

# Environmental economics approaches for the comparative evaluation of aquaculture and other food-producing sectors

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**Knowler, D.** 2007. Environmental economics approaches for the comparative evaluation of aquaculture and other food-producing sectors. In D.M. Bartley, C. Brugère, D. Soto, P. Gerber and B. Harvey (eds). *Comparative assessment of the environmental costs of aquaculture and other food production sectors: methods for meaningful comparisons*. FAO/WFT Expert Workshop. 24-28 April 2006, Vancouver, Canada. FAO Fisheries Proceedings. No. 10. Rome, FAO. 2007. pp. 55–70

## ABSTRACT

With human population and per capita incomes increasing it seems inevitable that the demand for food will grow in the future. Meeting this increasing demand requires decisions about which food production systems to encourage over the alternatives. In this paper, I review the use of economic analysis in making comparative assessments of the social benefits and costs of food production systems, concentrating on aquaculture and comparable intensive terrestrial systems. After setting out the basic approach used in cost-benefit analysis, I examine specific issues arising in applying this method to the comparative analysis of food production systems. These include the relative importance of private versus external costs, depletion of natural capital, and different perspectives in capturing the full social costs of production. Subsequently, I present several case studies to illustrate the approach. This is followed with a discussion of the strengths and limitations of the economic analysis approach, particularly in light of competing approaches for such assessments. Finally, the paper concludes with a summary of the findings and identification of key gaps in our knowledge that should be the subject of future research.

## INTRODUCTION

With human population and per capita incomes increasing it seems inevitable that the demand for food will grow in the future (Rosegrant *et al.*, 2001). Meeting this increasing demand requires decisions about which food production systems to encourage over the alternatives. The recent rise in aquaculture production is a case in point. Globally, cultured shrimp production has risen from a negligible amount in the mid-1970s to almost 30 percent of total shrimp production (including capture shrimp fisheries) in the last few years (FAO, 2000), while global aquaculture production doubled between

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1986 and 1996 (Naylor *et al.*, 2003). Should such production be encouraged over intensive terrestrial food production systems? How best to answer such a question and what are the key issues? Certainly, one must be cognizant of the full range of impacts arising from food production systems.

Shang and Tisdell (1997) provide a list of possible impacts from aquaculture development (Table 1). These include both positive and negative effects across a wide range of activities. Clearly, environmental damages are a key concern, one that has been expressed by a large number of researchers and advocacy groups (Naylor *et al.*, 2003, EJF, 2004). However, environmental costs are also cited as an important factor in the production of food in terrestrial systems, both intensive and extensive (Conway and Pretty, 1991). Several attempts have been made over the last several decades to place the environmental costs of food production on a common footing with either production costs or the retail value of food items (Pretty *et al.*, 2005; Smith, 1992; Adger and Whitby, 1991). For example, Pretty *et al.* (2005) state the environmental costs of food production as a percentage of the weekly food basket in the United Kingdom in 2000, finding that this amounts to about 1.69 percent (Table 2). Their analysis suggests that methane and other gaseous emissions to the atmosphere and effects of micro-organisms on human health account for just over half of the total environmental impact of the food basket.

Economic analysis provides one set of tools for assessing the environmental costs of production decisions and cost-benefit analysis (CBA) is usually the appropriate methodology. It involves identifying the full range of benefits and costs of an action, monetizing these using appropriate market or “shadow” prices and then determining the ‘net impact’ of the action. Implicit in CBA is the objective of maximizing net economic benefits from a human welfare perspective given a finite set of options. However, CBA requires detailed information on the impacts to be measured and is concerned strictly with the economic efficiency issues involved, and not with other issues which may concern decision makers. A good CBA will at least address uncertainty and distributional considerations, but is incapable of dealing with multiple objectives.

In this paper, I review the use of economic analysis in making comparative assessments of the social benefits and costs of food production systems, concentrating on aquaculture and comparable intensive terrestrial systems. After setting out the basic approach used for such an analysis, I examine specific issues arising in applying this method to the comparative analysis of environmental costs in food production systems. These include the economist’s notion of external costs, depletion of natural capital, and different perspectives in capturing the full social costs of production. Subsequently, I present several case studies to illustrate the approach. Finally, the paper concludes with a few parting thoughts and identification of key gaps in our knowledge that should be the subject of future research.

### **Basic considerations in cost-benefit analysis**

Perhaps the first question we must be concerned with in undertaking cost-benefit analysis is whether we are undertaking a financial or economic analysis, or both. The distinction between these two perspectives is important. With a financial analysis we take the viewpoint of a private firm or individual and measure the benefits and costs they would consider. In most cases, these would consist of the following:

- revenues as determined by market prices;
- production costs such as wages paid to labour, as well as on-site costs, again using market prices; and,
- taxes and other payments, either paid to or received from governments.

Thus, a financial analysis is concerned with actual monetary flows, either as revenues or costs, and is useful in answering specific questions concerned with these

flows of revenues and costs. For example, is a food production system likely to be financially attractive to private firms or individuals? What is the financial impact of the food production system on government budgets? Finally, how does the food production system affect the country's foreign exchange balance? A financial analysis typically does not concern itself with environmental impacts, especially where these affect someone else. Occasionally, a financial perspective may be useful if the goal is to assess whether producers would be prepared to adopt particular mitigating measures which may affect the profitability of their private operations. In contrast, an economic analysis is concerned with whether expansion of a particular food production system represents an efficient use of a nation's resources. This involves assessing the *opportunity costs* of the activity in question. Questions we might be concerned with include what we must forego in economic terms, as a result of the activity. Are these lost opportunities of greater or lesser value to the nation than the activity in question? Is the food production system likely to be sustainable in an economic sense? How we define *sustainability* will critically determine the answer here.

The emphasis is on the 'net' effect of an activity, regardless of who may be involved. Not surprisingly, this means that if a food production system affects third parties - that is, parties other than the interested parties considered in a financial analysis - these impacts must be taken into account. Additionally, we must extend the analysis to consider benefits or costs for which no market price exists, since these are important in assessing whether an activity has a net positive or negative effect on a nation's welfare. Even where market prices do exist, these might need adjustment because of government intervention in the economy. By paying subsidies, charging taxes or maintaining an undervalued exchange rate, for example, a government distorts prices so that they no longer reflect true market forces. When such adjustment is called for, or prices must be estimated for a good or service and no markets exist to help us, we refer to these prices as *shadow prices*.

Once we have established the correct prices to use, we must go a step further. Economists are not only interested in how much is actually paid for something, but also in how much individuals would have been willing to pay over and above that price, and refer to this concept as *willingness-to-pay*. With this information, economists can derive what is referred to as *consumers' surplus*. This measure of value captures the often greater amounts individuals would be prepared to pay, but need not pay because a single price governs the marketplace. Such amounts, while never actually collected, and difficult to measure, are an important component in the true economic value of food production. Typically, decision makers will want to adopt an economic perspective when determining how best to use a nation's limited resources for food production. Thus, economic analysis, as opposed to financial analysis, is the appropriate perspective to adopt for the analyses described in this paper.

A further consideration is the treatment of benefits and costs that occur in different time periods. Many researchers are familiar with the principle of discounting used in the treatment of cash flows over a multi-year period. When economists evaluate benefits and costs which extend over more than one time period they take this into account using one of two approaches, both of which involve the use of a *discount rate*.

In the first case, they must make allowance for the fact that individuals view more distant benefits and costs differently than more immediate ones. Generally, the pattern observed is that we prefer costs to be postponed and benefits to be received as soon as possible. This situation is referred to as *time preference*. It is mimicked by financial institutions in that they must pay interest on bank accounts, returning a higher amount to the individual at a later date to make it attractive for individuals' to deposit their savings right now (thus, requiring individuals to postpone their enjoyment from spending that money now). To account for time preference in valuation and cost-benefit studies, economists use a form of discount rate referred to as a *social time preference*

rate. Like all discount rates, the social time preference rate is used to weight benefits and costs occurring in different time periods, similarly to the use of an interest rate to calculate interest payable on bank accounts. Since we would prefer having a sum of money in the present to waiting until a later time period for it, we must place a greater emphasis (weight) on current values than on ones in distant periods. To accomplish this, we use a discount factor that incorporates the discount rate selected. Weighting a series of benefits or costs and summing these yields a *present value*.

A second approach is to look at the opportunity cost of capital invested in an activity, which refers to the profits which could have been obtained by investing this capital in the next best possible opportunity. These foregone profits represent the cost of the capital employed in the project. The net benefits of our project must at least equal these foregone profits if it is to be considered viable. Thus, when weighting benefits and costs in different time periods, we use the opportunity cost of capital as our discount rate to reflect what the activity should be generating in terms of benefits, if it is to be an attractive investment.

The choice of a discount rate is a controversial matter, and will depend in part on whether we are using a time preference or an opportunity cost of capital approach. Some researchers might argue that for intensive food production systems, the discount rate should be set high, since many of these activities impose damage on the environment and should be penalized. Some food production systems have positive environmental impacts, in contrast, suggesting a low or even zero discount rate might be appropriate, to encourage such activities. In reality, the impacts of food production systems on the environment range widely, suggesting that the appropriate discount rate might vary with the circumstances. However, it is generally preferable to use a single rate for all analyses to ensure consistency and to allow for comparisons amongst different activities. But if a single discount rate is to be used, then to accommodate environmental concerns we must decide whether the rate should be high, low or zero.<sup>2</sup> To avoid such uncertainty, there is an emerging consensus that no adjustment should be made to the standard, economy-wide discount rate when evaluating activities and, instead, other techniques be used to adjust for any special conditions associated with environmental benefits and costs (Markandya and Pearce, 1988).

### A conceptual model for comparative economic analysis

In this section, the application of a cost-benefit framework to a comparative analysis of food production systems is discussed. The key considerations in undertaking an economic analysis of competing food production systems include the willingness to pay of consumers for various food products and the full “social” costs of food production. Adapting Barbier (1994), we can express the comparative analysis in a very general sense as:

$$\Delta NB = NB_A - NB_T \quad (1)$$

where the term on the left represents the difference in the present value of net benefits from alternative food production and the two terms on the right hand side refer to the present value of net benefits of aquaculture ( $A$ ) and intensive terrestrial food production ( $T$ ), respectively. Net benefits comprise benefits ( $B_{A,T}$ ) and costs ( $C_{A,T}$ )

<sup>2</sup> Interestingly, the overall impact on the environment of a high or low discount rate applied to all projects is ambiguous. For example, a high discount rate discourages environmentally damaging activities and reduces the overall level of investment; therefore, the rate of natural resource use declines. But this result comes at the expense of emphasizing the interests of the current generation over those of future generations, since net benefits far in the future are heavily discounted. A high discount rate also discourages environmentally-friendly forest management activities (Markandya and Pearce, 1988).

of food production, expressed in present value terms. We can further disaggregate (1) to isolate these benefits and costs:

$$\Delta NB = (B_A - B_T) - (C_A - C_T) \quad (2)$$

This expression allows us to discuss benefits and costs separately. The comparison of benefits is not straightforward. Consumers may value competing food sources differently and this must be taken into account; therefore, a strict assessment of competing food production systems on the basis of costs alone is liable to be misleading. While the issue of benefit estimation can be important in undertaking a comparative economic analysis of food production systems, this is not pursued further here.

For some planning purposes, it may be valid to express food production on the basis of an equivalent per unit of food value (kg of protein or whatever). In this case, the benefit terms in (2) are equal and, therefore, cancel so that (2) becomes:

$$\Delta NB = (C_A - C_T) \quad (3)$$

In this case, we have an alternative cost model or this problem can be analyzed using a cost-effectiveness framework.<sup>3</sup> In such a case, we need to consider several components of the full opportunity cost of food production systems in undertaking an economic analysis. Following Pearce and Markandya (1996), these include the farm level costs of production or “private” costs, as well as the off-farm or “external” costs and an allowance for the using up or depletion of natural capital, if relevant. Formally, we can define the full social costs of food production as:

$$C_i = PC_i + EC_i + UC_i \quad (4)$$

where *PC* refers to private costs, *EC* refers to external costs, *UC* is the user cost and  $i = A$  (aquaculture) or  $T$  (terrestrial). These costs may be expressed on a common basis, such as per unit of food value or per unit of land or water consumed. For example, costs can be expressed per crop (Table 3).

The private costs of food production are reasonably well-known. In this paper, we are concerned with the environmental costs of food production, consisting of the latter two terms in expression (4) above, and these are less well-known. A brief description of each component is provided below.

### External costs (EC)

External costs are particularly important in comparing *intensive* food production systems because of the perceived importance of various externalities. With respect to US aquaculture, Goldberg, Elliot and Naylor (2001) suggest five main environmental externalities: (a) biological pollution, (b) fish for fish feeds, (c) organic pollution and eutrophication, (d) chemical pollution, and (e) habitat modification. To these we can add several items more relevant to aquaculture in tropical coastal areas, most of which were cited earlier (Table 1). Economic valuation of the environmental externalities in aquaculture is in its infancy, although some estimates exist.

External costs in intensive terrestrial food production arise from several environmental impacts, e.g. nutrient runoff, amenity effects, etc. Perhaps the most familiar are the effects of pollutants released by agricultural activity. According to Conway and Pretty (1991), the key pollutants are pesticides, nitrates and nitrous

<sup>3</sup> The alternative cost model is discussed in detail by Steiner, (1965), while Boardman et al. (1996) provide a description of the cost-effectiveness.

oxide, phosphates, organic and pathogenic wastes from livestock, silage effluents, ammonia and processing wastes, and their impacts on various systems are substantial. More research has been devoted to valuing the external costs of terrestrial agriculture but there is some overlap with aquaculture. For example, determining the external costs of nutrient runoff relies on a methodology that is similar to that used to value the eutrophication costs of aquaculture, since nutrient pollution in both cases may end up in the same freshwater and marine ecosystems and may even be indistinguishable.

The analysis of external costs can be somewhat complex, even in applied empirical studies.<sup>4</sup> It requires an understanding of the behavioural response of agents to the environmental problem. For example, where potential damages have been averted by instigating pollution control, the residual damages from the remaining pollution will be lower, once the control measures are in place. As a result, reporting these residual effects as the external cost of pollution would be misleading, since resources have been devoted to reducing damages already. For this reason, a more comprehensive measure of the external costs of food production systems is desirable comprising the following elements (Meade, 1989):

- the costs of abatement efforts to control external costs;
- the costs of adaptation to external costs; and
- the residual damages arising from external costs after control measures are in place.

In the case studies later on, sometimes only one of these costs is considered or perhaps several are captured in a more broadly specified cost measure.

### **User Costs (UC)**

Recognition of the harmful effects of the depletion of natural capital is one of the cornerstones of the emerging discipline of ecological economics (Jansson *et al.*, 1994). This depletion is a form of user cost, since it yields short-term gains but at the expense of future income. Leaving out this user cost can lead to an understatement of true production costs. The significance of user costs in intensive food production systems has not been explored. For example, the reduction in land use with many intensive production systems results in fewer concerns about the depletion of land productivity, as occurs with extensive, but overgrazed, pastoral systems. One example of the calculation of user costs is Knowler (2005) who values the depletion effects of over harvesting of forests in Nepal. Methods for estimating user cost are discussed in Kellenberg and Daly (1994) and are not discussed further here.

### **Case studies of the external costs of intensive food production systems**

In this section several case studies are presented, each of which addresses a specific external cost of aquatic or terrestrial food production systems, e.g. eutrophication, pesticide use, etc. Only the external cost issue is treated since this is the most controversial and it is perhaps the least known element of costs (except for user costs in some situations). Moreover, only a selection of representative external costs is presented, due partly to the availability of such estimates in the literature and space limits. Thus, the treatment of external costs in food production systems here should not be seen as exhaustive. Two case studies are presented for each of aquaculture and intensive terrestrial food production.

<sup>4</sup> In more formal analysis, the valuation of externalities involves assessing the adding marginal external costs to marginal production costs to form total marginal costs and then determining the point where marginal cost equals price, as determined by the demand curve. The resulting market equilibrium with externalities internalized has a lower output quantity and higher price, with consequent effects on consumer and producer welfare (Varian, 1984).

## External costs of aquaculture production

### *Nutrient Enrichment and Eutrophication*

As reported earlier (Table 1), nutrient runoff is a significant external costs of aquaculture, whether this is pond-based (effects on surface or ground water) or cage culture (effluent discharge to surrounding waters). In one study, Smearman, D'Souza and Norton (1997) estimate the external costs of trout farming in West Virginia. The authors consider as separate cases the costs of controlling nutrient runoff and the resulting damages if no control is undertaken, together with a constant 10 year production scenario. In the control case, engineering costs for the installation of filtration units under an assumed flow rate are calculated. These amounted to US\$0.11 per kg of trout produced (1993 prices), or about 6percent of the private production cost of US\$1.94 per kg. Under an assumption of no control, the resulting damages from nutrient runoff are determined using willingness-to-pay data for the maintenance of stream quality in the region. The authors find that the damages amount to US\$0.49 per kg of trout produced, when no abatement of nutrient runoff is adopted, or about 6 percent of the private production cost.

In another study, Folke, Kautsky and Troell (1994) estimate the cost of marine eutrophication from salmon aquaculture in Sweden. Their valuation of the costs is based on Swedes' willingness-to-pay to remove nitrogen and phosphorous using sewage treatment plants.<sup>5</sup> This approach assumes that nutrients originating from different sources have identical effects on marine coastal systems and, therefore, the resulting "marginal" values can be applied to any reductions in nutrients. Applying these values to an average salmon farm (producing 100 tonnes of salmon) leads to an estimated external cost of about US\$70 000 (SEK 425 000) in 1994 prices. These external costs represent SEK 4.25/kg of salmon, compared to a production cost in the early 1990s of SEK 27/kg. Thus, nutrient damages as assessed here constitute 15–16 percent of the cost of production.

### *Conflicts with capture fisheries*

A second key component in the external costs of aquaculture is the impact on adjoining or related capture fisheries, which has been a topic of research in the fisheries bioeconomics literature for some time (Hannesson, 2003; Ye and Beddington, 1996; and Anderson, 1985). Naylor *et al.* (2000) cite several ecological links between aquaculture development and capture fisheries, including habitat modification (e.g. loss of mangroves), use of wild seed to stock aquaculture ponds, food web interactions, introduction of exotic species and effluent discharge. Care is needed in assessing such impacts since they may not be distinct from those related to nutrients, discussed above. Drawing on the habitat modification aspect of aquaculture development, several attempts have been made to value the loss of mangroves as support areas for lagoon and marine fisheries (Gunawardena and Rowan, 2005; Barbier, 2003). Barbier finds that mangrove conversion for shrimp farming leads to total welfare losses from reduced capture fish catches of about US\$1.3 million annually. However, when this value is expressed as a percent of the border value of shrimp exports from Thailand, the value is quite low, at only 0.1 percent.

Another analysis assesses the impact of the collection of wild shrimp seed on commercial capture shrimp fisheries in West Bengal, India [Note: relatively little mangrove conversion is occurring in this area]. Approximately 50 000 shrimp fry collectors are engaged in this practice in the vast Sundarbans mangrove region that straddles the Indian and Bangladeshi borders. Nathan *et al.* (2006) develop a simulation

<sup>5</sup> Note that the willingness-to-pay estimate is based on the demand for reductions in nutrients and not the actual cost of removing these nutrients. Therefore, this valuation approach should be seen as providing a measure of "damages" and not "control costs".

model of the integrated ecological-economic system to measure the impacts of various scenarios of aquaculture development (fry collection) and their effects on the capture shrimp fishery. Adapting this analysis for the purpose at hand, the external costs from unregulated fry collection can be stated in terms of the foregone catches in the capture fishery and lost production of farmed shrimp. Since the fry collection industry operates under essentially open access, the fry stock suffers from over-harvesting, resulting in reduced availability of fry for both the capture fishery and shrimp farming. Thus, regulation of fry collection could provide win-win benefits in both sectors (Bhattacharya and Sarkar, 2003).

Since this is a dynamic analysis, we concentrate on year 20 in the simulation and examine the differences in collection of fry and catch of shrimp in the capture fishery under two scenarios (Current Situation versus Restricted Scenario). The main difference between the two scenarios is that the number of fry collectors is reduced from 50 000 to 20 000 and regulated so that catches per collector and total fry collected rise dramatically (due to better management). The following model assumptions and outputs are used in the calculation:

- current shrimp fry collection is about 43.5 million fry per year, which is capable of producing about 825 tonnes of farmed shrimp per year;
- incremental collection of shrimp seed in year 20 under the Restricted Scenario is about 70 million fry per year, which could produce an additional 1327 t of farmed shrimp (Kumar, BIRTHAL and Badruddin, 2004);
- gains in the capture shrimp fishery per year from regulation of fry collection are about 1 450 tonnes per year, yielding a total increase in shrimp production across both sectors of 2 777 tonnes/year due to regulation; and
- the total gain in revenue is about US\$25 million at an international price for shrimp of US\$9.00/kg (excluding any allowance for changes in production costs or marketing and distribution).

It should be noted that there is no allowance for the change in farming or fishing “costs” associated with higher yields so that the gains are not measured as a change in profits, which would undoubtedly be lower in reality. In addition, the use of an international price instead of an ex-vessel or farm gate price for shrimp similarly overstates the benefits. Assuming farm gate and ex-vessel prices are only 50 percent of international prices and that profit margins are 25 percent of production revenues, then a more realistic estimate of the true external costs might be estimated roughly at US\$72/1 000 shrimp fry collected or about US\$3.80/kg of farmed shrimp currently produced.

## **External costs of intensive terrestrial food production**

### *Pesticide use*

Pesticide use in terrestrial agriculture has a variety of environmental costs. Pretty and Waibel (2005) cite these as drinking water treatment costs, pollution incidents in watercourses, health costs to humans, adverse effects on biodiversity and impacts on climate change through energy use (also see Table 1). Various efforts have been made to value these costs, beginning with the pioneering work of Pimentel and Acquay (1992), who found that external costs from pesticide in US agriculture amounted to about \$5 billion per year. Updates of this value for the US suggest that the value may have been overstated (Pretty and Waibel, 2005), but is still substantial. Stating current estimates of the external cost of pesticides for the US and other countries on a per ha basis provides for a comparison (Table 4). Annual external costs range from US\$8.80/ha of cropland in the US to US\$46.60/ha of cropland in China, with treatment costs the most significant cost element.

We can also consider the farm level effects of pesticide use. A study conducted under the auspices of the IRRI in the 1990s examined the problem of pesticide use among

farmers in the Philippines (Pingali *et al.*, 1995). The authors first estimated the average annual health costs per farmer based upon treatment costs and the opportunity cost of farmers' time lost due to illness from pesticides. The equation they estimated by was:

$$\ln(\text{health cost}) = 4.366 + 1.192 \ln(\text{age}) - 0.0756 (\text{ratio of weight to height}) + 0.916 (\text{smoking dummy}) - 0.53 (\text{drinking dummy}) + 0.486 \ln(\text{insecticide dose}) - 0.042 \ln(\text{herbicide dose})$$

$$R^2 = 0.30, \text{ Degrees of freedom} = 100$$

This health cost function can be used to make estimates of the health cost of pesticide per farmer for different pesticide doses as shown in Table 5.

The significance of these external costs can be understood by comparing them with the market value of irrigated rice production for a farm in the Philippines. Antle and Pingali (1995) report the average yield per ha as 3 866 kg and a farm gate price of \$0.17/kg. Assuming a 2 ha farm (no average farm sizes were reported in the study), the external cost amounts to as much as 4.8 percent of the market value of rice production.

### *Amenity effects*

Amenity costs of intensive terrestrial agriculture refer to the impacts of these operations on visual values, odours arising from livestock operations and other similar effects. While in extensive agriculture the negative amenity effects may be relatively minor or perhaps even positive (e.g. as part of "multifunctionality"), this is much less true of *intensive* operations, particularly livestock feedlots (Naylor *et al.*, 2005). A substantive valuation literature has developed in response to concerns about the siting of intensive livestock production near residential areas, primarily in the US and Europe. Most studies use a hedonic pricing model to assess the effect of intensive livestock production on local house prices. The hedonic method treats the negative effects of these facilities as just one of numerous characteristics influencing the value of a house and then isolates the individual contribution to house value from this one characteristic. Impacts typically depend on the distance from the facility, wind direction, the number of livestock operations already in the area and other location-specific factors.

Palmquist, Roka and Vukina (1997) examine rural residential house sales in North Carolina to determine the effect of hog operations on nearby property values. The impact of these operations resulted in declines in real estate prices by as much as 9 percent per house but varied according to distance and the number of hogs. Herriges, Secchi and Babcock (2003) developed a hedonic model based on 550 livestock operations (most but not all hogs) in five rural counties of Iowa. Not surprisingly, the disamenity effects are greatest for houses downwind and closest to the operations. When a new livestock operation is sited in the area, the results suggest that this will decrease property values by an average of 10 percent.

Finally, Ready and Abdalla (2005) consider both the positive effects (e.g. open space) and negative effects (e.g. intensive operations) from agriculture on surrounding property values. They use a much larger sample (over 8 000 real estate sales) and allow for a wider range of amenity effects in their model. For intensive livestock operations alone, they find impacts on the price of a house of 1.6 percent (1 200 m distance), 4.1 percent (800 m) and 6.4 percent (500 m). The position relative to wind direction was not significant. At 800 m, very large-sized facilities demonstrate a higher impact on house prices (15.0 percent) than medium facilities (7.5 percent), while the effect of the intermediate-sized "large facilities" was not significant (perhaps due to modernization). In addition, poultry farms (5.8 percent) showed a slightly larger impact than hog operations (3.0 percent).

### Discussion and further directions for research

Several issues arise in considering the analysis and case studies presented above. Overall, the findings indicate that external costs can be identified and quantified over a range of environmental impacts, although the record remains spotty, particularly for aquaculture and further investigation of the credibility of the existing estimates is needed. There are few studies attempting to capture all external costs. The exception are several studies of the external costs of consumer food baskets but these do not isolate individual production systems as the source of damages. A comprehensive view of external costs from competing intensive food production systems (the “Holy Grail”) remains elusive.

One area for further exploration is the interaction of environmental effects of aquaculture and intensive terrestrial food production. For example, nutrient effluent from feedlots may impede downstream aquaculture efforts if it leads to unsuitable conditions for farmed fish. More obviously, both feedlots and aquaculture may contribute similar nutrients to the ecosystem and these may even be commingled in certain cases. Thus, damages may be interchangeable or difficult to disentangle. Issues of optimal management come into play as well. For example, the environmental impact of shrimp farming on mangroves can be viewed within an optimal land use framework (Barbier and Cox, 2004), which considers the problem of allocating land to competing natural (mangrove) or developed uses (shrimp farming). A similar debate is emerging over treatment of the opportunity cost of ocean space occupied by aquaculture cages or pens. Their position may impede fishing, recreation or other activities thereby creating an external cost if not properly internalized in private costs through a leasing or compensation scheme (Hoagland, Jin and Kite-Powell, 2003). However, this issue can also be analyzed using an optimal allocation modelling approach, as used in the assessment of competing land uses (mangroves versus shrimp).

Another interesting area not explored here is the interaction between aquaculture and intensive rice production, i.e. two alternative intensive food production systems may conflict directly, since land used for shrimp ponds may be used for rice production. Bhat and Bhatta, (2004) examine the case for Karnataka State in India, where extensive development of shrimp aquaculture has occurred on rice paddy lands. They use an optimization model to determine the optimal allocation of land to these two intensive food production activities, taking into account their respective impacts on the environment. In this case, the simple modelling framework set out in expression (1) refers to competing uses for the same land.

How do the estimates presented in this paper compare to other approaches for assessing comparative environmental impacts from intensive food production (Hospido and Tyedmers, 2005; Troell *et al.*, 2004)? Relatively few studies have made such comparisons. In one study, Subak (1999) considers the global environmental costs of beef production using several methodologies. The methodologies used are the embodied energy valuation approach championed by Costanza (1980) and a conventional environmental economics approach. These methods are applied to the greenhouse gas emissions from livestock production on feedlots versus pastoral systems in Africa. Without going into the details of the methods, it is interesting to note that the two analyses appear to reverse the ranking of livestock production systems in terms of total private and external costs. While the feedlot system performs less well using conventional analysis, it does better than the pastoral system using embodied energy analysis. Although this represents only a single example, and the credibility of the estimates requires review, it raises concerns about the consistency of results in comparing the environmental impacts of competing production systems using differing methodological approaches. Further research in this area is clearly needed.

Other research needs emerge from this study as well. For example, much of the research considered is seen in isolation and not linked to the broader notion of total

social costs of production introduced earlier, i.e. private, external and user costs. Thus, it is difficult to make firm assessments of these total social costs. Such efforts are confounded further by the challenges of reconciling differing units of measure for presenting external costs. For example, the amenity effects of intensive livestock production are typically expressed as a change in the value of a house and not as a percentage of livestock production costs (which would be quite difficult). Such disjointed ways of measuring impacts make it more challenging to derive the full social costs of production.

TABLE 1  
Possible socio-economic and environmental impacts of aquaculture development

Activities	Possible Impacts
Conversion of mangroves for fishponds	Reduced mangrove products Reduced fisheries production Coastal erosion Unemployment of unskilled labour Increased fish production in ponds
Conversion of cropland for fishponds	Reduced crop production Unemployment of unskilled labour Shortage of essential food Increased fish production in ponds
Use of ground and surface water	Reduced crop irrigation Land subsidence Saltwater intrusion Salinization of aquifers
Effluent discharge	Reduced downstream farm production Self-pollution Coastal or inland water pollution
Use of chemical, antibiotics, etc.	Public health risks
New (exotic) species	Altered biodiversity Spread of diseases
Large-scale intensive culture	Conflicts with small-scale farmers Uneven income distribution Reduced employment for unskilled labour
Cage and pen culture	Reduced pressure on land and water Reduced fisheries yield in same area Conflicts with navigation, recreation, etc.
Demand for feed and fertilizer	Competition leading to higher prices Increased employment in these industries
Sea farming	Preserved natural stocks Reduced pressure on land and water Increased marine fish production
Aquarium fish culture	Preserved natural stocks Increased export Employment effect
Increased aquaculture production	More fish and lower prices Increased employment in various sectors Increase in foreign exchange earnings Conflicts with other economic activities

Source: Shang and Tisdell (1997)

TABLE 2  
The negative externalities of United Kingdom agriculture (2000)

Source of adverse effects	External costs as percent of consumer food basket
Pesticides in water	0.16
Nitrate, phosphate, etc. in water	0.13
Eutrophication of surface water	0.09
Monitoring of water systems	0.01
Methane, NO <sub>x</sub> , NH <sub>4</sub> emissions to atmosphere	0.47
CO <sub>2</sub> emissions to atmosphere	0.11
Offsite soil erosion & organic matter losses	0.07
Loss of biodiversity & landscape values	0.17
Effects on human health from pesticides	0.001
Effects on human health from micro-organisms	0.48
Total	1.69

Source: Pretty *et al.* (2005 )

Note: Total may not add due to rounding

TABLE 3  
Comparison of land and financial status between rice and shrimp farming in Pak Phanang, southern Thailand

	Rice farming	Shrimp farming
Farm area (ha)	2	0.8
Land cost (Baht/ha)	3 000 – 10 000	300 000 – 600 000
Rental (percent)	10	46
Land ownership	100 percent local	27 percent outsider
Source of income	25 percent rice/ 75 percent other	75 percent shrimp/ 25 percent other
Market	100 percent local	95 percent export
Investment (baht/ha)	500 – 15 000	100 000 – 1 500 000
Net return (baht/crop)	3 000 – 10 000	100 000 – 1 000 000
Loss (baht/crop)	None	10 000 – 350 000

Source: Primavera (1997)

Note: 25 Baht = US\$1

TABLE 4  
External costs of pesticides in selected countries per Ha of cropland (US/ha/year)

Damage costs	China	Germany	United Kingdom	United States
Drinking water treatment	-	7.3	16.5	5.3
Health costs to humans	30.0	1.0	0.2	0.8
Pollution in watercourses	-	4.3	0.5	0.8
Effects on biodiversity	11.7	0.8	5.8	1.7
Effects on climate use	4.9	0.3	0.3	0.3
Totals	46.6	13.8	23.4	8.8

Source: Pretty and Waibel (2005)

TABLE 5  
Estimated incremental health costs of pesticide use versus natural control by Farmers in The Philippines (US\$ 1992)

Management strategy	Number of doses	Incremental health costs	As percent of value of rice production
Complete protection	6	62.11	4.80
Farmers' practice	2	27.82	2.15
IPM	1	15.82	1.22
Natural control	0	-	-

Note: Assumes a 2 ha farm

Source: Pingali *et al.* (1995)

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