IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)

GESAMP Working Group 31 on Environmental Impacts of Coastal Aquaculture

Environmental risk assessment and communication in coastal aquaculture

A background and discussion paper for GESAMP WG31

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Limited distribution.

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Preface

During the 2001 Session of GESAMP in New York, Working Group 31 on Environmental Impacts of Coastal Aquaculture was charged with the task of producing a review report and guidelines for risk assessment of coastal aquaculture, aimed at promoting harmonisation and consistency in the treatment of risk and uncertainty, and improved risk communication.

More specifically, Working Group 31 was requested to examine the whole issue of risk assessment and communication, with particular emphasis on the treatment of uncertainty, as it relates to coastal development, using specifically and primarily coastal aquaculture as a case study. The outputs of the study will comprise a review report and a set of guidelines for risk assessment of coastal aquaculture based upon this review. These will be targeted primarily at those undertaking environmental assessments and cost benefit analyses of coastal aquaculture development. They will seek to promote harmonisation and consistency in the treatment of risk and uncertainty, and improved risk communication.

Working Group 31 was charged with following tasks:

1. Review recent studies, publications and guidelines on environmental, social and economic risk assessment and explore their application to coastal aquaculture;

2. Explore the nature of the risks and uncertainties associated with coastal aquaculture development, and the feasibility of developing a more rigorous framework for risk assessment and communication that would address:

    i. the classification or risks (e.g. production risk; product risk, management risk environmental risk vis-à-vis human health risk);
    ii. the nature or character of risks (e.g. duration; extent);
    iii. the social and environmental risks associated with alternatives, including no development;
    iv. the estimation and communication of risks;
    v. the uncertainty associated with both nature of the risk and their estimation

3. Explore ways in which such a framework might be used to reflect and integrate the differing perceptions of the nature of risk on the part of different stakeholders;

4. Using the framework, develop broad risk profiles of different types of coastal aquaculture;

5. Develop guidelines on the use of the framework for more detailed and localised assessment of coastal aquaculture development and its alternatives, and on how it might be incorporated in environmental assessment and coastal management systems, including more localised and participatory management systems.

In order to facilitate the task of GESAMP Working Group 31, FAO invited the preparation of this background paper to identify and explore key issues, and to provide the Working Group with an informed starting point, and possible structure for their deliberations.

Readers who are interested in receiving further information on this current GESAMP initiative, or who would like to provide comments or suggestions on this Working Paper should feel encouraged to contact:

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1 SUMMARY

1. Aquaculture, and in particular coastal aquaculture continues to grow rapidly throughout the world. Actual and possible environmental impacts from coastal aquaculture include nutrient enrichment; chemical pollution; habitat loss and change; impacts on wild fish and shellfish populations; and upstream effects related to the production of fishmeal used in farmed fish feeds.

2. The precautionary principle is often invoked to support arguments for much stricter control and in some instances moratoria on further development. The principle arose from concern over the failure of the "monitor and respond" approaches to working within the assimilative capacity of the marine environment. The approaches typically led to critically delayed implementation of efforts to reduce potentially damaging inputs to the marine environment.

3. The precautionary principle was internationally agreed in Principle 15 of the Rio Declaration of the UN Conference on Environment and Development (UNCED):

   > *"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation"*

4. A recent GESAMP report (GESAMP, 2001[1]) includes adherence to the precautionary approach amongst a set of guiding principles for improved planning and management of coastal aquaculture development.

5. Application of the precautionary approach implies more thorough assessments of risk related to any new or expanding activity. It also implies the need for mechanisms to agree on appropriate levels of precaution. Reasonable precaution cannot be defined scientifically, although it can and should be informed by science.

6. Environmental risk assessment (ERA) is used widely to address the risks associated with industrial processes, and may serve as a useful tool to support an informed precautionary approach for coastal aquaculture development. It is a formal process consisting of four main steps: (i) hazard identification, (ii) hazard characterisation, (iii) exposure assessment, and (iv) risk characterisation.

7. ERA has been criticised by some environmentalists. It implies scientific rigour, yet may disguise subjectivity. The major output of most ERAs – an estimation of probabilities – is rarely adequately qualified in terms of the associated uncertainties. It can therefore be misused to justify inappropriate decisions. In practice this is not a weakness of the ERA process itself, but rather the way it has sometimes been used.

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[1] GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection), 2001. Planning and management for sustainable coastal aquaculture development. Rep.Stud.GESAMP, (68): 90 p. [ftp://ftp.fao.org/fi/document/gesamp/Y1818e00.pdf]

8. Uncertainty is a particularly important issue for coastal aquaculture development. While some of the impacts (such as deposition of organic matter) can be predicted with reasonable confidence limits, impacts on the wider coastal environment, and in particular on wild fish populations, are highly uncertain, and this uncertainty is unlikely to be reduced significantly even with detailed long term research.

9. It is crucial that the nature and degree of uncertainty associated with the impacts is clearly characterised in any ERA and effectively communicated to decision makers and interested stakeholders. There is little guidance available as to how this can best be achieved.

10. The high levels of uncertainty also imply the need for an informed political rather than purely scientific decision making process to define appropriate levels of precaution. Techniques such as multi-criteria decision analysis (MCDA), drawing on thorough ERA, may offer a possible way forward for dealing with the uncertainties, and agreeing on appropriate levels of precaution. These techniques need to be brought into existing or new decision making and environmental management frameworks for coastal aquaculture, including EIA and local and/or integrated coastal planning and management initiatives.

11. Only through better informed, more transparent, and more participatory decision and planning processes will broad agreement on levels of precaution appropriate to coastal aquaculture development be achieved. Comprehensive and well communicated environmental risk assessment, including a thorough appraisal of the degree and type of uncertainty, should feed into and serve (rather than direct) such processes, alongside thorough analysis of short and long term costs and benefits and their distribution.

12. At the present time the main weaknesses of environmental risk assessment is the lack of guidance on the analysis and characterisation of uncertainty. We suggest that the working group pay particular attention to this issue.

2 BACKGROUND

The precautionary approach, as presented and agreed as principle 15 of the 1992 Rio Declaration, states that "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". This principle has recently been included as one of a set of guiding principles for sustainable coastal aquaculture development in the 2001 GESAMP report on "Planning and management for sustainable coastal aquaculture development" (GESAMP, 2001). It also is an important element in recommendations of the internationally negotiated Code of Conduct for Responsible Fisheries (FAO, 1995a&b; FAO, 1996a&b [2]).

Coastal aquaculture exhibits a wide range of actual and potential environmental and social impacts. Many of these are uncertain and difficult to quantify. It has been argued by some that the precautionary principle should be invoked, and a moratorium on some forms of aquaculture development should be put in place. Others argue that this is unrealistic: the threats are not so serious, and the benefits tangible and significant. The application of the precautionary principle they argue, must also take account of the balance of benefits to risk. The extreme precautionists counter that such an approach has consistently favoured development over environmental interests, and that a balance in favour of the environment must be restored through strict application of the principle.

Wherever one finds oneself on the continuum of opinion, except for the most extreme interpretations, it is clear that the rational application of the principle requires an assessment of risk and uncertainty, and the identification of some level of risk and uncertainty which justifies precaution.

This paper explores the whole issue of how risk and uncertainty can be assessed and communicated in some consistent way, with a view to promoting consistent and conflict free application of the principle. Coastal aquaculture offers a fascinating case study in this regard, because of the diversity of the actual and possible environmental and social impacts associated with it.

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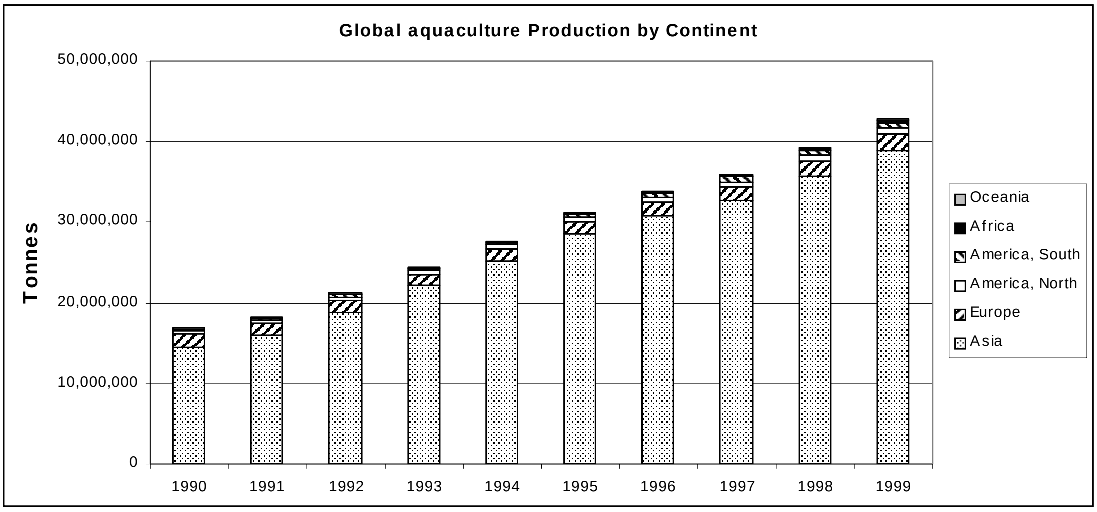
[2] FAO (1995a). Code of Conduct for Responsible Fisheries. Rome, FAO, 41p.
FAO (1995b) Precautionary approach to fisheries. Part 1: Guidelines on the precautionary approach to capture fisheries and species introductions. *FAO Fisheries Technical Paper No. 350, Part 1*. Rome.
FAO, 1996a. Precautionary approach to capture fisheries and species introductions. Elaborated by the Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introductions). Lysekil, Sweden, 6-13 June 1995. FAO Technical Guidelines for Responsible Fisheries. No. 2. Rome, FAO. 54p
FAO (1996b) Precautionary approach to fisheries. Part 2: Scientific papers. Prepared for technical consultation on the precautionary approach to capture fisheries (including species introductions) *FAO Fisheries Technical Paper No. 350, Part 2*. Rome.

3 AQUACULTURE AND ENVIRONMENT KEY ISSUES

3.1 Current status and trends in world aquaculture.

Aquaculture is a highly diverse activity in terms of species grown, scale of operation, technology and management practices. It ranges from small-scale “back-yard” ponds and hatcheries in developing countries to major high technology industrial operations with individual sites producing more than 1,000 tonnes.

A wide and ever increasing variety of species are produced and aquaculture maintains its position as one of the fastest growing food production system. Over the last decade global aquaculture production has increased at more than 10% a year, compared with just 1.5% annual growth in capture fisheries and 3% for terrestrial livestock[3].



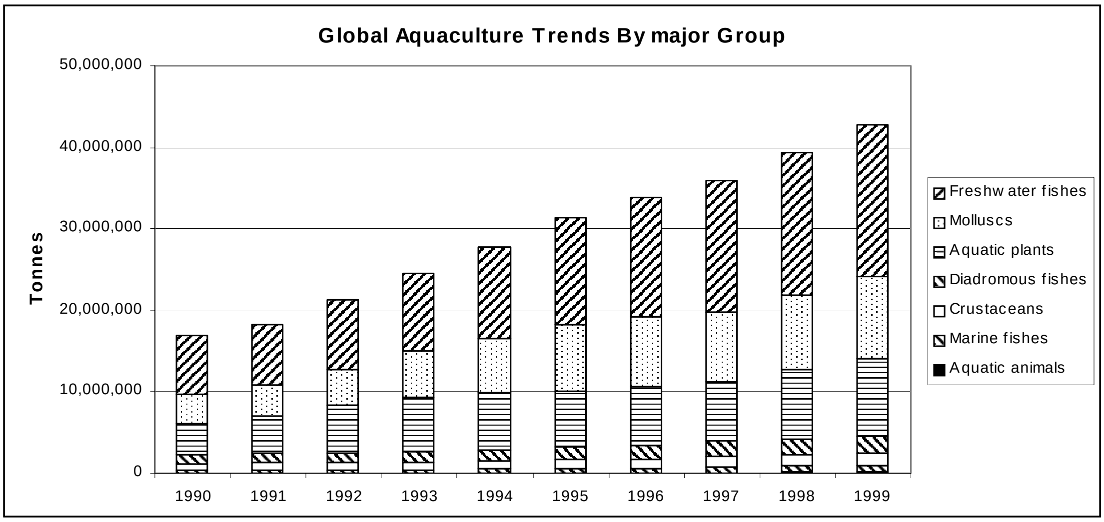


Fig 1 & 2: Global aquaculture production trends 1990-1999 (data source: FAO Fishstat Plus, 2001).

[3] GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection), 2001. Planning and management for sustainable coastal aquaculture development. Rep.Stud.GESAMP (68): 90 p.

The aquaculture production industry is dominated by Asian operations, which in 1999, were responsible for 90.9% of global production (FAO Fishstat Plus, 2001). The majority of the production (80%) is practised on a small scale in low-income food deficit countries.

In the marine environment the production of molluscs and aquatic plants are the dominant sectors although this area of coastal aquaculture production is generally practiced by small-scale extensive operations. The finfish sector contributes about 11% of global coastal aquaculture production; however this includes a large proportion of commercial and intensive production which enables this sector to contribute 27% of the economic value of all coastal aquaculture production (GESAMP, 2001).

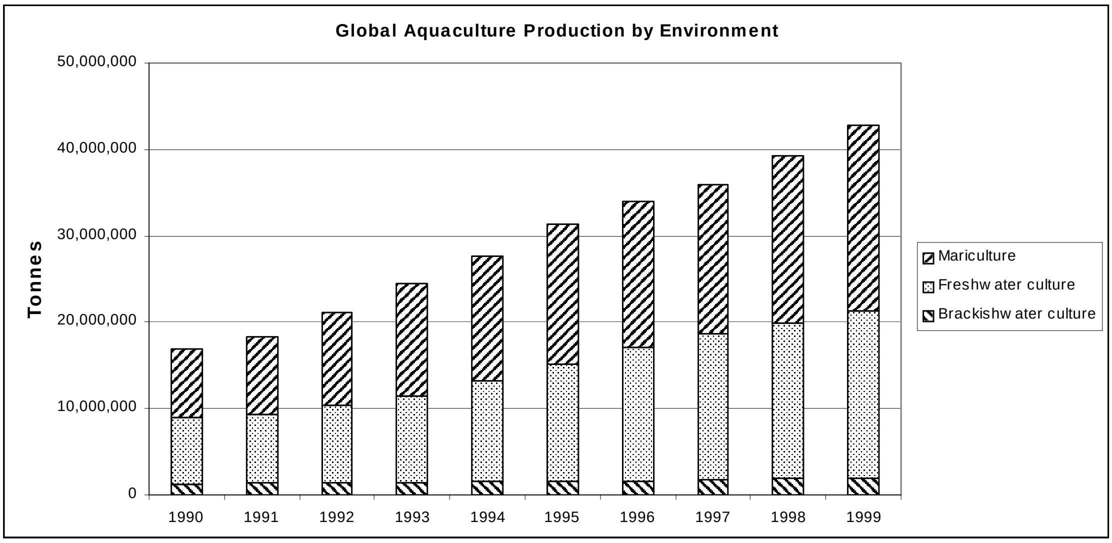


Fig 3: Aquaculture production by environment 1990-1999 (Data source: FAO Fishstat Plus, 2001).

The range of scale, species and technology means that aquaculture can be viewed on the one hand by aid agencies as a useful tool for small scale poverty alleviation, and on the other hand by large financial institutions as a sound investment area for commercial growth. It is this diversity which creates obvious difficulties when attempting to determine regulations or guidelines to apply across the board, and encompass companies employing many thousands of people and one man operations alike.

3.2 Environmental risks associated with aquaculture.

Most aquaculture production requires clean water with oxygen, pH and nutrient levels at a suitable level to support the farmed species (see for example Wallace, 1993[4]). The assumption for long term production is that these measures of water quality should be maintained at appropriate levels to ensure a disease free environment which causes minimum stress for the production species. Past experience shows that in many cases, aquaculture has been unable to maintain the water quality levels that were inherited at the commencement of production.

[4] Wallace, J (1993). Environmental considerations: *In*: Salmon Aquaculture. *Publ*: Fishing News Books. London: pp. 127-143.

On a global scale and across all production systems the major areas of environmental concern include:

- **nutrient enrichment** : the release of uneaten food, faeces, pseudo-faeces and dissolved metabolites to sediment and water column.
- **chemical pollution:** primarily related to release of therapeutic chemicals used in the treatment of disease and parasitic infections.
- **habitat change and loss:** changes in seabed or river bottom habitat due to the accumulation of organic matter; or the loss of habitat due to conversion of coastal land and wetland.
- **impacts on wild fish and shellfish populations:** the escape and interbreeding of farmed (which may be genetically modified) and wild fish; introduction of exotic species (including disease and parasites); increased abundance of pathogens in the water derived from farmed stock.
- **secondary impacts on other production systems:** social, economic and environmental impacts associated with increased demand for inputs such as trash fish and fishmeal

These effects have been discussed and reviewed in numerous papers and books (Black, 2001; Hindar, 2001; Asche et al., 1999; Naylor et al. 1998; GESAMP, 2001; GESAMP, 1991; Barg, 1992)[5]. Although these impacts are highly diverse, most share some key characteristics which must be taken into account if improved environmental management is to be achieved:

- many of the impacts are subtle and cumulative – often insignificant in relation to a single farm, but potentially highly significant for a large number of farms producing over a long period of time;
- some of the impacts may be highly dispersed through space and time;
- there is a high level of uncertainty and ignorance associated with many potential impacts.

3.3 Global experience of environmental management of aquaculture.

It is now generally agreed that aquaculture development needs to be better planned and managed if it is to achieve its undoubted potential and develop in a sustainable manner[6]. Many countries already attempt to manage the aquaculture sector through some form of regulation (e.g. licensing associated with design or operational conditions). This regulation is mainly *ad hoc*, arising as a result of specific problems or concerns. In some countries environmental impact assessment (EIA) is applied, which allows for a more thorough appraisal of social and environmental problems,

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[5] Black, K.D. (ed.) 2001. Environmental impacts of Aquaculture. Sheffield Academic Press; Hindar, K. 2001. Interactions of cultured and wild species. Marine Aquaculture and the environment. University of Massachusetts, Boston MA Jan 11-13th 2001; Asche F., Guttormsen A.G. & Tveterås (1999) Environmental problems, productivity and innovations in Norwegian salmon aquaculture. Aquaculture Economics & Management, vol. 3 No 1, pp 19-29. Naylor R.L., Goldburg R.J., Mooney H., Beveridge M., Clay J., Folke C., Kautsky N., Lubchenco J., Primavera J. & Williams M. (1998) Nature's Subsidies to Shrimp and Salmon Farming. Science vol.282, i5390, p883(1).. GESAMP 2001 op cit.. GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection), 1991. Reducing environmental impacts of coastal aquaculture. Rep.Stud.GESAMP, (47):35 p. Barg, U. (1992). Guidelines for the promotion of environmental management of coastal aquaculture development. FAO Fish.Tech.Pap., (328): 122 pp.

[6] GESAMP 2001 op cit

and possible mitigation measures related to the siting, design and operation of individual farms. Some countries take a more strategic approach, through sector level environmental assessment or aquaculture development plans. In a few cases the management of aquaculture has been addressed within the broader context of integrated coastal management (ICM). Finally, there is increasing interest in codes of conduct for the industry as a whole, and for individual farms[7].

Unfortunately, these various approaches have often failed. Regulatory approaches (such as discharge consents) and farm level EIA fail to address the cumulative, dispersed, and uncertain impacts of aquaculture development, since these cannot be tackled on an ad hoc basis or through assessment of the impacts of individual farms. There are still relatively few examples of sector level assessments[8] or management plans, or the effective integration of aquaculture development planning within broader integrated coastal management initiatives[9], and it is rather early to judge their success. However there remain some significant constraints to the effective implementation of these approaches.

The more integrated and participatory the planning process is, the longer it takes to develop and agree on development and environmental management plans for the sector. Unfortunately this constraint is most serious in precisely those situations where better planning and management is required – i.e. where the sector is developing most rapidly and uncontrollably (such as shrimp farming in Asia and Latin America; and salmon farming in more temperate regions).

A related problem is the difficulty in gaining broad stakeholder agreement on what is, or is not, an acceptable impact or level of impact. This problem is compounded when environmental management objectives and associated performance criteria (such as environmental quality standards) have not been previously set or agreed, and where there are high levels of uncertainty associated with possible impacts – as is the case with aquaculture.

It is this uncertainty and ignorance which has led to calls for moratoria on both shrimp and salmon aquaculture. The precautionary principle has been invoked as the basis and rationale for such moratoria.

3.4 Guiding Principles for Future Development

GESAMP (2001) has proposed a set of guiding principles that should inform the planning and management of aquaculture development so as to promote sustainable development of the sector. These guiding principles are consistent with the FAO Code of Conduct for Responsible Fisheries, and many other international commitments to promote sustainable development:

1. *Adherence to the Rio principles:* sustainable development; the precautionary principle; the polluter pays principle;
2. *integration or co-ordination:* with other sector activities or plans, with national sector plans, with ICM where such initiatives exist;

[7]FAO Fisheries Department, 1997. Aquaculture development. FAO Tech. Guidel.Responsible Fisheries, (5):40 p.
Phillips, M.J. & Barg, U., 1999. Experiences and opportunities in shrimp farming. In Svennevig, N., Reinertsen, H. & New, M. (eds). Sustainable aquaculture - food for the future. Proceedings of the Second International Symposium on sustainable aquaculture. Oslo, Norway, 2-5 November 1997. Rotterdam, Balkema, pp.43-72
Hambrey, J B. 2000. Environmental management of aquaculture development. Infofish International. Sept/Oct Issue (5) 2000 25-29.;
[8] Thompson S., Treweek J.R., Thurling D.J. (1995) The Potential Application of Strategic Environmental Assessment (SEA) to the Farming of Atlantic Salmon *(Salmo salar* L.) in Mainland Scotland. Journal of Environmental Management, vol. 45 pp.219-229.
[9] See GESAMP 2001 op cit for examples)

3. wide ranging *public involvement*;
4. thorough *assessment of costs and benefits* (financial, economic, social, environmental) of aquaculture in a specific area (e.g. estuarine or lagoon system) and *comparative* assessment of costs and benefits of aquaculture relative to other resource uses;
5. some assessment of *environmental capacity*;
6. the use of *incentives* rather than regulation where possible;
7. emphasis on the *control of effects,* rather than the scale of activity;
8. *monitoring and evaluation*, *iteration and adaptation;* and
9. *effective institutions* and representative organisations.

These principles, their application, and the tools, which can be used to support them, are reviewed in the GESAMP report (GESAMP, 2001). However, rather little specific guidance is offered on the application of the precautionary principle. Given the current debate over the impacts of aquaculture, and the widespread reference to this principle, it is clear that this limitation needs to be addressed.

4 THE PRECAUTIONARY PRINCIPLE

The need for precaution in environmental management has become increasingly clear in recent decades as the inadequacies of reactive and ad hoc approaches have become evident.

4.1 Assimilative / Environmental Capacity

Industry and society in general have had traditional rights of access to the marine environment and to make use of marine resources and capabilities. This has been based upon the view that the marine environment has a certain assimilative or environmental capacity. This presumes that all environments have a finite ability to accommodate exploitation or contamination without unacceptable consequences (Gray, 1998[10]). GESAMP describe this capacity as *"a property of the environment, defined as its ability to accommodate a particular activity or rate of activity without unacceptable impact"* (GESAMP, 1986[11]).

Traditionally, consent to discharge has been given conditional upon careful monitoring to ensure that the assimilative capacity is not exceeded. The obvious weakness of this approach is that impacts may only be evident once the environmental capacity to absorb pollutants has been exceeded. This is a particularly dangerous approach to planning and legislation where impacts are persistent and irreversible.

It is inevitable, if working to the assimilative capacity through a “monitor-response” regulatory framework that efforts to reduce potentially damaging inputs to the marine environment will only be implemented once it is too late. Not only is this harmful to the environment, but it can also be expensive, particularly if used in conjunction with the polluter pays principle. Industry may be locked into a cycle of low cost effluent disposal followed by high cost remedial action when the assimilative capacity has been exceeded.

A further criticism of such an approach is that it does not make any use of available scientific knowledge. Published scientific analysis and case studies provide valuable clues to likely consequences of actions. To be legally sanctioned to ignore this body of evidence and continue discharging to the point where negative impacts show up in monitoring is irresponsible[12].

This reactive approach has been referred to as the 'permissive principle' and the 'dump-monitor-act' logic behind regulation based upon the assimilative capacity has been strongly condemned[13].

4.2 Black and Grey Lists

The next stage in the development of marine legislation was the drawing up of black and grey lists. Over many years organisations such as UNEP and the Oslo and Paris Commission (OSPARCOM) with marine stewardship responsibilities have drawn up

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[10] Gray, J. S.(1998). Risk Assessment and Management in Exploitation of the Seas. *In*: Handbook of Environmental Risk Assessment and Management. *Ed*: Calow, P. *Publ*: Blackwell Science.

[11] GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) 1986. Environmental Capacity. An approach to marine pollution prevention. Rep.Stud.GESAMP, (30):49p.

[12] Gray, op. cit.

[13] Earll, R. C.(1992). Common Sense and the Precautionary Principle - An Environmentalists Perspective. *Marine Pollution Bulletin*, **24** (4), pp 182 -186.

lists of toxins, regularly updated, which should not be released into the marine environment.

These lists make good use of current scientific knowledge, but perhaps almost go too far in placing faith in science. The assumption is that science has successfully identified all substances that are potentially harmful to the marine environment. The associated assumption therefore, is that all other substances are free to be released until they are scientifically proven to be harmful. This is particularly problematic with new substances, metabolites or by-products from anthropogenic activities, which may take a while before they are identified as harmful and added to the lists.

The other difficulty for this approach to marine environmental regulation is that it gives little or no consideration to local variations in marine habitats in terms of sensitivity or assimilative capacity. Clearly some substances may be very harmful in certain marine ecosystems but have little or no negative impact in others. By contrast other substances that are revealed to be non-toxic in laboratory tests may be transformed in the marine environment or react with other substances in the water and cause harm[14].

4.3 The Montreal Guidelines

In 1985 UNEP attempted to overcome some of the difficulties of existing marine pollution control policy outlined above. The Montreal guidelines (UNEP, 1985[15]) to governments that were drawn up were an attempt to give greater consideration to local variations in the marine environment and finally tackle the problem of marine pollution from land based sources. The guidelines were based on a need to have strict emission and marine quality standards. These should give clear consideration to water sediment and quality, as well as looking at fish assemblages and community structure as an indicator of environmental health. The guidelines also included the need for planning applications to include environmental impact assessments.

In many ways these guidelines represented progress and took into account and built upon some of the principles of assimilative capacity and black list approach to marine environmental regulation. However, there were still concerns over the ability of these guidelines to promote full protection of sensitive marine ecosystems. The principal concerns were over ambiguity within the guidelines. For example, there was no consideration of ambient levels within an ecosystem prior to impact, nor was there any quantitative indication of the level of environmental standards. More particularly, no framework was provided for the process of deciding upon appropriate localised marine standards.

The guidelines do list practises that are 'incompatible with the marine environment' and clearly highlight the need for a regional management perspective. Overall the guidelines provide a valuable checklist of considerations for marine environmental regulation, but further work was still required for the evolution of an effective regulatory framework[16].

[14] Gray, op. cit.
[15] UNEP, 1985. Protection of the marine environment from land-based sources. Montreal guidelines, Environmental Policy and Law, 14/2/3,pp.77-83. UNEP, Nairobi.
[16] Gray, op cit

4.4 The Precautionary Principle

In 1987 at the 2nd International Conference on the North Sea in London, the regulations safeguarding the marine environment were taken a natural step further, by removing the need for concrete scientific proof of cause and effect, and rather shifting the emphasis to precaution.

The Ministerial Declaration agreed to *"accept the principle of safeguarding the marine ecology of the North Sea by reducing polluting emissions of substances that are persistent, toxic and liable to bio-accumulate at source by the use of best available technology and other appropriate measures. This applies especially when there is reason to assume that certain damage or harmful effects on the living resources of the sea are likely to be caused by such substances, even where there is no scientific evidence of a causal link between emissions and effects".*

The precautionary principle laid out in 1987 appears to offer improved protection to the marine environment. The spirit of the agreement is widely endorsed, although there are important questions of definition. The terms persistent, toxic and bio-accumulate are subject to differing interpretation, and can be assigned to any substance to some degree or other. Virtually all substances will persist to some degree and can be toxic in high enough concentrations. Conversely, substances may bio-accumulate without causing harm.

Clearly the difficulties lie with the interpretation of the agreement. Nowhere is this more clearly illustrated than in the lack of requirement for a scientific link between cause and effect. This throws open the possibility of suspicion ruling over science and effluents being unnecessarily banned.

The principle was re-stated and internationally agreed in Principle 15 of the Rio Declaration of the UN Conference on Environment and Development (UNCED):

> *"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation"*

The principle has since been adopted in Article 174 of the (EU) Treaty of Amsterdam, and has already been used to justify delayed approval for imports of GM crops, and the banning of imports of beef produced using hormone supplements. It is a major element in the rationale for the more recent UN Cartagena Protocol on Food Biosafety, which aims to regulate the trade in genetically modified products.

A major attraction of the precautionary principle is that precaution is a natural feature of human behaviour. We are all cautious to a greater or lesser extent, and the degree of our caution is related to uncertainty and ignorance, as well as the probability and severity of an undesirable outcome. The principle arose not from developments in environmental science or the philosophy of science, but rather from an awareness of past failures in dealing with environmental risks, coupled with a "common sense" approach to dealing with uncertainty.

4.5 Reversal of Burden of Proof

This agreement was outlined at the 4th International Conference on the North Sea, held in Esbjerg, Denmark in 1995 (Oslo and Paris Commissions, 1995[17]). This requires that there be scientific proof of a *lack* of eutrophic impact of nutrient inputs prior to consent to discharge being granted. In practice proving a negative in science is almost impossible, especially in complex physical and biological systems.

Notwithstanding this problem, many analysts link the precautionary principle to a reversal of the burden of proof (although the Rio statement does not strictly imply this). They suggest that it places the burden of proof firmly on the advocates of new technology to show that what they are proposing is safe. It is not for the rest of us to show that it is not (Saunders, 2001[18]).

4.6 Interpretation and application of the precautionary principle

The applications of the principle, and calls for the application of the principle, have generated much debate and controversy. One problem has been a proliferation of slightly different definitions of the principle, some of which directly reflect the perspective of the organisation. Thus *Greenpeace* has developed its own definition which would effectively prevent the implementation of most new technologies. In association with an international grouping of scientists, Greenpeace met in 1998 for a three-day conference at Wingspread, to discuss the implementation of the Precautionary Principle. The statement from this conference states that "*When an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not established scientifically"*[19]. On the other hand, some commentators have suggested that the principle is fundamentally flawed and logically contradictory with suspicion ruling over science[20].

However, most would agree that the spirit of the principle is simply this: we should be careful when embarking on something new; we should be *reasonably* convinced that no harm will come of it; and we should be particularly careful when there is much uncertainty or ignorance about possible effects. The principle is not and cannot be a decision criterion, since the word *reasonable* (as applied to suspicion, proof, certainty, uncertainty etc) is a key word in most definitions. It does not require developers to prove absolutely that something is safe[21]. As noted above, this is impossible from a logical and scientific viewpoint. It simply requires convincing evidence that serious harm is unlikely.

Although many have criticised the principle on the grounds that "reasonable" cannot be used as a scientific decision criterion, others point out that this is neither implied nor required. As in the case of criminal justice systems, proof beyond reasonable doubt can be established, using as a basis agreed guidelines, precedent, or the opinion of an expert or representative panel (such as a jury). Justice is what society as a whole perceives to be reasonable. The key requirement is that all available evidence is collected and assimilated (either impartially, or by advocates

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[17] Oslo and Paris Commissions, 1995. North Sea Ministerial Declaration, Esbjerg, June 1995. Oslo and Paris Commissions, London.
[18] Saunders, P T 2001. The use and abuse of the precautionary principle. ISIS submission to US Advisory Committee on International Economic Policy. Biotech Working Group, 13th July 2000 www. Ratical.com/co-globalize/MaeWanHo/PrecautionP.html
[19] Wingspread Statement on the Precautionary Principle. Greenpeace and Others. Febuary 2nd 1998
[20] Gray op cit,
[21] Saunders, op cit

representing opposed factions or positions); the key arguments presented; and a decision made by some impartial party or representative panel. The verdict, while not being prescribed, will be reasonably consistent, at least within a particular national framework or culture.

However, there is always a further dimension to environmental decision making which is not explicitly addressed in the precautionary principle (although it is implied in the words *cost effective*). In the face of risk and uncertainty decision-makers have always balanced possible negative impacts, and their likelihood, against probable or actual benefits. Where the likely benefits are high, and the possible costs of negative impacts low, decision makers will be less precautionary; where benefits are limited and costs potentially high they will be more precautionary. This explains national differences in the interpretation of the precautionary principle. Developing countries will tend to put more weight on the benefits and less on the risk, especially where the impacts relate to intangible or non-limiting (at least in the short term) environmental goods and services.

The European Commission, in its communication on the precautionary principle[22] qualifies the measures that may be taken under the principle. It proposes five “guidelines” which should lead to rational and transparent application of the principle. These include:

1. **Proportionality**: "Measures...must not be disproportionate to the desired level of protection and must not aim at zero risk"
2. **Non-discrimination**: "comparable situations should not be treated differently and... different situations should not be treated in the same way, unless there are objective grounds for doing so."
3. **Consistency**: "measures...should be comparable in nature and scope with measures already taken in equivalent areas in which all the scientific data are available."
4. **Examination of the benefits and costs of action or lack of action**: "This examination should include an economic cost/benefit analysis when this is appropriate and feasible. However, other analysis methods...may also be relevant"
5. **Examination of scientific developments**: "The measures must be of a provisional nature pending the availability of more reliable scientific data"... "scientific research shall be continued with a view to obtaining more complete data."

In practice this balancing of benefits and costs (as in 4 above), which has always been done explicitly or implicitly in development decision making, has tended to favour development at the cost of the environment. Indeed, it is this imbalance which the precautionary principle is designed to shift. However, only the most extreme would argue that this balance should not be taken into account in the application of the principle, albeit with the fulcrum shifted in favour of precaution. A court may convict a criminal, but impose no sentence, in the light of mitigating circumstances. There are measurable risks associated with vaccination, but most would rather accept these risks because they are perceived to be outweighed by the benefits. Invoking the precautionary principle is unlikely to change many such decisions; but it does imply that we need to be generally more cautious, especially when levels of ignorance and uncertainty are high. In essence we need to make a more informed assessment of risk and place more weight on ignorance and uncertainty as part of

[22] European Commission Press Release IP/00/96, 2nd February 2000 and related commentary.

this assessment. This implies significant cost in the short term; although if applied correctly it should result in long-term savings and benefits.

The principle has also given rise to debate over the role of science in decision making. Some scientists suggest that the principle is incompatible with science based decision making, since science can never prove a negative. Some environmentalists argue that it should supersede conventional scientific risk assessment, since the process lacks transparency, and neither fully admits nor puts sufficient weight on uncertainty and ignorance.

In practice this is a false dichotomy. Rational precautionary decision making can only be based on evidence provided by good science. But it must be recognised that science cannot provide all the information required for decision making; and decision making in an uncertain world is not itself a scientific process. Science should serve decision making; and the precautionary principle requires that it characterise and communicate the nature of risk and uncertainty more effectively. But this is not enough. Scientific assessment must feed into a more transparent and accountable decision making process that explicitly addresses risk and uncertainty, and sets precaution at a level compatible with international agreements and local needs.

This contribution to the decision-making process may better be described as Risk *Analysis* as this implies less judgement. The tendency for conventional risk assessment to prejudge the risk preferences of stakeholders or the public and go beyond the science into the decision making, has probably been a significant factor leading to its current bad press with many environmental groups.

In the next section we examine how far we can improve the analysis, characterisation, and communication of risk and uncertainty.

5 THE NATURE OF RISK AND UNCERTAINTY

We constantly make risk assessments in our daily lives. We take responsibility for our actions, however mundane, based upon an assessment of the likely dangers and outcomes. When making the assessment we are able to consider simple measures to reduce risk, and where we deem it necessary, alter our actions to minimise unnecessary risk.

When selecting a place to cross the road, our assessment may be influenced by the weight of traffic, the distance to a crossing point, our own mobility, our field of vision and in many cases, past experience. This process is a relatively complicated one, but one which we are able to do intuitively with little or no conscious thought. An individual's willingness to accept a certain risk threshold means that the resulting decision is likely to vary from person to person and we may find ourselves crossing alone. Similarly, the application of the precautionary approach is likely to vary according to culture and circumstance. It has to be agreed. It cannot be defined scientifically.

In other situations, the scale and number of factors influencing the assessment add to the degree of uncertainty. All else being equal, higher levels of uncertainty correspond to higher levels of risk, and influence our decisions accordingly. It is in the treatment of uncertainty and ignorance that traditional approaches to risk assessment have fallen down. Although uncertainty has usually been addressed – and is explicitly addressed in classic environmental risk assessment - its nature and importance are not always effectively communicated. And in EIA uncertainty is frequently lost or disguised in the calculations relating to the extent, significance and probability or likelihood of an impact. Since uncertainty is a major feature of many impacts on the natural environment, and since uncertainty is fundamentally different from probability, this is a major weakness.

There are two possible responses to this weakness: to quantify uncertainty more explicitly and rigorously in the EIA or risk assessment process; or to separate out uncertainty as something which should be treated subjectively rather than “forcing” it into an objective, and if possible numeric framework.

5.1 Risk objectivism versus risk subjectivism

The task of quantifying uncertainties in order to increase confidence in the risk assessment process can loosely be described as risk objectivism. This approach asserts that risk is omnipresent and mathematically measurable. Such probabilistic concepts are now well established in law and regulatory policy (Thompson, 1985[23]). Placing quantitative values on all variables and uncertainties enables objectivism to place a supposedly meaningful value on risk almost regardless of the situation. This enables risk managers to calculate willingness to take risks according to strict value criteria, and should, in theory, lead to consistent results.

The problem is that our concern about risk principally relates to uncertainty. This concern is inevitably greatest when confronted by events about which we are ignorant and for which it is difficult to assign meaningful probabilities. It can be reassuring in such situations to assign quantitative values in an attempt to eliminate uncertainty and reduce complexity. But is this practice placing faith in false gods[24].

[23] Thompson, P. B.(1985). Risk Objectivism and Risk Subjectivism: When are Risks Real? *Risk* **1**.3 (http://www.fplc.edu/risk/vol1/winter/thompson.htm)

[24] Thompson op cit

The fundamental question facing this objective approach to risk assessment is whether everything can be defined according to cause and effect and indeed, whether it is possible to assign consistent values for all uncertainties and variables.

Our willingness to judge is directly related to both the availability and credibility of our information. In situations where data is lacking an objective risk assessment is compromised. Uncertainty, by its very nature, cannot always be measured, and there are few clear conventions as to how it should be described. In such situations, the decision-maker may be forced to use subjectivism in their assessment of risk and allow perception, confidence and past experience to influence their decision.

The obvious weakness of this subjective approach is that the conclusions will be based upon personal reaction rather than scientific enquiry. If the risk assessment is based upon the subjective view of the risk analyst then this approach is fundamentally devalued. If the subjective assessment is made by an executive decision-maker, then he/she is assuming certain values on the part of those who might be affected by the decision. This may be acceptable if the decision-maker has some means of synthesising those values. In practice, politicians who are accountable to affected stakeholders normally take decisions relating to social values.

It is clear that we need both objectivism and subjectivism, but we need to clearly separate the two. Risk analysis must generate a comprehensive, objective and accessible description of the risk. Numbers, values, probabilities etc should be generated as far as possible. Uncertainties should be flagged up and clearly explained. The nature of trade-offs should be analysed comprehensively. But there should be no subjective assessment of the desirability or otherwise of these trade-offs by purely technical analysts. Such an assessment is necessarily subjective, and the more so when associated with high degrees of uncertainty.

The objective assessment must then feed into a subjective assessment and decision making process. This will be discussed further in later sections, but requires at minimum some means for the synthesis of perceptions and values relating to the risks at hand, or transparency and accountability on the part of decision-makers.

Whatever the subjective assessment and decision making procedure might be it is essential that objective risk analysis underpin it. This implies improved measurement and/or description of the nature of the risks and uncertainties.

5.2 The measurement or quantification of risk and uncertainty

There is still no universal method for communicating the level of uncertainty or risk and the method chosen will often depend upon the technical sophistication of the communicating parties (Caddy and Mahon, 1995[25]). A variety of tools are available to measure risk. Typically these are based on an estimation of the probability of a particular effect arising as a result of a particular action or cause. In more complex cases a probability distribution may be generated. Depending on the kind of data available, Bayesian analysis may be required to assign appropriate probabilities. These probabilities may be derived from experimental studies, from surveys, from time series data, or (more subjectively) by expert panels.

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[25] Caddy, J. F. & Mahon, R. (1995). Reference points for fisheries management. *FAO Fisheries Technical Paper. No. 347*. Rome.

In practice there is usually a chain of effects arising from a particular action. In this case multiplying probabilities down the chain may generate the probability of any particular effect, or the final effect. The problem with this is that any uncertainty associated with the probability of an individual link should also be multiplied down the chain. Uncertainty therefore increases exponentially as the number of links increases. While physical environmental effects may comprise only a few cause and effect links, and the probability associated with the final effect may be estimated with reasonable confidence, biological and ecological effects, especially in coastal systems, are typically generated through highly complex chains and networks of cause and effect relationships. The uncertainty associated with any probability estimate of an ecological effect is therefore typically very high.

The importance of uncertainty along the chain of effects can be illustrated by considering some of the key types of uncertainty. Measurement causes uncertainty due to inaccuracies in data collection. The natural variations of the process being observed may render observations inaccurate and add to uncertainty. Any attempts at modelling perhaps as part of an ERA process add further uncertainty due to the limitations of a best-fit interpretation. Finally, implementation and in particular the ability to match strategy with action adds to the uncertainty of impact[26].

So can the level of uncertainty be measured in any meaningful way? Scientists use *confidence limits*, and confidence limits are calculated from probability distributions. To generate a probability distribution for all the links in a typical environmental impact chain is likely to be unrealistic. Where this is possible confidence limits will in any case be wide for most ecological effects for the reasons given above (multiplication of uncertainty down the chain).

This has implications for the application of the precautionary principle. If we are to be more cautious in the face of uncertainty, and if most ecological effects are uncertain by their very nature, then we should avoid actions or developments that might generate these effects. Furthermore, even intense scientific study is unlikely to reduce uncertainty to low levels.

In practice however, uncertainty is only one of a range of factors that must be given due weight in decision making; and this is implicit in the wording of the Rio expression of the precautionary principle. This includes the qualifiers *serious or irreversible*, and *cost-effective.* It is notable that these qualifiers – essential if the application of the principle is not to be used arbitrarily to prevent any new development – are dropped from the definition used by Greenpeace and the "Wingspread"[27] group.

However it is interpreted, a precondition for consistent application of the precautionary principle is some standard procedure, framework or checklist for impact assessment, the characterisation of associated risks and uncertainties, and their communication . Existing relevant frameworks relating to risks and impacts include Environmental Impact Assessment (EIA), Environmental Risk Assessment (ERA). Broader techniques for decision-making drawing on the outputs from such studies include Cost Benefit Analysis (CBA) and Multi-criteria Decision Analysis (MCDA).

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[26] Caddy & Mahon 1995 op cit
[27] Wingspread Statement op cit

6 FRAMEWORKS FOR RISK ASSESSMENT

There are many different approaches to assessing environmental impacts and their associated risks. The most commonly used approaches in developed countries include:

- Environmental impact assessment (EIA);
- Environmental risk assessment (ERA);
- Cost benefit analysis (CBA);
- Multi-criteria decision analysis (MCDA).

We review these briefly below, particularly with regard to their approach to risk and uncertainty.

6.1 Definitions

There is much ambiguity in the common usage of the terms risk and hazard. There is also an increasing technical terminology related to different aspects of environmental risk analysis and assessment. A presentation of the most commonly used terms is provided in Annex 1.

6.2 Environmental Impact Assessment (EIA)

EIA is:

> *"the systematic, reproducible and interdisciplinary identification, prediction and evaluation, mitigation and management of impacts from a proposed development and its reasonable alternatives." (UNEP, 1996[28])*

Comprehensive guidelines for the application of EIA to coastal aquaculture have recently been developed (Hambrey et al. 2000[29]) building on widely accepted general frameworks for EIA. It is inappropriate to review the whole process here, but it is informative to examine the conventions for addressing the nature of environmental impacts and associated risks.

Impact identification in EIA is typically based on the use of checklists, matrices, networks and overlays, including GIS. Environmental specialists in consultation with industry specialists normally formulate these tools. The main types of impact considered include:

- effects on human health, well-being, environmental media, ecosystems and agriculture;
- effects on climate and the atmosphere;
- use of natural resources (regenerative and mineral);
- utilisation and disposal of residues and wastes; and

[28] UNEP, 1996. Environmental impact assessment training resource manual. Prepared for the United Nations Environment Programme by the Environment Protection Agency, Canberra, Australia under the guidance and technical support of the UNEP International Working Group on EIA. Nairobi, UNEP and Canberra, Australian Environment Protection Agency. 699 pp.

[29] Hambrey, J B; Phillips, M.; Chowdhury, M A K.; and Shivappa, R B. 2000. Guidelines for the environmental assessment of coastal aquaculture development. The secretariat for Eastern African Coastal Area Management, Maputo, Mozambique. See also: GESAMP, 2001; 1997; 1996; 1991. Barg, 1992.

- resettlement, archaeological sites, landscape, monuments and social consequences as well as upstream, downstream and trans-boundary effects.

Identified impacts are then analysed in three stages:

1. characterisation;
2. quantification and prediction; and
3. assigning significance

Impact characteristics are described in terms of:

- **nature** (positive, negative, direct, indirect, cumulative, synergistic with others);
- **magnitude**;
- **extent/location** (area/volume covered, distribution; local, regional, global effect);
- **timing** (during construction, operation, decommissioning, immediate, delayed, rate of change);
- **duration** (short term, long term, intermittent, continuous);
- **reversibility/irreversibility**; and
- **likelihood** (risk, uncertainty or confidence in the prediction);

In practice several of these, and particularly the last, overlap with quantification and prediction and are explored in parallel.

Impact prediction draws on a variety of methods including:

- professional judgement;
- quantitative mathematical models;
- experiments, physical models; and
- case studies

In all cases there will be some degree of uncertainty associated with the predictions or extrapolations, and this must be described, measured if possible, and taken into account in assigning significance.

Assigning significance is a largely subjective process, drawing on a synthesis of the above analysis. Logically, significance can only be described in relative terms, *and some agreed standard or baseline* (based on science, instinct or precedence) is required if it is to have any meaning, utility, or consistency. In practice such a baseline is often absent, and the assessment of significance depends on the knowledge, values and analytic ability of the EIA practitioner, or in some unfortunate cases, the company commissioning the EIA. In order to minimise the chances of bias, the analysis must be clearly and simply presented and independently reviewed. This is a major challenge when dealing with complex and in some cases hypothetical environmental impacts.

Does EIA tend to under-play uncertainty?

It is arguable that in the past, many EIA's have been weak on characterising impacts in terms of their likelihood, and in terms of the uncertainty associated with the predictions. As noted elsewhere there is typically very high and often unquantifiable uncertainty associated with many environmental and ecological impacts. In practice, it is probable that the true level of uncertainty is rarely emphasised in EIAs for professional reasons. EIA specialists are paid well to make impact predictions. Few developers or decision-makers want to hear a series of “don’t knows" from the experts.

Against this weakness should be set the clear precautionary requirement in best practice EIA. This requires the process to generate an environmental management plan, which, in addition to putting in place measures to minimise possible impacts, also prescribes a monitoring regime and response procedures in respect of possible but uncertain impacts.

It is clear that more attention needs to be paid to risk and uncertainty within the EIA process. A formal framework for risk assessment is already in wide use – environmental (ecological) risk assessment or ERA. It is arguable that ERA should be an explicit and significant component in EIA.

Other weaknesses

EIA is normally undertaken at farm level, and therefore cannot effectively address cumulative and wider environmental issues, such as nutrient enrichment and interactions with wild species. These need to be addressed at a higher strategic level. While this has been recognised for many years, and strategic, regional or sector level environmental assessment recommended, this is rarely undertaken in practice.

6.3 Environmental Risk Assessment (ERA)

Environmental Risk Assessment, or Ecological Risk Assessment, is a process for evaluating the likelihood of adverse environmental effects occurring as a result of one or more environmental stressors, usually of anthropogenic origin (Asante-Duah, 1998; Benjamin and Belluck, 2001[30]). All available data is collated and where necessary more data is assembled to help predict the relationship between stressors and ecological effects. To date the process has been applied mainly to the in depth examination of the effects of specific chemicals on soils, aquatic systems and atmospheric systems. It may form a part of an EIA or be undertaken separately in respect of specific chemicals.

The ERA process can be divided into three phases: problem formulation, problem analysis and risk characterisation. The problem analysis stage can be further sub-divided into 2 distinct sections: characterisation of exposure and characterisation of effect. This means, at least for descriptive purposes, that the risk assessment process has 4 fundamental elements as illustrated in Fig.4.

In spite of this clear indication of the process form, the assessment should be iterative. Information that is obtained at a later stage in the process may force a reassessment of an earlier step. In particular discoveries during the analysis stage may encourage a shift in emphasis in the originally determined endpoints. Rather than being considered a failure of initial planning, this constant reassessment enables the environmental risk assessment to be a dynamic process well suited to ecological study.

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[30] Asante-Duah, D. K.(1998). Risk Assessment in Environmental Management: a guide for managing chemical contamination problems. *Publ*: Wiley, Chichester; Benjamin, S. & Belluck, D. (2001). A practical guide to understanding, managing and reviewing environmental risk assessment reports. *Publ*: Boca Raton, Fla; London: Lewis Publishers

A key factor in environmental risk management is determining the scale and nature of potential adversity. Although considering all relevant stressors and variables may complicate the process, add increased uncertainty and potentially reduce the confidence in the findings, it adds greatly to the ability of the process to consider and predict for a wide variety of permutations.

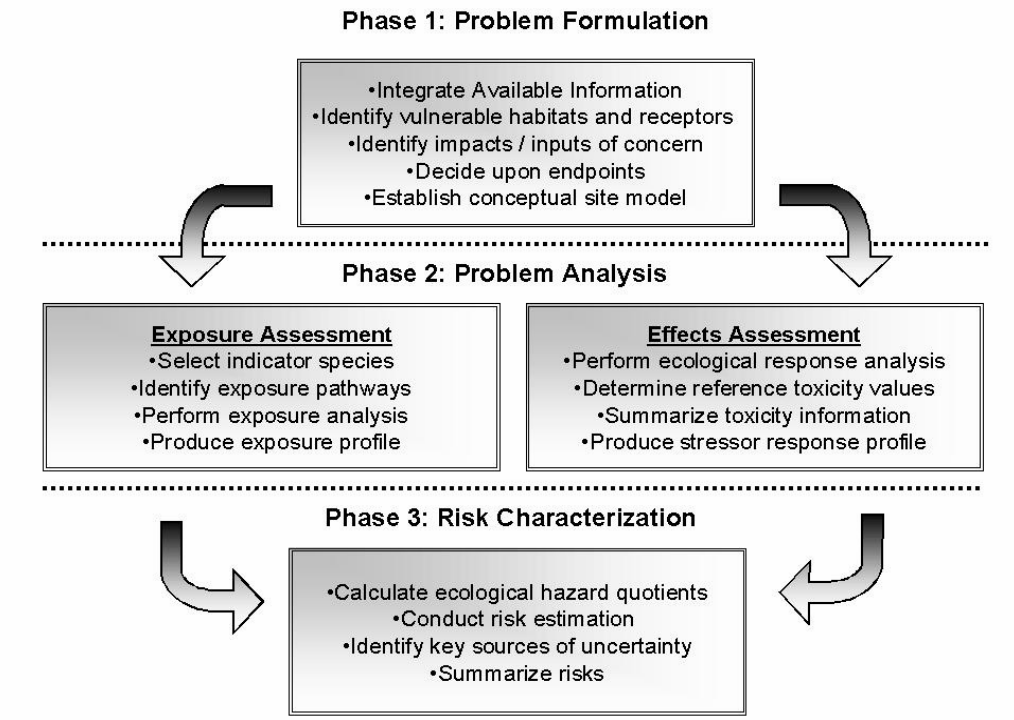

Fig 4: Schematic representation of the ERA process adapted from Asante-Duah (1998).

Adversity is ideally assessed by combining the estimation of exposure with information on the dose-response characteristics (with confidence limits) of key indicator species. The data to generate such curves may be collected experimentally or derived from field survey (ideally both). This then allows for the calculation of a key indicator of adversity and risk: the hazard quotient or ecological risk quotient. This is calculated as the exposure point concentration, or estimated daily dose, divided by the critical ecotoxicity[31].

Determining the nature of adversity can be complicated as detrimental effects to one aspect of the ecosystem may be beneficial to others. A key definition of negative environmental impacts are those which alter important structural or functional aspects of the ecosystem. The scale, intensity and duration of the impact along with the ecosystem's ability to recover will also be incorporated into the adversity calculation. A well designed Environmental Risk Assessment should also able to highlight beneficial changes in the ecosystem brought about by anthropogenic interaction.

Environmental Risk Assessments are also sufficiently robust to interpret future potential risks in historically heavily impacted ecosystems. The process can be used as both a prospective and retrospective tool. This enables risk managers to look at likely causal factors of observed effects as well as predicting the outcome of future actions. This aspect is particularly valuable in the natural world where it is almost

[31] Asante-Duah 1998 op cit

impossible to begin with a 'fresh canvas' with no prior external impacts. The flexibility of the tool also enables consideration of the chronic and catastrophic effects.

It is freely acknowledged by ERA practitioners that many possible impacts can not be assigned quantitative probabilities to comply with the objectivist ideal. The ERA process therefore allows for qualitative description, which should be highlighted in the conclusion. It has even been argued that the strength of an ERA does not lie in its predominantly objective stance, but instead in the way it treats subjective inputs (Hayes, 1998[32]).

The rise in interest in all kinds of risk assessment over recent years is primarily due to its role in informed decision making. Its role is particularly useful where there are substantial variable or uncertainties. Cynics, and in particular many environmental groupings argue that the risk assessment process provides an element of scientific credibility that disguises uncertainty and can be used to add weight to politically motivated decisions. While there is little doubt that the process can be abused, this in no way undermines its strength as a comprehensive framework for assessing impacts, quantifying them as far as possible, and describing the risks, uncertainties and probabilities associated with them.

ERA is designed to provide decision-makers and risk managers with comprehensive information relating to the complex consequences of actions in advance of any changes, and the trade-offs between different courses of action. It should therefore be a basic tool to inform the process of precautionary decision making. In light of the discussion in section 5 however, it may be appropriate to consider renaming the process of risk analysis, and shifting the emphasis from assessment to the provision of objective information to feed into a more subjective assessment and decision making process.

More detail on the process and methodology of ERA is provided in Annex 3.

6.4 Cost-benefit analysis (CBA)

CBA is a well established tool used in development decision making, principally in relation to large-scale government funded projects. The core of the CBA is the monetary valuation of the costs and benefits associated with a development, so that a benefit/cost ratio can be generated. The assumption is that a ratio greater than one suggests that the project is desirable.

The scope of CBA, in terms of the costs and benefits that it takes into account, is very variable. Increasingly, environmental costs and benefits are included, drawing on the tools associated with environmental economics.

In order to contribute to rational precautionary decision making, CBA should build on EIA, risk assessment, and financial and economic analysis to provide information to decision makers on the financial and economic trade-offs between different courses of action. This would allow them to compare these trade-offs with other values and with broader development strategy.

In practice the emphasis is more usually on the generation of simple decision criteria (benefit-cost ratio) to justify a particular course of action. This puts a large portion of

[32] Hayes, K.R. (1998). Ecological risk assessment for ballast water introductions: A suggested approach. *ICES Journal of Marine Science*. **55**, no. 2, 201-212.

the responsibility for the decision in the hands of those conducting the study, since it is typically they who make the subjective assessment of the values of uncertain or non-market costs and benefits. Again, the uncertainty associated with the monetary values generated is rarely emphasised. This uncertainty is typically very high, especially in relation to social and economic costs and benefits.

Cost benefit analysis is rightly termed analysis rather than assessment, but in practice the criticisms that are levelled at ERA – that it disguises subjectivity in highly questionable numbers, and therefore tends to prejudge what are essentially subjective issues – are also valid. Issues relating to uncertainty need to be given far more emphasis and explained with clarity, so that they can be fully taken into account within an improved precautionary decision making process.

6.5 International Commission on Radiological Protection (ICRP) Principles

Risk is a major issue for human health as it relates to environmental and food safety issues. Much work has been done in this area, and it is worth introducing 3 interactive concepts or principles used in protecting human health against ionizing radiation (ICRP principles[33]). These principles are relevant to any assessment and decision making framework related to environmental risks. They have, for example, been applied to waste management (see GESAMP, 1991b)

1. '*Justification'* states that no practice should be adopted by society unless it can be shown that the benefits outweigh the detrimental effects;
2. *'Optimization'* states that any 'exposures' (in a broad sense) should be kept as low as reasonably achievable;
3. *'Compliance'* requires the setting of exposure limits (or standards) which should not be exceeded. There is no reason why similar concepts should not be applied to the development and management of coastal aquaculture (GESAMP has already applied it to waste management. See Reports & Studies No.45 (GESAMP, 1991b).

Justification corresponds to thorough cost benefit analysis as described above. Optimisation is a universal common sense principle applicable to any activity. Compliance is a key element in any environmental management system (as described in section 8.2.). The principles however do not offer any guidance as to where or how to set precautionary limits (e.g. with regard to compliance standards).

6.6 Multi-criteria decision analysis (MCDA)

This approach is specifically designed to explore trade-offs and consider development options against different criteria. It may also be used explicitly to take account of different perspectives relating to subjective issues, risk and uncertainty. It bridges the gap between analysis (which should be a routine technical process) and precautionary decision making (which is subjective and political).

The core process of MCDA consists of:

1. Establish the decision context;

[33] ICRP 1977. Recommendations of the International Commission on Radiological Protection, ICRP, Publication No.26. Annals of the ICRP, Vol.1 No.3, Pergamon Press, Oxford.

2. Identify the options to be appraised;
3. Agree objectives and associated criteria;
4. Score the performance of each option against the criteria;
5. Assign weights to each criterion to reflect their relative importance;
6. Combine weights and score to generate an overall value;
7. Examine and discuss the results and adjust as agreed.

MCDA can be undertaken in workshops of representatives of different interests and technical specialisms, or it can be undertaken using questionnaires sent to a representative sample of the population. Relatively sophisticated statistical techniques have been devised to generate weights and assign preferences.

It is used increasingly for environmental planning and management in different parts of the world but generally on a small scale. For it to work in an informed way however, it needs the kind of information generated by SEA, EIA, ERA, CBA etc to be effectively communicated to all those involved. It also needs to be brought within an agreed strategic framework if it is to generate consistent decisions.

MCDA and its variants have been widely described (UK-DTLR, 2000[34]; Rios, 1994; Lootsma, 1999[35]).

6.7 Strengths and Weaknesses of these approaches

EIA and its variants, ERA, and CBA all address important dimensions of decision making under conditions of uncertainty. They generate vital information on the nature of the trade-offs associated with development decisions. In some cases however, they underplay uncertainty and introduce subjective valuation in a manner lacking transparency and accountability. In other words, they go beyond technical analysis into subjective assessment and “pre”-decision making. Since precaution is fundamentally subjective this is a major weakness.

In order to be more useful and effective, these techniques need to place far greater emphasis on risk and uncertainty, and greatly improve the presentation and communication of information, so that the various risks and trade-offs can be fully appreciated by decision makers.

In parallel with this there is a need to establish precautionary decision making and environmental management systems into which information on social and environmental effects, associated risks, and costs and benefits can be fed. The subjective values associated with precaution should only be introduced at this more transparent and accountable stage.

These issues are dealt with in the next two sections.

7 PRESENTING AND COMMUNICATING RISK INFORMATION

In the past ERA (and to some extent EIA) has been a rather technical process with the outputs couched in technical language, and with more emphasis on modelling and probabilistic impact prediction than on uncertainty and confidence limits.

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[34] UK Department of Transport and the Regions 2000. Multi-criteria analysis: a manual. http://www.dtlr.gov.uk/about/multicriteria/index.htm
Rios, S., 1994. Decision theory and decision analysis: trends and challenges. Dordrecht, Kluwer Academic Publishers Group, 312 pp.
[35] Lootsma, F. A., (1999). Multi-criteria decision analysis via ratio and difference judgement: applied optimization. Dordrecht, Kluwer Academic Publishers Group,P300 pp.

7.1 Basic information

We suggest that the characterisation of impacts and impact significance in EIA and ERA should be extended specifically to highlight risk and uncertainty issues, and should include the following:

1. Description, and where possible, modelling of the impact chain;
2. For each link in the chain:
    - Quantification of effect (dilution/concentration; dispersal; degradation; transformation; reaction; assimilation);
    - Probability associated with the effect(s);
    - Uncertainty associated with effects (probability distribution/confidence limits; where this is not possible an explanation of inability to define confidence limits (e.g. ignorance; complexity);
3. In respect of final effects (impacts): the overall probability, and cumulative uncertainty (i.e. multiplication of uncertainties down the chain);
4. A broad subjective description of the nature of uncertainty associated with the final impacts;
5. The likely costs of research to reduce uncertainty significantly in respect of each link in the chain;
6. The likely costs of research to reduce uncertainty significantly in respect of final impacts.

While 1, 2 and perhaps 4 are common to best practice ERAs and EIAs, the nature of the uncertainties are often not made clear. It is rare to find 3, 5 and 6.

7.2 The dimensions of risk

It is recognised that there is still no universally accepted version of the precautionary principle. Graduated systems of precaution have been proposed as a way of promoting rational and universal adoption of the principle. Levels of application for the precautionary principle have been proposed which tie in with the level of risk, irreversibility and uncertainty. For, example, where there is serious risk of irreversible impacts and the level of uncertainty is high a strict interpretation of the precautionary principle should be adopted. Whereas if there is a small risk of impacts which are not serious or irreversible and there is limited uncertainty, precaution could be replaced by more traditional cost benefit analysis[36].

Pearsons and Hopley (1999[37]) propose a precautionary matrix that summarises the risk and uncertainty characteristics of environmental effects, and offers some guidance on the degree of precaution required. This matrix divides levels of precaution depending upon the level of risk and uncertainty.

LEVELS OF CAUTION:	Low Risk	High Risk
Low Uncertainty	*Low*	*Very High*

[36] FAO (1996b) Precautionary approach to fisheries. Part 2: Scientific papers. Prepared for technical consultation on the precautionary approach to capture fisheries (including species introductions) *FAO Fisheries Technical Paper No. 350, Part 2*. Rome.

[37] Pearsons, T. N. & Hopley, C. W.(1999). A practical approach for assessing ecological risks associated with fish stocking programs. Fisheries. v.24, no. 9, pp 16-23.

High Uncertainty	*Medium*	*High*

The level of caution will then form the basis for deciding upon appropriate management measures. In short, the greater the level of caution, the greater the need for further works. This may target toward further data analysis to reduce uncertainty, or toward adoption of minimisation strategies to reduce the consequences of adverse events.

Level of caution (See above)	Need for further uncertainty resolution	Need for Risk minimisation Strategies	Need for Risk Containment Monitoring	Proposed Action
Low	*None*	*None*	*Low*	*Proceed*
Medium	*Some*	*Some*	*Moderate*	*Proceed with Caution*
High	*Much*	*Moderate*	*High*	*Risk containment and minimisation, then re-review*
Very High	*Little*	*Extensive*	*High*	*Risk containment and minimisation, then re-review*

7.3 Software packages

There are many new software packages on the market which allow for a comprehensive synthesis and presentation of risk and uncertainty. In many cases these are specifically designed to allow for user friendly interrogation in relation to specific links in the effects chain, issues of probability, uncertainty, and the nature of impacts. There is little doubt that these are powerful tools, and if used well could facilitate more open, transparent and participatory approaches to environmental decision making.

7.4 Software Solutions

There have been increasing attempts by software manufactures over the last few years to develop model tools for the conduct of environmental risk assessments. The ERA theoretical model is very well suited to software interpretations as the flexibility that is inherent in a successful process means that manual calculations would be highly complicated and prone to mistake. By incorporating all available information into a software model the effects of adjustments in input parameters can instantly be calculated.

One of the great attractions of the software tools that carry out the risk assessment procedures is their clear visualisation of the scenario. Undoubtedly in a management decision context it can be useful to see visual representations of the site and the potential impacts. If the effect of impacts can be clearly visualised, this can be helpful but can also be misleading. Just as things are taken as being true if they are seen printed in black and white, so a visual representation may tempt managers to ignore uncertainties and ranges in confidence that are highlighted elsewhere.

7.4.1 Potential for Application in Aquaculture

Good ERA software tools already exist for the air dispersion of chemicals. Aquaculture is very well suited for the adaptation of existing software formats for the marine environment. Aquaculture occurs in the marine environment that is characterised by relatively predictable hydrodynamics. The influence of tide is likely to be the main hydrodynamic force, although freshwater run-off, heat variations and wind generated turbulence will all effect local hydrodynamics in a less predictable way.

The fact that aquaculture represents a point source of a relatively predictable volume of inputs and effluents means that it can usefully be super-imposed onto this hydrodynamic model. The model must be relatively complex to deal with a wide variety of diffuse inputs and possible impacts; however recent models suggest that this is well within the realms of possibility. Simple hydrodynamic models already exist for predicting sediment effects, and these could be incorporated in ERA software.

From a management point of view a software solution to the ERA question may be particularly useful. Aquaculture is far from a uniform industry. Even within one production species there is a wide variety of scales, using many different production techniques in some dramatically different locations. An ERA software tool would facilitate exploration of the environmental risks of a wide variety of management options that may be in discussion at the planning and development stage.

8 ENVIRONMENTAL DECISION MAKING AND MANAGEMENT SYSTEMS

EIA and ERA do not make decisions regarding appropriate course of action for ecosystem remediation or effect minimisation, nor should these processes propose a single solution to an environmental problem. A well designed EIA or ERA will provide comprehensive quantified (as far as possible) and qualified (where necessary) information about the potential adverse environmental effect and associated risks of alternative management decisions on the receiving ecosystem (USEPA, 1998[38]). Environmental risk management on the other hand describes what we do with this information. According to the EU (CEC, 2000[39]), 'risk management' means the process, distinct from risk assessment, of weighing policy alternatives in consultation with interested parties, considering risk assessment and other legitimate factors, and, if need be, selecting appropriate prevention and control options" (See also Annex 1). Political, economic, social and legal factors will all have their place in environmental decision making and management. It is at this point that the precautionary principle can be invoked; and it can only be sensibly and consistently implemented if the nature of the impacts and their associated risks, cost and benefits have been comprehensively described in an EIA and/or ERA and or CBA.

The rigorous use of these tools to underpin environmental risk management will not however guarantee consistency in decision making. Attitudes to risk, the value of resources, the need for development and a range of cultural factors will, quite rightly, affect the decision and the level of precaution. However, their use should make decision making *more* consistent, well informed, and more transparent. *Adoption of the precautionary principle does not proscribe particular decisions, but it does oblige decision-makers to justify their assessment of risk and the trade-offs they have made.*

In practice frameworks for environmental risk management are weak in most countries, and tend to be reactive rather than strategic.

8.1 Conventional approaches

Decisions affecting, or in response to environmental issues are typically based on one or other of the following procedures:

Strategic planning sets down the basic objectives, procedures and presumptions with regard to development activity. To date this has been relatively weak in terms of environmental planning and management except for e.g. national parks and/or special conservation areas;

Consent and regulation. Most existing environmental risk management is based on project level EIA, ERA, or standard environmental risk criteria (such as effluent composition and concentration) feeding into some form of consenting and regulatory framework. This is typically technically driven with decisions commonly made by

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[38] US Environmental Protection Agency (1998).Guidelines for Ecological Risk Assessment. USEPA, Washington DC

[39] CEC (Commission of the European Communities), 2000. Proposal for a Regulation of the European Parliament and of the Council laying down the general principles and requirements of food law, establishing the European Food Authority, and laying down procedures in matters of food (presented by the Commission). Brussels, 8.11.2000. COM(2000) 716 final 2000/0286 (COD). 86 p.

technical specialists (e.g. staff of environmental protection agencies). The system is relatively efficient and straightforward, and works well when clear criteria have been established, and where these are based on sound science with limited uncertainty. When sound science is not available, decision making tends to be based on the risk profile and subjective judgements of technical staff, or decisions are delayed in favour of reactive monitor-respond strategies discussed in section 4, with their significant limitations, especially with respect to aquaculture impacts.

In most cases strategic environmental management systems are non-existent or inadequate, and risk and uncertainty is given very little public airing.

In recent years there has been much interest in more strategic environmental planning and management, exemplified in the processes of strategic environmental assessment and/or integrated coastal/watershed management.

Sector/strategic/integrated environmental assessment (SEA). This requires the strategic assessment of a set of development options, either for a sector or for several sectors within a defined area. The objective here is to look at the full range of environmental issues and develop a broad development strategy and environmental management plan. Widely promoted yet rarely implemented. Although costly (typically to the public purse) such assessments should form the starting point for the strategic planning and management initiatives, and reduce the need for, and/or increase the utility of, the specific tools described in section 6.

Integrated Watershed/River basin/Coastal zone planning and management. The ideal form of integrated planning from an environmental perspective, but very ambitious, and with limited successful implementation to date. Perhaps the best examples come from the USA, Australia and New Zealand [40].

There is little doubt that these more strategic and integrated approaches, at whatever level, are vital if the environmental management of aquaculture is to be improved. But they must feed into, or generate, an environmental decision making and *management system* if they are to have long term impact. They also need to incorporate some formal means to address issues of risk and uncertainty – and specifically to make the subjective assessments necessary for the reasonable implementation of the precautionary approach.

8.2 Environmental management systems

Strategic environmental planning and management systems are essential preconditions for effective utilisation of the kind of information and opinion generated by the tools (EIA/ERA/CBA) described in section 6. Risk, uncertainty, impact significance are all key concepts in environmental management and the application of the precautionary principle, but they are largely subjective, and have little meaning in the absence of agreed environmental objectives, standards and baselines, and broad environmental management strategy. As noted above, the precautionary principle itself is not, and cannot logically serve as, a decision criterion. It requires local interpretation, and this interpretation, and plans for its implementation, need to be agreed and articulated so that compliance can be demonstrated to the international community.

The main elements in such management systems, whether they be applied to a sector within a defined area (such as coastal aquaculture on the West Coast of

[40] See GESAMP 2001 op. cit. for further discussion and examples.

Scotland) or more ambitiously (as in integrated coastal management) to all sectors are shown in Figure 5. This makes clear the central point: EIA, ERA, CBA etc are not environmental decision making or management processes, rather they should serve to inform such a process.

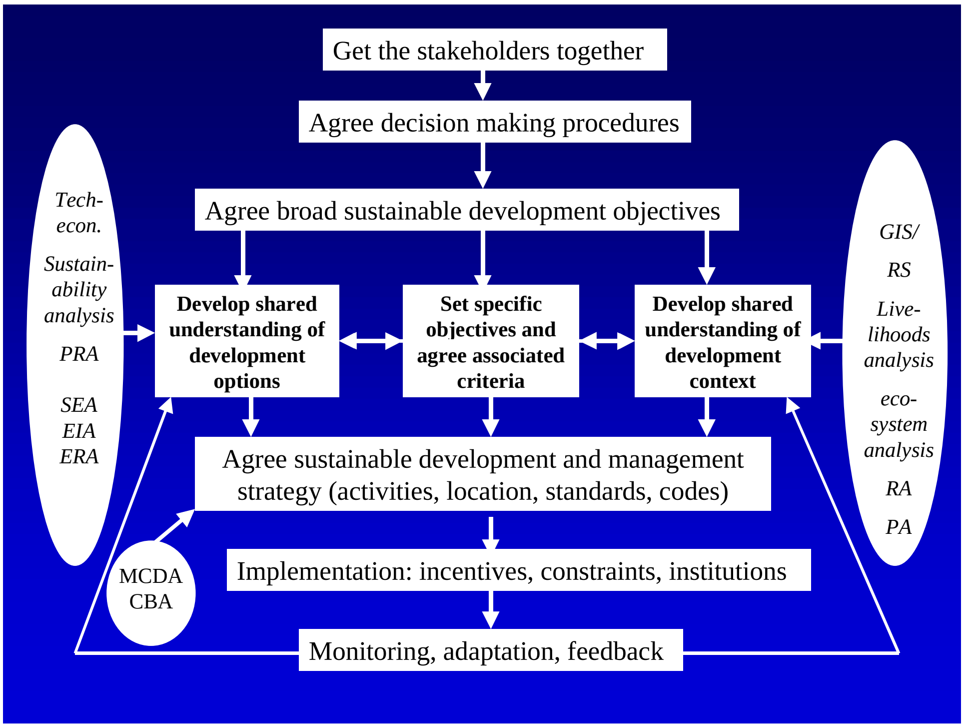

Fig. 5: The main elements in strategic environmental planning and management systems.

The procedures and standards for the application of the precautionary principle would be agreed at the fourth and fifth stages (set objectives, associated criteria and agree strategy). The strategy might include, for example, procedures to identify and avoid or manage at acceptable levels:

- known and predictable risks;
- uncertain and/or unpredictable but potentially serious risks

In the case of the latter it might (for example) be decided that either:

- development/activity is constrained until better information is available; or
- development activity is allowed with 'Best Available Techniques That do Not entail Excessive Economic Costs' (BATNEEC) and effective and precautionary monitoring and response procedures. This implies that limits of environmental change would be set well below those known to cause harmful effects and that benefits can be demonstrated to significantly outweigh the costs of the worst case scenario.

Procedures for interpreting words like serious, significant and excessive would be agreed across major stakeholders. Standards and formats for individual EIA, ERA etc would be set, including, for example comprehensive description and communication of risk and uncertainty issues.

8.3 Key requirements for more consistent and effective application of the precautionary principle

In summary, the key ingredients for more consistent and effective application of the precautionary principle are:

1. The right information:

    - Thorough review of environmental management issues relating to a sector, an aquatic system (watershed/river basin/coastal zone), or a local planning area (SEA);
    - Detailed analysis of risk and uncertainty relating to different activities and their environmental impact (ERA/EIA);

2. Effective dissemination and unbiased communication of key issues;
3. An environmental management system which draws on this information and the informed opinion and values of stakeholders to generate agreed strategy and environmental management procedures;
4. Effective monitoring and precautionary response procedures, preferably covering all activities which might contribute to future environmental problems.

9 RISK ASSESSMENT IN PRACTICE FOR COASTAL AQUACULTURE

In this section we examine in more detail some of the environmental impacts associated with coastal aquaculture in order to understand the nature of the risks and how these might be assessed, characterised and communicated. We also examine how the nature of these risks demands particular approaches to decision making and environmental management. Specifically, we explore the case for precaution, and the possible nature of that precaution, in view of international commitments to the precautionary principle.

Cage culture of salmon is used here as a topical example. Several groups have called on the authorities to impose a moratorium on salmon farming, justifying this by recourse to the precautionary principle.

Actual and potential impacts of salmon cage culture are illustrated in Figure 6.

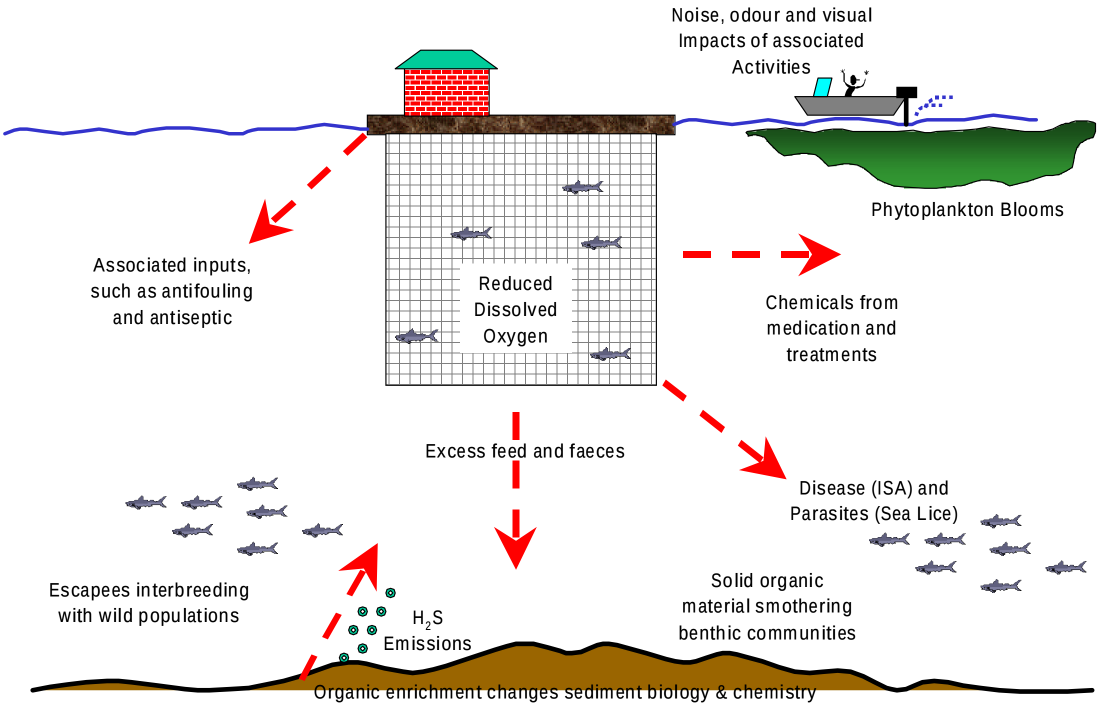

Fig 6: Main pathways associated with cage salmonid culture

9.1 Risks associated with waste food and faeces

9.1.1 Settling solids

Food and faecal wastes have direct impacts in terms of smothering the seabed below cages. This causes the following local changes:

- changes in physical nature of sediment;

- locally reduced dissolved oxygen related to organic matter oxidation;
- where accumulation is significant, gas emissions resulting from anaerobic decay;
- re-suspension of some sediments;
- changes in the flora and fauna associated with the changes in the sediment;
- nutrient release from degrading organic matter.

Some wastes will remain in the water column and be distributed depending on water currents and turbulence.

The physical and ecological changes in the seabed below and around the cages can be predicted with reasonable degree of certainty. Models have been developed to predict the pattern of dispersal of sediments (Gowen et al., 1989[41]). Corresponding local changes in flora and fauna can be predicted with reasonable accuracy. For most of these predictions, confidence limits could, in theory, be generated, although this is rarely done in practice.

The costs of making assessments of this kind of direct impact are modest, requiring the use of current meters and simple dispersion modelling software.

Relatively small areas of seabed are affected in this way, and the direct costs of the impacts (to other actual or potential resource users) could be estimated. These costs would be negligible or low in most circumstances. Only where siting was in an area of particular value for other users (e.g. shellfish beds, nursery grounds, and conservation areas) might these costs be significant.

In respect of direct impacts from cage wastes therefore, the impacts can be predicted approximately on the basis of known processes. The accuracy of these predictions can be improved significantly through field survey. The impacts are modest compared with other processes in the marine environment.

On this basis the precautionary principle would probably not require us to curtail salmon farming. Rather, it would require us to set precautionary siting guidelines to avoid possible impacts on other resource users or ecological values. Nor would it require us to undertake the dispersal modelling described above for every new farm, unless there was ambiguity or controversy over the application of the siting guidelines.

9.1.2 Suspended solids in the water column

Not all the solids accumulate below the cages. Some solids are very fine and are transported for large distances. It would be possible to predict the physical impact of these finely dissolved solids at different locations with sophisticated dispersion modelling. This would require substantially more resources than those required in respect of the easily settled solids, but could be done, albeit at substantial cost, and predictions could be made with reasonable accuracy and certainty. However, the ecological impacts of these solids on plankton production and/or community structure communities would be extremely difficult to predict with any degree of certainty. In other words the first (physical) effect link can (in theory) be modelled, but the ecological impact (our main concern) probably could not be. The value of any physical modelling is therefore questionable.

[41] Gowen, R.J. Bradbury, N.B., Brown, J.R., 1989. The use of simple models in assessing two of the interactions between fish farming and the marine environment. In de Pauw, N., Jaspers, E., Ackefors, H., Wilkins, N. (Ed) Aquaculture, a biotechnology in progress. European Aquaculture Society, Bredene, Belgium. pp 1071-1080.

We are left with a high degree of uncertainty, but no empirical evidence of adverse impact, and no theoretical basis for significant negative impact. It is unclear what the precautionary principle demands in this case. More extreme environmentalists might suggest that changes in plankton community structure are potentially serious since they may affect, indirectly, the entire food chain and hence other resource users. Others would argue that impacts are unlikely, and we should therefore base any response on precautionary monitoring. The dilemma is similar to that in respect of dissolved nutrients.

9.1.3 Dissolved nutrients

Dissolved nutrients, mainly nitrogen and phosphorus, are released directly as waste metabolites or indirectly from solid wastes during degradation. Their dispersal and dilution in the environment can be modelled (Aure and Stigebrandt 1990[42]) as for suspended solids, but with rather less certainty. Models would be required not only for dispersal and dilution, but also for the release of nutrients from sediments. It is probable that confidence limits could be developed for both of these, but the costs of establishing *accurate* confidence limits would be very high, and they are likely to be wide in any case (i.e. associated with high uncertainty), especially in open coastal systems.

In practice, analysts to date have tended to use simple mass balance models which calculate average flushing rate coupled with knowledge of nutrient inputs and nutrient removals from the system for semi-enclosed systems such as sea lochs and lagoons. These assume no significant impact on more open and well flushed systems. Confidence limits on these predictions are rarely given, and significant work would be required to generate confidence limits. The main uncertainties will relate to nutrient exchange dynamics between sediment and water column, assimilation and regeneration of nutrients by phytoplankton. However, worst case scenarios (in which all the nutrient ends up as dissolved nutrient in the water column) can be calculated with a high degree of certainty in semi-closed systems, and used as a precautionary basis for impact assessment.

The impact of slight increases in nutrient concentrations, or changes in the nutrient ratios, on phytoplankton communities, seaweeds and other ecosystem components is almost impossible to predict with any degree of confidence. Possible changes or events such as toxic blooms may be associated with changes in nutrient balance, but such changes take place naturally related to upwelling events and other natural phenomena. To generate predictions of these events will require vastly increased knowledge of plankton community dynamics; and it is unclear that research will ever allow us to make such predictions with any degree of accuracy. We are a long way from being able to generate dose-response profiles for plankton communities at the concentrations likely to be associated with coastal aquaculture.

Toxic algae blooms can have serious impacts on other resource users and human health, including death of wild and farmed fish and shellfish, and shellfish products toxic to human beings. The environmental and human costs could therefore be very high.

So does the precautionary principle require us to put a moratorium on finfish farming? This is high risk coupled with high uncertainty, and is therefore a classic example of the need for precaution.

[42] Aure, J., & Stigebrandt, A., 1990. Quantitative estimates of the eutrophication effects of fish farming in fjords. Aquaculture, 90:135-156

Although it is difficult and costly to predict the fate and impact of nutrients from aquaculture on the marine environment, the problem can be turned on its head. What are the overall nature of nutrient dynamics in coastal waters, and what quantities are involved? Nutrients enter coastal waters from up-welling, from run-off from the land, from the atmosphere, and from natural processes of decay within the system. They are taken out through assimilation, adsorbtion in sediments, and flushing (to other systems). In this overall picture, how significant are the quantities associated with salmon farming? And how significant are the quantities associated with other human activities?

It is probable that rough figures for these could be generated by ecologists so that quantities associated with salmon farming and other human activities can be put into context. Current research commissioned by the Scottish Environmental Protection Agency is examining this issue for Scottish waters. If this process shows significant levels, then the precautionary approach would require us to halt further increases until we have a better understanding of the plankton communities, and can generate predictions with reasonable confidence limits. If they are not significant in the wider coastal environment, precautionary monitoring related to individual sites or groups of farms might be an appropriate response.

This particular issue cannot be tackled through conventional EIA. It requires a much broader approach to coastal management, with a significant role for government in funding research and monitoring to ensure that precaution is indeed implemented. Ultimately the objective would be to establish the environmental capacity for specific coastal systems, and then to allocate that capacity in line with development objectives.

9.2 Chemical releases

Many chemicals are used in aquaculture, and these have been subject to much research and in some cases controversy.

Thorough classic risk assessment is the obvious approach to dealing with chemical releases, and indeed is the approach currently used in aquaculture regulation in the UK in respect of consents for chemical use. Impact predictions can be made with reasonable confidence limits. Fairly costly research is required to characterise new chemicals in terms of target or indicator organism dose-response relationships, but this is typically required for any new pharmaceutical product in most developed countries. Since most such products now emanate from, or are used in, developed countries, the necessary data relating to the chemicals is usually available. The problem arises in respect of predicting the effects in the wider environment. Small enterprises may not be able to undertake thorough risk assessment at reasonable (commercially feasible) cost. The industry as a whole, or government, may need to take a role in funding or assisting with such studies, possibly by undertaking generic studies within specific types of aquatic systems, in order to generate guidelines and/or regulations for their wider use, or ban them completely. If industry funded, the research would have to be reviewed by independent or government funded scientists.

9.3 Interactions with wild salmon

Between 1970 and 2000 worldwide catches of Atlantic salmon fell from ca 10,000 tonnes to 3,000 tonnes (ICES/WG NAS 1999[43]). This decline is blamed mostly on ocean climate (Friedland et al., 2000[44]) with the greatest negative impacts on Southern populations. Over fishing, partly related to mixed stock fisheries, has also been blamed, as have interactions with farmed fish. Kjetil Hindar has recently reviewed the issues (Hindar, 2001[45]).

Farmed (and wild colonial) animals and plants are prone to infectious disease outbreaks, and salmon are no exception. It is sometimes argued that large concentrations of farmed salmon result in higher incidence of pathogens in the coastal aquatic system, with negative impacts on wild stocks. The spread of furunculosis (probably from Scottish farmed salmon) in Norwegian farmed salmon and finally to Norwegian wild salmon has been well documented (Johnsen and Jensen, 1994[46]).

A more topical example relates to sea lice, a common parasite of salmon, and a significant problem for salmon farmers. The lice can have direct negative impacts on the salmon if present in sufficient numbers, and have been implicated in the spread of infectious salmon anaemia (ISA) which is deadly to farmed and wild salmon. The opportunity for the spread of this disease was limited in highly dispersed wild populations, but greater concentrations now present along Scottish and Norwegian coasts, possibly facilitate the spread of the disease and increased incidence in wild populations although this probability cannot be quantified and has not been empirically demonstrated.

A second issue relates to the impact of escaped, farmed fish on the breeding performance, genetic integrity, and survival of wild stocks. Possible impacts include the loss of adapted genes; competitive displacement of populations; and homogenisation of a previously structured population. The extent to which these impacts might take place depends on the number of escapes relative to the wild population.

Official estimates of fish escaping from net pens in Norway are in the range of 250,000 to 650,000 per year. Escaped farmed Atlantic salmon make 20-40% of the salmon in the fisheries off the Faeroes and a similar percentage of spawners in Norwegian rivers. In some rivers, 80% of spawners are of farmed origin[47]. Recent experimental studies (Fleming et al., 2000[48]) suggest that the reproductive and early survival success of farmed salmon and their offspring is substantially lower than that of wild salmon (16%) and that reproductive and survival success of the mixed population is depressed relative to pure wild populations. They demonstrate significant genetic flow from farmed to wild salmon, with potentially negative impacts on the overall survival fitness of affected populations. Although hybrid vigour rather than outbreeding depression could in theory result, the limited genetic variation in farmed salmon, and adaptation to farm rather than wild conditions, makes this less probable.

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[43] ICES/WG NAS, 1999. ICES Report of the working group on North Atlantic Salmon. Int. Counc. Explor.Sea CM 1999/ACFM:14

[44] Friedland, K D.; Hansen L.P., Dunkley, D.A., & MacLean, J C 2000. Linkage between ocean climate, post smolt growth, and survival of Atlantic Salmon (Salmo salar M) in the North Sea area. ICES J. Marine Sci. 57: 419-429.

[45] Hindar, K. 2001. Interactions of cultured and wild species. Marine aquaculture and the environment. Univ. Massachusetts, Boston MA Jan 11-13 2001.

[46] Johnsen, B.O., and Jensen, A.J. 1994. The spread of furunculosis in salmonids in Norwegian rivers. J. Fish Biol. 29:233-241.

[47] Hindar, op. cit.

[48] Fleming. I.A., Hindar, K., Mjolnerod, I.B., Jonsson, B., Balstad, T., and Lamberg, A. 2000. Lifetime success and interactions of farm salmon invading a native population. Proc. R. Soc. Lond. B 267: 1517-1524

Both issues are classic case studies for the application of the precautionary principle, since there is high uncertainty and potentially significant impact. Indeed, the Norwegian Ethics Committee for the Natural Sciences has reviewed the debate about farmed-wild salmon interactions, and concluded that the issue has all the characteristics required for the application of the precautionary principle: high uncertainties, and high values at risk. Management, they therefore suggest, should be precautionary.

So what should the response to this problem be? The extreme interpretation of the precautionary principle is to stop all salmon farming; or at minimum prevent any further expansion. A more considered response would be to move to a more integrated level of decision making and ask the following questions:

- Can the risks, however uncertain they are, be reduced to an acceptable level?; and
- What would be the cost be if the worst scenario came to pass (i.e. extinction of most populations of wild salmon). And how does this compare with the benefits of salmon farming.

There is little doubt that the risks can be reduced. Three main approaches are possible:

- The use of sterile farm stock, although this is controversial with some groups;
- Reducing the rate of escapes through adoption of improved management practices and technology; and
- Siting farms well away from migration routes of wild stocks and important salmon estuaries.

While these measures would greatly reduce the risks, it will still not be possible to quantify those risks, and high levels of uncertainty will remain. At this point we must address relative benefit. What is the value and benefit stream from the wild stock, and how does this compare with the value and benefit stream from salmon farming? If the two were similar, the precautionary approach would suggest that we wind down salmon farming. If salmon farming generates much greater overall benefits, then most members of society would allow it to continue, while at the same time undertaking to minimise the risk to wild populations.

These questions of value are of course complex, and will vary between different stakeholders. However, if these values are clearly laid out, along with costs and benefits to different groups in society, elected or appointed decision-makers will be able to make rational and justifiable decisions.

9.4 A typology of impacts

This brief and selective (there are other issues) overview of environmental issues related to salmon farming illustrates several features which are important both in terms of the assessment of risk, and in terms of the level of assessment and response. The impacts fall into three main categories in terms of the nature and extent of the associated risk:

1. Those which are *local and predictable*, and for which modest research and monitoring can provide the information needed to generate predictions with reasonable confidence limits. These impacts can be assessed and managed on a

site by site basis (e.g. the Norwegian MOM approach (Ervik et al., 1997[49]); and the Scottish discharge consent/EIA approach). Organic sediments and some chemicals fall into this category. However, effective management of these impacts depends upon agreed environmental standards (EQS), and these local standards should ideally be related to monitoring and/or EQS for the wider environment.

2. Those which are *non-local and difficult to predict*. They may affect an aquatic system or a significant area of coastline or wetland. Nutrient enrichment and its effect on plankton is an example. Although in theory the impacts can be predicted given enough research, this will be costly, and significant uncertainty will remain. However, thorough review of existing ecological theory and knowledge of total nutrient quantities and dynamics in coastal waters can assess the general degree of risk. These impacts cannot be assessed and managed on an aquaculture site by site basis, but require multi-sector assessment and management encompassing all anthropogenic sources entering a defined area or system.

3. Those which are *non-local and unpredictable.* Interactions between farmed and wild salmon fall into this category. Although research can be undertaken to inform the debate, it is unlikely (at anything approaching reasonable cost) that predictions relating to final effects can be made with any degree of confidence. Furthermore, although risks can be reduced (e.g. by sectoral measures such as reducing escapes) the potential severity of the impact (which might result from a single escape) remains unaffected.

It is notable that while efforts to manage the environmental effects of aquaculture have taken place mainly at the site level, the main risks apply at higher levels, requiring sectoral or multi-sectoral approaches. It is also notable that high levels of uncertainty will be associated with the second kind of impact, and almost infinite levels of uncertainty are associated with the third kind. The precautionary principle might therefore require significant research to reduce uncertainty to acceptable levels before allowing further development in the case of the second type; and arguably a complete moratorium in the case of the third type. The latter argument would centre on the inclusion or otherwise of cost-benefit estimations to set against the worst case scenario. Most would agree that cost benefit calculations should be made, and this would be relatively straightforward.

[49] Ervik, A., Hansen, P.K., Aure, J., Stigebrandt, A., Johanessen, P., and Jahnsen, T. 1997. Regulating the local environmental impact of intensive marine fish farming. I. The concept of the MOM system (modelling-ongrowing fish farms-monitoring). *Aquaculture*, **158**, (1-2): 85 - 94

10 CONCLUSIONS AND RECOMMENDATIONS

The precautionary principle is not a decision criterion, and does not imply specific measurable levels of precaution; rather it forces us to take greater account of uncertainty in environmental decision making. This in turn implies a more openly subjective decision making process, informed by improved analysis and communication of the nature of risk and uncertainty. Given the character of most environmental impacts, including those from coastal aquaculture, this decision making process needs to be more strategic, and must generate or feed into effective and long term environmental management systems.

We suggest that key requirements for an informed and pragmatic application of the precautionary principle include the following:

1. Thorough assimilation of existing evidence relating to possible negative and positive impacts;
2. A thorough analysis of risk and uncertainty relating to these impacts;
3. Synthesis of this information with parallel information on the likely costs and benefits associated with the development and its impacts, again with a clear indication of uncertainty associated with the values;
4. Effective communication of this evidence to the decision maker(s);
5. A transparent and accountable decision making process relating to environmental management;
6. Strategic environmental planning and management based on agreed levels of precaution;
7. On-going research directed at issues where uncertainty relating to important impacts can be reduced cost effectively;
8. Monitoring coupled with precautionary response/regulatory procedures;
9. Regular review and adaptation of precautionary measures and thresholds where these turn out to be unnecessarily restrictive or excessively slack.

Critical to the whole process is improved description of the nature of impacts and associated risks and uncertainties. Despite the existence of well established frameworks for environmental risk assessment, there appear to be no magic bullets which might allow us to “measure” uncertainty in relation to complex ecological processes. There are however opportunities to develop improved frameworks and typologies of different impacts and their associated risk characteristics, and these should be further developed and incorporated in standard approaches for the environmental management of coastal aquaculture.

A preliminary analysis of the environmental risks associated with marine cage culture of salmonids suggests that the character of the impacts varies substantially, with some being limited impact and low uncertainty (low risk), and others fairly high impact and high uncertainty (high risk). In the case of the latter, it is arguable that the precautionary principle requires fairly radical measures to reduce impacts and associated uncertainties. However, the level of precaution adopted will inevitably depend on the balance of costs and benefits between a worst case impact and expected social and economic benefits. This level can only be set through a subjective and accountable or political decision making process. The use of more participatory decision analysis and decision making tools such as multi-criteria decision analysis may facilitate such processes.

It is notable that the main risks associated with coastal aquaculture are highly dispersed, sometimes intermittent, and associated with the sector as whole, or indeed several different sectors, rather than individual farms. This implies the need for long term and adaptive sector or multi-sector planning management, and reinforces many of the points made in GESAMP (2001).

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ANNEX 1: TERMS AND DEFINITIONS

Examples of definitions of terms commonly used in the fields of human health and environmental risk assessment and management.
Sources: Codex Alimentarius Commission (2001); European Commission (2000); Duffus (2001) ; van Leeuwen (1995)

Term/Source	Codex Alimentarius Commission (2001)	European Commission (2000)	Duffus (2001)	van Leeuwen (1995)
Hazard	A biological, chemical or physical agent in, or condition of, food with the potential to cause an adverse health effect.	The potential of a risk source to cause an adverse effect (s)/event(s).	inherent property of an agent or situation capable of having adverse effects on something. Hence, the substance, agent, source of energy, or situation having that property	Hazard is the inherent capacity of a chemical or mixture to cause adverse effects on man or the environment under the conditions of exposure
Risk	A function of the probability of an adverse health effect and the severity of that effect, consequential to a hazard(s) in food.	The probability and severity of an adverse effect /event occurring to man or the environment following exposure, under defined conditions, to a risk source(s).	the probability of adverse effects caused under specified circumstances by an agent in an organism, a population, or an ecological system	Risk is the probability of occurrence of an adverse effect on man or the environment resulting from a given exposure to a chemical or mixture
Risk source		Agent, medium, commercial/industrial process, procedure or site with the potential to cause an adverse effect(s)/event(s)		
Risk Analysis	A process consisting of three components : risk assessment,	A process consisting of three components: risk assessment, risk	process for controlling situations where populations or ecological systems could be	

	risk management and risk communication	management and risk communication.	exposed to a hazard. It usually comprises three steps, namely risk assessment, risk management, and risk communication.	
Risk assessment	A scientifically based process consisting of the following steps: (i) hazard identification, (ii) hazard characterisation, (iii) exposure assessment, and (iv) risk characterisation.	A process of evaluation including the identification of the attendant uncertainties, of the likelihood and severity of an adverse effect (s) /event(s) occurring to man or the environment following exposure under defined conditions to a risk source(s). A risk assessment comprises hazard identification, hazard characterisation, exposure assessment and risk characterisation.	process intended to calculate or estimate the risk for a given target system to be affected by a particular substance, taking into account the inherent characteristics of the substance of concern as well as the characteristics of the specific target system. The process includes four steps: hazard identification, dose-response assessment, exposure assessment, and risk characterization.	Risk assessment is a process which entails some or all of the following elements: hazard identification, effects assessment, exposure assessment, and risk characterisation
Hazard assessment:			process designed to determine factors contributing to the possible adverse effects of a substance to which a human population or an environmental compartment could be exposed. The process includes three steps: hazard identification, hazard characterization, and hazard evaluation Note: Factors may include mechanisms of toxicity, dose-effect and dose-response relationships, variations in target susceptibility, etc.	
Hazard identification	The identification of biological, chemical, and physical agents capable of causing adverse health effects and which may be present in a particular food or group of foods.	The identification of a risk source(s) capable of causing adverse effect(s)/event(s) to humans or the environment species, together with a qualitative description of the nature of these effect(s)/event(s).	the first stage in hazard assessment, consisting of the determination of substances of concern, the adverse effects they may have inherently on target systems under certain conditions of exposure, taking into account toxicity data Note: Definitions may vary in wording, depending on the context. Thus, here: [RISK ASSESSMENT] the first stage in risk	Hazard identification is the identification of the adverse effects which a substance has an inherent capacity to cause, or in certain cases, the assessment of a particular effect

			assessment, consisting of the determination of particular hazards a given target system may be exposed to, including attendant toxicity data.	
Hazard characterisation	The qualitative and/or quantitative evaluation of the nature of the adverse health effects associated with biological, chemical and physical agents which may be present in food. For chemical agents, a dose-response assessment should be performed. For biological or physical agents, a dose-response assessment should be performed if the data are obtainable.	The quantitative or semi-quantitative evaluation of the nature of the adverse health effects to humans and/or the environment following exposure to a risk source(s). This must, where possible, include a dose response assessment.	the second step in the process of hazard assessment, consisting in the qualitative and, wherever possible, quantitative description of the nature of the hazard associated with a biological, chemical, or physical agent, based on one or more elements, such as mechanisms of action involved, biological extrapolation, dose-response and dose-effect relationships, and their respective attendant uncertainties	
Hazard evaluation:			hazard evaluation: the third step in the process of hazard assessment aiming at the determination of the qualitative and quantitative relationship between exposure to a hazard under certain conditions, including attendant uncertainties and the resultant adverse effect	
Effects assessment (dose-response assessment)	*Dose-Response Assessmen*t: The determination of the relationship between the magnitude of exposure (dose) to a chemical, biological or physical agent and the severity and/or frequency of associated adverse health effects (response).	Dose-response assessment: The determination of the relationship between the magnitude of exposure to risk source(s) [dose] and the magnitude or frequency and/or severity of associated adverse effect(s) [responses].	*dose-response assessment:* the second of four steps in risk assessment, consisting of the analysis of the relationship between the total amount of an agent absorbed by a group of organisms and the changes developed in the group in reaction to the agent, and inferences derived from such an analysis with respect to the entire population	Effects assessment, or more precisely dose or response assessment, is the estimation of the relationship between dose or level of exposure to a substance, and the incidence and severity of an effect
Exposure	The qualitative and/or	The quantitative or semi-	step in the process of risk assessment,	Exposure assessment is the

assessment	quantitative evaluation of the likely intake of biological, chemical, and physical agents via food as well as exposures from other sources if relevant.	quantitative evaluation of the likely exposure of man and/or the environment to risk sources from one or more media.	consisting of a quantitative and qualitative analysis of the presence of an agent (including its derivatives) that may be present in a given environment and the inference of the possible consequences it may have for a given population of particular concern Note 1: [engineering] determination, through the use of a variety of analytical techniques, of the quantity and fate of a chemical, physical, or biological agent in a medium of concern.	determination of the emissions, pathways and rates of movement of a substance and its transformation or degradation in order to estimate the concentrations/doses to which human populations or environmental compartments are or may be exposed
Risk characterisation	The qualitative and/or quantitative estimation, including attendant uncertainties, of the probability of occurrence and severity of known or potential adverse health effects in a given population based on hazard identification, hazard characterisation and exposure assessment.	The quantitative or semi-quantitative estimate, including attendant uncertainties, of the probability of occurrence and severity of adverse effect(s)/event(s) in a given population under defined exposure conditions based on hazard identification, hazard characterisation and exposure assessment.	integration of evidence, reasoning, and conclusions collected in hazard identification, dose-response assessment, and exposure assessment and the estimation of the probability, including attendant uncertainties, of occurrence of an adverse effect if an agent is administered, taken, or absorbed by a particular organism or population. It is the last step of risk assessment. Note: In ecological risk assessment, concentration-response assessment is carried out instead of dose-response assessment. or qualitative and/or quantitative estimation, including attendant uncertainties, of the severity and probability of occurrence of known and potential adverse effects of a substance in a given population	Risk characterisation is the estimation of the incidence and severity of the adverse effects likely to occur in a human population or environmental compartment due to actual or predicted exposure to a substance, and may include "risk estimation", i.e. the quantification of that likelihood
Risk management	The process, distinct from risk assessment, of weighing policy alternatives, in	The process of weighing policy alternatives in the light of the result of a risk assessment and other	decision-making process involving considerations of political, social, economic, and technical factors with relevant risk	Risk management is a decision-making process that entails considerations of political, social,

	consultation with all interested parties, considering risk assessment and other factors relevant for the health protection of consumers and for the promotion of fair trade practices, and, if needed, selecting appropriate prevention and control options.	relevant evaluation and, if required, selecting and implementing appropriate control options (which should, where appropriate, include monitoring / surveillance).	assessment information relating to a hazard so as to develop, analyze, and compare regulatory and nonregulatory options, and to select and implement the optimal response for safety from that hazard. Essentially, risk management is the combination of three steps: risk evaluation, emission and exposure control, and risk monitoring. Note: The intermediate step (emission and exposure control) was not listed in the survey, but is included here for the sake of consistency. Control is used here in a general rather than specific regulatory sense.	economic, and engineering information with risk-related information to develop, analyse and compare regulatory options and to select the appropriate regulatory response to a potential health or environmental hazard
Risk evaluation			risk evaluation: establishment of a qualitative or quantitative relationship between risks and benefits, involving the complex process of determining the significance of the identified hazards and estimated risks to those organisms or people concerned with or affected by them. It is the first step in risk management. Note: It is synonymous with risk-benefit evaluation.	
Risk monitoring:			risk monitoring: process of following up the decisions and actions within risk management in order to ascertain that risk containment or reduction with respect to a particular hazard is assured	
Risk reduction				Risk reduction is taking measures to protect man and/or environment from the risks identified
Safety			practical certainty that adverse effects will	Safety is defined as the high

			not be caused by an agent under defined circumstances Note: It is a reciprocal of risk.	probability that adverse effects will not result from the use of a substance under specific conditions depending on quantity or manner of use
Risk Communication	The interactive exchange of information and opinions throughout the risk analysis process concerning hazards and risks, risk-related factors and risk perceptions, among risk assessors, risk managers, consumers, industry, the academic community and other interested parties, including the explanation of risk assessment findings and the basis of risk management decisions.	The interactive exchange of information and science based opinions concerning risk among risk assessors, risk managers, consumers and other actual or potential stakeholders.	interactive exchange of information about risks among risk assessors, managers, news media, interested groups, and the general public	

ANNEX 2: WORKING GROUP COMPOSITION AND ISSUES TO BE ADDRESSED

Working group composition

The working group should include at minimum the following expertise:

1. A specialist in risk assessment, preferably with a mathematical background
2. An ecotoxicologist
3. A marine/coastal ecologist
4. A population geneticist
5. An epidemiologist
6. An aquaculture technology specialist
7. A environmental policy specialist
8. An economist

Possible structure/outline for review and guidelines:

- The precautionary policy at international and national level and its relevance/application to coastal aquaculture development
- Frameworks for risk assessment
- Risk analysis
- Risk characterisation and communication, with specific emphasis on the characterisation and communication of probability, ignorance and uncertainty
- Application of risk analysis to complex aquatic systems, and coastal aquaculture
- Risk analysis and decision making – where and how risk analysis can contribute to improved decision making in relation to coastal aquaculture development
- Guidelines for risk assessment for coastal aquaculture development and management
- Case studies in the application of risk analysis to coastal aquaculture development

ANNEX 3: A SUMMARY OF THE ENVIRONMENTAL RISK ASSESSMENT PROCESS

The process of environmental risk assessments can loosely be described as a framework of separate activities. The uniqueness of ecological systems and the nature of a specific set of stressors means it can be problematic to define a standardised procedure for carrying out the assessment although a general framework can be described. Essentially the processes can be divided into three phases: problem formulation, problem analysis and risk characterisation. The problem analysis stage can be further sub-divided into 2 distinct sections: characterisation of exposure and characterisation of effect. This means, at least for descriptive purposes, that the environmental assessment process has 4 fundamental elements as illustrated in Fig. A1.

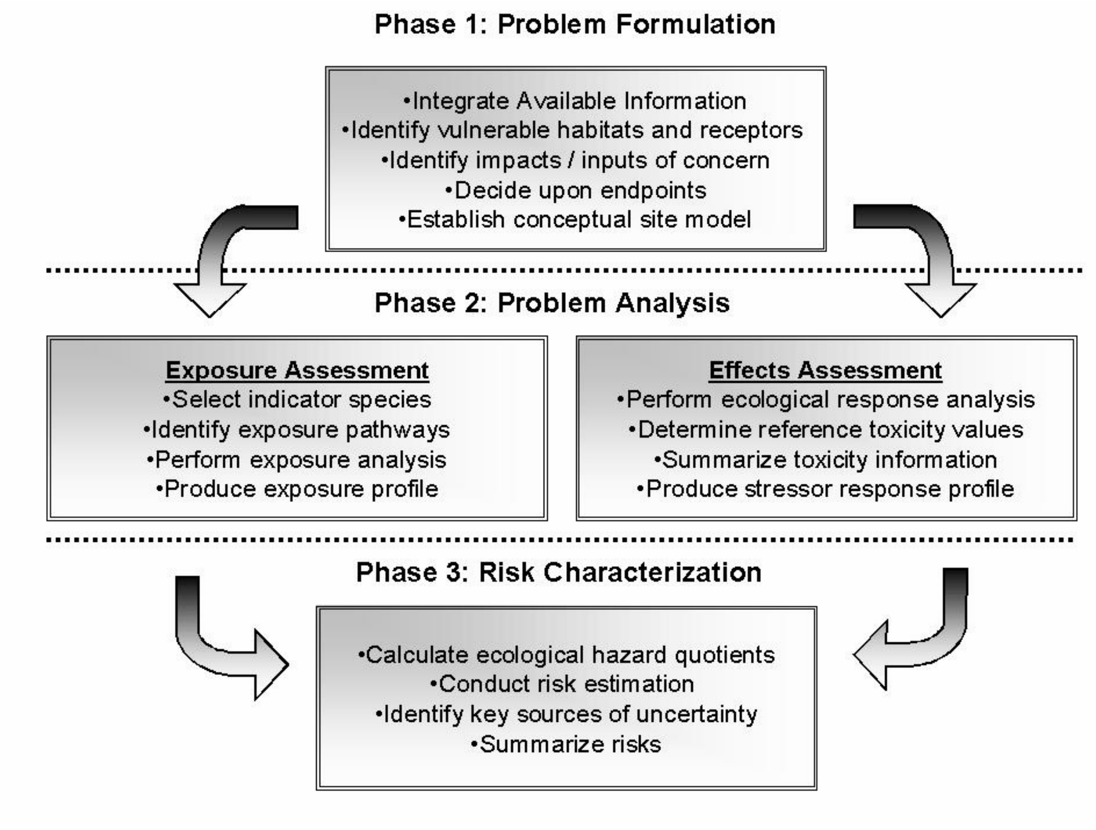

Fig. A1: Adapted from USEPA 1998[50] and Asante-Duah 1998[51].

In spite of this clear indication of the process form, the assessment remains fairly iterative by nature. Often information that is obtained at a supposedly later stage in the process will force a reassessment of an earlier step. In particular discoveries

[50] US Environmental Protection Agency (1998).Guidelines for Ecological Risk Assessment. USEPA, Washington DC.
[51] Asante-Duah, D. K.(1998). Risk Assessment in Environmental Management: a guide for managing chemical contamination problems. *Publ*: Wiley, Chichester

during the analysis stage may encourage a shift in emphasis in the originally determined endpoints. Rather than being considered a failure of initial planning, this constant reassessment enables the environmental risk assessment to be a dynamic process well suited to ecological study.

Problem Formulation

The nominal first stage of the environmental risk assessment is to understand to nature of the problem. In its most simple form the task of this first phase is to explain the purpose of the assessment, define the problem and develop a strategy for analysing the risk. As part of this process all of the available relevant information on sources, stressors, effects and ecological response is collated. This enables a conclusion as to the appropriate ecological endpoints of the assessment. These endpoints are representative of the environmental resources that are to be protected. Any impacts observed at these endpoints indicate the need for corrective action. This problem formulation stage also enables a conceptual site plan to be developed. The conceptual site model (CSM) is a written and visual representation of the ecosystem indicating the predicted responses by ecosystem to stressors. The complexity of the CSM depends upon the number of endpoints and stressors and the characteristics of the ecosystem.

The problem formulation stage has a key role to play in determining the overall success of the environmental risk assessment. The quality and appropriateness of this early work will play a strong role in determining the overall value of the assessment. The key factors that must be successfully completed for the problem formulation stage are firstly, the selection of endpoints that reflect the overall management goals and secondly, the development of clear and accurate conceptual models that correctly identify the key relationships between stressors and endpoints[52].

An analysis plan is carried forward from the problem formulation into the problem analysis phase. This plan highlights the critical relationships that are represented in the conceptual site model and indicates which data sets will be used in the later stages of the risk assessment. The strength of available data as well as the completeness of exposure pathways may influence the selection of these key relationships.

Problem Analysis

This can be divided into two distinct sections: exposure assessment and effects assessment. This phase is more technical than the problem formulation phase and involves detailed data evaluation of the ecological relationship between stressor and effects; in particular of those critical relationships identified in problem formulation.

The problem analysis phase takes its lead from the CSM and analysis plan from earlier in the assessment process. The problem analysis phase concludes with the development of exposure and stressor response profiles.

[52] Asante-Duah 1998 op.cit..

Exposure Assessment

The roles of the exposure assessment are to identify the behaviour and exposure routes of contaminants, thereby enabling calculation of the degree of contact between contaminants and potential ecological receptors.

The exposure assessment makes full use of the CSM and attempts to ascertain detailed contaminant migration pathways at every interlinkage identified in the conceptual representation of the ecosystem. Another approach sometimes used, is to work backwards from the ecological endpoint developing a simple foodweb which looks at consumption, uptake and absorption to calculate realistic exposure scenarios. The total daily exposure to target species can therefore be calculated by summing the maximum level of contaminants absorbed, inhaled or ingested from all sources. A typical formula to estimate the level of exposure to target species from contaminants is indicated below:

$$E = C \times F \times [\, \sum D_{di} D_{ci} D_{ui} \,] \times BAF \times (\, 1 / BW \,)$$

where:

E	= Average Daily Exposure
C	= Average chemical concentration in media
F	= Food consumption rate
D_{di}	= Component of diet
D_{ci}	= Consumption Factor
D_{ui}	= Uptake coefficient
BAF	= Bioavailability factor
BW	= Body weight

Effects Assessment:

This section of the environmental risk assessment process can sometimes be referred to as the ecotoxicity assessment and quantifies the cause and effect relationship between the stressor and the ecological endpoint. Crucially, the effect assessment also establishes the range in ecological effects that occur at varying stressor levels.

Information in scientific literature is reviewed at this stage to obtain ecotoxicology information for any contaminants that may be of particular concern. Where additional data are required, field sampling or bioassays may be undertaken to determine a stressor-response profile. This work enables critical toxicity values to be determined for the representative endpoints of the ecosystem, which can be carried forward into the risk characterisation phase.

It must be recognised at this stage that there maybe certain site-specific variations, that partially devalue any data derived from the literature or lab-based testing. Complex interactions at the site will alter the availability of contaminants due perhaps to sediment binding or degradation. Any failure to interpret conclusions from a local perspective may lead to an over or underestimation of risk when these details are carried forward to the risk characterisation phase.

Risk Characterisation Phase

The 3rd phase of the ERA combines the information and conceptual tools provided by the earlier phases, namely: the CSM, the exposure profile and the stressor-response profile. The aim of the risk characterisation phase is to calculate the likelihood and degree of any adverse effects on the ecosystem by stressors. Plausible ecological risk estimates are calculated by combining the toxicity tolerances determined during the effects assessment and the likelihood and scale of contamination determined during the exposure assessment. By comparing the critical ecotoxicity with the estimated daily dose it is possible to calculate and Ecological Risk Quotient, as illustrated below:

$$\text{Ecological Risk Quotient } (ErQ) = \frac{\left[\begin{array}{c}\text{Exposure Point Concentration} \\ \textit{or} \text{ Estimated Daily Dose}\end{array}\right]}{\text{Critical Ecotoxicity}}$$

Adapted from Asante-Duah 1998[53]

Another vital aspect of the risk characterisation phase is to discuss the overall adequacy and quality of the data and to highlight the assumptions and areas of uncertainty. This is particularly important for environmental risk assessments, as conceptual interpretations of ecosystems will inevitably involve certain simplifications and assumptions. When there are gaps in the data, which cannot practically be filled, extrapolations are often relied upon from similar data sources. In these cases, it is crucial that these are highlighted in the final report.

The extent of the uncertainties and assumptions highlighted in the risk characterisation phase will affect the final confidence that is placed in the entire assessment process. It may be tempting, therefore to gloss over certain assumptions in order to give the assessment increased credibility and weight. This approach would fundamentally weaken the entire assessment process and increase the likelihood of inappropriate or inadequate action being taken. When reviewing the ERA there is nothing wrong with intuition, provided the reviewer is fully aware of the strengths and weaknesses of the assessment (Benjamin and Belluck, 2001[54]).

Role of Monitoring.

Monitoring has a crucial role to play in the initial risk assessment process and the subsequent reviewing of measures taken. It can often be monitoring that first triggers the need for an environmental risk assessment. It can rightly be pointed out that a risk assessment should ideally be carried out well in advance of any negative input or consequent impacts. In reality, however, it is often evidence of an impact, obtained through monitoring that highlights the need for an assessment process and remedial measures.

During the actual ERA process monitoring can provide vital background information to the nature and range of the ecosystems physical, biological and chemical

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[53] Asante-Duah, D. K.(1998). Risk Assessment in Environmental Management: a guide for managing chemical contamination problems. *Publ*: Wiley, Chichester

[54] Benjamin, S. & Belluck, D. (2001). A practical guide to understanding, managing and reviewing environmental risk assessment reports. *Publ*: Boca Raton, Fla; London: Lewis Publishers.

characteristics. However, it is really after the assessment process and subsequent management steps that monitoring is of primary value. Monitoring can be used to evaluate the predictions that are made within the assessment. This is crucial to increase confidence in the environmental risk assessment. Monitoring can determine whether mitigation measures that have been implemented as a direct result of the ERA have been successful. Monitoring can also be used to verify whether efforts to reduce contamination at source have been effective and finally monitoring can evaluate the overall extent and nature of ecological recovery.

One of the great strengths of an environmental risk assessment is that information gained and lessons learned during subsequent monitoring can be fed back into the process to help improve assessments and add to the value of the tool. By making use of this iterative process, environmental decision making can be improved in a way that enables adaptive management of natural resources[55].

Use of Biomarkers.

The use of well-defined and appropriate biomarkers can provide inexpensive information to assist in the formulation and assessment of predictions outlined in an ERA. Biomarkers can be described as indicators of events in biological systems following chemical exposure. Organisms, populations or even communities that respond to environmental changes in a measurable way can be potentially act as biomarkers. The measurable response may be anything from a behavioural change to a change in community diversity.

Classification of biomarkers is not always clear and there remains considerable discussion over suitable terminology (Schlenk, 1999[56]). For example in some published work, the term biomarker refers to an individual response, whereas bioindicator refers to effects measured at population or community level. For the purposes of ERAs, it is convenient to classify biomarkers to fit in with the various phases of the risk assessment process. Each of these 3 categories of biomarkers (expose, effect & susceptibility) can be helpful in performing an environmental risk assessment:

Exposure Biomarkers: during the problem formulation stage biomarkers of exposure can provide both quantitative and qualitative estimates of exposure to various compounds

Effect Biomarkers: biomarkers that look specifically at the probable mechanisms of action are helpful for effect assessment

Biomarkers of susceptibility: these biomarkers can indicate susceptibility by providing a characterization of variability which can be used in defining uncertainty factors; thereby reducing the level of uncertainty over response .

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[55] US Environmental Protection Agency (1998).Guidelines for Ecological Risk Assessment. USEPA, Washington DC.

[56] Schlenk, D. (1999). Necessity of defining biomarkers for use in ecological risk assessments. *Marine Pollution Bulletin*, **39**, (1-2), 48-53.

ANNEX 4: CASE STUDIES IN THE APPLICATION OF ENVIRONMENTAL RISK ASSESSMENT

1. Environmental risk assessment for ballast water introductions.

Many varied management solutions have been proposed in order to overcome the problem of alien species introductions into new regions via ballast water from foreign vessels. Essentially these management options are required to break the chain that exists between intake of water in the 'donor' community and colonisation and establishment of introduced species in the receiving waters. There are numerous and varied solutions to this problem. To name but a few, these vary from ensuring intake of clean or treated water, filtration or UV treatment at the point of intake, continual reballasting during the voyage and discharging ballast to sewage treatment facilities.

It is reasonable to assume that each proposed solution to the problem will have slightly different efficiencies, impacts and cost-effectiveness (risk reduction per unit cost). The appropriateness of each solution is likely to vary according to the ports and vessels that are involved. Clearly it would be unreasonable to place a blanket legislative requirement covering all vessels in every situation as it is evident that there needs to be consideration on a case by case basis. According to what criteria should the appropriate solution be selected?

Hayes (1998) asserts that ecological risk assessment enables the probability and consequences of management failure to be evaluated. This provides a defensible technique to analyse cost efficiency and provides effective decision criteria appropriate to a wide variety of cases.

The proposed risk assessment for ballast water looks at a series of possible endpoints of management failures and looks at the probability and effect of each. No organisms in the ballast, no organisms surviving the journey and no organisms establishing in the new environment are all potential endpoints. Linking these endpoints are management failures and associated probabilities. Questions associated with a failure at one endpoint will influence probabilities at the next endpoint. For example, numbers, survival strategies and life stages of organisms in the ballast will dictate levels of organisms surviving to be discharged into the new environment. Minimum viable population size will dictate the chances of organisms becoming established in receiving waters. In this way, risk assessment is a cumulative process of probability. The risk assessment for ballast water introductions is complex, however, treating potential endpoints separately provides manageable risk assessment units, helping to reduce uncertainties.

The cumulative approach to risk assessment addressing a series of management failures, combined with the great number of possible management options means that there is an extremely large data requirement. It is however vital that multiple eventualities are considered and that assessments should be case specific (Hayes 1998).

As with all ERAs, modelling of stochastically complex population dynamics is crucial to the accuracy of the process. The ballast water risk assessment differs from other ERAs in that much of the dynamic process takes place within the mesocosm-like environment of the ballast, with well-defined variables. In this respect, this particular model of risk assessment is similar to those used in chemical and nuclear process industries.

Hayes suggests that a central agency with expertise and case specific knowledge must be responsible for carrying out the assessments. Initially it may be sensible to develop risk assessments geared toward certain key target species. This would allow refinement of a model framework before expansion into all key species. A byproduct of the assessment procedure is that it will provide valuable information to shipping companies, regulators and particularly regulators in the receiving countries, highlighting major risk routes.

2. ERA in fish restocking programs

Pearsons and Hopley (1999), look at an ERA designed and used alongside a hatchery reared salmonid stocking programme. This programme is particularly important given the importance of salmonid stocking programmes in North America and the high value or sensitivity of associated non-target taxa (NTT). This is a topical area and the question of genetic risk, associated with interbreeding has received some high profile public scrutiny. Interestingly, other ecological risks have received substantially less scrutiny even though the effects may be equally concerning and significantly more widespread. Hatchery reared fish tend to exhibit different behaviour and are bigger than wild conspecifics; in addition, they are usually released in large numbers. Competition, predation, behavioural anomalies and pathogenic interactions will all impact on non-target taxa. It is also conceivable that stocking programmes may have positive associated effects such as providing food for larger predators. Clearly the impacts are difficult to evaluate from a management or regulatory perspective and for a long time there had been little advice to guide sound resource decisions.

Pearsons and Hopley advocate a considerably more participatory approach to the ERA. Selecting a panel of experts including scientists, managers, policy makers and local stakeholders to work through the ERA template will avoid bias in the end assessment. They suggest that the panel should include equal numbers in support and against the project, those with no stake in the outcome and at least one representative of each stakeholder.

The panel will then collaborate over five tasks, which loosely follow the ERA framework outlined earlier in this report. These include determining acceptable impact levels on non-target taxa and going on to describe the risk or probability of failing to meet the NTT objectives. The uncertainty is calculated according to the standard deviation in the probability predictions of all of the different panellists. In short, the uncertainty is a function of agreement between assessors, and, if there is agreement there is little or no uncertainty. Finally Pearsons and Hopley advocate peer review before the assessment is submitted to decision-makers.

This inclusive and open approach increases the likelihood of the assessment being accepted by regulatory agencies and it makes the process fully socially and scientifically defensible. However does this transparent and collaborative approach give false credibility? If uncertainty is based upon the degree of disagreement between assessors then the level of uncertainty will be influenced by the scale of polarisation between the views of the pro and anti assessors. Peer review is certainly sensible to increase public acceptance, however, given some sectors of the public's scepticism toward science peer review in no way guarantees a smooth acceptance of the assessment.

3. ERAs and genetically modified fish

In the late 1980's Rex Dunham of Auburn University first submitted a request for field testing of aquatic GMOs. In their wisdom, the US Department of Agriculture recognised that the existing 'Co-ordinated Framework for the Regulation of Biotechnology' was insufficient and convened a working group on aquatic Biotechnology and Environmental Safety. This was a varied group of experts in their field and included molecular and population geneticists, ecologists, aquacultural engineers, legal people and people from government. The group was responsible for drawing up a risk assessment and management framework to enable biotechnology research to proceed without significant environmental risk or effect (Hallerman *et al.,* 1998).

As has been seen with other case studies, the aim of this assessment framework was to help the researcher to define appropriate endpoints, rather than be too prescriptive over exact design standards. The guidelines were to be geared toward defining ecologically safe practices for research and development. These guidelines would not be appropriate for addressing concerns over food safety, commercial aquaculture or fisheries stocking programmes.

The guidelines for risk assessment are based upon asking the assessor a series of preliminary questions to help identify the key areas of further work required to address uncertainty. The questions help to identify key areas of risk and steer the investigator toward associated risk management measures. In this way, questions about gene transfer, chromosome set manipulation and interspecific hybridisation are tackled. The next stage is for the investigator to answer a similar series of questions regarding ecosystem effects. Where risks are identified, the investigator is prompted to consider a series of confinement measures such as physical, chemical or biological barriers or if necessary, a reduction in the scale of the experiment.

One of the benefits of this process is that the investigator can document a pathway through the risk assessment process, clearly indicating justification for key confinement protocols. In spite of this benefit, Hallerman *et al.* (1998) fail to clearly identify how areas of uncertainty and assumptions are dealt with. Giving the impression that all eventualities can receive probabilistic evaluation and be remedied accordingly suggests that all things can be quantitivly appraised. It is possible that the highly scrutinised and criticised biotechnology industry does not wish to highlight areas of uncertainty or assumptions. A failure to accept the limitations of risk assessment and rely upon some degree of well-informed subjectivity may condemn the process to farce.

4. Norwegian Modelling of Ongrowing Fish Farms Monitoring (MOM System)

This model was devised in 1996/7 by a team of Norwegian scientists. The system was specifically designed to help meet the Norwegian national environmental objectives for fish farming. Essentially the model combines environmental impact assessments, with environmental quality standards and monitoring. This provides a tool that can be used in the planning stage of new developments to determine possible future impacts and can also be used in a more retrospective manner to assess levels of exploitation on operational farms (Ervik *et al* 1997).

The model is particularly geared toward sedimentation under cage or pen farms. When the benthic community become azoic due to smothering, the carrying capacity has been exceeded. In this way the model helps to ensure that the operation remains within environmentally sustainable levels. As with ERAs the MOM model enables various management options to be considered prior to deciding upon action. In this way, the environmental benefit or cost of adjusting stocking density, feeding practices, diet or site location can be evaluated.

The MOM system is a rather specific tool dealing primarily with single site influences rather than cumulative or regional effects of aquaculture. The effects of other environmental impacts that are not directly linked to sedimentation are not considered. As a result the impact or risk of escapees, disease, parasites, chemicals and associated farm activities is not considered.

The MOM system does provide a suitable tool for informing environmental management of individual farms. More strategic management systems, which address the more difficult dispersed, cumulative, intermittent and uncertain impacts, need to be developed if the precautionary approach is to be reasonably applied. However from a historical perspective the implementation of MOM by Norwegian Authorities in 1998 represented considerable progress on the road to informed decision making.

5. A possible role for ERA in Scottish salmon farming developments?

The Scottish salmon industry is currently under attack. Alarming accusations are fired at the industry by the mainstream press with depressing regularity. This exposure means that the public are becoming increasingly well informed by one side of this highly emotive argument. Some within the industry are rightly concerned by the potential impacts of this bad press, however there is little sign of their counter-arguments receiving useful coverage.

It is over-simplistic to say that the argument is simply between environmentalists and industry. It is untrue that there is no middle ground and it is untrue that the issues are clear and concrete. What is clear however, is that the two sides of the argument are entrenched in very strongly held views. The question is how well informed are these arguments and which side is correct?

Currently, this emotive argument over Scottish salmon is defined by one thing: uncertainty. Both the industry and the environmental lobby attempt to hijack this uncertainty to strengthen their case. Statements such as "almost certainly" or "there is no link" both address this uncertainty with a bias to either one or other point of view. The argument becomes a battle for the views of the middle ground or general public.

Both industry and environmentalists view the opposing camp with considerable suspicion and mistrust. There are educated and well-intentioned people on both sides of the argument and all genuinely believe that only they are correct in their opinions. Presumably therefore, all sides will be interested in any attempt to reduce the uncertainty that currently defines the argument. The difficulty is in agreeing the validity or impartiality of any process that contributes to the assessment of the environmental impact of the industry.

Agreement in the impartiality of the process will almost certainly be impossible once conclusions have been drawn. Instead, impartiality must be established and agreed upon by all stakeholders at the start of the process if there is any chance of conclusions being constructively accepted and interpreted by all sides.

Is it possible that Environmental Risk Assessments may contribute to this process of reducing uncertainty in a way that is acceptable to all parties? Can an ERA become independent of either one or other side of the emotive argument and make a reasonable attempt at determining the true situation? And will an ERA provide indications or answers to some of the raging debates that currently exist in the Scottish salmon industry?

A framework.

It is first necessary to decide upon who would carry out the environmental risk assessment, what would be their remit and who would fund them. Clearly the process should be as impartial as possible. Ideally therefore, the assessment should be constructed by an independent assessor, funded by government and with a remit to look at as broad a spectrum of impacts as is practically possible.

Problem formulation and initial participation.

The initial problem formulation stage of the environmental risk assessment addresses the available information, the main areas of environmental concern and the selection of suitable endpoints to alert of environmental impact. To avoid criticism for use of inappropriate data or the studying non-relevant areas of impact it is important that there is some level of participation in this first phase.

By involving representatives of all sides of the argument at this early stage, much of the obstacles to subsequent broad agreement may be overcome. In Scotland the independent assessor should at the very least invite initial comment and input from:

Scottish Environmental Protection Agency

Aquaculture Companies e.g.: Marine Harvest (Scotland)

Industry Bodies e.g.: Scottish Salmon Growers Association (SSGA)

Regional Councils e.g.: The Highland Council

The Environmental lobby e.g.: Friends of the Earth

Other relevant semi-state bodies e.g.: Scottish Natural Heritage

These representative bodies would be invited to indicate areas for particular attention and highlight any literature, with data sets that can be incorporated into the ERA model. In the interest of cost and time efficiency the assessor should limit the extent of this input and avoid entering into lengthy discussion. In no way does this consultation process devolve responsibility from the assessors, who must carry out their own exhaustive search of available data.

A vital role of the problem formulation stage of the ERA is to identify the vulnerable habitats and receptors. This will be partially informed by the consultation process and, in this Scottish example, is likely to identify the impacts on wild migrating fish stocks and benthic habitats as key. The major inputs of concern are most likely to be from excess feed, faeces, chemical treatments, antibiotics and blood loss from harvest.

The assessor must then attempt to integrate the available information into an initial conceptual site model (CSM), this provides a visual representation of the site and major impact pathways, but is also a detailed written account of the various interactions associated with the process. A very basic indication of some of the imoacting pathways that are likely to feature prominently on a CSM for a typical Scottish loch salmon farm are indicated in Figure A2. In many cases there will be additional, locally specific pathways to be included in the CSM.

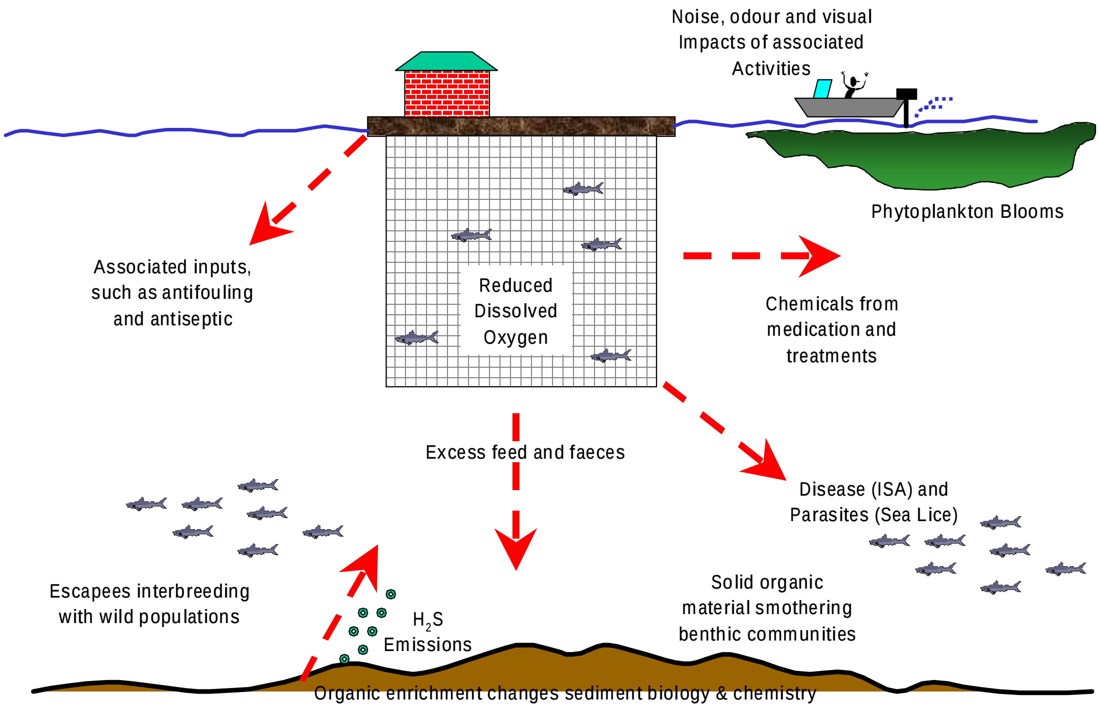

Fig. A2: Main pathways associated with salmonid cage culture.

In addition, it is vital that the CSM gives consideration to the regional interactions, that may be beyond the control of decision-makers, but nevertheless have considerable influence on the scale of impacts of the process. The most crucial of these is the local hydrodynamics. Additionally, in line with the need for an integrated approach to coastal management, it is important to consider the regional influences of other activities in the area. In the case of Scottish lochs, the impacts of forestry activities, coastal developments and local industry such as paper mills and aluminium plants should be fully considered in the CSM.

The assessor will also attribute values of certainty to each of the pathways that are highlighted in the CSM. In some cases, key pathways may coincide with reliable published data sets, in other cases further work will be needed to study key pathways. Where this is not possible, uncertainty must be accepted. The assessor should highlight important areas of further study, which may be integrated into the ERA model at a later stage.

At this point the assessor must view the whole situation and decide upon the main pathways of study and suitable endpoints that will act as environmental indicators. One of these endpoints will certainly be the regional benthic community, which is well suited to the assessment of marine environmental impacts. Antibiotics in the sediments and changes in toxin levels in local shellfish populations are also both readily measurable endpoints. The endpoints should be at the end of a pathway with as little uncertainty as possible. With this in mind, although wild salmon stocks may be selected as an endpoint, it is likely that this particular pathway would be characterised by a large degree of uncertainty. Due to the nature of the arguments that surround Scottish salmon farming, it seems sensible to predominantly select endpoints that provide a high degree of certainty, whist encouraging further work in remaining areas of uncertainty.

It may or may not be sensible at the end of the problem formulation stage to send out the proposed CSM and selected pathways to representatives of the bodies involved earlier in the process. Their comments may be welcome and highlight areas of concern, however, this consultative process could significantly slow the process. A solution would be for the assessor to press on with the problem analysis and risk characterisation and if there is major areas of valid concern highlighted by the consultation, these may be inserted at a later stage taking advantage of the iterative nature of the process.

The process of ERA

Problem Analysis

This section of the risk assessment is considerably more technical than the problem formulation and should be carried out by the independent, professional risk assessor in a non-consultative way. This is perhaps particularly important in the case of Scottish salmon farming where too high a degree of consultation may grind the process to a halt.

Exposure assessment

The aim of the exposure assessment is to calculate the degree of contact between contaminants and potential ecological receptors. At this stage of the process the assessor is likely to feed the available information into a software package, which has been specifically designed to integrate marine information and uses, detailed hydrodynamic information as the foundation for the model.

Information such as food input, food conversion rate, diet composition, treatment frequencies, volume and nature of chemicals used and much more, will be fed into the model. In the case of an ERA for a planned new development, data from existing farms of similar scale and process may be used. In addition to this farm data, quantitative information for the run-off of nutrients and chemicals from different activities in the loch should be included. Ideally the software will enable confidence levels that are associated with each set of data to be included. This may enable the cumulative uncertainty of each pathway to be determined.

The data that is inputted can be very detailed where available. Exact quantities of all inputs can be combined with detailed flushing rates and dilution factors to give a detailed evaluation of likely exposure to all inputs for given organisms. This figure will also have an associated confidence limit, based upon the data that has been used to generate the figure. For some pathways the confidence in the exposure levels will be high. For example, exact volumes of lice treatment chemicals can be combined with detailed hydrodynamic information to give a clear indication of the likely exposure of an organism at a given location. Other pathways, such as the impact of nutrient loading on distant phytoplankton populations will be characterised by uncertainty.

Effects Assessment

Again, available data will be fed into the software model. For any given exposure between aquacultural input and organism there will be a given effect. This effect will vary according to the exact amount of exposure and ideal data will be suitable for a range of exposure levels. Ecotoxicological data are available with a high degree of confidence for most of the chemicals used in Scottish aquaculture. Similarly much of the effects of nutrient enrichment can be quantified for target organisms, for a range enrichment levels. Additional effect studies can be carried out where necessary to determine the range in responses of biomarkers to any given input. Where uncertainty comes in is in the combined effect of a variety of inputs.

Risk Characterisation.

The risk characterisation will calculate a hazard quotient of any given impact, based upon the likelihood of exposure and the scale of impact. Uncertainty can be combined with the scale of potential negative impact to inform the level of precaution. The risk of impact to a particular endpoint can be calculated as a hazard quotient based upon a variety of given management options.

The level of risk to benthic communities 100m away from the pens can be calculated for a range of stocking densities. Chemical concentrations reaching nearby shellfish populations can be calculated and compared with levels for other treatment chemicals. Likely sea lice numbers and numbers of wild stocks migrating can be predicated although a high level of uncertainty will be highlighted in the pathway from source to endpoint, until further study is done.

Risk Management.

With the benefits of a fully flexible ERA that has the potential to increase in value as further research data are added, management decisions can be made in a more informed way. Although there remain areas of uncertainty, management know that decisions are being made with the benefit of all possible appropriate information.

Typical management decisions for a new salmon farm are very wide ranging in their scope. They must consider the size and stocking density of the unit, the diet selection, the feeding technique, the number of staff and auxiliary vessels, the exact location and the appropriate chemical treatments, to name but a few. For each of these considerations the ERA will provide a hazard quotient and an associated confidence in that figure for the impact of any given action on a particular endpoint.

Risk management is really about how these figures generated by the ERA are used. At this stage the framework may involve a legislative requirement to re-open up the consultative process in an attempt to have an open and fully participatory management process. Another requirement that may be proposed in the framework may be to invoke precaution where uncertainty and potential negative impacts are both high. This should be considered with caution, particularly given the concerns over the increased complexity and cost over resolving more of the complex micro-scale interactions that lie behind many of the process pathways. Often further research only serves to highlight further uncertainties.

The major questions for the industry in Scotland relate to what extent cost benefit analysis can be integrated into environmental management decisions. Where environmental impacts are identified, to what extent will there be legislative requirements for aquaculture management to take mitigative steps. In short, when all of the environmental consequences are apparent at the management table, where do they lie in order of priority with economic, social, legal and political considerations.

Appropriate scale of application.

The process outlined above details application of ERAs at individual farm level. It is evident that there are countless areas of potential impact and sources of varying degrees of uncertainty. At individual farm level the ERA may be at its most complicated as the levels of exposure are small and the impacts beyond the very local level will be highly uncertain. The great advantage that the ERA has over an

EIA for use as an assessment tool at site level is its flexibility. As a management tool the ERA may be used to look at the environmental consequences of slight changes in practice and selection of appropriate site location and size. In this way, it may be quickly possible to see the effects of a slight relocation, an adjustment of stocking capacity or an introduction of a more efficient feed system. When progress is made in reducing highlighted areas of uncertainty, these findings can be incorporated into the ERA to ensure its continued and improving environmental use.

For the initial adoption of ERA it may be more appropriate to make use of the tool on a larger scale. A national trial of ERAs on a project for the whole of the West Coast of Scotland may serve many purposes. It would act as a valuable way of developing a framework and software solution for ERAs geared toward aquaculture. It would highlight at a national level, areas of vital further research work where concerted and properly funded action could be initiated. Finally it would be a valuable exercise in its own right to try and assess the carrying capacity for salmon production and provide an indication of the relative environmental impacts of anthropogenic activities on the West Coast.

So could ERAs be of significant benefit?

Will this process of ERAs improve or inform the argument that currently surround Scottish salmon production? The first area of concern is that this new process will not remove all uncertainty and still allows for some degree of subjectivity in decision making. Given that uncertainty is the defining characteristic of this heated argument it is tempting to say that the ERA has been of little benefit beyond what would be offered from a detailed EIA.

In fact there are several advantages of the ERA, even given the continuing areas of uncertainty. In planning and development of further aquaculture expansion the ERA can come in a significantly earlier stage of the proceedings than an EIA. An EIA attempts to predict and, where possible, mitigate the impacts of a proposed development at a predetermined location, whereas an ERA can be used to evaluate the possible scale, location and production techniques, before a final proposal is decided upon.

By introducing a properly flexible tool at the early stage of the development it is possible to provide informed responses to a wide range of management questions. Questions about which location will have least impact, whether the impact dramatically increases above a certain production scale, or even whether an investment in automated feeding systems really make a difference environmentally, can all reasonably be answered.

The ERA is extremely good at highlighting areas of further study, which can kick-start a process of research. In this way, uncertainty is tackled and the subsequent findings can be added to the tool as soon as they are published. There are, however, some questions of concern around this highlight-study-incorporate, approach to uncertainty. Will new quantitative findings be of any real use in confidently removing assumptions? And will the investment in research be rewarded by a substantial reduction in uncertainty and a consequential environmental benefit? Many of the more basic research questions have been answered over the years. In the quest to solve increasingly detailed levels of uncertainty is there a risk of being caught in a trap of ever decreasing returns on the investment?

The ERA does not provide a clear set of management solutions from responses to questions. For example, if one location would have dramatically less impact on the benthic community, the decision may still be dominated by the increased cost associated with siting in deeper, faster flowing water. The ERA does not give a prescriptive suggestion of how uncertainty should be dealt with. Where there is high uncertainty and the potential impact is great, should a high level of precaution be invoked? For example, real uncertainty is likely to remain over the pathway between farm nutrient enrichment and toxic algal blooms. In this instance the potential cost is the closure of the shellfishery. So given that uncertainty and potential impact are high should precautionary principle be invoked? The ERA itself does not answer this question.