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Review

A discussion of the use of the sustainability index: 'ecological footprint' for aquaculture production

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Abstract − This paper critically reviews the theoretical and practical implications of adopting the original 'ecological footprint' concept as an index of the sustainability of aquaculture production systems. It is argued that the concept may provide a reasonable visioning tool to demonstrate natural resource dependence of human activities to politicians and the public at large. However, due to its inherent weaknesses, the 'ecological footprint' fails to provide a cohesive analytical tool for management. From an ecological perspective, its two-dimensional interpretation of complex ecologically and economically interacting systems is one major weakness. From an economic perspective, the 'footprint' fails to recognise factors such as consumer preferences and property rights which have a major influence on the allocation and sustainable use of resources. The interactions among social, ecological and economic factors are discussed in an attempt to foster a broader inter-disciplinary view of criteria required for a sustainable use of aquatic resources. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

ecological footprint / aquaculture / natural resources / sustainable use / management

Résumé – Une discussion sur l'usage de l'indice de durabilité : « l'empreinte écologique » dans la production aquacole. Cette étude fait le bilan critique des implications théoriques et pratiques de l'adoption du concept original de l'empreinte écologique. Ce concept peut offrir un outil d'observation raisonnable, pour démontrer la dépendance de l'activité humaine et des ressources naturelles, aux politiciens et au grand public. Cependant, dû à sa faiblesse inhérente, l'empreinte écologique ne réussit pas à fournir un outil analytique cohérent pour la gestion. Dans une perspective écologique, son interprétation à deux dimensions des systèmes complexes, interactifs au niveau écologique et économique, est sa principale faiblesse. Dans une perspective économique, cet indice ne réussit pas à reconnaître des facteurs, tels que les préférences des consommateurs et les droits de propriété, qui ont une influence majeure sur l'allocation et l'usage durable des ressources. Les interactions entre facteurs économiques, écologiques et sociaux sont discutées, en cherchant à favoriser une plus large vue interdisciplinaire, nécessaire à l'usage durable des ressources aquatiques. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

empreinte écologique / aquaculture / ressources naturelles / usage durable / gestion

1. INTRODUCTION

The publication of "Our Common Future" in 1987 (WCED, 1987) stimulated efforts to develop sustainability indices capable of measuring the development and status of natural systems and their response to our use and misuse of the renewable resources they generate. One of these indices is the 'ecological footprint' developed by Rees and Wackernagel (1994) which has it origins in the ecological-economy ori-

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ented school of scientists (for example: Net primary productivity: Vitousek et al., 1986; Environmental space: FoE Europe 1995). Other indices with similar goals include the 'Genuine Savings' (Pearce and Atkinson, 1993) and 'Green Net National Product' (Hartwick, 1990).

In its present form, the 'ecological footprint' represents a visualised expression of perceived demands for natural resources and pressures on ecosystems based essentially on environmental considerations. In contrast, the 'genuine savings' approach is based on mainstream economics principles. The two approaches represent very different ends of an analytical spectrum and cannot present a balanced assessment of management alternatives leading to sustainable use of the Earth's resources. An interdisciplinary approach aiming at drawing on findings from both economics and natural sciences would sit in-between these more polar approaches. Such an approach may be found in 'functional analysis' (De Groot, 1992; Costanza et al., 1997; Turner, 1991; Turner, 1998). The core concept is that of functional diversity in ecosystems and its representation in the social science analogue of functional value diversity. The latter notion combines the functions of an ecosystem with provision by the system of goods and services (direct and indirect) which are valued by human society. The ecosystem's role in providing such outputs (functions in the economic sense of the term) is the subject of attention in a management/policy context.

Given the generic policy objective of sustainable development, management agencies are encouraged to maintain or enhance the resilience of ecosystems in terms of their ability to cope with stress and shock, and thereby enhance their capacity to adapt to both physical and social demands. The resilience goal can be approached if efforts are made to manage systems in a way that maintains or increases functional diversity and the stocks of economic wealth and flows of income that are inherently related to the 'healthy' functioning of ecosystems. This strategy must embody extensive spatial and temporal scales, and seek to examine and manage large-scale processes (large marine ecosystems at sea opposed to landscape ecology on land) together with the relevant environmental and socio-economic driving forces (Turner et al., 1999; Gren et al., 2000; Turner, 2000).

The 'ecological footprint' concept is described by the original authors as a comprehensive and transparent planning tool, which can assist in the development of appropriate policy responses by translating the ecological aspects of sustainability into a common yardstick. The 'ecological footprint' sustainability index has (as indeed many other known sustainability indices) inherent strengths and weaknesses. The objectives, which should be fulfilled for any sustainability index, can be divided into those serving research, management and decision making, and those providing information for the general public. An index has to be empirically observable and data sources equally accessible for calculation purposes. For research purposes the consistency in methodology is imperative. For management and decision making purposes, indicators should relate to clear policy objectives and have predictive properties. As a source of information to the public the clear vision of complex issues may serve two purposes: (a) to inform the broad public, and (b) alter its behaviour.

The analogy of the 'ecological footprint' does present a graphic and easily communicated image. However, there are mounting concerns that its incorrect use and the inherent problems in its application to natural resources dependent activities, such as aquaculture, can mislead rather than inform policy makers, planners, managers and the general public. One of the examples of such misuse relates to the interpretation of the potential eutrophication effects of aquaculture in open waters (Black et al., 1997). Problems associated with the application of the 'footprint' concept are examined in more detail in the following paragraphs.

2. THE CALCULATION OF AN 'ECOLOGICAL FOOTPRINT'

The 'ecological footprint' is presented by Wackernagel and Rees (1996, p. 9) as an "estimate of resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area". The 'ecological footprint' of a defined population (from a single individual, a whole city, or a country) is the total area of biologically productive land and water exclusively used to produce all the resources consumed, and capable of assimilating all the wastes generated by that population using prevailing technology (Hansson and Wackernagel, 1999).

The 'ecological footprint' contains some elements related to the ecological concept of carrying capacity, which is the population of a given species that can be supported indefinitely in a defined habitat without permanently damaging the ecosystem on which it depends. In terms of human populations and terrestrial animals, the 'ecological footprint' is visualised in hectares per capita, whereas carrying capacity is generally expressed in units of individuals per hectare, making one concept the inverse of the other (Bicknell et al., 1998). In marine ecology, assimilative capacity can also be defined in relation to specific environmental target criteria reflecting dynamic ecological pathways rather than area-related measures (GESAMP, 1996).

The 'ecological footprint' of a human population is calculated through the determination of consumption in a given area and divided into relevant categories (food, housing, transportation, consumer goods and services) which are multiplied by the calculated land use for each consumption category. The sum derived from these results gives a hypothetical estimate of the 'ecological footprint' required to sustain that population within a given region at present consumption level.

3. INHERENT PROBLEMS IN THE APPLICATION OF THE 'ECOLOGICAL FOOTPRINT'

It is generally argued that the 'ecological footprint' captures all the biophysical impacts of a given community regardless of where those impacts occur. In effect the ecological footprint provides a 'snapshot' of the resources required to support consumption using available technology. As such, the ecological footprint can be compared with the land available to support human consumption to provide a static indicator of sustainability. Bicknell et al. (1998) call for modification to the existing methodology, and state: "the original results, cannot be easily reproduced or meaningfully compared across time or between populations. If a measure is not consistently applied and regularly updated, variations in the results may be attributed to variations in the method rather than the phenomena it claims to measure".

There are aggregation problems associated with Wackernagel and Rees's (1996) original methodology due to equal ecological weights being given to all land uses (i.e. 1 ha pasture is equal to 1 ha highway). For example, when the estimates are applied to imports it has an anti-trade bias; in the case where production flows from those countries where environmentally sensitive technology is used, trade may very well provide a means of reducing the global 'ecological footprint'. Unfortunately, the impact of 'ecological comparative advantage' cannot be explored without obtaining land and energy intensity figures for exporting countries, which is not included in the original 'ecological footprint' methodology (for further discussion please see van den Bergh and Verbruggen, 1999).

'Biocapacities' are expressed as productivity per unit area, assuming that industrial yields are designed to be at a sustainable level. If actual outputs are beyond the industrial sustainability level, biocapacity calculations become over-estimates. Therefore, the concept has a built-in default leading to an over-estimation of production options. Moreover, the sustainability concept should also include the conservation of biodiversity, as we believe that this conservation concept provides the option for building buffer zones from which yet unknown benefits might be derived.

Many organisations aim to develop buffer zones as a means of enhancing the capacity ecosytems to absorb human pressures. For example, Marine Protected Areas (MPAs) and Nature Parks adjacent to or within heavily utilised ecosystems provide 'buffers'. Such buffers help to compensate for uncertainties in both the productivity of the natural resource and in the market place.

Natural systems are inherently unstable and industrial yields from natural resources have to be seen in relation to potentially high fluctuations. Therefore, including 'buffer zones' (such as MPAs) serve a dual purpose: (a) providing systems for biodiversity preservation, and (b) allowing to 'trade' energy flows and bio-resources to replenish unstable systems in response to stress and external shock, thereby improving resilience of ecosystems. Similarly, such 'trading' of goods and services may also enhance socio-economic benefits. Restricting the footprint concept to local boundaries, without allowing for beneficial 'trades' (interactions) between areas or regions, seems to be inappropriate.

Although there is adequate knowledge to demonstrate that options for building the advantages of buffer zones into bio-capacity estimates, such concepts have not been adequately considered in the 'footprint' approach. Therefore, a critical component, which accounts for ecological factors such as buffer capacity as pointed out by the authors themselves (see p. 210 in Hansson and Wackernagel, 1999), is lacking.

In cases where an 'ecological footprint' incorporates technology that is not sustainable, it will give a distorted picture of our impact on the environment (Bicknell et al., 1998). Furthermore, standard ecological footprint calculations also imply that current land use practices are sustainable. In many instances this is clearly not the case. Unsustainable practices cannot, by definition, continue indefinitely and would at some point lead to decreased production.

It has been realised that the use of the analogy of an 'ecological footprint' as an index is a static measurement mostly used at country level (the political entity responsible for management and conservation of natural resources) and is not based on relevant border criteria for ecosystems (i.e. watersheds). A country's 'ecological footprint' is vulnerable to changes in population density, consumption per capita, availability of arable land, the resource content of foreign trade, and energy consumption. The resulting physical index, or 'ecological footprint', implies that a small footprint is better than a large footprint. Furthermore, it is implied that self-sustainability, i.e. each nation's 'ecological footprint', should be smaller than or equal to its own hypothetical land area. This is deemed better than production and consumption patterns in one country that are dependent on land-use in another country. In this context, an 'ecological deficit' or 'positive footprint' implies that either a country's natural capital is depleted or the country imposes part of its footprint on other countries via imports for consumption or disposal of wastes.

The 'footprint' concept can provide a useful tool. However, like most tools, it may be used in the wrong context and may yield results that are inappropriate to one field of application while possibly being useful to another. However, suggesting that the 'ecological footprint' can serve as a comprehensive planning tool is an overstatement of its potential. As tool for environmen tal analysis it has inherent weaknesses, particularly in the lack of proper quantification methodologies for estimating the budgetary flows in dynamic, interactive ecological systems.

While we appreciate the difficulty in dealing with multi-dimensional processes, it is still not acceptable to simplify the analytical approach to a linear, two-dimensional ('one-way shortcut'), area-related model that does not reflect reality and ignores earlier scientific findings on multi-dimensional interactions and ecosystem functions. While we appreciate the visioning aspect, sustainable use of ecosytems functions and renewable resources will have to be based on modern, multi-dimensional and multidisciplinary modelling approaches, for which reliable methodologies are being developed.

The 'ecological footprint' is a static measure and benefits derived from changes in stocks (support services) or improved management practices are not incorporated in the calculations, it therefore does not provide a reliable, predictive tool capable of delivering well balanced and detailed policy advice (Hanley et al., 1997; 1999).

The inherent weaknesses in the 'footprint' concept limit its practical application, especially in the aquatic environment and the assessment of the sustainability of aquaculture.

4. THE APPLICATION OF 'ECOLOGICAL FOOTPRINT' ANALYSIS TO AQUACULTURE PRODUCTION

The 'ecological footprint' concept has been applied to marine aquaculture of shrimp, tilapia, salmon and mussels, as well as consumption of fish in cities in the Baltic Sea drainage basin (Folke et al., 1998). A series of papers by Larsson et al. (1994), Kautsky et al. (1997), Naylor et al. (1998), Folke et al. (1998), and Shiva (1999) attempts to define the capacity of marine and coastal ecosystems to sustain seafood production. These authors have adapted the methodology used in defining an 'ecological footprint' for use as an analytical tool when assessing the sustainability of aquaculture. Their 'footprint' analogy has served to stimulate creative thinking concerning the assessment of sustainable use of natural resources. However, the management recommendations made by these authors concerning aquaculture are not in general agreement with well-proven natural science or economic methodologies used to assess the viability and sustainability of modern and traditional aquaculture systems.

Larsson et al. (1994) investigated the ecological limitations and appropriation of ecosystem support to shrimp farming in Columbia. The results show that a semi-intensive shrimp farm needs a spatial expression of ecosystem support – the ecological footprint – that is 35–190 times larger than the surface area of the farm. The estimates are – in the authors' own words – "helpful in indicating how big economic activities can grow in relation to their resource base or whether they might already have passed a limit that can be sustained". Furthermore, it is argued that estimates of ecosystem support may serve as guidelines for policy formulation and may be especially useful at highlighting areas of overlap between conflicting activities, not all of which may be directly apparent (Larsson et al., 1994, p. 664).

Kautsky et al. (1997) used the concept of 'ecological footprint' in a similar way for assessing resource use and development limitations in shrimp and tilapia culture industries. However, the conceptualisation of an 'ecological footprint' in this setting is much different from the sustainability index properties originally embedded in the country-based 'ecological footprint' described by Wackernagel and Rees (1996), where the various human demands are the baseline of the sustainability index. The estimates by Larsson et al. (1994) and Kautsky et al. (1997) are derived from production systems only, and do not have a reference point comparable to the hypothetical land area calculated by Wackernagel and Rees (1996). This aquaculture 'ecological footprint' method may at best be used to measure and rank the dependency of different production systems on external support/ecosystems, but does not in itself give the answer to whether the present system is ecologically sustainable or not. The papers by Larsson et al. (1994) and Kautsky et al. (1997) both draw implicitly on other theories in their discussions and conclusions.

The article by Naylor et al. (1998) "Nature's Subsidies to Shrimp and Salmon Farming" is a prime example of presenting quasi ecological arguments which, when divorced from economic logic, can create a distorted analysis of human attempts to utilize renewable natural resources in a sustainable manner. The methodological approach adopted by Naylor et al. (1998) tries to derive an "appropriate ecosystem area" as an "indicator" of essential ecosystem support required for human production and consumption of seafood. In practical terms this is the reflection of the land area necessary to sustain current levels of resource consumption and waste discharge by a given human population that has been adapted to the marine environment from the concept of an 'ecological footprint'.

The result from the Naylor et al. (1998) analysis is an estimate of the marine support area required to supply feed for the European salmon farming industry at 40 000 to 50 000 times the surface area of cultivation and equivalent to about 90% of the primary production of the fishing area of the North Sea. This gives the impression of a specific, tangible and measurable statement. However, on further thought, this approach represents random, partial and static measurements of resource use (e.g. restricted to factors associated with inputs to production and waste discharges).

4.1. Theoretical problems associated with the application of the 'ecological footprint' to aquatic systems and aquaculture

The 'ecological footprint' method implies that it is possible to keep track of most of the resources used in aquaculture production and the wastes generated. The theory assumes that most of these resources and waste flows can be converted to a corresponding biologically productive area. In the case of aquaculture this is expressed in terms of surface water area. However, insufficient account is taken in the calculation of the 'footprint' of differences in husbandry practices and the degree of efficiency in the use of inputs in producing desired outputs. This can lead to inappropriate assessments of the 'ecological footprint' of aquaculture and misrepresentation of the economic and social benefits and costs of developing aquaculture in respect to other forms of activity.

The ecosystem support area for aquaculture is calculated as the spatial sum of inputs and outputs from an aquaculture production site, assuming all interactions are a burden on the ecological system (for example see figure 1 in Kautsky et al., 1997). Small ecological footprints are assumed to be better than large footprints denominated in terms of ecosystem support area compared to surface area of the aquaculture operation (derived from Larsson et al. 1994, and Kautsky et al., 1997).

In calculating the area of water required to sustain aquaculture it is assumed that the water area serves only a single function. In many cases there are multiple functions served by open waters. For example, a given body of water may be used for both fishing for feed and as a sink of wastes. This suggests that calculations of ecological footprints may be double-counting the ecological impact within an ecological production system, whereas part of these externalities may be converted into goods and services within the system and not necessarily utilised directly by man. Multi-functioning effects of any input to the support area must be accounted for if ecological interactions between trophic levels are to be valued realistically.

The 'footprint' analogy does not appear to give sufficient regard to differences in water areas and the dynamic responses of the ecosystems in these areas, nor does it account for the multilayer processes in a three-dimensional space. Ecosystems may be very different and a direct comparison or transfer of results from one system to another may not be appropriate. Indicators also need to reflect both the quality and the quantity of renewable resources produced by different ecosystems and the manner in which the resources are used. This is particularly important where multiple uses of marine and coastal resources can be sustained through good planning and management. For example, integrating resource uses within aquaculture systems (i.e. polyculture), or in conjunction with fisheries, tourism, and others as interacting partners.

Both from a social and ecological point of view, the addition of different uses of an area of water for example for fishing fry, fishing for feed and as sink of waste to support aquaculture to derive a representative 'footprint' may not be possible. Such simple additions imply equal weights for these functions both socially and ecologically. It also implies equal substitutability between the different ecological services and resources required to sustain the different uses. The implications of this are, apart from the calculation of faulty results, that it is very difficult to use the 'footprint' method of accounting to assess trade-offs associated with environmentally safe and sustainable aquaculture procedures applied to different sensitive ecological systems.

The original 'ecological footprint' theory does not distinguish between sustainable and unsustainable land use practices, whereas Larsson et al. (1994) conclude that "Clearly the present behavior of the shrimp farming industry is ecologically unsustainable" (p. 671). The motivation for this conclusion may have been derived from the Rio declaration on environment and development, which states that unsustainable patterns of production and consumption should be reduced and eliminated. The logic for the deduction by Larsson et al. (1994) is not clear. We fully agree that unsustainable practices are unwanted, but the fact that other production systems exist, and other fish species may be cultured (lower in the food chain), with smaller 'ecological footprints', does not in itself lead to the conclusion that forms of production requiring larger 'footprints' are unsustainable.

4.1.1. Problems associated with ecological factors

When looking at biological ecosystem functions, simplifying complex response systems to a linear formula distorts reality. For example, the primary production and internal cycles of organic matter in the North Sea support a much larger standing stock biomass (including many carnivorous species) than would be needed to nourish the few one hundred thousand tonnes of salmon cultured in Nordic countries. Therefore, calculations like the one cited by Naylor et al. (1998) above are simply unrealistic and misrepresent reality by orders of magnitude.

Apart from the inconsistencies in the way the 'ecological footprint' analyses are applied, there are several other factors that reduce the credibility of the calculations of the 'footprint'.

– Firstly, the choice of certain types of resources for inclusion in the model seems specific but it is actually random in ecological systems. One could have chosen other factors instead of fish meal (for example, primary productivity or food web linkages) and would have reached totally different conclusions as to the 'size of the footprint'.

– Secondly, the methodology is not impartial, as it lays down physical limits for a series of random natural resources and their consumption, while in fact it does not offer any choice in prioritising between the different natural resources. This denies the existence of opportunities to more efficiently combine or recombine the use of resources derived from a given ecosystem in response to environmental and economic change.

– Thirdly, when the approach is static, one can only look at the consumption (or inputs, e.g. fish meal) by the present generation, without any time dimension and, therefore, no option is provided to allow trade-offs between present and future generations.

The present analytical methodology of the 'footprint' concept does not, therefore, present a consistent method for describing and analysing the problems of waste assimilation/conversion as a basis for developing environmentally, socially or economically responsible decision making and sound management practices.

4.1.2. Weaknesses in the economic logic of the 'ecological footprint'

The yardstick comparing surface area of intensive salmon farming with surface area of marine fisheries for industrial species cannot serve as a measure of sustainability, nor will it give an indication of the economic welfare gains derived from these activities. The multiple objectives of both environmental sustainability and economic sustainability may instead be viewed on their own merits. It can hardly be refuted that levels of harvesting (fishing mortality) which will lead to continued stock decline and eventual stock collapse (Fcrash) are unwanted, whereas maintaining stock levels capable of producing at maximum sustainable yield (MSY) may be discussed. For economic reasons the theoretical optimal utilisation (maximum economic yield, MEY) is most often traded for a development path where the social costs of people getting caught in the transition process weighs heavily upon the managers and decision-makers (for further details see OECD, 1997).

When fish are harvested for reduction purposes (e.g. feed for aquaculture and animal husbandry), this fishery must adhere to the same management objectives as any other fishery. Analytically, the aim of an economic utilisation of a single fish stock is to reach theoretically an optimal utilisation of this particular resource. This implies harvesting at 'MEY' (first proven by Warming, 1911), where the resource rent is optimised, and the income to society from the individual fish stock therefore attains an optimum level. In practice, many fish stocks are known to be overfished in terms of both biological and economic optima. However, this does not necessarily mean that the utilisation is unsustainable.

The transition from harvesting at a level where overfishing and overcapitalisation are present to a management scheme that meets analytical economic goals, results in direct social costs, by making both fisheries capital (boats, gear, etc.) and fishermen redundant. Therefore, management schemes must balance social, ecological, and economic costs, and still harvest at a level that allows for a safety margin (i.e. pre-cautionary principle).

The 'ecological footprint concept' cannot reach clear conclusions on either the optimum harvest decisions and the level of over-fishing, or the trade-off between economic and social costs of transition, because these functions cannot be based on area comparisons using surface area of aquaculture and surface area of harvest for fodderfish.

The 'footprint' approach has been used by some aquatic environmentalists (Folke et al., 1998) with the intention of creating a positive influence on environmental management at a global level and promoting equitable access to the natural resources available for all world citizens. This is certainly a very laudable and ethical objective, but somehow removed from reality. Economic variables, such as social choice, influence the exploitation of natural resources. In the article by Naylor et al. (1998), legitimate economic objectives, such as the generation of foreign exchange, or increased employment, are cast in a negative light. For example, "The explosive growth of shrimp farming has been supported by national governments, private investors, and international development agencies motivated to generate foreign exchange, private profits, and employment. Farmed shrimp is produced mainly in developing countries for markets in industrialised nations at a global value exceeding $6 billion annually." (Naylor et al., 1998, p. 883). It has to be recognised that in several areas where non-sustainable shrimp farming has developed, there are numerous causal factors that are not considered in the 'footprint' analyses. Some of the principal factors include: (a) unsuitable system design, (b) overstocking, (c) poor quality of feed, (d) poor management, and (e) inappropriate use of chemicals (Jiaxin and Zhimeng; 1998). Other factors contributing to negative externalities of shrimp farming have been identified by Vivekanandan and Kurien (1999) for India and these relate to lack of proper planning and environmental management at regional and community level.

This pejorative emphasis in the article by Naylor et al. (1998) continues with a listing of examples of environmental disasters in the Southeast Asian shrimp culture industry, which could be interpreted as a given fact that shrimp farming is, per se, not sustainable. What we are dealing with is poor planning and management of aquaculture. On the one hand, it is legitimate in a free market economy to accept market-driven incentives (high international prices for shrimp) in order to increase production and to raise national income and employment and generate foreign exchange. On the other hand, this development cannot proceed and be sustained without proper planning and environmental safeguards, e.g. appropriate site selection with estimates of an area's carrying capacity, competent environmental impact assessments prior to establishment of farms, high standards of farm management, and effective control of the expansion in the number of farms in specific habitats. Non-sustainability is far too often due to lack of knowledge on the part of the entrepreneur and regulatory authority, and sometimes corruption of officials, and the failure to adopt well established practices for appropriate planning, monitoring and management.

Sustainable production of shrimp in tropical coastal habitats is therefore not solely a question of physical and biological factors. It is also a question of appropriate aquaculture system planning and area management. A major problem of non-sustainable aquaculture in many areas is that it deprives local communities of opportunities to improve their welfare, and appropriate political measures are needed to create more equitable income distribution. These shortcomings have already been recognised during several special sessions of the latest 'Annual Conference of the World Aquaculture Society', where several drafts of a code of conduct on sustainable shrimp farming and the subsequent revisions have been repeatedly discussed.

The bias towards biophysical factors in defining the 'footprint' of any given activity does not address the question of property rights. This is crucial to the economic behaviour of man and the economic sustainability of commercial activities. Property rights are unfortunately not clarified in all countries, and here we need global solutions to address sustainability issues. Property rights may be regarded as a claim that the courts may recognise and enforce, and cover both legal and customary rights from direct private ownership to the use rights to a stream of benefits. For example, aquaculture should have equal access to and use of coastal lands and waters as other forms of natural resources dependent activities. Aquaculture should also be seen as having a right to high quality environmental conditions, and to be able to seek compensation where adverse external influences, such as environmental degradation of water, caused by others impose costs on their operations. Likewise, aquaculture has a responsibility towards the external environment (use rights within social acceptable norms) (Davidse et al., 1997).

Shiva (1999, p. 274) includes 'ecological footprints' in her descriptive economic analysis of international income allocation between rich consumers and poor coastal communities and calculates the non-compensated environmental costs of the shrimp industry in India (the economic reasoning does not lead to any recommendation of the optimal allocation of resources to the aquaculture industry; this is due partly to the used methodology – total cost calculated instead of standard marginal cost analysis – but more so by using incomplete data to formulate inadequate generalisations). The 'ecological footprint' is included as a visioning tool stating that "every 1 m^2 of an industrial shrimp farm can require up to 200 m^2 of marine and coastal ecosystems for input supply of shrimp seed and water and for sinks for waste and pollution" (Shiva, 1999). The consequences of this statement are not clear, and no indication is given in the analysis of whether this area is small or large compared to alternative forms of sustainable development of the required marine or coastal area, including shrimp farming.

The analysis of a given 'footprint', therefore, is an inappropriate methodology for prioritising and managing alternatives for achieving social development. The bias towards biophysical factors in assessing a 'footprint' implies that all limitations in a 'footprint' shall be met by society regardless of the costs. This makes it impractical to undertake a comparison of trade-offs between different 'footprints' by either consumers or decision-makers. It is also directly counter to the global aim of achieving as large an improvement in human welfare as possible under conditions of sustainable exploitation of renewable resources, with or without strong (maintaining all natural capital 'stocks' constant) or weak (allowing some substitution between natural and man-made resources) sustainability. Meeting individual needs safeguards welfare. Only the individual may maximise his or her own utility within the constraints of economic possibilities. Decisions to trade-off part of an ecological 'footprint' for other goods or services may actually raise the welfare of an individual (the right of choice).

The issue of free choice and equity in the distribution of social and economic costs and benefits associated with uses of natural resources to achieve alternative forms of sustainable economic development are dealt with in more detail by Daly (1995) and Munksgaard and Larsen (1999). If present day interpretation of the 'ecological footprint' philosophy would be strictly implemented into management, this would lead into an ex ante allocation of consumption and waste output per capita. This would certainly imply a strong limitation to economic welfare if these allocations were non-transferrable, thereby leading to limited options for alternatives (e.g. aiming at an optimum mix of goods and services utility).

5. CONCLUSION

The 'ecological footprint' may in principle be used for providing a visualised estimate of the resources and services required from an ecosystem to sustain aquaculture. In economic terminology the method establishes the absolute biophysical constraints for human economic activities, but it does not indicate how much should be produced and in what way. For example, the least cost method of production, including non-compensation of external costs, may be treated equally with other more socially, economically, and environmentally responsible forms of production. Nor does it provide a reliable tool for making decisions on how natural and human resources should be allocated to aquaculture as compared to other sectors (allocative efficiency), or which management tools should be adopted.

A static measurement of a footprint will not in itself ever explain the reason for non-sustainable development of aquaculture or other resources dependent activities. Nor will it give any indication of the most appropriate development path for human activities. As a result, it will fail to identify the different welfare options, which must be considered in the formulation of policies, plans and management strategies for sustainable and equitable resource development.

The 'ecological footprint' concept has inherent theoretical weaknesses. First of all, it is evident that there is a problem associated with the addition of unweighted natural services derived from an ecosystem. Secondly, the implicit assumption of mono functioning of the ecosystem makes the results unreliable for planning purposes. Third, the calculation of 'ecological footprints' does not differentiate between qualitative differences in similar types of ecosystems. Without considering the point of reference at which scarcity of a resource starts to occur in a given area, the 'ecological footprint' in itself does not indicate whether the production is sustainable.

The literature dealing with 'ecological footprints' and 'aquaculture' suggests very strict and radical solutions to management of the aquaculture industry when estimating ecological support areas. The authors argue for an understanding of the sustainability concept as one that should go beyond what is actually required for traditional perceptions of sustainability. Even if aquaculture is sustained with species high in the food chain, the advocates of the 'ecological footprint' approach argue that it is preferable to aim for the culture of species from lower trophic levels. In other words, the authors ask for nothing less than a fundamental change in social values, where we move from optimising to minimising the use of ecological services. Such arguments also imply that we should combine the ecological footprint tool with a strategy of re-embedding the human economy into a life-support context by localisation of ecological changes brought about by human consumption (Hansson and Wackernagel, 1999).

As a result of our concerns over the inherent limitations of the 'ecological footprint' approach, we have taken the liberty to present our criticisms of the concept in this volume and wish to stimulate a wider scientific audience to take part in in-depth discussions on the implications for society of applying this concept in an uncritical and ill-considered manner.

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