# 2 ENVIRONMENTAL INTERACTIONS AND IMPACTS, RISKS AND UNCERTAINTIES ASSOCIATED WITH COASTAL AQUACULTURE

## 2.1 Environmental interactions and impacts of coastal 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). Underlying plans for sustainable long-term production is the presumption that these water quality measures will be maintained at levels consistent with environmental conditions that minimise stress for the production species. Past experience shows that sometimes, when aquaculture is initiated, it has been unable to maintain the desired quality in the water or sedimentary environments.

On a global scale, the most common causes of environmental concern include:

- nutrient enrichment: the release of nutrients through uneaten food, faeces, pseudo-faeces and dissolved metabolites to the sediment and water column.

- habitat change and loss: changes in seabed or river bottom habitats due to the accumulation of organic matter or other waste; or the loss of habitat due to modifications of coastal land and wetland to meet the requirements of coastal aquaculture.

- impacts on wild fish and shellfish populations: the escape of farmed fish and their subsequent interbreeding with wild fish; introduction of exotic species (including disease and parasites); increased abundance of pathogens.

- chemical pollution: primarily related to release of therapeutic chemicals used in the treatment of disease, including parasitic infections.

- secondary impacts on other production systems: social, economic and environmental consequences arising from increased demand for inputs (goods and services) such as fish meal, or transportation.

Within these general topics there is a large number of specific environmental interactions. These have been discussed and reviewed in numerous papers and books (for example, Asche *et al.* 1999; Barg 1992; Black 2001; Cognetti *et al.* 2006; GESAMP 1991, 2001; Gray *et al.* 2002; Hindar 2001; Nash *et al.* 2005; Naylor *et al.* 1998; Youngson *et al.* 2001 ). Although the consequences of the interactions 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 consequences of the interactions are subtle and cumulative – often insignificant in relation to a single farm, but potentially significant for a large number of farms producing over a long period of time;

- some of the consequences may be highly dispersed through space and time;

- there is a high level of uncertainty and ignorance associated with many potential consequences.

## 2.2 Global experience of environmental management of aquaculture

It is generally agreed that aquaculture development needs to be well planned and managed if it is to achieve its full potential as a sustainable use of marine resources (GESAMP, 2001). Many countries already attempt to manage the aquaculture sector through some form of regulation (e.g. licensing associated with design, geographic or operational conditions). This regulation is often *ad hoc*, arising as a result of specific problems or concerns. In some countries, Environmental Impact Assessment (EIA) is applied, this allows for a more thorough appraisal of social and environmental problems, 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). There has been some application of Strategic Environmental Assessments (SEA) to coastal aquaculture to help ensure that significant environmental concerns arising from regional or national policies, plans and programmes are identified, assessed, mitigated, monitored and communicated to decision-makers. SEA also can create opportunities for public involvement. Finally, there is increased interest in codes of conduct, for the industry as a whole and for individual farms (FAO Fisheries Department 1997; FEAP 2006; Naylor *et al.* 1998; Phillips and Barg 1999; Hambrey 2000).

Unfortunately, these various regulatory approaches have often proved to be less than ideal, because assessment of the effects of individual farms, through an EIA, can fail to address the cumulative, dispersed, and uncertain impacts of aquaculture development. There are still relatively few examples of sector level assessments or management plans (Thompson *et al.* 1995), or of the effective integration of aquaculture development planning within broader integrated coastal management initiatives (GESAMP 2001), 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 are required – for example, where the sector is developing rapidly and is under little or no control (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 level of change in the environment. 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 can be the case with aquaculture.

This uncertainty and ignorance has led to calls for moratoria in some countries on some types of aquaculture, such as shrimp and salmon culture. The precautionary principle has often been invoked as the basis and rationale for such moratoria. However, that response is far from ideal. It reflects weaknesses in our ability to make decisions in the face of uncertainty. The effects of moratoria are almost all negative in that they create delays in the development process (where development is appropriate), imply uncertainty as to what is an acceptable level of development, and serve to maintain the state of incomplete scientific knowledge, uncertainty and lack of confidence in decision-making. The problem is the inability of many management systems to support managers making decisions in the face of uncertainty in the relevant risks.

An approach is required that :

- includes processes to clarify areas of ignorance and identify and isolate areas where knowledge is lacking;
- handles uncertainty in a constructive way while balancing realistic concerns and objectives and;
- provides a recognised and agreed sound basis for discussion.

In moving towards such an approach, it is helpful to consider in more detail the nature of risk and uncertainty, how they can be measured, and how regulatory processes have evolved to meet the challenge, for example, through the formulation of the Precautionary Principle.

## 2.3 Risk and uncertainty

### *2.3.1 The nature of risk and uncertainty*

We constantly make risk assessments in our daily lives. We take responsibility for our actions, however mundane, and the hazards associated with them, based upon an assessment of the likely dangers and probability of undesirable outcomes. Through making such an assessment, we are able to consider simple measures to reduce risk, and where we deem it necessary, alter our actions to reduce the intensity of the hazard, and thereby 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. Individuals differ in their willingness to accept risk, for example, display different risk thresholds, and therefore the resulting decision is likely to vary from person to person, and we may find ourselves crossing alone. Similarly, the level of precaution applied to the potential environmental effects of coastal aquaculture is likely to vary according to culture and circumstance, perhaps expressed as national or local policy. It has to be agreed. It cannot be established scientifically, although it may be expressed in quantified scientific terms.

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 modify our perception of the level of risk, and influence our decisions accordingly. It is in the treatment of uncertainty and lack of information 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. 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.

### *2.3.2 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).

The general public and experts can view risk from very different perspectives. In a 1987 publication by Slovic, experts and members of the public were given a list of 30 activities to rank according to the level of perceived risk. Slovic (1987) also investigated the attributes of an activity that affected people's view of the associated risks. The attributes broadly divided into two broad groups of factors. One group was typified as describing unknown risks, that is, those that where the activity was new, the associated risks were not generally well covered by science, and where the effect was delayed (after the activity) and the effects were not observable. Examples of these, at that time included: Laetril, microwave ovens, and electric fields. The other group describe a 'dread' of the risk. Those factors included the geographic extent of the effect and its severity (for example, was it globally catastrophic or lethal to humans) the duration of the effect (for example, was it going to affect future generations), was exposure a matter of personal choice, and were the effects controllable. Examples of risk with a high contribution of these factors included: nuclear warfare, nuclear fallout and nerve gas accidents.

If terminology used to express risk is to reflect and integrate differing perceptions of risk by different stakeholders in a participatory management scheme, Slovic's work makes it clear that communication (the topic of Chapter 5) is critical to risk management strategies and that the technical risk analysis performed by scientists must explicitly address issues such as geographic and temporal extent, the duration of the effect, how the effect is generated, and the degree to which it can be controlled.

From a science perspective, 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.

Public participation in the decision-making process will, in part, be determined by whether participants agree on the need for an analysis, their willingness to identify the agent of potential environmental change and, the specific mechanism of interaction of those agents with the environment. As mentioned in section 2.1, there are numerous published accounts of specific examples of an agent released by aquaculture (such as the placement of structures that may redirect currents, pathogens, the culture organism or organic matter) and the consequences of interactions involving the specific agent (such as the redistribution of sediments, reduced survival of a wild population due to disease or genetic interbreeding and displacement of bottom fauna). As the references in section 2.1 often demonstrate, most of the effects commonly discussed focus on a single agent and a single outcome. Most decision-making will ultimately is made on the basis of the possibility of one or a very few changes. However, most interactions between human activities and ecosystems are multifactoral and part of the challenge in preparing to make an evaluation of risk is to list the potential interactions and agree on the combinations of hazards and consequences that are of greatest concern. An example of an approach to identifying critical multifactoral causes and ecological effects as part of risk analysis for capture fisheries is presented by Astles *et al.* (2006).

In practice, there is usually a chain of effects arising from a particular action or release of a risk agent. In this case, combining the probabilities down the chain may generate the probability of any intermediate consequence, or of the final consequence. Physical environmental processes may provide only a few cause and effect links, and the probability associated with the final effect may be estimated with reasonable confidence. However, 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 unreliable 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 the effect (Caddy and Mahon 1995).

So can the level of uncertainty be measured in any meaningful way? Scientists use statistical 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 an unrealistic objective. Where this is possible, confidence limits will in any case be wide for most ecological effects through the necessary combinations of uncertainty down the cause/effect chain.

## 2.4 A precautionary approach

The need for precaution in environmental management has become increasingly clear in recent decades as the inadequacies of reactive and various *ad hoc* approaches have become apparent. Precautions, or at least enhanced levels of caution, are also a natural and appropriate response to uncertainty in the prediction of the outcomes of actions.

### *2.4.1 Regulatory approaches based on assimilative/environmental capacity*

Industry, and society in general, have had traditional rights of access to, and use of, marine resources. This has been based upon the view that the marine environment has an assimilative or environmental capacity. This presumes that all environments have a finite ability to accommodate exploitation or contamination without unacceptable consequences (Gray 1998). GESAMP described 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).

Traditionally, consent to discharge waste has been given on the condition that monitoring to ensure that the assimilative capacity is not exceeded. The obvious weakness of this approach is that the undesirable environmental consequences may only be evident once the environmental capacity to absorb the waste has been exceeded. This is a particularly dangerous approach to planning and legislation if the effects are irreversible.

It is inevitable, if working to the assimilative capacity through a ‘monitor-response’ regulatory framework, that measures 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 repeating cycle of low cost effluent disposal followed by high cost remedial action when the assimilative capacity has been exceeded.

A further criticism of this approach is that it makes little 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 (Gray 1998).

### *2.4.2 The Montreal Guidelines*

In 1985, UNEP attempted to overcome some of the difficulties of existing marine pollution control policy. The Montreal Guidelines (UNEP, 1985) for governments were an attempt to give greater consideration to local variations in the marine environment and tackle the problem of marine pollution from land based sources. The guidelines were based on a need to have strict emission controls and marine quality standards. These should give clear consideration to water and sediment quality, as well as using fish assemblages and biological community structures as indicators of environmental health. The Guidelines also recommend that planning applications should include Environmental Impact Assessments.

These Guidelines build upon some of the principles of assimilative capacity and other existing approaches 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 conditions within an ecosystem prior to impact, nor was there any quantitative indication of the levels of environmental standards. More particularly, no framework was provided for the process of deciding upon appropriate localised marine standards. Further work was still required for the evolution of an effective regulatory framework (Gray 1998).

### *2.4.3 The Precautionary Principle*

In recent years, the precautionary principle has emerged as a popular approach to deal with uncertainty in science-based decision making. Article 15 of the United Nations 1992 Conference on Environment and Development defined the precautionary principle as “lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation”. While the broad sentiment behind the statement is generally agreed upon, the principle has never been accepted as a general principle of international law. A number of factors contribute to the reticence to enshrine the principle in law. The precision of the definition has been problematic. Ronald Doerling, former Vice President of the Canadian Food Inspection Agency, illustrated several of these in an invited plenary speech at Aquaculture 2004 in Montreal, Canada. Among his comments, he pointed out that working interpretations of the principle varied significantly, and that the Swedish philosopher Sandin documented no less than 19 variations in the principle’s definition in laws, treaties and academic writings. The versions differed in the interpretation of how scientific uncertainty was evaluated, how severity of consequences is considered, how the costs and risks are to be balanced and, from a legal perspective, how the onus shifts to the proponent to prove (if that is ever possible) that the proposed process or product is safe.

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 crops containing material from genetically modified organisms, 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 lack of information, 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.

The 4th International Conference on the North Sea, held in Esbjerg, Denmark in 1995 (Oslo and Paris Commissions 1995), in formulating an approach to the control of eutrophication, stated that there should be scientific proof of a lack of eutrophication arising from anticipated nutrient inputs prior to consent to discharge nutrients being granted. In practice, scientifically proving a negative is impossible, especially in complex physical and biological systems.

Notwithstanding this problem, many analysts link the precautionary principle to such 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 and developments 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).

## 2.5 Interpretation and application of the Precautionary Principle

Applications of the precautionary principle or precautionary approaches, 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. For example, 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 outcome 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*" (Wingspread 1998); a definition that would effectively prevent the implementation of most new technologies. On the other hand, some commentators have suggested that the principle is fundamentally flawed and logically contradictory with suspicion ruling over science (Gray 1998).

However, most people would agree that the spirit of the principle is that we should be careful when embarking on something new; we should be reasonably convinced that no unacceptable harm will come of it; and we should be particularly careful when there is much uncertainty or ignorance about possible outcomes. 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. Further, what is 'reasonable' is a question of social values and not definable in the context of the physical, biological or ecological sciences. The principle also does not require developers to prove absolutely that something is safe (Saunders 2001). As noted above, this is impossible from a logical and scientific viewpoint. However, it does require 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 representing opposed factions or positions), the key arguments presented, and a decision is made by some impartial and transparent process. 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 goes some way to understanding how national differences in the interpretation of the precautionary principle can arise. Developing countries may 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 (European Commission Press Release IP/00/96, 2 February 2000 and related commentary) 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 part, explicitly or implicitly, of 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 alter. However, only an extreme position would hold 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 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 explicitly address risk and uncertainty, and feed them into a transparent and accountable decision-making process. This process should explicitly link the acceptable level of precaution with the requirements of international agreements and legitimate local needs and aspirations.

Only a socio-political process can determine what is acceptable. Consistent application of these criteria for acceptable environmental change requires that the changes be identified as measurable endpoints (parameters) of environmental significance. The designation of these endpoints is critical to the development of an accurate and effective environmental assessment (*see* EPA 2003) for a discussion on how endpoints may be derived). The endpoints generally will be applicable to the assessment of the environmental effects of a number of industries or activities (including fisheries activities such as stock enhancement or definition of gear types to be used in a particular fishery). To ensure that a particular economic or environmental assessment does not influence the derivation of these endpoints, they should be derived independently and prior to the initiation of a risk assessment.

Improvements to the decision-making processes can be provided through the procedures and protocols of risk assessment in a Risk Analysis framework. In the next section, we examine how Risk Analysis can improve the analysis, characterisation, and communication of risk and uncertainty.

It should be noted that this paper does not address the risks arising from the culture of newly introduced exotic species. The analysis of these hazards is covered by existing guidelines, for example the ICES Code of Practice for the Introduction and Transfer of Marine Species. In the European Union, statutory regulations built on the ICES Code are currently under discussion. Similarly, potential disease interactions are thoroughly covered by the ICES Code and the OIE protocols. Additionally, hazards associated with the quality of the foodstuffs produced through coastal aquaculture are controlled by application of the Codex Alimentarius (1999) and associated international/national legislation.

## 2.6 Objectives for risk assessment and analysis

The intent of this section is to define the objectives that risk analysis needs to achieve so that it supports effectively governance schemes promoting sustainable resource use that incorporate the precautionary principle as part of the management of the effect of Man's activities on the environment.

1. Integration into Sustainable Use Paradigms: Risk assessment (a science-based assessment) must be integrated into a broader socio-economic decision-making process to determine resource allocation for sustainable use. Risk analysis provides the basis for doing this through use of the table of levels of acceptable protection, as well as a consistent and explicit mechanism for transparent application of the precautionary principle.

2. Separation of Scientific Analysis from Valuation: Risk assessment is a science-based analysis. In itself, it does not determine if a predicted outcome is good or bad, acceptable or unacceptable. Determination of these values can only occur when the predicted outcome is combined with social and economic information.

3. 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.

4. Transparency: To optimise the accuracy, effectiveness and social licence for aquaculture activities, risk communication must start early in the Risk Analysis process and communicate the information stakeholders and decision-makers require in a manner they can utilise.

5. Consistency: Measures should be comparable in nature and scope with measures already taken in equivalent areas in which scientific data are available.

6. Proportionality: Risk management measures must not be disproportionate to the marginal change in risk and to the desired level of protection. Coastal aquaculture can represent only minor marginal risk of change when compared with a multitude of other coastal anthropogenic activities). Also, risk management must not aim for zero risk. Where no hazard can be identified, the risk assessment should be concluded and evaluated as non-significant.

7. Ongoing Monitoring of Predicted Effects: Where ongoing monitoring is identified as a necessary component of risk management, the initial analysis should be considered provisional. The availability of more reliable scientific data may lead to changes in our understanding of the mechanisms leading to environmental change and the level of risk (increased or decreased) associated with an aquaculture decrease. A requirement to monitor must be linked to requirements to regularly report on the outcome of the monitoring, and for regulators to make reasoned assessments of the significance of the monitoring results.

## 2.7 Literature cited

Asche, F., Guttormsen, A.G. and Tveterås, S. (1999): Environmental problems, productivity and innovations in Norwegian salmon aquaculture. Aquaculture Economics & Management, 3, (1),19-29.

Astles, K.L., Holloway M. G., Steffe, A., Green, M., Ganassin, C. and Gibbs, P.J. (2006): An ecological method for quantitative risk assessment and its use in the management of fisheries in New South Wales, Australia. Fisheries Research 82, 290-303.

Barg, U. (1992): Guidelines for the promotion of environmental management of coastal aquaculture development. FAO Fisheries Technical Paper No. 328, 122 p.

Black, K.D. (ed.) (2001): Environmental impacts of Aquaculture. Sheffield Academic Press, 214 p.

Caddy, J. F. and Mahon, R. (1995): Reference points for fisheries management. FAO Fisheries Technical Paper No. 347. FAO, Rome. 83 p.

CODEX (1999): Codex Alimentarius Commission. Principles and Guidelines for the conduct of Microbial Risk Assessment. CAC/GI-30, 6 p.

Cognetti, G., Maltagliati, F., Saroglia, M. (2006): The risk of genetic pollution in Mediterranean fish population related to aquaculture activities. Marine Pollution Bulletin 52, 1321-1323.

EPA (2003): Generic Ecological Assessment Endpoints (GEAEs) for Ecological Risk Assessment. Risk Assessment Forum, U.S.

Environmental Protection Agency, Washington D.C.,EPA/630/P-02/004F, October 2003. 59 p.

FAO Fisheries Department (1997): Aquaculture development. FAO Tech. Guide. Responsible Fisheries, No. 5, 40 p.

FEAP (2006). Federation of European Aquaculture Producers Code of Conduct. www.feap.info/FileLibrary/6/FEAP%20Code%20of%20Conduct.pdf, 9 p.

GESAMP (1986): GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Environmental Capacity. An approach to marine pollution prevention. Rep.Stud.GESAMP No. 30, 49 p.

GESAMP (1991): GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Reducing environmental impacts of coastal aquaculture. Rep. Stud.GESAMP No. 47, 35 p.

GESAMP (2001): GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Planning and management for sustainable coastal aquaculture development. Rep. Stud. GESAMP No. 68, 90 p.

Gray, J. S. (1998): Risk Assessment and Management in Exploitation of the Seas. In: Handbook of Environmental Risk Assessment and Management. Ed: Calow, P. Blackwell Science, 453-474.

Gray, J. S., Wu, R.S. and Or, Y. Y. (2002): Effects of hypoxia and organic enrichment on the coastal marine environment. Mar. Ecol. Prog. series 238, 249-279.

Hambrey, J.B. (2000): Environmental management of aquaculture development. Infofish International, 2000 (5), 25-29.

Hindar, K. (2001): Interactions of cultured and wild species (draft). Marine Aquaculture and the environment: a meeting for stakeholders in the Northeast, University of Massachusetts, Boston MA Jan 11-13 2001.

Nash, C.E., Burbridge, P.R. and Volkman, J.K. (2005): Guidelines for Ecological Risk Assessment of Marine Aquaculture. NOAA Technical Memorandum NMFS-NWFSC-71, 90 p.

Naylor, R.L., Goldburg, R.J., Mooney, H., Beveridge, M., Clay, J., Folke, C., Kautsky, N., Lubchenco, J., Primavera, J. and Williams, M. (1998): Nature's Subsidies to Shrimp and Salmon Farming. Science 282, 883-884.

Oslo and Paris Commissions (1995): North Sea Ministerial Declaration, Esbjerg, June 1995. Oslo and Paris Commissions, London. 21 p.

Phillips, M.J. and Barg, U. (1999): Experiences and opportunities in shrimp farming. In: Svennevig, N., Reinertsen, H. and 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, 43-72.

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/coglobalize/MaeWanHo/PrecautionP.html

Thompson, S., Treweek, J.R. and 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, (45), 219-229.

UNEP (1985): Protection of the marine environment from land-based sources. Montreal guidelines, Environmental Policy and Law, 14/2/3, UNEP, Nairobi, 77-83.

Wallace, J. (1993): Environmental considerations: In: Salmon Aquaculture. Fishing News Books, London. 127-143.

Wingspread (1998): Wingspread Statement on the Precautionary Principle. Wingspread Conference Center, Racine, Wisconsin, 23-25 January 1998. http://www.sehn.org/wing.html

Youngson, A.F., Dosdat, A., Saroglia, M., and Jordan, W.C. (2001): Genetic interactions between marine finfish species in European Aquaculture. Journal of Applied Ichthyology, 17, 153-162.