The Ecosystem Approach to Aquaculture

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Abstract

The Ecosystem Approach is “a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way.” It is implemented internationally through 12 principles of the Convention on Biological Diversity. The Food and Agriculture Organisation of the UN has applied this in the Ecosystem Approach to Aquaculture, which requires that aquaculture should (i) not harm ecosystem services; (ii) improve human well-being; (iii) be developed in the context of other sectors and policies. Since aquaculture needs also to be economically viable, this leads to the idea of three licences: an economic licence, an environmental licence, and a social licence. Monitoring and managing environmental effects of aquaculture are needed to: prevent ‘blowback’ that will damage a farm’s profitability; fulfil obligations of environmental licences; and maintain acceptability to society. Finally, monitoring is a crucial part of the adaptive management strategy recommended by the Ecosystem Approach when scientific knowledge is incomplete.

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1 Introduction

Before asking ‘what should we monitor, and how should we make the observations?’, we should consider the purpose and context of monitoring. The social philosopher Jürgen Habermas (1996) suggests that we obey laws not only because of the penalties for breaking them but also because, in a democracy, laws correspond to social norms, to which we conform because we know that that is ‘the right thing to do’. The Ecosystem Approach provides a norm at the global level: its principles tell us ‘the right thing to do’ when dealing with interactions between people and nature. They have been agreed amongst nations, and they are based on scientific understanding of ecosystems as well as principles of good management and social justice. In addition, they, or the thinking behind them, have influenced environmental protection laws including EU Directives and their transpositions into the laws of EU member states. Thus they guide public officials in their regulation of the effect of aquaculture on natural ecosystems.

2 Origin of the EA

The ‘Ecosystem Approach’ – or EA – is part of the Convention on Biological Diversity of 1992, itself a response to increasing concern about human impacts on ‘nature’ and the expropriation of natural genetic resources. Responding to this concern, the United Nations Environment Programme (UNEP) set up several groups of experts in 1988-1989 to develop an agreed approach to the preservation and proper use of biological diversity. This culminated in May 1992 with the Nairobi Conference for the Adoption of the Agreed Text of the Convention on Biological Diversity - hereafter, CBD. The convention contributes to the sustainable development goals of Agenda 21 of the UN Conference on Environment and Development (the Rio ‘Earth Summit’ held in June 1992), and it was opened for signature at this summit. It came into force in December 1993.

The forward to SCBD (2004) explains that the conservation of biodiversity “presents a formidable challenge for humankind [because] the processes linking ecosystems and species are complex”. As described on the the CBD website the parties to the Convention meet in conference every two years. The EA was identified as “the primary framework for action under the Convention” at the second Conference of the Parties (COP) in 1995. In 1998, a workshop of senior scientists in Malawi developed a list of principles of the EA (UNEP/CBD/COP/4/Inf.9), and these were accepted at the 5th COP in 2000 with some minor updates.

3 EA principles

The CBD (SCBD 2004 p.6) defines the EA as “a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way.” and states that the EA “recognizes that humans, with their cultural diversity, are an integral component of many ecosystems.”

The approach’s 12 principles are listed in Tables 1 and 2. In considering these, it is helpful to understand that the Convention is an agreement between many nations with differing histories, values and relationships with ‘nature’; and that the aims of the EA are social as well as ecological.

The principles, hereafter referenced as EA01…12, include a number of terms that
Table 1: Principles 1-6 of the Ecosystem Approach. These are, mainly, the ‘Malawi principles’ of 1998, as listed in Annex 1 of [Garcia et al. (2003)](https://www.cbd.int/ecosystem/principles.shtml), with my italics used to identify key terms. Text in square brackets summarizes significant additions adopted by Conferences up to and including COP 7 in 2004 [SCBD (2004)]. No further changes noted on CBD website ([https://www.cbd.int/ecosystem/principles.shtml](https://www.cbd.int/ecosystem/principles.shtml)) when visited in August 2017. SCBD (2004) is also the source of the italicised texts in the ‘Comments’ column. Plain text in this column used to paraphrase material in [SCBD (2004)](https://www.cbd.int/ecosystem/principles.shtml) or supply additional comments (source given).

<table>
<thead>
<tr>
<th>Principle</th>
<th>Comment</th>
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<tbody>
<tr>
<td>1 The objectives of management of land, water and <em>living resources</em> are a matter of societal choice</td>
<td>... and should be determined through negotiations and trade-offs among stakeholders having different perceptions, interests and intentions.</td>
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<tr>
<td>2 Management should be decentralised to the lowest appropriate level</td>
<td>Decisions should be made by those who represent the appropriate communities of interest, while management should be undertaken by those with the capacity to implement the decisions. See <a href="https://www.cbd.int/ecosystem/principles.shtml">Ostrom (2007, 2009)</a> concerning research into circumstances in which decentralisation leads to better decision-making.</td>
</tr>
<tr>
<td>3 Ecosystem managers should consider the effects [actual or potential] of their activities on adjacent and other ecosystems</td>
<td>For example, natural resource managers, decision makers and politicians should consider the possible effects that their actions could have on adjacent and downstream ecosystems (river basins and coastal zones) ...</td>
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<tr>
<td>4 Recognizing potential gains from management there is a need to understand the ecosystem in an economic context, considering e.g. mitigating market distortions, aligning incentives to promote [biodiversity conservation and] sustainable use, and internalizing costs and benefits.</td>
<td>... market distortions ... undervalue natural systems and populations ... most environmental goods and services have the characteristics of “public goods” ... which are difficult to incorporate into markets. “Internalizing” means (a) properly valuing ecosystem services and if necessary paying for their maintenance, and (b) properly costing damages due pollution and charging these to their producers. (Author)</td>
</tr>
<tr>
<td>5 A key feature [“priority target”] of the ecosystem approach includes conservation of ecosystem structure and functioning [in order to maintain ecosystem services].</td>
<td>Biodiversity conservation and the maintenance of human wellbeing depend on the functioning and resilience of natural ecosystems. ‘Well-being’ results from a supply of ecosystem services and their conversion into ‘benefits’ to societies (<a href="https://www.cbd.int/ecosystem/principles.shtml">Turner and Schaafsma, 2014</a>).</td>
</tr>
<tr>
<td>6 <em>Ecosystems</em> must be managed within the limits of their functioning</td>
<td>Our current understanding is insufficient to allow these limits to be precisely defined, and therefore a precautionary approach coupled with adaptive management, is advised.</td>
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<td>Principle</td>
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<tr>
<td>7 The ecosystem approach should be undertaken at appropriate spatial and temporal scales</td>
<td>[Monitoring and] management processes and institutions should be designed to match the scales of the aspects of the ecosystems being managed.</td>
</tr>
<tr>
<td>8 Recognizing the varying temporal scales and lag-effects that characterise ecosystem processes, objectives for ecosystem management should be set for the long term</td>
<td>...because it is the long-term, spatially extensive processes that both characterize and determine the broad ecosystem properties. ... [which, however] conflicts with the tendency of humans to favour short-term gains and immediate benefits over future ones.</td>
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<tr>
<td>9 Management must recognize that change is inevitable</td>
<td>Ecosystem components vary because of internal and imposed dynamics, and variability may be necessary for proper ecosystem functioning. Therefore, utilize adaptive management...be cautious in making any decisions that may foreclose options...consider mitigating actions to cope with [e.g.] climate change.</td>
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<td>10 The ecosystem approach should seek the appropriate balance between conservation and use of biological diversity</td>
<td>Biological diversity is critical both for its intrinsic value and because of the key role it plays in providing ...ecosystem ...services. Don’t manage [its] components either as protected or non-protected. [Instead] shift to more flexible measures, where ...measures [are] applied in a continuum from strictly protected to human-made ecosystems.</td>
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<tr>
<td>11 The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices</td>
<td>Doing this might lead to epistemological conflicts but is in the interests both of equity and a better understanding of relevant ecosystems.</td>
</tr>
<tr>
<td>12 The ecosystem approach should involve all relevant sectors of society and scientific disciplines</td>
<td>Many challenges encountered in the EA are complex, ‘wicked’ (Jentoft and Chuenpagdee 2009) problems needing multi-level, multi-sector solutions.</td>
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require definition (tables 3 and 4). ‘Environment’ is one such, especially as it is used with two apparently different meanings in the context of discussions of peoples’ relationship with nature. These are ‘environment’, the abiotic part of an ecosystem, and what will here be called the ‘natural environment’, that which is seen as being ‘outside’ the domain of humanity. Both meanings derive from the dictionary definition of environment as the surroundings or conditions in which a person or organism lives or operates. Systems Theory generalises this: what I will call ‘external environment’ is what lies beyond a system of interest, and which provides its ‘boundary conditions’.

Understanding what an ecosystem is, is central to understanding the Ecosystem Approach. ‘Ecosystem’ is, however, a complex and debated concept, as its different definitions in table 3 show, and is brought out in the further discussion in Appendix B. All definitions agree that the thing pointed to by the word ‘ecosystem’ includes biota (i.e. living organisms) and their non-living environment. The biological, or biotic, community is the aggregate of the biota in a given ecosystem. It was the conservation and proper use of biological diversity, or biodiversity that was the original motivation for the CBD. However, the viability of the biota depends on the conditions in their environment, which are in turn shaped by the activities of the biota. It is the combined management of both biotic community and abiotic environment that is, in my view, one of the crucial requirements of the Ecosystem Approach. Nevertheless, it can be seen from the list of EA principles that there is some tension between the CBD’s focus on the conservation and sustainable use of biodiversity, and the wider focus on the ‘structure’ and ‘function(ing) of ecosystems’ including their abiotic components.

Finally, ‘ecosystem services’ (see appendix B) are ‘exports’ from ecosystems (or, the natural environment) to human economies that bring benefits to the people in these economies. They include tangible things such as fish, obviously part of the biota, and less tangible things such as seascapes, which people are willing to spend money to see and enjoy.

4 The EA and SD

The United Nations has recently re-affirmed its commitment to Sustainable Development in a “plan of action for people, planet and prosperity” (UN General Assembly, 2015), and so it will be as well to consider the EA in this wider context.

In my interpretation, based on Daly (1990); Harris (2000), the three pillars of Sustainable Development (SD) are

**Planet:** the sustainability of ecosystems and their services;

**People:** the fairness with which society distributes the benefits it gets from ecosystems;

**Prosperity:** the efficiency with which humanity converts ecosystem services into benefits and well-being.

The Planet pillar requires a good understanding of ecosystem function, as considered by EA04, 05 and 10. While this depends on the scientific discipline of ecology, there is also a need for other forms of knowledge to be taken into account (EA11).

The People pillar embodies the ethical view that all humans are of equal worth (i.e. that all have interests that should be taken into account). Possession of a valid interest in an issue, such as the environmental effect of a fish farm or the distribution of benefits from farming, makes a person a stakeholder, a definition
Table 3: Definitions of **ecosystem** and some related terms. Emphases added.

<table>
<thead>
<tr>
<th>Definition</th>
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<tr>
<td>“[T]he ecosystem . . . is a particular category among the physical systems that make up the universe. In an ecosystem the organisms and the inorganic factors alike are components which are in relatively stable dynamic equilibrium.”</td>
<td>(Tansley, 1935)</td>
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<td>“The ecosystem may be formally defined as the system composed of physical-chemical-biological processes active within a space-time unit of any magnitude, i.e. the biotic community plus its abiotic environment”</td>
<td>(Lindeman, 1942)</td>
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<tr>
<td>“Any unit that includes all of the organisms (i.e. the “community”) in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity, and material cycles (i.e. exchange of materials between living and nonliving parts) within the system is an ecological system or ecosystem.”</td>
<td>(Odum, 1971)</td>
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<td>“Ecosystem means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit”</td>
<td>(CBD article 2)</td>
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<td>“An ecosystem can be defined at the most basic level as a natural unit of living things (animals, plants and micro-organisms) and their physical environment. The living and non-living elements function together as an interdependent system”</td>
<td>(Anon, 2007)</td>
</tr>
<tr>
<td><strong>Ecosystem performance and health</strong> can be characterized by three terms. “The vigor of an ecosystem is simply a measure of its activity, metabolism or primary productivity. . . . The organization of a system refers to the number and diversity of interactions between the components of the system. . . . The resilience of a system refers to its ability to maintain its structure and pattern of behavior in the presence of stress.”</td>
<td>(Costanza and Mageau, 1999)</td>
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Table 4: Definitions of key terms used in Tables 1 (EA01-06), 2 (EA07-12) and 3 (ES).

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td><strong>biodiversity, biological diversity (EA04,10)</strong></td>
<td>“the variability among living organisms from all sources including . . . diversity within species, between species and of ecosystems” (CBD article 2)</td>
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<tr>
<td><strong>biotic diversity (ES)</strong></td>
<td>null</td>
</tr>
<tr>
<td><strong>biodiversity conservation (EA04,10)</strong></td>
<td>equated by SCBD (2004) with the protection of biological resources</td>
</tr>
<tr>
<td><strong>biological resources</strong></td>
<td>defined by CBD article 2 as “genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity.”</td>
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<tr>
<td><strong>community and environment (ES)</strong></td>
<td>ecosystems comprise a living part (the community of organisms) and the non-living part that provides their physical-chemical environment</td>
</tr>
<tr>
<td><strong>dynamic, dynamic equilibrium (ES)</strong></td>
<td>‘dynamic’ refers to change under the influence of internal or external drivers or forces; a ‘dynamic equilibrium’ is an apparent steady-state resulting from a balance of forces</td>
</tr>
<tr>
<td><strong>ecosystem functioning (EA05,06) ecosystem processes (EA08)</strong></td>
<td>SCBD (2004) emphasises biological community functioning, includes the production of of organic matter and its flow through food webs; I would add biogeochemical cycling and other community-environment interactions</td>
</tr>
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<td><strong>ecosystem services (EA05)</strong></td>
<td>“services provided by the natural environment that benefit people” (Anon, 2007); ‘exports’ from ecosystems to human economies that bring benefits to the people in these economies (Turner and Schaafsma, 2014)</td>
</tr>
<tr>
<td><strong>ecosystem structure (P5) trophic structure (ES)</strong></td>
<td>SCBD (2004) equates “key structures and ecological processes” with “e.g., hydrological systems, pollination systems, habitats and food webs”</td>
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<td><strong>living resources (EA01)</strong></td>
<td>equated with biological resources</td>
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<td><strong>scales (EA07)</strong></td>
<td>can refer to: levels of organisation (genetic, species population, ecosystem; levels of governance (local, national, international); the spatial extent and grain that is appropriate to understanding and managing particular ecosystem processes; the time-scales over which processes operate</td>
</tr>
<tr>
<td><strong>space-time unit, functional unit (ES)</strong></td>
<td>‘space-time’ implies bounded and ‘unit’ implies a real entity, a thing that functions as a whole; ecologists argue about whether ecosystems exist as things in reality or only in our minds</td>
</tr>
<tr>
<td><strong>sustainable use (EA04)</strong></td>
<td>“the use of components of biological diversity in a way and at a rate that does not lead to a long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations” (CBD article 2); I add: the use of ecosystem services without depleting natural capitals or harming ecosystem resilience</td>
</tr>
<tr>
<td><strong>system (ES)</strong></td>
<td>“a set of elements standing in interrelation among themselves and with their environment” (von Bertalanffy, 1972); implicit in this is the distinction between a system and its (external) environment</td>
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</table>
sometimes expanded to representatives of organisations that have an institutional interest in the issue.

The Prosperity pillar is the most problematic of the three, in that the 2030 Agenda (UN General Assembly, 2015) seeks to reconcile prosperity for all with progress in harmony with nature. Thus it is clearly vital, in an age when humanity seems to be exceeding planetary limits to its use of natural resources (Rockström et al., 2009), that we use what we use as efficiently as possible. The EA concerns itself mainly with the intersection of ‘Environment’ and ‘Society’; the only ‘Economy’ principle is 4. It seems possible that those who conceived the EA thought that enterprises would look after their own economics, society being involved only in ensuring that this did not take place at the expense of other stakeholders. The ‘Ecosystem Services Approach’ provides an alternative to the EA, and one that stresses economics and the market rather than society and governance as the context for humanity’s dealing with nature (Waylen et al., 2014).

5 The EAF and the EAA

The EA is a set of general principles. How they are implemented will depend on the type of natural environment involved, the ecosystem services exploited, and the human technologies used. Explaining the Ecosystem Approach to Aquaculture (EAA) is of course the key purpose of this essay, but it will be useful to start with the Ecosystem Approach to Fisheries (EAF).

The production of populations of fish available for exploitation by capture fisheries is a ‘final ecosystem service’, a ‘bounty of nature’ available to anyone able to make the capital investment in fishing boats etc required to convert this service into an economic benefit (see appendix B). Overfishing occurs when fish are taken more quickly than they can be replaced by reproduction and growth, and the normal operation of markets seems unable to prevent such over-exploitation (Gordon, 1954). Concern about overfishing has intensified as capture fisheries approached (FAO, 2016) or exceeded (Pauly and Zeller, 2016) an annual global catch of 100 million tonnes. An apparently technical problem of how to manage a fish stock for Maximum Sustainable Yield (MSY) is complicated by awareness that stocks are part of ecosystems, and thus dependent on other components, and that management requires social and economic interventions. This led the Food and Agriculture Organisation (FAO) of the UN to campaign for the application of the EA to Fisheries. Garcia et al. (2003) define the EAF as striving:

“to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries.”

The EAF merges

“two related but potentially converging paradigms. The first is ecosystem management that focuses on protecting and conserving ecosystem structure and functions by managing the biophysical components of ecosystem (e.g. introducing marine protected areas (MPAs)), and the second is fisheries management that focuses on providing food and income/livelihoods for humans by managing fisheries activities.”

The challenge for the EAF lies in reconciling these two paradigms. Aquaculture uses different ecosystem services from those exploited by
capture fisheries, and arguably uses them more efficiently. Aquaculture’s common-property resources are not fish but the capacities of the natural environment to assimilate wastes from, or provide food for, farmed animals. As marine aquaculture has expanded during recent decades it has given rise to an industry that competes with others (such as capture fisheries or tourism) for physical space or the use of ecosystem-derived benefits such as assimilative capacity. The Ecosystem Approach to Aquaculture (EAA) was developed by Soto et al. (2008), as a way of dealing with these issues. A recent FAO/World Bank document (Aguilar-Manjarrez et al., 2017) lists the three principles of the EAA as follows:

Aquaculture should:

(i) “be developed in the context of ecosystem functions and services (including biodiversity) with no degradation of these beyond their resilience”;

(ii) “improve human well-being with equity for all relevant stakeholders (e.g. access rights and fair share of income)”;

(iii) “be developed in the context of other sectors, policies and goals, as appropriate”.

EAA objective (iii) suggests the need for spatial planning (Aguilar-Manjarrez et al. 2017) and for monitoring of aquaculture in order to avoid conflicts with other users of aquatic resources. Achieving objectives (ii) depends on the economic and governance arrangements in the region where the enterprise is located. Objective (i) requires both an understanding of local ecosystem function and a commitment to monitoring, in order to detect and avoid ecosystem degradation.

6 Three licences

Adding the requirement for an enterprise or industry to be profitable to the environmental and social concerns of the EA, leads me to the suggestion that the viability of aquaculture can usefully be thought about as dependent on three licences (Tett et al., 2015).

Figure 1 is a conceptual model of a local Social-Ecological System (or SES), centering on a fish-farming activity, and embedded with a larger SES. A SES is a system comprising both ecosystems and social systems, or the totality of ‘people’ and ‘nature’ in a defined region (Berkes et al., 1998). In the diagram, the larger scale SES is shown interacting with the local-scale SES through ecological, economic and social processes. Outside ecosystems provide the boundary conditions for the local ecosystem, and perhaps also the source of fish feed. The larger scale economy - shown here in terms of markets, owners, providers of capital, and taxes and subsidies - influences financial sustainability, and, more generally,
efficiency of utilisation of the finite resources available to a society. Larger scale society is shown acting on the local system through social norms and governance. The latter may be multi-tiered, as in the case of EU Directives transposed into member states’ laws and implemented by regulating agencies.

In order to operate successfully and sustainably, the farm requires three sorts of licence or permission:

**An ecological licence** to ensure that the farm is not, and will not, degrade the local ecosystem’s resilience and natural functions; in many cases this licence will correspond to one or more legal consents issued by public planning processes or environment protection agencies;

**An economic licence** to ensure that the farm will, or can continue to, operate profitably, and thus support the payment of wages, taxes and dividends or loan interest; without such licence, perhaps corresponding to approval of a business plan, farms will not receive capital investment.

**A social licence** to ensure that people find the farm’s operation to be acceptable, taking account of ecosystem disturbance, provision of employment, interests of other stakeholders, etc.; in many cases such a licence will have a formal component in a development permit obtained through public planning processes, and an informal component in ‘social licence to operate’ (Prno, 2013) from local communities.

In the final analyses, it may be argued that all these licences are in fact social, because they are granted within, or arise as a result of, various institutions of society. Or it may be argued that all are ultimately environmental, because societies that do not manage their ecosystem services sustainably, are unlikely to be viable in the long term. In any case, there will be interactions between economy, natural environment, and society. For example, the introduction of farm waste into the natural environment might increase the risk of harmful algal blooms or of the production of harmful gases from the seabed beneath the farm, with consequences for the farm’s economic viability. ‘Social licence to operate’ may be harmed by a community’s apprehension that a farm is damaging local ecosystem services, such as the provision of clean water for swimming.

7 Why monitor?

Thus there are at least three immediate and practical reasons for monitoring natural environmental conditions that might be affected by aquaculture. Monitoring is needed:

- as part of conditions set by licensing authorities to obtain and keep a formal ecological or environmental licence;
- to help gain social licence;
- to ensure no “blow-back” from impacted ecosystems to farms, which might directly harm economic licence (i.e. risk management)

As EA06 and 09 indicate, we know that natural ecosystems are dynamic and variable, and that we do not fully understand their functioning, especially as they are driven to the limits of their resilience. Thus there are two more reasons:

- to guide adaptive management;
- for research

Adaptive management is crucial if aquaculture is to develop. The alternative is extreme
precaution, so that society permits development to take place only slowly, and at low intensity, while the necessary research is carried out. Adaptive management will allow faster development. It still needs a morsel of precaution, to ensure that no irreversible harm is done to the natural environment, but the crucial part is a programme of monitoring, to observe the results of development, and to remedy problems before they lead to ‘undesirable disturbance’ to water quality and the ‘balance of organisms’ (Tett et al., 2007).

Where knowledge is inadequate, there research is needed. A properly planned scientific experiment, with well-thought-out controls, is still considered the best way to test hypotheses about the effects of human activities on the natural environmental. However, the pace of development, or the shortage of research funding, often does not allow adequate studies of the effects of aquaculture. Consequently, monitoring, especially when carried out as part of adaptive management and hence continuously reflecting on what is observed, can provide an alternative way to advance scientific understanding.

8 Who monitors?

Adaptive management is, thus, recommended in the interest of aquacultural enterprises as well as of broader society, as it will allow development to proceed without complete certainty as to its effects. Farm managers themselves have an interest in monitoring to avoid ‘blow-back’ as well as to satisfy environmental licences and social concerns. Because such managers’ risk-minimisation strategies will tend to prioritise their economic licence, however, society may also require public monitoring of the effects of individual farms. Society will almost certainly be involved in monitoring the aggregate effects of aquacultural industries.

In many cases, then, citizens will expect public officials, perhaps employed by a public Environmental Protection Organisation, to carry out monitoring. EA04 raises questions about who pays for this: should it be the aquacultural industry, through charges or specific taxes? Or should it be society through general taxation, because all citizens benefit from a good natural environment?

Finally, trust is important. If citizens do not trust farm managers to comply with the norms embodied in the EA and the EAA, or public officials to carry out their tasks competently, they may demand stricter public regulation, with attendant costs. Involving the public in monitoring respects EA11, and should increase trust, aid the development of social licence, and reduce overall costs.

9 Conclusions

In this essay I have tried to provide a broader context for monitoring the effects of aquaculture on the natural environment. Much of this context has come from the Ecosystem Approach, which takes account of social as well as ecological issues. Monitoring has a part to play in relation to both sets of issues, and I’ve argued that it also can aid the economic viability of an aquacultural enterprise or industry.

Given lack of scientific certainty about the environmental consequences of aquacultural development, a crucial role for monitoring is as part of adaptive farm management. Such monitoring requires ongoing skilled examination of the data collected by what may be routine observations, and is thus comparatively expensive. It is important that the costs of monitoring do not outweigh the benefits that it provides to society as well as farms. Thus my next essay (lecture) will begin to consider what needs to be monitored, where, and how often.
Appendices

A Ecosystem

The concept of ecosystem, which lies at the heart of the EA, is complex, as the definitions in Table 3 indicate. The concept must be distinguished from the thing or things that it purports to describe or explain.

Let’s consider Figure 2. This diagram, drawn by the marine biologist Alistair Hardy in 1924, shows what is now called a ‘food web’, and has been highly influential in how successive generations of marine biologists have understood marine pelagic ecosystems.

Figure 2: The relation of the herring to the plankton community. This drawing by Hardy (1924) has inspired the idea of marine ecosystems as ‘food-webs’. The organisms in the bottom row are members of the phytoplankton; above them are zooplankters.

What the diagram shows is a network of interconnected boxes, each one representing a kind of plant or animal plankton. Of course, the sea is not full of boxes; instead it contains a myriad of small animals, each seeking to eat, or avoid being eaten, by each other. By examining the stomach contents of many herring, and many larger plankters, Hardy was able to observe the results of these feeding encounters: his diagram aggregates his observations over each type of organisms and so leads to a deduction of the main feeding pathways in the sea. His diagram is one way to ‘see’ (with the mind’s eye) a marine ecosystem. That is to say, it is a ‘construct’, a way of imposing order on observations. Problems can arise when the construct is interpreted uncritically in terms of expected ecosystem behaviour.

For example, many ecologists (and I am one) interpret the set of interactions amongst organisms, and with their environment, as comprising a system as defined by General Systems Theory (von Bertalanffy 1972), i.e.

“a set of elements standing in inter-relation among themselves and with their environment.”

Ecosystems are seen by GST as complex systems, that maintain their internal states distinct from conditions in their external environment through (i) taking in resources (e.g. solar energy) from that environment and (ii) internal feedback loops. Although ecosystems are not organisms - for one thing, they are not precisely defined units with obvious peripheries - their definition in system terms is similar to that of Life. Indeed, it can be argued that Life on Earth began as what we would now call a biogeochemical system with some autopoietic ability, developed a genetic basis, and later evolved distinct species (Woese 1998). Some genes may have subsequently become selfish, some species likewise, but on this argument it is ecosystems and not particular species that we need to preserve, in particular because of their capacity for self-maintainance (Moss 2008).

From the systems perspective comes the conceptualisation of ecosystems in terms of (a) their structure or organisation and (b) their
vigour or function (Costanza and Mageau, 1999; Tett et al., 2013). In metaphor, and drawing on diagrams like those in Figure 2, organization can be imagined as a network of pipes and vigour as what flows through the pipes. Resilience is held to be an ‘emergent’ property of such an ecosystem, dependent on a balance between organisation and vigour. Overwhelming the resilience of an ecosystem, by placing it under too much pressure from human activities such as fishing or polluting, may result in a ‘regime shift’ and loss of what the ecosystem formerly provided to humans.

Some ecologists don’t see ecosystems in this way, but simply as a group of species with populations that cohabit because each is adapted to a particular (resource) niche that is realised in a given geographic area (e.g. Davis and Slobodkin, 2004). In this conceptualisation, ecosystem function depends on the diversity of species therein; loss of species is held to degrade function. The metaphor of an airplane with riveted wings is sometimes invoked: loosing one rivet would probably have no effect, but loose some critical number and the wings fall off. By analogy, loss of a critical (but unknown) number of species is supposed to lead to ecosystem collapse and loss of services.

B Ecosystem services

Ecosystem Services are ‘exports’ from ecosystems to human economies that bring benefits to the people in these economies (Turner and Schaafsma, 2014). If they are material things, the benefits are sometimes called ‘goods’. What motivates people to convert services into benefits is the desire to satisfy well-being needs.

Take a simple case: ‘nature’ provides a stock of fish such as herring. This is the ecosystem service. Humans must catch, land, process, distribute and cook these fish before they finally become a benefit to human society - i.e. before they can be eaten to satisfy hunger and thus supply a well-being need. The catching, etc, requires human action - usually called labour - plus the deployment of capital assets, such as ships, docks, processing plants and kitchens, and the input of energy to fuel the ships and fry the fish.

By analogy with human (physical, financial or intellectual) capital, nature can also be seen as a set of capitals - such as the stocks of herring - built up by, and involved in, natural processes. The modern idea of ecosystem services derives from Costanza et al. (1997), who estimated a cash value for the ecosystems of planet Earth. These authors wanted to increase the weight given to the natural capitals and services in human policy decisions, driven as these were by the aim of economic growth. Earlier ideas are described by Gómez-Baggethun et al. (2010).

A few years after the paper by Costanza et al., the Millennium Ecosystem Assessment (MEA, 2005) used the idea of ecosystem services as a framework for evaluating the state of the planet. This introduced four categories of service: supporting, regulating, provisioning, and cultural. Turner and Schaafsma (2014) incorporated these into a scheme (Figure 3) that distinguished intermediate services and final services from the structure and functioning of the ecosystem from which they were exported.

Some intermediate services of particular interest to aquaculture are those of ‘primary production’ - providing food for cultivated shellfish, for example - and ‘waste breakdown and detoxification’. The latter contributes to the final service of ‘clean water and sediments’. The benefit of assimilative capacity quantifies how much waste can be absorbed by an ecosystem (Tett et al., 2011) without damaging other benefits to human society.

The category of ‘cultural services’, estab-
established by the MEA, allows aspects of ecosystems that do not result in a material good or benefit, to be valued during economic assessment. Such services contribute to human well being through benefits such as those of an attractive seascape, or the sight of charismatic animals. To be clear: the ecosystem service, in this case, is the biophysical condition and the benefit is the informed perception of that condition.

**References**


Figure 3: Ecosystem services classification: modified from figure 2.6 in [Turner and Schaafsma (2014)] and showing how services flow through the ecosystem and are transformed into benefits.


Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E.,  


