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THE ENVIRONMENT AND THE SELECTION OF AQUACULTURE SPECIES AND SYSTEMS: AN ECONOMIC ANALYSIS

Abstract

Environmental conditions play a significant role in the economic success of aquaculture. This article classifies environmental factors in a way that facilitates economic analysis of their implications for the selection of aquaculture species and systems. The implication of on-farm as on-site environmental conditions for this selection are considered first using profit-possibility frontiers and taking into account the biological law of environmental tolerance. However, in selecting, recommending and developing aquaculture species and systems, it is often unrealistic to assume the degree of managerial efficiency implied by the profit-possibility function. It is appropriate to take account of the degree of managerial inefficiency that actually exists, not all of which may be capable of being eliminated. Furthermore, experimental R&D should be geared to on-farm conditions, and the variability of these conditions needs to be taken into account. Particularly in shared water bodies, environmental spillovers between aquaculturalists can be important and as shown theoretically, can influence the socially optimal selection of aquaculture species and systems. Similarly, aquaculture can have environmental consequences for the rest of the community. The social economic implications of this for the selection of aquaculture species and systems are analyzed. Some paradoxical results are obtained. For example, if the quality of social governance of aquaculture is poor, aquaculture species and systems that cause a slow rate of environmental deterioration may be socially less satisfactory than those that cause a rapid rate of such deterioration. Socially optimal choice of aquaculture species and systems depends not only on their biophysical characteristics and market conditions but also on the prevailing state of governance of aquaculture. Failure to consider the last aspect can result in the introduction of new aquaculture species (and systems) doing more social harm than good.

THE ENVIRONMENT AND THE SELECTION OF AQUACULTURE SPECIES AND SYSTEMS: AN ECONOMIC ANALYSIS

1. Introduction

Environmental conditions play a major role in the economic success of aquaculture. They affect significantly the economic value of farming particular species, the returns from genetically improving aquaculture species, the economic relevance of selection for particular genetic traits, and the economic value of particular aquaculture techniques and systems. The purpose of this article is to show how economic analysis can be used to guide the selection and development of aquaculture species and systems taking into account environmental factors.

The presentation will in turn examine on-site or on-farm environmental issues, those involving environmental spillovers between aquaculturalists, and wider ranging environmental spillovers from aquaculture. Considerations of these factors are important in trying to achieve sustainable aquaculture (Shang and Tisdell, 1997). Figure 1 illustrates schematically the areas of proposed coverage. However, the coverage is of necessity selective given that this is a very broad subject.

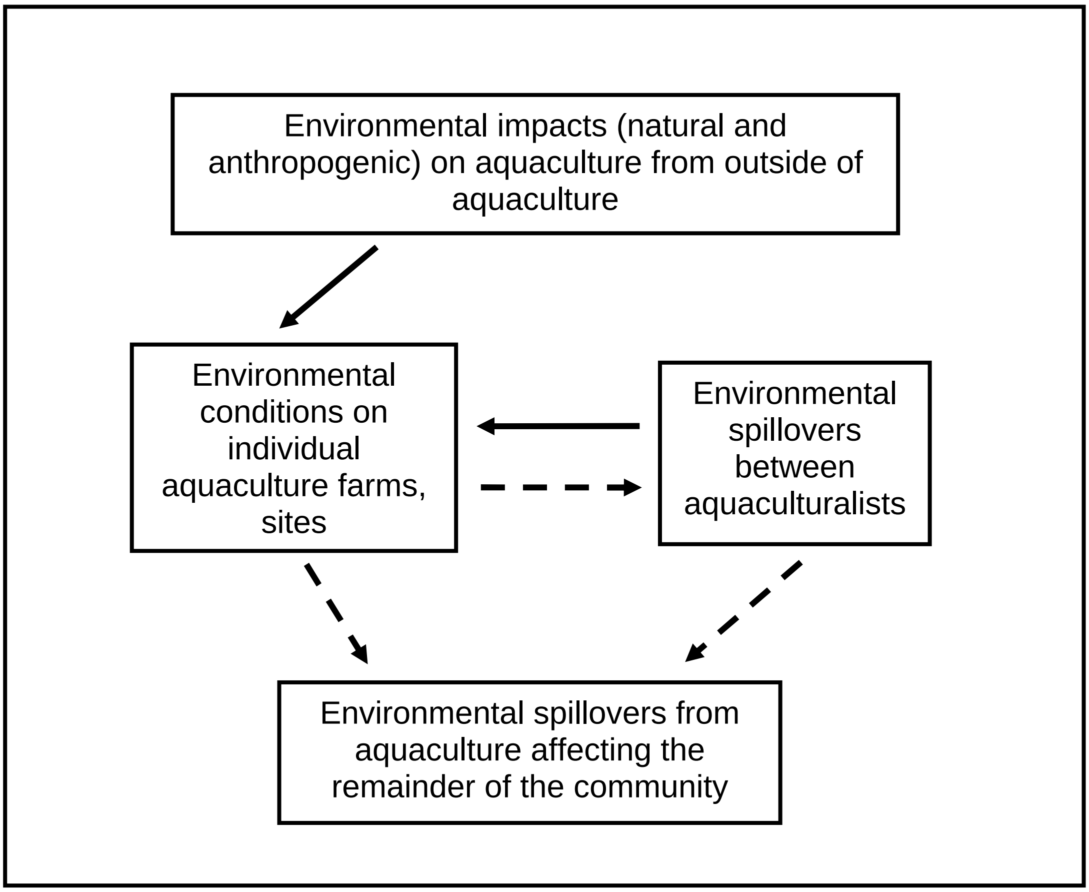

Figure 1 A representation of environmental factors of consequence for the selection of aquaculture species and systems.

At the outset, it should be noted that the rational selection of aquaculture species and systems depends on the objectives of the choice. These objectives can differ between stakeholders or groups of stakeholders. General objectives may include maximizing the economic benefits obtained by individual aquaculturalists, maximizing the benefits to a whole group of aquaculturalists, or optimizing social economic benefit. However, each of these objectives can have a variety of interpretations, and relevant objectives are to some extent situational.

Profitability may be used to measure of economic benefit in the first two instances, and the Kaldor-Hicks test is frequently applied in the last case to determine social economic benefit. The Kaldor-Hicks criterion (sometimes called the potential Paretian improvement test) judges an economic change to be a social improvement if the gainers could compensate the losers for their losses and remain better off than before the change. However, these are not the only possible measures of economic benefit, and even these measures are subject to varied interpretations.

2. On-site or On-farm Environmental Issues and the Selection of Aquaculture Species and Systems

When considering the impact on yields or profits from aquaculture of on-site or on-farm environmental conditions, it is useful to keep the biological law of environmental tolerance in mind (Tisdell, 2003, Ch.3). This law posits that the yields from a species (or a strain or variety of it) is a unimodal function of a relevant environmental variable, other things constant. It is commonly assumed to have the shape of a normal probability distribution, that is, to be bell-shaped. For a considerable proportion of its domain, the yield function is strictly concave.

Where y represents the level of yields and ξ is the value of an environmental variable, the left-hand curve in Figure 1 might represent the biological tolerance curve for one species or strain, A, and the right-hand curve that of another, B. If the environmental variable is less than ξ_1, then species A will be the best choice for maximizing yield, otherwise B is.

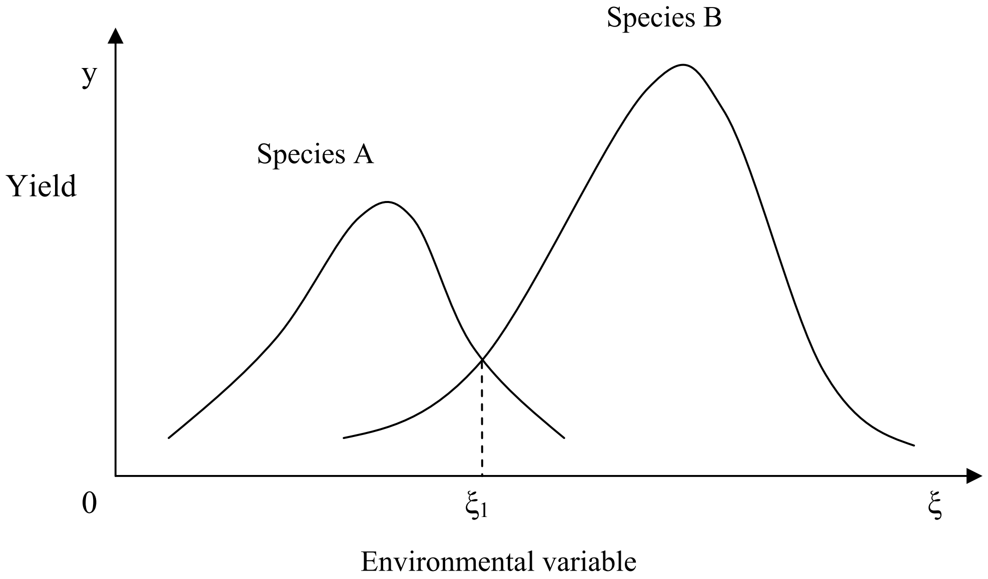

Figure 2 Biological yields for two different species. The relationships are of the type suggested by the biological law of environmental tolerance.

However, aquaculturalists can adjust their farming practices to prevailing environmental conditions so as to maximize their profit relative to environmental conditions. Taking into account the biological tolerance of a species, production control or transformation possibilities, and market conditions, the maximum profit an aquaculturalist can earn as a result of cultivating a particular species (given the available technologies or systems) can be expressed as a function of prevailing environmental conditions. Let π_i represent the maximum profit from cultivating the i-th species, p_i be the price per unit obtained from the sale of its produce, let f_i represent the production function, x represents the quantity of a controlled input, and w is its price per unit. Then the profit function of the aquaculturalists is

$$\pi_i = p_i f_i(x, \xi) - wx \tag{1}$$

This can be generalized to take account of multiple independent variables.

Consequently, maximum profit of an aquaculturalists, if the i-th species is selected, can be expressed as a function of the prevailing environmental condition, ξ, that is as

$$\text{Max } \pi_i = g_i(\xi) \tag{2}$$

This is illustrated in Figure 3 for two alternative species A and B. The profitability curve on the left shows maximum profitability if species A is adopted and that on the right shows this if species B is selected.

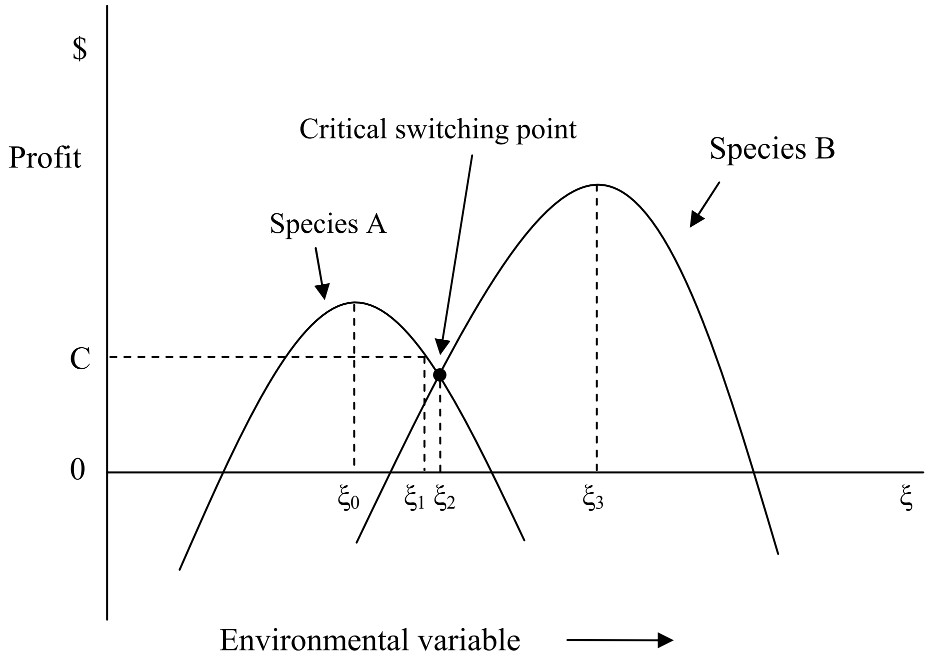

Figure 3 An aquaculturalist's maximum profit from two alternative species as a function of a relevant prevailing environmental condition. These functions are in effect profitability frontiers.

From an economic point of view, an environmental condition of ξ_0 is ideal for species A and ξ_3 for species B. However, environmental conditions may be such that maximum profit cannot be earnt from a species. For example, if environmental condition ξ_1 prevails, maximum profit of only 0C can be earnt. The value ξ_2 of the environmental variable is critical in determining the most profitable choice of species. If $\xi < \xi_2$, species A is most profitable and if $\xi > \xi_2$, species B is most profitable, provided the environmental condition is such as to make a profit possible.

In a dynamic situation, it is possible that ξ may initially exceed ξ_2 but drift downwards, either due to endogenous environmental change on the farm or due to exogenous environmental impacts. Therefore, while selection of species B is initially optimal, species B is subsequently optimal in the exogenous case. This may also be so in the endogenous case but the exact nature of the dynamics would need to be considered. There may, for example, be a possibility that the initial cultivation of species B may make the local environment very unsuitable subsequently for the culture of species A. For instance, if ξ is just slightly larger than ξ_2 and species B is cultivated, ξ may eventually collapse to a value near the origin in Figure 3.

The above theory assumes that aquaculturalists will be fully efficient in cultivating species. However, this is unlikely to be so and it is also possible that differences in efficiency exist between farmers in culturing different species. Furthermore, maximizing profit from some species may require greater managerial effort and skill than for others. When systematic differences of this type exist, this can alter the optimal choice of species. For example, let the upper curves in Figure 4 represent the maximum profit for culturing species A and species B as before. However, suppose that an aquaculturalist finds it difficult to manage species B optimally but not species A. After allowing for managerial inefficiency, the aquaculturalist's realized profits from cultivating species might be as indicated by the heavy line in Figure 4. Whereas, in the absence of managerial inefficiency, selection of species B would be optimal for $\xi > \xi_2$, this is not optimal when managerial inefficiency occurs. B should only be selected when $\xi > \xi_3$.

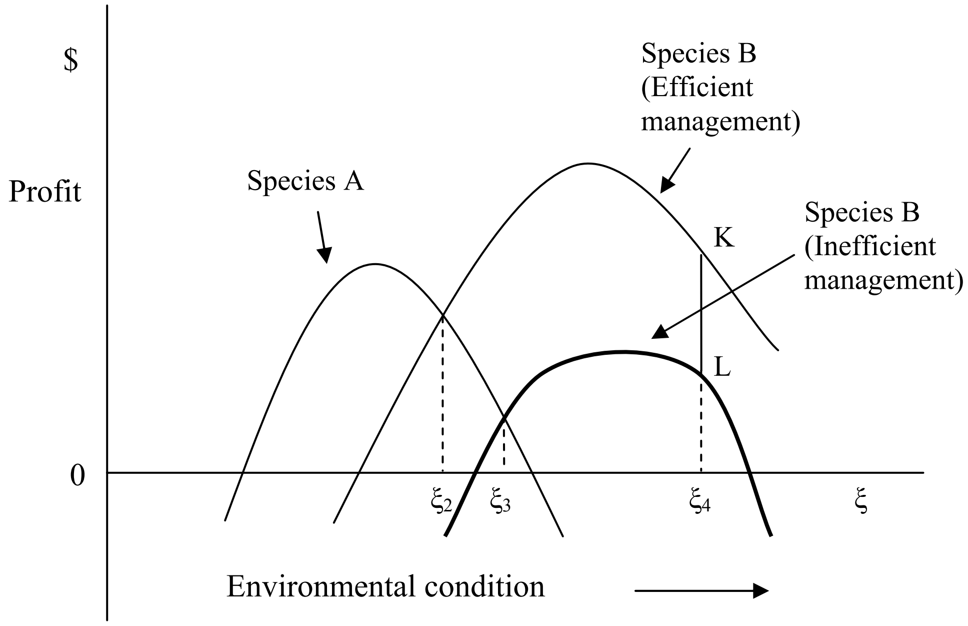

Figure 4 Differences in the efficiency involved in managing different species will affect their optimal selection relative to environmental conditions. In this illustration, KL represents the loss in profit due to managerial inefficiency when $\xi = \xi_4$ and species B is selected.

Instead of interpreting the above relationship as corresponding to different species or strains of the same species, they can be reinterpreted so as to apply to different aquaculture systems.

In practice, the optimal selection of species or systems is more complicated than allowed for in the above modeling. For example, on-site environmental conditions may be variable and subject to some uncertainty both in relation to time and the geographical location of sites. This will affect the optimal choice of species and systems (see Tisdell, 2003, Chs. 2 and 3) and the optimal type of research focus and extension recommendations by research bodies (Tisdell, 1996, Ch.10). Other things equal, greater variability of environmental conditions will favor species that are more tolerant of environmental change compared to those that are less tolerant and will favor those aquaculture systems for which profits are less sensitive to environmental variation.

Public research bodies, such as WorldFish, selecting species or strains of species (or production systems) for use on aquaculture farms need to pay particular attention to the environmental conditions that will be encountered on farms and the ability of aquaculturalists to manage the species given on-farm environmental conditions. There is little point in developing a strain of a species that is highly profitable under ideal experimental conditions but which does not adapt well to actual farm conditions. It needs also to be borne in mind that on-farm environmental conditions may vary between farms. Should a species or a strain be selected so that it is most suitable for average on-farm environmental conditions (Tisdell, 1996, Ch.10)? Should a range of strains be developed for farms with different environmental conditions? How many strains should be sought given that research funds are limited and extra cost in involved in selecting for different strains of a species? Similar types of issues arise in the development of aquaculture systems.

3. Allowing for Environmental Spillovers or Externalities between Aquaculturalists

Environmental spillovers can occur between aquaculturalists in a variety of ways (Tisdell, 2004, p.255; 2003, Ch.1). I'll concentrate here on just one simple case; a case in which several aquaculturalists share a common water body to which either their activities 'add pollutants' (e.g., reduce the oxygen content of the water) or extract nutrients from the water column in a manner that affects all equally. This may, for example, be approximately satisfied in some lakes in which cage culture is practiced, such as Lake Taal in the Philippines. There is in effect open-access to the shared water body for dumping pollutants or extracting nutrients.

My purpose is to illustrate how under these conditions the optimal social choice of species and aquaculture system can be quite different, depending upon whether or not the type of spillovers mentioned above can be controlled by authorities by regulating stocking of the shared water body with aquaculture specimens. It will also be shown that the socially optimal choice of species or techniques when open-access occurs is not intuitively obvious in these cases. Figure 5 will be used to illustrate this matter.

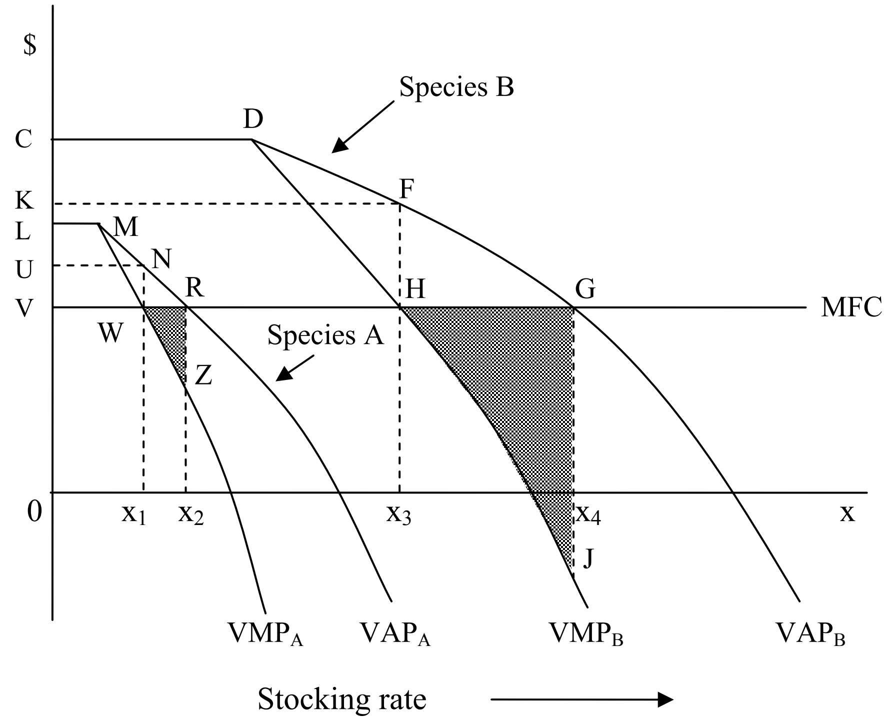

Figure 5 An illustration of how the socially optimal economic selection (using the Kaldor-Hicks test) of an aquaculture species alters according to the degree of collective control of its use

Suppose, for simplicity, that the marginal cost of the aquaculture operations in the shared water body is the same for all aquaculturalists and depends on the stocking rate. It is represented by line VG in Figure 5. Suppose that the farms may either be stocked with species A or B and that the marginal cost is the same for both. Assume further that the prices received for sales of species A and B are constant. The value of the marginal product of species B is indicated by CDJ and the corresponding value of its average product is CDG. The value of the marginal product of species A is shown by LMW and the value of its average product by LMR. Species A is less productive than B, and if the stocking rate could be optimally controlled, B would be economically preferred to A. The socially optimal level of stocking, if species A is adopted, is x_1 and if species B is adopted, it is x_3. For these stocking levels, the values of the marginal products equal their marginal factor cost. Species A earns a rent equal to the area of rectangle VWNU and species B a rent equal to the area of rectangle VHFK. The rent from the latter is much higher than the former and indicates that it is the superior social economic choice.

However, if access to stocking the water body is not controlled, x_2 becomes the stocking rate if species A is adopted and x_4 is the stocking rate if species B is adopted.

At these stocking rates, the average value of the product from aquaculture equals the average cost of the factors use to produce it and all rent is exhausted. When open-access occurs to a shared water body for its stocking with aquaculture specimens and those stocking it retain private property rights in the specimens they add to it, the level of stocking in the shared water body will increase until all rents from aquaculture within it are exhausted. This accords with the predictions of the economic theory of the use of open-access property (Gordon, 1954).

The marginal product from species A declines at a faster rate with its increased stocking (due to adverse environmental externalities) than it does for species B. This results in a smaller social deadweight loss for species A (an amount equivalent to the area of triangle WZR) than for species B, an amount equal to the area of triangle HJG. Thus, the social deadweight loss, given open-access, will be least if the species is selected that causes the most rapid decline in productivity, as a consequence of adverse environmental spillovers between aquaculturalists. To some, it may be surprising that the relationship is not opposite to this. The result is not at first intuitively obvious.

These relationships can also be easily re-interpreted so that they apply to two different aquaculture systems, A and B.

A policy implication of the above analysis is that if authorities cannot control common access to a shared water body, they should (if they permit aquaculture in it and if a series of alternative species or systems can be chosen) ensure that the aquaculture species or system chosen is the one that results in the most rapid reduction in the marginal productivity of aquaculture with increased crowding of aquaculture in the shared water body. Such a decision, however, is unlikely to be politically popular. However, the optimal choice of species or systems is likely to be different if aquaculture use of the shared water body can be effectively regulated by public authorities.

Observe that Figure 5 has another implication: new species, strains of species or new systems that increase aquaculture productivity may increase the social deadweight loss in the open-access case (cf. Tisdell, 2005, Ch.6). For example, this occurs if technological progress of this nature causes the value of the average product curve in Figure 5 to shift from VAP_A to VAP_B. This is the opposite effect to that which would occur if aquaculture use of the water body could be optimally regulated from a social point of view. With optimal social regulation or independent private property rights, technological progress will always result in a social economic gain and, in this case, an increase in rents earned by aquaculturalists, but not in open-access situations. One suspects the latter is quite frustrating for researchers and policy-makers. Note, however, that if technological progress in the open-access case causes the value of marginal product and value of average product curve of aquaculture to move to the right but to become steeper, then the social deadweight loss would decline in this circumstance.

4. Environmental Spillovers from Aquaculture on other Sectors of the Community

Aquaculture can have both positive and negative spillovers, some examples of which are given in Shang and Tisdell (1997, p.141), but adverse environmental externalities from aquaculture are the main analytical focus here. Aquaculture activity, although it can be economically beneficial overall, can have adverse external effects on other sectors of the community (Tisdell, 2004). This may have social implications for the optimal choice of aquaculture species and systems. In shared water bodies, there may, for example, be adverse environmental spillovers on the capture fisheries (Tisdell, 2003, Ch.28), on water-based recreational activities such as swimming and boating or on visual amenity. There may also be wider environmental spillovers of the type discussed by Barbier and Sathirathai (2004). Where aquaculture involves the introduction of exotic species for culture, there may be a risk of feral populations with adverse consequences for local biodiversity. Simple economic models can be used to help visualize the issues involved. For example, the social net benefit from the adoption of one aquaculture species or system may dominate that of another but private choice may not result in selection of the socially optimal species or system. Figure 6 illustrates such a case.

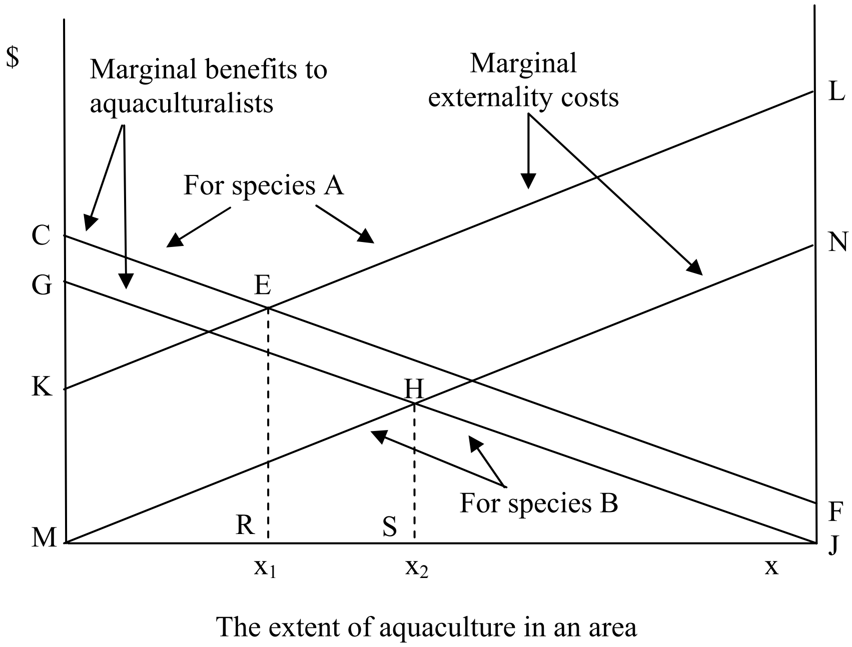

Figure 6 In the case illustrated, social cost-benefit analysis indicates that only species B should be cultured in the focal area and the aquaculture of species A should be banned.

In Figure 6, the line CF represents the economic benefit to aquaculturalists of culturing species A and GJ indicates that from cultivating species B. If left to make a free choice, aquaculturalists will select species A. Suppose that the marginal external costs imposed by the culturing of these species is as respectively shown by lines KL and MN. The comparative extra marginal benefit to aquaculturalists of culturing species A rather than B (equals GC) is less than the extra social marginal externality cost of cultivating it, MK. Therefore, net social benefit will be maximized if species B is cultured rather than species A. Authorities would maximize net social benefit by banning the culture of species A. Note that it would not be an optimal solution to place a tax of ER on each unit of aquaculture activity in the area because this will not induce switching to species B. It will, however, be socially better than not regulating the extent of aquaculture at all. However, if use of only species B is allowed, then a tax on each unit of aquaculture development of HS would generate a Pareto optimal solution.

Although in the case illustrated in Figure 6, culture of species B is socially better than the adoption of species A, culture of either species is socially better than no aquaculture if aquaculture is adequately (but not necessarily perfectly) regulated. In fact, if KL and MN are low enough compared to CF and GJ, aquaculture, even if unregulated, of either species will be socially better than no aquaculture. This assumes that the Kaldor-Hicks or potential Paretian improvement criterion is applied. Conversely, if KL and MN are high enough compared to CF and GJ, it will be socially unsatisfactory to culture either species. All the conditions can be easily specified for which aquaculture is socially superior to not having aquaculture and the aquaculture species for which this is so can be identified.

Figure 6 can also be used to demonstrate that technological progress that benefits aquaculturalists may result in reduced social economic welfare, if the new technologies (or species) generate significant negative environmental externalities that are not regulated. For example, if only species B is available initially (or a system corresponding to it), then when species A (or technique A) arrives or is developed, the social deadweight loss from aquaculture in the area increases from an amount equal to the area of triangle HJN to an amount equal to the area of triangle FEL. The area of quadrilateral GJFC represents the extra benefits to aquaculturalists of A compared to B. The size of this benefit may be less than the increase in externality cost occurring with the switch from A to B. Therefore, total economic benefit from aquaculture in the area may decline, even though a ‘superior’ aquaculture species or system is developed. This failure may occur because the social administration or management is defective.

It is, however, possible that a new technique or species may generate greater profits for aquaculturalists and also reduce negative environmental spillovers. In that case, its adoption would result in a win-win social change, even if there is open-access. For example, this would arise if the line of marginal external damages with species A, KL in Figure 6, happened to fall below MN rather than above it.

A non-trivial issue in practice is how should externality costs be estimated. For example, should they be based on the willingness to pay of ’victims’ of the adverse spillovers to avoid these spillovers or on their willingness to accept compensation to permit a negative externality. Knetsch and others (Knetsch and Sinden, 1984; Kahneman et al., 1990; see also Pearce and Moran, 1994, pp.17-18) have shown that these different approaches may yield substantially different estimates of spillover cost. In general, the willingness to accept estimates are higher than the willingness to pay amounts to avoid an adverse externality. These results imply that the Coase theorem (Coase, 1960) is unlikely to be satisfied even under ideal conditions.

Nevertheless, these results do not herald the demise of this type of social cost-benefit analysis. There are several reason why this is so. First, social decision-making does not require concentration on ideal solutions. For example, although willingness-to-pay and the willingness-to-accept compensation tests may indicate differing ideal amounts of aquaculture of each of the focal species, both tests may demonstrate that adoption of species B is socially preferred to A. So if the choice is just about species, no conflict between the tests will occur.

If conflict does occur, then a social choice has to be made between the tests. Such a choice will require consideration of issues involving social justice. However, even when there is no conflict between these welfare tests, questions of social justice, such as those involving income distribution and property rights, cannot be ultimately avoided. One needs to decide whether or not compensation or avoidance payments should actually be made, and on what scale, in the case of an adverse environmental spillover. If it is believed that payments should be made, this will also require account to be taken of the transaction costs involved. Such considerations cannot ultimately be avoided, even though the Kaldor-Hicks test only relies on potential interpersonal payments in the case of adverse environmental spillovers.

One of the arguments traditionally used to support the Kaldor-Hicks criterion is that on the whole, and over a period of time, gains and losses of affected parties from adverse externalities will balance themselves out so no compensation need be paid. This is also economically advantageous because transaction costs involved in money transfers are avoided. Unfortunately, this hypothesis does not always hold in practice. A further rationale was also developed in British tort law in the nineteenth century for not paying or for limiting the amount of compensation in the case of environmental spillovers; namely, that such payments would hinder economic progress (see Fleming, 1977; Tisdell, 1983). However, that begs the question of what exactly is economic progress, and whether or not economic growth is desirable no matter what environmental costs are involved.

5. Concluding Comments

It has been shown that environmental conditions are important in selecting aquaculture species and systems at the individual site or farm level; and because of spillover effects, they are also important within the aquaculture sector itself and for the welfare of society as a whole. Within the context of groups (aquaculture groups and the community as a whole), the ability of the government (or the relevant group) to regulate aquaculture activity influences the socially optimal selection of an aquaculture species and systems. The optimal selection depends on social governance. Limitations or shortcomings in social governance should be taken into account in recommending to governments the selection of particular aquaculture species or systems for adoption. Furthermore, the direction of aquaculture research and development, particularly by public bodies, needs to take account of prevailing managerial skills at the farm level in the regions targeted for adoption of new species (or selected stains of these) or for the introduction new aquaculture systems; as well as actual environmental conditions, including their variations; and the nature of social governance. Very often social governance is given insufficient attention in scientific research and development by public agencies. When this occurs, their scientific results may bring little economic benefit; and in some cases, may even result in an economic loss.

A social dilemma has been identified. New aquaculture species and systems able to bring substantial economic gain when the social administration or management of aquaculture is adequate can result in considerable social economic loss when social governance of aquaculture is inadequate. This can occur, for example, when there is relatively open-access to aquaculture. Furthermore, a paradox has been revealed. If social governance is lacking, aquaculture species and systems that cause a rapid rate of decline in environmental quality may be economically preferable to those that result in a more gradual reduction in environmental quality with higher levels of production. This is because the former results in a smaller social economic deadweight loss. The above analysis also implies that new aquaculture species and systems that could reduce poverty and increase economic wealth may only do this if social governance is adequate. Indeed the introduction of new species and aquaculture techniques that would reduce poverty and increase economic wealth given adequate social management of aquaculture can have the opposite result if social governance is inadequate. Therefore, in assessing the desirability of introducing new aquaculture species and systems to a region, social as well as biophysical and market factors must be assessed.

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