benefits from using water exchange are initially high but then decrease. This leads to an initial equilibrium where costs equal benefits and a farm chooses to exchange water at a rate X (say 10%), resulting in a given quantity of effluent loads and marginal damages to other water users. The optimal water exchange rate for society would be at the lower point Y where total private and social costs cross the benefit curve.

But considerable debate exists as to the nature of these externalities. Some shrimp farmers argue that their contribution to water quality is a positive externality if waters flushed out of shrimp ponds are cleaner than up-stream source estuary waters (Acuacultura de Ecuador, 1997). To date, there are few studies to support this claim; however, Teichert-Coddington (1995) reports mean concentrations of inorganic phosphorus and nitrogen are higher upstream in riverine estuaries of

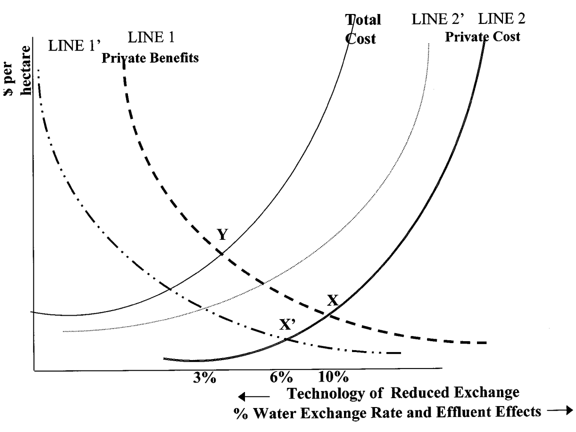

Fig. 2. Thick line represents private marginal costs water exchange (or benefits of reduced exchange). Medium thick line represents total cost of water exchange (private and social costs). Thin line represents benefits reduced exchange incorporating medium-term benefits. Broken thick line represents private marginal benefits of water exchange (or costs of reduced exchange). Thin broken line represents costs of reduced exchange incorporating smaller productivity losses.

southern Honduras than in gulf embayments below the shrimp farms. Other literature suggests aquaculture as an industry tends to produce a higher volume, but lower concentration, of effluents than other activities (Beveridge et al., 1991). Mariculturalists also argue they are victims of adverse externalities from other users of a waterway.

Thus the mariculture wastewater debate represents a non-point source pollution problem with moral hazard characteristics. Monitoring each farm's water canal is infeasible. Weather uncertainties and other stochastic variables outside a farmer's control complicate the matter. This creates an imperfect information scenario in which the management effort of an individual farm cannot be perfectly correlated with pollutant concentrations or other observed water quality indicators. And while pollution damage varies over time and distance, the dispersal path of shrimp farm waste has not been fully investigated. Additionally, confusion still exists as to the critical levels of waste from individual farms or whether farms as a group threaten ecosystem recovery by damaging ambient levels beyond a safe minimum standard. The pollution issue ultimately turns on the number and size of farms in an estuary, the carrying capacity of the watershed, and whether receiving waters can dilute wastes.

Griffin and Bromley (1982) suggest constructing a "pollution production function" relating inputs and management practices to the generation of such non-point source pollution. The aquaculture literature suggests a chain of causation between water quality damage and excessive feed rates, feeds with high nitrogen content, antibiotics and fertilizers, and high water exchange rates. These inputs have been targeted in the industry discussion of the voluntary adoption best management practices as a non-regulatory solution to the water pollution problem.

3. The voluntary adoption of best management practices

Best management practices (BMPs) are a logical short-run alternative given the informational problems around non-point source water pollution. An innovative aspect of many BMPs is their focus on pollution prevention by reducing the quantity of inputs that cause run-off and emissions. This, of course, parallels similar developments in the industrial ecology and green manufacturing literature around profit enhancement and pollution reduction through preventing waste or developing by-products that use waste products (Hawken, 1993). Such cost-saving strategies should be profitable or profit neutral to businesses. The following six best management practices could reduce mariculture water effluents while maintaining farm profitability (Hopkins et al., 1995; Dierberg and Kiattisimkul, 1996):

- On-farm intake or effluent treatment plants (settling basins or constructed wetlands)
- Sludge removal
- Co-production schemes
- Improved feed and fertilizer management
- Lower stocking rates
- Reduced water exchange or even closed recycling systems.

The first three options are 'structural BMPs', which require fixed investments and significant capital outlay (Lichtenberg et al., 1993). For instance, although settling basins remove significant amounts of suspended solids, BOD and phosphorus, this form of effluent treatment is problematic since it may require taking land out of production (Pillay, 1992, cited in Goldburg and Triplett, 1997). The last three are 'managerial BMPs' requiring changes in variable input use. Better feed management lowers costs while reducing pollution. Feeding trays are a small investment likely to lower feed conversion ratios.[3]

The analysis here focuses on the less-known option of reduced water exchange since it involves no fixed costs and gives immediate reductions in pumping operating costs. Reduced water exchange could involve lowering the daily rate, reusing water in a nearby pond, or complete recycling and elimination of exchange. Lower exchange reduces effluent quantities by decreasing the amount of water flushed from a pond. And reduced water exchange enhances in-pond digestive processes and shrimp growth rates under well-managed feeding systems (Leber and Pruder, 1988; Browdy et al., 1997).

Experiments at the Waddell Mariculture Center in South Carolina suggest water exchange of intensive shrimp farming can be reduced (or nearly eliminated) without sacrificing growth or survival as long as dawn dissolved oxygen levels are maintained (Browdy et al., 1993; Hopkins et al., 1993). Developing country farms stocking at lower densities without supplemental aeration represents a more challenging experimental setting. Lin (1995) and Dierberg and Kiattisimkul (1996) provide examples of successful reduced exchange in Asia with or without the use of supplementary aeration. A recent experiment in Ecuador reducing water exchange from 10% daily in a control pond to approximately 2.5% daily in neighboring ponds demonstrated no significant differences in survival and growth across ponds (Calderon et al., 1998). However, Martinez-Cordova et al. (1995) find high 10–15% daily water exchange rates are necessary for shrimp growth, survival and yields in the saline environment of western Mexico.

Reduced exchange is still not widely practiced among the thousands of shrimp farm operators in Asia and Latin America. Exchange rates of 5–25% daily in semi-intensive farming, and 30% daily for intensive operations, remain the norm (Rosenberry, 1997). Many farmers still do not perceive the private financial benefits of water amendments implemented on a commercial scale (Stern, 1995). The next section explores the logic of farmers' decisions and problems associated with this technical solution to water pollution.

4. The adoption dilemma around BMPs

Discussions with mariculture operators suggest at least two concerns around changing important management parameters such as water exchange. These issues of perceived profitability and risk management could be barriers to the adoption of waste reduction strategies in other forms of animal agriculture.

[3] The feed conversion ratio is the quantity of feed used per kilogram of shrimp biomass produced.

Table 1
Reduced water exchange BMP costs and benefits

Techniques	Private costs	Private benefits	Public benefits
Lowering daily rate of pond area exchanged; reusing water across ponds	Short-run: animal stress, possible smaller shrimp or mortalities (reduced pond productivity)	Short-run: lower pumping costs, maintenance/depreciation costs	Lower quantity of estuary water used
		Long-run: possible reduced fertilization needs; possible disease avoidance	Possible water quality enhancement: reduced suspended solids and dissolved nutrients help retain fish stocks; possible reduction of human health impacts; improved enjoyment of recreational users

4.1. Valuation problems

First, financial analyses to date have not demonstrated an overwhelming economic gain through the adoption of BMPs. Most scientific experiments examine how new practices affect farm productivity, with only a few enterprise budgets suggesting the innovations are profit-neutral rather than highly profitable. A recent experiment in Ecuador showed that the internal rate of return of a low water exchange system just equaled that of the higher exchange methods (Stanley, 1999). This is because although reduced water exchange decreases diesel-pumping expenses, algae growth and lower oxygen levels may compromise pond productivity resulting in smaller (lower-priced) animals and disease risk. And farmers often tend to overestimate these short-run pond productivity losses of reduced exchange. Returning to Fig. 2, the intersection of the reduced exchange costs and benefits of lines 1 and 2 at 10% incorporates such an overvaluation. If farmers knew the true marginal cost curve of reduced exchange (line 1′), a 6% water exchange rate could be both socially and privately optimal.

And the financial analyses often overlook important medium-term benefits of BMPs since they are difficult to quantify and value. Table 1 summarizes the wider range of financial benefits that could accrue to mariculture operations using reduced water exchange. Additional cost-savings may occur as benefits through reduced screen maintenance and soil fertilization costs. And reduced exchange may guard revenue streams by lowering the risk of cross-farm contamination of endemic water-borne diseases when a farm uses less incoming water containing wild animals or infected effluents.[4] If these longer-term benefits of reduced exchange were quantifiable, line 2 in Fig. 2 would shift left to line 2′—implying the lowest exchange rate at 3% (Y) is now privately optimal. Incorporating the public benefits of cleaner water makes the socially-optimal point of water exchange even smaller.

Yet in nearly every case, there is not enough scientific data to calculate the technical coefficients between water management and disease avoidance, yield changes, or other parameters necessary to value the benefits. Incomplete information about costs and benefits fuels the current logic of higher water use. As long as ecological benefits, and future private benefits, are omitted, the voluntary adoption of BMPs may be hampered.

[4] The transmittal process of some diseases facing the industry, such as Tauro syndrome, is still debated, but the links between water and other diseases (such as white spot and yellowhead) may be clearer (Rosenberry, 1997; Chou et al., 1998); for a description of relevant pathogens and their vectors, see Lotz et al., 1995.

4.2. Production uncertainty and income risk

Farmer risk aversion is an important barrier to the adoption of new technologies. Best management practices such as reduced exchange may appear profit neutral in one-time experiments. But production uncertainties of the new technique create a degree of downside income risk that necessitates a higher return. Income risk stems from two sources. First, some farmers believe there is a probability of greater disease transfer by reducing water use since animals become more stressed. Second, there is a low, but positive, probability of catastrophic losses if phytoplankton crashes create low dissolved oxygen levels in a pond. This loss from water quality deterioration could be especially painful as it most likely occurs in the latter part of the cycle after the largest cost outlays. Thus expected net returns (income levels weighted by the farmer's perceived probabilities of good and bad events) could be lower under some BMPs, such as reduced exchange, as compared to the traditional high exchange technique. Since exchange reductions increase yield variance, it may be expected that risk adverse farmers would use this practice less frequently than in a no-risk environment.

Inadequate risk-sharing mechanisms magnify this problem. Most shrimp farmers in developing countries have little recourse — in terms of ex-post-emergency lines of credit or state-contingent insurance payments — for production losses. The design of insurance contracts to assist in removing the downside risk associated with best management practices is just starting in US agriculture. The likelihood that such contracts are offered to the mariculture industry is low since there are few exposure units, it is difficult to separate the effects of management and nature in determining the cause of loss, and there is yet no calculable chance of loss.[5]

[5] For a description of the risks that are insurable, see Rejda, 1995.

5. Conclusions and returning to the role of policy

Mariculture waste disposal represents a thorny non-point source pollution problem with impractical monitoring and extreme informational uncertainties. Best management practices are the most commonly discussed solution to enhance the industry's own sustainability, with the side-effect of broader environmental benefits. Since, currently, there is little use for pond waste products, the BMP strategy aims to reduce waste by reducing inputs.

But the story of the reduced water exchange practice demonstrates some of the problems involved in finding environmentally friendly techniques that farmers are enthusiastic about. It suggests the voluntary approach — with little role for governments — is not likely to lead to adequate pollution reduction in the immediate future. Many farmers' high input use is logical given the business goals of assuring animal survival and maximizing harvest size. The inability of scientists and policymakers to quantify the longer run private and social benefits of best management practices adds to a misunderstanding of the sacrifices associated with changing techniques. Additionally, many farmers perceive that new practices have uncertain outcomes that create yield and income risk.

Producers hope demand-side interventions (eco-labelling) could give farmers a price premium for sustainable shrimp farming and increase the likelihood of voluntary adoption. Consumers will have a hard time visually distinguishing which shrimp are farmed with best management practices so certification is necessary. A sustainable product price premium — which may decrease the probability of purchase yet still increase total farmer revenues — is yet to be determined. Clearly this is a long-run approach which will have to consider differences by species, geographical region and consumer group (Wessells et al., 1999).

Meanwhile, the reality of imperfect and incomplete information about the causes of pollution, along with the absence of risk management devices, epitomizes a 'second-best' scenario with numerous market failures. There is a role for government since the social rate of return associated with best management practices is probably higher than the private returns (Leathers, 1991). Probably no single government policy, or producer association program, will be adequate to control the range of mariculture water pollution problems in a variety of settings. As moral hazard theory suggests, direct regulation of effluents and end-of-pipe solutions are problematic due to the imperfect correlation between shrimp producer actions and ambient quality levels. The difficulty in measuring effluents also reduces the feasibility of tradable permits or the strict enforcement of existing liability laws in developing countries.

Three logical alternatives stand out in the informationally-constrained setting of mariculture. First, better valuation of the private and public non-market benefits of best management practices is needed. Market valuation methods cannot yet capture the productivity changes of mariculture and artisanal fisheries due to farm water exchange. Once the correlation between disease transfer and high water exchange is established, then the disease avoidance-benefit of low water exchange may be calculable. The defensive treatment expenditures shrimp farmers currently make might provide a minimum value of the benefits of clean intake water. Likewise, a dose-response relationship between water exchange practices, nutrient loadings, and the quantity of artisanal fish declines must be established. Measuring the fishermen's defensive expenditures (i.e. travel to more distant, cleaner, sites) is an alternative valuation method. Willingness-to-pay (WTP) estimates derived from contingent valuation surveys are another option. As Smearman et al. (1997) mention, this WTP represents how much users would offer to restore the water to its former unpolluted state; it thus captures each shrimp farmer or fisherperson's estimate of the damage attributable to high loadings.

Measurement of the human impacts of shrimp farm water use presents an even greater challenge. Travel cost or contingent valuation surveys could provide estimates of how present or future recreational users of an estuary (national or foreign ecotourists, recreational boaters or hunting enthusiasts) value clean water. Information derived from previous valuation exercises of relevant ecotourism might be transferred to estimate the public benefits of cleaner coastal zone water quality around shrimp farms.[6] If scientific evidence emerges to clarify the dangers of waterborne disease transfer, calculations of the health care costs and loss of earnings by downstream estuary users would be appropriate in assessing the benefits to reduced exchange. Clearly, funding for research into the relationship between mariculture waste loadings and fish yields, and the risks associated with the waterborne transfer of diseases to shrimp farms and other pathogens, is needed.

Second, input-based incentives build on the momentum of producer-led initiatives around best management practices. The normal route is to tax inputs that increase a detrimental externality and subsidize inputs that reduce it (Griffin and Bromley, 1982). Since high stocking rates, feed and water use are detrimental to water quality, analysts are increasingly recommending taxes on inputs such as larva and feed (Thongrak et al., 1997; Brennan, 1999). Water use charges (or increases in the price of the complementary diesel input) would stimulate a reduction in exchange in a sensitivity analysis conducted on Ecuadorian data (Stanley, 1999).

Overcoming political obstacles to environmental taxation in developing countries requires innovative strategies. Removal of subsidies on feeds, diesel, therapeutics, and other inputs is a possibility. Another option (used for electricity nitrogen oxide emissions in Sweden) is to refund input tax revenues back to producers proportionate to their output levels (Blackman and Harrington, 1999). Such a scheme rewards producers who generate little waste and penalizes operations with inefficient input-output systems. Or tax revenues could fund a program of subsidies for 'improved' inputs. Low protein or organic feeds, and substitutes to the fishmeal base in mariculture (Goldburg and Triplett, 1997), would enhance water quality and reduce the threat of low dissolved oxygen levels under reduced exchange systems. Aerators, feeding trays to enhance feed conversion ratios, and pond liners also reduce

[6] For an overview of the benefits transfer method, see Desvousges et al., 1998.

stress in the water system. Since these innovations reduce the low dissolved oxygen risk, their subsidization would be an indirect method of enhancing the adoption of low water exchange systems.

Third, managerial practice standards could be incorporated in incentives and permits. Farmer payments or fines would be linked to observables correlated with their effluent abatement efforts and input purchases. Generally, the non-point source pollution literature recommends charging farmers with high input activity levels above a baseline while subsidizing those using lesser activity levels (Griffin and Bromley, 1982). For instance, mariculture operators who purchase feeds beyond a per-hectare quota could be charged an extra fee while farmers purchasing less receive a rebate. Tracing residues in shrimps as they are received at packing plants could provide a signal of farm chemical or antibiotic use. Other visual indicators (such as diesel expense records for water pumping) could be used in the allocation and renewal of operating permits and licenses, a policy advocated by environmental activists (ISAnet, 1998).

These alternatives suggest that a combination of several research and policy efforts may enhance the attractiveness of reduced exchange and improve water quality. Agricultural non-point source pollution programs in the United States are moving towards multiple policy instruments and mandating minimum enforceable BMPs (Malik et al., 1994; Segerson and Miceli, 1998). This means mixing the 'carrots' of cost-sharing and subsidies with 'sticks' of background threats of fines or penalties if voluntary adoption is not reached by a certain date (Segerson, 1998). Such an approach could be useful to guide the relationship between government regulators and the mariculture industry. Indeed, regulation as a background threat may spur cost-saving environmental innovations in mariculture. The well-known Porter hypothesis suggests that pressures placed on firms will provide incentives to innovate, and such innovations may be cost-reducing for a win-win private and public benefit (Porter and van der Linde, 1995; ELI, 1999). Ultimately, the reduction of waste by the mariculture industry will help ensure the ecological sustainability of many coastal zones as well as the industry's own future.

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