Contributed papers

Applying an ecosystem-based approach to aquaculture: principles, scales and some management measures

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ABSTRACT

As aquaculture growth worldwide involves the expansion of cultivated areas, a higher density of aquaculture installations and of farmed individuals, and greater use of feed resources produced outside of the immediate area, many negative effects are identified when the sector grows unregulated or under insufficient regulation and poor management. The group of experts meeting in Palma de Mallorca to agree on a main framework for an ecosystem approach to aquaculture (EAA) proposes that: *an ecosystem approach for aquaculture is a strategy for the integration of the activity within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems"*. This definition essentially recaps the ecosystem-based management proposed by the Convention on Biological Diversity and also follows recommendations of the Code of Conduct of Responsible Fisheries (CCRF). Aiming to enhance aquaculture contribution to sustainable development, the EAA should be guided by three key principles: i) aquaculture should be developed in the context of ecosystem functions and services with no degradation of these beyond their resilience capacity; ii) aquaculture should improve human-well being and equity for all relevant stakeholders; and iii) aquaculture should be developed in the context of (and integrated to) other relevant sectors. Three scales/levels of EAA application have been identified and are discussed here: the farm; the waterbody and its watershed/aquaculture zone; and the global, market-trade scale. Additionally some management measures oriented to policy making are proposed considering the above mentioned principles and scales.

INTRODUCTION

The 1992 Earth Summit in Rio de Janeiro addressed the issue that environmental management policies, with their traditional sectorial basis, were not adequately covering the full impacts of human development and exploitation on the environment. There was a concerted move then to incorporate a more holistic approach to policy decision-making in regard to sustainable development with an ecosystem approach based direction.

Aquaculture growth worldwide invariably involves (with differences amongst regions and economies) the expansion of cultivated areas, higher density of aquaculture installations and of famed individuals, and use of feed resources produced outside of the immediate area. Potential negative effects of aquaculture on the ecosystem often include[1]: (i) increasing demands on fisheries for fish meal/oil, major constituents of carnivorous/omnivorous species feeds, (ii) nutrient and organic enrichment of recipient waters resulting in build-up of anoxic sediments and modifying benthic communities (iii) eutrophication of lakes or coastal zones, (iv) restructuring of biological and/or social environments, (v) release of chemicals used to control water conditions and diseases (vi) competition for, and in some cases depletion of resources (e.g. water) and (vii) negative effects from escaped farmed organisms, often more relevant when exotics. But on the other hand aquaculture can have positive effects on the ecosystem, for example by providing the seed for re stocking of endangered or over exploited aquatic populations. Often as well, aquaculture is negatively affected by other human activities such as contamination of water ways by agriculture or industrial activities.

In an attempt to control inadequate developments countries worldwide have implemented a large number of aquaculture regulations. These have varied from general rules such as banning the utilization of mangroves for aquaculture practices to very specific regulations such as the establishing of maximum production per area, regulations for disease control, use of drugs, etc.

However, these regulations – neither on their own or taken together – provide a comprehensive framework ensuring a sustainable use of aquatic environments. That will happen when aquafarming is treated as an integral process within the ecosystem.

Development of advanced technologies has made production more efficient and facilitated intensification. But often the regulations in place can not guarantee sustainability, especially as most of them focus on the individual farmer and do not consider additive (cumulative) or synergistic effects of many farms on a particular area. Simultaneously, farmers' economic appraisal tends to have a narrow (short-term) view, focused on the more immediate production results. Such appraisals do not include the medium and long term revenues and costs that may be imposed to the farming activity itself and on the rest of the society in the form of a reduced supply of ecosystem goods and services.

An ecosystem approach to aquaculture (EAA) is not a new approach, it is rather an attempt to put together a common framework; the EAA has been in a way practiced since the early stages of aquaculture in small-scale inland aquaculture activities particularly in Asia where the use of poultry wastes (or other organic wastes) are commonly used as feed resources for the culture of carps and other freshwater fish. However, the EAA becomes more difficult and a real challenge in the case of intensive, industrial production but also as a result of the added effect of many small-scale aquaculture.

But equally important, the regulatory structure for aquaculture often does not allow, or facilitate, a production mode/approach that would lead to ecosystem balance. It is not uncommon that nutrient cycling and re-utilization of wastes by other forms of aquaculture (polyculture) or local fisheries, is not allowed, or is discouraged.

An ecosystem approach, like any system approach to management, accounts for a complete range of stakeholders, spheres of influences and other interlinked processes. In the case of aquaculture, applying an ecosystem-based approach must involve physical, ecological, social and economic systems, in the planning for community development, also taking into account stakeholders in the wider social, economic and environmental contexts of aquaculture. Several authors have addressed the need for a system's perspective to the management of this sector (Phillips, Boyd and Edwards, 2001; Muir, 1996; 2005). On the other hand, the first principle for an ecosystem approach, as described by the Convention on Biological Diversity (CBD), is that the

[1] This section takes many elements from *Selected Issues in SOFIA; Sustainable growth and expansion of aquaculture: an ecosystem approach* (FAO, 2007).

objectives of management of land, water and living resources are matters of societal choice (UNEP/CBD/COP/5/23/ decision V/6, 103-106). But, this approach also implies focusing on changing human behaviour and attitudes towards the use of natural resources and considering humans as part of the ecosystems.

In 1995, the Code of Conduct for Responsible Fisheries (CCRF) was adopted by the FAO Council. The CCRF also deals with aquaculture more specifically through Article 9 (FAO, 1995a) addressing many aspects relevant for its sustainable development, but this document only provides a very general framework although some general guidelines to assist its implementation have been developed (FAO, 1997).

During the Palma de Mallorca Workshop[2] a series of papers and presentations plus working group's discussions that continued after the workshop allowed to produce an agreed set of concepts, scales and some management measures for the implementation of an EAA and these are described in the following sections.

DEFINITION

The ecosystem approach to aquaculture is a strategic approach to development and management of the sector aiming to integrate aquaculture within the wider ecosystem such that it promotes sustainability of interlinked social-ecological systems.

This is essentially applying an ecosystem based management as proposed by CBD (UNEP/CBD/COP/5/23/ decision V/6, 103-106) to aquaculture and also following Code of Conduct for Responsible Fisheries (CCRF) indications.

KEY PRINCIPLES

The EAA can be regarded as "the" strategy to ensure aquaculture contribution to sustainable development and should be guided by three main principles which are also interlinked:

Principle 1

"Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society"

It is only realistic to expect that aquaculture, being a human activity, will lead to some loss of biodiversity or affect ecosystem services to some extent. Odum pioneered the concept of *the ecosystem* making the relationship between human activity and "natural processes" as essential part of this concept (Odum, 1953). Following this author it is useful to distinguish natural from human-dominated ecosystems, in particular farmed or agro-ecosystems. The latter as human dominated are simplified ecosystems to produce food in contrast to a more classical view of natural ecosystems without major human impact (e.g. the classical Tansley (1935) view[3]). Including humans within ecosystems results in changes from their natural state, therefore, we should consider aquaculture i.e. the production system or culture facility be it a cage or pond or other, as an "aqua (cf. "agro") ecosystem", and its surrounding or external environment embedded in the wider ecosystem e.g. a river, reservoir, coastal bay, open seas. This wider ecosystem may vary from essentially undeveloped to heavily modified. In the former case ecological issues are likely to be of greater concern (societal perception) than in the latter case where aquaculture is within an already changed agro-ecosystem.

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2 The workshop originating these proceedings.

3 Tansley coined the term *ecosystem* as the interactive system established between all living organisms and their surrounding environment; however his view was one of a rather pristine system with its natural functioning.

Some of these concepts have been applied in Asia where integration of aquaculture and agriculture has a long tradition especially at small-scale production. Nowadays such concepts face greater challenges in other continents where aquaculture is a newer activity and even in the Asian region due to aquaculture intensification (Troell, in press). Indeed they may be especially difficult to apply in intensive large-scale farming worldwide. Integrated aquaculture and more specifically integrated multitrophic aquaculture (IMTA) has been practised in Asia/China since the beginning of aquaculture, this due to their ancient concept of treating effluents and residues from farming practices as resources rather than as pollutants. However in the western world where aquaculture is more recent there is no tradition of using effluents as useful inputs for other production systems and it becomes more difficult to apply the idea of integrated aquaculture and IMTA not even at the small-scale farming.

A key issue here is to define or estimate the resilience capacity or the limits to the acceptable environmental change (Hambrey and Senior, 2007; Hambrey, Edwards and Belton, 2008, this document)[4]. In the case of biodiversity, local declines may be acceptable (e.g. below fish cages) as long as such losses can be compensated and restored, at least at the waterbody scale, in order to preserve ecosystem functions and services. For example after a cage farm operation is halted it is expected that the relevant biodiversity recovers if there is enough *green infrastructure*, that is conservation areas or more pristine areas to provide relevant colonization and restoration.

Many environmental impact assessments (EIA) will touch on these issues and yet the tools to address them are either not well developed or used; a promising one is that offered by risk assessment (RA). Relevant questions remain: How much biodiversity are we willing to loose?, at what scales?, which would be the cost?, and how is this balanced with benefits from aquaculture?. On the other hand, aquaculture effects have to be seen in context by comparing them with those from other food producing sectors such as agriculture and livestock farming. Most terrestrial food producing systems, and especially intensive ones, have been achieved after drastically transforming the landscape, (e.g. clearing native forests, grasslands for agricultural purposes) with permanent impacts on original biodiversity; but we historically grew used to those while aquaculture is a rather new development worldwide. Efforts need to be made in order to permanently monitor aquaculture effects on biodiversity to make sure that such effects do not result in serious/significant losses of ecosystem functions and services. In this respect real values of ecosystem "goods" and services should be integrated into micro and macro environmental accounting.

In summary, developing aquaculture in the context of ecosystem functions and services is a challenge that involves defining ecosystem boundaries (at least operationally), estimating some carrying capacity and holding capacity and adapting farming according to it. This requires to consider ecosystem services to be preserved or guaranteed. With more intensive aquaculture practices some modeling and predicting tools are needed and are becoming available. Mitigation practices which consider ecosystem processes such as integrated aquaculture should be considered more seriously particularly in the intensification process.

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[4] A whole range of terms has been coined or developed to give expression to the idea of limits to environmental change, including *environmental carrying capacity*, *environmental capacity*, *limits to ecosystem functioning*, *ecosystem health*, *ecosystem integrity,* f*ully functioning ecosystems*. All these concepts are more often very difficult to apply in practice because such definitions are subject to human consensual decisions.

Principle 2
Aquaculture should improve human well-being and equity for all relevant stakeholders

This principle seeks to ensure that aquaculture provides equal opportunities for development and that its benefits are properly shared, and that it does not result in any detriment for any groups of society, especially the poorest. It promotes both food security and safety as key components of well being.

Improving human well-being should go beyond the direct contribution of aquaculture (or the attempts to use it for the purpose) to solve hunger especially in the regions where this activity is newer. In these cases its main contribution to local livelihoods comes from the increase in employment opportunities and also from the direct small business, local marketing of products. However often the low interest and consumption of fish by locals (e.g. in some countries in Latin America and Africa) becomes a bottleneck which may prevent the successful development of small/family type of farming in rural areas.

Any new aquaculture project should ensure that well-being of relevant stakeholders, especially rural and poorest groups will improve (or at least will not deteriorate), especially if there are environmental costs. These should be accepted and dealt with when the sector truly provides relevant social benefits. However, presently, the overall social, economic and environmental effects of aquaculture (at different scales) are rarely considered all together to determine the final balance and to decide positively or negatively on a project.

In this context, it would be relevant to define ecosystem boundaries from the social and economic perspectives although it is clearly more difficult to do than for environmental purposes because the extent of aquaculture trade and other indirect effects related to provision of seeds, feeds, services etc.

Principle 3
Aquaculture should be developed in the context of other sectors, policies and goals

This principle recognises the interactions between aquaculture and the larger system, in particular, the influence of the surrounding natural and social environment on aquaculture practices and results. Aquaculture does not take place in isolation and in most cases is not the only human activity – often leading to a smaller impact on waterbodies than other human activities e.g. agriculture and industry. This principle also acknowledges the opportunity of coupling aquaculture activities with other producing sectors in order to promote materials and energy recycling and better use of resources in general. Such integration has existed mostly in Asia. There are indeed many examples of integrated production systems e.g. livestock-fish farming (Little and Edwards, 2003) and fish-rice production (Halwart and Gupta, 2004).

As mentioned above, most terrestrial food producing systems have been achieved after drastically transforming landscapes, but society historically grew used to this while aquaculture is a rather new development worldwide. Therefore worldwide norms and regulations, policies etc. have been made well adapted to agriculture sector but not so much to aquaculture. The later needs an enabling policy environment to grow in a sustainable manner and to be integrated into the agro-ecosystem also minimizing conflict occurrence. Aquaculture can compete for freshwater and for land with agriculture but it can also use agriculture products for feeds. Plans for aquaculture development also need to be included within wider development and management schemes, e.g. integrated coastal zone management (ICZM), integrated water resources management (IWRM). Cooperation and integration of sectors in a better planed landscape particularly caring for water resources could yield greater benefits.

The connection with the fisheries sector is obvious from various perspectives e.g. production of fishmeal from fisheries (a fishery service to aquaculture), aquaculture based fisheries (where fisheries is benefiting from aquaculture) but often such connections are not formally dealt with or operational. Some of the potentially negative interactions deal with the competition for common markets, the potential damage to fisheries from the escaped farmed individuals (e.g. the case of escaped Atlantic salmon in Norway).

On the other hand, terrestrial food production systems and other industrial activities can impact on aquaculture deteriorating water quality and quantity; they can also affect feed's quality and potential safety (Hites *et al*., 2004).

EXAMINATION OF PRINCIPLES AT DIFFERENT SPATIAL SCALES

The single *farm scale* is easy to picture; this is the relevant and meaningful extent of the farm which could be few meters beyond the physical boundary of the farming structures (in many cases it could be a backyard pond). However the increasing size and intensity of some farms (e.g. large-scale shrimp farming or salmon farming) could have effects beyond farm limits (concession site) extending to the whole waterbody (e.g. a lake).

While in some cases it may be difficult to identify the relevant *waterbody* to which aquaculture, together with other activities, will have an impact should be clear that in inland and coastal aquaculture, in most cases we are talking about *watersheds*. This includes land and inland waterbodies as well as circumscribed coastal areas in the context of the integrated ecosystem. This is or should be an integrated land-water resource management level (ILWRM) and it is clear that this should be a final aim/goal for policy-making.

In some cases these may be within a single country or cross national boundaries e.g. lower Mekong Basin. National or international policy and other issues would often mostly relate to the ILWRM level where the aquaculture system/s are under consideration. The watershed or waterbody scale becomes more difficult to apply (but not impossible) in the case of complex coastal fjords where the watershed boundary or the "common waterbody" becomes relevant e.g. for evaluations of carrying capacity or for the implementation of biosecurity measures.

Another scale may be useful and needed; and that is the *aquaculture zone or aquaculture region*. An aquaculture zone or aquaculture regional level is a scale that even go beyond perceivable ecological boundaries/significance and could be more relevant to social/economic and political issues although there may be some common relevant ecosystem issues for example; diseases, seeds and feeds trade, climatic and landscape conditions etc. However, in practical terms many issues and management measures could be similar at the watershed and aquaculture zone/region; therefore we will consider them together in the following analysis while indicating when an independent view may be needed. For example, offshore and open-seas aquaculture pose a challenge to the "waterbody/watershed" boundary scale while it may be easier to apply the aquaculture zone or regional scale, (e.g. Exclusive Economic Zones).

A major practical problem with the implementation and use of this scale of ecosystem relevance is that often this does not coincide with administrative and even national scales. Therefore the concept of watershed management may require creative approaches and political willingness of different administrative entities. For example it may be the case of the Mekong River and its delta, the Lake Victoria in Africa or the Mediterranean Sea.

The *global scale* refers to the global industry for some commodity products (e.g. salmon and shrimp) but also to global issues such as trade, certification, technological advances, research and education of global relevance etc.

For the above mentioned reasons, the breaking down of principles' implications and issues at each scale are only attempting to exemplify the potential differences and similarities amongst different scales. Clearly there could be a lot of overlapping of issues amongst scales and there could be as well other scales.

Production scales/farm size

Obviously the proposed principles will have to apply to all production scales and as discussed above the magnitude and effects of ecosystem interactions depend more on the recipient waterbody capacity, structure. In that respect the total production is often more relevant (e.g. the sum of many small farms) therefore regulations should focus more on the recipient body rather than on the farms.

Production scale and intensity are a continuum and it may be a challenge to develop policies for small-scale aquaculture (or "small farmers") [5] when getting to the point of defining it. Some countries have produced definitions based on maximum annual production for a certain area in order to adapt regulations for different farm and productions sizes.

Temporal scales

These are not directly addressed here but it is clear that in this respect, it may be necessary to permanently apply a precautionary approach due to unknown ecosystem threshold or resilience including the human components. Some external forcing factors such as climate change, climatic variability, population growth, global trade will affect all scales with a temporal dimension adding to the unknown component. Precautionary approach is being included as one of the management measures below.

SOME OF THE MAJOR ISSUES AT DIFFERENT SCALES

The farm scale

At the *farm scale*; issues pertaining to *Principle 1* usually have to do with the management practices in the production processes. Most management practices are developed for this scale and most top down regulation measures worldwide apply at this scale. However the ecosystem concept is rarely applied for example for proper site selection for aquaculture farms particularly in open aquatic environments. In general the carrying capacity for one new farm is rarely estimated and one of the problems/ challenges is to define the physical boundaries for such capacity and in some cases conservative approaches are used within environmental impact assessment (EIA) protocols.

Although it may seem less relevant or meaningful to talk about alteration of ecosystem services at this scale, individual large intensive farms often alter local/ site ecosystem functions e.g. the oxygenation of sediments provided by natural bioturbation (this may happen after sharp biodiversity declines).

Another important issue is that farmed species escapees and diseases originate and can be prevented/ controlled at this scale although their effects usually occur at the next spatial scale: the watershed.

Integrated aquaculture usually can take place at this scale and can be a very useful tool to mitigate impacts from excessive nutrient from the farming process out puts while increasing productivity. As mentioned earlier such practices have been common in many places in Asia (Little and Edwards, 2003[5]; Halwart and Gupta, 2004)' where integrated practices often involve individual farms and collectives of farms reaching the watershed scale. A relevant issue is that such integration practices seem to be receding

[5] There are not globally agreed meanings for "small-scale production" aquaculture and definitions such as commercial and non commercial are being discussed, therefore here we use this term to indicate family-type aquaculture or artisanal aquaculture; one pond, one or two fish cages where workers are the family members/close neighbours and there is minimum use of technology.

especially with aquaculture intensification and although some efforts are been made to keep such systems in place (Troell, in press), more relevance should be given to this matter. One of the main difficulties is that economic assessments and valuation of products of such practices not always consider the "cleaning" benefits of such practices with negative consequences for prices associated with the secondary products.

Regarding *Principle 2* several issues are relevant at the farm scale. In regions where aquaculture is more recent the low interest and consumption of fish by locals could be a bottleneck for the development of family-owned farms and also for the use of the opportunity of increasing protein consumption.

At the farm scale, aquaculture can offer family improvement options and employment opportunities however; returns to owner-entrepreneur (that is the overall profitability of aquaculture) are often unfair. Additionally, working conditions may not always be adequate and there may be gender discrimination and unregulated child labour.

Food safety is a concern that should start at a farm scale, yet for small-scale farming, especially for rural farms often there are no conditions and infrastructures (e.g. refrigeration capability) to implement food safety measures and controls.

When following *Principle 3*, the integration of aquaculture to other sectors may not seem to apply easily at the *farm scale* however a more efficient use of on-site and immediate surrounding resources can take place, examples in Asia are shown above. Integrated aquaculture at the farm scale offers the opportunity to integrate to other sectors such as agriculture also avoiding or minimizing conflicts for resource uses. A problem is that particularly in western countries integrating aquaculture to other coastal activities and multitrophic aquaculture is not facilitated by norms and regulations and often such practices are not even allowed especially in marine coastal areas (Barrington, Chopin, and Robinson, in press). This makes individual aquaculture farms separated from other activities and increases the likelihood of conflicts with other individual users of the coastal zones and aquatic resources.

The watershed/aquaculture zone scale

Regarding *Principle 1,* while the environmental impacts of a single farm could be marginal more attention needs to be paid to ecosystem effects of collectives or clusters of farms and their aggregate, potentially cumulative contribution at the *watershed/zone scale*, for example the development of eutrophication as a consequence of excessive nutrient outputs. Evaluations and monitoring of the overall effects of aquaculture (plus other sectors) at this scale are rare; a good example of this approach is the Modelling-Ongrowing fish farms-Monitoring (MOM) system in Norway (Ervik *et al.*, 1997) and some pilot initiatives in Ireland (Ferreira *et al*., 2007). Similarly, strategic environmental impact assessments are not common while individual farm oriented EIA are the norm and the base of environmental regulations within the sector.

While it is recognized that aquaculture could have an impact on ecosystem services at the watershed scale, there is scientific debate regarding the resilience needed to preserve essential ecosystem services. However the level of resilience it is a question of societal awareness, and decision (informed by science) must be made considering what is acceptable. Additionally, there is not enough knowledge on methods and approaches to ensure/enhance resilience capacity, for example the amount of "green infrastructure" or conservation areas needed within a watershed to provide the required resilience. Yet, on the positive side, integrated multitrophic aquaculture and various forms of integrated aquaculture are becoming better known for their potential in this respect (Troell, in press; Barrington, Chopin and Robinson, in press). Considering aquaculture within the watershed/aquaculture zone context increases the possibility for integrated aquaculture/farming and could facilitate trade of feeds and seeds.

A very relevant issue is that introductions of alien species or alien genotypes take place at this scale with often relevant impacts on biodiversity in whole watersheds.

Similarly, disease outbreaks take place first at the farm scale but often need a control and management at the watershed scale. Such management and mitigation necessarily require the watershed approach.

When aquaculture activities are not well planned and regulated they can increase inequality at the *watersheds scale*, and in the aquaculture zone, region, therefore violating *Principle 2.* For example some benefits can be felt upstream (would be the case when there is more water and of better quality) but not downstream. Aquaculture can create opportunities for a broad range of resource users; however, often the sector does not offer equitable access to resources and benefits failing to recognise that different stakeholders have different abilities/opportunities to access these.

Increasing equity and well-being simultaneously will not always be possible and over time, the balance between the two will change, and regional and local scale initiatives especially those that promote well-being and equity are often ignored. Ultimately, transfer of benefits from regional, national and other scales should get to locals in which aquaculture takes place.

Regarding *Principle 3*, in general, at the *watershed/zone* scale the integration of aquaculture to other sectors performing and development is difficult, and it does not happen in general. Perhaps Asia has been a special case where the integration as a process seems to start at the farm scale without much planning for integration at the watershed. Although recommended and with theoretical potential, freshwater aquaculture use is seldom planned and developed in conjunction with irrigation and water resources enhancement (Haylor and Bhutta, 1997; Brugère, 2006). Watershed/zone scale activities and initiatives most often are not subsidiary to the wider context of watershed, coastal zone and other integrated management policies and programmes particularly those extending beyond administrative borders (i.e. larger political boundaries or ecosystem functional boundaries).

Networking activities within the aquaculture sector and amongst sectors at the *watershed/zone scale* could be relevant. Integration between different sectors should be facilitated within the ecosystem perspective (for example the trade of feed resources and fertilizers); and increasing connections between agriculture and aquaculture through the trade of soy bean, corn gluten etc. While such trade is mostly market driven the ecosystem consequences should be sought, for example trading products within a watershed makes more sense from the ecosystem perspective than exporting resources beyond the boundaries in order to keep biogeochemical balances.

Geographical remit of aquaculture development authorities (i.e. administrative boundaries) often do not include watershed boundaries and this is a particular challenge. For example; facing climate change threats to aquaculture will require a watershed approach since prevention and mitigation measures need watershed management, e.g. protecting coastal zones from landslides, siltation or just even providing enough water etc.

The global scale

Under *Principle 1*, core issues at a *global scale* include; pressures on small pelagic fisheries for fishmeal to feed aquaculture; concerns for the unknown biogeochemical consequences of global net transport for elements such as nitrogen, phosphorus and carbon (N, P, C) mostly from the southern hemisphere to the northern hemisphere, partly driven by aquaculture. Other relevant concerns are those related to the global environmental costs of aquaculture in terms of energy, water usage, carbon production etc. Some relevant tools for the comparison of foot prints of food sectors in general are being developed (Bartley *et al*., 2007).

Climate change will affect aquaculture development in the ecosystem context and it is important to consider such effects at global scales (e.g. effects related to fish meal production) and also by regions considering particularities of each (droughts, floods etc.).

Following *Principle 2* at the *global scale* can be challenging. There is a need to improve the well-being of all relevant stakeholders within the context of trans-national aspects of production, markets and other decision-making (e.g. promoting global common standards and social policies/practices for international companies with activities in different countries). However, inequity can grow amongst producers (countries, regions) with very different capacities and technological development particularly regarding the compliance of global standards. Opportunities at the global scale could compromise regional and local opportunities. On the positive side, the global scale offers an opportunity for enforcement of food safety procedures to comply with global market demands.

The development of aquaculture in the context of other sectors, following *Principle 3*, becomes relevant at the *global scale*, when positioning food fish within the global food

TABLE 1
Summary of guiding principles, scales and major issues under each

PRINCIPLES	1	2	3
SCALES	**Aquaculture should be developed in the context of ecosystem functions and services (including biodiversity) with no degradation beyond their resilience**	**Aquaculture should improve human-well being and equity for all relevant stakeholders**	**Aquaculture should be developed in the context of other sectors, policies and goals**
Farm	Better/best management practices implemented at this scale Large intensive farms may significantly alter local/site ecosystem functions farmed species escapes and diseases take place and can be controlled at this scale Integrated aquaculture can be an opportunity for mitigation of environmental impacts	Returns to local farmer are often unfair Aquaculture can offer family improvement options and employment opportunities Working conditions are not always adequate Food safety can often be a concern at this scale especially for small farmers	Use of on-site and immediate surrounding resources more common in Asian countries (e.g. integrated agriculture-aquaculture)
Watershed/zone	Environmental effects of clusters of farms are rarely being evaluated Limited knowledge to define ecosystem resilience capacity Diseases and establishment of alien species take place at this scale and could be prevented, mitigated	Unplanned/unregulated aquaculture activities could increase inequity Often different stakeholders have different abilities/ opportunities to access resources and benefits from aquaculture Increasing equity and well-being simultaneously will not always be possible Transfer of benefits from regional, national and other scales should get to the local scale Local scale initiatives promoting well-being and equity are often ignored	Lack of support and/or regulations for integrated aquaculture and multitrophic aquaculture Local scale activities/initiatives most often are not subsidiary to the wider context of watershed, coastal zone management policies and programmes Integration between different sectors are not been facilitated within the ecosystem perspective Geographical remit of aquaculture development authorities' remit (i.e. administrative boundaries) often do not include watershed boundaries
Global	Increasing pressure on small pelagic fisheries for fishmeal to feed aquaculture Unknown biochemical consequences of N, P, C transport among regions partially driven by aquaculture Climatic change affecting aquaculture development in the ecosystem context	Improving the well-being of relevant stakeholders within the context of trans-national aspects of production, and markets is a challenge and an opportunity Food safety globally enforced due to global markets Development of global opportunities can compromise regional and local opportunities	Fish and aquatic proteins are increasing in world diets, and aquaculture is rapidly increasing its relevance Competition with other food and energy sectors for vegetable proteins (feeds) is increasing Competition for freshwater use with other food sectors will increase

sector. It is clear that fish and aquatic proteins are increasing in human diets, and aquaculture is rapidly increasing its relevance to fulfil such demand. In parallel and as a consequence, competition with other food and energy sectors for vegetable proteins (feeds) is increasing (e.g. use of corn for bio-fuels), and competition for freshwater use with other food sectors will increase especially under climate change scenarios. Therefore there is a clear need for aquaculture to be integrated with other sectors particularly other food sectors and those using aquatic spaces and aquatic resources at the global scale. The increasing requirements of protein for feeding human population could be a main driver.

Table 1 provides a matrix for easy reference of different issues under at the light of each principle and under different scales.

SOME MANAGEMENT MEASURES TO ASIST POLICY-MAKING THAT ENSURE ENVIRONMENTAL, SOCIAL AND ECONOMIC SUSTAINABILITY OF THE AQUACULTURE SECTOR

In general and at all levels, policies should be generated from a participatory processes, they should be adaptive, transparent and open to the general public; they must ensure and promote people consciousness of the value of ecosystem approach. They should also reconcile temporal scales facing the fact that aquaculture growth/development and governance capabilities have been moving at two different speeds.

It is also important to consider that management measures should aim to the compliance of the three EAA principles in order to ensure aquaculture contribution to sustainable development, in most cases the management measures proposed below do this and there is also some degree of overlap between them.

1. Apply the precautionary approach (PA) /adaptive management (AM)

"Unexpected changes occur"; management should allow to be prepared to deal with them. Some important elements regarding PA and AM have been thoroughly discussed for fisheries and the following paragraph has been adapted from the guidelines for precautionary approach to Fisheries (FAO, 1995b). Management according to the precautionary approach exercises prudent foresight to avoid unacceptable or undesirable situations, taking into account that changes in ecosystems could be slowly reversible, difficult to control and not well understood. A precautionary approach to aquaculture production should involve developing, within management strategies and plans, explicit consideration of precautionary actions that will be taken to avoid specific undesirable outcomes. For example as the overloading of the waterbody's carrying capacity to receive nutrients is a common cause of undesirable outcomes (e.g. losing biodiversity or ecosystem services), a management plan should include estimates of the carrying capacity and mechanisms to monitor and control the filling up of such capacity. Another typical example is that of culturing exotic species or genotypes. Consideration needs to be given to how uncertainty and ignorance are to be taken into account in developing and varying management measures. Plans should be developed or revised to incorporate precautionary elements; adaptive management practices and tools such as risk analysis and geographic information systems could be used.

Adaptive management has emerged as the "best practices" approach to ecosystem management. Adaptive management consciously considers both social and bio-physical systems part of a common system that is constantly changing unexpectedly (Bailey, 2008, this document; Berkes and Folke, 1998). Adaptive management is an iterative process of taking actions, evaluating the consequences of those actions, and adjusting future actions in light of changed conditions.

It may be important to judge if applying a precautionary approach due to unknown ecosystem threshold or resilience could apply at the scale of *watershed and* *coastal zones*. Society may be willing to pay a premium for the preservation of key environmental resources or areas.

Both precautionary approach and adaptive management require using the best, relevant, accurate, recent, available and most reliable information. This should include traditional and scientific ecological and societal data and knowledge to make decisions. *Policy* is informed by knowledge of the role that aquaculture may play in the regional, national and local economies and the social setting. Information is needed on the nature of stakeholders; economic factors related to the activity; details on costs and benefits; the role of aquaculture in providing food and employment; the status of access to, or ownership of, the resource; the institutions involved in planning and decision-making; and the complex interactions that occur within the ecosystem[6].

It is important to promote the capture of existing knowledge to design best sustainable approach to farm production, knowledge on production technologies and species requirements considering the estimation of site carrying capacity or holding capacity. The design and use of simple/inexpensive physical, chemical and/or biological indicators of ecosystem health (Secchi disk, dissolved oxygen, key species etc.) and sustainability at the different levels can be very useful for the latter purpose.

At the same time policies should ensure the dissemination of knowledge on adverse impacts of improper practice and better alternative technologies and better management in general. These management measures are obviously needed at the farmer and at the watershed/coastal zone scale For example, the dissemination of information in coordinate manner is essential for the control of diseases.

The promotion of risk analysis as a tool for farm decisions can ensure wiser decisions guaranteeing more sustainability of the activity. At the same time monitoring programs proportional to the level of risk and extents of impacts to society (levelling/ equity among sectors) can be very useful especially at the watershed scale. Such tool can be very useful for the adaptive management process. The promotion of insurance systems (including environmental insurance) when appropriate can be also of help in many cases.

Improved input quality, farm management practices and waste or effluent treatment as well as integrated aquaculture, including integrated multitrophic aquaculture can be promoted as precautionary tools for preventing and diminishing impacts related to excessive nutrient outputs.

It is relevant to promote the PA and AM at the watershed scale as the focus of adverse impacts and assessments and enforce regulations concerning unsustainable practices, ensuring permanent review and implementation of better management at this scale. This requires to consider the influence of all sectors (aquaculture and agriculture industry and other interacting sectors) and to do so it may be necessary to facilitate decentralization of management at the watershed scale. As this may be a great challenge, it may be necessary to go by steps, starting with a certain aquaculture waterbody or cluster of farms, later to go to a portion of the watershed and to finally to be able to manage the whole watershed or coastal zone.

Promoting monitoring programs and use of easy sustainability indicators at the watershed scale is most relevant. Existing management models; hydrodynamic circulation/deposition models and the knowledge of local institutions, universities etc. can be very useful for the estimation of carrying capacity and use of indicators. For example, be aware of local regional particularities when importing technological packages developed in other regions as it may be necessary to develop proper management models or other tools that are more appropriate to specific local characteristics. It may also be relevant to facilitate the acquisition of reliable data/ knowledge including the delegating of authority in terms of ecosystem monitoring to

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[6] Information requirements for policy-making, adapted from FAO (1995).

general public/industry if needed (final validation of such monitoring should remain within the relevant agency for legitimacy).

At this scale it may also be necessary to facilitate the understanding of competing demands; and use best information for settling multi-user conflicts. Promote certification systems based on best information to differentiate sustainable practices.

At the *global scale*; PA and AM can be promoted through knowledge enhancement and dissemination of risk assessment tools, risk communication (e.g. GESAMP, 2008) and other similar practices to deal with the management of uncertainties. Developing global agreements on better management practices and facilitating dissemination of appropriate information to consumers allowing them to differentiate products according such practices can be also relevant.

Promotion of global sharing of sustainable practices, sustainable technologies particularly for the use of less developed nations and regions can be important. The permanent review, evaluation and improvement of management practices at all scales is at the core of AM recognizing the value and need of new information, new technologies as well as responses of ecosystems to pressures and changes.

2. Promote appropriate "proactive" and long term goal-aimed research, guided by a participatory process and focusing on ecosystem functioning and services (also using traditional and scientific ecological and societal knowledge)

Making sure to promote independent research to facilitate compliance of the 3 principles at the farm scale and beyond is at the core of EAA. Of particular relevance is to promote research contributing to the understanding and planning of the production process within the ecosystem framework. At all scales research needs to be interdisciplinary and multidisciplinary and long-term, there is also the need for research on governance/regulation which includes/considers a balanced ecosystem. Governments should have a more inclusive process for decision-making regarding aquaculture and appropriately devolved power at the local scale. Of great relevance is the development of Simulation Models as decision tools at different scales. Research on valuation of ecosystem services which may be undermined by aquaculture are most important in order to properly plan location of farms and aquaculture zones, mitigation measures, maximum production allowances etc.

For the *farm scale* research should focus on developing tools to evaluate externalities of inputs and outputs, to estimate carrying capacity for individual farms, and tools and technologies for improving the feeding process and conversion ratios. It is also very important to promote permanent and proactive research on new species and strains offering enough information for the selection of the right species based on ecosystem functions and market demands, considering species requirements and ecological/nutritional efficiency. Aquaculture rapid development and risks for sudden crash should be avoided/prevented ensuring continuity in following-up in regulation management and reinforcement processes, irrespectively of changes in governments, and authorities in charge.

Although there has been relevant research advances on integrated aquaculture further research is needed to comply with particularities of many regions. Research on the feasibility of integrated multitrophic aquaculture (IMTA) projects is very relevant especially considering the economic and social implications (Barrington, Chopin and Robinson, in press).

At the *watershed scale* research should consider the examination of the most appropriate species to farm, including potentially new species, while closing the life cycles of species of interest could also be important for the diversification of aquaculture within a watershed or at least to keep a wide number of candidate species as an insurance for the sustainability of the sector in the watershed. At this scale, proactive research should also cover health management and biosecurity.

Research should also focus on the considerations of externality costs and socioeconomic implications of alternative development pathways for a locality within a watershed or for watersheds *per se*. Studies should also cover the development and improvement of markets and consumer-awareness, certification and eco-labelling based on an Ecosystem approach.

Research priority should also be given to the development of models to evaluate and simulate cumulative, additive and synergistic effects of aquaculture and other sectors on biodiversity and ecosystem functions thus estimating carrying capacity also considering other users and inputs (e.g. simulation models).

Studies on comparative evaluation of policies and regulations can also be useful both for the watershed and the farm scales. Research should also help to develop regulatory and governance tools and this may involve international initiatives touching on the global scale.

Global research should permanently focus on producing more environmentally friendly feeds with ecosystem consideration and global accounting (e.g. lifecycle analysis), it should also prioritize the development of energy and nutrient efficient technologies and safer containment technologies to minimize energy uses, to improve effluent treatment and to avoid escapes respectively. Genetic research of a more open nature, available to all countries and regions, which can produce better and safer strains is and will be most relevant for the world development of aquaculture. Research on health management should also be approached globally or at least regionally. Research on climate change effects, adaptation and mitigation should occur at the global scale but also at the regional and even watershed scale including the interactions with other sectors, e.g. agriculture, forestry.

3. Promote sectoral integration when appropriate (e.g. to implement mitigation approaches and to enhance overall productivity)

The promotion of integrated aquaculture including integrated multitrophic aquaculture (IMTA) is a logical way to insert aquaculture in an aqua-system or aqua-agro system where there is proper recycling and full utilization of resources and energy while diminishing risks associated to by-products and increasing productivity of the sites. However, a proper valuation of the externalities in monocultures needs be consider in order to enhance integrated aquaculture.

For the implementation of EAA to be successful, stakeholders must understand and accept the need for this more integrative approach to aquaculture production. This will require a proactive effort by management agencies particularly ensuring effective and appropriate training for all staff having to deal with the changes required for EAA. Scientists and management authorities will need to recognize the value of the knowledge of fisherfolk and aquafarmers, their representatives and communities (particularly regarding the ecosystem). They must also recognize that with the ever-broadening range of stakeholders under EAA, the potential differences in capacity to participate in management will also increase which, if uncorrected, will lead to unbalanced and poor decisions.

Spatial tools could be necessary for organizing and reporting the information so that it can be viewed from single interest or multiple use viewpoints[7]. Integrated coastal zone management plans, in many countries and regions are already in progress and advanced on this subject while some facilitating tools such as geographic information systems (GIS) are becoming more readily available for this purpose.

At the *farm scale* it is necessary to facilitate access to proper technologies and possibly use some form of incentives (see management measure 5). The widespread dissemination

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[7] GIS tools are well known for bringing together experts in a variety of disciplines in order to solve complex problems. The capacity to broadly view and spatially analyze competing and conflicting uses exists, but has yet to be fully realized. This could be one of the most important contributions of spatial tools to EAA.

of effective and sustainable traditional technologies; integrating traditional and modern practices; IMTA and integrated crops/livestock/fish should also be considered.

At the *watershed* scale it may be necessary to facilitate integration amongst farmers, and amongst farmer's associations (e.g. mussel farmers and fish farmers) also facilitating integration with fisheries and fisherfolk, with agriculture, recreation, urban and industrial activities and stakeholders. This should also involve research, common resource management, education; etc. Clearly, facilitating decentralization of management at the watershed level can be an important step.

At the *global scale* it is important to promote generation of information with transparency to aquaculture and to other sectors and consumers on the advantages of such integration. It could also be possible to contribute/promote the development of ecolabels and or other certification tools to acknowledge integration and the implementation of EAA.

4. Broaden stakeholder participation

Policies must create mechanisms to guarantee farmer (and his family when appropriate), employees and extension agencies the adequate participation. Policy-making and development of norms and regulations must be participatory, timely and transparent.

At the *watershed/coastal zone scale* it is important to facilitate capacity building and empower all stakeholders (particularly those in disadvantage) to ensure equitable participation, this may require mechanisms to guarantee equitable participatory extension, cooperation, research and development.

Another important approach for broadening stakeholders participation is to facilitate (create mechanisms) integrated coastal zone management (ICZM) and management of connected water ways considering EAA and involving stakeholders and institutions in other productive sectors (e.g. Agriculture and Fisheries/Aquaculture, Forestry ministries etc.). GESAMP 68 (GESAMP, 2001) goes in to this subject with some practical guidelines for coastal aquaculture.

Equitable participation can often be triggered by decentralized management measures.

At the *global scale*, connections and cooperation of farmer associations, international institutions, NGOs, IGOs etc can be promoted.

5. Implement proper incentives

According to the EAF practical manual (FAO, 2005), "incentives provide signals reflecting public objectives while leaving some room for individual and collective decision-making to respond to them". Different kinds of incentives can be developed in isolation or in combination, as follows:

- improve the institutional framework (definition of rights and participatory processes);
- develop collective values (education, information, and training);
- create non-market economic incentives (e.g. tax mechanisms and subsidies) such as special advantageous licences (for example for integrated aquaculture, polyculture or for implemented better management, etc.); and
- establish market incentives (ecolabelling and tradable property and access rights, e.g. aquaculture concessions).

Incentives work indirectly through affecting those factors that lead to particular individual or collective choices. Market or social forces can be very efficient means to force the global outcome of individual actions towards collectively set objectives". It may be necessary as well to create mechanisms to internalize externalities through advice and development support, training.

Often a very important but simple non market incentive is to implement gradual mechanisms for the compliance of norms, regulations and agreements including aspects of economic assistance to bear especially with initial costs. This needs to go along with a simplification of mechanisms for example for EAA certification or compliance.

Although incentives may tend to focus on the individual farm or farm clusters, some incentives can work at the *watershed scale*. For example the facilitation and promotion of waterbody/watershed certification of EAA compliance, ecolabelling etc. This should involve other stakeholders/sectors and could promote integration and better perception and implementation of the ecosystem approach.

At the *global scale* incentives may de developed by promoting EAA markets with demand for appropriate certification and proper taxation.

6. Promote the understanding and inclusion of people/societal values (their context)

Considerations should be made to whom is working at the farm weather a family, children, women, mostly men etc. Such information must translate in adequate working conditions in the farm. There must be also considerations and respects of cultural, ethnic and religious aspects. Such aspects should also be considered when facilitating market conditions. All of this is valid for the *farm scale* as well as for the *watershed/ coastal zone.* At this later scale its may be important to promote consideration and respect of community decisions for development options. Participatory decision processes need to include the different communities, localities even countries which share common watersheds/waterbodies.

Relevance should be given to socio-cultural markets, governance systems and regulatory systems considering historical reasons and present appropriateness.

7. Promote education and disseminate information on better practices considering ecosystem based management

At the farm scale it is important to target education and training to the farm stakeholders (farm owners, workers, site managers) focusing on EAA and emphasizing on management-oriented knowledge. The development of collective values and the understanding of externalities of the farming process are very relevant at this scale. The valuation and understanding of ecosystem services has to start at this scale.

At the *watershed scale* it is also relevant to target education to the right portion of the population (aquaculture associations, companies, other relevant sectors e.g. agriculture, industry, general public and policy makers). Orient education to the watershed issues focusing on EAA and promote education fostering integration of sectors.

At the *global scale* the education of consumers and public opinion becomes very relevant. For example the dissemination of scientific-based information on the use of therapeutants, bioavailability of hazardous substances etc. At this scale is also possible to promote education fostering integration of sectors. Education and information on EAA should also target trans-national institutions, global traders, global policy fora etc.

Table 2 provide a matrix to examine various management measures at different scales.

TABLE 2
Summary of management measures at different scales

Farm	Watershed/coastal zone	Global
1: Apply the precautionary approach (PP) /adaptive management (AM)		
Farm	**Watershed/coastal zone**	**Global**
• Promote capture of existing knowledge to design best sustainable farming approaches (e.g. production technologies and species requirements considering site carrying capacity) • Disseminate knowledge of adverse impact of improper practice and better alternative technologies • Promote the use of risk analysis as a tool for farm decisions and promote monitoring programs proportional to the level of risk • Promote the design and use of simple/inexpensive physical, chemical and biological indicators of ecosystem health (Secchi disk, dissolved oxygen, key species etc.); and sustainability at the different levels • Promote integrated (INTAQ) or multitrophic aquaculture (IMTA) where appropriate • Promote environmental insurance systems when appropriate • Promote better management practices in general	• Promote regulations which consider this scale as the proper focus when relevant • Ensure permanent review and implementation of better management practices at this scale considering the influence of all sectors (aquaculture and agriculture industry and other interacting sectors) • Facilitate decentralization of management at the watershed/coastal zone level • Promoting monitoring programs and use of easy indicators at this level is most relevant • Consider existing management models; circulation/deposition models; or develop proper management models considering local particularities • Facilitate the acquisition of reliable data/ knowledge • Understand competing demands; and use best information for settling multi-user conflicts • Promote certification systems based on best information to differentiate sustainable practices	• Knowledge enhancement and dissemination of risk assessment tools and other similar practices to deal with the management of uncertainties • Develop global agreements on better management practices • Promote dissemination of appropriate information to consumers allowing them to differentiate products regarding sustainable and unsustainable practices • Promotion of global sharing of sustainable practices, sustainable technologies • Promote certification systems based on best information to differentiate sustainable practices
2: Promote Appropriate "proactive" and long term goal-aimed research, guided by a participatory process and focusing on ecosystem functioning and services		
Farm	**Watershed/coastal zone**	**Global**
Research to: • Define the proper species to culture • Estimate externality costs and alternative development pathways • Improve management and especially feed conversion ratios and minimize effluents and wastes • Improve feasibility and promote integrated aquaculture (multitrophic aquaculture / polycultures) at the farm level and at the following scales • Facilitate budget calculations (e.g. Biomass, nutrients, monetary etc.) • Facilitate evaluation of farm carrying capacity • Facilitate the understanding and value of ecosystem goods and services • Carry on studies on comparative regulatory and governance studies	Research to: • Close the life cycle in captivity of many species • Estimate externality costs and socioeconomic implications of alternative development pathways • Evaluate and model cumulative, effects of aquaculture and other sectors on biodiversity and ecosystem functions • Develop tools for evaluating carrying capacity at this scale also considering other users, inputs • Understand and value of ecosystem goods and services • Promote the right species based on market demands, ecosystem functions, species requirements and to facilitate integration with other sectors • Develop, improve markets and consumer awareness/certification and eco-labelling • Develop regulatory and governance tools • To enhance integrated aquaculture practices • To improve biosecurity, health management • Use genetics for better management and increased production	Research to: • Produce more friendly feeds with ecosystem considerations and global accounting (e.g. Lifecycle analysis) • Develop energy efficient farming technologies and the treatment of effluents • Improve health management • Develop safer containment technologies • Develop further integrated aquaculture/integrated multitrophic aquaculture (IMATA) • Improve management in general on genetics for better management and increased production
3: Promote sectoral integration when appropriate		
Farm	**Watershed/coastal zone**	**Global**
• Facilitate access to proper technologies • Widespread dissemination of effective and sustainable traditional technologies; integrating traditional and modern practices; IMTA, Integrated crops/ livestock/Fish (IAAS), IMTA	Those measures at the farm level also apply here. • Facilitate integration IMTA (within farm and amongst farmers, prompter farmers associations interactions (e.g. mussel farmers and fish farmers) • Facilitate integration with fisheries and fisherfolk, with agriculture, recreation, urban and industrial activities and stakeholders involving R&D, common resource management, education. • Facilitate decentralization of management at the watershed level	• Must promote connections, cooperation of farmer associations, international institutions, NGOs, IGOs, etc.

TABLE 2 (Continued)
Summary of management measures at different scales

4: Broaden stakeholder participation		
Farm	**Watershed/coastal zone**	**Global**
• Policies must create mechanisms to guarantee farmer (and his family when appropriate), employees, and extension agencies the adequate participation	• Facilitate capacity building and empower all stakeholders to ensure equitable participation • Create mechanisms to guarantee equitable participatory extension, cooperation, R&D • Facilitate (create mechanisms) integrated coastal zone management (ICZM) and management of connected water ways considering EAA principles and involving stakeholders and institutions in other productive sectors (e.g. Agriculture and Fisheries/Aquaculture, Forestry ministries etc.) • Facilitate equitable participation by decentralized management measures	• Must Promote connections, cooperation of farmer associations, international institutions, NGOs, IGOs, etc.
5: Implement proper incentives		
Farm	**Watershed/coastal zone**	**Global**
• Improve the institutional framework (definition of rights and participatory processes); • Develop collective values (education, information, and training) • Create mechanisms to internalize externalities • Implement gradual mechanisms for the compliance of norms, regulations and agreements including aspects of economic assistance to bear especially with initial costs • Create tax mechanisms, special advantageous licences • Simplify mechanisms for EAA certification or compliance	• Facilitate area-geographic zoning, regulations (Licensing, Certification) • Facilitate and promote waterbody/ watershed certification of EAA compliance, ecolabeling etc. This should involve other stakeholders/sectors and could promote integration and better perception and implementation of the ecosystem approach	• Promote EAA markets with demand for appropriate certification. Proper use of Taxation (int. market)
6: Promote the understanding and inclusion of people/societal values (their context).		
Farm	**Watershed/coastal zone**	**Global**
• Considerations should be made to whom is working at the farm weather a family, children, women, mostly men etc. Such information must translate in adequate working conditions in the farm	• Promote the consideration and respects of cultural, ethnic and religious aspects • Ensure proper markets and market conditions • Promote consideration and respect of community decisions for development options • Facilitate participatory decision processes for the different communities, localities even countries which share common watersheds/waterbodies • Relevance should be given to socio-cultural markets, governance systems; regulatory systems considering historical reasons and present appropriateness	• Promote the considerations to socio-cultural markets, governance systems; regulatory systems: historical reasons and present appropriateness taking in account inter regional differences and developing countries/regions needs
7: Promote education and disseminate information on better practices considering ecosystem framework		
Farm	**Watershed/coastal zone**	**Global**
• Target education and training to the farm stakeholders (farm owners, workers, site managers) focusing on EAA principles and knowledge-management oriented	• Target education to the right portion of the population (aquaculture associations, companies, other relevant sectors e.g. agriculture, industry, general public and policy makers) • Orient education to the watershed issues focusing on EAA principles and knowledge-management oriented. • Promote education fostering integration of sectors	• Target education to trans-national institutions, policy makers • Promote education of public opinion based on scientific-based information particularly regarding some aquaculture myths, e.g. nutrients are "pollutants", use of some therapeutants, bioavailability of hazardous substances, etc.

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APPENDIX 1

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Human dimensions of an ecosystem approach to aquaculture

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ABSTRACT

This paper analyses the social implications of EAA and presents evidence to support the central argument that social and biophysical dimensions of ecosystems are inextricably related and mutually supportive, and that a change in one dimension is highly likely to generate change in the other. A review of the literature on aquaculture development demonstrates that ecological concerns that reflect an EAA are of relatively recent origin. This document argues that an ecological approach to aquaculture must focus on change, acknowledge potential vulnerabilities associated with change, and utilize an adaptive management approach to promote system resilience in the face of such change. Seven issues that are directly related to resilience of social systems are identified; these include i) creation of broadly-shared entrepreneurial opportunities and employment generation; ii) consideration of gender roles and relations so that both men and women benefit; iii) promotion of economic diversification that reduces the vulnerability associated with economic specialization; iv) investment in infrastructural development to support both production and social well-being; v) promotion of local food security through development of systems that meet local needs; vi) avoidance of user conflicts; and vii) promotion of change that does not create greater imbalances in wealth, income, and power. An ecosystem ecological approach to aquaculture cannot follow a precise blueprint, which is why the concept of adaptive management is important. Each of the seven social issues identified above are directly related to resilience of social systems.

Ecosystems and resiliency

Humans are part of virtually all ecosystems on earth. Due to the combination of expanding populations and increased technological power over the past 200 years, people have become the primary drivers of ecological change everywhere in the world. To separate human/social from biophysical aspects of ecosystems represents an artificial divide. Mangrove ecosystems, for example, consist of trees, plants, soils, water, microbes, insects, benthic organisms, fish, crabs, and birds. Humans interact with these biophysical aspects of mangrove ecosystems both directly and indirectly. Directly, people harvest plants, fish and crabs, cut timber, make charcoal, or clear mangrove for urban expansion, agriculture, or aquaculture. Indirectly, human impacts on mangrove might include sedimentation from urban development or agricultural operations, or pollution from industrial chemicals. Both social and biophysical dimensions of ecosystems are vulnerable to disruptive change. So tightly linked are these two dimensions that disruption in one is likely to cause disruption in the other (Adger, 2000; Adger *et al.,* 2005; Berkes and Folke, 1998). To continue with the example of mangroves, disruption of biophysical processes can undermine the material stability of associated human communities which rely on mangrove for food, building materials, fuel, and cash income from the sale of mangrove products. Disruption of biophysical processes also is likely to adversely affect a wide range of those crustacean and finfish species which spend part of their life cycle in mangroves, which in turn will affect people in fishing communities that depend on those species.

Thirty years ago Gould and Eldredge (1977) introduced the concept of punctuated equilibrium, the theory that evolutionary change occurs not as a process of slow and gradual change but rather during relatively brief periods of rapid change. For their part, social scientists had figured this out a decade earlier, turning away from their own equilibrium models (e.g., structural functionalism; see Parsons, 1951) during the tumultuous decade of the 1960s and into the 1970s. Just as the realization that change is a natural phenomenon freed biological scientists from viewing ecosystems as static, social scientists have focused attention on technical and institutional instigators of societal change.

Contemporary theory has come to understand ecosystems as being both dynamic and vulnerable. Resilience, which is defined as the amount of disturbance that a system can withstand without changing self-organized processes and structures, focuses our attention on the dynamic qualities of systems rather than on some imagined steady state (Gunderson, 2000). The contemporary focus on system resilience has led to a greater appreciation of the co-evolutionary nature of ecological and social systems (Holling, Berkes and Folke, 1998).

Resilience can be illustrated by considering a marine stock assemblage exposed to selective fishing pressure. Up to a certain point, fishing does not irreversibly alter population dynamics. If pressure increases, however, a species could be fished to the point of virtual extinction leading to dramatic changes in population dynamics. The commercial extinction of the Northern Cod off Newfoundland represents a case in point. During the 1970s and 1980s this stock was exploited beyond its capacity to reproduce, and other species (e.g., Arctic cod) moved in to occupy the available niche. The self-organized processes and structures were altered and the system has been transformed into something new.

Resilience can also be applied to human communities closely associated with a resource like the Northern cod. Cod stocks supported an important fishery since the seventeenth century, proving a remarkable level of resilience in the face of three centuries of continuous fishing pressure. This resilience ended when a series of institutional and technological changes starting in the late 1960s resulted in the collapse of this stock by 1992 (Finlayson, 1994).The coastal communities dependent upon this resource were devastated economically and have experienced significant out-migration over the past decade (P. Sinclair, personal communication, 2007). Communities capable of withstanding annual fluctuations in harvests were unable to adjust to the total closure of the fishery. The absence of viable alternatives to fishing provided no basis for resiliency in the face of this crisis. The major fishing corporations largely responsible for the collapse, however, were able to shift operations and continue operating at a profit, reflecting differences in resiliency resilience between communities of fishers and corporate capital.

The case of Newfoundland illustrates the connection between biophysical and social dimensions of ecosystems and ecosystem resiliency. Resiliency focuses on system change, a subject of interest to both biological and social scientists. In the context of interconnected biophysical social systems, resiliency provides a conceptual framework for productive research and responsive management of natural resources and development processes.

Ecological consequences of aquaculture development: initial concerns

Concerns regarding the ecological consequences of aquaculture development are of relatively recent origin. Bardach, Ryther and McLarney (1972) devoted nearly 900 pages to a state of the art treatment of aquaculture without expressing concerns other than that the costs of treating wastes would make aquaculture production too costly. In his historical review of aquaculture in Southeast Asia, Ling (1977) expressed concern that pollution from other sectors might adversely affect aquaculture production.

Only in the 1980s did ecological concerns regarding the impact of aquaculture begin to attract widespread attention. Social scientists working in Latin America (Meltzoff and LiPuma, 1986) and Southeast Asia (Bailey, 1988; Hannig, 1985) were among the first to report the disruptive impact of intensive shrimp farming on coastal ecosystems and communities. This early literature made the point that rapid expansion of coastal shrimp farming in the 1980s resulted in the conversion of complex coastal ecosystems with multiple uses and multiple users into a vastly simplified landscape dedicated to a single use – shrimp farming – benefiting a single user – the shrimp farmer. Disruption of natural coastal ecosystems carried with it significant disruption of human communities, who lost access to natural resources vital for their material survival.

By the 1990s, environmental concerns began to attract the systematic attention of aquaculturists (e.g., Pullin, Rosenthal and Mclean, 1993), though most of their work during this decade focused on technical fixes to resolve problems of water quality and disease. Gradually, as evidence that technical fixes were unlikely to resolve problems associated with intensive production systems, researchers started to adopt an explicit ecosystems approach to aquaculture. Costa-Pierce (2002; 2003) drew a clear connection between aquaculture as a production system and the ecosystem upon which aquaculture depends for long-term viability. The experts who participated in this FAO Expert Workshop initially defined an ecological approach to aquaculture as one that "strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems…" referring to an initial attempt to define an ecosystem approach to the management of the sector by FAO (2007). This statement is notable for making clear that societal objectives can only be met by taking into consideration biophysical and social issues, using all forms of knowledge available and acknowledging that our knowledge may have limits.

Resource dependency and societal resilience

Social scientists have long been concerned about the connection between natural resources and community stability (Kaufman and Kaufman, 1990. The term "resource dependency" has come into common usage to denote conditions under which particular communities or regions are heavily reliant on one type of economic activity (e.g., farming, mining, fishing, or logging). Much of the research in the field of resource dependency has focused on forestry in North America (e.g., Machlis and Force, 1988; Lee, Field and Burch, 1990; Peluso, Fortmann, and Humphrey, 1994). The central insight from this body of literature is that communities dependent on natural resources for a high proportion of their jobs and income tend to be vulnerable to externally driven changes, including external control over the resource, changing government policies that affect resource availability, market valuations, or competition from other producers (Freudenburg, 1992; RSS Task Force, 1993; West, 1994). These forms of vulnerability affect the resilience of communities dependent upon natural resources.

Communities which are resource dependent may lack resilience in part because they are specialized producers whose success depends on a simplified ecosystem. In forestry, an increasingly large portion of all harvests come from even aged plantation monocultures vulnerable to sudden and widespread diseases or insect infestations. In agriculture, specialization may be driven by increasing economies of scale resulting from land consolidation and mechanization, leading to farm enterprises specialized in one or two crops rather than a more diversified rotation. Similar processes affect capture fisheries as the scale and technological sophistication of fishing vessels continues to increase. Aquaculture too has experienced a tendency towards specialization. In China, the introduction of intensive single-species carp production dependent on purchased inputs competes with multispecies carp polyculture systems. In many places of Southeast Asia, the traditional polyculture of *penaeid* shrimp and milkfish (*Chanos chanos*) has given way to intensive shrimp monocultures.

Resource dependency need not result in poverty nor lack resilience. Coastal communities in much of Southeast Asia are dependent upon coastal resources, but utilize multiple terrestrial, intertidal and marine niches in the coastal ecosystem (Bailey and Pomeroy, 1996). These resources and associated economic opportunities tend to follow known seasons and to be sufficiently distinct in nature that shortfalls in production from any one activity are likely to be balanced by other opportunities. Diversity of economic activities based on utilization of multiple niches provides the material basis of societal resilience. Specialization tends to increase vulnerability within resource dependent communities.

Integrating social and bio-physical dimensions of aquaculture development

Just as social and biological scientists have begun to realize the advantages of working together to understand the dynamic qualities of ecosystems, so too a more integrated systems approach to understanding aquaculture development is emerging. Success in this venture calls for mutual respect across disciplinary lines, a willingness to learn different languages, but also agreement on some basic fundamental qualities associated with ecosystems. Gunderson (2000) refers to ecosystems as "emergent phenomena," a phrase also used in the social sciences to describe the continual process of creating and maintaining relationships characteristic of effectively functioning human communities (Wilkinson, 1986). The concept of resiliency provides an additional foundation for inter-disciplinary discussions.

Aquaculture development takes place in a social, economic, and political context which can either increase or reduce vulnerability to producers. Communities divided by ethnic or class boundaries, and societies without adequate governance structures which provide clear policies and assurances of stability provide inhospitable settings for success even when the biophysical conditions are favorable. Aquaculture development also may require physical and economic infrastructure including roads and markets for both inputs and products. Where monopolistic or oligopolistic markets exist, or corrupt political systems set policies and issue permits, producers can be vulnerable to forces beyond their control.

An ecological approach to aquaculture involves understanding that success depends on both biophysical and social linkages beyond the immediate production system. Pollution from neighbouring farms, industries, and roadways may adversely affect production, most often through surface or groundwater contamination. Similarly, aquaculture production can affect downstream activities, either by diverting water or discharging wastes into public waters. Production facilities also might result in significant change to the bio-physical environment. Mangrove conversion to shrimp farms is an example of an activity which may no longer be as common as it was during the 1980s, but nonetheless has had a significant impact in many coastal areas of Southeast Asia and Latin America. Other reported ecological consequences which have caused concern include deposition of wastes under salmon cages affecting benthic organisms, the escape of exotic species, and possible problems associated with parasites and diseases that could move between cultured and wild stocks.

Aquaculture development has the potential to increase or reduce resilience of human communities. Adger (2000; see also Adger *et al.*, 2005) is the only author who has applied the concept of resilience to aquaculture, doing so in the context of shrimp farming in Vietnam. Adger (2000) observed that construction of shrimp ponds in that country decreased social resilience by reducing the availability of mangrove, which provided a wide array of important resources to people living in coastal communities. Shrimp farming generated profits, but these were highly variable and not widely distributed among the population. The owner of the shrimp farm benefited from "enclosure" of the mangrove "commons" (Hardin, 1968), but most local residents lost access to a source of food, building materials, and firewood. This loss of access resulted in reduced social resilience, according to Adger.

Aquaculture can also contribute positively to social resilience by diversifying the portfolio of household economic activities and making fuller use of available resources (e.g., labour, management skill, water, agricultural wastes). Rural producers in most parts of the world engage in a diversity of enterprises that serve simultaneously to maximize income (including non-cash income) and minimizing risks of failure in any one activity. The logic of such occupational diversity is particularly compelling for limited resource rural producers in developing nations.

Characteristics unique to social systems

To this point, this report has argued that biophysical and social dimensions of ecosystems should be considered as parts of a larger whole. It is important to recognize that these two dimensions not only are connected, but that they have some unique characteristics relevant to our discussion of ecosystems and resiliency.

Social systems are made complex by human needs, aspirations, and cultures. To generalize across the spectrum of human social experience is fraught with difficulties, but there do seem to be a common set of issues which, depending on how they play out, can either enhance or diminish the resilience of social systems (and therefore biophysical systems) associated with aquaculture development. These include:

- entrepreneurial opportunity and employment generation;
- gender relations;
- economic diversification;
- infrastructural development;
- food supply;
- user conflicts; and
- balances in wealth, income, and power.

Entrepreneurial opportunity and employment generation

Job creation through aquaculture development usually represents a positive impact on social resiliency at the community level, particularly in developing nations where unemployment and underemployment are endemic and enormous demand for jobs is enormous. Aquaculture development, which is scale-appropriate for the host community and region, creates opportunity for entrepreneurial development among local residents, with potential ripple effects across the entire local economy. Most small-scale aquaculture activities involve family labour, allowing for fuller utilization of available human resources within the household. Where producers hire workers, the impact on social resilience with a community will depend on how such workers are recruited and compensated. Some producers hire local residents so that others in the community benefit from the enterprise. In other cases, producers prefer to hire outsiders, in which case few benefits accrue to the local community (Muluk and Bailey, 1996).

Gender relations

Aquaculture development can have an effect on divisions of labour and access to resources between men and women. Here the role of culture plays a central role in determining appropriate gender roles in production, processing, distribution, and marketing of fish or other products. As a general statement, women may gain additional responsibilities in production systems oriented toward household consumption or sales within the immediate community, while men may play a more central role in activities associated with production of goods destined for more distant commercial markets. Either of these changes can alter the relationships between men and women, with consequences which may be unforeseen and unintended. A new production and marketing system which increases the money controlled by women may create increased independence of women. Since household expenditures in many rural cultures are the domain of women, increased availability of money may be used for food, clothing, and other household needs. Gender relations also can be changed when new production and marketing systems are controlled by men. The essential point to be made here is that the introduction of a new production system may have consequences for relationships within a household, and it is important to know how existing divisions of labour based on gender might be affected by any form of innovation, including aquaculture.

Economic diversification

One of the most important benefits of aquaculture development lies in its potential to diversify economic activities at the household, community, and regional levels. If resource use conflicts can be avoided, aquaculture may allow for greater integration of other household economic enterprises. Water from ponds can be used for limited irrigation needs while crop residues and animal wastes can be used to fertilize ponds for production of carps, tilapias, or other appropriate species. Most small-scale rural producers around the world engage in a diversity of economic activities as a conscious strategy to minimize risks while maximizing income opportunities. Considerable research effort has been devoted to integrating aquaculture with small-scale farming and animal husbandry. The introduction of aquaculture may fit into this adaptive strategy which is central to the resilience of rural economies around the world. The introduction of production systems which require increasing technical sophistication and investment of financial and human capital would tend to promote specialization rather than diversification of enterprises.

Infrastructural development

Modern aquaculture depends on roads, electricity, and a technically competent workforce. Aquaculture development can have a positive impact on rural communities through construction of roads that link areas of production with centers of demand. Such roads may have important indirect consequences for local communities, opening up market channels of other goods from the community to wider markets, and also allowing the penetration of new commercial goods into previously isolated rural areas. The availability of roads can lead to improved access to labour markets, health care facilities, and educational opportunities for local residents. The demand for an educated workforce can create incentives for improved local education, and job opportunities for well-educated individuals from the local area. Electricity supply can bring about important changes in personal lives and create new entrepreneurial and employment opportunities. Improved local schools, roads, and health facilities, and access to electricity, are all examples of indirect changes which may occur as a result of aquaculture development.

Food supply

Aquaculture is an increasingly important source of high quality animal protein for direct human consumption. In some parts of the world, fish is the only affordable source of animal protein available to the poor. Given the state of wild fish stocks and the high cost of other sources of animal protein, the FAO and other development agencies often promote aquaculture as an important contributor to feeding an increasingly hungry world. To a large extent, aquaculture production does just that, it supports the nutritional needs of a wide cross section of human populations. Small-scale and subsistence aquaculture generates food for residents either in the producer's own household or in the immediate community, and this would be regarded as a plus in terms of social resilience. When aquaculture production is geared towards urban and international markets, local resources of land and water and labour used to produce goods for consumption elsewhere contribute to local social resilience to the extent that local people earn incomes sufficient to purchase foods produced elsewhere.

User conflicts

Aquaculture development can generate conflicts between competing uses and users of land and water resources. Upstream and downstream water users affect or are affected by aquaculture, generating conflicts which can disrupt the social fabric of communities if not carefully managed. Agricultural chemical use can lead to fish kills, and discharge of nutrient-laden pond water can affect downstream users. Where aquaculturists depend on groundwater, such use may conflict with others both in terms of supply and quality. Saltwater intrusion is a common problem in coastal areas where shrimp farmers pump freshwater from coastal aquifers to control salinities. Conflicts also arise when property rights are unclear. Mention has already been made of mangrove conversion into shrimp ponds, a widespread problem during the 1980s in Southeast Asia and Latin America. Mangroves typically are public lands only loosely managed by governments, and conversion to shrimp ponds is the clearest example in the literature of aquaculture development representing a threat to resilience of local social systems. An ecological approach to aquaculture needs to take such conflicts into account, recognizing the likelihood that aquaculture affects and is affected by the wider ecosystem, including both biophysical and social aspects of ecosystems.

Balances in wealth, income, and power

Aquaculture development can have adverse impacts on community resilience if it leads to extremes of inequality in wealth and income, and particularly if such economic inequality is used to establish political power and make rigid class distinctions. Pullin (1981) describes a case of highly capitalized fish farmers in the Philippines who enclosed a large portion of a lagoon with fish pens, excluding local fishers from their traditional fishing grounds. The literature on shrimp farming in Southeast Asia suggests that both local elites and urban-based entrepreneurs built fortunes based on shrimp exports, leaving the bulk of the coastal population worse off both relatively and absolutely. Recognizing the role of different cultures in interpreting economic inequality, the emergence of rigid class distinctions between haves and have-nots undermines the resilience of social systems by generating envy and resentment. This is likely to increase as the wealthy do all in their power to protect their interests, including hiring armed guards. Increasing inequality can be disruptive of social systems in a variety of ways ranging from divergence in class interests to active conflict. People who become marginalized and left behind may have few options available to them, and will resort to increasingly desperate means of survival, including destructive farming or fishing activities that undermine biophysical resiliency. In other cases, marginalized local residents might engage in theft or even destruction of equipment or facilities if they feel their interests are threatened (Emmerson, 1980; Bailey, 1997). An ecological approach to aquaculture must consider the distribution of direct and indirect costs and benefits within society. An aquaculture production system may be fully compatible with the biophysical aspects of an ecosystem but be disruptive of social harmony by leading to increased social and economic disparities.

In sum, aquaculture development can promote social resilience but it cannot be assumed that this will occur. Social resilience is promoted by aquaculture development to the extent that the generation of entrepreneurial opportunity and employment for local residents (1) does not disrupt culturally accepted gender divisions of labour;

(2) creates greater diversity of economic activities in the local economy; (3) increases the local availability of food; (4) minimizes user conflicts; and (5) does not increase inequalities of wealth, income, and power. Conversely, aquaculture development that limits opportunities for local residents, reduces the diversity of local economic activities, adversely affects the local supply of food, generates user group conflict and increases inequalities of wealth income and power will tend to reduce social resilience. People who are at the margins of society are likely to take what actions they find necessary to survive, even if those actions involve degradation of the biophysical environment. The more social resiliency is eroded, the more likely desperate people will engage in short-term survival behaviour that is injurious to ecosystem health.

Towards an ecosystem approach to aquaculture development

Adoption of a comprehensive and workable ecosystem approach to aquaculture development involves integrating the social and biophysical dimensions of ecosystems into research, program development and policy. Two actions in support of this goal would be to (1) follow the principles of adaptive management, and (2) doing so on a scale that makes both social and biophysical sense.

Adaptive management has emerged as the "best practices" approach to ecosystem management. Adaptive management consciously considers both social and bio-physical systems part of a common system that is constantly changing, presenting surprises (Berkes and Folke, 1998). Adaptive management is an iterative process of taking actions, evaluating the consequences of those actions, and adjusting future actions in light of changed conditions. Policies are viewed as hypotheses rather than laws. The principle of adaptive management shares with Korten's (1980) "learning process" approach to rural development characterized by the willingness to embrace error, to learn by doing, and to adapt. The antithesis of the learning process approach is the blueprint that serves as blinders to those who implement the plan without pausing to evaluate whether the original assumptions and methods remain valid and effective. Similarly, the antithesis of adaptive management would be rigidity in managing an ecosystem as if the natural state was a stable equilibrium. Adaptive management places an emphasis on linkages and feedback mechanisms within systems, and consciously includes social systems and institutions within the analytical framework.

The question of scale is not amenable to a single blueprint remedy, but local watersheds make a useful starting point given the connective capacities of water. Watersheds often do not neatly coincide with political boundaries (though sometimes they do), but they do represent a biophysical and connective reality understood by many residents.

CONCLUSIONS

Ecosystems are subject to constant change, sometimes rapid and traumatic. Since the industrial revolution of the Nineteenth-Century, humans have been the primary cause of such change. System resilience has replaced equilibrium as the conceptual framework for managing ecosystems. This paper argued that social and biophysical dimensions of ecosystems are inextricably related such that a change in one dimension is highly likely to generate a change in the other. Change is not to be feared, but it does need to be monitored and even managed if the rate and direction of change threatens to undermine system resilience. An ecosystem approach to aquaculture development would identify factors contributing to resilience of both social and biophysical systems.

Resilience of social systems was described as closely linked with the biophysical dimensions of ecosystems. The focus of this report is on human dimensions of an ecological approach to aquaculture. A set of seven issues related directly to social resilience were identified as being relevant to changes that could be introduced as a result of aquaculture development. These included: (1) entrepreneurial opportunity and employment generation; (2) gender relations; (3) economic diversification; (4) infrastructural development; (5) food supply; (6) user conflicts; and (7) balances in wealth, income, and power. Each of these issue areas represent points where change can support or undermine social resilience.

An ecological approach to aquaculture cannot follow a precise blueprint, which is why the concept of adaptive management is important. Each of the seven social issues identified above are directly related to resilience of social systems. Not all changes automatically will result in change supportive of social resilience, nor will aquaculture development or any other change automatically produce harm. The point of considering these issues is to incorporate these concerns into an ecological approach to aquaculture.

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Economic implications of an ecosystem approach to aquaculture

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ABSTRACT

Much has been written about the economics of sustainability in aquaculture. This paper concentrates on how economics can contribute to the design and understanding of an *ecosystem approach to aquaculture* (*EAA*). An *EAA* implies looking at the economics of aquaculture production from a broader social and environmental perspective. For this purpose, the paper proposes the use of an agro-ecosystem framework and introduces the concept of marginal opportunity cost, which measures what society must give up to obtain a little more of some particular good or service (e.g. farmed shrimp). Recognizing the full set of costs incurred from production, regardless of where they occur or on whom they fall, captures the idea of an *EAA* from an economic perspective. The paper also recognizes that it is difficult to "internalize externalities" without a better idea of the extent of the externalities at issue. A total economic value (TEV) framework is proposed to capture the notion that the ecological qualities of natural ecosystems lead to a flow of ecosystem goods and services that are valued by humans. Simply put, TEV makes a fundamental distinction between use values and non-use values. There are a number of increasingly established techniques to estimate how these values may change as a result of aquaculture development; several aquaculture examples are presented. However, valuation is not enough. Other important considerations are of a more institutional nature, such as markets, property rights and the incentives for collective action in certain settings. To motivate this discussion, two case studies of "enduring" aquaculture systems are described, along with the role of institutions in their survival. The paper concludes with a plea for more and better valuation estimates but recognizes a need for evaluations of the effectiveness of such exercises.

INTRODUCTION

Economic analysis provides a set of tools for assessing the environmental costs of production and these can be applied readily as part of an ecosystems approach to specific activities, such as aquaculture (we will call this an *EAA*). The purpose of such analyses is to distinguish production situations that produce a positive net benefit to society from those that may not do so. Such analyses would not be needed if the information available and incentives facing producers were consistent with the net benefit criteria, since producers would naturally choose the preferred scale and type of activity that is in society's best interest. However, a review of the history of aquaculture development reveals incentives for ecologically sound production often have been distorted by economic, social and policy related factors. In this paper, we concentrate on the former two of these factors. Some authors refer to the type of incentives involved as "indirect incentives", to isolate these influences from the direct production incentives offered by governments (e.g. subsidies).

In an early study, Pearce, Barbier and Markandya (1988) argued that indirect incentives consist of variable and user enabling elements, as follows:

- *variable incentives*, such as prices, exchange rates, trade restrictions, interest rate policy, taxes and subsidies, etc.;
- *user enabling incentives*, referring to elements in the producer's environment that affect decision-making behaviour, such as security of tenure, socio-economic conditions, information about technologies, producer support services or credit availability.

We will concentrate on a selected number of the issues listed above, as determined by the needs of applying economics to an *EAA*, but retain the variable/user enabling distinction. The key advantage of such an approach is its ability to identify producer incentives that may be undesirable (pre-*EAA*), identify more socially optimal production opportunities (using the *EAA*) and then develop the incentives needed to correct the situation.

Typically, the appropriate methodology for assessing variable incentives is a mix of private financial analysis and cost-benefit analysis (CBA). It involves identifying the full range of benefits and costs of an action, from both the producer's *and* society's perspectives. These benefits and costs then are monetized using appropriate market or "shadow" prices and the 'net impact' of the action from the private and social points of view is determined. Ultimately, the objective of CBA is maximizing net economic benefits from a human welfare perspective given a finite set of options, while producers are assumed to maximize their profits. Ultimately, CBA is somewhat limited as an indicator of social desirability. It requires detailed information on the impacts to be measured and is concerned strictly with the economic efficiency issues involved, and not with other issues that may concern decision makers. A good CBA at least will address uncertainty and distributional considerations, but is incapable of dealing with multiple objectives or social and institutional concerns.

Enabling incentives instead stem from policies that bear on the enabling environment and, therefore, work indirectly on producer behaviour. Of principle interest is the influence of property rights or tenure on decision-making, which we explore in some detail below. However, the enabling environment also includes incentives issues relating to collective action in the management of common property resources and some less direct forms of government intervention. For example, enabling incentives can include information about environmentally friendly technologies provided to producers via government research and extension programmes. Added to these enabling incentives are modifications to other government services, such as marketing assistance, which can similarly influence producer behaviour in an indirect way.

In this paper, I review the use of economic analysis as a one tool in *EAA* toolbox. In the next section an argument is made for the use of an agro-ecosystems approach to aquaculture because of its recognition of the managed nature of the aquaculture enterprise, and the better opportunities for including social and economic influences. After setting out the basic approach used in an economic analysis of aquaculture production, selected components of the social costs of production are discussed in more detail. These costs include the economist's notion of external costs and the depletion of natural capital, and they must be included to capture the full social costs of production. Subsequently, several case studies are presented to illustrate the economist's approach. The next section deals with institutional considerations in assessing aquaculture development and using this understanding to help identify good prospects for aquaculture development, particularly when cooperation becomes necessary (e.g. shellfish farming). Again, several case studies are provided to illustrate the main points. The paper concludes with a few parting thoughts and the identification of gaps in our knowledge requiring further research.

An agro-ecosystem approach?

In order to apply an ecosystems approach to aquaculture, it is important to recognize that aquaculture is a food producing activity that relies on managed ecosystems or sites. In turn, these managed ecosystems or sites are embedded within a broader terrestrial ecosystem (e.g. catchment) or marine/freshwater body (e.g. basin). Thus, we identify two scales at which the ecosystems approach is relevant: the site or aquaculture production unit level and the broader local or regional ecosystem level at which impacts from production are felt (Table 1). Each scale is distinguished by unique features, such as private operator versus public agency responsibilities for management at the site and catchment scales, respectively (Table 1). As a consequence, the type of financial and economic analysis required at these two scales is quite different. In the site level case, the focus needs to be on private profitability, but studies should assume an agro-ecosystem view in considering (and pricing) inputs properly. Integrated aquaculture systems require this type of analysis, in part, to demonstrate their worth to the operator and, secondarily, to identify inadequate incentives for integrated production that need to be addressed by policy-makers (Table 1). In contrast, economic analysis at the broader catchment or basin scale is more concerned with valuing environmental impacts to ensure the true costs of production are captured. In addition, when aquaculture development occurs where there are competing users demands (e.g. site values), comparative cost-benefit studies are helpful in determining whether aquaculture is the wisest use of land or sea (Table 1).

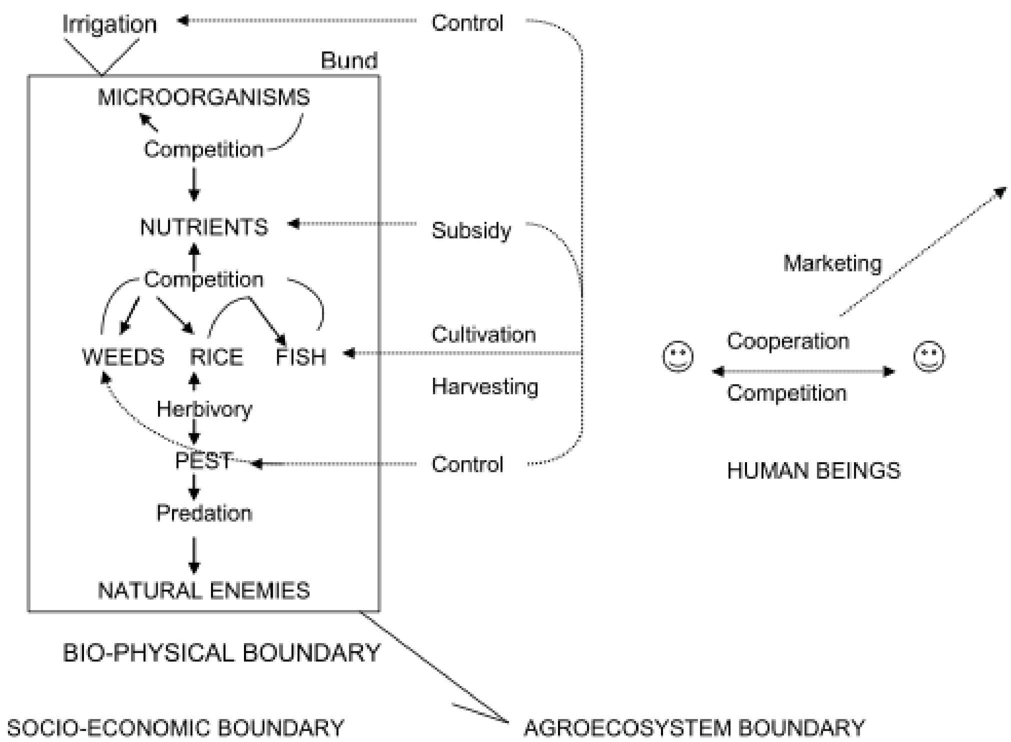
A particularly useful concept that captures the two scales for analysis cited above is the "agro-ecosystem" described by Conway (1993) and others. In his example of a managed rice-fish system (Figure 1), Conway draws the boundaries of the agro-ecosystem to recognize the important influence of human systems on ecosystems, not just as agents of change but as an integral component in the agro-ecosystem itself. An extended socio-economic border is drawn around the biophysical system at the site level to include environmental impacts from production and the marketing and distribution system, both of which involve off-site concerns at the wider scale. For the purposes of this paper it is this wider boundary and the inclusion of socio-economic considerations at this scale that is of importance in defining the "ecosystem" of interest.

TABLE 1

Economic considerations in applying economics to an aquaculture agro-ecosystem

Considerations	Agroecosystem scale	
Unit of management	Site level/farm	Catchment/Basin
Management authority	Aquaculture farmer	Public agency
Management objectives	Maximize private profits	Resource management; may involve multi-objectives and stakeholders
Institutional situation	Property or access rights usually private or concessionaire; may involve encroachment/open access	May be multijurisdictional or even multinational
Economic implications	Respond to private incentives in designing and operating farm; no consideration of offsite externalities	Need to "internalize" externalities and consider tradeoffs among competing resource use demands
Analysis required	Comparative financial analyses of alternative technologies under varying incentives (prices)	Valuation studies and economic cost-benefit analysis

FIGURE 1
Rice-fish system as an agro-ecosystem



Source: Conway (1993)

Some basic economics of an EAA

Much has been written about the economics of sustainability, including such lively debates as the merits of weak versus strong sustainability. It is not the goal here to revisit this territory. Instead, I wish to concentrate on how economics can contribute to the design and understanding of an *EAA*. While *CBA* provides a broad framework for looking at the economics of aquaculture production from a broader social and environmental perspective, we will instead use a narrower approach.[1] A useful concept for this purpose *marginal opportunity cost*, which refers to the next best use of the resources that are consumed in producing small increments of some output (Pearce and Markandya 1996). It tells us what society must give up to obtain a little more of some particular good or service. The marginal opportunity cost (*MOC*) of production consists of:

$$MOC = MPC + MEC + MUC \qquad (1)$$

where: *MPC* = private costs, *MEC* = external costs and *MUC* = user cost. The marginal private costs of food production are reasonably well-known. In this paper, we are concerned with the environmental costs of aquaculture production, consisting of the latter two terms in expression (1), and these are less well-known. A brief description of each component is provided below.

[1] The usual methodology for such a study is cost-benefit analysis. This involves measuring the benefits (*B*) and costs (*C*) from a proposed activity, taking care to value these in terms of opportunity costs, and expressing these as *B*-*C*. When these occur in different time periods a discount factor is used, 1+*r*, where *r* is the social discount rate. Discounted net benefits for each year *t*, $(B_t-C_t)/(1+r)^t$ are then summed over the project life. While useful in many applications of economics to aquaculture, the focus on the ecosystem approach here suggests more narrow attention on measuring the full social costs of production.

Marginal external costs (MEC)

Goldburg, Elliot and Naylor (2001) suggest five main environmental externalities in the United States of America aquaculture: (a) biological pollution, (b) fish for fish feeds, (c) organic pollution and eutrophication, (d) chemical pollution, and (e) habitat modification. Shang and Tisdell (1997) add several socio-economic concerns and items more relevant to aquaculture in tropical coastal areas (Table 2). Valuation of the environmental externalities in aquaculture is in its infancy, although some estimates exist. The analysis of external costs can be somewhat complex, even in applied empirical studies. 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 aquaculture systems is desirable and should comprise the following elements (Meade, 1989):

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

TABLE 2

Possible socioeconomic 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)

In many case studies, only one of these costs may be considered or perhaps several are captured in a more broadly specified external cost measurement.

User costs (MUC)

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 much. For example, a reduction in nearby marine productivity can occur with some intensive cage aquaculture systems but very few measurements of such effects are available. 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.

"Internalizing" externalities

By recognizing the full set of costs incurred from production, regardless of where they occur or on whom they fall, we begin to capture the idea of an *EAA*. In a sense, what we are striving for is the notion of "getting the prices right". When some costs are not internalized and fall on others the producer responds to incorrect signals in making production decisions. His/her costs appear too low in relation to revenues so it stands to reason that production will be stepped up in response. Perhaps new producers will enter the market. When the wrong signals (or incentives) are provided we as society get the wrong levels of production and suffer as a result. Note that internalizing externalities does not mean that production should be zero (although it might), just that it should be less or perhaps carried out differently.

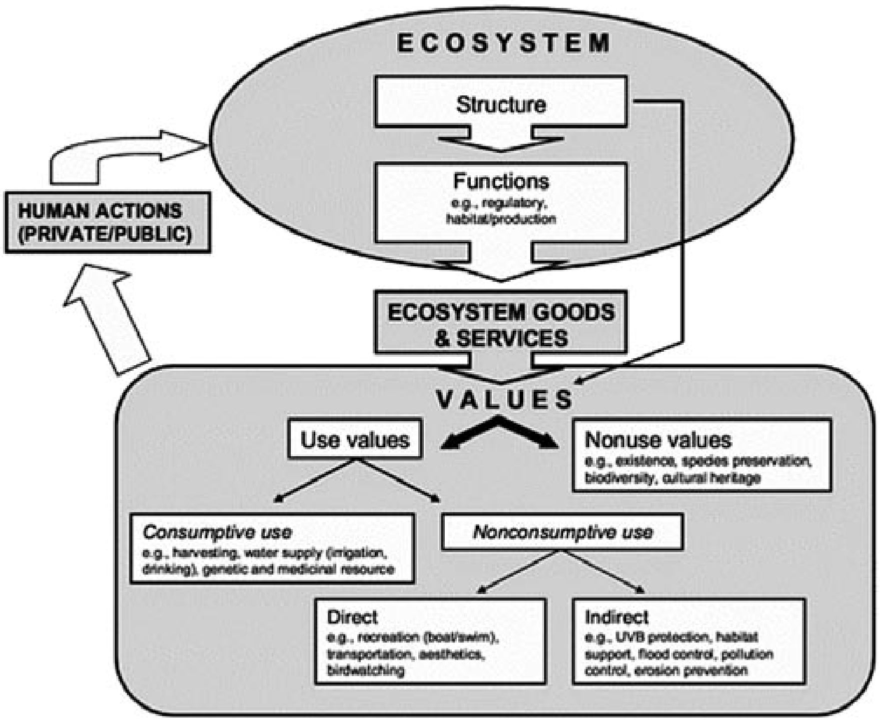
Opportunity costs are key in aquaculture, particularly when it comes to site values, but have not always been recognized properly. In managed terrestrial farming systems the opportunity cost of land is a standard cost that is included in any economic analysis of production alternatives. In aquaculture, the attention to this varies with type of site. For freshwater fish ponds the situation is much like any terrestrial agriculture (with some multi-use dimensions thrown in). In coastal areas, the opportunity costs of converting mangroves and marginal lands has not traditionally been considered but is increasingly recognized now. In open waters (e.g. pen systems), recognition of the opportunity cost of the aquaculture site is in its infancy (Hoagland, Jin and Kite-Powell, 2003).

What can we do to better recognize opportunity costs and internalize externalities? There are a variety of approaches, each with greater/lesser applicability depending on circumstances (examples include regulation/containment systems, economic instruments, insurance schemes, etc.). However, it is difficult to implement these solutions without a better idea of the extent and value of the externalities at issue.

Ecosystem services and valuation

We can begin by recognizing that the ecological characteristics of an ecosystem are associated with a particular flow of ecosystem goods and services that are valued by humans. Externalities and depletion of natural capital stemming from production activities disrupt this flow of goods and services. If researchers are to measure the impacts of aquaculture on the value of goods and services produced by aquatic ecosystems, then a framework is required for distinguishing and grouping these values. The concept of *total economic value* (TEV) provides such a framework. Simply put, TEV makes a fundamental distinction between *use* values and *non-use* values (Figure 2). But it takes this further. According to a recent comprehensive study (Water Science

FIGURE 2
Ecosystems and total economic value indicating Use values and *Non-use values*



Source: Water Science and Technology Board (2004).

and Technology Board, 2004), we can distinguish use values according to consumptive versus non-consumptive use and the latter can be divided between direct (active uses) or indirect (more passive). But there are other taxonomies too.

Economic values are measured as our *willingness-to-pay* for something, less what it costs to supply it. Where an environmental resource simply exists and provides us with products and services at no cost, it is *willingness-to-pay* alone that describes the value of the resource, whether or not we actually make any payment. Measuring these values relies on a number of valuation techniques. There are a number of ways of classifying or grouping these techniques. A relatively simple approach is used here, one which accords with most classifications found in the technical literature. Valuation techniques can be divided into those that use market prices to directly measure the economic value of environmental impacts, and those that do not (some techniques here use market prices but valuation is more indirect). The latter group constitute methods for non-market valuation, and these can be subdivided into: (i) expressed preference methods; (ii) revealed preference methods; (iii) production function approaches; and (iv) cost-based and related goods approaches. A brief description of each group of techniques is provided in an appendix.

Choice of valuation technique depends upon the resources, time and data at hand. As should be clear from the range of techniques described in the appendix, valuation is likely to play a central role in the use of economics as part of an *EAA.*

Economic applications of the EAA to shrimp farming in Asia

The previous sections outlined the basic principles of ecological/environmental economics and non-market valuation that are important in applying an *EAA*. In this section, we employ two examples from shrimp farming in Asia to illustrate the practical aspects. In each example we concentrate on the impact of shrimp farming on the wider ecosystem (beyond the site), but the examples differ in terms of the intensity of the aquaculture activity and the mechanism leading to an externality from shrimp farming. As a first example, we use an analysis of wild shrimp seed collection to supply primarily extensive shrimp farming in West Bengal and its effects on the commercial capture shrimp fishery in the Bay of Bengal [note: relatively little mangrove conversion is occurring in this area]. For the second example, we draw on a comprehensive study of more intensive shrimp farming in Thailand that assessed the social costs of mangrove loss due to encroachment by shrimp farms.

Application 1: Collection of shrimp fry in West Bengal, India

Approximately 50 000 shrimp fry collectors are engaged in the collection of wild shrimp seed in the vast Sundarabans mangrove region that straddles the Indian and Bangladeshi borders. This shrimp seed is then sold via market intermediaries to mostly extensive shrimp farmers throughout coastal West Bengal. Nathan, Knowler and de la Mare (2006) developed a simulation model of the integrated shrimp-mangrove system to determine the impacts of various scenarios of aquaculture development (fry collection) on the capture shrimp fishery. Thus, the analysis is concerned with assessing the value of the externality imposed by shrimp fry collectors (and by inference, shrimp farming) on more distant economic activities.

Since the fry collection industry operates under open access, the fry stock suffers from over harvesting, resulting in reduced availability of fry for both the capture fishery and local shrimp farming. Thus, the external costs from unregulated fry collection need to be formulated in terms of the foregone catches in the capture fishery *and* lost production of farmed shrimp. Applying the *EAA* would imply recognizing and then internalizing this externality via taxing or regulating fry collection, providing win-win benefits in both sectors.

As the analysis was carried out over a 20 year simulation period, only the results from the final period in the simulation (year 20) are discussed. Further, differences in the collection of fry and the catch of shrimp in the capture fishery are considered for two scenarios (Current Situation versus Restricted Scenario). In the latter scenario (Restricted), 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 additional model assumptions and outputs are used in the calculation:

- current shrimp fry collection is about 43.5 million fry, 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, which could produce an additional 1 327 tonnes of farmed shrimp;
- gains in the capture shrimp fishery 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 per year; and
- the total gain in revenue is about US$25 million at an international price for shrimp of US$9.00 per kg (excluding any allowance for changes in production costs or marketing and distribution).

The loss in shrimp production revenues from unregulated shrimp seed collection was estimated roughly at US$575 per 1 000 shrimp fry collected or about US$30 330 per tonnes of farmed shrimp currently produced.[2] It should be noted that there was 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

[2] Updated values from revised simulations are shown here.

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 per 1 000 shrimp fry collected or about US$3.80 per kg of farmed shrimp currently produced.

Application 2: Mangrove degradation and intensive shrimp farming in Thailand

Many attempts have been made to assess the value of the ecosystem services provided by mangroves. However, few such studies have used rigorous valuation techniques to determine theoretically correct economic welfare values. One exception is the study by Barbier, Strand and Sathirathai (2002) concerning mangrove deforestation for shrimp farming in Thailand. As many readers will be aware, the situating of intensive shrimp farms in mangrove areas has led to a significant reduction in mangrove area throughout the semi-tropical and tropical worlds. This loss has been particularly pronounced in Thailand, where 50 to 65 percent of the mangrove forests have been converted to shrimp farms since 1975 (Sathirathai and Barbier, 2001).

Undisturbed, mangroves produce a host of direct use benefits, such as fuelwood, timber, non-timber products, shellfish, as well as indirect use benefits, consisting of ecosystem services such as storm surge protection, nurseries for fisheries, etc. When mangroves are removed to make way for shrimp farms these benefits are lost and, as a result, should be counted as opportunity costs of shrimp farming. While shrimp farms produce a net benefit that is easily extracted by private producers, the net benefits of mangroves in their pristine state are not so easily captured, leading to a tendency to ignore these benefits or treat them as zero. As a result, the conversion of mangroves incurs social costs that are rarely taken into account or compensated. In this study, the net economic benefits produced by mangroves in their undisturbed state are valued and then compared to the net economic benefits from conversion to shrimp farms. Thus, it is possible to evaluate the opportunity costs (including externalities) of developing new commercial shrimp production.

Three key benefits from mangroves were evaluated in the study: (i) collection of forest products, (ii) nursery support for offshore fisheries (demersal and shellfish) and (iii) coastline protection. In the case of (i), valuation was relatively straightforward and involved village surveys to determine the collection of wood, non-timber and fish products from the mangroves. The gross values were then reduced by the costs of extraction to yield net income. Fishery-mangrove linkages were determined using a more sophisticated production function technique (see above) that estimated the value of mangroves as an input into the production of fish that are subsequently targeted in the offshore demersal and shellfish fisheries. Finally, the storm surge protection service was valued using an expected damage function approach. In this technique, an estimate is made of the expected number of economically damaging storm events using a count data model. This relationship was then combined with information about the loss of mangroves over the 1979-1996 period to determine the effect of incremental losses of mangroves on expected storm damages. The authors were able to demonstrate a strong effect on the expected damages, in the order of US$585 000 per km^2 of lost mangroves. Their final tally for the net economic benefits for undisturbed and converted mangrove areas is revealing (Table 3).

It is evident from the study that the mangroves produce substantially greater net economic benefits in an undisturbed state, even though these benefits may be subject to problems of “capture”. In effect, the results argue for a net loss from conversion to shrimp farming of approximately US$8 938 to 11 314 per ha in net present value terms. However, it is noteworthy that this is only true when the analysis is broadened to include the wider ecosystem effects and the loss of indirect use values are counted. In a comparison of direct use values alone, shrimp farming is favoured.

TABLE 3
Comparison of land use values (per ha), Thailand, 1996-2004 (1996 US$)

Direct/Indirect Use Value	Shrimp Farming	Undisturbed Mangroves
	(Net present value per ha, 10 – 15% discount rate)	
Direct Use Values		
- Commercial shrimp production	1 078-1 220	-
- Collected forest products	-	484-584
Indirect Use Values		
- Habitat-fishery linkage	-	708-987
- Storm protection service	-	8 966-10 281
Total net economic benefits	1 078-1 220	10 158-12 392

Source: Barbier, Strand, and Sathirathai (2002); Sathirathai and Barbier (2001)

Both case studies indicate that economic valuation techniques can be applied consistently with the *EAA.* In some cases, this expanded analysis may demonstrate that the social costs of aquaculture production outweigh its benefits at the larger ecosystem level. Of course, this need not be true in all situations. For example, intervention in fry collection in West Bengal would yield environmental and shrimp production benefits. The key point is that by applying economics as part of an *EAA*, it is possible to identify situations where intervention or adjustments in incentives are needed to achieve socially desirable outcomes.

Institutional considerations in aquaculture development

Despite the contribution that valuation can make to implement an *EAA*, valuation and cost-benefit analysis alone is not enough. Economic calculations typically provide only a measure of the net economic benefits from an activity, ignoring other important considerations. Many of these are of a more institutional nature and include the role of markets, property rights and cooperation or collective action issues. We referred to these factors as enabling conditions.

Markets

Even in more conventional analysis the role of markets in economic analysis is a critical one. For example, when aquaculture production supplements wild fisheries the consequent shift in the supply curve to the right (more supplied at every price) means that prevailing prices will drop. This change results in benefits for consumers but deteriorating profitability for the producers relying on wild stocks. Obvious cases of such a "pecuniary externality" include the farming of shrimp and salmon. A recent study of the prospect for farming of sablefish in British Columbia (Canada) concluded that the overall economic benefits, once this market price effect on the wild sablefish fishery was considered, were negative and, consequently, farming of sablefish was discouraged (Sumaila, Volpe and Liu, 2005).

Markets can have other more indirect influences on producer behaviour. When products are exported abroad (e.g. shrimp) there is an increased linkage with the international market system. This can lead to greater volatility in prices and therefore risk, leading to risk aversion behaviours by aquaculturists that may have negative environmental consequences. In contrast, the international marketplace has become highly sensitized to the origins of food products and shrimp and salmon are among those products most affected. This awareness has pros and cons since consumers may succumb to inaccurate information or may be seen as a force for driving improvements in practices (Young, Brugère and Muir, 1999). However, it is best to treat products exported internationally differently from those consumed locally, since consumer knowledge of the latter may be quite different.

Property rights

Property rights are an important determinant of producer behaviour and may create incentives quite distinct from those associated with net benefit calculations (the "efficiency" sense). Tenure (land, coastal zone or sea) may be subject to formal institutions that are established in law. In contrast, informal institutions and organizations are those without comprehensive formal recognition by the modern state - the habitual ways by which a society manages its affairs, such as customary land tenure rules and procedures to resolve conflict over access to natural resources. The strength of these institutions may be limited, as when formal regulations over resource use are not enforced, or they may erode, as when traditional property rights institutions degenerate under pressure (Berkes, 1989). Often the institutions in question are concerned with commonly used natural resources (e.g. village tanks, coastal wetlands, nearshore areas, etc.), but not always. Where no institutional regime governs resource management, then a situation of *open access* is said to exist, but this rarely exists in reality. Instead, there is almost always some form of, often unformalized, management or control over access to the resource.

Property rights issues are relevant in applying an *EAA* to aquaculture, since without strong and viable tenure arrangements production conflicts are likely to arise and sustainability, at least in the social and economic sense, will be difficult to attain. When economic incentives are high then poor institutional conditions can have catastrophic results (e.g. Chilika Lake in Orissa, India). Establishing secure tenure arrangements depends upon the location and nature of production. A distinct gradient seems to govern the ease of establishing secure tenure that runs from terrestrial pond systems to coastal wetlands/brackish water systems, to near shore areas and then to open sea. In terrestrial pond systems, ownership of pond land is often private or may be vested in village authorities (e.g. village tanks in India). As a result, tenure is clear and generally uncontested. It is no surprise, then, that traditional pond systems generate relatively few conflicts and can be highly integrated into the farm household's wider livelihood system, such as in the integrated pond culture of China (Chen, Hu and Charles, 1995).

A distinctly different picture emerges as one move along the gradient to increasingly marine dominated production systems. In coastal and brackish water systems (e.g. shrimp farming) ownership of production sites may be highly contested because of inappropriate transfers of rights from local people to wealthy and powerful outsiders. Furthermore, property rights may be neither clear nor adequately enforced, as has occurred with coastal paddy lands in India (Brugère, 2006); and with mangrove areas or other nationalized coastal "wastelands". The problem worsens in near shore areas since traditional concepts of tenure are less common, with some obvious exceptions (e.g. mollusc farming in France). This zone has the characteristics of a classic shared resource and, therefore, assigning property rights are more difficult. Who are the relevant stakeholders in determining use rights? How are other users affected by assigning rights to aquaculture? Such problems become even more challenging in offshore pen systems where the notion of user rights to the marine surface is even less familiar. Only now are we beginning to recognize that there may be multiple stakeholders with an interest in open ocean sites (e.g. grey whales in the bays of the Pacific coast of North America, where cage culture is expanding rapidly). When planning authorities hastily promote aquaculture development at such sites, perhaps in response to high potential profitability, the potential for conflict is substantial.

Collective action and aquaculture management

Intervention in the management of terrestrial and marine resources for aquaculture through formal mechanisms (e.g. titling), presupposes that alternative institutional strategies are not viable. But there is ample evidence that cooperative arrangements, often based on traditional institutions, can work in the management of certain types of natural resources, aquaculture development involving common property resources being an obvious example.[3] However, cooperative arrangements may be important for other aspects of the aquaculture production system. For example, cooperation amongst several or many farmers can be required in coordinating the location of *bouchots* (stakes) in French mollusc farming, determining the optimal number of cages in an enclosed basin, or for regional collaboration on marketing and distribution. From an economic perspective, collective action may reduce significantly the costs of repeated transactions amongst many individuals by establishing a single set of rules and reducing the requirement for individualized negotiation and transaction (Berkes, 1989). However, collective action is not automatic. Poor information or institutional incentives may inhibit action, and this can result in the poor management of natural resources. Additionally, there may be a threat of 'free-riding' by individuals who may benefit from collective action without contributing, and this may lead to insufficient collective incentives.

The conditions under which collective action is most likely to emerge has been the topic of extensive study by institutional theorists such as Eleanor Ostrom (Ostrom, 1990). Substantial progress has been achieved in defining the conditions where the conditions for success of cooperation are most likely to be present (Table 4). When

TABLE 4
Conditions for successful cooperation in common property resource management

1. Resource System Characteristics
Small size
Well-defined boundaries
Overlap between resource and users' residence
2. External Environment
Low cost exclusion technology
Central government should not undermine local authority
Supportive external sanctioning institutions
Nested levels of appropriation, provision, enforcement, and governance
Appropriate external aid to compensate local users for conservation activities
3. Group Characteristics
Small size
Clearly defined membership
Shared norms
Past successful collective action experiences
Strong leadership
Interdependence among group members
High level of dependency of users on resource system
Heterogeneity of endowments, homogeneity of identities and interests
4. Institutional Arrangements
Rules are simple and easy to understand
Locally devised access and management rules
Ease in enforcement of rules
Graduated sanctions
Availability of low cost adjudication
Accountability of monitors and other officials to users
Restrictions on harvest match regeneration of resources
Fairness in allocation of benefits

Adapted from Agarwal (2001)

[3] This class of goods or services, referred to as *common pool resources* by some and subject to depletability but difficulties in limiting access, can be distinguished from other types, such as *pure public goods*, which are not depletable and also demonstrate difficulties in excluding individuals (e.g. national defence); *club* or *toll goods*, which at least up to some point are not depletable but excluding other users is possible (e.g. toll roads, golf clubs, etc.); and, of course, *private goods.*

more of these conditions are present, the likelihood of achieving a lasting common property resource management regime is commensurately higher.

In the next sections we describe two cases where institutional arrangements are critical to the realization of economic benefits from aquaculture.

Case studies of enduring institutional arrangements in aquaculture

In this section we turn to some case studies of "enduring" aquaculture systems characterized by important cooperative institutional arrangements. Enduring does not coincide necessarily with sustainable, since the latter is a more formal (and troubled) concept. Instead, it refers to systems (generally extensive) that have persisted for decades if not centuries or millennia. What is it about the economic and, especially, institutional aspects of cooperation in these systems that help to explain their durability? Key issues are liable to be markets and pricing, property rights, externalities and depletion, and how these are treated by the collective. Two examples are considered in the next sections: tank fisheries in India and blue mussel farming in northwest France.

Application 3: Village tank systems in Madhya Pradesh, India

Freshwater aquaculture in India is dominated by the use of pond systems, many of which are located in the village tanks that dominate community life in rural India. Production in these systems is often quite low in relation to its potential and contrasts markedly with more intensive fish pond enterprises on private lands. Yet fish production from village tank systems has persisted for centuries and continues to serve as a source of additional protein for villagers. Why has this occurred? Certainly, village tanks fulfill the definition of a common property resource: they can be used by all villagers and, typically, this use involves a range of activities, from livestock watering to bathing, laundry and even drinking water. One of these shared uses is fish production. Since all villagers have access to the tank resource, and many uses are competing, complex institutional arrangements have evolved to govern how the tank is managed. Often, the most successful cases have arisen where a village *panchayat*[4] has authority over the tank and can set and enforce these rules. Clearly, these regimes differ markedly from the case where the fish pond is located on private land and can be managed for multiple or sole use, as the sole owner sees fit.

Marothia (1997) examined a sample of village common and private tanks that included fish production in Raipur District in Madhya Pradesh (Table 5). Thus, the sample consisted of tanks under differing institutional arrangements concerning their use for fish production. Although most tanks averaged between 1 and 2 ha in size, some were much larger and for these the fishing rights were granted to more organized fishing cooperatives. All tanks were subject to multiple uses, even private tanks. However, they differ in the importance attributed to non-fish use. Private ponds generally emphasized fish production more and used much more manure and fertilizer, as a consequence. As a result, the yields in these ponds are substantially higher (Table 5).

In some quarters, this lower yield has been attributed to inefficient management of village tanks. While there is certain to be some truth in this explanation there is more at work. Village tanks may be subject to stringent rules governing fertilizer and manure use since use of these inputs is in conflict with other uses of the tank (e.g. bathing, drinking water). Even though the net returns from fish production in village tanks is at most half that of the private ponds (Table 5), this must be viewed from the wider perspective of joint production from the village tanks. It is likely (but not confirmed in the study) that the combined value of uses from the village tank exceeds that for the private pond, but only if all non-fish uses are considered as well.

[4] Unit of governance at the village level that typically consists of members of the community, either elected or otherwise.

TABLE 5
Economic data for Indian village tanks under different institutional arrangements

Item	Village Tanks			Private Ponds
	Fish cooperatives	*Fish groups*	*Individual fishers*	
No. of ponds	10	6	5	5
Average pond size (ha)	2.3	1.0	1.4	1.2
No. of fishing households	70	6	1	1
Operating cost (Rs/ha)	3 668	3 133	2 989	6 355
- lease/rent	765	1 282	1 335	3 475
- feed and manure	149	-	-	250+
- liming and fertilizer	120	65	45	180
Yield (quintals)	10.6	6.7	6.1	17.5
Gross return (Rs/ha)	14 205	8 940	8130	25 450
Net return (Rs/ha)	10 537	5 807	5 141	19 095

Source: Marothia (1997)

The Indian village tank situation demonstrates how property rights can influence net economic benefits. Economically viable aquaculture in the common village tank without conflict is only possible if the appropriate institutional arrangements are in place. Since the village tank situation meets many of the criteria for successful cooperation set out above (Table 4), it should not be surprising that an enduring common property resource management regime has developed in many villages.

Application 4: Blue mussel farming in northwest France

Aquaculture production in the northwest of France has occurred for over a century but as a more organized commercial enterprise for only the last 50 years.[5] Farming of molluscs in the near shore zone is subject to several important input constraints. The best production sites are limited so that user rights must be allocated under an appropriate property rights regime. Furthermore, molluscs are filter feeders and commercial production, therefore, is dependent on sufficient quantities of primary production. This primary production is a common property resource and one that may be much harder to control and allocate efficiently. Mongruel and Thebaud (2006) studied the economics of mussel farming in the Bay of Mont-Saint-Michel, taking these biophysical and institutional factors into consideration.

The production technology involves fastening bags containing mussel spat to lines of stakes (*bouchots*) close to shore and then the mussels are grown out before harvest later in the year. The origins of mussel farming at Mont-Saint-Michel are symptomatic of aquaculture development in several other locations. Initially, there was unbridled expansion of production capacity, as measured by the number of stakes, but soon productivity and profits began to decline, particularly after an outbreak of the parasite, *Mytilicola intestinalis*. However, rather than settle down to a modest production level with overcapacity and recurring parasitic outbreaks, a series of cooperative agreements were put in place through the combined efforts of the mussel producers and adjacent oyster producers, with policy support at the national level. These measures involved switches of production areas between oyster and mussel farmers, to make more efficient use of higher natural productivity, while maintaining optimal numbers of stakes throughout. At present, despite some production-related concerns, the system appears to be maintaining its profitability, with returns on capital exceeding 15 percent per year.

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[5] However, the technique has been in practice in other parts of France for much longer, as suggested by the following anecdote: "Myticulture, as the cultivation of Mussels is known, was one of the earliest forms of aquaculture, dating to at least 13th century France. A story tells of an Irishman shipwrecked on the western coast of France near La Rochelle who made a chance discovery that poles he erected in the mudflats to support nets for catching birds became a breeding ground for Mussels. So he drove in more stakes, closer together, and joined them with bundles of branches ('bouches') at low tide level and turned his hand to myticulture." [www.showcook.com/Mussels.htm, accessed April 11, 2007].

Why was this aquaculture system able to overcome apparent challenges that have hindered other aquaculture and natural resource production systems? In part, success was the result of a collaborative approach to management involving producers, scientists and government managers. However, we also can refer to the earlier discussion of conditions conducive to successful cooperation that were present amongst the producers themselves (Table 4). Fontanelle *et al.* (1998) suggest a number of the factors consistent with collective action were present, including:

- a highly homogenous group of producers, most having emigrated from the same area of France;
- general consensus on the causes of productivity decline;
- agreement on the objectives and means of cooperation, including agreed upon sanctions for "free riding";
- acknowledgement of the legitimacy of the producer leadership and the relevant producer organization; and
- a transparent and participatory decision-making system.

A few lessons emerge from a brief review of these "enduring" aquaculture systems. For example, all depend on local markets and local price determination. We can also ask if demand and prices are more stable as a result. Property rights are well-established, whether private or common property, and there are systems for dispute resolution. Externalities are generally internalized or minimal (even positive) so there are few conflicts. In terms of resource management, there is little over-exploitation of local resources because of the use of organic recycling and low input technologies. Analyzing institutional incentives in a given setting, such as those examined here, can provide insights that complement more efficiency-oriented cost-benefit and valuation calculations.

DISCUSSION AND FUTURE RESEARCH REQUIREMENTS

Globally, it seems almost certain that aquaculture will be needed to meet nutritional requirements. By pointing out problems due to poor variable economic incentives (e.g. sablefish farming), severe externalities (e.g. intensive shrimp farming) and doubtful institutional/enabling conditions (e.g. shellfish farming in hostile settings), this paper has demonstrated the use of economics in promoting improved decision-making through an *EAA*. Too much aquaculture development has occurred at inappropriate locations or scales when the application of an *EAA,* using the economic and institutional approaches outlined in this paper, would have helped to avert a disaster. The use of economics (comprising conventional cost-benefit analysis, environmental economics and new institutional economics) in applying an *EAA* can help ensure that aquaculture development in the future happens in a sustainable manner.

It also seems clear that the impact of aquaculture development on ecosystem goods and services (external costs) can be valued to a degree. An *EAA*, if it becomes common practice in the future, presents a real opportunity to include these non-market/environmental values in appraisals of aquaculture activities, certainly more than is the case at present. This could lead to the formalization of the use of environmental economics and related techniques for environmental valuation in aquaculture development, in *ex-ante* and *ex-post*/monitoring settings.

However, the record of applications of valuation remains spotty for aquaculture, and few studies capture all external costs or make comparisons. Thus, the current state of valuation research in aquaculture presents an obvious gap for further research. However, a more general observation on valuation appears warranted. Even though progress has been made towards improving valuation techniques, as evidenced in the increasing array of more sophisticated valuation models, the potential for misuse, outright error and for inappropriate applications remains. Moreover, as the number of valuation case studies increases, it seems appropriate that evaluations be carried out to assess the impact of valuation on policy. The obvious question to be asked is whether, and to what extent, valuation has improved decision-making. After all, once the novelty of pricing the unpriced wears off (as may be the case in some quarters), it is the influence that these techniques have on the development of better policies that really matters.

Additionally, the complex characteristics of aquaculture situations need to be recognized, such as unique (and perhaps contested) property rights, the nature of the ecosystem goods and services produced from sites under pristine conditions (as a reference point), the opportunity costs of these sites and the distribution of impacts when ecosystem goods and services are disrupted. Identifying the variable and enabling incentives facing producers (and decision-makers!) is one step but could help dramatically in making better technology and sitting choices.

Finally, it needs to be recognized that institutional considerations are necessary in applying an *EAA*: institutions are the 'glue' among all components of wider ecosystems (environment; technology; and human, including social and economic) and set the rules for interactions (including use) among all these components. Therefore, they are key factors in developing and implementing an ecosystem approach, whether this concerns aquaculture or any other activity. Extending the argument related to the longevity/duration of some aquaculture systems, *EAA* will only stand the test of time if it is supported by adequate and accepted institutional arrangements.

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APPENDIX: DESCRIPTION OF VALUATION TECHNIQUES THAT CAN BE USED IN AN EAA

Expressed preference methods

The first group of non-market techniques are referred to as expressed, direct or stated preference methods and the most commonly used of these is the *contingent valuation method (CVM)*. These techniques involve constructed markets: in the absence of real market information or possibilities for inferring values indirectly, they ask individuals directly about their willingness-to-pay for an environmental good or service using a survey format. In current recommended practice, individuals are asked whether they would pay a specified amount for some environmental benefit. The amounts are randomly varied from one individual to the next. The method for collecting the hypothetical bid is called the payment vehicle, and this may be a tax, membership fee or entry charge to a forest reserve, for example. Additional expressed preference techniques include *contingent ranking* and *choice modeling*. Expressed preference methods often are used to capture non-use values associated with changes in environmental quality (e.g. aquatic biodiversity), since other methods do not apply.

Revealed preference methods

Revealed preference methods attempt to elicit values indirectly. Two often used techniques are the *hedonic pricing method (HPM)* and the *travel cost method (TCM)*. HPM derives values from the influence that environmental quality has on certain market prices, especially property values. The approach involves assembly of cross-sectional data from real estate sales, along with data on factors liable to influence these prices, including environmental quality (visual amenities, noise, air pollution, etc.). Multiple regression is then used to relate these factors to the prices and from this a measure of the impact of environmental quality can be derived. HPM has been used extensively in valuing external costs of intensive terrestrial food production (Palmquist, Roka and Vukina, 1997; Ready and Abdalla, 2005). The technique does not provide a true economic welfare measure but may have some applicability to aquaculture when visual or other impacts affect coastal real estate values.

In contrast, TCM is used to measure values associated with recreational site characteristics. It obtains an estimate of how much individuals are willing to pay to visit a site, given site characteristics, other competing sites and the distance from the site. By controlling for differences in demographic characteristics, site quality and the presence of competing sites, the relationship between distance (and therefore travel costs and travel time) and the number of visits to the site in question can be estimated. Specifying this relationship allows construction of a *demand curve* for the site in question (which is generally required to get an appropriate value measure) that can be used to assess changes in environmental quality. Some of the problems associated with TCM include the treatment of travel time, multiple-site trips, competing sites and the use of estimated rather than real travel costs (Randall, 1994).

Production function techniques

Production functions model the contribution of various inputs to the output in a production process. Where an ecosystem service serves as an input to production, the production function technique allows the analyst to isolate the contribution to output arising from that ecosystem service. If aquaculture disrupts or enhances an ecosystem service then it is possible to measure the effect by tracing its impact on production (Knowler, 2002). For example, a coastal wetland may support fish reproduction for species subsequently caught in a capture or sports fishery. Both the wetland area and the commercial fishing gear are inputs into the production of fish. Modelling this production process, and including the wetland area as an explanatory variable, allows the analyst to determine the impact of aquaculture on offsite fishery values when aquaculture operations displace the natural wetland.

Cost-based valuation

The final group of valuation techniques make use of market prices but emphasize the cost side. For example, the value of an environmental impact can be measured by estimating the cost of replacing or reproducing the environmental service or benefits lost. Techniques using this approach include *replacement, restoration and relocation costs*. Alternatively, the costs of avoiding or mitigating damages to environmental services can be estimated using the *preventive cost* approach. Related to these methods is the *indirect opportunity cost* method, which considers the labour time involved in collecting or harvesting forest produce and values this with a local wage rate. These and similar cost-based techniques suffer from disadvantages and should be treated as second-best methods.

Legal implications of an ecosystem approach to aquaculture

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ABSTRACT

As part of the proceedings to the FAO Expert workshop *Building an ecosystem approach (EAA) to aquaculture*, held in Palma de Mallorca 2007, this chapter seeks to outline the legal implementations of EAA, considering: i) The Principles of EAA in the context of the Environmental and Sustainable Law ii) Current institutional and legal frameworks relevant to EAA; and iii) Reflections on the applicability of EAA from a legal perspective and the legal issues which are vital for implementing EAA. This approach focuses on the already existing activities for sustainable aquaculture reflected in international treaties and guidelines, and the national legislations and their compliance.

INTRODUCTION

Different aspects of an ecosystem approach to aquaculture (EAA) are treated in these proceedings of the FAO Expert workshop *Building an ecosystem approach to aquaculture.* This legal part seeks to outline the legal implementations of EAA considering: i) the principles of EAA in the context of environmental and sustainable law ii) Current institutional and legal frameworks relevant to EAA; and iii) reflections on the applicability of EAA from a legal perspective and the legal issues which are vital for implementing EAA. A legal analysis towards the EAA has to be based on comprehensive scientific, technical and socioeconomic arguments and proposals, and ideally should be developed in close discussion with all involved parties. This is quite difficult at this early stage of the EAA discussion.

The legal support of the innovative aspects of EAA have to be discussed in the context of the already existing initiatives for sustainable development in general and in aquaculture, e.g. the ECASA[1] project in the Mediterranean sea or the inclusion of aquaculture in the Ecologically Sustainable Development (ESD) framework in Australia. Central topics of the present debate on EAA are those related with the shift in perspective from the single farm to the ecosystem as a whole, and the changes in culture systems from monoculture to integrated systems (Barrington *et al.*, 2008). Legal implications emerging from EAA have to be discussed against the background

[1] ECASA is an EU funded Framework 6 RTD project with 16 research partners from 13 member states. It is the successor to several 4th and 5th Framework Programme projects which have helped to push forward research on ecosystem approach to aquaculture especially in the Mediterranean. www.ecasa.org.uk/index.htm.

of the principles of international environmental law and the existing institutional and legal framework for aquaculture at the international and national level.

It is important to bear in mind that usually international law consists of commitments among or guidelines between States, and needs to be implemented at the national level to be fully operational. On the other hand, national laws are enforced and controlled by national authorities. The efficiency and capacity of the institutional framework at the national level is therefore crucial for the implementation and enforcement of existing regulations and new principles and policies that have to be adopted both at the international and at the national level.

The principles of EAA in the context of the environmental and sustainability law

The three key principles to guide EAA, agreed during the FAO Expert workshop in 2007 (Soto *et al.*, 2008) are:

Principle 1: "Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society."

Principle 2: "Aquaculture should improve human well-being and equity for all relevant stakeholders."

Principle 3: "Aquaculture should be developed in the context of other sectors, policies and goals."

These principles formulated specifically in the context of EAA focus on the integrity of aquaculture within the ecosystem, improvement of human well being and equity and the integration with other human activities and goals, intentions that could also be claimed for many other human activities.

The EAA principles, in particular the first one, are mainly considered in the principles of international environmental and sustainability law (Box 1), which are a set of general rules that are extracted from the treaties, the proceedings of international organizations, State's practices and the instruments of soft law (Sands, 2003). These principles are general and potentially applicable to any human activity, and therefore also apply to aquaculture. The fundamental principles of international environmental law are sovereignty over natural resources and the responsibility not to cause damage to the environment of other states or to areas beyond national jurisdiction; principle of preventive action; precautionary principle; responsibility or polluter pays principle; cooperation principle; sustainable development; principle of common but differentiated responsibility. The principles 2 and 3 are also considered in economic and social law.

BOX 1

The principles of EAA and their relation to the principles of international environmental and sustainability law

EAA Principles (Soto *et al.*, 2008)	Principles of Environmental Law
Principle 1: "Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society"	Sovereignty over natural resources and the responsibility not to cause damage to the environment of other states or to areas beyond national jurisdiction Principle of preventive action Precautionary principle Responsibility or polluter pays principle
Principle 2: "Aquaculture should improve human well-being and equity for all relevant stakeholders"	Sustainable development
Principle 3: "Aquaculture should be developed in the context of other sectors, policies and goals"	Cooperation principle Principle of common but differentiated responsibility

Current institutional and legal frameworks for sustainable aquaculture activity

In the last decades sustainability of aquaculture has got attention worldwide (Pillay, 2004). Initiatives towards sustainable aquaculture are taken up by diverse organizations, institutions and stakeholders at the local, national, regional and global level. Depending on the kind of actors and their geographical area of activity, different ways towards sustainable aquaculture, different competencies and different legal tools come into play. Box 2 shows a sample listing of institutions and activities with focus on sustainability in aquaculture, in order to give an idea of the diversity of the activity.

National aquaculture administration can be considered part of the States' duty to implement and enforce national legislation. That is, States have to control aquaculture

BOX 2

A sample listing of institutions relevant to aquaculture and their scope at different geographical levels

Geographic area	Institutions/Organizations	Tools towards sustainable aquaculture
Farm level	Producers, owners Employees, workers Consultants	Standard operation procedures Contingency plans Good production practices Participation in certification systems
Watershed level	Producer organizations Neighbourhood organizations	Control of environmental changes Integrated watershed management
Local	Provincial Administration Local stakeholders Aquaculture facility	Specific regulations for Environmental Impact Assessment (EIA) in Aquaculture. Land tenure and land use planning Salmon Aquaculture Review, EAO British Columbia (British Columbia Environmental Assessment Office) Canada[2], 1997 Aquaculture Act, South Australia[3]
National	National governments	Participation in international agreements National Legislation National Policy for Aquaculture
Regional	APEC[4] (Asia Pacific Economies) FEAP[5] (Federation of European Aquaculture Producers) ECASA NACA (Network of Aquaculture Centers in Asia Pacific)[6]	APEC action plan for Sustainability of the Marine environment (Toronto 1997) PEMSEA (Partnerships in Environmental Management for the Seas of East Asia) Agreement. FEAP Code of Conduct (Izmir, 2000) NACA research centers
Global	FAO GESAMP[7] (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) WAS (World Aquaculture Society) GAA (Global Aquaculture Alliance) WorldFish Center[8] Greenpeace	FAO Code of Conduct, Art. 9 (FAO, 1995) Rio declaration[9] CBD The Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000 (NACA/FAO, 2001) Commonly accepted environmental principles WorldFish Center Protocol for exchange of fish

2 www.eao.gov.bc.ca/
3 www.legislation.sa.gov.au/LZ/C/A/AQUACULTURE%20ACT%202001.aspx
4 www.apec.org/
5 www.feap.info/feap/
6 www.enaca.org
7 gesamp.net/page.php
8 www.worldfishcenter.org/v2/index.html
9 Shorthand for the Rio Declaration on Environment and Development adopted at the Rio Conference, the UN Conference on Environment and Development in 1992. Set of 27 Principles on sustainable development.

like any economic activity in the country, thus their authority should be present even at the farm level.

On regional and international level, there is no single international organization, as subject of international law, with a specific mandate related to aquaculture: rather, normally aquaculture represents only a part of their mandate or a tool to achieve broader goals, e.g. improving livelihoods, reducing hunger as in the case of the FAO. Many initiatives arise from private organizations, like the World Aquaculture Society or the Global Aquaculture Alliance, with a global aspiration, such as to facilitate market access or to harmonize regulations. Finally, there are international networks that provide information or raise awareness about negative impacts of aquaculture and how to deal with them (illness, parasites, invasive species, chemicals, etc.) or about aquaculture technology, methods, new products, etc.

International legislation related to aquaculture activity

Important instruments for sustainable aquaculture in international environmental law are multilateral binding agreements and nonbinding legal instruments. When a country becomes a party to a binding agreement, it accepts the international obligations that arise from the agreement. The control over the implementation of the treaty at the national level is diverse and varies from one treaty to another. The non-binding legal instruments (or so-called soft law instruments), like Declarations, Codes of Conduct and guidelines usually embody political commitments (rather than legally binding obligations), but are still expected to be followed up by States. Both types of international legal instruments play an important role in the development of international environmental law as well as in that of national legislations.

BOX 3

International binding agreements relating to aquaculture activity and EAA

Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar 1971)[10]. The Ramsar Convention is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

Convention on International Trade on Endangered Species of Wild Fauna and Flora, CITES (Washington 1971). CITES strives to ensure that international trade in specimens of wild animals and plants does not threaten their survival.

United Nations Convention on the Law of the Sea, UNCLOS (Montego Bay 1982). UNCLOS governs all aspects of ocean space, including environmental protection, and provides the framework for further development of specific areas of the law of the sea.

Convention on Biological Diversity, CBD (Rio de Janeiro 1992). The CBD calls upon member States to conserve and use biodiversity in a sustainable way, and to ensure access to and benefit-sharing from genetic resources. The CBD supports ecosystem-oriented research, through promoting *in situ* conservation in protected areas.

United Nations Agreement on Straddling and Highly Migratory Fish Stock (New York 1995). The Straddling Stocks Agreement is intended as a framework for the management regimes governing straddling stocks and highly migratory species that span Exclusive Economic Zones and the high seas.

Cartagena Biosafety Protocol (Cartagena 2000). The Protocol seeks to protect biological diversity from the potential risks posed by living modified organisms resulting from modern biotechnology.

[10] www.ramsar.org

Contrary to the case in fisheries, it is hard to find *legally binding environmental agreements* specifically dealing with aquaculture, however, several could directly or indirectly apply to aquaculture (Box 3).

The lack of specific international agreements on aquaculture might be attributed to the fact that aquaculture is seen as part of an industrial activity which it is covered by the general treaties.

Several *non legally binding international environmental instruments* (Box 4) of general or aquaculture specific character are relevant for EAA goals.

One of the fundaments for the development of environmental law is the *Rio Declaration on Environment and Development*. In the context of EAA, in particular Principles 2 (sovereign right to exploit their own resources and do not cause damage to the environment of other States) and 4 (integration of environmental protection and development) should be mentioned[11].

The *Agenda 21* is a comprehensive plan of action to be taken globally, nationally and locally by organizations of the United Nations System, governments, and major groups in every area in which human impacts on the environment take place. The agenda contains a Chapter related to the "Protection of the oceans, all kinds of seas, including enclosed and semi-enclosed seas and coastal areas and the protection, rational use and development of their living resources, in programme areas". Under section D, sustainable use and conservation of marine living resources under national jurisdiction, coastal States, individually or through bilateral and/or multilateral cooperation and with the support, as appropriate of international organizations, whether subregional, regional or global, area called upon to: *Implement, in particular in developing countries, mechanisms to develop mariculture, aquaculture and small-scale, deep-sea and oceanic fisheries within areas under national jurisdiction where assessments show that marine living resources are potentially available* (17.79(c)).

BOX 4

International nonbinding agreements related to sustainable aquaculture activity

International nonbinding environmental agreements of general nature

Rio Declaration on Environment and Development

Agenda 21

Some aquaculture specific nonbinding agreements

Kyoto Declaration on Aquaculture (Kyoto 1976)

FAO Code of Conduct for Responsible Fisheries, Art. 9 (FAO 1995)

Declaration and Strategy for Aquaculture Development Beyond 2000 (FAO/NACA, 2001)

FAO international principles for responsible shrimp farming (FAO/NACA/UNEP/WB/WWF, 2006)

ICES code of practice on the introduction and transfer of aquatic organisms (ICES, 2005)

Global Aquaculture Alliance (GAA) specific guidelines for certain procedures in Shrimp culture [12]

FEAP European Aquaculture Code of Conduct

[11] Rio Declaration, Principle 2: States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction. Principle 4: In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.

[12] www.gaalliance.org/revi.html

There are several non legally binding instruments that are specifically related to aquaculture, which can be of quite different origin and specificity.

Kyoto Declaration on Aquaculture (Kyoto 1976), which supports the idea of integrated aquaculture in the following terms: "[...] *aquaculture can, in many circumstances, be combined with agriculture and animal husbandry with mutual advantage, and contribute substantially to integrated rural development"*.

Code of Conduct for Responsible Fisheries, article 9 (Rome 1995), which promotes the role of the States to ensure that the livelihoods of local communities, and their access to fishing grounds, are not negatively affected by aquaculture developments (art. 9.1.4), and to establish effective procedures specific to aquaculture to undertake appropriate environmental assessment and monitoring with the aim of minimizing adverse ecological changes and related economic and social consequences resulting from water extraction, land use, discharge of effluents, use of drugs and chemicals, and other aquaculture activities (art. 9.1.5). At the production level responsible aquaculture implies, for example, that States should promote *"active participation of fish farmers and their communities in the development of responsible aquaculture management practices" (9.4.2)";* and *"effective farm and fish health management practices favouring hygienic measures and vaccines. Safe, effective and minimal use of therapeutants, hormones and drugs, antibiotics and other disease control chemicals should be ensured"* (9.4.4).

The *Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000* (FAO/NACA, 2001) is a result of the Conference on Aquaculture in the Third Millennium, held in Bangkok Thailand, for the purpose of developing a strategy for aquaculture development in the next 20 years in the light of the future economic, social and environmental issues and advances in aquaculture technologies. This was in a way a response to the Kyoto Conference. Statement 2.8 is related with one of the key aspects of EAA *"2.8 aquaculture complements other food production systems, and integrated aquaculture can add value to the current use of on-farm resources"*.

National legislation for regulation of aquaculture activity

The development of aquaculture-specific legislation and its administration are generally located on national level. Aquaculture is regulated in accordance with the general legal framework applicable to any economic activity, thus legislation is called upon to focus not only on ecological aspects, but also to ensure positive economic and social benefits.

Legal issues linked to aquaculture are quite diverse. Comprehensive national aquaculture legislation must cover a variety of issues; e.g. sitting, environmental impact assessment, production control, waste management, product safety and traceability, disease and parasites. This means that many aspects are covered by different areas of law, e.g. environmental protection, public health, trade, property, land use, planning, animal health. Specific examples can be found in the FAO online data base 'National Aquaculture Legislation Overviews'.[13]

Countries with high aquaculture production have more sophisticated legislation on aquaculture than countries where aquaculture is less developed. Countries with significant interest in aquaculture activity have thus developed aquaculture-specific regulations, for example the Aquaculture Act of South Australia (FAO, 2008b), or the Chilean General Act for Fisheries and Aquaculture (FAO, 2008c). In these cases, most of the elements related to aquaculture have been addressed in one legal instrument, with a view to control the sector in general as well in the different variants and scales of the activity.

[13] www.fao.org/fishery/nalo/search/en

BOX 5

Aquaculture-related issues regulated in national legislations

Issue	Component of the legislation
Allocation of aquaculture activity/sitting	Permitted areas Forbidden areas Interaction with protected areas Operation license First nations/artisanal fishermen communities rights
Production systems	Mono specific Polyculture Integrated systems Environmental product and process standards Product safety and traceability Animal welfare Genetically modified organisms
Control of production volume	Restriction Restriction with specific conditions Increase of production only with previous permission Free
Water use	Use rights Emission standards Water quality Sedimentation models
Environmental impacts	Accidental release of farmed species Disease and Parasites Therapeutants and other chemicals used Transport of species Interactions with other species Waste management
Education, research & development	Training, education and awareness raising Research and development Capacity building
Control mechanisms	Environmental impact assessment Periodic environmental reports Economic Instruments Certification systems Self monitoring Citizens' participation, audiences

Box 5 shows a list of elements that can be included in national legislation. New aspects arising from the debate on EAA may be introduced by modifying the elements already identified or by integrating new elements.

The wide spectrum of legal issues should not be seen as a limitation to the aquaculture sector development, because the role of the law is not necessarily and exclusively the banning and punishment of unacceptable practices (Howarth, 2006). Appropriate regulations support the development of the sector as a whole: in fact in some countries the rapid growth of aquaculture is linked with suitable regulation e.g. rules about distribution of the space, use rights and licensing[14]. The existence of appropriate regulations does not mean that every single legal issue has to be regulated in each country, as this depends on the specific balance between environmental protection, social impacts and economic profitability in each country and the general legal framework. The result of this balancing exercise would entail an emphasis on some aspects rather than others, depending on the importance of the sector for the country, its stage of development, its social implications, etc.

[14] In the case of Chilean aquaculture, one of the reasons for the growth of the sector is the establishment of appropriate areas for aquaculture and a concession system, which solved problems about the use of the space in maritime waters.

Legislation is not the only determining factor for adequate aquaculture activity, significant differences in implementation and law enforcement can be found from nation to nation. Some reasons for the lack of implementation are listed in Box 6.

Reflections on the applicability of EAA from a legal perspective and legal issues which are vital for implementing EAA

EAA is defined as a strategy for the integration of the aquaculture activity within the wider ecosystem in order to promote sustainable development, equity and resilience of interlinked social-ecological systems[15]. The *translation* of such a complex aim, into

BOX 6

Limitations to legal implementation of aquaculture regulation

Unclear distribution of responsibilities *among national authorities*: aquaculture uses and impacts upon a wide range of environmental elements (e.g. water body, soil, landscape, native habitats, etc.). Thus, law enforcement and monitoring is a shared responsibility of different governmental bodies under different legal frameworks and some times under political direction rather than technical.

Contradicting legislation: it depends on the State's organization (federal, unitary), but even in unitary States it is not unusual to find conflicts among legislation from federal, regional or local level. For the farmer, these contradictions cause a waste of time and money trying to comply with regulations that do not fit one with the other.

Incomplete legislation: Box 5 shows a wide range of legal issues related to aquaculture. In each case, regulatory bodies have to decide which specific topic is required to be regulated. However, the aquaculture sector, like in other economic activities, usually develops faster than the law. Thus, aqua-farmers find sometimes that their projects are unviable because of lack of legislation. A good example in this respect is the generalized lack of regulation on aquatic genetically modified organisms in comparative legislation.

Legislation does not take into account all cultivation systems or the opportunities and requirements of small-scale farmers: it is very difficult and often impossible to promote low-impact aquaculture, such as integrated multitrophic aquaculture (Barrington, Chopin and Robinson, 2008), when existing legislation and planning usually focus on mono-specific intensive systems (Neori, 2007). Even among mono-specific systems a different legal response is often required, distinguishing for example between intensive or extensive cultures, finfish or seaweed, native or exotic cultivated species and industrial facilities or small-scale cultures.

Geographic, economic and technical limitations to law enforcement: In most countries, aqua-farmers are increasingly fulfilling legal requirements on a voluntary basis and enforcement measures may not be necessary. There are, however, always exceptions and farmers that violate the law have to be identified and held accountable. The problem of aquaculture regulation is that sometimes authorities are not able to follow up with implementation and enforcement. Reasons for this may vary from the geographical distances between aquaculture facilities (e.g. isolated fiords in the south of Chile) and the authority's base, to the technical lack or deficit of monitoring, and of course to an insufficient budget for monitoring and control.

Lobbying of large-scale aquaculture companies: the development of the legal framework on aquaculture, especially the norms related to environmental protection, is often delayed because of opposition from large aquaculture clusters, which tend to resist regulation and often lobby for lower standards. Today the aquaculture industry is global, and may have considerable leverage over one particular government.

[15] The detailed version on this can be found in the introduction to these proceedings and in Soto *et al*., 2008.

specific legal terms is quite complicated, in particular when taking into consideration the diversity of aquaculture activities. The legal application of EAA has to base on comprehensive scientific, technical and socioeconomic arguments and proposals, and ideally should be developed in open discussion, with a multidisciplinary focus and with all involved parties. Technical and scientific issues have been intensely discussed in other chapters of these proceedings (Soto *et al.*, 2008; Bailey, 2008; Knowler, 2008; Costa-Pierce, 2008; Hambrey, Edwards and Belton, 2008), a sample of issues is presented in Box 7.

It should be mentioned in this context that the role of the law is to serve as instrument to transfer the scientific, technical and socioeconomic arguments and

BOX 7

Aspects which are important for implementation of EAA

Issues	**Related aspects**
Holistic principle	Multidisciplinary, scientific and applied view of EAA. Availability of consistent environmental policies. Protection of aquaculture against other contaminating activities.
Legal framework	Multidisciplinary approach in legislation and implementation. International guidelines and a harmonization of national policies and legislations. Interaction and harmonization on all geographical levels. Development of enforcement measures at all geographical levels.
Institutional framework	Institutional and administrative capacity. Efficient cooperation at all geographical levels. Creation of efficient common database systems for EAA relevant aspects (e.g. FAO FIGIS).
Public awareness building	Clear perception of the objectives and benefits of an ecosystem approach. EAA can only be implemented successfully when it is fully understood and adopted by all stakeholders.
Cooperation principle	Mechanisms for responsible public participation and information sharing. Guidelines, quality standards. Certification systems as an initiative from aquaculture industry.
Efficient control mechanisms	Technical and financial capacity for implementation.
Production standards	Shift to integrated aquaculture techniques might cause consumer concerns.
Multidisciplinary research	Organization and cooperative financing of international, cooperative and multidisciplinary research on EAA aspects (e.g. ECASA). Improvement of ecological, economic and social indicators for sustainability. Periodic revision and actualization of technical guidelines. Improvement of protocols. Integration of Life Cycle Assessment (Bartley *et al.*, 2007). Integrated Coastal Management. Environmental and Strategic Impact Assessment.
Economic instruments	Incentives. Certification. Investment in infrastructural development.
Integration of sectors, policies and goals	Neutral mediation between sectors. *Two speed* aquaculture. Different possibilities of *developed world vs developing world* aquaculture and family type, small farms *vs* big companies, have to be respected.
Human well-being equity	First nations. Fishermen rights. Employment generation.
Simplicity	Complexity of measures might paralyze aquaculture activity. Efficient administrative procedures.

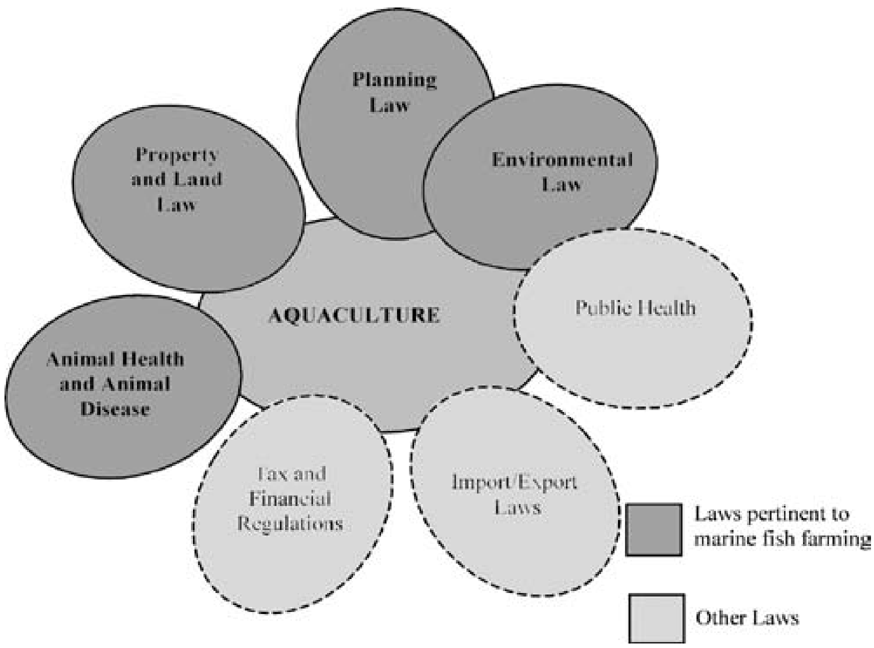
proposals for EAA in mandatory obligations. The complexity of EAA could involve almost all branches of public and administrative law (Figure 1).

The Ecosystem Approach to Fisheries (EAF) might serve as a model for the EAA. However, the implementation of EAA is more complex than the EAF, for the following reasons: i) Fisheries is mainly an extractive activity from an ecosystem, while aquaculture activity represents an multifaceted industrial activity whose impact on the ecosystem is much more complex. ii) Fishery activity has generated several international agreements since the international community wants a fair distribution and conservation of the common natural resources. iii) Aquaculture is a productive industrial activity with the peculiarity that an important part of aquaculture activity takes place in public natural spaces (marine and inland waters).

The principles of EAA are to a certain extend already represented in general policies and legislations which support sustainable development. Environmental consciousness, socioeconomic equity and interaction of sectors are common challenges to any kind of economic activity and are therefore more and more integrated in legislations. One central question therefore is to analyse up to which extend EAA relevant issues are handled in general policies and legislation for industrial activity (e.g. animal health standards, zoning) or whether they should be handled specifically for aquaculture activity. Regarding the concept of integration and the interaction with other sectors a more general perspective of legislation could allow a better integration and avoid an exponential growth of *eco-approach* legal texts. Further details could then be controlled by diverse specific technical norms.

The appropriate sequence for the legal implementation of EAA is to start with international policies, guidelines and agreements. These would then influence regional and national policies and legislations. The FAO legal department or other institutions serve as catalyser for developing, adapting and harmonizing national legislations towards EAA.

FIGURE 1
Sectors of law which could be involved in EAA



Source: Glenn and White, 2007.

CONCLUSION

A sound reflection about the applicability of EAA from a legal perspective needs the integration of scientific, practical, economic and social aspects. The different possibilities of developed and developing world aquaculture and the different production scales of aquaculture activity might be a challenge for legal solutions. The effectiveness of general solutions and the need to adapt to specific conditions might be another. The implementation of EAA should start from a global perspective with international policies, guidelines and agreements. These would then influence regional and national policies and legislations, and their respective technical norms. Well functioning administrative structures and national legislations are essential tools for achieving the aims of EAA. Several aspects of EAA are represented in general policies and legislations for sustainable development. Environmental consciousness, socioeconomic equity and interaction of sectors are common challenges to any kind of economic activity, it might be therefore worth to analyse up to which extend EAA relevant issues can be handled in general policies and legislation for industrial activities (e.g. animal health standards, zoning) or whether there is a need for aquaculture specific legal framework.

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