Contributed papers

Comparative environmental costs of aquaculture and other food production sectors: environmental and economic factors conditioning the global development of responsible aquaculture

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ABSTRACT

With its growing global output, aquaculture is ever more challenged to develop in an environmentally-sustainable manner to maintain and increase the role it plays in food production. Some environmental measures and agreements such as Convention on Biodiversity and the Code of Conduct for Responsible Fisheries have been adopted by the international community as a first step in this direction but questions remain regarding the evaluation of the environmental costs of aquaculture development in comparison to other food production sectors. The diversity of fish farming activities tends to hamper the application of comparative assessment methods, and, although useful, environmental economics tools may not have been used to their full potential in the valuation of environmental resources upon which aquaculture systems are based. Furthermore, addressing non-technical factors such as diverging views of economists and environmentalists regarding pollution and levels of acceptable environmental damage, market failures and conflicts over natural resources, dis-functioning institutions, the power of consumer demand and uncertainty about the future, also constitute challenges for policy-makers. Approaches combining environmental and economic perspectives such as adapted Environmental Kuznets Curves (EKC), the Ecosystem Approach to

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Aquaculture (EAA) and Policy-Relevant Monitoring Systems (PRMS) are highlighted as possible to assess the development and impact of aquaculture in the context of other productive, natural resource-dependent activities and to guide policy-making.

INTRODUCTION

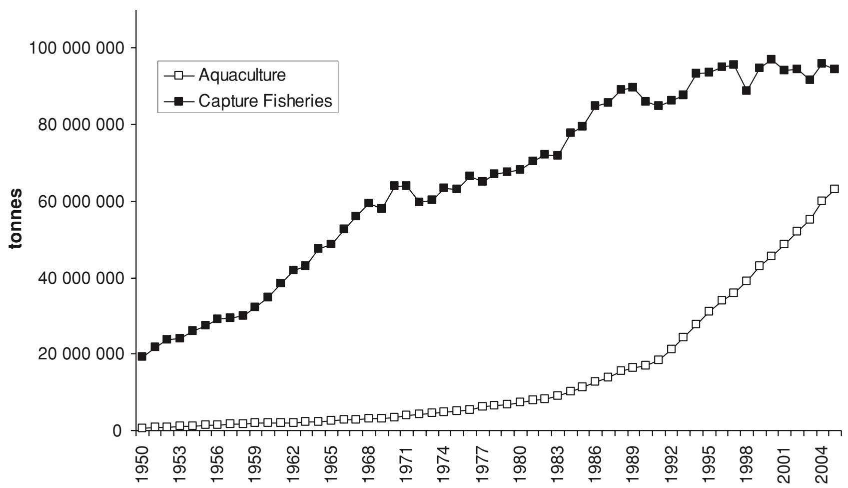
Aquaculture production has increased steadily in recent years; it is the fastest growing food production sector and has become a valuable component of national development and poverty reduction plans in many areas. At a time when capture fisheries are leveling off, aquaculture production continues to increase (Figure 1). The increase in production is greatest in developing countries where about 93 percent of aquaculture production originates (Figure 2), but many developed countries also have national strategies to increase production of key species.

Increasing intensification of aquaculture systems has led to increased intervention into ecosystems with attendant increased inputs of energy and feed (Muir *et al.*, 1999), and an increased risk of adverse environmental impacts. It has therefore become clear that, in order to maintain and increase the role aquaculture plays in food production, accurate environmental accounting will be necessary to help policy makers make informed decisions and to ensure aquaculture develops in a sustainable manner.

This paper has two objectives. The first is to highlight some of the environmental measures/agreements taken by the global community to ensure the sustainable and environmentally-friendly development of aquaculture. The second is to show that this may however not be sufficient because of a number of other factors influencing the development and sustainability of aquaculture. As such, the paper provides a background to the other papers contributed to the workshop.

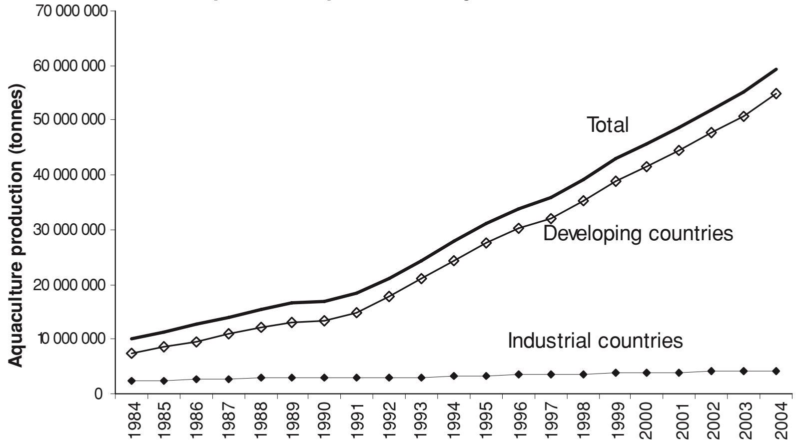
The paper presents an environmental perspective on aquaculture development, followed by a short synopsis of the methodological challenges associated with comparative analyses of food production sectors. What environmental economics can bring to the debate is presented in a third section, followed by a description of the non-technical factors influencing policy making and the overall development of aquaculture. A last section attempts to bring environmental and economic approaches together in the assessment and monitoring of food production sectors.

FIGURE 1
Global capture fisheries and aquaculture production



Source: FAO, 2006

FIGURE 2
Aquaculture production by economic status



Source: FAO, 2006

ENVIRONMENTAL PERSPECTIVES ON AQUACULTURE DEVELOPMENT

The international community has recognized the need to address environmental impacts from development. The Convention on Biological Diversity (CBD, 1994) and the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) are key international instruments that have called for development to address environmental concerns and strive to protect natural biological diversity (Table 1). In acknowledgement of the problems of adverse environmental impacts from the food production sector, the First Session of the Sub-Committee on Aquaculture of the Committee on Fisheries, Beijing, People's Republic of China, 18–22 April 2002, recommended future work be devoted to, "undertaking comparative analyses on the environmental cost of aquatic food production in relation to other terrestrial food production sectors". This request is a sign of the concerns that remain regarding sustainable aquaculture development, and an indication of the urgency to work towards the provision of a science-based and authoritative statement on the issue.

TABLE 1
International instruments for tackling environmental impacts of development

FAO Code of Conduct for Responsible Fisheries (1995)	**Article 6.1 General Principles** -The right to fish[2] carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources.
	Article 6.19 -... States should ensure that resources are used responsibly and adverse impacts on the environment and on local communities are minimized.
	Article 9.1.2 - States should promote responsible development and management of aquaculture, including an advance evaluation of the effects of aquaculture development on genetic diversity and ecosystem integrity, based on best available scientific information.
	Article 9.1.3 - States should produce and regularly update aquaculture development strategies and plans, to ensure that aquaculture development is ecologically sustainable and to allow the rational use of resources shared by aquaculture and other sectors.
	Article 9.1.5 - States should establish effective procedures to undertake environmental assessment and monitoring with the aim of minimizing adverse ecological changes and related economic and social consequences resulting from water abstraction, land use, discharge of effluents, use of drugs and chemicals, and other aquaculture activities.
Convention on Biological Diversity (1994)	**Article 14.1(a) -** Introduce appropriate procedures requiring environmental impact assessment of its proposed projects that are likely to have significant adverse effects on biological diversity with a view to avoiding or minimizing such effects and, where appropriate, allow for public participation in such procedures
	Article 14.1(b) - Introduce appropriate arrangements to ensure that the environmental consequences of its programmes and policies that are likely to have significant adverse impacts on biological diversity are duly taken into account;

[2] "Fish" is used in its broadest sense in the Code: as a verb it includes also fish farming; as a noun it includes other aquatic organisms, such as invertebrates and plants.

METHODOLOGICAL CHALLENGES OF COMPARATIVE ANALYSES RELATED TO FOOD PRODUCTION SECTORS

All development will by definition have impacts. For impact analyses to be truly useful to development agencies who may be looking at a range of development or resource management scenarios, they must be *comparative*, and include the comparative costs of development options. In other words, the ability of aquaculture to provide food, income, and maintain an acceptable environment must be compared to other food producing sectors. Comparisons must also be of similar items or of development in similar areas. For example, useful comparisons may include analysis of production of high value protein for export and could then look at beef versus salmon farming. Conversely, decision makers who wish to know the environmental costs of developing arid sections of land may wish to compare fish production with irrigated crop production.

In relation to aquaculture, there is an incredible diversity of farming systems, even if one only examines one species of farmed fish. The farming systems may be classified as commercial/industrial and rural depending on the scale of the enterprise, and as intensive, semi-intensive or extensive depending on the level of inputs (Troell *et al.*, 2004). Therefore to generalize on the environmental costs of, for example, European seabass or seabream, one would need to look at land-based-recirculated systems, extensive coastal ponds and raceways, and offshore cage culture – all with different environmental impacts and costs. Similar differences in culture systems can be found in most farmed species. Terrestrial animals can be farmed in diverse systems as in "free-range" systems, or in intensive feed-lots. A general approach and methodology is needed to compare the environmental costs of potential farming systems (aquatic or terrestrial) that may be proposed for a given area.

A wide range of methods, each with specific strengths and weaknesses, have been developed in order to assess environmental costs of development. Although not common, comparative analyses have been done. Troell *et al.*, 2004 have ranked industrial energy inputs per protein energy output for some aquaculture, capture fisheries and agriculture systems and reported that intensive salmon and shrimp farming is similar to feedlot beef production. These authors pointed out that their data (i.e. rankings) should be discussed in relation with other environmental considerations and externalities. Pimentel *et al.,* 1997 looked at the amount of water required to produce agriculture commodities and reported that vegetable crops required amounts of water of a similar order of magnitude, but that the production of beef required two orders of magnitude more water. However, in production areas where water is abundant or energy is either abundant or sustainably used, these broad comparisons and rankings lose much of their significance.

In order to be useful to FAO and in turn useful to decision makers, the challenge is to develop methods of assessment of environmental costs that are scientifically-based, comparable across different sectors, expandable to different scales, practical to implement, and easily understood.

These methodological challenges do however not only arise from the diversity of production systems and the range of environments in which they take place. They are in a large part also due to the fact that aquaculture and food production in general are economically and socially important activities, at country and farm levels, satisfying both people's wellbeing and GDP purposes. Production takes place in a context of competition for scarce natural resources. Resource competition and welfare maximization is an economic discourse. This discourse is complicated by the monetary and non-monetary values individuals place on natural resources and by preferences and demand for produced goods. The first difficulty is thus related to the adequate valuation of these values and their reflection in the true cost they bear on the environment (or natural resource stock) in the final product price. A second difficulty relates to the formulation of policies dealing adequately with trade-offs and which are economically and environmentally coherent, in particular when economic realities and levels of development vary widely from country to country.

ENVIRONMENTAL ECONOMIC PERSPECTIVES ON AQUACULTURE DEVELOPMENT

Environmental economics provides tools for establishing a "total economic value" of a product; this includes the market value of goods, as well as their non-market value, i.e. the option and existence value of natural resources and habitats that may be exploited in support of production processes[3] (Pearce and Turner, 1990). Environmental economic methods are generally not applied to aquaculture production (the "farm") *per se*, but to the natural environment and resources upon which it depends. Quantification of these costs is based on indirect valuation methods since environmental services do not usually have a market. The applicability and relevance of methods of assessment is summarized in Table 2, with examples provided of two environments supporting intensive aquaculture use systems (coastal areas for shrimp farming and sea lochs for salmon farming).

Based on the methodological limitations highlighted above, effect on production and replacement cost methodologies may be better adapted to valuing the natural resource base used for intensive shrimp aquaculture (in a developing country context).

TABLE 2
Application of environmental valuation methods to ecosystems supporting aquaculture production

Method of valuation	Limitations of the method of valuation*
Effect on production Where environmental damage is responsible for a change in output and associated income, the measure of this change can reflect the value of environmental impact.	Ex-post assessment, i.e. once environmental damage is observable and has an effect on production (e.g. reduction of output or increased costs of production). May be more immediately observable in confined production systems (e.g. shrimp ponds) than open-water systems (e.g. salmon cages in a sea loch).
Replacement cost Cost to restore an altered environment to its original state (or in some cases, partial replacement or compensation to an agreed standard).	Willingness to pay for restoration may be lower in poorer countries. Restoration may only be partially effective in the long term (e.g. tropical coastal mangrove areas replanted or land conversion for agriculture in the presence of acid-sulphate soils).
Opportunity costs (of natural resource used) Foregone income resulting from the decision of "preserving" rather than developing.	Opportunity costs may be underestimated, especially when alternative uses are limited and competition for the resource and space is limited (e.g. mangroves, or remote and low-density population areas such as southern Chile in the case of salmon farming).
Travel cost Inferred value from the time and money people spend traveling to a place.	Perceived amenity value likely to be lower in poorer countries or in remote areas of low population densities.
Hedonic pricing Identifies how much in property prices is due to environmental attributes, and how much people are willing to pay for an improvement in quality of their surrounding environment.	Dependence on well-developed and well-functioning property markets (limited in developing countries). Hedonic pricing does not capture option and existence values of sites.
Contingent valuation Assesses how people would value environmental changes based on their willingness to pay for environmental benefit or willingness to accept compensation for loss of environmental quality.	Willingness to pay for conservation likely to be lower in developing countries where tangible benefits from resource exploitation may be considered as immediately more important than environmental services (option or existence values), e.g. as in developing countries using coastal mangrove fringes to develop shrimp ponds.

*Limitations of each method in their application to aquaculture systems are further discussed in Muir *et al.* (1999), from which this table was developed.

[3] Total economic value = actual use value (market value) + option value (also called bequest value, non-market) + existence value (also called intrinsic value, non-market).

On the other hand, effect on production, hedonic pricing and contingent valuation may be better adapted to valuing the environment in which salmon farming takes place. While market prices provide estimates for actual use value of products, they reflect only partially, if at all, the cost to society of the environmental degradation caused to produce goods. To correct for this, an estimate of the environmental service lost in the production process should be added to market prices. Environmental service values of aquaculture supporting environments, inferred from option and existence values of these environments, have however, with a few exceptions (Gammage, 1997; Barbier and Sathirathai, 2004 – see also this volume) been seldom calculated. This shortcoming may be attributed to the limitations faced by each type of valuation method in their application to specific contexts (Table 2), and to the fact that adequate accounting of environmental degradation in production processes and meaningful comparison across a number of food production activities remain challenges.

Table 2 also suggests that the context of application will have a critical bearing on the choice of the valuation tools, their effectiveness and accuracy, and on the outputs they generate. The dichotomy between developing versus developed country context is likely to be one of the most prominent factors influencing environmental values obtained. However, the calculation of environmental values is only relevant if taken one step further, i.e. in the policy realm where decisions made and measures taken to reflect the need to protect, to the necessary extent, the natural resource upon which economic activities are based. A number of other factors can influence the way decisions and policies are made and implemented, and the ways in which production systems impact on the environment. These are outlined in the next section.

ECONOMIC FACTORS AND CHALLENGES TO POLICY MAKING FOR SUSTAINABLE AQUACULTURE DEVELOPMENT

Several factors, based on basic economic concepts and assumptions, influence the degree food production systems, or any other economic activity, can impact on the environment, and how the negative effects of such impacts may be mitigated. While the influence of technical factors is evident, those outlined hereafter are economic and institutional in essence, and set the context in which policy-making has to take place. They are reminders of the challenging environment in which policies and measures aimed at translating findings from the comparative studies discussed in this book will have to operate in.

Antagonism of economists and environmentalists' views with regard to pollution and environmental damage

Environmentalists and economists tend to regard pollution and degradation of ecosystem services differently: the physical presence of pollution, for example, does not necessarily mean that "economic" pollution, or externality, exists. First because externalities occur only when the degradation of the environment (through biological/health/aesthetics loss, chemical change, noise, etc.) is combined with a loss of human welfare, and that loss remains uncompensated for (Pearce and Turner, 1990). Second because "even if economic pollution exists, it is unlikely to be the case that it should be eliminated" (ibid, p. 62). For economists, the rationale behind this statement is that, under specific market conditions of "perfect competition"[4], an optimal externality is not necessarily zero as there exists an optimal level of activity and associated with it, an optimal level of pollution. Food production will always generate waste. However, minimizing its effects on the environment may be possible through pollution abatement

[4] Perfect competition is characterised by markets with a large number of buyers and sellers with no influence on market prices, no barriers to entry or exit, full knowledge (no information biais) and homogenous products.

equipment and when the waste produced remains within the assimilative capacity of the environment. When this is no longer the case, it can nonetheless be argued that a "right" amount of damage or pollutant may be left in the environment when the social cost of eliminating damage from an incremental unit of pollution equals the social benefits of doing so (Zilberman, Templeton and Khanna, 1999).

Market failures and conflicts over natural resources

The previous section has highlighted that economists' argument in support of an optimal level of pollution and environmental degradation is underlined by an assumption of perfect competition. This state assumes well-functioning markets and well-defined property rights, whereby polluters and sufferers, i.e. those affected by the pollution, will tend to come together to bargain for compensating one another. Striking a deal (or bargain) will lead the system to tend towards a social optimum, regardless of who holds the property rights (the Coase Theorem, after Coase, 1960) so long as each group has equal power. However, in the real world, perfect competition is fictional, bargaining powers are uneven and bargaining often prevented by the existence of high transaction costs. The consequences in terms of pollution linked to productive activities are that optima will not be reached, with uncompensated degradation occurring to the advantage of the one with the strongest bargaining power. The likelihood of fair bargaining is further complicated in the context of common property resources, where the polluters, resource users, beneficiaries and sufferers may be the same people. Other complications can arise when some information is known to some people but not to others prevails, or when developers are powerful and influent and sufferers are not. These reasons underlie why an equilibrium is not spontaneously reached and why environmental damage keeps occurring. Governments and institutions should be correcting for these imbalances, but as the next paragraph highlights, they are often not in a position to do so.

Disfunctioning institutions

The critical role of institutions, including states and governments, should be to create stable structures for human interactions while minimizing costs and uncertainty in transactions (North, 1990; 1993). Historical evolution, combined with the growing impact of global markets, lack of human capital and suitable communication infrastructures can be held responsible for the prevalent inadequacy, if not failure, of institutions predominantly in developing countries where transaction costs are usually higher (North, 2000). While polluters are often assumed to be private firms, they are also governments, through poor legislation and rules. By setting up inadequate incentives, 'bad' policies and institutions can be as damaging to the environment as inappropriate technology (Zilberman, Templeton and Khanna, 1999). One manifestation of disfunctioning institutions is the difficulty to access formal forms of credit by poorer households whose ability to smooth consumption out, as a consequence, becomes reduced and its dependency on natural resources exacerbated. Without changes in conditions to access credit, investment in environmentally-friendly production systems is unlikely to occur, and even more so if regulatory frameworks in place are not adequately tackling environmental and social equity issues. This implies that a complementary area of study in the evaluation of environmental costs would be to look at the functioning of institutions and their efficiency in terms of promotion of sustainability.

The power of consumer demand

In addition to the above factors, consumers' perception of environmental attributes of aquaculture and other agricultural food commodities condition the final value of products and their markets. On one hand, consumer demand for "green" or ethically-produced food commodities can force producers to implement pollution and environmental damage minimization measures, and as such, "over-rule" the role of the state. The share of corporate enterprise spending to minimize environmental damage in the total production costs of a commodity, after internalization, could be an indicator of the ecological sustainability of an enterprise. However, on the other hand, while consumers may be the ultimate bearers of the environmental costs through a higher 'green' premium they are willing to pay, some issues remain on how this premium may be redistributed and benefit the primary users of the natural resource it aims to represent and protect (Young, Brugère and Muir, 1999).

Uncertainty about the future

Uncertainty relates to our current lack of knowledge on environmental damage and wider negative effects of food production impacts (see for example Brooks, this volume). However, uncertainty also relates to the unknown benefits individuals may withdraw (called the "consumer surplus") from maintained or enhanced environmental conditions in the future. This means that, from a demand perspective, we, as individuals may not be sure of how much we will be able to pay for environmental conservation or a product price premium in the long term. From a supply perspective, this means that we also do not know how the environment will react to a given level of exploitation, pollution or intervention, and if it will still be there for us to enjoy in years to come (Pearce and Turner, 1990). Hence the difficulty to determine the limits of exploitation for economic purposes, stand on our incomplete knowledge of environmental processes.

BRIDGING PERSPECTIVES BETWEEN ECONOMIC AND ENVIRONMENTAL APPROACHES FOR POLICY MAKING

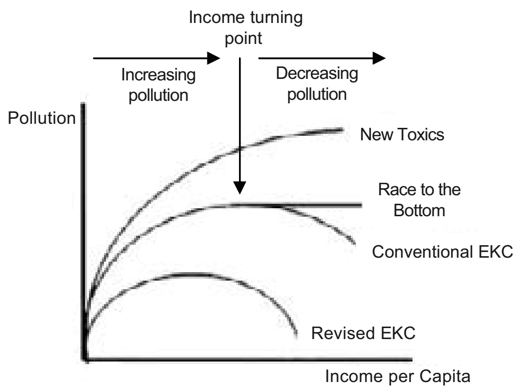
Broadening perspectives and suggesting alternative approaches may be useful in bridging economics and biology-based methods to monitor the development of sustainable food production systems, as well as guide policy making. The definition of monitoring and policy-relevant indicators of sustainability of food production systems also requires integrated approaches encompassing both economic and ecological aspects. Although a review of the advantages and disadvantages of the approaches proposed hereafter is beyond the scope of this paper, it is felt that they deserve further investigation in their application to specific food production systems. As such they should be treated as "food for thought" for further discussion and as possible research avenues towards the design of effective ways to compare the environmental costs of all food production systems.

Environmental Kuznets Curves

Environmental Kuznets Curves (EKC) are curves linking environmental degradation with income (Webber and Allen, 2004). They indicate that pollution rises with income until a turning point is reached after which pollution levels will decrease (Figure 3: "conventional EKC"). Many factors, for example technology and the consequences of disfunctioning institutions as indicated above, can influence the shape of the curves (Essati, Singer and Kammen, 2001). Figure 3 illustrates alternative scenarios. "Revised EKC" (downward shift of the curve) shows the positive influence of technological change in reducing pollution. Conversely, "new toxics" curve suggests that as new and more damaging pollutants replace traditional ones, and their use is not curtailed by suitable policies and regulations, pollution is not reduced. Finally, the "race to the bottom" scenario, giving more emphasis to the situation of developing countries, stipulates that while pollution from developed countries will have been reduced by outsourcing dirty production to developing ones, the latter will find it more difficult to curtail their own emissions and pollution as they develop.

FIGURE 3

The simple Environmental Kuznets Curve (EKC)



Source: Stern (2004), Webber and Allen (2004), Dasgupta *et al.* (2002).

The empirical application and use of EKCs for policy formulation in relation to sustainable development are still much debated (e.g. review of case studies focusing on water quality and deforestation in Webber and Allen, 2004). However, with adequate data, modified EKCs could be built to plot pollutant release or other environmental damage from a specific food production system against income from the activity. Provided that the analysis can also incorporate feedback from the state of the environment on the economic activity (Stern, 1996), the change of the shape of the curve over time could provide an indicator of the necessity of an environmental or economic growth-focused policy and the point in time when such policy measures may be necessary. This would be the case when production and environmental degradation are tightly linked and when incomes decline because the carrying capacity of the environment has been reached, unless specific investments in environmental restoration are made.

The Ecosystem Approach to Aquaculture[5]

Environmental cost analysis will be a key feature of an "Ecosystem Approach to Aquaculture" (EAA). The EAA is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way (UNEP/CBD, 2000). It should aim at sustainable use of aquatic environments by treating aquaculture as a part of the entire ecological and socio-economic systems, rather than as a distinct unit. By doing this humans and their activities are also specific components of the ecosystem. Although the principles upon which the EAA is based are not new, the broad interpretation of the ecosystem approach brings out four points new to traditional ecological analysis, but that will be necessary for development or conservation programmes: i) it represents an institutionalization of the concept – it is now part of binding international legislation in the Convention on Biological Diversity; ii) it stresses that decisions will be based on societal preferences; iii) it acknowledges the complexity of the real world and the problems with resource management in an age of globalization, technology, limited resources, an increasing human population; iv) it reflects the fact that developers, ecologists and resource managers will never have all the information necessary to understand and predict how an ecosystem will respond to development. In order to be operational this approach should have three main components: a) human well being, b) ecological well being, and c) good governance, that is, the ability to achieve both a and b.

Policy relevant monitoring systems (PRMS)

If countries are striving to put in place economic development strategies that do not jeopardize their natural resource base, they need systems of monitoring that will allow them to react in time to ensure that productive activities do not cause irreversible environmental damage (Hazell *et al.*, 2001). To be policy-relevant, monitoring systems should go beyond a periodic assessment of the status of natural resources in order to generate quantitative estimates of benefits and gains, leading, where necessary, to

[5] This approach was pioneered in the context of capture fisheries (FAO, 2003). The principles upon which it is based could however be applied to any other productive activity.

the implementation of corrective policy measures. By combining the attributes of an analytical framework (a pay-off matrix) fed on data from "alarm" and "diagnostic" indicators and those of a participatory, institutional framework to identify stakeholders (those who will be using, managing and monitoring the resources and food production systems) and distributional impacts, PRMS can allow policy makers to identify policy trade-offs and rank environmental externalities and associated corrective measures based on dialogue and consensus among stakeholders.

CONCLUSIONS

Constant efforts are being made to address the negative impacts food production systems have on the environment. Through increased awareness both at individual, institutional and global levels, perspectives of economic and environmental strategies have started to converge. Yet, many challenges remain, a number of which are methodological in nature. They deal with the scientific comparison of production processes and their related optimal uses of resources, and whether impacts are viewed on a local or global basis, as explored in this volume's papers. Despite progress made towards addressing them from various angles, a number of problems are likely to remain because of the fundamental nature of the concept of sustainability, of different valuation systems and of the diversity of societies and environments. Linkages among various scales e.g. increasing production intensity or increasing the number of "farms", or local versus global impact analysis, is likely to remain problematic because the sustainability of a system is not the sum of the sustainability of its components (Ellis, 2000). Integration of the true cost of food production in final prices and basing development decisions on an accurate assessment of the cost of various food production systems are issues that need to be addressed directly. Taking into environmental factors to do so is a prerequisite, but should nonetheless not be at the expense of other less "visible" factors such as institutions and markets. This message is not new, but still remains a long way from implementation in many areas.

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