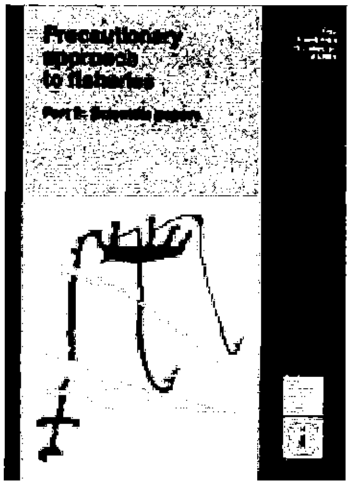

FAO FISHERIES TECHNICAL PAPER 350/2

Precautionary approach to fisheries
Part 2: Scientific papers

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to Capture Fisheries (Including Species Introductions)
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PREPARATION OF THIS DOCUMENT

This document contains the invited scientific papers prepared as background material for the Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introductions) organized by the Government of Sweden in cooperation with FAO in the Fisheries Laboratory of Lysekil (Sweden, 6–13 June 1995) with the participation of the following experts:

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Bronze-age rock carving from the parish of Kville, Bohuslän, Sweden. From thousands of rock-carvings in western Sweden this is the only known scene showing fishing. Originally described by Åke Fredsjö, 1943: En fiskescen på en bohuslänsk hällristning- Göteborgs och Bohusläns Fornminnesförenings tidskrift 1943: 61–71. Later documentation by the same author in: Hällristningar i Kville härad i Bohuslän. Kville socken. Del 1 och 2. - Studier i nordisk arkeologi 14/15, Göteborg 1981, 303 pp., Pl. 158 II. Published by Fornminnesföreningen i Göteborg.

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ABSTRACT

The document has been prepared to be used as a background document to the FAO Guidelines on the Precautionary Approach to Fisheries and Species Introduction (FAO, 1995). It contains a series of scientific papers prepared to provide a comprehensive review and analytical background for the drafting of guidelines on the precautionary approch to fisheries by the Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introductions) organized in Lysekil, Sweden, 6–13 June 1995 by the Government of Sweden in cooperation with FAO. It provides a comprehensive review of the concept of precaution in all aspects of fisheries and of its implications for fishery research, technology development and transfer, as well as for conservation and management. It also provides with a series of topical papers on: (a) the development of scientific advice with incomplete information; (b) risk assessment, economics and precautionary fishery management; (c) precautionary management reference points and management strategies; (d) the assessment of the precautionary nature of fishery management strategies; (e) the precautionary approach to species introduction; and (f) the precautionary aspects of fishery technology development.

Distribution:

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THE PRECAUTIONARY APPROACH TO FISHERIES AND ITS IMPLICATIONS FOR FISHERY RESEARCH, TECHNOLOGY AND MANAGEMENT: AND UPDATED REVIEW

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Abstract

The uncertainty attached to the available understanding on the bio-ecological, economic and social processes in the fisheries systems are now formally recognized in the major international instruments such as the UN Agreement on the Implementation of the Provisions of the 10 December 1982 Convention on the Law of the Sea Relating to Straddling Fish Stocks and Highly Migratory Fish Stocks (1995) and the FAO International Code of Conduct for Responsible Fisheries (1995). The effective implementation of the precautionary approach in all the aspects of fisheries requires understanding from all concerned. This paper, which follows and updates a document presented in 1994 to the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, clarifies the objectives of the precautionary approach, reviews the trends and perspectives in the perceptions, adoption, and application of the precautionary principle and approach in fisheries, at UNCED, in FAO, UN, ICES, IMO, ICLARM, CCMLAR, and by non governmental organizations (NGOs). The paper examines the issues of uncertainty, error and risk in fisheries and their potential consequences. Subsequently, the paper identifies the implications of the concept of precaution for fisheries research, technology development and transfer, as well as for conservation and management, offering in each case a set of guidelines for implementation. In so doing it offers some analysis of key related issues such as: the burden of proof and the use of the "best scientific evidence" in a precautionary context, the potential for Prior Informed Consent (PIC) and Prior Consultation Procedures (PCPs), Environmental Impact Assessment (EIA), pilot projects and technology lists, the concept of "acceptable impacts", the role of Target Reference Points (TRPs) and Limit Reference Points (LRPs) in precautionary management. In conclusion, the paper proposes a typology of approaches including the preventive, corrective, and precautionary approaches as well as the precautionary principle itself, showing their respective complementary roles in relation to the degree of uncertainty and resulting amount of risk.

INTRODUCTION

There is an obvious link between the sustainable development of fisheries and their precautionary management. In 1988, the 94th Session of the FAO Council agreed that "*Sustainable development is the management and conservation of the natural resource base, and the orientation of* *technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development conserves land, water, plant genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable.*" This definition applies well to sustainable fisheries development and management.

The strategies required to ensure a high degree of sustainability in human use of natural renewable resources systems are not easy to conceive and implement for at least two reasons: (a) our insufficient understanding of the laws governing these systems and the inherent uncertainty about the consequences of our decisions, and (b) the inadequate nature of our institutions and controls (Holling, 1982; 1994), particularly on access to resources. It is generally agreed that the inadequacy in management results essentially from the open access nature of the fisheries and the lack of effective mechanisms to directly control fishing effort levels in the absence of an explicit agreement on the allocation of resources between users. It is also being realized that, in addition, the problem lies partly in the non-recognition of the high levels of uncertainty that characterize fisheries and the related lack of precaution in most management regimes. The review of the state of world fishery resources undertaken by FAO and the global analysis available in the FAO report on the State of Food and Agriculture (SOFA) show that, although management practice has favourably evolved during the last half century, it has tended to lag behind management theory and that progress towards sustainability, since the first FAO Technical Committee on Fisheries in 1945, has been insufficient. It is now recognized that the biomass of many important fish stocks is close to or even below the level that could produce the maximum sustainable yield (MSY), leading to resource instability and economic losses. A number of fisheries have collapsed ecologically or economically and the situation in the high seas raises particular concern. In many areas, the present situation is one of resource erosion, economic losses and social dislocations that illustrate the fisheries management risk and reflect behaviour which in the last decades has been neither sufficiently responsible nor precautionary (Garcia, 1992; FAO, 1993; Garcia and Newton, 1994; 1995).

The increased recognition that conventional fishery management needed to be improved has been accompanied by a growing concern for environmental management, particularly as a result of the World Conference on Human Environment (Stockholm, 1972), the FAO Technical Conference on Fishery Development and Management (Vancouver, 1973), the FAO World Conference on Fisheries Management and Development (Rome, 1984), the United Nations Convention on the Law of the Sea (hereafter, the 1982 Convention), the work of the Brundtland Commission from 1984 to 1987 (World Commission on Environment and Development, 1987), the United Nations Conference on Environment and Development (Rio de Janeiro, 1992), the International Conference on Responsible Fishing (Cancun, Mexico, 1992) and the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (New York, USA, 1993–1995). Moreover, the emerging awareness of the complexity of marine ecosystems and related scientific uncertainty, particularly in the high seas, and of the risk of error in management, requires an acceleration of the evolution of fishery management, a broadening of its scope and a change in attitudes. Two important and related requirements of the new management context are the need for more caution and for better inter-generational equity. The latter issue concerns the ethics of renewable resource use and the moral obligation placed on the current generation to exploit the resources and enact conservation measures in such a manner as to preserve options for future generations.

The poor control of fisheries development by fishery management authorities is one of the major reasons for the present state of fisheries. In natural ecosystems, the abundance of preys and predators, and their variations, are controlled and maintained within limits compatible with the ecosystems sustainability by a set of complex interactions and feed-back mechanisms. In ecological terms, fisheries are organized "top predators". As such, their survival depends on the survival of their living resources and they are certainly far more sensitive to natural feedback information on the state of the resources they exploit than industrial systems using oceans as a resource for waste-dumping. However, contrary to natural predators, fishermen are not entirely controlled by feedback signals of resource stress. Their operations are not totally dependent on the abundance of the various elements of the resource ecosystem and, indeed, are partly isolated from such feedback controls by various mechanisms such as price increases (as resources become scarcer), technological improvements in efficiency, shifts to other species or areas, and governmental subsidies. They can, therefore, continue and even expand their operations despite the environmental and resource degradation they may produce.

Section 1 of the document defines the objectives of the precautionary approach in the specific field of fisheries. Section 2 proposes some definitions of key concepts used in the document. Section 3 provides an updated review of trends and perspectives in the development in the concepts and applications of the principle of precautionary action, including both the precautionary principle and precautionary approach. Section 4 concentrates on one of the major issues related to, and indeed justifying, precaution such as the uncertainty due to incomplete knowledge, the potential errors in decision-making and the consequent potential risk. Sections 5, 6 and 7 describe the implications of the precautionary approach and provide practical guidance for its application in the respective areas of research, technology development and transfer, and conservation and management. The conclusion provides a summary of the approach and its prospects, focusing particularly on management.

1. OBJECTIVES OF THE PRECAUTIONARY APPROACH

The modern requirement to deal explicitly with uncertainty, in order to reduce risks to the resources and their environment (and indeed to the fishing communities), requires significant changes in the fields of science, technology and fishery management. Such changes are required in order to effectively deal with the unprecedented shift in policy and international relations and with the metamorphosis of public perceptions and political demands resulting from the 1982 UN Law of the Sea Convention, UNCED and its Agenda 21. One of the elements of change is the requirement for a more precautionary approach to natural resources management. The **concept of precautionary action** aims generally at improving conservation of the environment and the resources by reducing the risk of inadvertently damaging them. More specifically, it aims at helping decision-makers and regulators to take a safeguarding decision, when the scientific work is inconclusive but a course of action has to be chosen. In addition, it intends to promote a more equitable balance between the short-term considerations (which led to the present environmental degradation and overfishing) and long-term considerations such as the need to conserve resources for future generations. It aims at promoting inter-generational equity by reducing the cost of our decisions for future generations and by counteracting the effects of current high economic discount rates which provide a strong incentive to overfish, maximizing the discounted net benefits from a stock and, *de facto*, giving preference to present consumption over future consumption[1]. By comparison, and despite the fact that it theoretically aims at sustainability, conventional fishery management addresses primarily, and rather inefficiently, the issue of inter-generational equity and allocation of resources between present users. The concept of precautionary action will also directly benefit present generations of fishers and consumers if fishery authorities and industry actively promote its implementation by other economic sectors whose activities damage ocean productivity, fishing communities' livelihood and consumers' health[2].

[1]This factor often leads to proposals to introduce a social discount rate. However, there are severe practical difficulties in determining and implementing such rates. A more satisfactory solution would appear to be through proper pricing of resources, including not only the marginal cost of harvesting, but also the foregone value of catches no longer available to future generations

[2]Opportunity to promote this approach is given by the growing requirement to integrate coastal fisheries management into the Integrated Coastal Areas Management (ICAM) within which inter-sectoral competition for resources should be organized and controlled

2. DEFINITIONS

The literature on the precautionary principle or approach is loaded with terms the meaning of which may not always be obvious or universally agreed and, in order to facilitate common understanding, this section proposes some definitions with their source. The original ones draw heavily from the discussions in the following sections and should be considered together with them.

Acceptable impact: A negative, or potentially negative, alteration of the exploited natural system, resulting from human activities (i.e., fisheries and other impacting industries), the level and nature of which, on the basis of available knowledge, is considered as representing a low enough risk for the resource, system productivity, or biodiversity. Its acceptability is continuously kept under review and can be revocated on the basis of new knowledge.

Approach: "A way and means of reaching something. The method used in dealing with or accomplishing something" (Houghton Miflin Co., 1992).

Precaution: "An action taken in advance to protect against possible danger or failure; a safeguard. Caution practised in advance. Forethought or circumspection" (Houghton Miflin, 1992). Action taken in advance of scientific certainty but within the bounds of scientific uncertainty, to avoid or minimize negative impact, taking into account the potential consequences of being wrong (modified from a definition in relation to global climate change by Turner, O'Riordan and Kemp, 1991).

Precautionary approach: A set of agreed cost-effective measures and actions, including future courses of action, which ensures prudent foresight, reduces or avoids risk to the resources, the environment, and the people, to the extent possible, taking explicitly into account existing uncertainties and the potential consequences of being wrong[3].

Principle: "A basic truth, an assumption. A rule or standard, especially of good behaviour. A fixed or predetermined policy or mode of action" (Houghton Miflin, 1992)[4].

Reference points: "A (management) reference point is an estimated value derived from an agreed scientific procedure and an agreed model to which corresponds a state of the resource and of the fishery and which can be used as a guide for fisheries management"[5]:

> **Limit Reference Point (LRP)**: indicates the state of a fishery and/or a resource which is not considered desirable. Fishery development should be stopped before reaching it. If a LRP is inadvertently reached, management action should severely curtail or stop fishery development, as appropriate, and corrective action should be taken. Stock rehabilitation programmes should consider an LRP as a very minimum rebuilding target to be reached before the rebuilding measures are relaxed or the fishery is re-opened.
>
> **Target Reference Point (TRP)**: corresponds to the state of a fishery and/or a resource which is considered desirable. Management action, whether during a fishery development or stock rebuilding process, should aim at maintaining the fishery system at its level.
>
> **Threshold Reference Point (ThRP)**: indicates that the state of a fishery and/or a resource is approaching a TRP or a LRP, and a which a certain type of action (usually agreed beforehand) needs to be taken. Fairly similar to LRPs in their utility, the ThRPs' specific purpose is to provide an early warning, reducing further the risk that the TRP or LRP is inadvertently passed due to uncertainty in the available information or to the inertia of the management and industry system. Adding precaution to the management set-up, they might be necessary only for resources or situations involving particularly high risk.

Risk: In general, "the possibility of suffering harm or loss; danger. A factor, thing, element, or course involving uncertain danger, a hazard" (Houghton Miflin, 1992). In decision theory "the degree of probability of loss. A statistical measure representing an average amount of opportunity loss" (Kohler, Cooper and Ijiri, 1983). This terminology is used "when large amounts of information are available on which to base estimates of likelihood, so that accurate statistical probabilities can be formulated" (Pass *et al.*, 1991). The Technical Consultation on the Precautionary Approach to Capture Fisheries (FAO, 1995), in this case, refers instead to "*expected loss*" or "*average forecasted loss*" to clearly distinguish between the general meaning and the decision-theoretic one (see also Shotton, 1993).

Risk analysis: "Any analysis of unknown chance events for purposes of effecting or evaluating decisions in terms of possible penalties and benefits attending these events. A method for generating different probability distributions with accompanying cost and benefits that may attend different courses of action. Generally uses computer simulations" (Kohler, Cooper and Ijiri, 1983).

Uncertainty: "The condition of being uncertain. Doubt. Someting uncertain. In statistics, the estimated amount or percentage by which an observed or calculated value may differ from the true value" (Houghton Miflin, 1992). "The incompleteness of knowledge about the states or processes in nature" (FAO, 1995).

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[3]There is paradoxically no definition of the precautionary approach which is generally related to the need to take action even in the absence of "full scientific certainty" and defined by its implications. This definition has been developed by the author based on the definitions of "precaution" and "approach", above, and on UNCED Principle 15

[4]It can be noted that while the first part of this definition differentiates between the precautionary "principle" and "approach", the second part tends to blur the difference between the two concepts

[5]According to the *ad hoc* Working Group on Reference Points established by the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks in New York, in March 1994 (cf. Annex 5)

3. TRENDS AND PERSPECTIVES

There is no explicit reference to the principle in the 1982 Convention. Part XII, on "Protection and preservation of the marine environment", does not contain detailed instruments for implementation of the conservation of the marine ecosystem, but it does state in a global instrument, in article 192, the following general obligation: "*States have the obligation to protect and preserve the marine environment*" (Burke, 1991). In addition, ecosystem conservation also requires measures for the fisheries sector, striking a balance between the provisions for environmental conservation and fisheries management to ensure sustainable exploitation.

However, in fisheries, the concept of precautionary action seem to have progressively become an important factor in negotiations between States to establish management measures in circumstances where there is an obligation to negotiate in good faith to reach agreement (e.g., with respect to highly migratory, straddiing or shared fish stocks, under the 1982 Convention). It can be assumed that, given the wide support for this concept in environmental law, a State which refers objectively to it will hope that it cannot be accused of bad faith (Burke, 1991). The concept is also developing in national fisheries management regimes. The concept of precaution has been expressed as "the **precautionary principle**" (hereafter, the principle) or "the **precautionary approach**" (hereafter, the approach). Although the two terms relate equally well to the concept of caution in management, and sometimes not differentiated by scholars (e.g., Bodansky (1991) uses the two terms alternatively), they are differently perceived by international lawyers, negotiators and industry, as shown below. The term "approach" is apparently more generally accepted by Governments in the fisheries arena because it implies more flexibility, admitting the possibility of adapting technology and measures to socio-economic conditions, consistent with the requirement for sustainability. It is particularly more appropriate for fisheries because consequences of errors in their development or mismanagement are unlikely to threaten the future of humanity and, in most cases, are reversible. On the contrary, the term "principle" has developed a negative undertone

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because it is usually given a radical interpretation and has led to the outright ban of technologies, e.g., in the case of whaling (Bodansky, 1991) and the Large Scale Pelagic Driftnet Fishing (see below), and is sometimes considered incompatible with the concept of sustainable use. These two concepts are further elaborated below.

3.1 The Precautionary Principle

This principle's most characteristic attributes are that: (a) it requires authorities to take preventive action when there is a risk of severe and irreversible damage to human beings; (b) action is required even in the absence of certainty about the damage and without having to wait for full scientific proof of the cause-effect relationship, and (c) when there is disagreement on the need to take action, the burden of providing the proof is reversed and placed on those who contend that the activity has or will have no impact.

It seems generally agreed that the precautionary principle has originated in Germany as the "Vorsorgenprinzip" (Dethlefsen *et al.* 1993). The principle has been referred to and applied at national level in relation to human activities with potentially severe effects on human health (engineering, the pharmaceutical and chemical industries, nuclear power plants, etc.). In international environmental law, the principle has emerged as a recognition of: (a) the uncertainty involved in measuring the impact of toxic substance on the ecosystem and the human health, and (b) deciding on the "assimilative capacity" of such ecosystems (i.e., their ability to absorb a certain quantity of the substance in question without unacceptable impacts). In the 1970s, following the 1972 Stockholm Conference, concern for human safety was progressively extended to the human environment and to other species. This led to increasingly frequent reference to the principle in international agreements and conventions, often with limited consideration of its practical implications. It has been introduced at international level at the First International Conference on the Protection of the North Sea (1984) in relation to persistent toxic substances susceptible to bioaccumulation in the marine ecosystem. The 1987 Declaration of this Conference contains an example of the concept of precaution in relation to coastal States' jurisdiction, habitats, species and fisheries, including pollution from ships. It provides that "*States accept the principle of safeguarding the marine ecosystem by reducing dangerous substances, by the use of the best technology available and other appropriate measures*" and that "*this applies especially when there is reason to assume that certain damage or harmful effects on the living resources are likely to be caused by such substances and technologies, even where there is no scientific evidence to prove a causal link between practices and effects.*"

The scope of application of the precautionary principle was successively broadened from persistent toxic substances to all synthetic persistent substances, natural substances released in large quantities (e.g., nutrients responsible for eutrophication) and finally to all emissions responsible for global warming (Dethlefsen *et al.*, 1993). The principle has been invoked in issues related to the ozone layer (1985 Vienna Convention for the Protection of the Ozone Layer and the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer) where States agreed to reduce emissions of certain substance at a time when the causal links had not yet been firmly established (Boelaert-Suominen and Cullinan, 1994). It has also ben referred to in relation to the greenhouse effect and the conservation of nature. It has touched indirectly on fisheries through provisions in the international convention on dumping at sea (the Paris and Oslo Conventions, Marpol) relating to pollution by fishing vessels. The 1991 International Conference on an Agenda of Science for Environment and Development into the 21st Century (ASCEND 21) referred to the principle, stressing "*the central importance of the precautionary principle according to which any disturbance of an inadequately understood system as complex as the Earth system should be avoided*". Broadus (1992) asked whether that meant "any disturbance" and at "any cost" indicating that the principle was not a principle but a range of more-or-less rhetorical prescriptions for choice in front of uncertainty. The principle has also been considered as particularly appropriate in the context of Integrated Coastal Areas Management (Boelaert-Suominen and Cullinan, 1994) because of the vulnerability of coastal resources, the likelihood of swift and irreparable harm, and the incomplete understanding available on the complex web of interconnected biological processes in the coastal area. More recently, the precautionary principle has also implicitly been included in the Convention on Biological Diversity (UNEP, 1992) which noted, in its preamble "*that, where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimizing such a threat.*"

The principle remains contentious both within the scientific community and from the point of view of policy-makers and these controversies are illustrated in the fact that there is, as yet, no generally accepted formulation of the principle. When the interpretation of the principle is softened, the border between it and the approach is significantly blurred. For instance, Young (1993, cited by Dovers and Handmer, 1995), proposes to consider four different levels of application of the principle, corresponding to decreasing levels of risk, potential degree of irreversibility, and uncertainty:

> Level 1: Impacts are potentially serious (unacceptable) or irreversible and uncertainty is high: a strict application of the principle is required, insisting on complete reversibility and putting a strong burden of proof[6] on development proponents.
>
> Level 2: Impacts may be serious but potentially reversible and a reasonable amount of data is available to appreciate risk: large safety margins should be ensured in assessments and decisions and use of the best available technology should be strictly required, i.e., regardless of costs.
>
> Level 3: Impacts are considered largely acceptable (and/or potentially reversible) and reasonably good scientific and other information is available: lower safety margins are accepted. The best available technology is required only if economical.
>
> Level 4: Potential losses are considered neither serious nor irreversible: decisions could be based on traditional cost-benefit analysis.

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[6] See discussion on the burden of proof in Section 5

The conditions for the application of levels 3 and 4 and their implications are very similar to the conditions and implications of the precautionary approach and illustrates that these two related concepts are sometimes difficult to distinguish.

The large-scale pelagic driftnet issue

The UN General Assembly Resolution 44/225 of 22 December 1989, on large-scale pelagic driftnet fishing and its impact on the living marine resources of the world's oceans and seas, could be considered a case of radical application of the concept of precaution, despite the lack of explicit reference to the principle. The resolution expressed concern about the size of the fleets, the length of the nets, their mode of operation, their potential impact on anadromous and highly migratory species, their by-catch and the concern of coastal countries on the state of resources close to their exclusive economic zones. It recommended that a worldwide moratorium should be imposed on all driftnet fishing by 30 June 1992 and it established a set of immediate and regionally tailored interim measures. It also provided that such measures would not be imposed in a region or, if implemented, could be lifted, should effective conservation and management measures be taken upon *statistically sound analysis* to be made jointly by concerned parties. The proposal is rational but the flaws in the process followed for the implementation of the resolution have been underlined (Miles, 1992, 1993; Burke, Freeberg and Miles, 1993).

The consequences of this resolution, after heated international debate and political pressure, has led to the discontinuation of the issuance of fishing licences and research for alternative fishing techniques, in Japan and Taiwan (Province of China); the docking and conversion of driftnet fishing vessels in the Republic of Korea and a regulation by the European Union (see below). Large-scale driftnet fishing stopped in the South Pacific in 1992–93 but some fishing continued in the Mediterranean and Bay of Biscay, where scientific experiments were conducted to assess the fishery's impact on the associated small cetaceans. Many other Mediterranean countries, however, have taken regulations prohibiting driftnet fishing in their waters. Following up on the UN Resolution, the European Community adopted a Council Regulation (N° 345/92 of 27/1/1992) limiting to 2.5 kilometres the length of the driftnets authorized, but granting a derogation to 5.00 kilometres, until 31 December 1993, to vessels having fished for at least three years preceding the implementation of the regulation. This derogation was to expire by the indicated date unless scientific evidence showed the absence of "*any ecological risk*".

3.2 The Precautionary Approach

In considering the introduction of more precaution in fisheries management and development, the main differences between fisheries impacts and chemical industries pollution (for the control of which the precautionary principle was created) must be kept in mind:

a. the assimilative capacity in relation to fisheries impact (i.e., the quantities of fish that can be removed without damaging the system's productivity) exists without doubt and can be determined with some accuracy, even though it varies, and

b. the impacts are, in most cases, reversible and, as a result, the potential consequences of an error would rarely be dramatic, even though they can be significant in socio-economic terms.

In the early 1990s, the precautionary approach has been progressively more accepted and its field of application has been broadened to include the management of natural renewable resources, including fisheries. The aims of the precautionary approach are similar to those of the precautionary principle from which the approach is sometimes difficult to distinguish. The main difference between the principle and the approach might be that the latter considers explicitly the social and economic implications of its application in order to ensure that: (a) it does not lead to imbalance in favour of non-fishery uses and future generations with undue strain on present generations and the fishery sector, and (b) that unavoidable short-term costs to the fishery sector are mitigated and equitably shared. The various interlinked processes that lead to the widespread adoption of the precautionary approach in fisheries, are briefly described below.

The UNCED process

UNCED stressed the need for a precautionary approach to ocean development in its Rio Declaration and in Agenda 21, particularly in its chapters on the management of coastal areas, resources under national jurisdiction and high seas resources. The principle 15 of the Declaration states that "*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 be not used as a reason for postponing cost-effective measures to prevent environmental degradation.*" The wording, largely similar to that of the principle, is subtly different in that: (1) it recognizes that there may be differences in local capabilities to apply the approach, and (2) it calls for cost-effectiveness in applying the approach, e.g., taking economic and social costs into account. UNCED led to agreement on two principles which are intuitively reasonable and potentially contradictory: the precautionary approach and the principle of economic efficiency. The delicate co-existence of these two principles impedes the development of safeguards against uncontrolled decisions (or lack of decisions).

The FAO process

Many years before the issue became fashionable in the fisheries circles, FAO, through its European Inland Fisheries Advisory Commission (EIFAC), collaborated with the International Council for the Exploration of the Sea (ICES) in the development of ICES/EIFAC Codes of Practice and Manual of Procedures for Consideration of Introduction and Transfer of Marine and Freshwater Organisms (Turner, 1988)[7]. This Code stresses that, in a context of rapidly changing population pressures, the impact of the introduction of species to enhance the potential of sustainable fisheries should be examined in the light of the likely impacts of alternative development strategies, involving environmental degradation and likely to result in changes in species composition of both the

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terrestrial and aquatic ecosystems.

More recently, in a review of the FAO programme in marine fisheries management, Garcia (1992) identified some of the challenges to be faced by fisheries in the period 1993–2000. These included: the uncertainty in the scientific information, the need for a more precautionary approach to management, the burden of proof and the need to define "acceptable" levels of impact. At the 1992 FAO Technical Consultation on High Seas Fishing, Garcia (1992a) stressed the uncertainty in the "best scientific evidence available" for management and drew attention to issues of precaution and burden of proof, the non-precautionary nature of the traditional MSY reference point, and the need for more and different reference points to be used as a basis for more precautionary management strategies. The Consultation provided guidance to the Fisheries Department of FAO on how to proceed (FAO, 1992) and, *inter alia*, agreed that:

- fisheries should be managed in a cautious manner;
- precaution did not necessarily require a moratorium on fishing;
- there was a need to identify methods to handle uncertainties;
- the objective was to safeguard both people's livelihood and biodiversity;
- existing precautionary measures should be included in the Code of Conduct;
- precautionary measures should be based on science and not be discriminatory, and
- measures should be revised or revoked when new information became available.

[7] A full-scale practical application of this Code has been undertaken by FAO in Papua New Guinea (Coates, 1994). starting from the premise that introductions of new species in an aquatic ecosystem should be subject to prior evaluation. irrespective of whether species are "exotic" or not

The International Conference on Responsible Fishing (Mexico, 6–8 May 1992), organized in close cooperation with FAO, defined the concept of responsible fishing as encompassing "*the sustainable utilization of fishery resources in harmony with the environment; the use of capture and aquaculture practices which are not harmful to ecosystems, resources or their quality; the incorporation of added valued to such products through transformation processes meeting the required sanitary standards; the conduct of commercial practices so as to provide consumers access to good quality products*". The Cancun Declaration contains a fairly complete prescription for modern fishery management covering environmental impacts; multispecies by-catch and discards issues; effort control requirements; etc., but did not include any explicit reference to the precautionary approach. One year later, however, the Inter-American Conference on Responsible Fishing (Mexico City, July 1993) referred to the need to take precaution into account in the Code of Conduct on Responsible Fishing, particularly in the high seas.

In 1993, the review of the state of highly migratory species and straddling stocks, prepared by FAO at the request of the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks indicated that it was necessary "*to analyse the potential role and agree on possible ways of implementing cautious management approaches compatible with sustainable fisheries*" (FAO, 1994, page 65). Following a first attempt to analyse in detail the various implications of the concept of precautionary action in fisheries research, management and development (Garcia, 1994), a document was prepared by FAO, to comply with a request by the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (Second Session, July 1993). This document (United Nations, 1994; Garcia, 1994a) was presented to the UN Conference at its meeting of March 1994. Even though it was prepared for a meeting on straddling and highly migratory resources, the document was considered by FAO as generally pertinent for all resources and fisheries, whether in the high seas or under national jurisdiction, because it was felt and stated that, if a resource required precaution, it should be provided regardless of the type of jurisdiction, and the set of management measures applied to the various life stages of a transboundary resource should be coherent across its entire area of distribution. Unfortunately, this logical and basic biological requirement became, at the UN Conference, one of the major points of disagreement because some coastal countries considered that the need for overall "coherence" or compatibility between the management regimes inside and outside the EEZ could represent or be interpreted as an encroachment on their sovereign rights[8].

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The issues of scientific uncertainty and precaution were also addressed in another document prepared by FAO for the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, on management reference points (United Nations, 1994a; FAO, 1994). This report recognized that "*most of the difficulties experienced in using any target reference point results from the considerable uncertainties as to the current position of the fishery in relation to it*". It suggested using limit reference points (LRPs) as a way to increase the precautionary nature of the management set-up. Such LRPs, to be used alone or in combination, could correspond, for example, to situations where: (a) spawning biomass or proportion of mature individuals fall below, say, 20% of the values for the virgin stock; (b) fishing mortality falls below, say, 30% of the virgin stock biomass-per-recruit or reaches 80% of the rate of natural mortality; (c) total mortality reaches the level corresponding to Maximum Biological Production for the stock; (d) mean individual size fall below the mean size at maturity; (e) annual recruitment levels remain below a certain level (or average level) for a certain number of years, and (f) the resources rent have been totally dissipated (i.e., the total cost of fishing, including reasonable revenues to manpower and capital, are equal to total revenues), etc.

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[8] A situation could be foreseen in which a sovereign coastal State could see its right to introduce a technology (e.g., a new fishing gear, or practice, or genetically modified organisms) questioned by non coastal countries exploiting the same straddling or highly migratory stock

FAO has started the preparation of a **Code of Conduct for Responsible Fisheries** following the International Conference on Responsible Fishing, held in Cancun (Mexico, 1992). The Code includes a section on precautionary approach as part of the Article 6 on Fisheries Management[9]. The implementation of the Code of Conduct will be facilitated by a series of specific guidelines, one of which will address the precautionary approach to fisheries management (including aspects related to the introduction of new species). The precautionary approach promoted by FAO is being progressively reflected in the fishery sector reality. The applications to inland fisheries and aquaculture have been already mentioned above. In addition, in the last session of the Working Party on Resources Evaluation of the Committee for Eastern Central Atlantic Fisheries (CECAF) it was recommended that, *as a precautionary approach*, the fishing effort exerted on horse mackerels in Morocco, Mauritania, Senegal and Gambia, should be kept at the level as in the late 1980s. A practical application of the precautionary approach to management of tropical shrimp fisheries has also been proposed (Garcia, 1996) illustrating the possibility to make maximum use of the available scientific information, with its uncertainty, to elaborate precautionary management advice.

More recently, and in direct relation to the process of development of the FAO International Code of Conduct, the Government of Sweden, in close cooperation with FAO, held a Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Interaction) in Lysekil, Sweden, 6–13 June 1995 (FAO, 1995). This meeting drafted a set of guidelines (which will support the Code of Conduct) and produced a number of technical background documents dealing in detail with specific technical issues addressed in the guidelines (Fitzpatrick, 1995; Hilborn and Peterman, 1995; Huppert, 1995; Kirkwood and Smith, in press; Rosenberg and Restrepo, 1995). including the present review.

The United Nations process

At its first substantive session, held at New York in July 1992, the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (hereafter called the Conference) also addressed the issue. It could not reach consensus on the precautionary principle, which many countries equated with a moratorium on fishing and considered too radical for such environmentally soft industries as fisheries. A consensus developed instead on the need to introduce or strengthen the precautionary approach to fishery management. During its Second Session, in July 1993, the Conference considered again the issue. The Chairman negotiating Text (A/CONF.164/13*) contained only one reference to the precautionary approach, in Article 4: "*Use of the precautionary approach shall include all appropriate techniques, including, where necessary, the application of moratoria*". A paper submitted at this meeting by Argentina, Canada, Chile, Iceland and New Zealand (United

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Nations, 1993) proposed selected precautionary measures on the High Seas, distinguishing between existing and newly discovered fisheries. **For existing fisheries**, the text suggested *inter alia* that: (a) TACs and effort limitations shall be established to maintain exploitation rates below the level of MSY and, where appropriate, to allow the stock to rebuild; (b) precautionary management thresholds shall be established at which pre-determined management courses of action should be taken; (c) where stocks decline over time, TACs and effort shall be reduced to arrest the decline and subsidies for fishing operations shall be stopped, and (d) by-catch limitations should be established and stocks of associated or dependent species should be maintained or restored. **For newly discovered stocks**, the text suggested also that: (a) early large-scale development of fisheries on newly discovered stocks shall be prohibited and limitations shall be applied immediately on effort and on Government assistance, and (b) precautionary Total Allowable Catches (TACs) and quotas shall be established below the MSY level. In addition to these largely technical measures aiming at increasing precaution, the document contained proposals aiming at giving to the coastal States special prerogatives to establish interim management measures: (a) in case of discovery of a new straddling or highly migratory resource and (b) when the coastal State has established that an emergency exists. The heated debate on this latter aspect of the proposal has overshadowed the other aspects of the proposal.

[9] The text of this section (Annex 1) is only provisional and will be revised on the basis of the outcome of the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks

Nonetheless, during its 1993 Session, the Conference requested the Food and Agriculture Organization (FAO) to prepare two information papers: one on the precautionary approach in fisheries management and one on management reference points. During its Third Session, in March 1994, the Conference considered again the issue of precaution, based on the document prepared by FAO and the proposals included in paragraph 5 of the Chairman's Negotiating Text (Annex 2) which referred specifically to the precautionary approach to management. Two working groups were held: on the precautionary approach and on management reference points. The outcome of the heated debate on precaution during the following sessions of the Conference was reflected in a number of modifications of the draft Chairman Negotiating Text which represented a substantial elaboration on the approach (cf. Annex 3 and 4). The UN *ad hoc* Working Group on Management Reference Points reached consensus on all but one of a set of Technical Guidelines on Biological Reference Points (see Annex 4). The only serious conflictual point, already referred to above, related to the need for coherence in management measures across the area of distribution of the species.

The NGOs process

Non-Governmental Organizations (NGOs), both international and national, environmental or professional have participated actively in the UN process, lobbying for recognition of the need for a precautionary approach to fisheries which would involve, *inter alia*:

- taking decisions even with inadequate evidence;
- reversing the burden of proof;
- requesting Environmental Impact Assessments;
- avoiding non-reversible impacts;
- adopting management reference points;
- establishing action-triggering thresholds points;
- allowing people's participation;
- promoting transparency;
- establishing sanctuaries;
- taking into account combined stresses on resources;
- reducing by-catch and increasing selectivity;
- conserving also associated and dependant species;
- testing management regimes robustness;
- allowing new fisheries only at very low pilot level;

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- establishing dispute settlement mechanisms, and
- promoting inter-generational equity.

NGOs have generally welcomed the FAO efforts towards the operationalization of a precautionary approach to fisheries which recognized the need to: (a) apply it to all fisheries; (b) apply it throughout the stock range, and (c) agree on criteria and actions to be taken before a crisis occurs. Despite complaints of insufficient opportunity for interaction in the Code of Conduct process by some NGOs, it is clear that there is a large coincidence between the NGOs' proposals and the FAO code and guidelines. Some environmental NGOs, however, considered that the FAO approach was too much oriented towards the protection of the fishery sector, making excessive reference to the socio-economic burden associated with it. Some criticized the proposed use of "reversibility" as a criteria for acceptability, considered as a loophole. A fishermen's association, on the contrary, considered that some the FAO proposals were unbalanced, setting an impossible burden for industry. It is clear that more interaction is needed even though there is a basic agreement on what should be done. Expectations of Governments and NGOs may never be identical and differences will also exist between different NGOs. It is therefore probably not reasonable to expect full agreement, by everyone, on all aspects of such a critical issue.

International Council for the Exploration of the Sea (ICES)

Another example of the precautionary approach can be found in the form in which the Advisory Committee on Fisheries Management (ACFM) of the International Council for the Exploration of the Sea (ICES) delivers its advice to its member States. The ACFM states that "*for stocks where, at present, it is not possible to carry out any analytical assessment with an acceptable reliability, ACFM shall indicate precautionary total allowable catches (TACs) to reduce the danger of excessive efforts being exerted on these stocks*" (Serchuk and Grainger, 1992). The implicit assumption in the ACFM advice is that, in the absence of scientific assessments, uncontrolled fisheries are likely to build up overcapacity and overfish the resources. The preventive action is to establish TACs at conservative levels to limit fishing until better assessments become available. The implication is that such conservative measures would be lifted only if better information, in the form of an acceptable analytical assessment were provided.

In addition to the work on species introductions undertaken with FAO-EIFAC (referred to above under the FAO process), ICES also developed a Code of Practice on the Introduction and Transfer of Marine Organisms (ICES, 1995) dealing more specifically with the introduction of Genetically Modified Organisms (GMOs). It is worth noting in this respect that in considering this Code of Practice, the FAO-SWEDEN Technical Consultation on the Precautionary Approach to Capture Fisheries (FAO, 1995) indicated that "*because of the high probability and unpredicted impacts, many species introductions are not precautionary*" and that "*a strictly precautionary approach would not permit deliberate introductions and would take strong measures to prevent unintentional introductions*".

International Maritime Organization (IMO)

Although not directly related to the fishery sector, the efforts of IMO to reduce the impact of accidental introduction in ballast water and sediment of tankers as well as hull fouling, are worth mentioning. Such accidental introductions are numerous and have resulted in serious damage to the fisheries and aquaculture ecosystem and resources in some cases (Bartley and Minchin, 1995; Mee, 1992; Zaitsev, 1993). The IMO guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ship's Ballast Water and Sediments (IMO, 1994) addresses the issue and aim at minimizing the risk of introduction. The issue was also addressed by the FAO-SWEDEN Technical Consultation on the Precautionary Approach to Capture Fisheries (FAO, 1995) which stressed that present practices were largely non-precautionary and that major changes in behaviour, technology and enforcement were required.

The World Conservation Union (IUCN)

The IUCN view on precaution is that "*a precautionary approach should underlie all fisheries management, rather than being restricted to special cases*" and that "*major interventions in the natural environment should not be conducted in the absence of information to assess the potential consequences*" (Cooke, 1994). Cooke stressed that it was necessary be not only set and declare the management objectives but also to ensure (through scientific simulations or otherwise) that the management procedures in place result in a high probability to meet these objectives under a wide range of scenarios with respect to stock dynamics and ecological interactions. In order to qualify as "precautionary" a management approach would therefore have "*to be sufficiently fully specified to enable its simulation, and to pass at least a minimum checklist of tests*". Cooke, further proposed that authorized levels of catches be inversely related to the amount of data available and that considerations related to protection of fishery habitats, non-target species and biodiversity be included in a precautionary approach. When describing the elements needed to test a management procedure, Cooke lists all the sources of uncertainty regarding the stock, required to predict how the stock might behave (e.g., sampling variability and biasses; uncertainty and long-term fluctuations in stock productivity, dynamics and structure, recruitment, mortality and growth and interactions with other species). Conspicuously lacking from the recommended approach are, however, all the important and often driving sources of uncertainty regarding the fishery sector itself, the fleet and capital dynamics, the alternative employment, the fishermen's behaviour, etc. Without such elements, simulation of management systems in most fisheries would be fairly unreliable.

International Center for the Living Aquatic Resources Management (ICLARM)

The International Center for Living Aquatic Resources Management (ICLARM) has recently developed its position regarding the introduction of species and the need for a precautionary approach (Pullin, 1994) which promotes adherence to the ICES-EIFAC guidelines and acknowledges the potential impact of genetically modified organisms.

Commission for the Conservation of the Antarctic Marine Living Resources (CCAMLR)

While not referring to the precautionary approach explicitly, the CCAMLR Convention includes important principles of ecosystem conservation[10] such as:

- " *Prevention of decrease in size of any harvested population to levels below those which ensure stable recruitment. For this purpose its size should not be allowed to fall below a level close to that which ensures the greatest net annual recruitment;*
- *Maintenance of ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels defined in sub-paragraph (a) above;*
- *Prevention of changes or minimization of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, taking into account the state of available knowledge of the direct and indirect impacts of harvesting, the effect of introductions of alien species, the effect of associated activities on the marine ecosystem, and of the effects of environmental changes, with the aim if making possible the sustainable conservation of the Antarctic marine living resources.*"

[10]Conservation taken as explicitly including sustainable use

The last principle is particularly typical of the precautionary approach as it addresses the concepts of risk and reversibility in a broad ecosystem concept (see Kirkwood and Smith, in press) for more details. CCAMLR has also introduced precautionary catch limits for krill fisheries (in 1991 and 1992) and for *Electrona carlsbergii* (in 1993). It instituted, in 1992, the requirement for advance notification and data requirements prior to the development of a new fishery. Finally, in 1993, in the absence of sufficient data for the establishment of a management regime, it authorized the starting of an experimental fishery for the crab *Paralomis* spp.

4. UNCERTAINTY, ERROR AND RISK

Uncertainty

In the definition section above, uncertainty has been defined as "*the condition of being uncertain. Doubt. Something uncertain. In statistics, the estimated amount or percentage by which an observed or calculated value may differ from the true value*" (Houghton Miflin, 1992) or as "*the incompleteness of knowledge about the states or processes in nature*" (FAO, 1995)

The incompleteness of knowledge derives from: (a) ignorance (i.e., no data at all); (b) inaccuracy (i.e., potential bias in the data), and (c) variance (i.e., statistical confidence limits of the data). More specifically, statistical uncertainty (or variance) is related to stochasticity or error from various sources estimated using statistical methods. In its taxonomy of uncertainty, Wynne (1992) distinguishes between: (a) risk, when the system is basically known and outcomes can be assigned a probabilistic value; (b) uncertainty, when important parameters are known, but not the probability distributions; (c) ignorance: identified lack of knowledge of parameters and relations known to exist and for which are researchable, and (d) indeterminacy: when causal chains and processes are open and thus defy prediction. In decision theory, it is indeed customary to refer to "risk" and "uncertainty" when referring to situations where the outcome of a particular event is unknown, but to use "risk" when the probability of the future event is quantifiable ("knowable") and "uncertainty" when such probability is unmeasurable ("unknowable") (Luce and Raifa, 1957; Knight, 1965; Granger and Henrion. 1993). For a discussion on the use of the terms "risk" and "uncertainty" in fisheries, see Shotton, 1993.

In fisheries, the impact of the extracting activity on the resources and the environment needs to be accurately assessed and forecast in order to propose management options reducing to a minimum the possible risk of severe and costly or irreversible crisis[11]. However, the scientific understanding of the fisheries ecosystems and capacity to predict their future status in accurate quantitative terms is limited by the properties of fishery resources, their "fluid" nature and interconnectedness; the limited knowledge on genetic stock structure and impacts of fishing on resources genetics; the complexity of the interactions between species and gears and fisheries; the poor quality of the available fishery data; the limitation of scientific models and research funds, and the fluctuations of economic parameters. This leads to a degree of uncertainty in the scientific, technical, economic and political information upon which managers and industry leaders base decisions which may not always be wholly appropriate. There are numerous illustrations of this and the most recent relates to the management of the Northern Cod stock in the Northwest Atlantic where, following a collapse of the resources, it was necessary to establish a very expensive emergency welfare programme to support a stunted coastal fishery sector. A polemic has started as to whether research, management, industries, national decision-makers or foreign fleets, were responsible for the mistakes (Finlayson, 1994) and it appears that, as usual, the responsibilities are to be shared and the debate comes too late.

Scientists have repeatedly addressed the issue of uncertainty and the related risk, trying to find ways of identifying and quantifying better the levels of uncertainty in their statements as well as more robust (forgiving) management approaches (Walters and Hilborn, 1978 and 1987; Shepherd,1991; Smith, Hunt and Rivard, 1993). Hilborn (1992) distinguishes between "*noise*", "*uncertain states of nature*" and "*surprises*". Noise includes the elements of uncertainty for which historical experience is available, such as year-to-year variations in weather, prices, administration decisions, political setup and directions, etc. and for which probabilities can be usually worked out. Uncertain states of nature refer to elements of uncertainty that have been explicitly identified but for which no experience is available and, therefore, no probabilities can be obtained. These include, for instance, major shifts in ecosystem structure, impact of global change, etc. Surprises refer to elements of the uncertainty that were never considered.

Errors

When decision-makers take the necessary decisions, while both the present situation and the future outcomes are not fully understood, they implicity accept a certain probability to make some mistake and make the assumption that this mistake will either have a negligible cost or would be easily corrected. Errors that might be made may affect: (a) the basic fishery data used for analysis such as on catches, effort, sizes landed, etc. (**measurement error**); (b) the estimation of populations and parameters derived from such data (**estimation error**); (c) the understanding of relationships between the different elements of the fishery system and their interaction (**process errors**); (d) the way these relationships are mathematically represented (**model error**); (e) decisions that management takes on the basis of such information (**decision error**), and (f) the way in which management measures are implemented (**implementation error**). The errors affect both the biological, economic and social component of the fishery system. They may affect, for example, the decision-maker's expectation regarding fishermen's reaction to a proposed measure, as a consequence of errors in the explicit or unformulated behavioural model, used in forecasting such a likely reaction. Management errors can lead to two types of situations:

a. **necessary management measures were not taken** and, as a result, the resource is damaged. There are short-term costs for the resource and, possibly, for the fishing community if not compensated by government subsidy. The biological impact is usually reversible if a corrective measure is applied, except perhaps in the case of major damage to the habitat. This type of error may also carry the risk of major economic consequences (e.g., in Peru or. more recently, on the Eastern Coast of Canada), and
b. **unnecessary management measures were taken** and, as a result, fishing activities were curbed. The cost of the error is borne by the fishery. The biological effects of the measure, if any, would usually be positive and reversible soon after the measure is suppressed. The socio-economic impact may or may not be reversible (e.g., where there the error resulted in the loss of the market).

[11] See a detailed discussion on fisheries impacts in the section on Management Implications

It must, therefore, be accepted that management decisions addressing actual or perceived risks will often be necessarily taken with less than complete and accurate information which may lead to errors. The question is: how to deal with the problem while minimizing the risk of error in the short and long-term? The responses are: (a) improving information to reduce the level of uncertainty, and (b) improving robustness of decision-making to a given level of uncertainty. Improving information and understanding to the point of reducing substantially the risk of error implies data and financial resources requirements which would often be unrealistic, particularly for high seas or highly unstable resources. As a consequence, while research efforts should be pursued, efforts have tobe made to improve decision-making. Hilborn (1992) distinguishes two types of management response to uncertainty. The "*blind faith strategies*" are based on the best available evidence and applied without any explicit feed-back mechanism for improving them on the basis of performance. These strategies are also called "*open-loop strategies*" in optimal control theory. On the contrary, "*learning strategies*" explicitly provide for adaptation and improvement on the basis of more or less active learning gained from experience and surprises. Most management system "learn" but usually do so in a passive or reactive mode, at a very low pace and at the price of costly crises. Active learning would improve performance by accelerating strategy optimization through feed-back loops, and involves "*taking management action deliberately designed to be informative in addition to the explicit monitoring and regulation function of management*".

Risk

In the section on definitions, risk has been described as "*the possibility of suffering harm or loss. A factor, thing, element, or course, involving uncertain danger, a hazard*". This is the general meaning intended in most environmental conventions. In more technical literature, risk refers to potential negative consequences (or undesirable outcomes) of a decision, quantitatively assessed and often referred to as "*expected loss*" or "*average forecasted loss*". Turner, O'Riordan and Kemo (1991) stress that "*risk is not merely an objective phenomenon but a hazard clothed with social meaning* *and judgement*".

No matter how much effort is made in research and through adaptive learning, acertain level of uncertainty will remain and, therefore, a certain level of risk when making decisions. A fishery management strategy aiming at no risk at all for the resource and the fishing communities would imply either research costs beyond the value of the fishery or no development at all (in the case of an extreme interpretation of the concept of precaution). Few Governments would find either of these two extreme options viable. Cautious management will therefore deal explicitly with risk and aim at a compromise and it should be clear that the higher the uncertainty and/or risk the greater will be the need for caution, particularly in the selection of management reference points (FAO, 1993a). Particular caution may be necessary when resources and people are in a highly vulnerable situation as, for example, in small island countries where the erosion of natural resources may lead to the degradation of the coral reef ecosystem and, beyond a certain threshold, to the breakdown of development opportunities, life support and social order. An important and difficult task for cautious management authorities will be to develop a societal consensus about the nature and levels of the biological and societal impacts (and risks) that might be considered acceptable (tolerable) and to highlight and address the fundamental trade-off implications of the decisions, for different elements of the society and for both the short- and long-terms. Shrader-Frechette (1995) stress that the development of such a consensus would benefit from a science-based **comparative risk assessment**, to improve the objectivity of possible perceptions of risk and ranking of the various threats to the aquatic system and the fisheries. Such assessment would also help optimize the allocation of human and financial resources available for research, technology development and management. It must be accepted, however, that people are concerned not only with ecological risk, e.g., resource depletion, but also with inequities with regard to risk distribution, lack of concertation on acceptable risks, inadequate insurance or compensation for risk and other non-quantifiable aspects of risk which cannot be easily captured by comparative risk assessment and simple cost-benefit analyses.

Solutions often proposed to the problem of uncertainty tend to be simplistic (e.g. take the "lower bound" of the range) or oversimplistic (discontinue an activity, do not allow it to start), neglecting to compare the cost of this decision to the resulting benefits. Shane and Peterman (in preparation) stress that a precautionary measure "can only be justified if it improves management performance, i.e. if the benefit of reducing overfishing exceeds the cost of reducing harvests". They suggest whether adjustments to take uncertainty into account are worthwhile and how large they should be.

5. IMPLICATIONS FOR FISHERIES RESEARCH

All expressions of the concept of precaution require that the "*lack of full scientific certainty shall be not used as a reason for postponing cost-effective measures to prevent environmental degradation*" (Principle 15 of the Rio Declaration). The requirement for precaution may, therefore, have been interpreted as requiring no input from fishery research. Gray (1990), for instance, stated that the "*acceptance of the precautionary principle has nothing to do with science*" and that it leads to arguments "*that do not have the required objectivity and statistical validity*". In practice, however, and as proposed below, the effective implementation of precaution requires substantial support from fishery science, which needs to be adapted to the new requirements.

5.1 The "Best Scientific Evidence Available"

Scientific cooperation to develop a consensus on the state of nature and cause-effect relationships, appropriate models and the potential consequences of fishing has been the basis for cooperation in international fisheries management and the major "raison d'être" of ICES and it should continue to be one of the most neutral contributions to the resolution of conflict between nations and competing user groups. The Christiania Conference, in 1901, held just before the creation of the International Council for the Exploration of the Sea (ICES), endorsed the principle of scientific inquiry as a basis for rational exploitation of the sea. The same principle was also agreed at the International Conference on the Conservation of the Living Resources of the Sea, hosted by FAO (Rome, 1955). The 1982 Convention provided that the best scientific evidence shall be taken into account by the coastal State when designing and adopting management and conservation measures in exclusive economic zones (Article 61). For the high seas, this Convention provides that measures are designed on such scientific evidence (Article 119). More recently, the General Assembly Resolution 44/225 recognized, in its preamble, that "*any regulatory measures ... should take account of the best scientific evidence available*". The 1982 Convention, however, does not define the evidence required in any quantitative manner.

Regarding the necessary amount of data, Cooke (1994) proposed that there be a relationship between the amount of data available and the level of catches allowed, indicating that a **minimum information requirement** be established, such as a recent estimate of the low end of the likely available biomass. This might sometimes be difficult to obtain without any fishing at all, although, for many resources, some rough estimate could be obtained through trawl or acoustic surveys. Cooke specifically proposed that "*permitted catches be lower when data are sparse than when data are plenty*" and stressed that this "*attaches a positive effective value to fisheries data and opens the way to data collection programmes financed by the users*".

Regarding the quality of the necessary data, the requirement that the evidence should be the best available implies that even poor evidence can be used in designing conservation measures provided it is recognized as the best available. The 1982 Convention does not provide any guidance on how to decide which is "*the best*" scientific information. Nor does it indicate how to operate in the absence of a scientific consensus, which it implicity assumes, or when no scientific information is available at all. Although the 1982 Convention does not foresee that an existing fishery could be closed if not enough scientific information is available, it does not impose a great burden to be discharged before the necessary conservation measures can be taken (Burke, 1991). One would assume therefore that, in such a case, the spirit of the Convention is that the missing scientific information should be urgently collected but this does not preclude measures being taken in the meantime. The concept of precaution would ensure that action is not deferred *sine die*.

Concern has been expressed that the adoption of the precautionary approach could imply that scientific facts to back up management decisions were no longer considered necessary. There is an obvious risk that, by referring to the concept of precaution, scientific objectivity could be less rigorously applied and that international dialogue could be negatively affected. It is hardly debatable, however, that when scientific data are available together with a monitoring and management system, the basic requirement of the 1982 Convention should prevail and decisions should be taken on that basis. It should also be clear that, in order to satisfy the requirement of the 1982 Convention for the best scientific evidence available, the information must be scientific(i.e., obtained and presented in an objective, verifiable and systematic manner)[12] and it does need to be made "available" to all concerned. This, in the context of straddling and highly migratory resources, requires the existence of effective international scientific cooperation and the elimination of non-reporting and misreporting.

In the absence of a scientific consensus, emergency action should, therefore, only be justified when there is the risk of severe and irreversible effects and the concept of precaution may be seen as filling the gaps in the 1982 Convention, preventing the absence of scientific data or consensus from opening a loophole leading to "laissez-faire"management and development strategies with damaging or irreversible consequences. In an international fishery management body, a State willing to invoke the need for a precautionary approach in order to promote exceptionally stringent management measures, would have to convince the other parties that exceptional conditions are met for its application, i.e., that there is indeed a high risk of severe and irreversible damage. Science should, as far as possible, demonstrate the existence and extent of risk through risk analysis. If the available information was considered insufficient to demonstrate objectively the risk, forced application of the concept of precaution could become counter-productive. It is recognized, however,that in such a case, the management authority would have to face "perceived risks", in the absence of objectively demonstrated ones as is often the case with global societal risks and a consensus will have to be achieved through a largely political process involving as much consultation, participation and transparency in decision-making as possible.

[12]This implies that the "traditional knowledge", the foundation and accuracy of which is largely unknown, be collected and assessed in order to eventually become part of the "scientific" basis for management

5.2 The Role of Statistical Methods

The 1982 Convention does not give any indications on how to determine which scientific evidence is the "best". General Assembly Resolution 44/225 required "*sound statistical analysis*" and this new terminology could be considered an attempt to clarify further the concept of "best evidence", equating it with "*statistically sound evidence*". The advantage of incorporating statistics into the concept is that it offers a way of using well-established mathematical techniques and tests to assess the probability that a certain action has had or may have a certain type of effect. It also forces scientists and decision-makers to recognize and measure explicitly the levels of uncertainty and the risks attached to these decisions. A research programme to monitor a fishery will use statistics to test, for instance, a null hypothesis (Ho) that the ongoing fishing, or planned increase in fishing effort or change in fishing strategy, will not drive (or has an acceptably low probability of driving) the reproductive capacity of the species below some pre-determined safe threshold level. Scientists must still agree on which type of statistical methods to use (parametric, non-parametric, geostatistics) and which test is most appropriate for a particular problem. Fisheries do not usually conform strictly to the requirements for unbiased application of conventional statistical methods and the reliability of many statistical tests might still be a matter for debate. As a consequence, obtaining a consensus on the "best statistical analysis" to use might not always be easy. In this respect, Peterman and M'Gonigle (1992) have stressed the potential contribution of Statistical Power Analysis to the issue. They remind us that *"statistical power is the probability that a given experiment or monitoring programme will detect a certain size of effect if it actually exists"*. Related to the example given above, it means that the statistical power measures the probability that the fishery monitoring programme will effectively detect the reduction of the reproductive capacity below the safe threshold level. Peterman and M'Gonigle suggest that the lower the statistical power of an experiment, the more precautionary the management response should be. In addition, it is clear that the best statistical methods can only lead to unreliable results if applied to unreliable data. It is, therefore, obvious that rigorous statistical methods should also be applied in data collection systems, particularly for collecting fisheries data.

5.3 The Burden of Proof

The "Proof"

The concept of "burden of proof" is often used in conventions and other texts referring to the precautionary approach. Considering the level of uncertainty which characterizes aquatic systems and socio-economic systems, it should be clear that absolute "proof" *stricto sensu* is hardly available. The concept, whether of an impact or of the absence of an impact, implies usually a level of certainty that is generally not reachable in fisheries research. In fisheries, the concept of "proof"could be related to the concept of "scientific evidence" established by the 1982 Convention on the Law of the Sea. The "burden of proof"could, therefore, be interpreted as the burden of providing the scientific evidence. It must be noted that just as there is no criteria in the 1982 Convention to define what information is "best", the references to the "burden of proof" do not provide any guidance as to the "standard of proof" (i.e., the criteria by which to judge whether a "proof" is acceptable). In this respect, the concept of scientific evidence has the advantage to specify that the evidence must be scientific, i.e., obtained and presented in an objective, verifiable and systematic manner.

The Burden

In conventional fishery management, the "burden of proof", i.e., the responsibility of providing the "best scientific evidence available" required by the 1982 Convention, has fallen traditionally on research and management institutions. It has been necessary for them to demonstrate, with the available data, that the stock could be (or had been) damaged, or that fisheries performance could be improved, before management measures could be imposed. In many instances, this approach has not been effective because fishery research lagged behind development and was not in a position to anticipate changes in techniques and practices. The principle of precautionary action provides a partial solution to this important and recurrent problem in requiring that action be taken even in the absence of "full scientific certainty" about the extent of the risk and the causal relationships. This is often associated with the proposal to "reverse the burden of proof", i.e., reverse the responsibility to provide the necessary evidence, implying that:

a. human actions should be assumed to be harmful to the resource unless proven otherwise, giving systematically to the resources the benefit of doubt, and

b. the responsibility to prove that human action is harmless or that the impacts are acceptable[13] lies on those who intend to derive benefits from the ecosystem and not on the management authority.

Proposition (a) may be taken as implying that any fishing technique, which has not been formally authorized, in a given fishery or management area, or for a particular species, is forbidden, a principle enshrined in the FAO International Code of Conduct for Responsible Fisheries. The requirement is related to the notion that an environmental impact assessment should be presented before a new technology or practice is introduced into an ecosystem. It is also related to the concept of prior consent or prior authorization (discussed below Section 6.2). Proposition (b) above, might be more easily implemented in an international agreement, when the party bearing the burden would be a flag State with research capacity. This proposition could, sometimes, be more difficult or impossible to implement at national level when the fishery sector is informal, financially and technically weak or poorly organized as in many developing countries coastal and small-scale fisheries, as well as in overfished fisheries where most of the initiative for corrective action (e.g., fisheries reconversion) starts from governmental initiative.

In most cases a simple Environment Impact Assessment (EIA) based on evidence available locally, or in similar fisheries elsewhere, could be sufficient to produce the evidence required(cf. Section 6.3). In the case of a completely new methodology or fishery (e.g., on a non-traditional species) a major difficulty in the implementation of the concept is that it will be difficult or impossible to forecast, with any degree of accuracy, the impact that the new fishery will have before it has started and some data have been collected. There is, therefore, a real risk that no new fishery could be developed because evidence of the absence of adverse impact cannot be given by those involved in the venture. A reasonable precautionary approach, in such a case, should lead to agreement for a pilot fishery large enough to collect data and build up the scientific evidence required, but small enough to ensure that no irreversible effect is likely[14] (cf. Section 6.4).

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[13] For a discussion on "acceptable" impacts, see Section 7.4

An example of application of the concept to international fisheries can be found in the UN General Assembly Resolution 44/225. This resolution recommended a total ban on large-scale driftnet fishing in the absence of scientific consensus on the likely long-term impact, implying that the prohibition of a disputed fishing technique is in order until its acceptability has been demonstrated. It stated that "*such a measure will not be imposed in a region or, if implemented, can be lifted, should effective conservation and management measures be taken based upon statistically sound analysis to be jointly made by concerned parties…*". This resolution reversed the conventional course of action. recommending immediate and drastic action (i.e., a total ban of the offending gear) on the basis of international concern assuming that driftnets had an undesirable impact on resources, until shown otherwise. It was agreed that such action could, in principle, be reversed should the joint scientific analysis lead to consensus on the effectiveness of management measures. The UNGA Resolution 44/225 gave no guidance or criteria on how to judge the quality or adequacy of the available evidence or the effectiveness of the management measures. The action was confirmed by General Assembly Resolution 46/215 of 20 December 1991, which called for action against this type of fishing on the basis that "*the international community [has] reviewed the best available scientific data and [has] failed to conclude that this practice has no adverse impact … and that … evidence has not demonstrated that the impact can be fully prevented*". Another example of reversal of the burden of proof can be found in Council Regulation 345/92 of the European Economic Community (EEC).

which regulated the use and the length of driftnets (limited to 2.5 km) in EEC waters. Article 9(a) granted a derogation until 31 December 1993 to some vessels for the use of longer gear, stating that "*The derogation shall expire on the above-mentioned date,unless the Council, acting by a qualified majority on a proposal from the Commission, decides to extend it in the light of scientific evidence showing the absence of any ecological risk linked thereto.*"

In addressing the issue of the burden of proof, the Technical Consultation on the Precautionary Approach to Capture Fisheries, held in Lysekil, Sweden, 6–13 June 1995 (FAO 1995), considered that adherence to the guidelines it produced, and particularly to the elements contained in its summary statement (Annex 6), would ensure and appropriate placement of the burden. In addition, the Technical Consultation recognized that the following elements would help clarifying further the issue:

- "*all fishing activities have environmental impacts and it is not appropriate to assume that these are negligible until proved otherwise;*
- *although the precautionary approach to fisheries may require cessation of fishing activities that have potentially serious adverse impacts, it does not imply that no fishing can take place until all potential impacts have been assessed and found to be negligible;*
- *the precautionary approach to fisheries requires that all fishing activities be subject to prior review and authorization; that a management plan be in place that clearly specifies management objectives and how impacts of fishing are to be assessed, monitored and addressed, and that specified interim management measures should apply to all fishing activities until such time as a management plan is in place, and*
- *the standard of proof to be used in decisions regarding authorization of fishing activities should be commensurate with the potential risk to the resource, while also taking into account the expected benefits of the activities*".

[14]The question is more complicated in the case of introductions of species and GMOs where there is no guarantee that the introduced elements could be safely eradicated once introduced, even on a pilot phase, and there is opposition, in this case to the concept of pilot experiments REF

5.4 Practical Guidelines

In order to support the effective implementation of a precautionary approach to fisheries management and development, fishery research needs to be adapted to the new requirements and should, in particular:

1. ensure that the "*lack of full scientific certainty shall be not used as a reason for postponing cost-effective measures to prevent environmental degradation*" (principle 15 of the Rio Declaration);
2. take into account the best scientific evidence available when designing and adopting management and conservation measures, in accordance with the provisions of the 1982 Convention;
3. require a minimum level of information to be made available for any fishery to start or continue;
4. make all necessary efforts to collect the required scientific information. For new fisheries, data collection should start with the fishery, including data on genetic and stock structures. For existing fisheries, data collection should start as soon as possible and any increase in effort should be preceded by a research or assessment programme;
5. ensure and require that information provided as a basis for management be "scientific" (i.e.,

obtained and presented in an objective, verifiable and systematic manner) and "available" to all concerned;

6. develop the effective international collaboration required to collect and jointly analyse the scientific information, particularly inthe case of trans-boundary, highly migratory or high seas resources;
7. take measures aiming at eliminating or reducing non-reporting and misreporting, *inter alia*, by ensuring that the fishery sector cooperates in data collection and is fully informed of the results and uncertainty in the assessment;
8. relate the allowance in terms of TACs, catch quotas, number of licences, etc. to the amount and quality of the available data, ensuring that permitted catches be lower when data are sparse rather than when data are plenty;
9. generalize the use of standard statistical procedure to judge the quality of the scientific evidence available and ensure that such information and the analysis therein is statistically sound;
10. improve statistical methodologies for assessing the biological and economic parameters, testing their sensitivity to uncertainties in the data used and systematically estimating bias and precision in the derived parameters. The sensitivity of models to uncertainties in their parameters and functional structure should also be tested;
11. assess the statistical power of the tests and methodologies used for comparing the relative "soundness" of the information available. The lower the statistical power of the assessment, the more precautionary the management measures;
12. develop standards of proof and agreed protocols for Environmental Impact Assessment, pilot projects and experimental management projects;
13. promote multidisciplinary research, including: (a) social and environmental sciences, and (b) research on management institutions and decision-making processes, because the availability of biological evidence alone has not prevented overfishing;
14. expand the range of fishery models (e.g. bio-economic, multi-species, ecosystem and behavioural models), taking into account: (a) environmental effects; (b) species and technological interactions, and (c) fishing communities' social behaviour;
15. systematically analyse various possible management options using the whole range of available models, showing: (a) the likely direction and magnitude of the biological, social and economic consequences, and (b) the related levels of uncertainty and the potential costs of the proposed action (risk assessment), and no action (*status quo* scenarios);
16. systematically analyse and highlight the most pessimistic scenarios[15], in situations of doubt and high risk of irreversible damage to the resource;
17. develop scientific guidelines and rules for multi-species and ecosystem management as a basis for agreement on acceptable degrees of disturbance;
18. agree on quantitative reference points and thresholds as well as on methods to establish them[16];
19. systematically quantify the risk associated with scientific advice at the various reference levels selected;
20. improve understanding of environmental impact, raising the awareness of fishermen to the possible impact on fisheries potential resulting from fisheries as well as from environmental

degradation caused by other industries, and

21. improve technological research on fishing gear and practices and their environmental impact.

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[15]For instance, models which assume strong dependence of recruitment on adult stock size and predict rapid collapse when effort develops beyond a critical level (such as the Gulland-Schaefer production model or the Ricker stock-recruitment model), should be used rather than models assuming no relation between stock and recruitment and high resilience of stocks to high fishing rates (such as the Fox production model or the Beverton and Holt yield-per-recruit and stock-recruitment models)

[16]For instance, if it is agreed that it is safe to exploit a resource at two thirds of its MSY, it will be necessary to agree on the reference data set and on the conventional model on which to base the calculations because the true value of 2/3 MSY, and of its corresponding level of effort, will never be exactly known and may vary according to the model used

6. IMPLICATIONS FOR TECHNOLOGY DEVELOPMENT AND TRANSFER

Fishing affects targeted stocks and associated species, reducing their abundance and spawning potential, changing size structure and species dominance or composition and modifying the trophic chain. These effects are "normal" in the sense that they result from the need to exploit fish, and must be addressed and kept at acceptable levels by management (see Section 7.4). Fishing also has side effects on the flora and fauna living in the exploited environment (birds, turtles, marine mammals, benthic communities, coral reefs, seagrass beds) as well as on the bottom itself (trawls and dredges). In addition, "ghost fishing" by lost or discarded driftnets or pots has been suspected and, in some instances, demonstrated. It is not by chance that the very first discussions, in FAO, on the concepts of responsible fisheries, focused on responsible "fishing", i.e., on responsible fishing gear and technology, before broadening the concept to cover also management, research, fish processing and trade and aquaculture.

An example of international concern is given by the reaction to the rapid expansion of the large-scale pelagic driftnet fishing (see Section 5.3). The problem has been apparently "solved" by a moratorium on all driftnets of more than 2.5 km in length, through heated debate and political wrestling, but Miles (1992) indicated that the application of the same flawed process and criteria to EEZ fisheries would lead to closing down of many of them[17]. Another example is the concern expressed regarding impacts on cetaceans off Ireland and Denmark (Schoon, 1994) by bottom gillnets of up to 7 miles long, used in coastal waters, for the last 15 years to catch bottom fish such as turbot, plaice and cod.

The following sections, which draw from the work of Boutet (1995), will address various ways in which the problem could be addressed in the context of a precautionary approach to fisheries, i.e., through the adoption of responsible fishery technology and practices, the establishment of technology lists, the adoption of Prior Informed Consent and Prior Consultation Procedures, the requirement for Environmental Impact Assessment and the implementation of pilot or experimental development projects.

6.1 Classification of Responsible Fishery Technology

In international environmental law, the precautionary principle is often associated with the requirement to use the "*best available technology*", an obvious parallel to "*best scientific evidence available*". This wording has sometimes been interpreted as requiring the technology which has the smallest environmental impact, regardless of the short-term socio-economic costs. This interpretation has, however, been questioned on the basis that such technology might not always be affordable by all countries and, in particular, by developing countries (GESAMP, 1986). General Assembly Resolution 44/228 of 22 December 1989 on UNCED referred instead to "*environmentally sound technology*", stressing the need for socio-economic constraints to be taken into account. The wording does not pretend to limit the choice to a single "best" or soundest technology and does not preclude, therefore, the use of many "sound" technologies together, depending on the socio-economic context of their introduction. The Cancun Declaration (Mexico, 1992) provides that "*States should promote the development and use of selective fishing gear and practices that minimize waste* *of catch of target species and minimize by-catch of non-target species*", focusing on only one of the challenges of responsible fishing.

[17]As a matter of fact, arguments similar to those used to request the closure of the large-scale pelagic driftnet fisheries were invoked to force the closure of the small-scale bottom gillnet fishery in California, showing both the potential and the danger of media-driven campaigns against fishing techniques

The development of typologies and classifications is usually the basis of a process of normalization or standardization of technology in view of its regulation. The basis of a classification in fisheries could be horizontal or vertical. A **vertical classification** would involve classifying gears according to their priorities with the aim to regulate their use. An **horizontal classification** would classify ecosystems and species assemblages, or parts of them, as a basis for the regulation of their use. In practice, both classifications would be required in order to develop flexible regulations taking into account the diversity of gears and ecological situations (and even socio-economic situations). The use of lists to classify chemical substances, techniques, species[18], weapons, etc. is fairly frequent. In environmental law, technologies are often catalogued on separate lists, the "colour" of which reflects the perceived degree of environmental friendliness. For instance:

"Black" or "Red" lists would identify technologies for which the likelihood of producing unacceptable impacts in most or all of their application.

"Grey" and "Orange" lists would identify technologies susceptible to produce potentially acceptable impacts in most of their applications but which should be used under some conditions and require a specific impact assessment before being introduced.

"White" or "Green" lists would identify those technologies believed to be harmless or producing only acceptable levels of impact and which could be introduced without a particular precautionary procedure.

The task is not easy. One problem is in deciding whether one would catalogue gear, aid to navigation and detection (which increase fishing power) or fishing practice, or both. Another problem is to decide on the objective criteria for the classification. If responsible fisheries is the objective, gear should be classified according to related criteria (referring for instance to selectivity and by-catch rate; impact on bottom, navigation and environment in general; relative energy consumption; biodegradability; difficulty to control and monitor, etc.). For fishing gear, the classification of a technology will depend, *inter alia*, on the type of habitat. Heavy trawls may be considered"green" on deep muddy grounds but "red" in shallow estuaries and coastal zones or coral reefs. Artificial reefs might be on a grey or orange list because their impact on coastal habitat is long-lasting and, if made of derelict material, they may contaminate the environment.

This list approach has been indirectly applied to fisheries by reference to the Convention on the Conservation of European Wildlife and Natural Habitats (Bern, 1979). The Convention gives, in its Annex IV, a list of non-selective gear to be banned, which includes all nets. Although it had been designed for migratory birds, the list has been referred to, in Italy, in connection with the banning of large-scale pelagic driftnet fishery. The importance of nets in fisheries and their contribution to the livelihood of small-scale fishermen and indigenous people illustrates the need for careful consideration before referring to lists contained in non-fishery agreements and before elaborating specific lists for fishery technology.

[18]CITES, has recorded species in lists, according to their status, and specific measures correspond to each list

Considering that, in fisheries, the concept of responsible fishing is well defined and that a Code of Conduct for Responsible Fishing has been prepared and will be adopted, it may be of value to refer to the requirement for "**Responsible Fishery Technology**" (including capture and post-capture technology) as defined in the Code and its different guidelines. Responsible technology will have to be used in all areas of fisheries, including capture, land-based or sea-based processing and distribution. As a consequence, although some general guidelines can be given, based on known characteristics of types of resources and technology, the most responsible mix of technologies to be used in a particular fishery will have to be agreed on a case-by-case basis with explicit reference to the agreed management reference points and acceptable levels of impact agreed for that fishery. The implication is that technology lists could not be for general application and would have to be established locally, at regional and national level.

One must recognize, however, that lists of prohibited gears and practices exists in most national legislations and that these are frequently ignored. Examples are: fishing with dynamite or poison, fishing with scuba-diving equipment, use of obstructive shaffers on trawls cod-ends, use of driftnets, of small-meshed beach-seines, etc. The efficiency of technology classifications and list of authorized gears is therefore strongly dependant on the capacity of monitoring and enforcement.

Care would also have to be taken to ensure that the use of gear lists does not lead to freezing the evolution of technology and that mechanisms exist (including the use of pilot projects) to allow this evolution while keeping the overall fishing mortality under control. Fitzpatrick (1995) also stresses that, in many instances, the technology necessary for fishermen safety, also improves the fishermen's ability to locate and catch fish and, therefore, contributes to overfishing. Such technology, often required by international conventions on safety on board of fishing vessels cannot however, in most instances, be removed from the vessel. The implication is that fleet size may have to be reduced when fishermen safety is improved, in order to stabilize fishing mortalities.

Moreover, a "better" technology might be theoretically available on the market but in effect not accessible to some countries because of its cost or its sophistication and, in many instances, the generalization of the use of responsible technology will require an improvement in international cooperation in technology transfer, as underscored in Agenda 21[19].

6.2 Prior Informed Consent (PIC) and Prior Consultation Procedures (PCPs)

For dangerous polluting industries, reference has often been made to Prior Informed Consent (PIC) and Prior Consultation Procedures (PCPs). The practical significance of the procedures involved is that, before introducing a dangerous technology or any new technology in a controlled or sensitive area, the proponent must produce a substantial amount of information about the technology to be introduced and its potential impact and, eventually, obtain the consent of the State or the managing authorities. If the introduction is agreed, a number of specific measures are usually foreseen such as limiting the scale of the initial project, special monitoring and reporting requirements, etc.

These practices are rare in fisheries. An example can be found in the ICES/EIFAC Code of Practice to Reduce the Risk of Adverse Effects Arising from Introduction and Transfers of Marine Species including the Release of Genetically Modified Organisms (Turner, 1988) which has been adopted by the International Council for the Exploration of the Sea (ICES) and the European Inland Fishery and Advisory Commission (EIFAC) of FAO. The ICES/EIFAC Code foresees that "*Member countries contemplating any new introduction should be requested to present to the Council, at an early stage, information on the species, stage in the life cycle, area of origin, proposed plan of introduction and objectives, with such information on its habitat, epifauna, associated organisms, potential competitors with species in the new environment, genetic implications, etc., as is available. The Council should then consider the possible outcome of the introduction, and offer advice on the acceptability of the choice.*"

[19] The successful efforts made by the Inter-American Tropical Tuna Commission in the Eastern Central Pacific area to train crews of the region in effectively avoiding by-catches of dolphins through the use of appropriate technology, is a good example of what can be achieved in this respect

The European Directive 90–220 on dissemination of genetically modified organisms intends to frame the development of biotechnologies in Europe and address the "genetic risk" potentially represented by these technologies, which are of great potential interest also for fisheries (EEC, 1990). Hermitte and Noiville (1993) stress the precautionary character of the Directive, which applies the precautionary principle, not to a single product (chemical substance), or to a specific problem (ozone hole), but to a whole new mode of production, even before any incident has been registered. The Directive recognizes that a new production mode carries with it significant social (societal) changes and potential risks and, contrary to what has happened in industrial development since the 18th century, attempts to foresee and limit the negative impacts of this new technology. It reverses the traditional industrial culture and freedom to undertake, produce and sell as long as a danger has not been proven.

In exclusive economic zone fisheries, where effective effort controls have been established, there is often a requirement to obtain prior consent from the management authority before a new vessel is ordered or even before the banks are approached for a loan for this purpose. A similar approach might be used for some particularly efficient and potentially dangerous technologies and/or for particularly vulnerable resources or fragile ecosystems when severe, irreversible effects are possible. In a regional or international context, Prior Informed Consent of the competent regional management organization or arrangement would be required before introducing a new methodology. The procedure would be better accepted if the new technology was patented, limiting the risk that the benefits to the "discoverer" could be jeopardized in the process. In such an international or regional mechanism, a State willing to introduce a new technique would be requested to present a report, comparable to an **Environmental Impact Assessment** (see section on EIA below). Such an assessment would address potential effects on the target species, on associated species which might be targets for other fisheries in the area or food items for such target species and on the environment.

It has been mentioned that an overly stringent application of the precautionary principle might be contrary to the willingness and need to ensure technological progress. Hermitte and Noiville (1993), however, indicate that the prior authorization process, the resulting direct involvement of industry in promotion of data collection and research, and the transparency resulting from the public information and participation would, on the contrary, contribute to dissipate the fears towards technology and, indeed, limit irrational reactions to innovative technologies. One major benefit from a prior authorization process, beyond the limitations of risk, would be in the mandatory delivery, by industry, its scientists and experts, and at industry's expense, of information on ecosystem functioning and technological impacts and of the resulting "memory" that Hermitte and Noiville call "*scientific jurisprudence*". These authors state that the acceptance of the procedures by scientists and industry would be a sign of good faith given to a more and more suspicious, sceptical and unforgiving society and that these procedures may in fact be the only way to avoid irrational bans on research and development avenues and the development of "wild" experiments.

The administrative burden imposed by prior authorization procedures could be overwhelming and, at least in fisheries, there would be obvious advantages if the procedure could remain exceptional. The scope of application (and unnecessary burden) of the measure could be reduced using the concepts of "*familiarity*" and "*previously acquired experience*" (Hermitte and Noiville, 1993) or referring to "*evidentiary presumptions*" (Bodansky, 1991) to take into account available knowledge obtained elsewhere in similar or sufficiently comparable conditions, to reduce the amount of uncertainty and presumption of risk. In order to avoid repeating the impact assessment of similar technologies on similar species and ecosystems, it would be useful to develop a general typology of fishery technologies, gears and practices and their potential impact, leading to a general impact-oriented classification of gear/species/ecosystems interactions, to be used as a guide, by management authorities, at regional or national level, to develop local gear and technology classifications based on local characteristics of the resources and the environment[20](see also Section 6.1). The special monitoring and reporting procedures could then be limited to new technology/species/ecosystem combinations and to existing technologies recognized as unacceptable in the long term and for which phasing out might have been decided (and for which interim reports could be requested during the phasing out period).

In the case of high seas areas not covered by any specific international agreement, there would be no competent authority to which the request for prior consent could be made. In addition, there would also be no monitoring or enforcement system in place, making it impossible to detect the introduction of harmful techniques and to measure impact. This is a case where the legal responsibilities of the flag States would need to be clearly determined, especially if the flag State registers all vessels authorized to fish in the high seas as provided for in the 1993 Agreement on the Promotion of Compliance with Conservation and Management Measures by Fishing Vessels in the High Seas.

6.3 Environmental Impact Assessment (EIA)

Impact assessment is a major instrument of environmental law, which conditions the beginning of an activity or the deployment of a technology to an assessment of the consequences on the environment. Generally, an EIA provides not only an assessment of the impacts but also proposals aiming at mitigating the impact if necessary. As it would not be practical to condition all fishing activities to EIA it might be necessary to define the conditions under which an EIA might be necessary. This could be done: (a) through preliminary studies, on a case-by-case basis, and (b) through an overall identification and cataloguing of the technology/resource combination requiring such approach (see above).

The EIA seems to have been rarely used in fisheries (except possibly in aquaculture and for species introductions). If generally adopted, the EIA procedure would be part of the legal procedure leading to the granting of a fishing right or license for a particular fishing activity by an authority with the legal competence required to authorize or deny such a right. This authority would define the requirements and specifications of the EIA. An EIA procedure would require the establishment of a system to control the conditions of the assessment, its relevance and objectivity. This implies that:

[20]This comparative approach is not really new in fisheries, but the process of fisheries law development, in developing countries, to which FAO contributes actively, involves already a lot of transfer of experience from area to area. The approach could however be formalized and more systematically applied

- the proponent would be allowed to appeal if the procedure imposed is not in line with the established specifications, or if the decision of the authority does not appear in line with the conclusions of the EIA;
- the authority, which would decide on the acceptability or otherwise of a new technology or practice, would have to be able to oversee the whole EIA process to guarantee to all users the quality and reliability of the assessment;
- the procedure should be transparent to all users who receive information on request and on the EIA process. It might be necessary to organize a debate on the issue to have all views. It would be essential to ensure that the authority keeps the necessary prerogative to ultimately decide;
- the other users (and in particular the users of a different technology on the same resource) should have the possibility to appeal on a decision if it appears to be in contradiction with the conclusions of the EIA, and
- as a last resort, recourse to tribunals (in EEZs), or to dispute settlement mechanisms (in international fisheries), should always be possible if one of the parties in the EIA process believes that its interests are being unduly affected.

There should be some relation between the cost of the EIA and the cost of the potential negative consequences of the proposed development and its potential benefits. There should also be some relation between the cost of the foreseen investment and the cost of the EIA. In some instances, participation by the authority or State in the EIA might be worthwhile and equitable, particularly when the technology being considered has general potential application. State participation in the EIA would certainly be necessary for coastal and small-scale fisheries, particularly in developing countries (see Section 5.3 on the burden of proof).

6.4 Pilot Projects

Despite their relatively smaller size, fishery pilot projects can be considered a s"full-scale" experimentations, only limited in duration and geographical extension. They could be a useful way to implement a precautionary approach to fishery development provided that specific rules are adopted for their conduct, data collection, and analysis. They have the advantage of being less theoretical than EIAs, and therefore more convincing, while limiting the probability of inadvertently damaging the resource, and allowing a more realistic approach to socio-economic impacts than otherwise possible. Allowing for a phased approach to application of technology at a larger scale, they represent a practical tool for implementation of a "*stepwise decision making*" and "*progressive deconfinement*" of a new technology, advisable to situations of high uncertainty (Hourcade, 1994). Pilot projects have been extensively used in the past, including in FAO fishery development programmes, to demonstrate the technical and economic feasibility of a development or management measures. An experimental fishery has been developed for instance on *Paralomis spinosissima* crab fishery in the Antarctic (CCAMLR area) (Watters, 1993) and the concept is one with which industry is generally familiar. A basic assumption behind the concept of pilot projects is that the large-scale implementation of the technology is a simple extrapolation of the pilot scale. This may not always be the case and a significant involvement of basic and applied sciences is necessary for improving the protocol and specification of traditional pilot projects allowing them to become also useful and reliable elements of a precautionary fishery development policy. Another implicit assumption is that all traces of the experiment can be eliminated if the pilot-scale project indicates that the tested approach or technology results in unacceptable consequences. This may not always be true and explains the opposition of some scientists to the concept, particularly in cases where the consequences detected in the pilot project are not reversible (as may be the case with introduction of GMOs). The implication is that only part of the cost of a pilot project could be considered as additional charge required for precaution. Most of it could, in many cases, be considered as normal pre-investment expenses.

The management authority should have enough latitude to impose, to a proponent of a new technology or new fishery, the type of experimentation considered most appropriate. A contractual agreement between the authority and the proponent would improve the probability that the rights of the "discoverer" of a technology or a stock are respected.

The pilot project goes beyond the EIA in the sense that real development will occur, even though at small scale. In some cases, the authority itself could be (and often has been, in the past) the promoter of the initiative. In some cases, both an EIA and a pilot project might be required and executed sequentially when the EIA is not totally negative but some aspects may not be addressed without experimentation.

6.5 Practical Guidelines

A precautionary approach to fisheries should ensure the use of responsible fishery technology in all sub-sectors, including capture, land-based or sea-based processing and distribution and ensure that:

1. technology, formally recognized as "responsible", is compatible with long-term resource conservation, minimized by-catch of endangered species and discards, as well as other non-acceptable impact;

2. the mix of responsible technologies (and practices), to be used in a particular fishery, is agreed on a case-by-case basis with explicit reference to the management reference points and acceptable levels of impact agreed for that fishery. This mix should be compatible both with local conditions for sustainability and socio-economic conditions of the operators;

3. recommended technologies are easily available on the market and affordable for developing countries and that their transfer is promoted through international cooperation;

4. criteria for the selection or determination of responsible technology include local biological and

environmental conditions and socio-economic constraints;

5. selection or determination of responsible technology is based on an objective assessment of the actual or likely impacts and of the risks involved, for the resources, associated species and, in the long term, for the fishing community, taking into account the type of resources, ecosystem characteristics, and habitat;
6. technological requirements are defined with a view to maintaining (or reducing) the accidental effects of capture and post-capture fishery activities within pre-defined acceptable (tolerable) levels, allowing general application by all countries or parties involved;
7. States and management organizations and mechanisms undertake to list the fishery technology used or potentially usable, the "colour" of which would reflect the perceived degree of environmental friendliness;
8. before introducing a new technology in a controlled or sensitive area, on a low-resilience or particularly vulnerable species, the proponent is asked to produce a sufficient amount of information about the technology to be introduced and its potential impact and that the prior consent of the other users is required when appropriate;
9. if the introduction of a new technology is agreed, a number of specific measures should be foreseen such as limiting the scale of the initial project, special monitoring and reporting requirements, etc.;
10. when adopting PIC or PCPs, States or regional management, organization or arrangements should ensure that the potential rights (interests) of the inventor of the resource or of the technology can be protected;
11. request for the introduction of new techniques be supported by documentation amounting to an EIA identifying potential effects on the target species, and on associated species, which might be targets for other fisheries in the area or food items for such target species;
12. PIC and PCPs procedures should remain exceptional in order to reduce the administrative burden imposed to fishermen, and
13. special monitoring and reporting procedures should also be used for activities recognized as unacceptable in the long term and for which phasing out has been decided. Interim reports could be requested during the phasing out period.

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More details

THE PRECAUTIONARY APPROACH TO FISHERIES AND ITS IMPLICATIONS FOR FISHERY RESEARCH, TECHNOLOGY AND MANAGEMENT: AND UPDATED REVIEW (Continued)

7. IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

The imperfections in the fisheries management system, including uncertainties in management objectives, fishery and biological data, environmental oscillations, stock assessment methods, economic parameters, management advice, management measures and fishermen's behaviour have been recognized long ago (Larkin, 1972; Gulland, 1983). Gulland stressed the fact that "*imperfections that exist in all parts of the system…should not be an excuse for postponing action until matters are improved*" and that management action should be modified "*recognizing these imperfections and learning to live with them rather than attempting to eliminate them*". It is easy to recognize the precautionary approach in this 12 year old prescription to (a) recognize and accept uncertainty; (b) not delay action until more is known, and (c) learn to live with incomplete information. The solutions offered included, raising awareness on uncertainties and developing opportunism, flexibility and adaptation in management and development. These and other precautionary measures for fisheries management, have long been advocated as a means to avoid crises and higher costs to society (Walters and Hilborn, 1978). They have not often been applied in practice because more attention has been paid to short-term costs while long-term benefits have not been properly valued. Crisis management is unlikely to offer sustainable solutions to the problems encountered by fisheries.

Risk is unavoidable when deciding on harvest levels aiming at a range of conservation, social and economic (and political) objectives (Shotton, 1994). In such situations, decisions should be consistent with the theory of rational choice but the uncertainties on the data and models, as well as the differences and changes in the various users' preferences, make it impossible to define any optimum to be used as a single, resultant, management target. As a consequence, it is necessary to reflect the targets and constraints (both biological and economic) as "Reference Points", as landmarks which flag desirable or critical states of the known components of the system and which can be used to determine and influence the "position" of the fishery in relation to the multi-dimensional environment they materialize.

What is new in the modern requirement for precaution is not so much the sort of management measures that are suggested but the fact that they would be automatically enforced, with no exceptions, and that they should be implemented as soon as a serious and potentially irreversible effect is detected (Hey, 1992). In recent years, the major impulses towards precaution have been associated with crises. The stand taken by FAO (similar to that taken by IUCN (Cooke, (1994); see Section 3.2), is that a progressive but systematic and decisive shift towards more risk-averse exploitation and management regimes is preferable, for all users, to the present combination of a general "laisser-faire" policy with a few mediatic bans and with significant negative socio-economic impacts. The problem is, therefore, one of promoting effective caution in fisheries to the point where the risk of an irreversible impact on the environment and resources (and ultimately on the fishing communities) will be reduced below the level which would call for drastic measures with potentially irreversible damage to the fishery sector and the coastal communities. This could be achieved by exerting caution systematically, at all levels of the management process, to reduce substantially the probability of errors and the level of potential damage.

It must be realized, however, that extreme interpretations of the concept of precaution, which would lead to unnecessarily stringent and costly measures, could rapidly become counter-productive by deterring fishery authorities from using the concept as widely as possible.

It is often supposed that preventive (or proactive) approaches to management are more precautionary than reactive ones because they anticipate unwanted events through knowledge of the system. According to Boelaert-Suominen and Cullinan (1994), the principle of preventive action is based on "*the recognition (or assumption) that it is cheaper, safer, and more desirable (in the long term) to prevent environmental harm than to rectify it later, if indeed this is feasible at all*" (comments between brackets added by the writer). A strong and unwarranted assumption behind the principle of preventive action, however, is that there is enough knowledge to allow such events to be reliably anticipated and avoided. Unfortunately, as shown in Section 4, fishery systems are not fully predictable and errors are always likely. As a consequence, a precautionary management strategy would need both sufficient foresight to avoid predictable problems, and enough reactive (corrective) capacity, flexibility and adaptability to ensure a safe "trial-and-error" process, as knowledge about how the system works is collected (stepwise decision-making). In this respect, the importance of feed-back, adaptive probing strategies, and learning, for the improvement of management regimes, have been stressed *inter alia* by Walters and Hilborn (1976), Walters (1981, 1986), Parma and Deriso (1990), Hilborn (1994) as well as Hilborn and Smith (1995). In theory, probing should provide the optimal solution but Shane and Peterman (in press) provide a "Bayes equivalent" approach which should give a close approximation of the optimal strategy.

Because of uncertainty, it is not prudent for management to rely on deterministic pseudo-quantitative reference points of dubious precision for a target-based management (e.g., a management regime based on deterministic targets such as TACs and quotas). Precautionary management strategies would recognize the uncertainties in the data and promote adaptability and flexibility through appropriate institutions and decision-making processes, according priority attention to the biological limits of the resource. These strategies would rely not only on expert advice but also on effective people's participation. In case of doubt, decisions rules should "err on the safe side" having due regard to the risk for the resource and to the social and economic consequences in both the long and short term. A precautionary approach to fisheries management implies agreement on action to be taken to avoid a crisis as well as action required if such a crisis occurs unexpectedly. Agreement on such action, at national or international level, implies the existence of agreed standards, rules, reference points, critical thresholds and other criteria as well as consensus on acceptable levels of impact. These concepts will be examined in detail below.

7.1 Acceptable Impacts

There is no doubt that fisheries have an impact on the ecosystem, reducing species abundance and reproductive capacity, possibly affecting habitats and genetic diversity. Some species might be endangered, especially when fisheries, natural variability and environmental degradation by other industries combine their effects. An impact on the resource base cannot be totally avoided if fisheries are to produce a significant contribution to human food and development. However, the biological effects of fishery activities are usually reversible and experience has shown that trends in biomass and species composition can be largely reversed when fishing effort is curtailed or fisheries are closed, even though rehabilitation may take some time and the characteristics of the "rehabilitated" system may not be accurately predicted[21]. Degraded habitats may require particularly long recovery times and higher rehabilitation costs.

If development and benefits are to be obtained from fish resources, some level of impact has to be accepted and a zero-impact strategy would be impossible to implement in practice. It would therefore be necessary to: (a) identify and forecast fishery effects (and risks) accurately enough; (b) agree on acceptable levels of impact (and risk), and (c) develop management structures capable of maintaining fisheries within these levels. The wide use of such subjective terms as "*detrimental*", "*harmful*" and "*unacceptable*" to qualify unwanted impacts in expressions of the need for precaution is not very conducive to consensus and more efforts are required to specifically identify (preferably, by species and by region) what constitutes a risk and what risk is acceptable or not.

An **acceptable impact** could be defined as a negative, or potentially negative, alteration of the exploited natural system, resulting from human activities (i.e., fisheries and other impacting industries), the level and nature of which is considered as representing a low risk for the resource, system productivity, or biodiversity, on the basis of the available knowledge and level of uncertainty. Such a definition implies that: (a) the risk has been assessed using the best available evidence by all parties concerned, which agreed to it, in the light of the objectives stated for the resource, and (b) the impact will never be fully accepted (in the sense of definitely approved) but it will be kept continually under review and a decision about its acceptability eventually modified as knowledge progresses. The concept of acceptable impact may be related to that of **assimilative capacity**. This capacity, which has generated considerable debate amongst those concerned with environmental protection (Hey, 1992), has been defined as "*a property of the environment which measures its ability to accommodate a particular activity or rate of activity without unacceptable impacts*" (GESAMP, 1990). It assumes that nature might be able to absorb a certain quantity of contaminants (e.g., effluents from urban concentrations, radioactive waste, heavy metals and other causes of dramatic and potentially non-reversible impacts) without significant effect. The debate and opposition to the concept stemmed *inter alia* from: (a) opposition to the idea that oceans could legally be used for dumping, and (b) difficulty of determining objectively and agreeing on the evidence of innocuity or harmfulness of small concentrations of contaminants.

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[21]The introduction of exotic species and genetically modified organisms may be the most notable and serious exception to this observation as it is generally impossible to remove species (and certainly genes) from the ecosystem once successfully introduced

In fisheries, however, the problem is different. Fishery resources do possess an assimilative capacity in terms of the fishing mortality they can withstand while still conserving most of their resilience or capacity to return to their original state once the fishery-induced stress is removed[22] In a way, the concept of Maximum Sustainable Yield, enshrined in the 1982 Convention, could be considered a reference point corresponding to the "maximum assimilative capacity" of a stock in terms of fishing stress, i.e., a level of stress beyond which fisheries should not be allowed to go and, perhaps, not even to approach (see Section 7.2 on MSY as a reference point). The situation becomes more complex when considering the assimilative capacity of a multi-species resource or an ecosystem for which no means of measurement is yet available.

The degree of acceptability of impacts (or risks) will be determined, *inter alia*, in terms of risk-benefit trade-offs with proper weighting given to long-term societal needs and value of natural assets. This requires research capacity to separate the effects of "natural" year-to-year fluctuations and the impacts of fishing from anthropogenic degradation, including global climate change. It requires the development of an effective enforcement capacity to ensure that such levels will be respected. Finally, it may also require the establishment of "**safety net arrangements**" (e.g., in terms of insurance, compensation, etc.) to protect the users from hazardous occurrences.

There is no scientific criteria to determine objectively what is acceptable to society[23]. It is likely, however, that what may be acceptable to some countries or user-groups may not be acceptable to others (an argument developed by Dommen, 1993), and the relevance and importance of traditions and culture in this respect should not be underestimated. One of the important prerequisites for the effects of fishing to be acceptable to society could be that they should be **reversible**[24] if the fishing pressure is reduced or suppressed. Referring specifically to ecosystems, Holling (1994) stressed that "*temporary erosion of any one (of the sources of renewal capacity) might be bearable as long as recovery occurs within the critical time unit of one human generation. But continued erosion of even one (of these sources) eventually reaches the point where it cannot be reversed by normal internal recovery*".

Decisions on what impact could or could not be allowed are comparatively easy when risks are known and extremely high. Proposals to prohibit, even without any scientific background, the use of explosives to fish (say, in the high seas) would probably not meet with much international opposition because harmful fisheries techniques (e.g., dynamite and poison) are normally banned by national fisheries legislation. However, deciding whether a 5% by-catch of sharks in a long-line tuna fishery (or whether a 10% probability to drive a stock below its theoretical biological safe limits) is acceptable would require more careful consideration and debate. Science should provide the methods needed to forecast and measure the impacts, as well as objective criteria on the basis of which agreements can be reached. The difficulty in this regard will not be less than in other scientific mandates (e.g., that of determining MSY) and we should expect considerable scientific argument on the type of impact one might expect and on the level of certainty with which it can be determined.

[22]Except in the case of serious damage to the habitat, introduced species and GMOs

[23]Even though alternatives and their consequences (including for society) can be scientifically analysed and transitory agreements might be reached on their basis

[24]It has already been mentioned that this requirement was particularly critical in the case of introductions of species and GMOs

The degree of acceptability of any impact will only be established after intense negotiations between the parties concerned. These are unlikely to proceed easily or rationally if undertaken in a context of crisis. It is, therefore, advisable to integrate negotiations on impact into the management process before stocks are damaged and before potential socio-economic problems reach an overwhelming level. Cooke (1994) proposes, for instance, that when information to set a full-fledged management system is lacking, precautionary exploitation rates could be limited to 1% of the original biomass estimate. He argues, rightly, that this rate might still be too high for some very long-lived species. One could argue, however, that such a rate would be extremely low and hardly justifiable for short-lived tropical species where sustainable annual catches can be equal or higher than standing stock biomass and might sustainably be about 30–50% of the virgin stock biomass. Returning to the old approximative rule that the fishing mortality at MSY is close to natural mortality (Gulland, 1971) and while recognizing its shortcomings, one could nonetheless suggest a less arbitrary and more flexible precautionary rate of exploitation. One could, for instance, decide that precautionary exploitation rates should never approach natural mortality rates (if only because catching MSY is not desirable) and be limited to, say, 25% of these levels. For example, it could be decided that the precautionary level of fishing mortality in absence of data, F_{prec}, should never be higher than 25% of the natural mortality rate, leading to catches below 1% of the biomass per year for very long-lived animals, but well above 25% for others, with equivalent degrees of precaution.

7.2 Management Principles and Decision Rules

Once agreement has been reached on what risk and what levels of impact are acceptable, one of the major tasks for research and management is to develop agreement on standards, rules, reference points and critical thresholds by reference to which decisions will be made to meet the selected management objectives and the requirements of the 1982 Convention, UNCED Agenda 21 and the FAO Code of Conduct. Over-restrictive rules (e.g., rules implying socio-economic consequences without proportion to the risks involved) or recommended without a clear understanding of their practical implications, are not likely to lead to the level of consensus required for the wide application of a precautionary approach required in UNCED Principle 15.

Because of the universality of conservation principles, precautionary management rules need to be established for all resources whether in EEZs or in the high seas. Because of the transboundary nature of many high seas resources, straddling stocks and highly migratory species, precaution should be applied across the entire area of distribution of the stock. This implies that coherent precautionary management regimes should be put in place, taking into account the geographical location of critical life phases (e.g., nursery, feeding or spawning areas) and ensuring that the measures taken inside the EEZs, and outside them, are coherent and are, overall, conducive to stock sustainability at safe levels of abundance. The following list gives some examples of principles or decision rules that have been proposed in the literature with a view to illustrating both the need for them and the difficulty of defining them in realistic terms:

1. fisheries should not result in the decrease of any population of marine species below a level close to that which ensures the greatest net annual increment of biomass;

2. fisheries should not catch amounts of either target or non-target species that will result in significant changes in the relationship among any of the key components of the marine ecosystem of which they are part;

3. the mortality inflicted on any target or non-target species is unacceptable if it exceeds the level that would, when combined with other sources of mortality, result in a total level that is not sustainable by the population in the long term;

4. fish management authorities should set target species catch levels in accordance with the requirement that fishing does not exceed ecologically sustainable levels for both target and non-target species;

5. fisheries management should take into account the combined stresses imposed by fishing, habitat loss and destruction, point and non-point sources of pollution, climate change, ozone level changes and other environmental and human impacts, and

6. fishery management should preserve the evolutionary potential of aquatic species.

The first principle implies that populations should not fall below the level of abundance corresponding to MSY, where their annual rate of biological production (turnover) is the highest. This is in line with the 1982 Convention requirements. It has been repeatedly shown, however, that it is often inadvisable to try to extract the MSY from a resource. Moreover, for multi-species fisheries, this principle would require that all species be exploited below their MSY abundance and, therefore, that the overall level of exploitation be fixed at the lowest level required by the species with the lowest resilience, reducing drastically the utility of the resource[25].

The second principle, which rightly aims at preserving the qualitative parameters and fundamental integrity of the ecosystem mechanism, implies that fishing will not "significantly" disturb the food chain (an unreasonable assumption), without guidance on how to judge whether an observed or potential disturbance is significant. Moreover, fishing all species at MSY, if at all possible, would lead, in practice, to applying different fishing mortalities to different species and this would lead to a change in relative abundance of species, affecting the food chain. As a consequence, the second principle may be difficult to implement in many fisheries and may not even be always consistent with the first.

The third and fourth principles require that all sources of mortality are taken into account when assessing fisheries impact. These would include natural mortality as well as direct and indirect fishing mortalities (through by-catch, drop-out, damage, ghost-fishing, etc.). In practice, this principle implies also that mortalities imposed by non-fishery users (e.g., through environmental degradation) should also be taken into account. A very demanding task indeed, in most cases beyond the present capacity of research systems, even in the developed world. Assuming that the task implied by the third principle is feasible, a problem remains with the vagueness of the term "sustainable" in the formulations. In theory, fisheries are "sustainable" at various levels of stock abundance and rates of harvesting, but these are not equivalent in terms of risk of recruitment collapse. Surplus production models, on which the concept of MSY is based, assume that natural renewable resources are "sustainable" (i.e., able to regenerate themselves year after year) at various levels of abundance depending on the level of harvest (Figure 1). A stock can in theory reproduce itself, and be considered sustainable, at high (virgin state), medium (MSY level) and even low levels of abundance, except for some species such as marine mammals and sharks. However, as stocks are fished down, their variability and the risk of collapse increases and it should be clear that all levels of theoretical "sustainability" are not equivalent in terms of risk for the resource. To be of practical use in fishery management, the concept of sustainability needs to be combined with the notion of risk for the resource and consequently to the fishing communities.

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[25]In a typical Mediterranean multi-species trawl fishery, where long-lived bottom species (e.g., seabream and red mullet) are targeted together with short-lived pelagics (e.g., sardine), this would imply fishing sardine well below the possible level of harvest in order to comply with the guidelines for seabream and mullet. The problem has been recognized in the report of the FAO Expert Consultation on Large-Scale Pelagic Driftnet Fishing (Rome, 1990)

The fifth principle, which in itself is perfectly laudable, has been reproduced only to illustrate the difficulty in practical implementation of some prescriptions. It is clear that the scientific data necessary to understand and forecast the impacts of all the sources of stress listed in the principle, some of which are still in the very early stage of study, are not available. As a consequence, they cannot be "taken into account". The point, however, that all stresses need to be addressed, including those imposed by non-fishing or related to natural fluctuations, is well taken and has been underlined in the FAO Code of Conduct.

The sixth principle would imply that fishing should only be allowed in a way which would not affect the ability of an exploited population to respond and adapt to natural and anthropocentric perturbations (including by fishing) on the population or its environment. This is a commendable proposal considering our uncertainty, on the value of specific genes and genetic variations, on the number of sub-populations necessary for ensuring stock viability in all conditions and on how fishing affects genetic resources. To comply with the proposal despite all uncertainties, however, management would actually have to aim at maintaining all the genes and genotypes present in the virgin stock. Since genetic variation is directly related to population size, such a management scenario would not allow any reduction of the population size at all and, therefore, any fishing at all. A proposal unlikely to generate consensus.

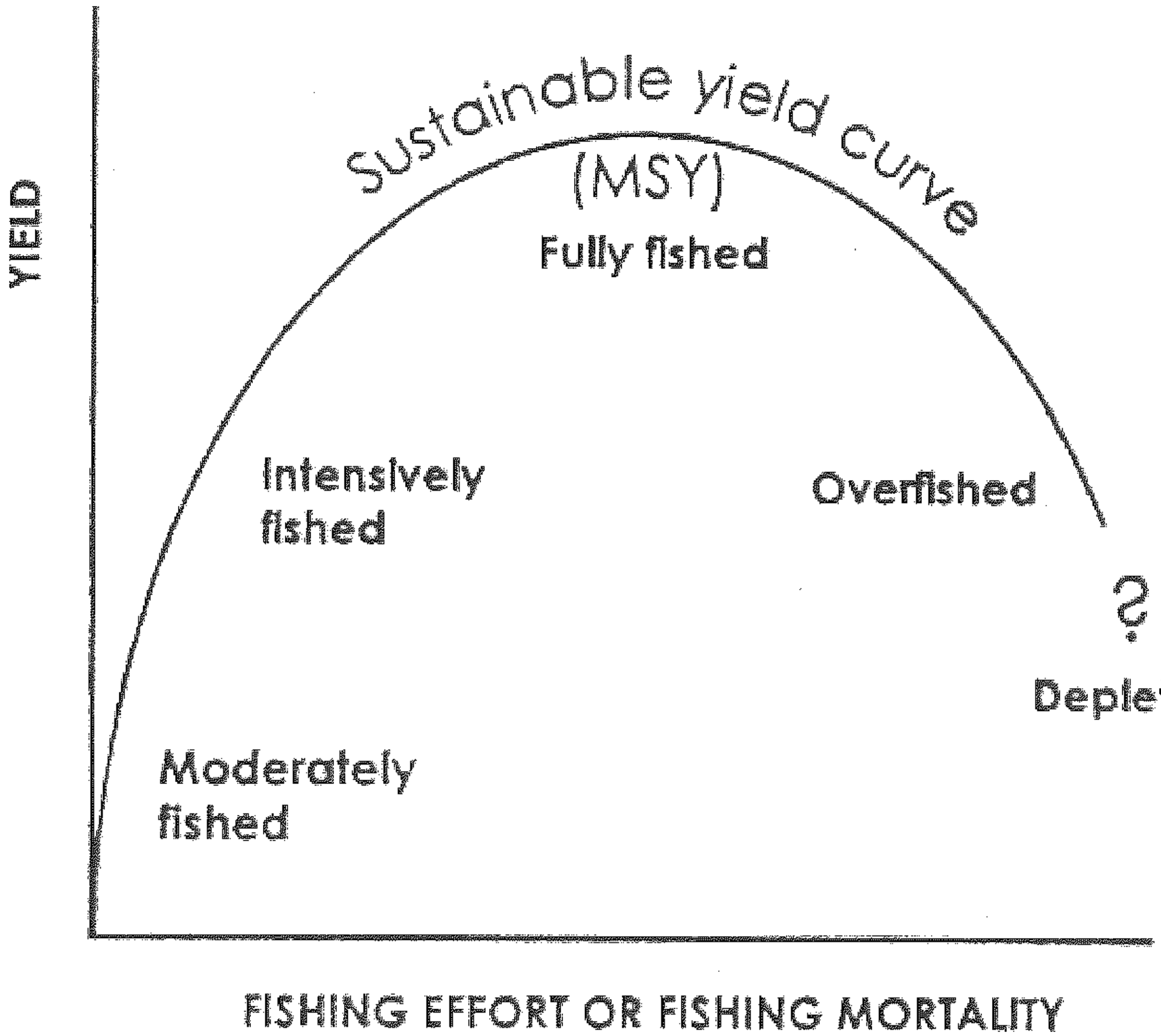

Figure 1: Relationship between fishing mortality (or effort) and sustainable yield.

7.3 Precaution and Management Reference Points

Reference points have always been used in management, explicitly or implicitly, and are not a particular characteristic of the precautionary approach to fisheries. Precaution will relate to the choice of reference points (and their resource-related properties) and to the way in which they are used.

A management reference point is "*an estimated value derived from an agreed scientific procedure and an agreed model to which corresponds a state of the resource and of the fishery and which can be used as a guide for fisheries management*"[26]. This definition stresses the fact that reference points are conventional constructions based on the knowledge and often on a model available at the time of their adoption. As a consequence, they are meaningful only with a reference to the underlying theory and model, method and data used for their estimation as well as species to which it applies. The consequence is that reference points should be re-assessed periodically as new data is collected and as new understandings or methods become available, there would be great danger of "chiselling them in marble" as was done for MSY in the 1982 Convention. In the paper prepared by FAO for the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, (FAO, 1993a) two types of management reference points are described: Target Reference Points (TRPs) and Limit Reference Points (LRPs). The review has been further developed in Caddy and Mahon (1995) and additional references can be found in Rosenberg and Restrepo (1995). A tentative definition of these points is given below.

The MSY Reference Point

The 1982 Convention states that stocks should not be driven below the level of abundance that could produce the Maximum Sustainable Yield (MSY). For decades, MSY has been used, explicitly or implicitly, as a reference point by research, development and management and considered as a bottom-line threshold for stock "sustainability"[27]. Research has amply argued, since the early sixties, that even at MSY, stock instability and risk of recruitment failure are sometimes already high (Christy and Scott, 1965; Larkin, 1977; Gulland, 1969, 1977, 1978; Sissenwine, 1978). This, added to the fact that MSY and the fishing rate corresponding to it are usually difficult to determine accurately, should lead to consider MSY as a non-precautionary target, particularly for stocks with low resilience or high natural variability. At the 1992 FAO Technical Consultation on High Seas Fishing, attention was drawn to the non-precautionary nature of the traditional MSY reference point and to the need for more and different reference points as a basis for more precautionary management strategies (Garcia, 1992). New reference points, not foreseen in the 1982 Convention are, therefore, required if management aims at a low risk of collapse.

Target Reference Points (TRPs)

A Target Reference Point (TRP) corresponds to a state of a fishery and/or a resource which is considered desirable and at which fishery management aims. In most cases, a TRP will be expressed in a level of desirable output from a fishery (e.g., related to catch) and will correspond to an explicit objective of the fishery. As mentioned above, MSY (and F_{MSY}) have been considered as TRPs for decades and the dangers of that strategy have been clearly indicated by the scientific community. F_{MAX}, corresponding to the maximum yield per recruit is an even less precautionary target reference point disregarding the risk of recruitment overfishing. Other TRPs may be used which would aim at conserving higher levels of biomass and at reducing the risk of overfishing. These are, for instance, $F_{2/3\ msy}$ (aiming at an annual catch of 2/3 of the MSY), F_{MBP} (where the stock is maintained at its level of Maximum Biological Production), and $F_{0.1}$ (where marginal yield is 10% of the marginal yield of the virgin stock).

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[26]*Ad hoc* Working Group on Reference Points established by the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks in New York, in March 1994 (cf. Annex 3)

[27]Understood by all States as the highest level of withdrawal from the resource (and fishing intensity) allowed by the 1982 Convention. Understood by some States as the recommended target level of development

When a target reference point is reached during a development process, management action should aim at maintaining the fishery system at its level, e.g., through establishment of total allowable catches and quotas or through effort controls (see below the section on Precautionary Use of RPs).

Limit Reference Points (LRPs)

A limit Reference Point (LRP) indicates a state of a fishery and/or a resource which is not considered desirable. Fishery development should be stopped before reaching it and the risk of inadvertently "crossing" the limit should be very low. Limits are usually expressed in biological terms (e.g., minimum spawning biomass required) but could be expressed in economic terms also (e.g., minimum profitability) even though this does not seem to have been done yet. Biological LRPs have a conservation function and are particularly required in a precautionary approach to set the constraints within which the management strategy must operate (Rosenberg and Restrepo, 1995). These LRPs aim, in particular at conserving an appropriate reproductive potential and at avoiding recruitment overfishing. The most important LRPs developed during the last decade are related to the stock-recruitment relationship (Sissenwine and Shepherd, 1987; Rosenberg and Restrepo, 1995; Garcia, in press). LRPs can also be expressed in terms of mortality or biomass limits (see Caddy and Mahon, 1995; Rosenberg and Restrepo, 1995).

A common way to specify LRPs is to express them as a percentage of the virgin biomass (B_0) below which the stock should not be driven. A typical value often referred to is 20% B_0. ICES has adopted the concept of *Minimum Biological Acceptable Level (MBAL)* defined, for each stock, as the level below which the recruitment has a 50% chance of falling below the critical level beyond which it will decrease as a function of stock size. MBAL could also be the level at which residual spawning biomass has a 50% chance of falling below the established 20% B_0safe limit. In practice, these points are not easy to establish and may have fairly large confidence limits. Garcia (in press) describes a methodology to reflect a precautionary approach to tropical shrimp management, based on these concepts, in data-poor situations.

When a LRP is reached, management action should severely curtail or stop fishery development, as appropriate, and corrective action should be taken. In case overfishing has occurred, stock rehabilitation programmes should consider the LRP that would have been adopted for a healthy resource as a very minimum rebuilding target to be reached before the rebuilding measures are relaxed or the fishery is re-opened. An example is given by the rebuilding strategy adopted for the Southeast Australian stock of orange roughly *(Hoplostethus atlanticus)* following heavy overfishing between the late 1980s and the early 1990s. The Australian Fisheries Management Authority has endorsed, starting in 1995, a strategy to base Total Allowable Catches (TACs) with a view to ensure a 50% probability that the stock is at or above 30% of the spawning biomass present at the beginning of the fishery (Phillips and Rayns, 1995). This latter figure will be used, first, as a rebuilding target and, as soon as it is reached (in 2004 according to forecasts), as an LRP.

Precautionary Use of RPs and Threshold Reference Points (ThRPs)

Two major sources of bad performance in a reference points system will be examined below: (a) the accuracy and precision with which the RPs are determined, and (b) their adequation to the fishery system dynamics.

First, because of the uncertainty inherent in their determination, reference points should preferably relate to probabilities[28] (e.g., specifying both their central value and confidence limits). This uncertainty as well as the uncertainty in the current value of the fishing mortality or stock biomass, imply a certain probability that these RPs be “missed”. For example, management regimes using MSY or FMSY as TRP will meet the objective only **on average**, with 50% chances of a slight “overfishing” or “underfishing”, in case of a normal distribution of probabilities. Assuming full control of the fishery, the seriousness of the “statistical” vagaries around the objective will depend on the breadth of confidence limits of the TRP estimate and the potential consequences of a exceeding the target with a certain frequency and to a certain extent. If these consequences appear unacceptable, a more precautionary approach will be needed.

Second, the fishery system has its own dynamics and fishing fleets have a high level of inertia (resistance to change), due to various financial, technical, cultural and administrative reasons. As a consequence, stopping their evolution and expansion and reversing or only modifying historical trends are not trivial tasks and may require time in addition to political will and incentives. Similarly, the life parameters of long-lived target species (e.g., low natural mortality and fecundity, late maturation and slow growth) are such that reversing resource trends and promoting their recovery once depleted may require some luck (on the environmental side) and some time. There is therefore a risk that, having reached a TRP or approached a LRP, in the course of a dynamic development process, it takes too long to effectively stop the fishery's evolution in this desirable situation, overshooting the target and, possibly, crossing the limit. As a consequence, more precautionary reference points and decision rules might be required in order to avoid or reduce the need for costly corrective action and to limit the amplitude of the oscillations of the fishery around its target and limits.

Two solutions are generally offered to deal with both of these problems: (a) choosing more precautionary references, and (b) using the references in a more precautionary way.

Firstly, it is possible to select different reference points based on the level of precaution desired, or risk considered as acceptable, as shown in the two preceding sections, and this is usually achieved at the expense of foregoing some potential economic benefits. It is self-evident that selecting $F_{0.1}$ or

$F_{2/3\ MSY}$ as TRPs instead of F_{MSY}, for instance, is sufficient to reduce the risk of overfishing. Similarly, choosing 20% of the virgin stock spawning biomass as a LRP is less precautionary than putting this limit at 30%[29]. In addition, some reference points can be used either as TRP or LRP depending on the level of precaution to be ensured. In principle, trying to avoid reaching a reference point (i.e., using as a limit) instead of trying to meet it on average (e.g., using it as a target) should reduce the probability to go beyond it. It is for this reason that F_{msy}, which has been considered as a target for decades, is now proposed as a LRP, as a **minimum international standard**, or as a minimum target for stock rebuilding strategies (cf. Annex 5, paragraphs 1 and 16), illustrating the shift of contemporary scientific advice towards more precautionary strategies. One could select $F_{2/3MSY}$ as a TRP because of its *a priori* better performance in terms of risk to overfish and this strategy could be as precautionary as using F_{MSY} as a LRP. In practice, the two references could be indeed used together, e.g., $F_{2/3MSY}$ as a target and B_{MSY} as a limit.

[28]For example, a "**Minimum Biological Acceptable Limit**" (MBAL), related to recruitment or reproductive biomass would be defined as a level beyond which the recruitment has a 50% chance to fall below a critical level (R_{max} for instance or R_{mean}) or the residual spawning biomass (escapement) has a 50% chance to fall below 20% of the virgin stock spawning biomass

[29]An example of such conservative setting of biological limits is given by the Revised Management Procedure of the International Whaling Commission (IWC) which sets the lower stock limit at 54% of the carrying capacity, a level sometimes considered as excessively conservative (Kirkwood and Smith, 1995)

Secondly, it is possible to keep the same RPs, using them differently. The probability to inadvertently "cross" a TRP when aiming strictly at it, is 50%. A different and more precautionary probability could, however, be in-built in the related decision-rule, e.g. by deciding that annual fishing mortality should not be allowed to exceed the TRP value more than 10% of the time instead of 50% of the time, or by leaving the LRP value at 20% of the virgin stock but agreeing that the acceptable probability to exceed the limit should be 25% and not 50%. These results could indeed only be obtained by fishing at a level somewhat lower than otherwise possible, on average, and this second solution is therefore equivalent to replacing the reference point by a more precautionary one (see Figure 2). Similarly, Caddy and Mahon (1995) stress that the lower the precision of the mortality estimates (e.g., their coefficient of variation), the lower the "safe" target fishing level for a given level of risk.

Precaution will be ensured by combining TRPs and LRPs which will most often refer to different control or status variables of the fishery system. For instance, a TRP might be established in terms of a proportion of MSY (e.g., two thirds of MSY) and used simultaneously to LRP established in terms of spawning biomass (e.g., 20% of the virgin spawning biomass). The implication is that the manager will develop the fishery towards producing two-thirds of MSY while monitoring carefully the decreasing spawning biomass as effort increases (just as a captain would aim the vessel towards a destination while watching the depth under the vessel's keel). The manager will immediately change the fishery TRP, or the way the TRP is being approached, if the LRP is being too rapidly approached or is dangerously close (e.g., just as the captain would modify the destination or the route with its equipment to indicate a reef ahead or a rapidly decreasing depth). A non trivial consequences of this approach is that the TRPs and LRPs should be compatible (e.g., the fishing mortality at which the TRP catch is obtained should obviously be significantly lower than that at which the LRP spawning biomass could be "crossed").

Another solution suggested in Garcia (1994a) is to use **Threshold Reference Points (ThRPs).** A ThRP indicates that the state of a fishery and/or a resource is approaching a TRP or a LRP and that a certain type of action (preferably agreed beforehand) is to be taken to avoid (or reduce the probability) that the TRP or LRP is accidentally exceeded. It provides an early warning when critical reference points are being approached, reducing the risk that these points (and the management objectives they materialize) be violated. Just as in high inertia computerized tankers, alarms are pre-set to be automatically triggered if the distance to other vessels or the depth under the keel falls below a pre-determined safety value. This could be done, if the cost of permanently reducing the fishing mortality (and fisheries output), as suggested above, was not considered justified in regard to the risk. Adding precaution to the management set-up but also burden, ThRPs might be necessary only for resources or situations involving the particularly high risk related to the nature of the target stocks or the type of fishery development process.

It is paradoxical, however, that ThRPs might not be usable when they would be most needed, i.e., when natural variability is high or data is scarce. Under these conditions, the confidence limits of the estimates of the current level of exploitation (e.g., in terms of fishing mortality, $F_{current}$), the TRP (e.g., the target level of fishing mortality, F_{TRP}) and the LRP (e.g., the higher limit allowed for this mortality, F_{LRP}), might be too large to allow statistically significant discrimination between them. The precision with which the estimates can be made determine therefore the **resolution of the reference points system**, and the number of points that can realistically be used simultaneously (see Figure 3).

The medium-term oscillations of the resources potential and properties (e.g., on circa-decadal scales) can be a significant cause of loss of performance of management systems and of serious crashes of the resource base. Famous examples are given by the collapse of the Peruvian anchoveta stock under El Niño, in the early seventies and, possibly, the collapse of the Atlanto-Scandian herring and Canadian Cod stocks in the North Atlantic. It is difficult to give a generic prescription relating RPs to these events. Cooke (1994), stressed that in order to be useful for management, reference points should retain their validity in the face of short- and long-term fluctuations in fish stocks due to recruitment variability and other factors. For events already observed in the past, the probabilities of their occurrence should be taken into account, including through their forecasting and related adjustment of the TRP. If such probabilities are not available a fully rational approach is probably not possible but some contingency plans or other safety-net arrangements might be instituted.

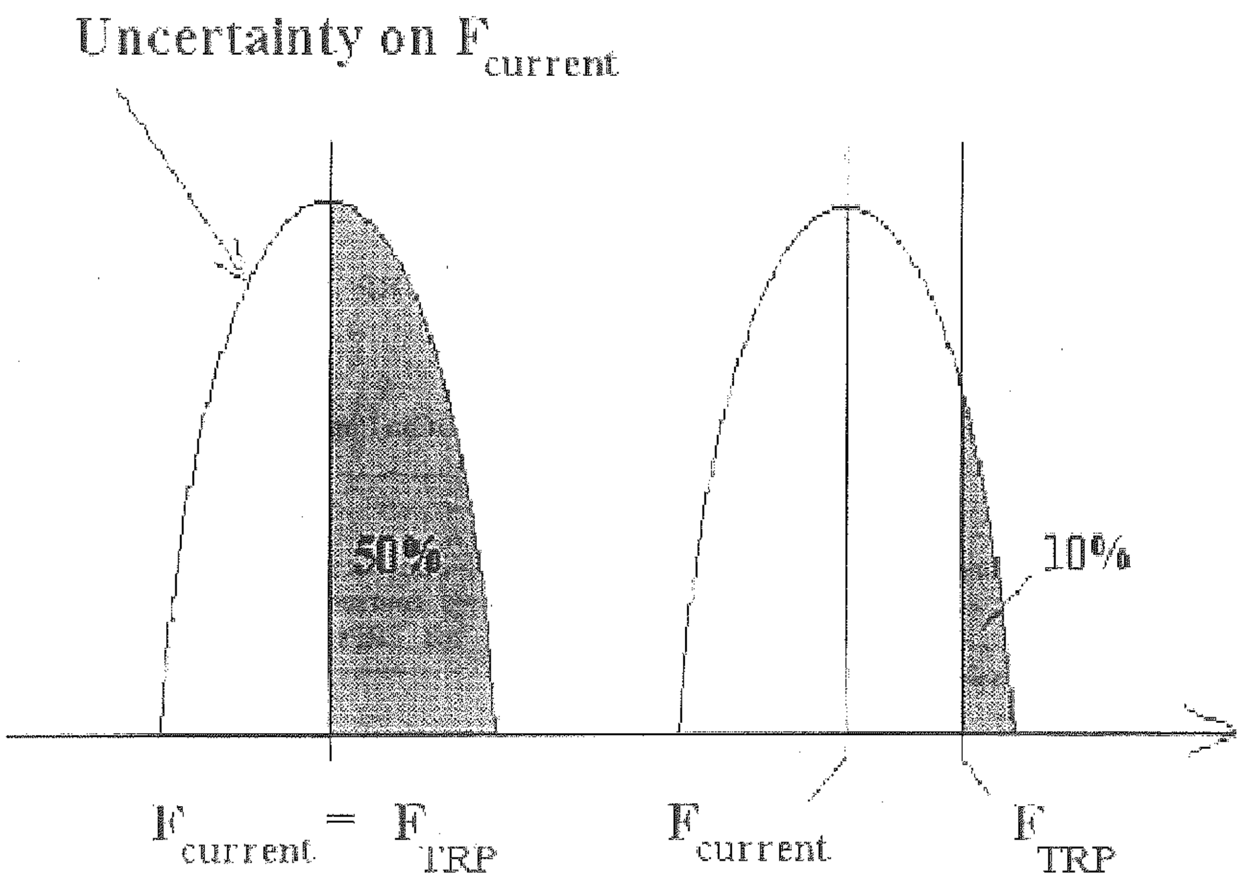

Figure 2: Relation between the effectively achieved level of mortality ($F_{current}$) and TRP

level (F_{TRP}) when a 50% or 10% probability to inadvertently exceed the TRP is accepted.

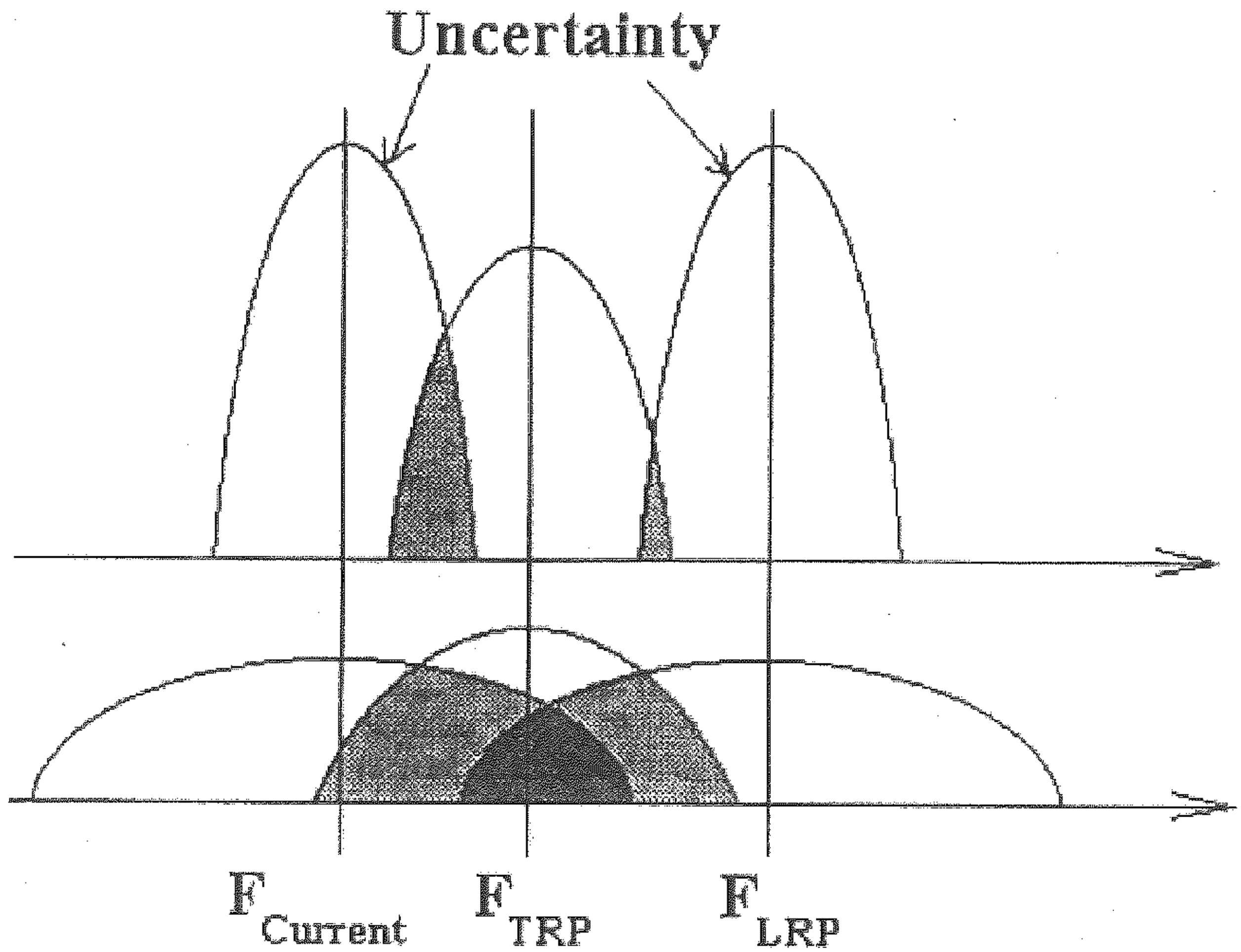

Figure 3: Illustration of a low variability/high resolution (top) and a high variability/low resolution reference points system.

As mentioned earlier on, preventive action is preferable but not always possible, and effective reactive capacity is important. In this respect, **pre-agreed courses of action**, "automatically" triggered when TRPs are reached, ThRPs are crossed, and LRPs are approached, would be particularly advisable, in particular:

- when the probability of occurrence of an unwanted negative outcome is particularly high (e.g., in areas of high environmental variability such as upwellings or semi-arid climates;
- for species which are at the extreme end of their geographical range of distribution or with particularly low resilience (e.g., small cetaceans, sharks, etc.), and
- when the potential cost of inadvertently "breaking the rules" could be particularly high.

Management strategies and control laws

The management strategy which establishes the way by which it is planned to reach stated objectives is largely determined by these objectives (which also determine the selection of TRPs), the conservation constraints imposed on the fishery (as materialized by the selected LRPs), and the pre-agreed course of action to be taken depending on the position of the fishery in relation to the RPs system. The management strategy will state, *a priori*, the acceptable probability that the LRP is violated (while apparently it is not!). The related decision-rules will be case-specific, depending on the characteristics of the stock (its resilience) and the type and flexibility of the fishery. A management strategy or control law can be graphically represented and summarized as in Figure 4. Its performance in terms of satisfying the objective (meeting the TRPs) and the conservation constraints (meeting the LRPs), can be tested by simulation (Restrepo and Rosenberg, 1994).

Socio-economic reference points

Some economic TRPs are available in theory but have been rarely applied in practice, such as MEY or F_{MEY} (the level of effort corresponding to Maximum Economic Yield) at which the fishery generates its highest rent. This reference point is usually located well below F_{MSY} and has, therefore, better conservation properties. On the contrary, the Maximum Employment criteria (a level never defined in theory but one of the most used, at least implicitly, by "laisser faire" management strategies) implies developing fisheries well beyond F_{MSY}, generating high risk for the resource.

The concept of socio-economic LRP does not seem to have been used or even formally proposed but they could be developed as management systems will make more explicit use of economic theory. For instance, in order to avoid having to subsidize a national fishery, a reference point could be determined, at an effort level (fleet size) where the revenue would be equal to **all** costs, including the cost of research, control, surveillance and enforcement, indicating the maximum acceptable fleet size or effort level.

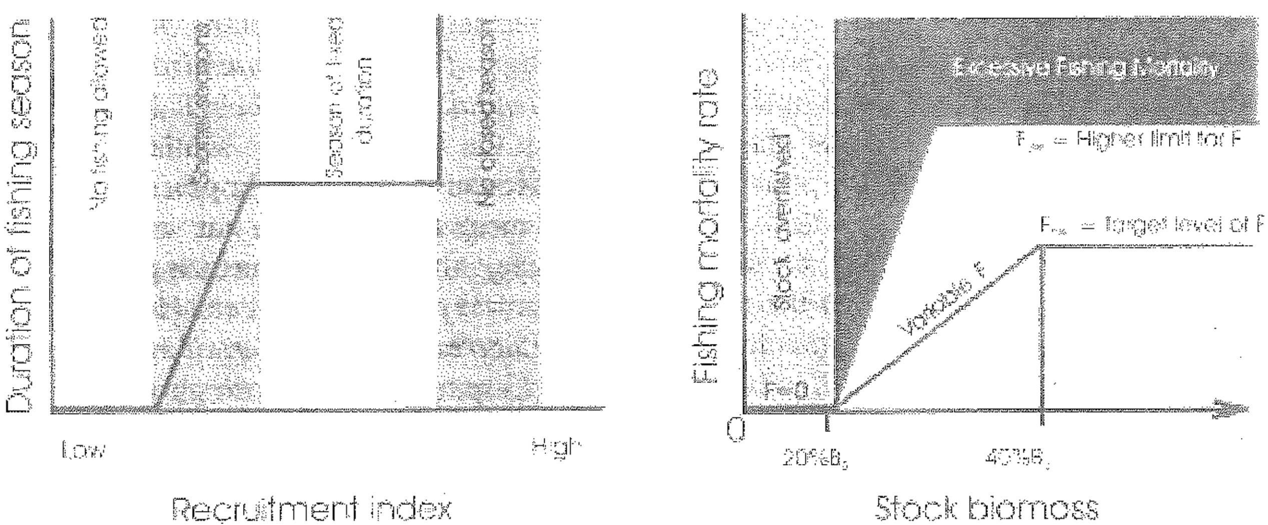

Figure 4: Representations of management strategies. Left: Regulation of the duration of the fishing season as a function of annual recruitment (from Garcia, 1996). Right: regulation of fishing mortality as a function of the stock biomass (modified from Rosenberg and Restrepo, 1995).

A major difficulty in selecting socio-economic reference points for management, including reduction of overcapacity, resides in the task of determining the appropriate position (level of effort, or fleet capacity) corresponding to the mix of socio-economic objectives, often ill-defined, assigned to a fishery. The little success met by the concept of Optimum Yield (OY) illustrates this problem. The difficulty in confronting the socio-economic complexities of a precautionary approach to fisheries was reflected in the difficulties met by the Technical Consultation on the Precautionary Approach to Capture Fisheries (FAO, 1995) to deal properly with artisanal fisheries for which a particular reflexion is still required.

Another difficulty is in cost-benefit analysis. It should be evident that the cost of the measure should be matched by its future benefits but that calculation is not trivial and is complicated by the multiplicity of stakeholders, the diversity of their objectives and time preferences, the different implications of the so-called "future discounting" for different groups[30], and the likelihood that they will effectively receive the theoretical benefits (Shotton, 1994).

To circumvent, at least partially, these difficult, pragmatic decision rules could also be established on economic grounds, related, for instance, to fishing capacity: e.g., if capacity increases faster than catches for a given number of years, then some capacity freezing action is taken. If capacity is higher than that required to take the allowable catch by more than a given percentage, then it should be reduced, etc. The selection of socio-economic decision rules and economic reference points is difficult enough in national fisheries. In management of high seas, straddling and highly migratory stocks, the difficulty is even higher owing to the divergence of economic situations of the various national stakeholders. In such a situation, the selected rules and references would have to be general enough to be acceptable to all parties and specific enough to be of practical use.

Ecosystem reference points

Ecosystem management is being recognized with increasing frequency as the necessary basis for fisheries management and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is often cited as the champion of the ecosystem management concept. The CCAMLR convention refers to "*the maintenance of ecological relationships between harvested, dependent and related species*" as well as the "*prevention of change or minimization of the risk of change in the marine ecosystem which are not potentially reversible*". This requirement is precautionary in nature in the sense that it requires that the integrity and essential functions of the ecosystem must be preserved as a prerequisite to fisheries sustainability. In practice, however, we do not yet know how to manage entire ecosystems. In most cases we have not yet even understood completely how they function, why and how they fluctuate, what are the structuring variables and we cannot predict the future states of the ecosystem we are exploiting. Walters (1986) stresses that "*ecosystems are moving targets, with multiple potential futures that are uncertain and unpredictable. Therefore management has to be flexible, adaptive and experimental at scales compatible with the scales of critical ecosystem functions*". The recognition of this uncertainty has sometimes led, in the international debate on the precautionary approach, to replace the requirement for ecosystem management (implying control on all elements of the ecosystem) by the more specific and practical goal of conserving not only the target species but also the associated and dependant species. If the balance between ecosystem components must be maintained, minimizing by-catch or using extremely selective gear, as common sense suggests, might not be the best solution. It has been proposed, for instance, that in multi-species management, a reasonable strategy would be to exploit all species in proportion to their abundance in order to maintain the overall ecosystem structure (Garrod, 1973). This is, however, not easy to achieve without wastage of less demanded species and additional work is certainly required on this matter before objective guidance can be given.

[30] Considering the major impact of discount rates, the uncertainty about their future evolution, and the likely difference between "local" and "global" rates, a key problem of establishing socio-economic reference points is that of agreeing on these rates

More research is needed to develop specific guidelines and reference points for a precautionary approach to aquatic ecosystems exploitation, related for instance to global stress indicators, resilience factors, critical habitat conditions, acceptable impacts etc. Clarification is also required on the meaning of **ecosystem sustainability** and on the issue **"impact reversibility"**. Ecosystems have a degree of natural variability and can shift from one equilibrium state to another because of natural environmental variability or human stress and under these conditions sustainability cannot mean constancy. As far as reversibility is concerned, fisheries management may be able to suppress unwanted fisheries impacts (e.g., through fleet reduction schemes, protected areas, etc.) and rebuild productivity but there is no assurance that the ecosystem could be returned exactly to its **pristine state**.

Some of the aims and principles of ecosystem management can be found in the management charter of CCAMLR and in the 1990 Strategy for Sustainability elaborated by IUCN. These include: minimizing conversion of critical ecosystems to "lower" conditions, compensating habitat conversion with restoration (allowing no net loss)[31], maintaining ecological relationships, maintaining populations at greatest net annual increment, restoring depleted populations, minimizing risk of irreversible change in the marine ecosystem, etc. Holling (1994) maintains that ecosystems are structured by a small number of biotic and abiotic processes which organize its behaviour and that when investing in the protection of ecosystems (biodiversity), priority should be placed on maintaining these structuring variables. A useful principle could be to aim at maintaining all the fundamental components of the ecosystem (nurseries, spawning areas, feeding areas, migration routes, etc.) in order to ensure permanency of the ecosystem structure even though the abundance (or even the permanence) of some of its species components cannot be absolutely warranted. Genetic conservation guidelines, when introduced, will make matters even more complicated as management will have to meet conservation requirements at the ecosystem, biodiversity, species and genetic levels (cf. ICES. 1995).

7.4 Practical Guidelines

In most fishery systems, a progressive but systematic and decisive shift towards more risk-averse exploitation and management regimes is advisable. This implies that precautionary measures for fisheries management should be widely used as a means to avoid crises and reduce long-term costs to society. Because uncertainty is pervasive in the ocean ecosystem and fisheries, precaution should become an integral part of fishery management systems, to be applied routinely in decision making. Unnecessarily stringent and costly measures, should be avoided as they would rapidly become counter-productive by deterring fishery authorities from using the concept as widely as possible and discrediting the approach among industry.

A precautionary management strategy would need both a sufficient **preventive capacity** to avoid predictable problems, and enough **reactive (corrective) capacity**, flexibility and adaptability to ensure a safe "trial-and-error" process, as knowledge about how the system works is collected. It should recognize the uncertainties in the data and promote adaptability and flexibility of management regimes through appropriate institutions and decision-making processes. It would rely not only on expert advice but also on people's participation. As stated by Holling (1994) *"effective investments in a sustainable biosphere are therefore ones that simultaneously retain and encourage the adaptive capabilities of people, of business enterprises and of nature"*. In case of doubt, decisions should **"err on the safe side"** with due regard to the risk for the resource and the social and economic consequences.

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[31] This concept of "compensation", which proposes that human activities should lead to "no net loss of habitat", implies that, if some part of a habitat must be damaged somewhere, compensation is provided somewhere else

A fishery management policy based on a reasonable interpretation of the concept of precaution should: (a) explicitly adopt the principle of sustainable development as defined by the FAO Conference (given in the introduction to this paper); (b) explicitly state a set of objectives that are compatible with this principle, and (c) adopt a precautionary approach based on the following measures:

Promotion and use of research

1. Promote research in support of the precautionary approach to management, e.g., research aimed at understanding better the conservation requirements of the ecosystem, biodiversity, species and genetic levels as well as research towards a better definition of management reference points, including economic ones.

2. Use the best scientific evidence available and, if it is not sufficient, invest in emergency research while interim management measures are taken at the level required to limit risk of irreversible damage.

3. Improve information systems commensurate with the level of risk, covering costs through fishing fees as required, addressing all resources, directly or indirectly affected and promoting joint research programmes in international and regional arrangements.

4. Experiment with management strategies and pilot development projects with the support of

research, generalizing the use of Environmental Impact Assessment (EIA).

Reference points, rules and criteria

5. Adopt a set of objectives for the fishery and a related set of reference points (broader than the traditional MSY) and management benchmarks, and use the latter to measure the efficiency of the management system (e.g., in terms of achieving production targets, controlling fleet capacity, and maintaining spawning stock size or recruitment levels).

6. When alternative options are considered, adopt a risk-averse attitude, considering *a priori* that: (a) fisheries are likely to have a negative impact on the resource, and (b) risk of unacceptable or irreversible impact should be minimized.

7. Ensure that precautionary management plans specify, *inter alia*, the data to be collected and used for management and their precision, the methods of stock assessment, the decision rules and reference points needed for determining and initiating management measures as well as contingency measures to be taken in case of danger for the resource.

8. Adopt provisional reference points when data are poor or lacking, establishing them by analogy with other similar and better known fisheries and updating/revising them as additional information becomes available.

9. View Maximum Sustainable Yield (MSY) as a minimum international standard, ensuring that fishing mortality does not exceed the level needed to produce it and that stock biomass is maintained above it (or rebuilt at least at this level).

10. Adopt precautionary management reference points defined on the basis of agreed scientific procedure and models, including Target Reference Points (TRPs) and Limit Reference Points (LRPs). Because of the uncertainty inherent in their determination, these reference points should preferably be expressed in statistical terms (i.e., with a central value and a confidence interval).

11. Adopt action-triggering thresholds and management strategies which include pre-agreed courses of action, automatically implemented if the stock or the environment approaches or enters a critical state as defined by pre-agreed rules, criteria and reference points[32].

12. Adopt Threshold Reference Points (ThRP) where specific conditions require added precaution, to indicate that the state of a fishery and/or a resource is approaching a TRP or a LRP and that a certain type of action (preferably agreed beforehand) is to be taken, to avoid (or reduce the probability) to accidentally go beyond the selected TRPs or LRPs.

13. Ensure that management action maintains the stock around the selected TRP on average (e.g., through establishment of total allowable catches and quotas or through effort controls) and that the probability of exceeding the target, and the extent by which it is exceeded, are kept at acceptable levels.

14. Severely curtail or stop fishery development, as appropriate, when the probability of exceeding the adopted LRP is higher than a pre-agreed level and take any corrective action deemed necessary. If the LRP is indeed exceeded, implement a stock rehabilitation programme using the LRP as a minimum rebuilding target to be reached before the rebuilding measures are relaxed or the fishery is re-opened.

15. Bring into force, “automatically” the set of pre-established measures, or courses of action, when a ThRP is reached particularly in cases or situations involving high risk.

16. Ensure that selected reference points are robust to short- and long-term fluctuations in fish stocks due to recruitment variability and other factors and that they are periodically re-assessed as new data is collected and new understanding or methods become available.

17. For newly discovered stocks, establish safe biological limits (in absolute or relative terms[33]) and threshold reference points from the onset; prohibit large scale development; limit removals, through effort and catch limitations and resource allocation schemes, to a fraction of the stock well below annual natural mortality; set-up monitoring and assessment programmes on the target and associated species.

18. Aim at maintaining the fundamental components of the ecosystem (nurseries, spawning areas, feeding areas, migration routes, etc.), minimizing their degradation and, where possible, re-establishing them in order to ensure permanency of the ecosystem structure and productivity mechanisms even though the abundance (or even the permanence) of some of its species components cannot be absolutely warranted.

[32] One of these courses of action could be a moratorium. However, if reference points are selected on a cautious basis, and monitoring produces information on a quasi-real-time basis, a range of more cost-effective alternatives should be available (seasonal or temporary closures, modification of fishing patterns, significant reduction of effort, etc.)

[33] That is, as a proportion of the virgin stock

Acceptable impacts

19. Promote discussion and agreement on acceptable levels of impact (and risk) in a process that will identify trade-offs and promote transparency, particularly in relation to public opinion.

20. Take into account the combined stresses of fishing and environment on resources. Effort reductions may be imposed or special measures affecting fisheries taken when the stock faces unusually unfavourable environmental conditions.

21. Address as far as possible all combined stresses to the resource, including those imposed by non-fishing activities or related to natural fluctuations[34].

22. Prohibit irreversible impacts as well as decrease of any population of marine species below the which ensures the greatest net annual increment of biomass (i.e., the MSY level). For overfished fisheries, an important objective should be to rebuild the stock at least to that level.

23. Set catch and effort levels for target species in accordance with the requirement that they do not result in unsustainable levels of mortality for both target and non-target species.

Management framework

24. Manage fisheries in the context of integrated management of coastal areas, raising sectoral awareness about exogenous impacts on the state of the resources and on fisheries productivity.

25. Improve public awareness, as well as consultation of non-fishery users, taking all interests into account when developing and managing fisheries, as required in Agenda 21, improving management transparency and reporting procedures.

26. Improve decision-making procedures, replacing consensus decision-making by voting procedures wherever possible.

27. Strengthen monitoring, control and surveillance, thereby improving detection and enforcement capacity (including legal tools), raising penalties to deterrent levels, and exerting more effectively the responsibilities pertaining to the flag or the port States.

28. Avoid overburdening of management systems and industry by limiting the number of precautionary devices and measures implemented at all times, based on an analysis of the probability of occurrence of negative impacts of a certain magnitude, pre-agreed as part of the

management scheme and reflected in appropriate reference points.

29. Establish safety-net arrangements (e.g., in terms of insurance, compensation, etc.) to protect the users from the consequences of exceptional hazardous occurrences.

30. Establish precautionary management regimes for all resources, across their whole area of distribution, whether in EEZs, in the high seas, or both (high seas, straddling and highly migratory resources).

[34] This means that restrictive action on fishing might be needed even when the causal mechanism is natural (e.g., related to El Niño, droughts, or other medium-term natural fluctuations)

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More details

THE PRECAUTIONARY APPROACH TO FISHERIES AND ITS IMPLICATIONS FOR FISHERY RESEARCH, TECHNOLOGY AND MANAGEMENT: AND UPDATED REVIEW (Continued)

CONCLUSIONS

The present status of many fishery resources around the world indicates that management practices need to be improved. An acceleration of the process of evolution of fisheries management and a broadening of its scope are required to take fully into account the explicit requirements of the 1982 United Nations Convention on the Law of the Sea, UNCED Agenda 21, the Convention on Biological Diversity, the outcome of the International Conference on Responsible Fishing (Mexico, 6–8 May 1992), the outcome of the UN Conference on Straddling Fish Stocks and Highly Migratory Fish stocks (New York, 1993–95), and the FAO International Code of Conduct for Responsible Fisheries. The uncertainty and risk resulting from the limitations in fisheries management systems and scientific information, as well as natural variability (including climate change) is progressively being recognized and should be taken into account by adopting more precautionary management strategies.

The need for precaution in management has been reflected in the precautionary principle and the precautionary approach, two concepts sometimes difficult to distinguish perfectly. The precautionary principle has suffered from lack of definition, extreme interpretations leading to moratoria and lack of consideration of the economic and social costs of its application. The precautionary approach has been more closely associated with the concept of sustainable development and sustainable use, recognizing that the diversity of ecological and socio-economic situations each may require different strategies. This concept has, therefore, a more acceptable "image" in the various development and management sectors and is considered more readily applicable to fisheries management.

An objective analysis of the sources and nature of the uncertainty, its potential consequences in terms of an error, its cost, and its potential reversibility, leads to the conclusion that the sustainable development of fisheries requires indeed a combination of approaches (i.e., corrective, preventive, or precautionary) and may even, in extreme cases, resort to the precautionary principle. Considering the range of uncertainty that affects various areas of fisheries and the magnitude of potential costs of errors that might be made, it is possible to represent the respective domains of application of these approaches on an uncertainty/cost diagram (Figure 5). While it is recognized that the position of the current fishery issues on such diagram may be sometimes a matter of debate and will vary from case to case, some of these issues, and the instruments available to address, them have been tentatively represented in Figures 6 and 7 respectively with a view to illustrate the proposed typology of approaches.

1. **The preventive approach** intends to actively prevent (avoid the occurrence of) unwanted consequences of human action. It is justified and safely usable, irrespective of the cost of potential errors, when the uncertainty is so low (and the scientific and other understanding so comprehensive) that measures can be designed with a very large probability of success (e.g., of achieving what was intended) avoiding major drawbacks and, in conditions of full or very

high reversibility, any negative impact. This approach relies on engineering research and deterministic science and is usually appropriate for micro-issues (e.g., improving gear selectivity, reducing environmental damage from land-based fish processing, engine exhausts fumes, or refrigerating equipment and improving compliance, etc.).

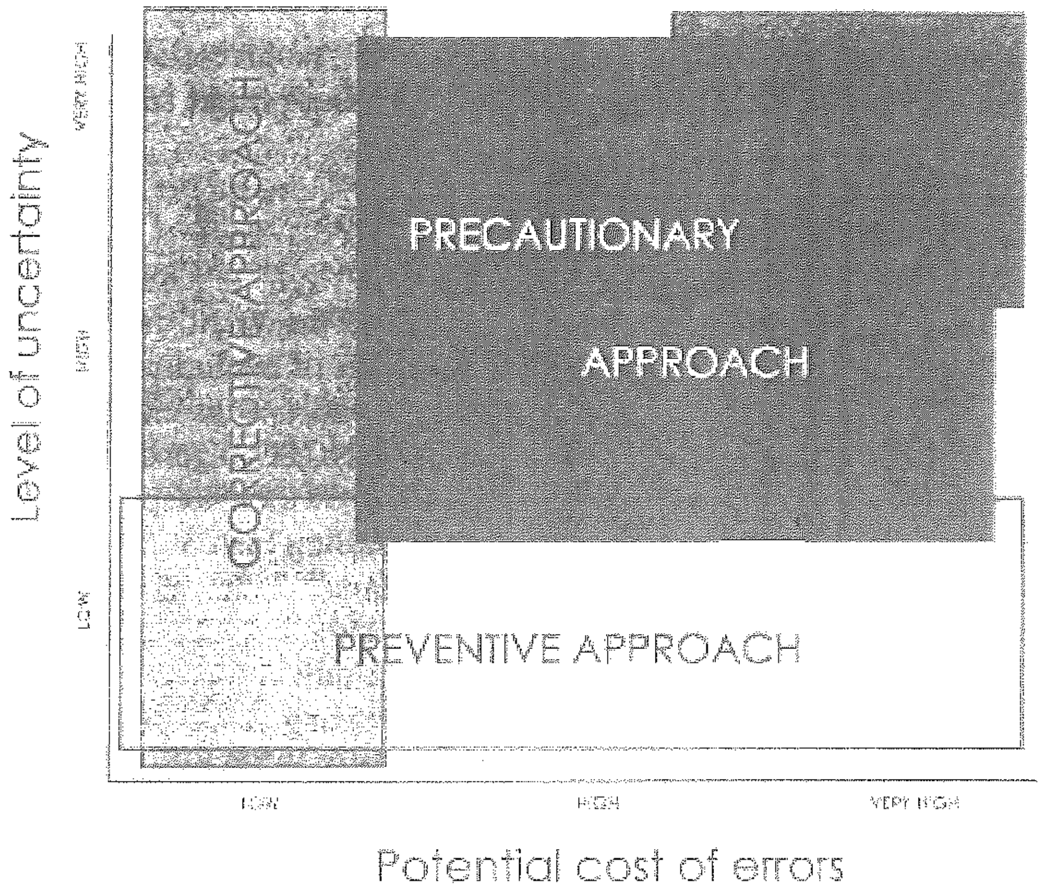

Figure 5. Domains of application of the various possible approaches to fisheries development and management in relation to the level of uncertainty and potential cost of errors.

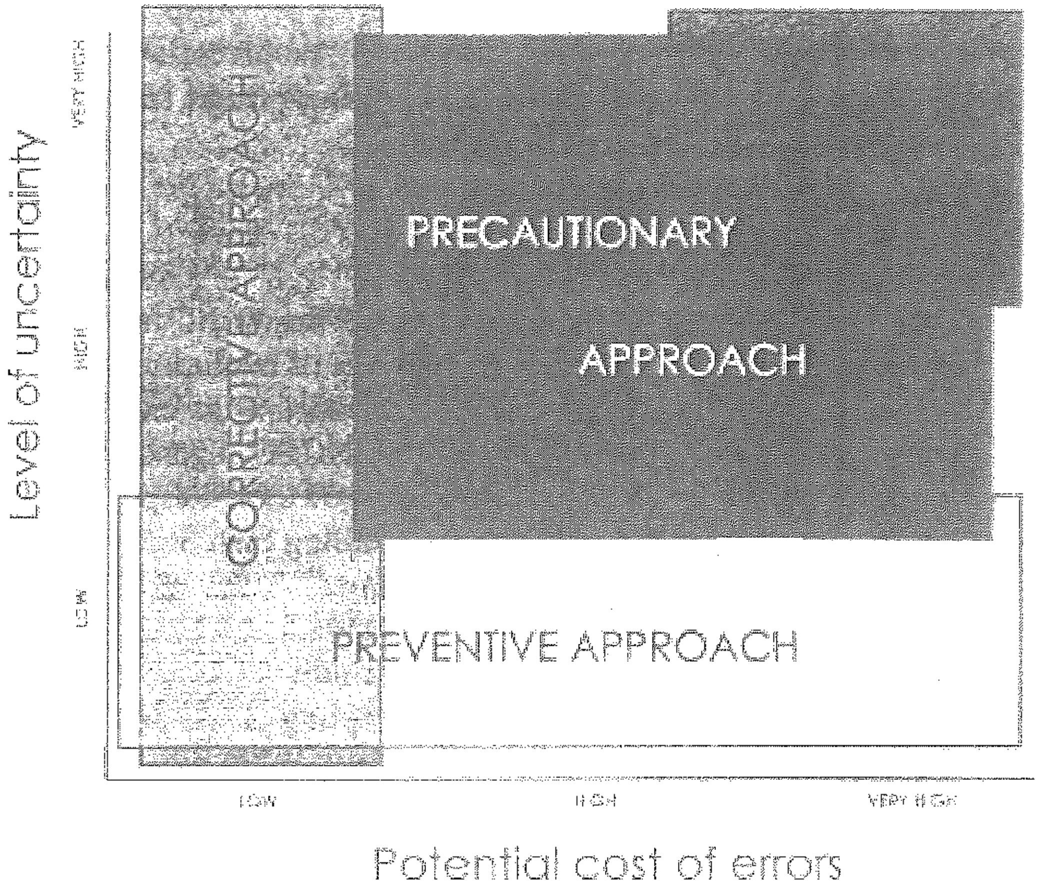

Figure 6. Positioning of current fisheries issues in relation to potential approaches on the uncertainty-cost diagram.

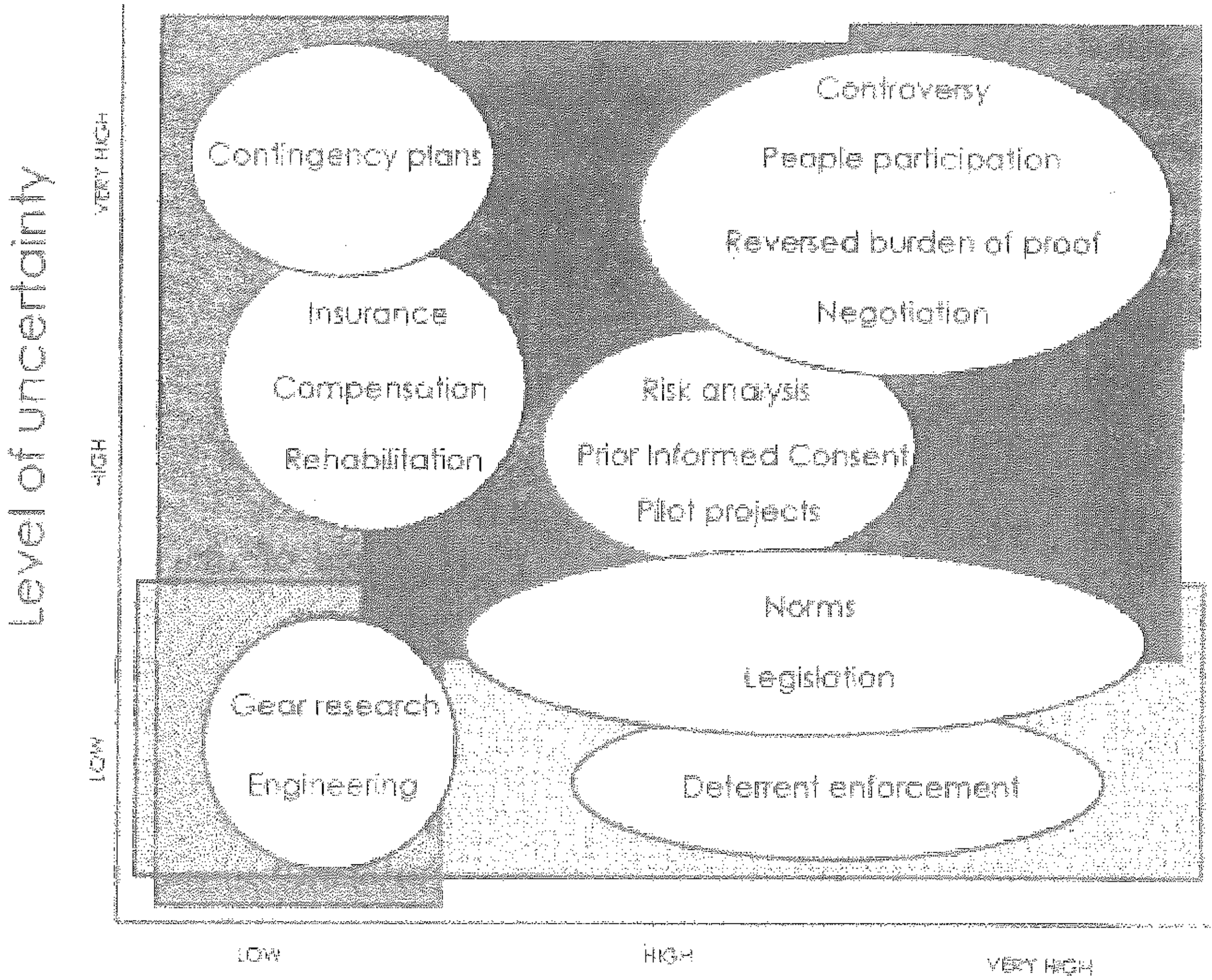

Figure 7. Positioning of currently used fishery regulations in relation to potential approaches on the uncertainty-cost diagram.

2. **The corrective approach** is empirical and intends to correct effectively the consequences of actions, the potential consequences of which were not considered *a priori* or disregarded as negligible. This approach is justified, irrespective of the level of uncertainty, when the cost of the potential errors are negligible, or low, and in any case much lower than the cost of avoiding the errors (cost-benefit analysis), and when the consequences are perfectly reversible or totally acceptable (even though not reversible). The approach consists in taking the best measures possible (the easiest to implement), not assuming perfect knowledge, but assuming that progress will be ensured through "trial and error"[35] with no long-term risk for the resource. It would be also relevant for micro-issues (e.g., to improve vessel safety, gear selectivity, closed seasons, etc.).

3. **The precautionary approach** aims at reducing the probability of occurrence of bad events within acceptable limits and is used when the level of uncertainty and the potential costs are significant, when full reversibility may not be ensured (but AT LEAST partial reversibility[36] is highly likely). It requires, *inter alia*, the maintenance of a flexible, resilient fishery system (including the fish stock, the associated species, the fleet and the management agency regulating it). It addresses meso-issues which are central to the management of the fishery system such as resources sustainability and recruitment overfishing, protection of non-target and endangered species, environmental management of aquaculture, development of new fisheries and maintenance of ecosystem productivity.

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[35] Adaptive learning is recommended under the precautionary approach but it has applications across the entire

uncertainty/cost diagram

[36]Partial reversibility is achieved when the system can be returned to a state (in terms of health or productivity) equivalent, but not identical, to the pristine state

4. **The precautionary principle** aims at avoiding irreversible damage and high costs to the resources (and society) in cases of high uncertainty (edging on ignorance). It corresponds to situations where scientific theories are not yet formed, or controversial and where the scientific process tends to lead to conflictual polarization instead of consensus. Under these circumstances, the scientific debate tends to be replaced by political lobbying and negotiation, often with a large contribution by the media and NGOs. This instrument would be used, in most cases, to deal with on macro- and mega-issues and where reversibility (even partial reversibility) is highly unlikely. There are few issues of this nature in fisheries, e.g., perhaps species introductions (whether voluntary and accidental). Some problems affecting fisheries directly, however, could require the application of the principle, e.g., the destruction of critical habitats by other sectors, the ozone depletion, and the global warming.

Close to the origin of the graph (on Figure 5), where both uncertainty and potential costs are low, the corrective and preventive approaches overlap significantly in a "neutral area" where both approaches could be justified. As a matter of fact, Figure 5 shows that the area of application of the four strategies overlap and the meaning of the often used expression "erring on the safe side" or "giving to the resource the benefit of doubt", in this particular context, is that issues falling between two or more approaches should be addressed using the more precautionary approach.

The existing set of principles and guidelines agreed at international level, in the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, and in the FAO Code of Conduct for Responsible Fisheries relate in fact to the first three approaches indicated above. It appears therefore that the operational understanding of a "precautionary approach" *lato sensu* to fisheries in the inter-governmental quarters (and also of many NGOs) includes all the methodologies, instruments and devices which ensure that the consequences of human action on the resource and its environment are acceptable because either: (a) we know what to do to avoid the problems; (b) or the cost will be negligible and the error can be corrected, or else (c) we are conscious of limitations in data and act accordingly. The present state of fisheries indicate clearly that up to now, Governments have used corrective or "preventive" strategies in cases where more precaution was required.

The problem lies in using the proper approach for each type of issue. On the one hand, over-protecting the resource (by taking a highly precautionary approach) may have significant consequences in terms of foregone development options and could lead to economic and social chaos in fishing and related industries and communities and the fishery sector which rightly refuses to be assimilated to a polluting industry. On the other hand, being over-optimistic as to human capacity to regulate sustainably the production system for its benefit while preserving the options of future generations, could also have significant negative consequences for the resources and, ultimately, for fishing communities.

The real challenge in the implementation of the precautionary approach to fisheries, assuming that Governments' political will and commitment is granted, is therefore to distinguish in which area of the conceptual uncertainty/cost diagram an issue falls when a decision is required. This is an area where fishery science can help and towards which fishery research agendas should be directed. Section 5 of this paper and the "Lysekil Guidelines" (FAO, 1995) provide useful indications for that purpose but a lot more work is required to allow all countries, at all levels of research capacity, to apply the approach effectively.

The principle of precautionary action, as traditionally stated, required fisheries management authorities to take action where there is a risk of severe and irreversible damage to the resources and the environment, even in the absence of certainty about the impact or the causal relationships, giving the resource the benefit of the doubt, with due consideration to the social and economic consequences. The broader precautionary approach described in this document, and transpiring from the agreements being developed in the international fishery arenas (particularly in the UN and FAO), consists in applying systematically an appropriate level of caution in research, technology development and transfer, and management, with a view to avoid situations in which the use of the precautionary principle *stricto sensu* would be unavoidable. This line of action changes the status of precaution from an exceptional requirement to an integral part of good management practice.

During the last three years, the concept of precautionary action has become more familiar to fishery management authorities and NGOs who have significantly contributed to the awareness-raising process. The fishery sector's commitment to the approach, however, will still require a lot of effort from both Governments, NGOs and FAO. The approach is now embedded in the outcome of the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks and in the FAO International Code of Conduct for Responsible Fisheries, correcting its omission from the 1982 Convention and the 1984 FAO Conference on Fisheries Management and Development. The detailed Guidelines on the Precautionary Approach to Capture Fisheries, now available in support of the FAO Code of Conduct, will help in promoting its application by States and industry, assisted by the NGOs. In addition, the approach offers the fishing sector the opportunity to request a more responsible behaviour from all those non-fishery sectors which are damaging the marine ecosystem.

The requirement laid down in the UN Convention on the Law of the Sea for the "best scientific evidence available" remains the first condition for effective and equitable management and the concept of precaution does not exempt fishing States and management authorities from their responsibilities to build up the necessary scientific information and cooperation. It seems evident that, in most cases, the State, through its research and management agencies, will continue to be responsible for the establishment of the databases, research and the forecast and assessment of the impacts of its fishery policy (particularly in relation to its coastal and small-scale fisheries). However, in some instances, e.g., in a situation of high potential risk and lack or inadequacy of information, the onus of scientific proof could be put be on industry, e.g., in the form of an Environmental Impact Assessment or pilot project. Expertise is required to support the development of national, regional and international norms of good conduct and advise on the precautionary nature of a proposal in particular situations[37]. The active participation of industry is essential even though experience has shown the dangers of normative systems controlled by industry (Hermitte and Noiville, 1993) and the State must be the warrant of the adequacy of the advisory and decision-making system.

It would not be prudent to forget that precautionary management measures have often been advocated in the past but they have rarely been implemented because of resistance due to their potential short-term costs. The same causes could produce the same effects in the future and it may, therefore, take a decade or so to see the approach as widely applied as recommended in the UN and FAO guiding documents.

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[37] A gear might be innocuous in a given ecosystem, under normal conditions, but not advisable in others (e.g, in an ecosystem damaged by other factors than fishing, a series of droughts, an ecosystem in a rebuilding phase, etc.)

Until now, the rationale used (mainly by NGOs) in support of a precautionary approach referred to the risks to the resource and its environment. However, following the economic and social disaster in the Northwest Atlantic, the issue of socio-economic risk to the fishing sector and communities may start taking more relevance as fishermen and governments realize that "future generations" are not only those of the next decades but also those of tomorrow.

The view has become generally accepted, if not yet implemented, in a wide range of fora, that a generalized application of the precautionary approach at all levels of the fishery system, and at all times, is preferable to corrective costly measures rendered necessary by irresponsible development. An effective application of the precautionary approach requires, therefore, a large range of more or less difficult measures throughout the fishery system, its research structure and programmes, its development options and programmes and its management regimes and institutions. The practical guidance contained in the various sections of this paper represent a comprehensive "toolbox" from which elements can be selected to elaborate a precautionary strategy adapted to the various situations. The precautionary level of the strategies so designed will depend on the number and types of precautionary elements selected, the local biological and environmental, economic and institutional conditions, and the type of fishery. The degree of precaution achieved could be assessed as suggested by Kirkwood and Smith (in press).

In summary, a precautionary strategy would have to be consistent with the internationally agreed principles of sustainable development included in the 1982 Convention, the Rio Declaration, the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, and in the FAO International Code of Conduct for Responsible Fisheries and would, *inter alia*:

- prohibit any fishing that is not explicitly authorized;
- reflect precaution in the explicitly stated objectives;
- develop an independent and effective research capacity;
- be based on the best scientific evidence, taking account of uncertainty;
- consider all potential management alternatives and their consequences;
- adopt a broad range of management reference points;
- agree on acceptable (tolerable) levels of impact and risk;
- adopt action-triggering thresholds and pre-agree on courses of action;
- integrate them in a management strategy (and management plan);
- aim at preserving flexibility at all levels;
- introduce impact assessment and recurrent evaluation of management;
- implement experimental management and development strategies;
- improve participation (including non-fishery users);
- establish explicit user-rights;
- improve decision-making procedures;
- promote the use of more responsible technology;
- strengthen monitoring, control and surveillance;
- raise enforcement to effectively deterrent levels, and
- institutionalize transparency and accountability.

In designing precautionary management strategies, it will be important to realize that fishermen are part of the ecosystem (as top predators) and that without an appropriate consideration of the risk to their community (both in the short- and long-term), the level of compliance will be low and enforcement excessively costly. This does not mean that when necessary conservation measures appear to be costly they should not be applied. It means, however that, whenever possible, precautionary objectives should be met, minimizing to the extent compatible with these objectives, the costs to the fishing community (including through financial support or compensation). This aspect is of particular relevance for small-scale fisheries and traditional coastal communities which have usually few alternatives to fishing.

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ANNEX 1

DRAFT FAO CODE OF CONDUCT FOR RESPONSIBLE FISHERIES

(Extract from Article 6: Fisheries Management)

6.5 Precautionary Approach

6.5.1 In order to reduce the risk of damage to the marine environment and living aquatic resources, the precautionary approach should be widely applied.

6.5.2 In applying the precautionary approach, fisheries management authorities should take into account, *inter alia*, uncertainties with respect to the size, productivity and state of the stocks, management reference points, levels and distributions of fishing mortality and the impact of fishing activities on associated and dependent species including discard mortality, as well as climatic, environmental, social and economic conditions.

6.5.3 The precautionary approach should be based on the best scientific evidence available and include all appropriate techniques aimed at setting stock-specific minimum standards for conservation and management. Fishery management authorities should be more cautious when information is poor. They should determine precautionary management reference points and apply precautionary measures consistent with management objectives.

6.5.4 When precautionary or limit reference points are approached, measures should be taken to ensure that they will not be exceeded. These measures should where possible be pre-negotiated. If such reference points are exceeded, recovery plans should be implemented immediately to restore the stocks.

6.5.5 In the case of new or exploratory fisheries, conservative measures, including precautionary catch or effort limits, should be established as soon as possible in cooperation with those initiating the fishery and should remain in force until there are sufficient data to allow assessment of any increase in fishery intensity on the long-term sustainability of stocks and associated ecosystems.

ANNEX 2

EXTRACT FROM THE NEGOTIATING TEXT OF THE UN CONFERENCE ON STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS

(A/CONF.164/13, Article 5, 30 March 1994)

5. In order to protect the environment and the living marine resources, the precautionary approach shall be applied widely by States to fisheries management and exploitation, in accordance with the following provisions:

a. states shall act so as to obtain and share the best scientific evidence available in support of conservation and management decision-making. States shall take into account uncertainties with respect to the size and productivity of the targeted stock levels and distribution of fishing mortality, and the impact of fishing activities on associated and dependent species, as well as other relevant factors, including climatic, oceanic and environment changes;

b. the absence of adequate scientific information shall not be used as a reason for failing to take strict measures to protect the resources;

c. use of the precautionary approach shall include all appropriate techniques, including, where necessary, the application of moratoria;

d. in cases where the status of stocks is of concern, strict conservation and management measures shall be applied and shall be subject to enhanced monitoring in order to review continuously the status of stock(s) and the efficacy of the measures to facilitate revision of such measures in the light of new scientific evidence, and

e. in the case of new or exploratory fisheries, conservative catch and/or effort limits shall be established as soon as possible and shall remain in force until there are sufficient data to allow assessment of the impact of the fishery on the long-term sustainability of the stocks and associated ecosystems.

ANNEX 3

EXTRACT FROM THE NEGOTIATING TEXT OF THE UN CONFERENCE ON STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS

(A/CONF.164/13/Rev.1 of 30 March 1994)

B. Precautionary Approaches to Fisheries Management

In order to protect the environment and the living marine resources, consistent with the Convention, the precautionary approach shall be applied widely by States and by regional or sub-regional fisheries management organizations or arrangements to fisheries conservation, management and exploitation, in accordance with the following provisions:

a. in order to improve conservation and management decision-making, States shall obtain and share the best scientific information available and develop new techniques for dealing with uncertainty. States shall take into account, *inter alia*, uncertainties, including with respect to the size and productivity of the stocks, management reference points, stock condition in relation to such reference points, levels and distributions of fishing mortality and the impact of fishing activities on associated and dependent species, as well as climatic, oceanic, environmental changes and socio-economic conditions;

b. in managing fish stocks, States should consider the associated ecosystems. They should develop data collection and research programmes to assess the impact of fishing harvesting on non-target species and their environment, adopt plans as necessary to ensure the conservation of non-target species and consider the protection of habitats of special concern;

c. the absence of adequate scientific information shall not be used as a reason for postponing or failing to take measures to protect target and non-target species and their environment;

d. the precautionary approach shall, based upon the best scientific evidence available, include all appropriate techniques and be aimed at setting stock-specific minimum standards for conservation and management. States shall be more cautious when information is poor. States should determine precautionary management reference points taking into account the guidelines contained in Annex 2 (see below), and the action to be taken if they are exceeded. When precautionary management reference points are approached, measures shall be taken to ensure that they will not be exceeded. If such reference points are exceeded, recovery plans shall be implemented immediately in order to restore the stock(s) in accordance with pre-agreed courses of action;

e. in cases where the status of stocks is of concern, strict conservation and management measures shall be applied and shall be subject to enhanced monitoring in order to review continuously the status of stocks and the efficacy of the measures to facilitate revision of such measures in the light of new scientific evidence, and

f. in the case of new or exploratory fisheries, conservative measures including catch and/or effort limits shall be established as soon as possible in cooperation with those initiating the fishery and shall remain in force until there are sufficient data to allow assessment of the impact of the fishery on the long-term sustainability of the stocks and associated ecosystems.

Suggested guidelines for applying precautionary reference points in managing straddling fish stocks and highly migratory fish stocks. (Annex 2 of A/CONF.164/13/Rev.1)

1. Management strategies should seek to maintain and restore populations of harvested stocks at levels with previously agreed precautionary reference points. These strategies should include measures which can be can be adjusted rapidly as reference points are approached.

2. Conservation and management objectives should be stock-specific and take account of the characteristics of fisheries exploiting the stock.

3. Distinct reference points are used to monitor progress against conservation and management objectives. Reference points should incorporate all relevant sources of uncertainty. When information for determining reference points for a fishery is poor or absent, provisional reference points should be set. In such situations, the fishery should be subject to enhanced monitoring so as to revise reference points in the light of improved information as soon as possible.

4. Reference points related to conservation should be chosen to warn against over-exploitation. Management strategies using such reference points should ensure that the risk of exceeding them is low. In this context, Maximum Sustainable Yield should be viewed as a minimum international standard. Conservation-related reference points should ensure that fishing mortality does not exceed and that stock biomass is maintained above, the level needed to produce the Maximum Sustainable Yield. For already depleted stocks, the biomass, which can produce Maximum Sustainable Yield, can serve as an initial rebuilding target.

5. Management-related reference points provide an indicator as to when and how quickly maximum allowable levels of stock removals are being approached. Management action should ensure that such reference points, on average, are not exceeded.

ANNEX 4

DRAFT AGREEMENT FOR THE IMPLEMENTATION OF THE PROVISIONS OF THE UNITED NATIONS CONVENTION ON THE LAW OF THE SEA OF 10 DECEMBER 1982 RELATING TO THE CONSERVATION AND MANAGEMENT OF STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS

(A/CONF.164/22/Rev.1)

Article 6: The Application of the Precautionary Approach

1. States shall apply the precautionary approach widely to conservation, management and exploitation of straddling fish stocks and highly migratory fish stocks in order to protect the living marine resources and preserve the marine environment.

2. States shall be more cautious when information is uncertain, unreliable or inadequate. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures.

3. In applying the precautionary approach, States shall:

   a. improve decision-making for fishery resource conservation and management by obtaining and sharing the best scientific information available and implementing improved techniques for dealing with risk and uncertainty;

   b. apply the guidelines set out in Annex 2 and determine, on the basis of the best scientific information available, stock-specific reference points and the action to be taken if they are exceeded;

   c. take into account, *inter alia*, uncertainties relating to the size and productivity of the stock(s), reference points, stock condition in relation to such reference points, levels and distributions of fishing mortality and the impact of fishing activities on non-target and associated or dependent species, as well as oceanic, environmental and socio-economic conditions, and

   d. develop data collection and research programmes to assess the impact of fishing on non-target and associated or dependent species and their environment, adopt plans as necessary to ensure the conservation of such species and protect habitats of special concern.

4. States shall take measures to ensure that, when reference points are approached, they will not be exceeded. In the event that such reference points are exceeded, States shall, without delay, take the additional conservation and management action determined under paragraph 3(b) to restore the stock(s).

5. If a natural phenomenon has a significant adverse impact on the status of straddling fish stock(s) or highly migratory fish stock(s), the relevant coastal States and States fishing those stock(s) on the high seas shall, directly or through the relevant subregional or regional fisheries management organization or arrangement, cooperate for the adoption, without delay, of emergency conservation and management measures to ensure that fishing activity does not exacerbate the adverse impact of the natural phenomenon on the stock(s). Such emergency measures shall be temporary in nature and shall be based on the best scientific evidence available.

6. Where the status of target stocks or non-target or associated or dependent species is of concern, States shall subject those stocks and species to enhanced monitoring in order to review regularly their status and the efficacy of conservation and management measures and shall revise those measures in the light of new information.

7. For new or exploratory fisheries, States shall establish conservative conservation and management measures as soon as possible, including, *inter alia*, catch and effort limits. Such measures shall remain in force until there are sufficient data to allow assessment of the impact of the fishery on the long-term sustainability of the stocks, whereupon conservation and management measures based on that assessment shall be implemented, which, if appropriate, allow for the gradual development of the fishery.

ANNEX 5

REPORT OF THE WORKING GROUP ON REFERENCE POINTS FOR FISHERIES

MANAGEMENT[38]

(A/CONF.164/WP.2 of 24 March 1994)

Technical Guidelines on Biological Reference Points

1. INTRODUCTION

1. The United Nations Convention on the Law of the Sea (articles 6 and 119) obliges States to take measures, based on the best scientific evidence available, to maintain or restore harvested stocks at a level which can produce MSY as modified by relevant environmental and economic factors. In order to accomplish this goal, MSY should be adopted as a limit reference point rather than target reference point as described below. However, for already depleted stocks the biomass which can produce MSY may serve as an initial rebuilding target.

2. Many fish stocks around the world are currently depleted. Improvements in fishing technology have allowed fleet fishing power to increase rapidly and to move quickly from one fishery to another. Maximum Sustainable Yield (MSY) can often be exceeded in the early period of a fishery, resulting in resource depletion, associated ecological changes and serious economic problems. Although this is largely due to the lack of efficient controls, enforcement and compliance, the establishment of a set of biological reference points would contribute to better and more precautionary management.

3. Distinction should be made between limit reference points and target reference points. Limit reference points are boundaries which constrain utilization within safe biological limits and beyond which resource rebuilding programmes are required. Target reference points guide policy makers in resource utilization.

4. Reference points for a given stock are developed from biological models which need to take into account the best possible estimates of all sources of mortality and should incorporate the special biological characteristics of each stock. Therefore, to develop reference points, stocks must be regarded as a biological unit throughout their range of distribution. Information on the state of the resource should cover the entire biological unit for comparison with reference points. This will require the identification of biological units for straddling fish stocks and highly migratory fish stocks.

5. As pollution from land and sea-based sources affects fishery resources productivity and resilience, as well as fishery product safety and quality, management should include not only reference points and measures to control fishing, but also action to promote the reduction and, where feasible, the elimination of pollution and degradation of critical habitats.

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[38]This document is the report of the Working Group on Reference Points for Fisheries Management. The Group agreed that all concepts contained in this document reflect its consensus. However, there was insufficient time available to polish the drafting of paragraph 4 in this report

6. The documents prepared by FAO for the Conference on the precautionary approach and reference points for fisheries management, contains useful information and further guidance on these subjects and should be used in conjunction with the present document.

2. DEVELOPMENT OF MANAGEMENT OBJECTIVES

7. Prior to deciding upon a set of reference points, management objectives must be agreed upon. Reference points are not management objectives; they simply serve as a guide to aid managers in choosing from the range of options open to them.

8. The concept of optimal utilization in the United Nations Convention on the Law of the Sea includes the importance of economic and environmental factors as a basis for setting fisheries

management objectives. However, optimal utilization does not have a simple technical definition and cannot be addressed with a single reference point. Therefore, a set of reference points is needed to take these factors into account, on the basis of the best scientific evidence available and with an explicit recognition of uncertainty.

9. Objectives must be set explicitly in order to be able to assess the success of the management procedures. The setting of objectives should, whenever possible, include the specification of the relative importance of different objectives in the overall policy. As objectives are often not explicitly stated, scientific advice must aim at providing an analysis of management options and their implications for the fishery.

10. There are a wide variety of complex objectives in the development of management policy for straddling fish stocks and highly migratory fish stocks. States may have many, sometimes competing, management objectives. However a fundamental objective for all concerned must be the long-term conservation and utilization of fishery resources and, where feasible, other species of concern. That objective can be achieved, *inter alia*, through a precautionary approach to management of fisheries resources in their ecosystems.

3. TARGET AND LIMIT REFERENCE POINTS

11. A reference point is an estimated value derived from an agreed scientific procedure and an agreed model to which corresponds a state of the resource and of the fishery and which can be used as a guide for fisheries management. Reference points should be stock-specific to account for the reproductive capacity and resilience of each stock and are usually expressed as fishing mortality rates or biomass levels.

12. Two types of reference points, limit reference points and target reference points, should be used. Limit reference points are designed for conservation and warn against the risk of over exploitation. Target reference points are designed to indicate when an objective is being approached.

13. Agreement on the appropriate technically defined set of reference points is a prerequisite for a common approach to the management of straddling or highly migratory resources. By introducing limit reference points for triggering pre-agreed management responses, action may be facilitated when a problem occurs.

14. The fishery management strategy should be developed in a multispecies context and describe the action that is taken as the resource status changes. Management strategies need to be developed for each fishery, including newly developing fisheries and account for the biological characteristics of the resources by the use of appropriate reference points. These management strategies should take into account species belonging to the same ecosystem or dependent on, or associated with, a target species.

15. Provisional limit and target reference points can usually be established, even when data are poor or lacking by analogy with other similar and better known fisheries. In all cases, reference points should be updated as additional information becomes available.

16. For broad application of the precautionary approach to stock conservation, it is important to agree on a minimum international guideline for management. With respect to the use of reference points, an appropriate minimum guideline is to apply MSY as a limit on fisheries. Fishing mortality should not be permitted to exceed the level that would produce MSY and stock biomass should be maintained above the level needed to produce MSY. The choice of target reference points should be made such that there is low risk of exceeding the MSY limit reference point after accounting for all major sources of uncertainty. This guidance should be viewed as minimum and not preclude more conservative management strategies.

4. ACCOUNTING FOR UNCERTAINTY

17. To account for uncertainty, management strategies should be so designed that they will maintain or restore the stock at a level consistent with the selected reference points. Uncertainty always occurs in the advice with respect to the current position of the fishery in relation with the reference points. It is vital that uncertainty be quantified and used explicitly in the analysis.

18. The major sources of uncertainty are incomplete and/or inaccurate fishery data, natural variability in the environment and imperfect specification of models of the resources. Simulation studies which incorporate the expected variability and bias in input parameters and uncertainty concerning the factors controlling stocks should be used to scientifically evaluate management strategies. Results must be interpreted in a probabilistic way to reflect these uncertainties.

19. For a limit reference point, management actions should be taken if analysis indicates that the probability of exceeding the limit is higher than a pre-agreed level. If a stock falls below a limit reference point, or is at risk of falling below it, action on the fishery is required to facilitate the rebuilding of the biomass whether or not the decrease is caused by the fishery or is related to environmental fluctuations.

20. The estimates of the reference points should be continuously revised as fisheries evolve and new information is obtained, particularly in the case of stocks subject to strong environmental fluctuations. Both biological and environmental studies will be necessary to facilitate this updating.

21. To be amenable to scientific evaluation, management plans should specify, *inter alia*, the data to be collected and used for management and their precision, the methods of stock assessment, as well as the decision rules for determining and initiating management measures.

5. LINKAGE TO MANAGEMENT

22. In order to estimate reference points, states should cooperate to promote the collection of data necessary for the assessment, conservation and sustainable use of the marine living resources and develop and share analytical and predictive tools. Precaution should be exerted at all levels of management in, defining data requirements, developing stock assessment methods and elaborating management measures. The need for precaution requires the development of an effective capacity to rapidly take action for resource conservation and management. To facilitate this, the selection of reference points should be flexible to allow for practical approaches to management.

23. To design effective management strategies, the management process needs to be clarified. It should include the specification of management objectives, development of limit and target reference points, agreement on management actions and assessment of management performance with respect to the accepted reference points. Management steps should ensure that target reference points are not exceeded, on average, and that the risk of exceeding limit reference points is low.

24. In some fisheries, the management approach used has had the undesirable effect of deteriorating the quality of the data collected. Management procedures should specifically be designed to reduce uncertainties in the data.

ANNEX 6

EXTRACT FROM THE GUIDELINES ON THE PRECAUTIONARY APPROACH TO CAPTURE FISHERIES

(Lysekil, Sweden, 6–13 June 1995)

The Technical Consultation on the Precautionary Approach to Capture Fisheries, held in Lysekil, Sweden, 6–13 June 1995 (FAO, 1995), elaborated the following statement which could provide a useful operational summary of the approach:

Within the framework outlined in Article 15 of the UNCED Rio Declaration, the precautionary approach to fisheries recognises that fisheries systems are slowly reversible, poorly controllable, not well understood, and subject to changing human values. The precautionary approach involves the application of prudent foresight. Taking account of the uncertainties in fisheries systems, and the need to take action with incomplete knowledge, it requires, *inter alia*:

- consideration of the needs of future generations and avoidance of changes that are not potentially reversible;
- prior identification of undesirable outcomes and measures that will promptly avoid or correct them;
- that any necessary corrective measures are initiated without delay, and that they should achieve their purpose promptly, on a timescale not exceeding two or three decades;
- that where the likely impact of resource use is uncertain, priority should be given to conserving the productive capacity of the resource;
- that harvesting and processing capacity should be commensurate with estimated sustainable levels of resource and that increases in capacity should be further constrained when resource productivity is highly uncertain;
- all fishing activities must have prior management authorization and be subject to periodic review;
- an established legal and institutional framework for fishery management, within which management plans that implement the above points are instituted for each fishery, and
- appropriate placement of the burden of proof by adhering to the requirements above.

THE DEVELOPMENT OF SCIENTIFIC ADVICE WITH INCOMPLETE INFORMATION IN THE CONTEXT OF THE PRECAUTIONARY APPROACH

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Abstract

Scientists and decision makers involved in fisheries management will always be faced with uncertainties and risks, yet decisions have to be made. We discuss seven sources of uncertainties and illustrate how these have affected the success or failure of past decisions in fisheries management. We then describe how scientists should incorporate information on uncertainties into the advice given to decision makers by using the formal techniques of decision analysis and statistical power analysis. Despite the limitations of quantitative techniques, these methods are the best way of informing decision makers about the implications of uncertainties in fisheries management, regardless of whether decisions are made in a risk-neutral or a risk-averse, precautionary context. In addition, we discuss the findings of cognitive psychologists on how best to communicate information about uncertainties to managers, user groups, and scientists. Finally, in situations where weak data create large uncertainties, institutional mechanisms that internalize feedback may create incentives for a longer-term viewpoint among harvesters.

INTRODUCTION

The precautionary approach to fisheries management has emerged from several decades of experience with managing fish as well as other natural resources. Management of these resources is typically characterized by large uncertainties, and human activities in the face of such uncertainties have sometimes led to undesirable consequences such as depleted fish stocks or tropical forests that have failed to regenerate due to eroded soils. Obviously, if consequences of management actions were known exactly prior to implementation, there would be no need to take a cautious approach — an appropriate decision could be made without being cautious. However, such perfect knowledge is not possible. Because of the complexity of fisheries systems and their large variability, all forecasts of expected consequences are made with considerable uncertainty. Therefore, the role of scientists in the fisheries management process is to:

a. provide decision makers with an analysis of the expected consequences of different management actions;

b. provide them with analyses of the sensitivity of these consequences to various assumptions and input data;

c. collect data to support these analyses; and

d. advise decision makers on what data should be collected in the future to improve the understanding of the system so that advice will become more useful.

Often a by-product of carrying out these steps is to help decision makers clarify their objectives and formulate alternative management plans. In cases where management objectives can be quantified, a fifth role of scientists is to help identify which of the contemplated management actions is most likely to meet the objective.

In this paper we concentrate on the problem of providing an analysis of expected consequences of management actions and the robustness of the analysis to different assumptions. This is the most visible role of scientists in the fisheries management process and is where concerns about precaution are most likely to enter. Our other purposes are to review the sources of uncertainty in scientific advice, consider the factors that may contribute to undesirable outcomes of management actions, discuss briefly what can be done to reduce uncertainty, and describe methods for incorporating information about uncertainties into scientific advice to help improve the quality of management decisions.

In this paper we use the terms “caution” and “precaution” to mean the desire to reduce risks. We use “risk” to mean “expected loss,” which is how statistical decision theorists define it (Berger 1985), i.e., the weighted average loss, or the sum of the probability of each potential magnitude of event occurring times the loss if that event occurs. This definition of risk is different from the more common usage of risk, which is “the probability of some undesirable event occurring.”

1. SOURCES OF UNCERTAINTY

We identify seven major sources of uncertainty in fisheries stock assessments. These are uncertainty in:

a. estimates of fish abundance or other measures of the state of the system,
b. model structure,
c. estimated model parameters,
d. response of users to regulation,
e. future environmental conditions,
f. future social, political and economic conditions, and
g. future management objectives.

Estimates of Abundance

One purpose of stock assessments is to estimate abundance. These assessments depend heavily on data (most commonly estimates of catch in weight and often length or age distribution), indices of abundance such as research surveys, estimates of the stock structure, and information about the basic biology of the stock. It is common practice to estimate the reliability of data sources using some measures of variance associated with the sampling scheme — in surveys for instance, the sampling variability of the survey will determine the confidence limits on the survey result. Two of the most common methods for determining abundance, catch-per-unit-effort (CPUE), and virtual population analysis (VPA) are extremely fallible. CPUE is often strongly biased by technological change (increases in catchability with time). VPA rarely provides reliable estimates of current abundance and can be strongly affected by incorrect estimates of the natural mortality rate (Sims 1984, Lapointe et al. 1989), among other errors. Furthermore, many stock assessments have been seriously flawed because catch data were incomplete (biased downward due to under-reporting), the purported index of abundance did not reflect actual abundance, or the stock structure was different from that assumed (number of populations, age distribution, etc.).

Uncertainty in Structure of the Model

Uncertainty in model structure is rarely dealt with explicitly in fisheries stock assessments despite the general recognition that models are not well specified from existing data (e.g., uncertainty about stock structure is often large). Most assessments are based on a single model and uncertainty reported to managers usually refers to uncertainty in the parameters of the model without mentioning how different results might have been had different models been used. Such situations can lead to overconfidence in a decision about an appropriate management action because managers are not told how robust that choice is to different models.

Furthermore, while it is generally recognized that competition and predation are common features of marine population dynamics, most assessment models are based on single-species population dynamics. One notable exception is the multi-species VPA approach used in ICES (International Council for the Exploration of the Sea) for determining natural mortality rates in stock assessments. Unfortunately, the difficulties of obtaining good data have led some scientists to conclude that this method is not very reliable.

Uncertainty in Parameters of the Model

Almost all stock assessments have some form of model at their core and these models have parameters that are estimated with some uncertainty from the data. The commonly used assessment procedures based on age-structured models have parameters for natural mortality rates, growth rates, age-specific selectivities, and stock-recruitment functions. Agencies compute and report the uncertainty in some of these parameters to various extents, although the methods for computing the uncertainty, and the extent and format for reporting this uncertainty, differ greatly between agencies and localities. The methods normally consider variance associated with the data, but do not usually quantitatively address the more serious problem of bias in the data and resulting estimates. This will result in an underestimate of the uncertainty in the parameters of the model. Whereas standard methods only consider variance about the individual data points, the method proposed by Schnute and Hilborn (1993) considers uncertainty about the appropriate variance of the entire data series. Even when uncertainty in parameters is considered, it is common practice to assume that all of these parameters are time invariant. However, some stock assessments allow for temporal changes in some of the parameters (Walters 1987).

Uncertainty in Future Environmental Conditions

It is widely accepted that environmental conditions frequently have a significant impact on fish stocks and therefore any projections of future conditions must make assumptions about future environmental conditions. The simplest assumption is that the environmental conditions will be constant at the historical average. Most commonly stock assessment projections allow for random variability about past average conditions, but in some cases, scientists consider systematic environmental change such as linear trends, periodic changes, or even jumps in conditions (Parma 1990). The probabilities associated with these scenarios are very difficult to estimate.

Uncertainty in Response of Humans to Management Regulations

Most fisheries management activities are directed at people; gear restrictions, fishing seasons, restricted areas and quotas are all regulations on harvesters, not on fish. When scientists provide advice on the expected consequences of actions, they must make assumptions about how harvesters will respond to regulations. The simplest approach is to assume that regulations will not be violated. However, harvesters may change the temporal and spatial distribution of effort in unexpected ways, they may switch the way they use their gear, the species targeted, etc. Changes in regulations may also lead to a change in the rate of bycatch of some species or size classes of fish, discarding, and non-reporting of catches. When these types of responses are not incorporated into stock assessments, then the uncertainty associated with the forecasted outcomes of management actions will be underestimated. More realistic assessments allow for consideration of how well regulations will be obeyed and how the regulations will affect the fishing process (Rosenberg and Brault 1993; Gillis et al. 1995).

Uncertainty in the Future Economic and Social Situation

Equally uncertain is the future of the social and economic system in which the fishery is embedded. In the early 1980s, fisheries on both coasts of Canada were in crisis, prompting a Royal Commission on the west coast and a Task Force on the east coast. In both cases it was found that the crisis was mainly social and economic in origin due to overcapitalization of the fishing fleet, competing user groups, and other non-biological problems, with no major stock collapses or other biological catastrophes (Hilborn 1985). Such problems commonly emerge in many fisheries, yet we know of no assessments that routinely make projections about these social and economic factors and the key social or economic components that affect them such as prices, interest rates, fuel costs, etc.

Uncertainty in Future Management Objectives

Finally, not only are the objectives of management often vaguely defined, but they may change with time. The objective of today may not be tomorrow's objective and we would like to avoid actions today that may adversely affect future objectives. For instance, managers are now trying to rebuild, at considerable expense, the Snake River sockeye salmon population, the first salmon stock placed on the endangered species list in the U.S. However, within the past few decades, the local management authority attempted to eradicate part of this population by poisoning some of its rearing lakes in order to promote a sport fishery on another species (D. Bevan, University of Washington, Seattle, USA, personal communication, 1995). Similarly, whereas many salmon fisheries used to be managed with a focus on yields, now there is more emphasis on maintaining genetic variation among subpopulations because it is known that variation adapts them to local environments (Taylor 1991).

Table 1 summarizes elements that are commonly either included or excluded from analysis of uncertainty in fisheries advice.

It is worth noting that scientific research has generally underestimated uncertainty, even in the relatively well-understood physical sciences. Henrion and Fischhoff (1986) and Freudenberg (1988) have examined the history of parameter estimates in several fields, including measurements such as the speed of light , and found that confidence intervals were frequently too narrow and that subsequent estimates often fell outside of previously published confidence intervals.

Table 1

Components of uncertainty that are either commonly or rarely considered in providing management advice

Source of uncertainty	Commonly considered	Rarely considered
Data inputs to assessments: catch, indices of abundance, stock structure, basic biology	Precision; variance as estimated from internal variability in data	Bias
Structure of the model	Single model, single-species models	Alternative model structures, multi-species models
Parameters of the model	Uncertainty due to data precision	Uncertainty due to bias in data or alternative models
Response of users to regulation	Not usually considered	Changes in behaviour

Future environmental condition	White noise around historical average	Periodic changes, linear trends, jumps in condition
Response of users to regulations	Not usually considered	Changes in behaviour
Future social or economic conditions	Not usually considered	Changes in prices
Future management objectives	Not usually considered	Objectives that are qualitatively different from current ones

2. CONTRIBUTION OF UNCERTAINTY TO UNDESIRABLE OUTCOMES (MANAGEMENT FAILURE)

While the purpose of this paper is to highlight uncertainty and its role in management advice, we need to put this into a broader context. There are at least three major causes of failures of fisheries management (defined as reductions of stocks to the point of economic inviability). First, many failures resulted not from uncertainty but rather from institutional inability to implement scientific recommendations. Excess exploitation rates on many North Sea stocks were identified in Beverton and Holt (1957) and yet have persisted, despite repeated scientific advice that lower exploitation rates would lead to higher yields. In another instance, the long decline of the U.S. northeast groundfish stocks came despite repeated warnings from scientific advisors that exploitation rates were too high (Overholtz et al. 1986).

It can be argued in these cases that the user groups and decision makers were uncertain that the benefits of lower exploitation predicted by the scientists would come to be, or at least that the current participants in the fishery would reap these forecast future benefits. Indeed it is hard to believe that if managers and users actually thought that they would be better off by accepting catch restrictions that they would still refuse such restrictions! However, it may be that the continued overexploitation or decline of these fisheries is due to some perverse outcome of game theory or relatively high discount rates.

Second, some “failures” resulted from economic or environmental forces beyond the control of industry or management. The decline in price and high interest rates of the early 1980s drove many fishing firms to bankruptcy because of their previous capital investment decisions. If reliable forecasts of the economic factors were available, it is possible that many such problems could be avoided, or at least such decisions would be made with more complete knowledge of the risks. Environmental changes have also affected productivity of fish populations. For instance, the decline of the California sardine population was due in part to a change in the ocean, and in part to exploitation.

Third, failure to recognize uncertainty and error in stock assessments has unquestionably caused many failures in fisheries management. The recent rapid reduction in abundance of northern cod in Canada appears to have been due in part to errors in assessing the stock size in the 1980s and to predictions of large sustainable yields, which led to the development of an entirely new Canadian offshore trawl fishery (Parsons 1993, Finlayson 1994). In Peru, the dramatic reduction in the anchoveta fishery in the early 1970s was due in part to stock assessment advice that the annual sustainable yield was 7–10 million tonnes. In retrospect scientists recognize that pelagic fisheries such as the anchoveta in coastal upwelling zones are subject to large interannual fluctuations in abundance and survival rates. Thus, it is not appropriate to make management decisions based on analyses that only consider the single, best-fit relationship for such dynamic processes.

Many experienced stock assessment scientists could generate a long list of fisheries failures that were due in part to uncertainties and poor stock assessment advice. The following are common mechanisms that have contributed to these failures.

Mis-specification of regulations due to errors in estimation of abundance

Stocks may be overharvested due to overestimation of stock abundance. In the case of the Canadian northern cod, "...harvest rates in the 1980s greatly exceeded the targeted F0.1 level, largely because of overestimation of stock size ... coupled with great uncertainty in abundance estimates derived from research surveys" (Hutchings and Myers 1994). In the early 1990s the assessments were revised and quotas were reduced, but not fast enough and a complete depletion of the spawning biomass followed. The errors in estimation of abundance in the 1980's caused the spawning stock in the early 1990s to be much lower than desired, which set the stage for a variety of factors, including increased discarding, targeting on young fish and fishing outside the EEZ to contribute to reduced abundance.

Mis-estimation of potential yield leading to over-development of capacity

In both the northern cod and Peruvian anchoveta fisheries the forecasts of sustainable yield were much higher than proved to be true. Excess industrial harvesting and processing capacity was built and when it became necessary to reduce catches, the economic influence of this capacity made it impossible for the regulatory agency to reduce catches as fast as was required. This led, in turn, to a more severe decline in stock abundance than would have occurred if the industrial capacity had not been as large. It is difficult, however, to determine the extent to which overoptimistic forecasts contributed to overcapacity in these cases because economic and social forces also often tend to increase fleet capacity with time.

Another related issue, which is more of a management problem than a scientific issue in stock assessment, is that this overcapacity of the fishing fleet makes it more difficult for a regulatory agency to achieve its harvesting goal. For instance, the large fishing power of the eastern North Pacific halibut fleet led to a drastic decrease in the length of the openings to two 12-hour openings **per year** in recent years from the previous 150-day-per-year openings in 1970 (International Pacific Halibut Commission 1987). In such "knife-edge" situations, an opening that is slightly too long may have devastating effects on the spawning population and future production. There is little margin for error in these situations and therefore one component of taking a precautionary approach is to limit the fishing power in a specific area and time.

Mis-estimation of potential yield leading to continued overexploitation

From about 1950 to the mid-1980s the International Pacific Salmon Fisheries Commission (IPSFC) managed the harvest of Fraser River sockeye salmon in Canada. The IPSFC regulated the fisheries to allow target numbers of fish to spawn in the Fraser River. Some scientists had suggested that the escapements allowed by the IPSFC were too low and that allowing more fish to spawn would produce a significant improvement in total returns. Beginning in the 1980s, the escapements were roughly doubled and during that time the number of fish returning to the river also doubled. Some portion of the increase was due to improved oceanographic conditions but most was due to increased escapements, which suggests that the stock had been harvested at a higher rate than necessary to maximize yields from about 1950 to 1980 (Hilborn, unpublished data).

Overestimation of ability of fish population to withstand fishing pressure, especially in the face of environmental variability

Scientific analyses that fail to fully incorporate data on age structure may tend to overestimate the ability of a fish population to withstand fishing pressure, especially in the face of environmental variability. This is because fishing mortality generally shortens the expected life span of fish and thereby leads to a truncated age distribution, with a smaller proportion of the larger, more fecund individuals remaining than in an unfished population. This effect of fishing tends to decrease the effectiveness of the bet-hedging life history strategy that many long-lived species have evolved in response to highly variable environments for survival of their offspring (Leaman 1991). By spreading out their reproductive effort over many years, individual females are more likely to successfully reproduce large cohorts in such variable environments (Murphy 1968). Thus, after prolonged or intensive harvesting, such long-lived species will be more vulnerable to recruitment failures arising from natural environmental variability. For this reason, models of iteroparous species that do not explicitly include age- or size-specific reproductive rates (e.g., many surplus production models) will underestimate the risks of particular harvesting strategies. The seriousness of this omission depends on the normal life span of the species -- the longer it is, the worse the situation will be.

Failure of scientists to fully communicate the uncertainties of their analyses to harvesters and decision makers

While this is hard to document, most of us are probably aware of cases where scientists provided their "best estimates" of parameter values, stock abundance, or recommended TACs without stating uncertainties associated with these numbers, or at least not presenting those uncertainties in an easily understood form. In some cases, the presentation of only point estimates might have resulted from the decision makers wanting a straightforward answer or explicitly wanting to avoid providing an opening for harvesters to pressure for higher quotas. In any event, after many years of this, such advice with "best estimates" might have acquired more of an air of certainty than was justified, thereby leading to more aggressive management decisions than the population could withstand in some years.

3. HOW TO REDUCE UNCERTAINTY

There are many obvious ways to reduce uncertainty in advice provided to managers. One is to do sensitivity analyses with quantitative models to identify research priorities. By ranking needs for new information in this way, research funds can be used efficiently to reduce future uncertainty in stock assessments. Another is to continue to develop more sophisticated quantitative methods for estimating components of stock assessments from data sets. In addition, a less well recognized way to reduce uncertainty is to set up management actions as part of a rigorous experimental design. This will reduce uncertainty about the effectiveness of particular management actions (Walters and Hilborn 1976; Walters 1986). This is because in the past, simultaneous changes in environmental conditions and one or more management actions has made it difficult to uniquely attribute an observed change in a fish population to some hypothesized cause. This has perpetuated uncertainty about the effectiveness of management actions. However, once managers recognize that uncertainty about their future choices of actions can be reduced by taking present actions in some experimentally designed manner, new opportunities emerge. For instance, Sainsbury's (1991) experimental management of a mixed species trawl fishery has provided a clear example of the benefits of taking such an experimental approach. The alternative hypotheses about the mechanisms affecting the fish communities have now been narrowed down considerably as a result of the experiment and appropriate management actions are now much clearer than they were before the experiment began (K. Sainsbury, CSIRO, Hobart, Tasmania, personal communication 1995). Other authors have also demonstrated through quantitative models that benefits can be expected from experimental management in part because of the decrease in uncertainty (reviewed by Peterman and Mc Allister 1993).

However, regardless of how much research and experimental management there is, there will always be uncertainties in scientific analyses. The next section discusses how to deal with these inevitable uncertainties in a systematic, productive manner.

4. INCORPORATING UNCERTAINTY INTO MANAGEMENT ADVICE

We recommend using decision analysis to deal with uncertainties in fisheries management. This is a comprehensive method that incorporates uncertainties explicitly into making appropriate choices of management actions (Keeney 1982). This method will lead to a more cautious or risk-reducing approach than ignoring uncertainties (where one uses only the best-fit parameters) or dealing with uncertainties in some arbitrary way because decision analysis expressly considers a variety of possible conditions of the stock, fishing powers of the fleet, or whatever other quantities are considered uncertain. To put our recommendations into context, first consider the various ways in which scientists can analyze data and make recommendations.

Levels of Analysis and Presentation

Scientists' advice for managers usually takes the form of predicted outcomes for alternative management actions. Depending upon what kinds of uncertainty are taken into account during the analysis, this advice can be presented in a variety of forms.

Level 1 - No uncertainty is considered in the analysis. The simplest form of management advice is a simple table or graph depicting the expected outcome as a function of the management action chosen. Yield isopleth diagrams are the classic example, although it is now more common practice to provide several indicators of performance such as average catch, average stock size, etc. In the simplest form, no uncertainty is admitted and the indicators represent deterministic projections of the model in use. To some managers this is the preferred form of presentation because explicit statements of uncertainty often provide an opening for aggressive harvesters to push for higher quotas. As well, some managers do not have a systematic method for treating complicated information.

Level 2 - The analysis includes stochastic outcomes for a single model with fixed parameters. The next level of complexity is to admit stochastic variation in future environmental conditions, but no uncertainty in parameter values or structure of the model. In this case the outputs such as annual harvests, average stock abundance, lowest stock abundance, etc. must capture not only the expected (or weighted average) values, but some measure of how variable the outputs would be over time. This variability is often provided as a frequency distribution of each indicator or error bars.

Level 3 - The analysis includes stochastic outcomes for a model that considers various parameter values and/or structural forms of the model. Once we consider the possibility of alternative parameters or models, the advice can take the form of the classic decision table from stochastic decision theory (Table 2), where rows represent alternative management actions and columns represent alternative hypotheses about the parameter values (or possibly model structures). Each cell then represents the outcome if a certain management action is taken and if a certain parameter or model happens to be true. Within each cell, the stochastic nature of the outcomes may be presented as averages or distributions of outcomes. For each alternative indicator, a different table or entry in each cell of the master table will be needed. Two other items are usually included in such presentations, an assessment of the relative probability associated with alternative parameters or models and an expected value (or weighted average outcome) of each management action, found by multiplying the outcome of each combination of action and parameter value by the probability associated with that parameter value. Such outputs integrate across the uncertain parameters or models.

Decision Analysis

The 3rd level of analysis and presentation of results described above is an example of formal decision analysis, which has been used for decades in business (Raiffa 1968) but has only recently started being applied in natural resource management. Uncertainties are found not only in fisheries management but also in other fields that deal with highly variable and difficult-to-measure natural or human systems. As a result, various techniques have evolved in these cases to deal with making decisions under these circumstances, one of which is optimization. However, the complexities of fisheries management situations usually preclude application of formal optimization techniques (see Clark 1985 and 1990 for notable exceptions). A more practical method for fisheries management is decision analysis. This method was originally developed in business to cope with investment decisions being made by private firms in the context of a variable marketplace (Raiffa 1968). Decision analysis is a structured, formalized method to enable analysts to rank proposed actions by quantitatively taking into account the effects of probabilities of uncertain events and the desirability of the potential outcomes (Keeney 1982; Howard 1988). The technique is designed to improve the quality of decision making. Although it cannot guarantee that the "correct" decision will be made each time, the extensive literature on applications of decision analysis shows that it will outperform other approaches to dealing with uncertainty (Raiffa 1968; Keeney 1982). Many of the decision analysis techniques require considerable time and resources, and would likely be implemented for higher valued fisheries on an occasional, rather than an annual basis.

Table 2

Key elements of a decision table

Alternative management actions	**Alternative hypotheses about parameter values or models**			**Expected Value**
	Hypothesis 1	**Hypothesis 2**	**Hypothesis 3**	
	Probability of Hypoth. 1	**Probability of Hypoth. 2**	**Probability of Hypoth. 3**	
Option A	Forecasted outcome A1	Forecasted outcome A2	Forecasted outcome A3	Expected Value of Option A
Option B	Forecasted outcome B1	Forecasted outcome B2	Forecasted outcome B3	Expected Value of Option B
Option C	Forecasted outcome C1	Forecasted outcome C2	Forecasted outcome C3	Expected Value of Option C

One purpose of decision analysis is to provide insight into some complex decision problem by breaking the complexity into its constituent parts. Those parts are then reassembled to determine the optimal management action; uncertainties are taken into account explicitly, rather than hidden. The components of a decision analysis are:

a. a management objective that specifies criteria for ranking contemplated management actions;

b. a set of alternative management actions to choose from;

c. alternative states of nature or hypotheses about parameter values or processes;

d. probabilities for each of those states of nature;

e. a model (or models) to calculate the consequences of each combination of management action and state of nature;

f. a decision tree or decision table to systematically lay out the components;

g. a ranking of management actions after the analysis, and 8) a sensitivity analysis to determine how robust the rank order of management actions is to various assumptions, parameter values, model structure, and management objectives.

Management Objectives

It is not the role of scientists to define management objectives. However, it is often useful for managers to provide clearly defined objectives or goals to scientists so that the scientific analysis can indicate to decision makers how different the recommended management actions might be for different objectives. For instance, when managers are considering various magnitudes of safety margins in setting quotas for harvesting fish, the management objective is extremely important in determining the optimal safety margin. For example, Frederick and Peterman (1995) showed that if the management objective is to maximize the expected long-term yield of the Atlantic menhaden stock off the east coast of North America, then the optimal safety margin for a constant harvest rate policy is about a 12% reduction from the deterministically optimal harvest rate (the one based on the best point estimates of all quantities in the analysis). However, if the management objective is to minimize the probability of annual harvests falling below some minimum level, then the optimal safety margin is about a 20% reduction.

Similarly, the choice of the optimal management action is affected by the degree of risk aversion expressed by managers. However, managers must carefully define what they are risk averse to -- is it low abundance of the fish stock or small commercial harvests? Avoidance of one of these would lead to a different optimal management action than avoidance of the other. In formal decision analysis, the standard way in which risk aversion is taken into account is through a curvilinear utility function, where the value placed on each additional unit of abundance, for instance, decreases with increasing abundance (Keeney and Raiffa 1976).

Experience in ecological modelling over the last 25 years shows that it is not easy for resource managers to clearly state their objectives. There are many indicators and as well there are diverse groups of stakeholders that want to participate more actively in the decision making. In this situation, it is incumbent upon scientific analysts to do a thorough sensitivity analysis to identify the range of objectives over which a given management option is preferred, and the range over which the optimal action differs.

Another important issue in situations where there is large uncertainty, like fisheries management, is that the risks estimated by experts differ from the risks perceived by others, including the public. Slovic (1987) noted that this commonly observed difference can be created by lack of control over exposure to the risk, potential for extreme or catastrophic outcomes, mistrust of experts, etc. The question for managers is, should they make decisions based on what the experts say the risks are or what the non-experts *perceive* the risks to be? This is further complicated because often managers give more weight to the views of the commercial fishing industry than some scientists believe is appropriate.

Management Options

Since one purpose of decision analysis is to help rank alternative management actions, considerable thought should be put into which options are reasonable and feasible. In the context of the precautionary approach, such options might be various magnitudes of safety margins by which the total allowable catch or other regulatory control would be reduced to allow for uncertainty. However, the optimal safety margin should be estimated for each specific situation rather than setting it arbitrarily at a value such as quota 20% or 30% below the TAC that is otherwise thought to be "best" because such arbitrary estimates can generate suboptimal results (Frederick and Peterman 1995).

Identifying Alternative Parameters or Models

One of the key methodological problems in incorporating uncertainty into assessment advice through decision analysis is identification of alternative parameters or models and quantification of the probabilities of these alternatives.

If we include alternative parameter values or models in an analysis, we must first decide which models to consider and then how to measure the uncertainty associated with the parameters of each model. We must also consider how to assign probabilities to alternative models. When confronted by alternative models, the most common practice is to write a more general model so that each alternative model is a special case of the general model, controlled by a parameter (the 1982 Shepherd stock-recruitment model is a good example, where the Beverton-Holt or Ricker forms fall out as special cases of the more general model). The uncertainty in this parameter of the more general model then reflects the uncertainty about the alternative models. For instance, if there is uncertainty about whether there is depensation in the spawner-recruit relationship, the formal way to assign probabilities to these alternative hypotheses is to consider a model in which no-depensation is a special case and then evaluate the uncertainty regarding the intensity of depensation through a Bayesian analysis.

Assigning Probabilities to Parameters or Models

There are three primary methods used to assign probability distributions to alternative parameter values. First, maximum likelihood is the most traditional method used and involves specifying a likelihood function for the data as a function of the parameters and then computing the likelihood of the data across all combinations of parameters. In models with a few free parameters to be estimated from data, maximum likelihood involves rather straightforward computation, but for complex models with several uncertain parameters, it is much more difficult to estimate the probability distribution across a high-dimensional space. Currently many stock assessment groups that use a maximum likelihood procedure now combine it with some form of Bayesian analysis described below. Maximum likelihood theory can be used to determine traditional confidence intervals without invoking Bayes' theorem, but in order to calculate the probabilities of alternative models or parameters one must, strictly speaking, use Bayesian methods. However, many stock assessments either simply report likelihood-based confidence bounds, or use relative likelihoods of alternative parameters as approximations of Bayes posterior distributions.

Second, bootstrapping is a technique that is commonly used to represent uncertainty in model parameters and structure and requires a number of less rigorous assumptions about the underlying statistical processes that lead to the data. In many cases bootstrapping has proven to be a simpler way of computing a probability distribution similar to the Bayesian method (Mohn 1993). However, bootstrapping makes no claim to represent the probability of alternative hypotheses and results can differ, depending on the assumptions made in the bootstrapping procedure (Smith et al. 1993).

Third, Bayesian estimation uses the basic laws of probability in the form of Bayes theorem to compute the probability that alternative parameter values exist, given the assumptions of their statistical distributions. Bayesian methods have two impediments to successful implementation. First they can be, and often are, very computationally intensive, with solutions often requiring dozens of hours of computer time. More importantly, Bayesian methods also require a specification of "prior knowledge" about parameter values and Bayesian assessments are sometimes strongly affected by what appear to be minor assumptions about these prior values (Adkison and Peterman 1995; Butterworth and Punt 1995). At present both bootstrapping and Bayesian methods are used frequently and there is considerable and lively discussion among specialists over their relative merits.

Whichever method is used, the ultimate objective of maximum likelihood, bootstrap, or Bayesian methods is to assign relative degrees of belief to alternative parameters or models. However, Bayesian methods are the only way (in theory) of placing a *probability* on the alternative outcomes of each management action.

Model to Calculate Consequences

Another key element of the decision analysis is the model used to forecast the future, i.e., to calculate the consequences of each combination of management action and set of parameter values. These models can be the standard stochastic, age-structured simulation models of fisheries management or simpler forms. However, whatever type of model is used, it must produce indicators of the consequences that appear in the cells of the decision table (Table 2). Those indicators must relate directly to the management objective stated in the initial step of decision analysis.

The "loss function" is an essential characteristic of a model in the context of choosing the appropriate level of precaution. This function describes the losses (or decrease in benefits) that are expected for each level of precaution (e.g., % reduction in the harvest rate below the supposedly optimal value estimated deterministically from the best point estimates of all quantities). The loss function may be derived directly from data or generated indirectly by a complex model. A key general result from the decision analysis literature (Morgan and Henrion 1990) is that the asymmetry in the loss function can have a major influence on how different the optimal decision that takes uncertainty into account is from the deterministic case. For example, Frederick and Peterman (1995) found that in some marine fishes, the loss function appears to be relatively symmetric, in which case a deterministically optimal strategy will perform almost as well as the optimal strategy found by a complete decision analysis that includes uncertainties. However, this was not true in other cases where a depensatory recruitment process was included because this increased the possibility that there would be a large, long-term loss if the stock was overharvested (Frederick and Peterman 1995). In effect, this latter situation created an asymmetric loss function and in that case, large safety margins and a very precautionary approach were warranted (Frederick and Peterman 1995).

Decision Tree or Decision Table to Calculate Ranking of Management Actions

Analysts can combine the elements of a decision analysis discussed above through the step of calculating the weighted average outcomes for each action. That is, each outcome is weighted by the probability assigned to each alternative parameter value or model, as shown in Table 2. These expected values for each action then provide a ranking of the alternative management actions. In more complex situations, where there are several categories of uncertainties or a sequence of decisions, then one must use a decision tree to lay out the calculations (Raiffa 1968). However, the principle of weighting each state of nature by its probability is the same as in a decision table.

Another value of using decision analysis is that it helps to circumvent the problem that arises from the burden of proof being on management agencies. For instance, a common approach to making decisions in fisheries management has been to continue with some "default" harvesting regime unless there was strong evidence that a change was needed. However, with decision analysis, there is no single default action; each alternative action is given equal *a priori* consideration. This forces managers to identify the best action among a range of actions and the question of "burden of proof" is circumvented.

Sensitivity Analysis

Assessment groups almost universally present some sensitivity analysis to the basic assumptions of their main assessment. For instance, expected consequences of management actions might be presented for changes in assumed natural mortality rate. Sensitivity analysis is a valuable tool for scientists to explore how robust their results are to assumptions. However, assuming that the results were sensitive to a parameter, how would a manager use such results of a sensitivity analysis unless the scientists assigned probabilities to each case? Thus, sensitivity analysis has two types of results. If it can be shown that the results are not sensitive to alternative assumptions (models, etc.), then such alternatives can be ignored. However, if the results are sensitive, then we see no choice except for the scientist to include uncertainty about the parameter (or model structure), assign probabilities to the alternatives, and then carry out the decision analysis described above again.

The critical question, of course, is whether the choice of the "best" policy changes with alternative assumptions. Even if the expected yield, population size, or other indicator variable is sensitive to an assumption, so long as the ranking of the alternative actions is *not* sensitive to the assumptions, then the managers need to be less concerned with the validity of the assumption.

5. BUILDING CONFIDENCE IN THE ANALYSIS

One way to build confidence in the results of an analysis is to submit it to rigorous external peer review, as many agencies now routinely do. This generates constructive criticism that will lead to improvements in the analyses in the next iteration. In addition, there are several other aspects of building confidence in an analysis.

Validation and Invalidation

Models are the nearly universal tool for formulation of management advice in fisheries and there obviously is concern about the reliability of the models — users seek assurance that the models have been "validated". However, some authors (Holling 1978) have argued that the term model *validation* is inappropriate and that instead the process of establishing degrees of belief should be known as model *invalidation*. In this view, one must explicitly consider a set of alternative models, which may differ only in the set of parameter values used or may differ structurally in the form of one or more hypothesized components. These alternative models are then compared with respect to various features such as descriptions of past observations, ability to forecast well in new situations not included in the input data, etc. The object is to specify the relative degree of belief in the different models. The greatest potential pitfall of "validation" is to assume that once a model has been validated, by whatever method, it is a true representation of nature and to exclude from consideration other alternatives (i.e., place a zero probability on the possibility that those other models exist). This can create a serious problem when scientists arbitrarily choose the range of possible models or parameter values and inadvertently make it too narrow. Adkison and Peterman (1995) describe such a case where Geiger and Koenigs (1991) did a Bayesian analysis to identify the appropriate escapement goal in Alaskan sockeye salmon. Geiger and Koenigs excluded from consideration the range of parameter values that would have been much more consistent with the field data than the range they did consider. This resulted in inappropriately high posterior probabilities on the set of alternative models that they evaluated and also led to unjustified recommendations for the escapement goal (Adkison and Peterman 1995).

The view of Holling (1978) also considers that all models are wrong to some degree. What is important is that a certain model can only be judged against other approaches to using the data. In other words, while any mathematical model may not be correct, managers must ask whether the use of a particular model is likely to be better than an intuitive analysis or "back-of-the-envelope" calculations. We believe that the answer is usually yes, if the model includes an appropriate level of detail relative to the data. Better yet, scientists should develop a range of alternative models for comparison. Once one accepts the stochastic nature of future events and the reality of uncertainty about model structure and parameters, model validation ceases to be an issue and the question is whether the alternative models and parameters considered represent an appropriately broad range and whether the probabilities of alternative models have been assigned using all current knowledge. If so, then the most relevant question for managers is whether the final recommended management action is affected by the range of models considered or the relative weighting put on each.

Limitations of Quantitative Analysis

Decision analysis accounts for uncertainties more comprehensively than most other approaches and it is therefore one of the best ways to identify the best management strategy. However, because of the incompleteness of ecological data, we will still tend to be overconfident in our results from a decision analysis. For instance, if we included a Bayesian analysis of some model and related data, the posterior probability density function will probably be narrower than it would be if more factors were admitted as being uncertain. In other words, the posterior probability density function will become flatter (broader) the more uncertain quantities there are in an analysis, and the optimal decision will be less clear. In the case where we are trying to determine the appropriate level of precaution or safety margin in a fishery, a particular analysis will likely only give the minimum size of that margin; if other uncertainties were included, the margin would probably be larger, as long as they did not introduce a bias. In other words, we may wish to act in an even more cautious manner than indicated by a decision analysis in order to reduce risks. As we gain more experience in admitting uncertainty, we will better understand how the final results depend upon admitting different types of uncertainty.

Hypothesis Testing and Statistical Power

Traditionally, scientists have built confidence in their analyses by applying statistical inference techniques to test some null hypothesis. The result is to either reject or not reject the null hypothesis. Thus, it is important to review the often-neglected issue of statistical power even though, as we have noted, this is not as appropriate of a way to deal with uncertainties as Bayesian decision analysis.

Table 3

Four possible outcomes for a statistical test of some null hypothesis, depending on the true state of nature The probability for each outcome is given in parentheses

	Statistical Decision	
State of nature	**Do not reject null hypothesis**	**Reject null hypothesis**
Null hypothesis actually true	Correct (1-&agr;)	Type I error (&agr;)
Null hypothesis actually false	Type II error (&bgr;)	Correct (1-&bgr;)=statistical power

Reprinted from Peterman (1990)

Statistical power is the probability of correctly rejecting a null hypothesis (Table 3; and Dixon and Massey 1983). For instance, if the null hypothesis is that there has been no decrease in recruitment over time, then it is feasible to calculate the probability of rejecting that null hypothesis (at the stated &agr; level) under each conceivable real magnitude of effect, including no effect. One can calculate statistical power, given the &agr;, sample size, and sampling variability, for each postulated magnitude of effect.

Statistical power analysis is best carried out *before* some monitoring program or stock assessment method is implemented. This *a priori* power analysis can identify where the experimental design or data collection method should be improved in order to have an acceptably high probability of detecting the effects that managers are concerned about, such as large decreases in recruitment or abundance of the stock. However, most scientists do not calculate power of their methods of stock assessment. This is a serious omission because the large interannual variability in fish populations and the large sampling variance often lead to low power (Peterman 1990). These circumstances have contributed in the past to a high frequency of cases of type II error, where a real effect went unnoticed because the null hypothesis was not rejected and regulatory action was not taken when it should have been (Peterman 1990). This type of error can often be more costly than a type I error, which scientists usually focus on avoiding by setting &agr; at a low value, usually 0.05. A type I error may involve *incorrectly* concluding that there *is* a decrease in abundance, for instance, resulting in reduction in fishing time. However, the analogous type II error would involve *incorrectly* concluding that there is *not* a decrease in abundance, resulting in *no* reduction in fishing time. If this lack of regulatory action leads to overexploitation of the stock, then the long-term costs of the type II error may be much larger than the costs of the type I error.

Statistical power analysis should also be done after a statistical inference fails to reject a null hypothesis in order to find how large an effect would have to have been present in order to have an acceptably high power (e.g., 0.8). In many fisheries situations, this "detectable effect size" is unacceptably large in biological or economic terms because of the large variance or small sample size (Vaughan and Van Winkle 1982). Thus, attempts to rely on statistical inference tests without noting the power of those tests to detect important effect sizes may lead scientists and managers to **not** take regulatory action when they should.

Scientists can do a simple decision analysis to weight these types of outcomes and errors by their probabilities of occurrence in order to choose the appropriate action (Peterman 1990). Table 3 summarizes the probabilities of the four different potential outcomes of a statistical test of some H_0. There is a predefined probability, &agr;, of making a type I error and a probability, &bgr;, of making a type II error, as defined by the experimental design (sample size, sample variance, true effect size, and &agr;). The complement of &bgr; (1-&bgr;) is defined as statistical power, or the probability of correctly concluding that some effect exists.

As noted by Peterman (1990), most fisheries scientists and decision makers do not realize that *making a decision about some management action as a result of a statistical analysis that* ***fails*** *to reject some null hypothesis automatically implies an assumption about the ratio of costs of type I and type II errors.* That assumption may be quite different from the real costs of those errors. In particular, where &bgr; is > &agr;, they assume implicitly that the costs of type I errors exceed those of type II errors *if they take action as if H_0 were true*. For example, suppose that data from a harvested fish stock did not reject the H_0 of no decrease in abundance over time at &agr; = 0.05 and that a &bgr; = 0.4 was calculated by statistical power analysis using the sample size, sample variance, and the best estimate of the effect size from current data. Suppose further that decision makers wanted to take the action with the lowest *expected* cost of an error (*expected* cost = probability of an event x cost if the event occurs). If the data analysis failed to reject H_0 and if they took action to avoid making a type I error (assuming the H_0 to be true and allowing fishing to continue at the current intensity), then they would implicitly be assuming that the **expected** cost of a type II error is less than the expected cost of a type I error. This is demonstrated by solving for the ratio of costs of type II to type I errors, C_{II}/C_I, given &agr; and &bgr; and assuming that action was taken as if H_0 were true: &agr;C_I > &bgr;C_{II}, or &agr;/&bgr; > C_{II}/C_I. Since &agr; = 0.05 and &bgr; = 0.4 here, $0.125 > C_{II}/C_I$, or $C_I > 8C_{II}$. In other words, by taking the action that they did, the managers implicitly assumed that the cost of making a type I error was more than 8 times the cost of a type II error (Peterman 1990). But as noted above, the reverse is more likely type II errors are often more costly than type I errors in fisheries management. Such implied cost ratios of acting on results of statistical tests are rarely reported by scientists, let alone considered by decision makers. If they were, managers might make different decisions.

Thus, statistical power analysis can provide useful information about uncertainties that is relevant to scientists and decision makers. It is a different way of characterizing uncertainty than the components of decision analysis discussed earlier. Statistical power analysis may be particularly appropriate in cases where there is little expertise available for applying the more advanced techniques of Bayesian analysis. We should also note that some scientists prefer to state confidence intervals on parameter estimates to give an indication of their uncertainty, rather than testing hypotheses, but this is *not* the same as providing a probability or relative degree of belief in each of the alternative values of the parameter (Sokal and Rohlf 1969).

6. COMMUNICATING INFORMATION ABOUT UNCERTAINTIES

Morgan and Henrion (1990 p. 220) raised an important but often neglected issue when they stated that "... one of the most important challenges of policy analysis [decision analysis here] is to communicate the insights it provides to those who need them." The "insights" that they refer to include the following.

a. What is the overall degree of certainty about the conclusions? In other words, how robust is the choice of the recommended action? Is one action the best under 85% of the analyses performed or are any of, say, 7 different alternatives about equally likely to be the best?

b. How is the optimal decision affected by different assumptions, parameter values, structure of the model, etc.?

c. Which components of the analysis most affect the recommended optimal action? This will influence priorities for research.

The literature discusses several aspects of effective communication about uncertainties to resource managers, the public, and other scientists. We synthesize these into specific recommendations. First, take the time to provide good documentation. This is one of the least favourite activities of analysts but it is crucial to successful use of information on uncertainties. Good documentation requires the analyst to: (i) decide what the intended audience needs, (ii) decide which subset of information to display, (iii) decide which information to treat deterministically and which to treat in a probabilistic form, (iv) decide which sensitivity analyses are most important to show, and (v) document assumptions, data used, methods, caveats, uncertainties, sensitivity analyses, and their implications. This takes considerable effort but may make the difference between having the analyses used or ignored. Second, show decision makers the **implications** of uncertainty **directly** in terms of expected outcomes or optimal actions, rather than just some statement about how uncertain you are about some component parameter of the model. Third, establish a process for iterative interaction among resource managers, the public, and scientists, *starting early* in the analysis. This might involve a series of workshops with stakeholders and decision makers leading up to meetings where these users interact with the models used in the analysis. This interaction with other people might require considerable programming effort to set up an easy-to-use interface. Fourth, choose appropriate methods for presenting results, again depending on the needs of audience and what has been learned by cognitive psychologists about how people interpret information. For instance, in order to represent uncertainty in some estimated quantity like abundance, scientists are used to showing some normal or skewed probability distribution as a function of discrete intervals of abundance. However, some researchers (Ibrekk and Morgan 1987) found that the *cumulative* probability distribution is one of the best and most easily understood and interpreted modes of presentation. This is true even for people who have taken university statistics relatively recently and even after some background explanation is given to the test subjects. The *cumulative* probability distribution is better because users can read directly off the graph the probability that the X variable will be less than some amount.

To our knowledge, relatively little research of this type has been done on how accurately people interpret more sophisticated graphs such as isopleth diagrams or 3-D perspective plots. However, it appears that even some experienced and well-respected scientists cannot easily interpret isopleth diagrams but they fully understand when the same results are shown as families of curves in a single X-Y plot.

The last aspect of communication is that results from sensitivity analyses should focus on how the recommended management action changes as the assumptions or parameter values change. This relates directly to the decision maker's choices.

7. SITUATIONS WITH FEW DATA

Fisheries managers and scientists often face situations in which the data are so incomplete that only the most rudimentary quantitative analysis is possible. In such cases, scientists should not present the results as the final answer but instead should emphasize that at best, the analysis might point in a general direction and that future research priorities are a key output at that stage. In these cases with weak data, scientists should be prepared to admit that a decision analysis is not possible or credible.

Instead of a thorough evaluation of management options when data are extremely weak, scientists should emphasize (i) what needs to be done to improve information for future analyses, and (ii) what management actions would be appropriate in the meantime. A three-part approach would lead to improved information. First, if any quantitative analysis has been done on similar fisheries systems, scientists should examine them to determine the most sensitive components. These would then be high priority for collection of new data. Second, scientists should recommend specific monitoring programs to ensure that appropriate data are gathered in a rigorous and usable form. Third, if managers wish to implement preliminary management actions until such time as better data become available, then those actions should be set up as part of an experiment with adequate monitoring (see earlier section on experimental management).

It is less clear what to recommend generally about which management actions to pursue while the above steps are being taken to improve data. One obvious recommendation would be to allow very limited harvesting so as to not overharvest the resource but the tradeoff here is that less information will be gained early about the potential productivity of the stock. An important additional element of this would be to take steps to prevent fishing power from increasing too rapidly. There are few risks associated with slowly developing a fishery, but many risks with rapid development. Slow development might be achieved through reversing the usual burden of proof. Currently, the onus is on many management agencies to show that overharvesting is occurring before they take strong action to regulate the fishing industry. However, because of large uncertainties in the information, particularly in this situation with weak data, such agencies would probably not be able to show such an effect of harvesting until there was a drastic decline in abundance. If instead the burden of proof is placed on industry (Wright 1981; Sissenwine 1986) or a joint industry-government team (Peterman and Bradford 1987) to show that harvesting is not having a detrimental effect on fish populations before the fleet is allowed to increase its cumulative fishing power, this will tend to drastically slow down the rate of development of most fleets. This may enable the increase in knowledge to keep ahead of the increase in fishing power, which will help eliminate some of the problems seen in past fisheries. If the argument is made that such a reversal of the burden of proof would stifle the economic development of certain regions, then we simply ask managers to consider what *long-term* purpose has been served by allowing the overcapitalization of fleets (and overharvesting of some fish populations) in the past?

Uncertainties in managing natural resources has led to new institutional arrangements in Europe and the United States that are more cautious than traditional approaches (e.g., the Marine Mammal Protection Act, the Michigan Environmental Protection Act, etc.). The Oslo Commission's (OSCOM) Prior Justification Procedure requires industry to go through stringent steps before they are allowed to use the historically common practice of dumping wastes in the ocean (OSCOM 1989). Some situations in fisheries, where there is a long-lived, slow-growing species, for example, are candidates for applying this approach as well because the "permissive" approach (allowing human activities such as harvesting to proceed relatively unchecked until a problem appears) is often not viable due to the usually lengthy period required to identify a problem. Thus,

"The permissive model is no longer viable because it cannot work well in the face of the large uncertainties presently found. Its failure demands a comprehensive rethinking... Instead, the inescapable presence of uncertainty should lead to a shift of the regulatory burden onto those seeking to utilize, and profit from, [natural resources]." (M'Gonigle et al. 1994).

8. RISK ANALYSIS

Risk analysis is a generic term for advice to management that considers uncertainty in states of nature. Thus, the methods and issues discussed previously in this paper can be considered as part of risk analysis. Smith et al. (1993) presents a collection of papers from a conference on risk analysis in fisheries management advice. While most of the approaches at that conference used either maximum likelihood or bootstrapping to evaluate the consequences, there was little representation of Bayesian methods or decision analysis.

9. NEW TYPES OF RESPONSIBILITIES AND REGULATIONS TO DEAL WITH UNCERTAINTIES

Some authors have suggested that one way to avoid many of the past problems with overharvesting is to create incentives for users to maintain the resource in the long term. This would involve having them essentially own the resource and be responsible for managing it. This approach may work best for situations such as sessile shellfish, where there may be a relatively stable local community of harvesters. However, aside from the issue of how to initially allocate partial ownership of the resource among interested people, this suggestion still does not get around the problem that Colin Clark (1973) identified. That is, many long-lived resources have such slow rates of growth in abundance that from purely an economic perspective, harvesters would be better off simply harvesting that resource to extinction and putting their short-term earnings into other investments to earn interest at a higher rate than the resource would have generated. They could then move onto some other economic activity. This is especially a problem where major multi-national companies move large operations to new countries when local conditions become unfavourable. Furthermore, the comparison between the benefits of private agricultural farms and privatizing fisheries illustrates the difficulty of maintaining long-term stewardship of the resource. Farming practices in North America have created serious problems with soil erosion as well as depletion of nutrients and productivity of the soils. There is no guarantee that turning fishery resources over to private owners will avoid this same myopic view of the future.

Individual transferable quotas (ITQs) are being used widely now in New Zealand, Australia and Canada as a means of internalizing some of the allocation problems. While these are generally working well, they are not universally successful, with problems of high-grading and illegal fishing common complaints.

Finally, regulations could be structured to give incentives to individuals who harvest in a responsible manner. For instance, there is a serious problem with by-catch of non-target species in the Alaskan groundfish fisheries. In order to reduce by-catch, an incentive for "clean fishing" is being considered. Vessels that have a lower rate of by-catch than other vessels (verified by on-board observers) will be given more fishing time. Captains thus have the incentive to choose geographical locations, depths, and ways of fishing that reduce the bycatch.

CONCLUSIONS

Scientific advice to managers will always need to be given with incomplete information. There are now many computational and statistical tools available to incorporate uncertainty into our assessments of expected consequences of alternative actions.

However, one could ask, "Will better management decisions be made and fewer losses occur if the scientific advice takes uncertainty into account?" **It depends on how the uncertain information is used.** There is a history of debate among fisheries scientists regarding the advisability of providing measures of uncertainty in stock assessments. When users and decision makers are simply provided with a range of potential long-term yields, there is a common tendency for harvesters to pressure managers to choose values towards the high end of the range and for conservation groups to pressure them to choose from the low end of the range. Instead, we recommend that scientists avoid simply presenting a range of potential yields. Instead we should show alternative consequences of alternative hypotheses as well as alternative actions. Thus, instead of saying "The sustainable yield may be between 50 and 100 tons, with our best guess being 75 tons", the advice should take the form of "There is a 40% chance of being able to take 50 tonnes per year for the next 20 years, a 50% chance of being able to take 75 tonnes per year, and a 10% chance of being able to take 100 tonnes per year". More fully informed decisions will likely result.

We cannot say for certain whether the methods that we discuss would have prevented the fisheries failures described earlier. However, if a full accounting of uncertainty in the assessments had been made available to managers and users, it is likely that different decisions would have been made. For instance, scientists did not recommend that strong action be taken to control fishing on several North Atlantic and North Sea herring fisheries of the early 1970s until they were convinced that recruitment was decreasing. Because of the large interannual variability in recruitment, this convincing evidence did not appear until the spawning biomass was drastically reduced and severe depletion resulted for several stocks (Saetersdal 1980). It is possible that managers would have reduced fishing mortality earlier if they had been shown the consequences of various management actions in combination with several different biological hypotheses about the state of the stocks.

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RISK ASSESSMENT, ECONOMICS, AND PRECAUTIONARY FISHERY MANAGEMENT

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Abstract

This paper reviews basic concepts of decision making under risk, and it describes risk assessment and risk management approaches developed for environmental protection decisions in the United States. Formal decision models quantify the value of strategies based upon probabilities of various outcome. Economic valuation of those outcomes can be used to rank strategies and to select the best ones. Fishery management decisions often can be assessed with this analytic method. However, differences between public perceptions of risk and technical measures of risk create problems. To reduce political opposition to implementing precautionary harvest policies, fishery managers could collaborate with interest groups (including the fishing industry) to communicate the risk information before adopting an arbitrary risk-avoidance strategy. The numerous types and sources of risk in fisheries are summarized in the paper, including those that affect the safety of fishermen, economic prosperity, and fish stock condition. Where fish stock collapse is the main risk, rational economic harvest policy safeguards against stock collapse by establishing an adaptive annual harvest quota and minimum stock level where harvest is curtailed. This is similar to biological benchmarks developed in the technical fisheries literature.

INTRODUCTION

Depletion of the world's marine fish stocks by overfishing and habitat degradation, the most alarming risk facing fishery managers, accounts for current emphasis on the precautionary approach. Many people perceive that high rates of harvest can more-or-less permanently diminish economically valuable fish stocks and marine mammal populations. The collapses of Newfoundland cod, of Bering Sea red king crab, of Peruvian anchoveta, of north Atlantic herring, and of Antarctic blue whales are celebrated cases. If such collapses result from resource management decisions, then it is reasonable to expect managers to take more prudent actions to avoid such negative outcomes. Much of the technical literature addressing biological reference points (see Smith, Hunt, and Rivard 1993 or Hilborn and Peterman, this volume) concerns the appropriate quantification and presentation of the degree of fish stock risk inherent in harvest decisions. There are numerous other risks having important social and economic aspects. Examples include safety risks to seagoing workers, market price risks in the fishing industry, and risks of social disruption due to changes in fishery regulations, fishing industry technology, or resource abundance. Fisheries are largely economic in function, and fishery management has numerous economic and social, as well as fish stock conservation, objectives. This paper considers precautionary management in context of many sources of risks that are related to management decisions. I draw upon the risk assessment and decision analysis literature, and emphasize the social and economic dimensions of decisions regarding fish stock conservation. We begin by exploring concepts and processes common in risk assessment, extend the discussion to economics of risk management, and relate that information to the ongoing discussion of risk and biological reference points in the fisheries management literature.

1. SOURCE AND NATURE OF RISK

Every human activity involves risk in the sense that negative and unintended outcomes occur in an unpredictable fashion. Traffic accidents, disease outbreaks, criminal activities are common sources of risk to individuals. Actions to avoid or control exposure to risk are equally common. Fire insurance on structures and personal liability insurance for auto accidents, for example, reduce the individual's risk of monetary loss. Individuals spend significant amounts to assure safety of financial assets, to avoid injury in accidents, and to insure personal safety from criminal activity. Still, individuals and groups intentionally and voluntarily take uninsured risks. Going to sea in fishing vessels poses risks of bodily harm, but promises economic benefits or increased incomes. Investing in fishing vessels or fish processing plants carries the risk of bankruptcy and poverty, but promises the careful investor a reasonable return on capital. People are generally aware of the trade-off between economic benefits and risks implicit in these actions. People everywhere routinely commit themselves to risky actions, but they also commit resources to reduce these risks. Precaution in fishery management is an extension of individual risk-taking behavior to broader community programs of fish conservation and economic development.

In fishery management, there are a number of risks whose significance in particular cases depends upon the objectives of the manager or fishery community. Risks include the stock collapses mentioned above, but also include more common occurrences such as temporary harvest reductions due to recruitment failures. A management strategy aimed at sustained yield has the risk of destablizing instead of stabilizing the harvest level. A plan of limited entry to a fishery may require the commitment of administrative resources while failing to diminish the fishing capacity and economic investment in the fishery. A management action intended to assist the economic development of a rural community may set into action social changes that cause disharmony and social distress. To think clearly about these risks it is useful to consider the general nature of risk and the specific sources of risk in fisheries.

There are two main sources of risk: Lack of Control and Lack of Information[1]. **Lack of control** implies that some events, like the roll of a dice, cannot be influenced significantly by people. Fishery managers do not control the weather, the ocean currents, the climate, or the mysterious processes of recruitment to fish stocks. Fishery managers are also not in control of social and economic processes that unfold as fishery plans and regulations are implemented. Even if we fully understand the physical and social processes involved, lack of control makes the outcomes uncertain. **Lack of information** causes risk independently of ability to control the underlying process. For example, a storm without warning may cause substantial loss of life at sea. Given appropriate weather information, we know in advance that a storm is imminent, fishing vessels will stay in port, and losses will be minimized. If we know that conditions for recruitment failure are occurring, we could reduce harvest levels in advance. But we do not have intimate knowledge of ocean conditions nor the understanding of the recruitment process necessary to make good predictions. Technical analysts can attempt to quantify the extent of risk associated with particular harvest levels, and this is a useful addition to the information set. But, harvest levels may still be too high or too low. Thus, where events are controlled, better information makes it possible to avoid some disasters and to use knowledge of a fishery system's operation to anticipate problems. Where information is good but control is lacking, it may be impossible to respond to imminent negative effects of change. Most fishery managers exercise fairly loose control over fishing activities, and most fishery information is rudimentary and unreliable. Hence, risks of unwanted negative outcomes are fairly high. Some common examples of fishery control and information problems in both the bio-physical and socio-economic spheres are listed in Table 1.

[1] This discussion is a simplified version of that in MacCrimmon and Wehrung (1986)

Table 1

Relationship Between Components and Determinants of Risk in Fishery Management

	Components of Risk:	
Determinants of Risk	***Type and Size of Potential Loss***	***Chance of Potential Loss (Statistical risk)***
1. Lack of Control		
Oceanic Regime Change or Climate Change	Large potential losses and/or gains depending on what changes occur in fish stocks and yields. Disruption of existing investments and social organizations.	Unlikely over a short period; inevitable in long run.
Natural Disaster (Flood, Storm).	Acute losses of infrastructure in specific regions. Capital	Geographic distribution and frequency predictable from
Spread of Fish Disease or parasites	investments and lives lost. Lost production until disease cured or new stocks of fish established.	historical occurrence. Sporadic and poorly predictable.
Fishing Gear Improvements	May defeat effort-control measures, reduce economic	High likelihood of some effect.
Rapid Drop in Market Price	benefits of management. Substantial loss of fishing incomes	Can follow development of competing suppliers, e.g. aquaculture, or health risk.
Ecological effects of Introduced Species	Introduced species can cause decreased population of target fish stocks, reduced incomes.	Ecological linkages are very complex and difficult to anticipate. Low likelihood, but unpredictable.
2. Lack of Information		
Poor forecasts of annual recruitment.	Short to medium term loss in harvest levels an incomes.	Fairly high chance of occurrence
Unknown "Threshold" for Stock Collapse	Collapse of stock and economic disaster for fishing community.	Relatively infrequent.
Poorly understood economics and social values of fishing	Non-optimal levels of fish stocks and fishing fleets, loss of economic benefits.	Prevalent in fisheries, high probability of occurrence.
Unknown costs to fleet of complying with management regulations.	Excessive costs of management, lower long term economic benefits of fishery.	Prevalent in fisheries managed by centralized agencies with low level efforts to coordinate with fishers.
Poor knowledge of non-use values of non-target species.	Failure to adequately conserve for amenity and other purposes. Loss of non-market economic values.	High chance, especially where fishery management regimes are controlled by fishing interests.

2. NATURE OF RISK

"Risk" refers to situations where people able to formally calculate or intuitively gauge probabilities of losses based on past experience, experimentation, and/or statistical estimation. Repeated small-stakes gambling is a classic case of risk. It is possible to learn through experience the likelihood of a pay-off in games of dice, cards, and so forth. The gambler is accepting a risk of losing the initial bet in exchange for a probability of winning a much larger amount. Investing in a fishing vessel carries this sort of risk. Repeated experience shows that some vessels sink in accidents and storms; some fishing businesses go bankrupt due to poor luck or changing market conditions. The investor takes these risks into consideration. On the broader scale relevant to outcomes of fishery management, probabilistic risks can be calculated for recruitment levels, harvest rates, or economic returns to a fishing fleet. In many cases, the probabilities are gauged using standard statistical methods and based upon frequencies of observed past events.

Some people use a different term, "Uncertainty", for situations where quantitative assessment of risk is impossible. "Uncertainty" would pertain to unpredictable events such as loss of fishing vessels in a war or in a tsunami, collapse of ecosystems due to invading organisms or climate change, collapse or sudden expansion of markets for the fishery's output due to technical innovations or medical research results. The conditions causing these outcomes can be understood and described, but lack of previous experience and consequent lack of information on likelihoods make statistical reasoning inapplicable. The importance of distinguishing risk from uncertainty has been emphasized, for example, in the economics of endangered species. In his version of the Safe Minimum Standard of conservation, for example, Bishop (1978) notes that we cannot know, even in a probabilistic sense, what large economic losses might be imposed on future generations by decisions to allow species extinction. He recommends taking actions to conserve all species until we can value the species and assess costs of preservation correctly.

In contrast to Bishop, Hirshleifer and Riley (1992, p. 9) consider the distinction between risk and uncertainty to be a sterile one. It does not matter whether risks can be quantified by statistical procedures. Hirshleifer and Riley deal solely with a "subjective" probability concept which they attribute to Savage (1954). Probability in this formulation is simply a *degree of belief*. They note that "Even in cases like the toss of a die where assigning "objective" probabilities appears possible, such an appearance is really illusory. That the chance of any single face turning up is one-sixth is a valid inference *only if the die is a fair one* -- a condition about which no one could ever be "objectively" certain. Decision-makers are therefore never in Knight's world of risk but instead always in his world of uncertainty."

On a similar vein, in his major and influential work on ecological risk assessment Glenn Suter,III states that "frequentist concepts of risk are seldom applicable to ecological risk assessments because the endpoints are levels of effects on population or ecosystem properties, not the fate of their individual components" (p. 44). Suter claims that the most applicable type of probability is Bertrand Russell's (1948) notion of "credibility." This notion is illustrated by reference to the weather forecaster, who uses a variety of models, information, and assumptions to estimate the probability of an unrepeated event. Cumulative probability curves can be developed based upon probabilistic models. The spread of the resulting probabilities depends upon "both the stochasticity of the environment and ignorance concerning measurable characteristics" of the system being forecasted. This concept is consistent with the Hirshleifer and Riley notion of uncertainty. I follow this logic in using the terms risk and uncertainty interchangeably to reflect subjective beliefs about the likelihood of outcomes. I assume that experience and scientific reasoning contribute to degrees of belief in various outcomes. But subjective judgements and other factors are also important in forming probabilities.

3. TECHNICAL AND PERCEIVED RISKS

Some authors make the important distinction between "technical risk" and "perceived risk"[2]. Technical risk is probability-based assessment by experts using statistical methods, controlled experiments, and computer modeling. Technical risk uses the language of mathematics and expresses its conclusions in precise but often arcane terms. The community of people making technical assessments often have difficulty communicating their reasoning and conclusions to the non-technical audience. The practice of risk assessment described below is largely within the purview of technical risk analysis.

"Perceived risk" concerns the way in which the general public, those affected by fishery management decisions, understand the risks facing them and how they rank the various risks. Extensive research on the issue of public perceptions of risk finds that people often have difficulty in understanding probabilistic expressions of risk, even though they use similar concepts in assessing repeated risky decisions[3]. People frequently over-state risks of infrequent and relatively unknown events (e.g., nuclear reactor accidents) while under-stating risks of common, known events (e.g., auto accidents, disease due to smoking tobacco). Research also shows that people adjust their perceived risks in the face of new information. People may experience significant shifts in belief based upon single, disruptive events (e.g., an earthquake, major oil spill, disease outbreak, stock collapse,etc.). Further, perceived risk of an event is influenced by numerous contextual conditions. Among the factors listed by Merkhofer (1987;p.22) which have been found to influence the public's perception of risk are (a) severity of consequences, (b) familiarity of the risk, (c) reversibility of consequences, (d) impact on children, (e) whether distribution of consequences is equitable, (f) whether the risk is associated with dreaded fears (e.g., cancer risks), and (g) whether the risk is taken voluntarily or imposed.

The discrepancy between expert assessment and public perception of risk may be attributable in part to differences in information. Presumably, the scientists have data covering a wider range of empirical experience. If so, the public may need to be educated about the nature of the risks. But the fundamental differences in the way people commonly perceive risks are not necessarily susceptible to education. These and other sources of difference between expert and public risk perceptions cannot be taken casually. In particular, economic assessment of the costs of risk avoidance or benefits of risk-taking often rely on expressions of concern or willingness to pay derived from analysis of individual actions or responses. This is clearly true of economic analyses using market demand curves to assess economic values, and is likewise true of more modern methods of measuring non-market values, such as contingent valuation research. As a consequence, one cannot understand the degree of risk-avoidance or risk acceptance exercised by the public without direct investigation of the perceived risks. Public programs to avoid risks must include efforts to understand the perceived risks and to inform the public about the meaning of technical risk assessment. This two-way process of "risk communication" is normally the responsibility of public agencies and government officials.

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[2] I borrow this distinction from Leiss and Chociolko (1994, pp 36–37)

[3] Kahneman, D., et al. (1982)

4. TECHNICAL RISK ASSESSMENT AND RISK MANAGEMENT

Adam Finkel defines risk assessment as "a multidisciplinary method ... for estimating the probability and severity of hazards to human health, safety, and the natural environment."[4] A quantitative risk assessment provides:

Qualitative descriptions of the type and magnitude of adverse effect or hazard.

Numerical estimates of the probability of the hazard.

Discussions of the knowledge base on which the predictions of hazard are made. Risk assessment uses science to determine the probability of losses and to estimate the magnitude of the potential loss. The large and growing literature on risk assessment covers auto safety, engineering safety of offshore oil platforms, nuclear fuel disposal, pharmaceutical drug testing, environmental hazards from agricultural chemical applications, psychological risks associated with child abuse and suicide, investing in the stock market, water and air quality regulations, and global climate change. Any program or policy which significantly involves multiple outcomes with uncertainty can be subjected to risk assessment.

Comparative risk assessments are used to rank environmental risks and to determine which should be addressed first with limited resources. In the human health risk area, comparative risk assessments quantify the number of expected deaths per 100,000 population due to hazards posed, for example, by nuclear power plant accidents, radon contamination in private homes, excessive nitrates in drinking water, and airborne particulates from coal-fired electrical generating plants. The US Environmental Protection Agency has adopted risk-based priority setting methods that quantify the relative risks associated with various hazards[5]. The agency uses this information to decide whether a program to reduce levels of risk of one type should have priority over another. The goal of risk-based priority setting is to balance the environmental risks permitted against the cost of risk reduction and against competing risks[6]. In establishing budgetary priorities, the comparative risk assessment approach is linked to cost-effectiveness analysis. That is, given the budget available, it helps to select the mix of risk reduction actions that yield the greatest overall reduction in human health risks. When the kinds of risks being compared differ in significant ways(e.g., risk of morbidity versus immediate death, risk of birth defects versus risk of airline crashes), the comparative risk assessment must confront the problem of quantifying relative values, which raises conceptual complications often encountered in economic benefit-cost analysis. Without directly confronting this issue of relative value, comparative risk assessment can provide little guidance in setting priorities. Nevertheless, by identifying, describing, and quantifying what is risked and by whom, technical risk assessment can lead in a logical way to risk management.

Comparative risk assessment leads to comparisons of one risk with another (called "risk-risk" comparisons). For example, adopting groundfish trawls may risk disruption of benthic habitat and concentration of economic wealth, while use of gill nets may risk harvest of non-target migratory species and weak catch monitoring associated with widespread small-scale fishing fleets. Where benefits of risk-taking are calculable, a "risk-benefit" tradeoff analysis is possible. For example, one could array the likely economic benefits of increased harvest rates along with the associated risks of stock collapse. Similarly, one could assess the risk associated with introducing drift gill nets versus the economic benefits likely to result from improving gear efficiency. Where losses associated with the risks also can be estimated, one could perform a full "benefit-cost analysis". In the benefit-cost framework, we subtract the expected economic losses from the expected economic gains for a particular action. Where net benefits are positive, the policy has potentially acceptable consequences. A major difficulty in using the net economic benefit criterion for making decisions is that the burden of losses and reward of benefits may be imposed on distinctly different people. Hence the question of equity in the burden of losses is an important policy issue in its own right.

[4] Finkel and Golding (1994; p. 6)

[5] See Kent and Allen's description of the EPA system in Chapter 4 of Finkel and Golding (1994)

[6] Paraphrased from Glenn Suter, II (1993; p. 3)

Risk management goes beyond assessing the probability and size of possible losses in hazardous conditions, and beyond ranking actions by comparative risk. It entails deliberate attempts to reduce, diversify, or insure against risks. One means of reducing risk is to take cautious steps, planning ahead to avoid incurring excessive risks. Another is to eliminate hazardous activities entirely, but this is of limited use in the uncertain world of fishery management. Another is to spread risks more broadly and to diversify activities, making the aggregate program less subject to large negative outcomes. Explicit management of risks is, of course, not a technical analysis, but rather involves responsible agencies or community groups with authority to make decisions. Public decision processes are typically run by representatives seeking input from individuals, and this process is attentive to individual concerns. One cannot substitute expert opinion, based on technical risk assessment, for public perception on the assumption that a more fully educated public would agree with the experts. It apparently helps little for experts to "educate" citizens to the fact that nuclear power plants are safer that alternate sources of energy, for example. Similar dilemma's arise in marine fisheries. In the United States, for example, public pressure prevented the National Marine Fisheries Service from taking the gray whale off its endangered species list for many years after it was technically possible to do so. Hence, a direct and rigorous examination of what the public thinks the risks are, and how the public ranks various risks would be a useful adjunct to the model-based risk assessment methodology.

Leiss and Chociolko (1994) provide substantial evidence that intractable public controversies over management of health and environmental risks often stem from disagreements among technical experts on the magnitude and degree of risks. Further, these technical differences often stem from subjective judgements made in the risk assessment process. When technical disputes are combined with disparities between technical and publicly perceived risks, there is a tendency for the public to distrust the technical experts and for the technical experts to distrust the public statements by interests groups. Another important concern is that every decision to accept or control risk is paired with an assignment of responsibility for dealing with the consequences of taking risky actions. For example, the manufacturer of agricultural pesticides may demonstrate technically that there is little danger of environmental effects. But it is also likely that the manufacturer seeks to shift the responsibility for cleaning up waterways and compensating those affected by fish kills when the occasional accident occurs. This shifting of responsibility is another reason the public remains skeptical of public policies directed by technical risk assessment. One strong conclusion from Leiss and Chociolko is that risk management must involve a process of risk communication and of negotiation between parties with contesting interests. A negotiated agreement needs to define what risks are acceptable and who takes on the responsibility for those risks.

5. A FRAMEWORK FOR TECHNICAL RISK ASSESSMENT

To clarify the nature of technical risk assessment in fisheries, it is helpful to use a framework from the economics of uncertainty and information theory (Hirshleifer and Riley, 1979 and 1992). First, there are alternative actions that can be taken. In a fishery we can think of these as various forms of regulations, institutional designs, incentive systems, and research strategies. It is obvious that the actions are uniquely human and are intended to achieve ends determined by humans. Actions may be single, once-for-all measures (also called "terminal" actions) such as prohibition of marine mammal harvests or limiting a fishery to hook and line gear. They may be repetitive actions such as annual setting of Total Allowable Catch. They may be contingency plans (e.g., a formula relating annual TAC to stock assessments). They may be informational actions or actively adaptive actions involving research programs or experimental fishing.

Second, there are **states of the world** (or simply States) which are largely uncontrollable and only partially observable, understandable, and predictable. The life history characteristics of fish, the mechanisms governing recruitment, the trophic dynamics among fish and their ecosystem co-habitants at various life stages, and the dynamics of ocean currents and primary productivity are important components of the State. For fishery managers there are social aspects to the State as well. The technology of fishing, economic characteristics of fishing fleet, the rituals and taboos that drive fishing behavior, and dynamics of fish marketing systems are examples of these social dimensions. Researchers seek constantly to improve knowledge of the State of the world, but its complexity eludes us[7]. We develop probability concepts to give shape to our ignorance and to quantify our inability to predict and to establish ranges of uncertainty.

Third, the State of the world determines how particular actions lead to specific **outcomes** or **consequences**. Outcomes are multidimensional, having both natural and social components. For example, adoption of a "conservative" fishing rate is generally thought to result in relatively small and benign changes in ecosystem structure, to long term sustainability or even stability of harvests, and to relatively low levels of aggregate economic production (food, recreation, subsistence, or whatever). An outcome of socially unrestricted fishing(e.g. open access) in the face of rising market prices and improving fishing technology is likely to be stock depletion, significant ecosystem restructuring, and unstable supplies of seafood. How much sustainability or depletion is caused by any specific action is, of course, uncertain. If the actions considered are complex, for example a harvest quota strategy involving adaptive management, the definition of the outcome is also complex. In economics as in ecology, everything is connected to everything else. There is seldom an unmitigated "good". High levels of harvest are linked to lower prices and elevated harvest costs. That is good for consumers, but not so good for producers.

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[7] Jack Ward Thomas, Director of the US Forest Service, at the "Salmon Summit" in Portland Oregon in 1991, noted that "the ecosystem is not only more complex than we think, it is more complex than we can think."

Fourth, the decision maker's **preferences** reflect individual preferences for various outcomes[8]. One may prefer high, unstable levels of fish production or low and more stable level of production. Regarding preferences, economics is typically non-judgmental; it takes people as they are (or they say they are), and accepts satisfaction of people's preferences as an adequate goal of decision making. Preferences may distinguish between any and all social and ecological attributes of the outcomes, and may even be expressed directly for States of the World. People may prefer the ocean with whales in it even if the presence of whales has no influence on the production of anything else of value, a situation giving rise to the economist's notion of existence (or passive use) value. A preference-scaling function is used to rank these values among the various outcomes. For simplicity, a complex economic outcome might be evaluated in terms of expected net present values of economic returns from the fishery. Preferences, however, may pertain also to the distribution of income or wealth among people -- an aspect that we broadly refer to as “economic equity”. Hence, use of whales for food diminishes the existence value held by mammal conservationists, while it increases the use value enjoyed by harvesters. Preference ranking by decision makers must deal with this inter-personal distributional issue[9]. Finally, the very presence of risk implies that a given action can result in various outcomes. Each outcome has a likelihood or probability. Hence, we need a preference ranking function that deals with multiple and uncertain outcomes.

Figure 1. A Framework for Risky Decisions

	State 1 Population Stable & Resilient	State 2 Population Variable & Resilient	State 3 Population Variable & Fragile	
Action 1 - Fixed Quota	$v(C_{11})$	$v(C_{12})$	$v(C_{13})$	$U(A_1)$
Action 2 - Harvest Adaptively	$v(C_{21})$	$v(C_{22})$	$v(C_{23})$	$U(A_2)$
with Ave. Catch near MSY				
Action 3 - Harvest Cautiously with low Ave. Annual Catch	$v(C_{31})$	$v(C_{32})$	$v(C_{33})$	$U(A_3)$
Subjective Likelihood of State	p_1	p_2	p_3	

[8] I am using the abstraction of “a decision maker” in order to avoid the extensive extra language I would need to introduce the concepts of social or collective preferences. It is assumed that the decision maker somehow reflects collective preferences. Aggregating from individual preferences to a social or collective preference-scaling function requires consideration of inter-personal and inter-generational effects. In practice, the use of aggregate preference functions in economic research generally relies on some strong simplifying assumptions (e.g., that individuals are all affected in the same way by outcomes and have the same preferences). In more complex formulations, various social or economic classes may be identified and relative weights could be placed upon economic benefits for each class

[9] A deep issue concerns the ethical force of preferences or values concerning others behavior. We accept the notion that our feelings about another's behavior, when that has only indirect or ephemeral affects on us, do not create a strong ethical obligation on the other person. This is at the heart of social toleration of aberrant grooming habits, religious practices, etc. That ethical tolerance apparently extends to the Hindu prohibition on harming cattle, for example. We do not accept an ethical duty on the part of non-Hindus to comply with that prohibition. Similar ethical tolerance could be accorded marine mammal harvests, bycatch, and other “demonized” aspects of fishing

6. AN EXAMPLE WITH THREE POSSIBLE “STATES OF THE WORLD”

We can illustrate these rather cryptic concepts with an example. With three possible states of the world and three management actions, we can depict the situation as in Figure 1 below. For concreteness we can think of State 1 as a world in which the fish population under management is “resilient”. Although it is affected by environmental variation and managers are unable to predict annual variations precisely or to measure the population with great accuracy, the range of variation in stock size is not great and it rebounds readily from episodes of excessive fishing. Consequently, it is relatively easy for managers to adjust fishing rates to rebuild stock abundance in response to declines. In State 2, the population variation covers a wide range (e.g., something like a coastal pelagic schooling fish stock) but the stock is still resilient in the sense that it will rebound over a reasonable period of time (5 – 10 years?). In State 3 the fish population is part of a complex, nonlinear ecosystem in which significant fishing triggers a change in trophic dynamics rendering the population prone to replacement by competing species. Once the population is significantly disturbed it declines to levels of near commercial extinction. Each combination of management action and State is identified with a particular consequence, C, and we presume the decision maker to have a utility function, *v*, which expresses a ranking of preferences across consequences.

A manager can select Action 1 -- an aggressive, **MSY**-type management strategy, Action 2 -- a strongly monitored and regulated adaptive management strategy, or Action 3 -- a minimal harvest rate strategy. The choice depends on which yields the greatest pay-off or value. For purposes of the example, we assume that $v(C_{11})>v(C_{21})>v(C_{31})$, $v(C_{12}) < v(C_{22}) > v(C_{32})$, and $v(C_{13}) < v(C_{23}) < v(C_{33})$. Hence, a manager who is able to determine the state of the world chooses Action 1 in State 1, Action 2 in State 2, and Action 3 in State 3. It is easy to conclude that, without risk, the selection of management action is immediately connected to the State of the world and the consequences. This is the sort of decision consumers and producers are normally expected to make in microeconomic theory. If the state of the world is that your shoes are worn out; you can buy a new pair of shoes, and the outcome is obvious and immediate. However, once we introduce uncertainty, choosing an action is not equivalent to choosing anoutcome. For any given action, numerous consequences are possible. The shoes may turn out to hurt your feet, or a defect in manufacture may cause the sole to detach during the next rainstorm. The action -- buying shoes -- does not provide with certainty the desired outcome. Hence, rational behavior under uncertainty cannot be equivalent to choosing the outcome which maximizes the preference ranking function defined over outcomes. We must choose actions based on an evaluation of numerous possible outcomes and their likelihood.

In the simple example of Figure 1, the manager faces a risky decision because he cannot tell exactly which state of the world prevails. To resolve this, she may choose the action which maximizes the expected utility function defined as:

$U(A_i) = p_1 v(C_{11}) + p_2 v(C_{12}) + p_3 v(C_{13})$. Here, the function $U(A_i)$, is a von Neumann and Morgenstern utility function which is defined over actions having uncertain outcomes. This says that the utility of an action can be computed from the elementary utilities of consequences via a simple linear weighting, using probabilities (p_i) as weights; i.e. the mathematical expectation or probability-weighted average. As stated by Hirshleifer and Riley: "The great contribution of Neumann and Morgenstern was to show that, given plausible assumptions about individual preferences, it is possible to construct a v(c) -- "cardinal" in that only positive linear transformations thereof are permissible -- function whose *joint* use with the Expected utility Rule will lead to the correct ordering of actions." (p. 15). The cardinal v(c) function can be constructed in a special way called the reference lottery technique[10].

For simplicity, we could assume that the consequences are quantified in terms of net increments to economic income, and that the elementary utility function v(c) assigns utility to income. Further, if the v(c) is a simple linear function like v(c) = ac, more income is preferred to less, and proportionally more income generates proportionally more utility. Here, the decision maker using the expected utility rule will seek to maximize expected income. In this construction the decision maker would be indifferent between any two prospects having the same expected income even the two prospects have difference risks of loss - he/she would have a **risk neutral** preference ordering. By extension, a decision process seeking to maximize a more complex concept of expected economic benefits (e.g., consumer and producer surplus) is acting in a risk neutral manner. This does not mean that the decision maker is careless or lacks prudence, it is simply a technical statement about the shape of the utility function. If the utility function is convex, like v(c) = alog(c), the decision maker will prefer the prospect with lower risk of failure. The resulting behavior is termed **risk averse**[11]. A risk averse person is willing to accept lower expected value in exchange for lower risk. A **risk-preferring** (also called risk-prone) decision maker would do the opposite -- choose a riskier option even if it had lower expected value. Generally speaking, most decision makers exhibit characteristics of risk aversion; although, when risks can be broadly diversified, individual decisions may appear to be risk neutral. This could be the case, for example, of small program decisions by a large government agency. Consistent risk-preferring behavior, when extended beyond moderate small-stakes gambling, is generally treated as a pathology, and often leads to ruin.

Elaboration of this formal model of decision making helps to focus attention on the risk assessment and evaluation on the following decisions components.

1. Outcomes or consequences of harvest strategies. Socio-economic dimensions of the outcomes may differ those typically examined in biological/ecological models. Economists concern themselves with net economic returns (or rents) generated by the fishery. They also develop more complicated models which deal with consumer surplus, willingness to pay (or sell) for non-market use values (e.g., recreation), existence or passive use values, short-run versus long-run costs and returns, employment and regional income generated by fisheries, and costs of management actions. In a simple fishery market model, for example, some outcomes of a harvest policy would include the mean and variance of market price, supply, incomes, and employment.

2. Preference-ranking functions over outcomes. Rigorous assessment and quantification of a publicly-acceptable preference ranking is critical, but is generally beyond the scope of fishery models. Simple preference rankings often used in fisheries research tend to be linear or logarithmic functions of average harvest or weighted combinations of average harvest and stock size. Economic preference rankings would incorporate the consumer benefits, producer benefits, non-market benefits, and all costs into a single scalar "net social benefits" measurement. An alternative is to display alternative ranking using different systems of weights for the component net benefits variables. If the fishery strategy is dynamic, the preference ranking function must deal with outcomes and preferences at different points in time. This raises the question of how to incorporate opportunity costs of capital and social time preference rates as discount factors.

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[10] This technique is explained in detail by Hirshleifer and Riley (p. 16–21)

[11] Actually, this statement is not quite correct. Hirshleifer and Riley carefully show that the shape of the v(c) function depends upon both attitudes towards risk and marginal utility of income. A risk neutral decision maker with a declining marginal utility of income will have a convex v(c) - resulting in decisions that are commonly characterized as "risk averse". I ignore this important distinction throughout, because the common practice in the fisheries literature is to label as "risk averse" any utility function that is convex in consequences

3. The harvest strategies to be considered. Biologists' models frequently examine fixed catch or fixed fishing mortality rate or fixed escapement strategies. There is no particular reason to choose these options except that they are easily represented algebraically, given the usual structure of the population models. Economic optimization models typically yield feed-back control strategies which assign annual quotas based upon perceptions of the state of the fishery. In simple cases, this control policy sets a threshold stock size below which no harvest is allowed, because harvesting is less valuable than investment in larger stock size. Above the threshold stock, annual harvest level is an increasing and generally nonlinear function of measured stock size.

4. Assessment of risks. Assigning probabilities to the alternative outcomes under each state of the World involves both a decision regarding which States to consider and how to quantify the risks. Introduction of measurement errors, model errors, noise and implementation errors into management models has been well developed in biological models. Economic models are not as tractable, since it is nearly impossible to conceive of risks as one dimensional. A risk of lower harvest is tied to a risk of higher price. The two variables affect consumers and producers differently. And the outcomes in one fishery tend to affect conditions in other fisheries.

7. QUANTITATIVE RESEARCH TO IMPLEMENT THE DECISION MODEL

Much of the hard scientific research effort in fisheries decision analysis emphasizes alternative harvest management strategies, quantifies consequences in terms of average harvest and variance of harvests over time, and assesses the probabilities of those consequences. Social and economic consequences, such as income and employment in the fishery, can be evaluated as well, and these are often as difficult to predict and measure as biological and ecological consequences. For example, commentators during the Symposium on Fishery Management: Global Trends in June 1994 noted the difficulty of forecasting the effect of individual transferable quotas (ITQs) on the economic structure of the fishing industry[12]. Experience shows that in some fisheries ITQs encourage consolidation and increased scale of firms, while in other fisheries they strengthen the small, owner-operated fishing firms. Further, because neither economic benefits nor aquatic ecosystems are directly observable, measurement of ecosystem status and measurement of economic benefits are equally difficult. An additional problem is that the economic values being measured are subject to exogenous change over time. From the perspective of a given fishery management regime, a change in foreign exchange rate or the emergence of a new product which competes with the managed fish species will cause an unexpected shift in the economic value generated by the fishery.

Regarding non-market values, special skills and research efforts are needed to adequately quantify economic benefits[13]. Recreational values are important for some fish species in the US and Europe, yet the economic value of recreation is not well documented in the statistics normally collected by management agencies. Studies to document the value of recreational fishing using well known techniques are expensive and therefore scarce. Further, the concepts involved in extending economic value to non-market goods are misunderstood by many authorities making management decision. These problems are even worse in the area of existence value or passive use value, which can be estimated only by well-designed and executed contingent valuation surveys. In conducting such surveys for measuring, the research approach must take into account the behavior of people in responding to solicitations. The research methods are fairly well developed now[14], but there are significant outstanding controversies concerning the accuracy and usefulness of contingent valuation methods for estimating benefits, for determining adequate compensation, and for ranking of social program objectives.

12 The Proceedings of that symposium are still in preparation. The particular comments are attributed to Dr. James Wilen, Dr. Harlan Lampe, and Philip Major who were drawing upon experience in Canada, Chile, and New Zealand respectively

13 Freeman (1993) provides a useful overview of the entire field of non-market values

One logical response to inaccuracy and in-comparability of economic value estimates would be to stop short of providing a single, comprehensive measure of economic benefits (or expected utility). Instead, one could provide the decision maker 'with a display of alternative social and economic consequences for each action under consideration. The display would logically include some information about variances and covariances as well as means of the key variables. This approach raises the problem that alternative actions and consequences are infinite in number. So a process of reducing the set of options to those most appropriate and acceptable needs to be pursued along with the technical analysis. For example, in presenting technical information to the Fishery Management Councils in the US, technical advisors often provide a range of estimates for alternative management approaches. These may include the average and statistical range of harvests or stock abundance under exploitation strategies; and this is frequently augmented with expected distribution of harvests among important gear groups and/or fishing ports. Economic value of harvest, recreational share of harvest, and economic impacts of harvesting activity on coastal communities are also provided occasionally to Fishery Management Councils. This approach is consistent with multi-objective framework for decision making and seems to be the approach increasingly advocated by researchers involved in providing information to managers[15].

8. FISHERY MANAGEMENT DECISION MAKING MODELS

Models of fishery management that incorporate uncertainty in population dynamics, in measurement of stocks, and in behavior of fishing effort in response to management are well developed. These seem to be generally consistent with the framework described in Figure 1. The compendium of papers presented at a workshop in Halifax, Nova Scotia edited by Stephen J. Smith, Joseph J. Hunt, and Denis Rivard (1993) is a recent example of that literature. To date much effort is focused on foreseeing the possible biological outcomes of various harvest strategies and estimating the probabilities of various fish stock levels, recruitment failures, and stock collapse. Little analytical effort seems to be focused on other kinds of risk, and little is devoted to deep understanding of the social and economic consequences of the outcomes (e.g., the utility functions).

It is clear that formal fishery decision models constitute a form of ecological risk assessment. The National Research Council's Committee on Risk Assessment used a study of George's Bank fishery as an example of risk assessment, and it was their only example of a well quantified ecological risk assessment[16]. Fisheries research is far ahead of other branches of ecological risk assessment, at least is developing quantitative models. The frameworks used in most fisheries models pay special attention to the process of quantifying particular outcomes using specific assumptions regarding fishing strategies. These strategies are frequently expressed in terms of a fishing mortality rate (F) or a harvest amount (C) or a combination of F and minimum spawning stock biomass (SSB). Recent innovations in the techniques include bootstrapping and Monte Carlo modeling of fisheries populations under exploitation. The sources of uncertainty introduced in such models focus on biological/ecological concepts and measurement error problems. For example, recruitment is often taken as a random process -- either uniformly distributed or normally distributed about some stock-recruitment function. Error in the estimation of stock-recruitment functions and randomness in natural processes are recognized as major sources of risk. In addition, errors in measurement of stock size, natural mortality, fishing effort rate can be introduced to such models.

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[14] See Mitchell and Carson (1989)

[15] Hilborn, Pikitch and Francis (1993)

Technical analysts typically search for strategies that are robust to the underlying modeling errors, measurement errors, and unpredictable fluctuations in recruitment. Examples of such strategies are the familiar $F_{0.1}$ fishing rate, establishment of threshold stock size, and constant escapement strategies. Biological reference points are extensively reviewed in the Smith, Hunt, and Rivard report on the Halifax Workshop, and the consequences of adopting various such reference points in several fisheries are examined there.

Given the discussion of risk assessment and risk management objectives from above, it is clear that the models pursue technical risk assessment and that they are clearly intend to feed directly into risk management processes. Because most such models focus rather narrowly on one or two simple outcomes -- catches (average or sustained) and stock biomass, they provide limited information for managers concerned about social and other aspects of management. The Halifax Workshop report highlights the important distinction between management objectives and risk assessment. For example, the Working Group Reports (pp. 5–12) concludes that additional work is needed to develop an analysis of outcomes in the social and economic dimensions and that the process of management needs to formally incorporate these diverse analyses along with input from client groups. “Biological objectives” are conceived as ways of limiting the scope of harvest strategies considered by managers. Working Group #1 concluded that “Science should not presume or establish objectives or socioeconomic strategies”, but it should determine biological constraints on the management system and translate the scientists level of uncertainty into ranges of possible outcomes. On the other hand, some papers in the Workshop proceedings[17] suggest particular conservation strategies without explicit reference to any of the social or economic effects.

From the perspective of social science, fishery decision analyses available in scientific journals illustrate the kinds of risks posed by uncertainty in the biology and stock assessment side of the business. Less has been learned of the social and economic aspects, but there are certainly a number of useful studies and conclusions worthy of consideration. One approach is to expand a biological model by including economic benefits and costs in the objective function. Some examples of this are published in the Halifax Workshop report. Another example that I am particularly familiar with is the analysis of alternative harvest strategies for the northern anchovy fishery off southern California[18]. Because the anchovy stock was considered of major importance as a prey species for more valuable sport-caught fish, a key prey species for the brown pelican nesting colonies, and a prime live-bait source for recreational fishermen, there was substantial interest in being cautious about the exploitation strategy. One of the analytical efforts was a dynamic programming model which focused on optimal net economic return from the commercial anchovy fishery. The economic criterion was the expected discounted commercial value minus cost of harvesting over time. Because the anchovy stock tended to vary significantly from year to year, we introduced a stochastic error term to the estimated year-to-year population biomass transition model. The mathematical statement of the optimization exercise was expressed as:

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[16] National Research Council (1993) p.252

[17] G. Thompson. (1993)

$$(1) \qquad \underset{h}{Max}\ E\left[\sum_{t} V(\mathbf{h}_t, \mathbf{B}_t)\left(\frac{1}{1+\mathbf{i}}\right)^{t}\right]$$

Subject to:

$B_t = G(B_t, y_t)e_t$

The variables are defined as follows: **h** is the annual yield, **B** is the anchovy biomass, **i** is the annual discount rate, and **e** is a log-normal random error. V(..) is a net economic value function defined to include the economic value contributed by the combined fishing/processing industry. G(..) is the estimated year-to-year biomass transition equation. The economic model of the harvesting assumed fishing costs were simply proportional to number of days fished, but also recognized that catch per day of fishing was non-linearly related to biomass. This resulted in the following cost per unit catch equation:

(2) $c = aB^{-.04}$

This implies that cost per unit harvest increases as biomass declines. Given the fixed demand curve for the product of the fishery (fish meal), and this cost function, it is relatively straightforward to see that there is some minimum biomass at which the annual net value of harvest will be zero. This level of biomass could be considered an "economic reference point" of sorts. When biomass is below this level, it is sensible to have a harvest rate of zero -- to allow the stock to grow at its natural rate. We solved the problem by discrete dynamic programming, and obtained an optimal harvest strategy which assigns a specific harvest level to each year's spawning biomass estimate. Because the optimization problem is dynamic, the optimum harvest strategy must satisfy the following condition: at each perceived stock size (i.e., State of the World) the harvest should be adjusted until the marginal current value (contribution to net economic value in the current year) just equals the marginal value, discounted one year, of increased biomass. An increase in biomass generates a future value because it decreases future harvesting costs and because in contributes to future sustainable yield. As noted by Clark and Munro (1975), the dynamic economic optimum treats biomass as an investment. We apply the standard investment criterion of adding more to the asset so long as the return on investment is at least equal to opportunity costs of investment. The opportunity cost is represented by the discount rate times the current net value of a unit harvested.

18 The models are documented in Huppert (1981) and Huppert, MacCall, and Stauffer (1980)

In the dynamic formulation of the harvest optimizing problem, the economic reference point is a biomass greater than the level at which annual net value equals zero. Not only do we want a biomass large enough to yield positive net benefits (market value of fish less costs of fishing), but we also want to cover the opportunity costs of discounted net revenues generated by larger biomass. Hence, the economic "reference point" is sensitive to the discount rate, but will generally be a biomass at least equal to the level where cost per unit just equals price per unit. It is well known that competitive market economies with no property rights in fish stocks commonly overexploit fisheries, depleting stocks well below this economic reference point[19]. As further explained by Smith (1968) and Clark (1973) there may even be pathological cases in which a present value maximizing strategy drives the stock to very low levels, possibly even to extinction. In those cases, the managers need to explore public perceptions and values to determine whether extinction of the stock would generate significant non-market losses not incorporated in the net present value formula.

In some respects, the economically optimal harvest policy developed for the anchovy stock, and similar harvest strategies developed elsewhere, have characteristics of a precautionary policy. That is, the economically sensible thing is to protect the stock when spawning biomass is low. A complete shut-down of the commercial fishery at low stock biomass is completely consistent with the usual notion of economic rationality. This is true even though future returns are discounted, even though the decision criterion is risk-neutral, and even though non-market or non-economic ethical values were not considered. Whether proponents of the precautionary approach accept this economic optimization approach to biomass management will depend in large part on whether it adequately represents the perceived risks and is adequately protective of fish stocks.

That this conclusion is not widely understood or appreciated may perhaps be attributed to two circumstances. First, many technically competent fisheries researchers (and certainly many influential conservation leaders) have little or no serious training in quantitative economics. Second, many people have come to understand "economics" to be whatever local, commercial interests say it is. Entrenched economic interest groups often have very narrow agendas and myopic views of conservation. This is often due to a history of operating in an open access fishery, where individual incentives to conserve fish are very weak at best. It may also be due to the notion of "individual risk" that I mentioned earlier. The problem is that an individual fishing operator may be unable to survive an extended fishery closure because she is financing capital investment in vessels through bank loans. In this case, even though the individual understands that a period of stock re-building is the best strategy for the fishery, she may feel compelled to advocate continued fishing, hoping that the stock will recover anyway. Hence, individual survival incentives may drive industry economic interests to fight for collectively irrational policies. Another way to state this is that the burden for risk-reduction may fall disproportinately on the small fishing operations. The solution to this dilemma is not be to criticize economics or the use of economic criteria in establishing precautionary fishery management approaches, but rather to alter the social system so that individuals can survive the occasional closed fishery, that is to reduce the individual risk.

A component of a fully developed precautionary fishing policy could be a form of insurance or compensation fund that could be triggered when stocks decline below economic reference levels. A credible commitment by the authorities to help individual firms and families to survive these situations might go a long way towards bringing rational attitudes to the management decision process. There is, of course, another side to this policy dilemma. The establishment of such a policy could become a continual subsidy to the fishing community, and this might encourage fishing fleets to expand because the compensation will essentially lower long run average private costs of fishing. A different approach would be to create and enforce individual, durable fishing rights in the fishery individual fishing quotas (IFQs) or individual tradeable quotas (ITQs). A successful conservation program will generate capital asset values for the ITQ holders. Financially strapped individual fishers could draw upon that asset to survive occasional low quotas or prices. Banks are more willing to extend credit to owners of these assets. This may alleviate individual risks sufficiently to moderate short run anti-conservation incentives.

[19] See any textbook of fisheries economics or bioeconomics, for example L. Anderson (1986) or C. Clark (1976)

9. IRREVERSIBILITIES, EXTINCTION AND ECONOMICS OF CAUTION

When species extinction is threatened, a new set of social and economic considerations becomes relevant. Economists often introduce the notions of "existence value" or "passive use value" to represent the value that people place on maintaining a natural asset even if those people expect never to consume or otherwise directly use the asset. Existence values have been estimated for everything from clean air in Los Angeles, to marine mammals, to grizzly bears in Montana. The technique used to estimate these values is called "contingent valuation" because it typically calls upon survey respondents to make decisions regarding payment, contingent on apostulated market. Recently, John Loomis completed a survey from which he estimated a value in the US for elimination of two hydroelectric dams on the Elwha river in Washington state. The policy issue is restoration of salmon runs to a part of the river that has been inaccessible to salmon for 50 years. His estimated total annual value for the US population (expressed by the survey respondents as willingness to pay higher taxes to finance the dam removal) ranged from roughly $3 to 6 billion. The large value is likely due to salmon's status as a "charismatic megafauna", at least in the Pacific Northwest region of the US. It is unlikely that a north sea plaice would generate a similar existence value, but you never know what the value might be until you take the effort to estimate it. The existence value of a fish stock would be expected to become a greater and greater portion of the total economic value as the stock is pushed towards extinction. Hence, when included in the economic assessment of harvest strategy, these existence values militate against depleting stocks to a point that raises the likelihood of extinction.

The greatest threats of extinction in capture fisheries occur when the stocks affected have low production rates or depend upon specific ecological niches that are altered by fishing. Significant levels of harvest can drive stocks to below threshold levels before managers have an opportunity to evaluate the risk and arrest the decline. Here, the precautionary approach would call for the slow build-up of the fishery while information collection and analysis accumulates. Most species with low production have predictable characteristics (sharks and mammals have low reproduction rates, rockfishes and orange roughly live to advanced ages) that can be assessed in advance. Sensitivity to ecosystem structure is essentially more difficult to appraise. For example, some mammalogists suspect that harvesting at a moderate levels in the Bering sea sets in motion a long term process of ecosystem restructuring that threatens the northern sea lion. Managers expect the evidence of imminent extinction to increase over time, giving the decision makers time to adapt the associated harvesting activity while monitoring the sea lion population. Whether this approach to species conservation is successful will hinge on uncertainties concerning the ecological linkages between species and errors in measurement of population sizes and trajectories. In the US, where people place a lot of passive use value on sea lions, there is pressure to reduce and restructure the fishery more than fishery managers suggest. An economic approach to the decision would call for evaluation of the passive use values along with a net benefit analysis of alternative harvest rates and fishing patterns. Whether more extreme restrictions on fishing are appropriate would depend upon whether the costs of precautionary measures exceed the benefits decreased chance of extinction.

In his economic analysis of species extinction Bishop (1978, 1993) relies on the twin notions of irreversibility and uncertainty to justify a more cautious decision criteria which he calls the Safe Minimum Standard approach. Because the full consequences of species loss is unknown and extinction is irreversible, Bishop reasons that the future economic loss due to extinction could be very large and not calculable. Further, lacking probability estimates associated with the unknown losses, we cannot maximize expected benefits. Bishop concludes that a reasonable economic decision criteria for endangered species is minimizing the maximum possible loss (minimax loss). If the potential long term losses are seen as arbitrarily large, we should always preserve the species. Bishop adds a proviso to his "safe minimum standard" approach that extinction may be selected if the social costs of preservation are intolerably high. In responding to the critique of Smith and Krutilla (1979), who suggested that a better approach would be to maximize the expected value of future net benefits, Bishop (1979) noted that he had in mind a situation of "true uncertainty", where expected losses cannot be computed and entered into a net benefit assessment. This Safe

Minimum Standard approach to endangered species has much in common with the so-called "precautionary principle". Critics of that approach point out the excessive emphasis it places upon unmeasured large losses having very low probabilities -- a criticism that essentially says the decision criterion is too risk averse[20].

A problem ignored by Bishop and his critics is that actions needed to save a species are also risky. It is uncertain that species conservation efforts will be successful. In terms of the formal decision model, this is another form of uncertainty about the State of the World. Montgomery and Brown (1992) develop a constructive analysis of this uncertainty in the context of the endangered spotted owl in the US Pacific Northwest forests. In their formulation, the probability of survival is the key variable. There is essentially nothing we can do to **guarantee** the long term survival of the species. Still, the larger the amount of forest that is preserved as owl habitat, the higher the probability of survival. They used two different models to generate the probabilities of owl survival one using a group of experts and the other an explicit population model. Directly linked to the magnitude of forest preservation is the opportunity cost of foregone timber production. This approach displays the cumulative economic cost and cumulative gains in survival probability associated with forest protection. The economic value of saving owls has also been estimated, but these numbers seem to be less reliable at present. The display of trade-offs between costs and owl survival is a useful example of cost-effectiveness analysis.

Finally, Walters (1986), Kai Lee (1994), and others emphasize that estimates of probabilities and of costs can be improved over time through adaptive management -- that is, by treating management actions as experiments from which we learn about the system being managed. The Safe Minimum Standard approach could be a reasonable risk management strategy when used as a first step in an adaptive learning strategy. That is, we would preserve every species even at high cost until we understand more about its role in the ecosystem, its chemical composition, etc. After that, the life-or-death decision could be based upon constructive estimation of survival probabilities and associated costs and benefits. To the extent that stock collapses and ecosystem catastrophes are analogs of a species extinction, the same approach could be used -- that is, take extreme caution and forego the short-term economic benefits of aggressive harvesting in order to avoid extreme outcomes. Devote resources to assessing the productivity of the fish stocks and to economic benefits of further expansion, and experiment with harvest levels of learn from experience. This is a narrow version of the precautionary approach that ignores social and economic consequences of reduced food supplies. However, most fishery decisions, even in risky environments, do not involve significant probabilities of catastrophic outcomes. Learning to scale the degree of caution to the likelihood of negative or catastrophic outcomes is the major task of risk assessment and management.

[20] Bishop could respond, of course, that the critics can not logically assess how risky the strategy is since neither probabilities nor potential losses are quantifiable

Some people place such high negative value on the stock collapse or species extinction outcome that they act in accord with the "precautionary principle" -- permit no harvest until it can be proven safe. That commercial fishing interests view this approach as irrational stems from disagreement over values, not over technical risk assessment. No amount of scientific, economic, or social research will solve the problem of divergent values. But we can attempt to avoid allowing the fundamental differences in values becoming tangled up with differences in risk management approaches. This is where the risk communication and policy negotiation processes become extremely important.

10. ECONOMIC RISKS AND PRECAUTIONARY FISHING

Risks commonly affecting fisheries include market price fluctuations, operating cost increases, adverse weather patterns, onboard crew safety, and fishery-unrelated shifts in species composition of harvested stocks. Any significant shift in conditions that underlie economic returns to fishing pose a risk to those investing capital in or dedicating their lives to fishing. For example, reduced ex-vessel prices severely depressed incomes in the Alaska salmon fishing fleet during the record levels of salmon production in 1989–1992, and a similar drop in worldwide cod and related species prices reduced incomes in fisheries from Iceland to Alaska. The salmon industry experience suggests that world demand for salmon is elastic, and it has brought into question economic benefits of the vast investment in salmon hatcheries in Alaska. Managers of other large commercial fisheries may need to anticipate effects of harvest volume on market price, especially in fisheries (e.g., Norwegian farmed salmon, Alaska wild salmon, north Pacific walleye pollock, Peruvian anchovy) which contribute a large portion of the world's supply. If fishing fleet prosperity is a management objective, existence of a price-elastic demand suggests that managers should place less weight on large harvests in their objective functions.

Serious fluctuations in the costs of inputs to fishing are less frequent and should be less of a concern in developing management strategy. However, during the Arab oil embargoes of the 1970s, fishing fleets in the US were suddenly unable to buy or, if they could buy, unable to afford the normal quantity of fuel. There is little that fishery managers can do or are expected to do about input price risks. They can provide information to fishing firms that would help them choose fishing patterns that reduce exposure to input price risk. For example, if small, inshore fishing operations are less dependent on purchased inputs (fuel, manufactured gear) than larger offshore operations, then the type of fishing fleet developed could affect risk due to input price fluctuations.

Safety risks are a major factor in many US north Pacific commercial fisheries. An American Journal of Public Health paper[21]claims the death rate of 414 per 100,000 fishermen per year is 53 times the US national average industrial mortality rate. Especially in small boat fisheries operating under strict fishing season regimes, competitive open access fishing can encourage vessel operators to fish during high wind and wave conditions. The **Seattle Times** calls for "Congress and the North Pacific Fisheries Council to confront an outdated open-entry management that encourages people to risk their lives for somebody's seafood dinner. A system of individual quotas would change those incentives, and minimize the hazards." That editorial perspective is shared by many participants and managers in the north Pacific. They claim the safety advantages of individual fishing quotas arise because each fishing vessel operator can choose to avoid bad weather without sacrificing ability to harvest a fair share of the annual quota. IFQs can reduce (but certainly not eliminate) the economic incentive to take undue risks at sea.

21 Quoted in a Seattle Times Editorial (Tuesday, March 1, 1994)

Finally, there is increasing evidence that ocean "regime shifts" cause significant and widespread changes in abundance and species composition of ocean fish stocks. For example, Hare and Francis[22] find a shift in the Aleutian low is associated with changes in north Pacific salmon abundance. If it is true that these kinds of shifts have unpredictable and uncontrollable effects on fish stock abundance, then the associated risk is not avoidable. Even so, the presence of this sort of risk has an important implication for fishery managers. Since the maintenance of stock biomass as an economic investment -- which increases future potential harvest levels and decreases average cost of harvest -- ecological risks translate into economic risk. The expected return on that investment is less when random stock collapse may occur. Managers could respond by investing less in the stock, harvesting more and maintaining a smaller fish stock over time. The presence of this "ecological risk" alters the trade-off between fairly certain short term economic benefits of higher current harvests and the less certain long term benefit of fish stock investment. One suspects that many "environmentalists" would take the opposite tack; they would reduce harvest levels in the face of ecological risk. Another response to unavoidable ecological risk would be to encourage development of multi-purpose fishing fleets, broadening the species and stocks supporting the economic enterprises, and hence reducing the exposure to risk of economic collapse from shifts in any particular stock.

When random stock collapse is considered to be a continuing risk, the effect on expected utility maximization is similar to the effect of an increased interest or discount rate. If the discount rate is 5% and the probability of stock collapse is 2% each year, the economic optimum for the fish stock would be like the risk-free optimum but using a 7% discount rate. Similar kinds of risk might arise from market phenomena. Some fisheries are strongly dependent upon maintenance of prices in regional markets. Alaska sockeye salmon producers, and numerous other North American and Asian fisheries, are heavily dependent upon the Japanese market, for example. If there exists a probability that an international trade war, exchange rate shift, or alternative source of supply could suddenly make the market unavailable or unprofitable to the fishery for extended period of time, then this risk of future economic collapse would dilute the perceived future economic benefits of stock conservation.

A different source of risk is stock collapse precipitated by over fishing. In this case the probability of collapse is an increasing function of harvest. Intuition is less reliable here, but I think it is likely that in most such circumstances, the optimal risk averse economic strategy would dictate a lower exploitation rate for any given stock biomass. The logic is not very abstract. If speed increases the likelihood of a costly or disastrous accident, slowing down is both intuitively and economically a good strategy. Environmentalists are likely to support this approach.

One difficulty in using economic models and consequences as a basis for judging the outcomes of alternative management strategies is that there are several, connected, inconsistent measures of economic benefit. Agricultural economists have for decades confronted the problem that policies which stabilize farm prices differ from those which stabilize farm incomes and both of those differ from policies which optimize consumer benefits of farm production or which best protect water quality. In the formal decision model the question of who is being served by the policy is subsumed in the formulation of the preference function. In practice, establishing economic objectives is a participatory process that resists simple description by convenient mathematical functions. This characteristic of decision processes again suggests that technical analysis be focused on providing quantitative descriptions of outcomes under alternative policy regimes. Interaction with the policy makers can help to make the analysis relevant from the perspective of both the outcomes to be evaluated and the policies to be considered.

[22] Presentation to the Fishery Management: Global Trends Symposium, June 16. Seattle, WA.

11. ARE DECISIONS ADEQUATELY CAUTIOUS?

We are bombarded with strident voices objecting to an economic approach to risk management on grounds that it fails to protect future generations, that it takes unconscionable risks. Those working within the decision framework can interpret these concerns in various ways: (1) the preference functions of their critics express more risk averseness, or (2) the expected future losses from risky decisions are being underestimated, (3) the range of feasible actions is not adequately explored, or (4) the risks perceived by the critics are over-stated relative to the technical risk assessment. The first interpretation objects to the preference ranking function, to the weight placed on security or safety. Some people are more inclined than others to avoid risks and to seek security. The second interpretation concerns mainly the quantification of potential losses. For example, when the commercial fishery causes the decline in benthic organisms or marine mammals, this is considered a minor side-effect by industry participants, but is a major negative outcome in the minds of many others. This is essentially the source of conflict that fueled the campaign leading to the United Nations ban on high seas drift net fishing.

The third possibility is that the objectors to technical risk management see feasible solutions where others see none. In western Northwestern America, there is a continuing crisis over extinctions of salmon stocks. Supporters of salmon protection and recovery see relatively painless and practical solutions that focus on habitat protection and modest harvest reduction. Others see these solutions as unproved, unwise, and exorbitantly expensive. As in the safe minimum standard approach to endangered species decisions, the protectors of salmon assume that we can "choose species preservation". Opponents see this as practically impossible and the attempt to accomplish it as harmful to their interests. The fourth interpretation flows from the technical versus perceived risk discussion. Where some see looming catastrophe, others see manageable risks. Further, as noted earlier, people tend to underestimate familiar risks and to overestimate unfamiliar risks. There seems a particularly intractable division between those who view natural systems as finely-tuned and fragile versus those who see nature as robust and adaptable. I might add that this division extends into the social and economic realm. Some view with great alarm any changes in fishing method, economic power, and related social organization, while others see adaptation and change in technology, social organization, and the laws as normal and desirable.

All four of the issues described above concern controversial aspects of risk management that cannot, in principle, be solved by technical analysis. Because people differ, and because their views change with experience, risk communication and participation in negotiating sessions are necessary to select management measures.

In practice it is difficult to determine objectively whether a rational, utility-maximizing decision process is "cautious". The choice of actions depends upon attitudes towards risk (risk aversion), the perception of risk (risk assessment), and perceived outcomes of alternative actions (system models). Decision makers incur costs in the form of lower average economic returns in order to avoid other negative outcomes. As indicated above, even a risk neutral person will rationally anticipate the likelihood of negative effects and take actions to avoid negative outcomes so long as the costs do not exceed the benefits. So, risk aversion is not necessary to motivate actions that avoid large negative outcomes. How could one determine whether fishery managers are cautious? Suppose there are a thousand marine fish stocks, that each is susceptible to both natural fluctuations and exploitation, and that one stock crashes each year. Is that too little precaution, or too much? One answer is that is depends on how the risks of collapse are related to the benefits of fishing. Another answer is procedural; if the technical decision information did not adequately display the degree of risk involved, then the decisiona were likely inadvertently risky. The issue of adequate precaution has to be evaluated against a background level of stock variation and collapse that occurs in the absence of fishing. It is also crucially dependent upon whether the collapses are irreversible or simply inconvenient and temporarily disruptive to the human economy.

CONCLUSIONS

The discussion of risk assessment and economic concepts in decision making shows that there are ways to incorporate a variety of considerations in formulating precautionary fishery management policies. Among the important characteristics of decision making under uncertainity are:

1. The process of formalizing technical advice to managers must focus on estimating the degree of risk, establishing realistic alternative management strategies, and gauging the magnitudes of biological and economic losses associated with those risks.

2. The technical risk assessment procedures need to be combined with risk communication processes in order to reconcile or negotiate significant differences between technical and publicly perceived risks.

3. Rational economic harvest policies exhibit a degree of precaution, incorporating safeguards against stock collapse, commercial extinction, market price collapse, social instability or whatever outcomes are considered to be "bad". Whether such a policy satisfies the more extreme demands for safety in stock conservation and ecosystem stability is unclear, since it remains to be shown that representative values and risk attitudes of the affected public would give heavy weight to safety.

I conclude with the following observations.

First, although the formal analysis sketched out in this paper seems complicated, it may admit of simple, intuitive strategies for action. The basic notion of precautionary action -- to proceed cautiously to avoid catastrophic results -- may be given fuller expression through the development of rigorous models. But the final results of that research -- suggested rules of conduct -- need not be complicated. An example is the economic reference point biomass, which can be roughly calculated from rudimentary cost and fish value information. Analogous biological reference points are analyzed in the technical fisheries literature.

Second, it is essential to include economic and social considerations in the formulation of management strategies. In a rational decision process, economic objectives do not make fishery management more risky. However, the interests of participants in a free access fishery tend to be myopic and short-run concerning fish conservation. If these economic interests dominate the decision process, conservation practices may suffer as the desperation of individuals under economic stress makes precaution a distant concern. Hence, institutions matter greatly, in particular those property rights institutions that create longer term interests and security of tenure to fishing people. This does not mean that individual property rights, like individual fishing quotas, need to be implemented in every fishery. Institutions that strengthen the hold of fishing people over the fish stocks on which they depend, however, should increase the receptivity of fishing interests to precautionary measures.

Third, although I have suggested economic and social concerns can be considered in risk assessment and in the decision process, this does not mean that extensive social science research is necessarily the path to better management. The stochastic modeling approach already developed by fishery modelers could be expanded to test whether precautionary approaches are significantly different with explicit social and economic objectives. That research would suggest specific social-economic research projects that could improve decision processes. How such information can contribute to better management of fishery risks depends upon particular contexts and needs to be determined case by case.

If precautionary biological reference points are roughly equivalent to economic reference points, there may be little to gain from the added complexity to management analyses inherent in multiple objectives. The greatest contribution of the economics is often a deeper understanding of the main consequences of risk and of the importance of the role of risk in human organization and action. But the selection and implementation of conservation objectives needs to incorporate the risk communication and negotiation processes mentioned earlier. These processes provide means to incorporate public perceptions and ancillary concerns, such as costs of enforcement, effects of regulations on social institutions, and economic impacts. The collaborative process tends to expose the socially acceptable forms of fishery intervention, to expand the menu of organizational responses to risk, and to reconcile differences in values and risk perceptions between fishing groups and between technical analysts and the general public.

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PRECAUTIONARY MANAGEMENT REFERENCE POINTS AND MANAGEMENT STRATEGIES

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Abstract

Precautionary management reference points are those intended to prevent recruitment overfishing, even if a direct link between spawning stock size and subsequent recruitment cannot be established statistically. In order to be precautionary, the appropriate null hypothesis is that the stock does not compensate for reduced abundance by increasing productivity. There are many limit reference points that can be used to prevent recruitment overfishing. However, it is unlikely that a single limit reference point can provide protection for the resource under all foreseeable circumstances and, thus, it is useful to define harvest control laws which combine several thresholds. A precautionary management strategy should contain, in addition to limit reference points, a priori decision rules on the acceptable probability (risk) that recruitment overfishing will take place, given the target harvest and the estimated stock status. The choice for a particular definition of risk should be tied to uncertainty and precautionary management dictates that more uncertain situations require more conservative measures.

INTRODUCTION

The precautionary approach to fishery management, as described by Garcia (1994) seeks to protect fishery resources from fishing practices which might put their long-term viability in jeopardy. In order to take appropriate precaution, fishing activities may need to be controlled even before there is clear scientific evidence that current practices can not be sustained by the resource. In order to develop fishery control policies, biological reference points are needed for measuring current resource status and the projected effects of fishing.

Biological reference points (BRP) have long been used in fishery management as benchmarks for the development of management strategies. The most widely cited such benchmark is maximum sustainable yield, often thought of as a default management objective from a biological perspective (Hilborn and Walters 1992). Biological reference points really are not objectives in and of themselves, however, but quantitative indicators of variables such as fishing mortality rate, yield or stock biomass by which the current state of the fishery can be judged. For example, if the objective is to obtain the largest possible yield on an ongoing basis from a resource, comparing the time stream of catches to the estimated level of MSY and its uncertainty may indicate if the objective is being achieved over time. Alternatively, a management strategy to approach the objective may be based on estimates of MSY and its uncertainty as well as on other aspects of the dynamics of the resource and the fishery. In the first instance, the reference point, MSY, is used retrospectively to evaluate past performance. In the latter example, it is used prospectively for the development of future management tactics. These two usages of biological references points are needed for both developing and developed fisheries.

There are a very wide variety of reference points available as bechmarks for different management objectives. For most fisheries, more than one reference point is needed to outline the overall management strategy. FAO (1993) describes most of the commonly applied reference points and that summary will not be repeated here. Exceeding a reference can, in one way or another, be classified as overfishing. However, overfishing can take a number of forms; for example, target overfishing, growth overfishing, recruitment overfishing, and economic overfishing. While the first type of overfishing is associated with a *target*, growth and recruitment overfishing are generally associated with *thresholds* or limit reference points (FAO 1993), and economic overfishing may be expressed in terms of either targets or limits, depending on the definition used. The difference is that while fishing activity is expected to fluctuate about targets, limits should generally not be crossed. Strictly, target overfishing could be said to occur whenever the target is overshot; however, small deviations would not generally be considered serious until and unless a consistent bias became apparent. Conversely, even a single violation of a limit reference point may indicate the need for immediate action to reduce fishing mortality.

For the development and evaluation of precautionary management strategies, limit reference points for biological conservation are the most important, to set the constraints within which the management strategy must operate. In particular, to maintain a sustainable resource recruitment overfishing must be protected against, and precautionary management would seek prevent recruitment declines due to overharvesting even if the scientific evidence of the impact of fishing is weak and a causal link has not been established. Fishing effects on recruitment may be related to such factors as habitat loss, disturbance of egg beds or harvesting of prerecruits, but the major factor in most fisheries is the relationship between the spawners or the eggs they produce and the recruitment of young fish to the fishable or spawning population. The relationship between spawning stock or other factors and recruitment may be weak in many cases, but must exist in the limit as the number of spawners is reduced to very low levels. In a study of empirical stock-recruitment data sets from around the world, Myers and Barrowman (1994) found that lower stock sizes were generally associated with lower recruitment levels. In order to be precautionary, the appropriate null hypothesis is that spawning biomass or egg production is linearly related to subsequent recruitment (Fogarty et al. 1992). That is, that the population does not compensate for increasing mortality or reduced abundance of adults by increasing productivity. Unfortunately, the lack of a clear relationship between spawning stock and recruitment has led some fishery managers (and scientists !) to conclude that the appropriate null hypothesis is a line with slope 0. Such a null hypothesis can result in continued harvesting until a major decline in recruitment is observed at low biomass, the antithesis of precaution.

1. LIMIT REFERENCE POINTS

The need to define recruitment overfishing reference points has been largely neglected until recent times, as the number and diversity of fisheries that are considered overfished continues to increase. Even now, far fewer BRP's have been developed to identify recruitment overfishing than to identify growth overfishing, and their generality is often questioned. Once $F_{0.1}$ was invented (Gulland and Boerema 1973), fisheries scientists often advocated the use of $F_{0.1}$ as a target and F_{max} as a limit. Other early limit reference points included minimum spawning biomass levels based on observed stock collapses, and 20% of the unfished stock biomass (20% B_0; e.g., Beddington and Cooke

1983). Alternative indicators of poor stock condition that have long been advocated are truncated age distributions, small or decreasing mean size in landings, and a markedly declining survey index, but these have rarely been articulated into measurable, unambiguous quantities.

Within the last 10 years, an important new class of reference points associated with recruitment overfishing have been developed based on percentiles of survival ratios estimated from stock and recruitment observations. This work began with Shepherd (1982), who showed how a standard spawner per recruit (SPR) analysis could be combined with stock and recruitment observations to generate reference fishing mortality rates. The relationship between the two types of information is straightforward (Gabriel et al. 1989; Mace and Sissenwine 1993); for any constant F, there is a corresponding SPR level that can be inverted and used as the slope of a straight line through the origin of the stock and recruitment data. Points along the line represent the average survival ratio (R/S) required to support that particular constant F. Percentiles of observed survival ratios can therefore be used to define threshold and target levels of F, which can then be translated back to the SPR scale (see Gabriel et al. 1989 for the computational details).

Two percentiles that have been advocated as reference points for overfishing thresholds are the 90th percentile (denoted F_{high}; Shepherd 1982) and the median (denoted F_{med}; Sissenwine and Shepherd 1987). Both are intended as indicators of *recruitment overfishing*. The tangent through the origin of a stock and recruitment relationship corresponds to $F_{extinction}$. F_{high} may overestimate the tangent, since the highest survival ratios may just reflect anomalously favorable environmental conditions, not the ability of the population to sustain fishing under average environmental conditions. On the other hand, F_{med} may underestimate the slope if the data exhibit compensation (concavity). It is more correct to use F_{med} as an estimate of F_{rep} (F-replacement), the fishing mortality rate corresponding to the observed average survival ratio. Thus, F_{rep} is the fishing mortality rate that, on average, allows for replacement of successive generations over the observed range of stock and recruitment data. F_{rep} is a valid approximation of the slope at the origin in the case where the observations are restricted to low stock size, or where there is little compensation in the relationship. However, F_{rep} may forego potential yield if the stock has a recent history of light exploitation, and F_{med} may underestimate F_{rep} if the distribution of recruitment is highly skewed.

Mace and Sissenwine (1993) surveyed 91 well-studied European and North American fish stocks with sufficient data to construct stock-recruitment plots and conduct yield per recruit and spawning per recruit analyses to obtain estimates of reference points such as $F_{0.1}$, F_{max}, F_{med} and associated levels of %SPR. They estimated the median ratio of F_{med}/F_{max} at 1.3 and the median of $F_{med}/F_{0.1}$ at 2.3. The average %SPR corresponding to $F_{0.1}$ was 38%, the average %SPR corresponding to F_{max} was 21%, and the average %SPR corresponding to F_{med} was 19%. Mace and Sissenwine advocated use of 20% SPR as a recruitment overfishing threshold for stocks believed to have average resilience and 30% SPR for little-known stocks. That study complements earlier theoretical and empirical work by Goodyear (1977, 1980, 1989, 1993), Gabriel et al. (1989) and Clark (1991) that has resulted in SPR becoming the most common basis for recruitment overfishing reference points in U.S. fishery management plans (Rosenberg et al. 1993). The choice of reference level is usually based on theoretical considerations and analogy with other stocks, such that most definitions use either 20% SPR and 30% SPR as the recruitment overfishing reference point.

There have also been developments in the use of stock and recruitment observations to define biomass reference points. Despite the fact that theoretical stock-recruitment curves (e.g., Ricker 1954, Beverton and Holt 1957, Shepherd 1982) have been widely used for decades, there are no generally accepted methods for calculating biomass thresholds from the parameters. Some methods require that the data be fitted by theoretical relationships, whereas others are based on the observations themselves (non-parametric methods). The latter includes subjective, visual approaches that may be able to identify critical biomass levels below which recruitment appears to begin to decline rapidly. The main problem with subjective methods is that they do not always give consistent answers, and are often biased by the status quo.

Serebryakov (1991) and Shepherd (1991) suggested an objective, non-parametric method for estimating a threshold biomass. They defined the threshold by the intersection of the upper 90th percentile of the observed survival ratio and the upper 90th percentile of the recruitment observations. This intersection approximates the minimum stock size within the range of the observations that, based on the data, can be expected to be capable of producing a good year class when environmental conditions are favorable for survival. Unfortunately, although this method generally performs well based on several different types of evaluation criteria, it is extremely sensitive to the range of the data observed (Myers et al. 1994), with the threshold tending to get revised downward as a stock is fished down and new S-R observations are added.

A more common method of specifying biomass thresholds is to express them as a percentage of the unfished, virgin biomass (%B_0), most often using 20% B_0 as a default. However, it may be difficult to estimate B_0 for stocks that have been fished down substantially from virgin levels. In some cases, it may be reasonable to define virgin biomass as the point where the F=0 replacement line intersects a fitted S-R relationship, or the average or median observed recruitment. This method of estimation is likely to be less valid for stocks far below the virgin state, particularly if the observations cover only the recent history of the fishery. Indeed, Myers et al. (1994) found that the point of intersection often occurs well outside the range of observations, at stock sizes where density-dependent effects may well differ from those in operation during the period of observations.

Ideally, threshold levels of biomass should be based on the associated level of recruitment relative to some reference level. Although some definitions of biomass thresholds refer to recruitment levels, the association is often somewhat vague. For example, the Advisory Committee on Fishery Management of the International Council for the Exploration of the Sea has adopted the process of specifying the minimum biologically acceptable level (MBAL) of biomass, defined as the biomass level below which the probability of poor recruitment increases as spawning biomass declines further. In practice, there are no set standards for calculating MBAL levels, and "poor" recruitment has not been defined explicitly.

Few BRP's have been expressed in terms of recruitment, *per se*. One possibility that has recently been suggested by Mace (1993) is to define a threshold biomass which corresponds to the point on the SRR where expected recruitment is 50% of the maximum. A model presented by Thompson (1993b) supports the use of the 50% recruitment level in that 50% is the maximum reduction in recruitment that could be observed in equilibrium for a stock that is fished at the MSY rate. Myers et al. (1994) evaluated this reference point for 72 sets of stock-recruitment data from around the world. Although these analyses all measure relative recruitment in terms of the underlying (deterministic) stock-recruitment relationship, the 50% reduction can be generalized by framing it in terms of expected recruitment, and may provide a robust safeguard against recruitment overfishing. The challenge is in estimating the maximum recruitment, analogous to previously mentioned difficulties in estimating B_0.

This recruitment-based reference point can be translated into either a biomass-based or F-based reference point. When cast as a biomass threshold, this reference point has an advantage over biomass thresholds expressed as a fixed percentage of B_0, in that it takes account of the degree of compensation in the S-R relationship, setting more conservative (higher) thresholds for stocks with lower compensatory reserve. Such methods should be preferred over the blanket adoption of 20% B_0, which is unlikely to be applicable across the entire range of observed levels of stock resilience. However, rarely are there stock-recruitment data with sufficient contrast to estimate stock resilience precisely. For example, Myers et al. (in press) found that the biomass at 50% R_{max} sometimes appeared overly risky, particularly when the available historical data exhibited zero or negative slope, resulting in extremely high estimates of the slope at the origin of the S-R curve. Conversely, for data exhibiting a positive slope overall, the method often estimated a threshold that was extremely large. These problems are related more to a lack of contrast in the data and the validity of the fitted curve than to the definition of the reference point itself.

When cast as an F-based threshold, a reference point based on relative expected recruitment can be expressed in terms of equilibrium spawning per recruit, providing (as above) that the degree of compensation in the S-R relationship can be estimated.

There are many cases where neither F nor B can be estimated explicitly, due to lack of data. The only option in such situations is to develop proxies based on the type and quality of data that are available. Proxies that may index F include truncated age distributions and small or decreasing mean size in landings or measures of fishing effort; those indexing biomass include low commercial catch per unit effort (CPUE) and low or markedly declining research survey indices. For example, overfishing could be specified as a ratio of current commercial or research CPUE compared to the CPUE of some historic period when the stock was lightly exploited. It is sometimes difficult to use such proxies to develop measurable, unambiguous and meaningful overfishing definitions. Proxies for F may be difficult to specify and interpret due to departures from a stable age distribution (e.g., a decrease in mean size may indicate a strong incoming year class rather than high F); proxies for B may be difficult to specify, due to the problem of selecting a suitable base period and changing catchability related to the efficiency of fishing or the distribution of the stock.

2. EXPRESSING THE LIMIT AS MORTALITY RATE OR BIOMASS

One persuasive argument in favor of specifying the limit reference point for recruitment overfishing as a maximum fishing mortality rate (F) is that it relates to the act of fishing and therefore can be controlled directly. In fact, the amount and characteristics of fishing on the stock are the only components of stock dynamics that can be controlled by management. However, the ultimate intent of management with respect to conservation of the resource is to ensure that there is sufficient spawning stock remaining after the harvest for the stock to sustain itself.

Reference points that give a maximum fishing mortality rate have the further advantages that: (1) There is a theoretical and empirical basis for the selection of maximum F levels, such as F_{med}, $F_{20\%}$, or $F_{35\%}$ (Goodyear 1977; 1980; 1989; 1993; Sissenwine and Shepherd 1987; Gabriel et al. 1989; Clark 1991; Mace and Sissenwine 1993); (2) when the fishery is operating near the limit a maximum harvest rate strategy may not result in fishery closures, but rather require substantial reductions in catches or effort if the threshold is crossed; (3) an appropriate limit reference point can be estimated from relatively sparse fishery data and information on the life history characteristics of the stock in question; and (4) setting a maximum F can prevent the stock from depletion due to fishing in the long term.

On the other hand, there are some disadvantages in limits specified in terms of a maximum fishing mortality rate only. Maximum fishing mortality rate strategies do not increase the protection afforded to the stock when it is in poor condition. An F-based definition that is appropriate over some middle range of biomass levels, may not necessarily be appropriate at the extremes of biomass. For example, a maximum harvest rate, such as $F_{20\%}$, set to prevent long-term decline of the stock from its current level will not necessarily allow rebuilding of a stock that was seriously overfished in the past. Nor will it allow a fishery to develop its full potential if estimated from data obtained only from a period of light fishing. Further, changing environmental conditions and life history characteristics may necessitate changing the threshold harvest rate in the definition.

Reference points that specify a minimum biomass level for the stock, below which the fishery is curtailed or, in the extreme case, closed, have the advantages that: (1) Biomass is more directly linked to recruitment than is the fishing mortality rate; (2) minimum biomass levels provide a guide for management of stocks that are already depleted by setting a standard for rebuilding; and (3) during periods of adverse environmental conditions, a minimum biomass level provides a seed stock for eventual recovery when conditions are more favorable.

However, specifying minimum biomass levels can be difficult and is often more demanding of the data than determining a maximum harvest rate. This is particularly true if the biomass threshold is treated as absolute, i.e., the fishery is closed if the estimated biomass falls below the threshold, rather than indicative, i.e., when the stock is below and indicative biomass threshold the maximum allowable F is reduced. The problem of lack of observations over the full range of stock conditions (i.e., lack of contrast in stock abundance or changing environmental conditions) may cause the minimum biomass to be mis-estimated. The strategy of closing a fishery below a biomass limit and opening it above may also result in highly variable fishery yields and economic dislocation. Because the consequences of crossing an absolute biomass limit are so extreme, their use will often be accompanied by intense controversy about the accuracy of stock size estimates. In addition, managers and the public may misinterpret a biomass limit as the point at which the resource will collapse, heightening the controversy.

While F-based reference points applied in a multispecies fishery afford some protection to the suite of stocks fished, a biomass limit is, of necessity, set on a stock-by-stcok basis. A maximum fishing mortality rate is needed for multispecies fisheries in particular, even if a minimum biomass level is set for some of the principal species in the suite.

Using a combination of a maximum fishing mortality rate, a indicative biomass level below which the maximum allowable fishing mortality rate is reduced, and an absolute minimum biomass limit may provide good protection for the resource. This is illustrated, schematically in Figure 1 in the form a harvest control law, such as are used for some U.S. Pacific coast stocks. The harvest control law specifies a maximum fishing mortality rate for a stock in healthy condition, some strategy for reducing F progressively as biomass falls below some precautionary level of stock biomass (regardless of the reason for low stock size), and a (lower) absolute biomass threshold below which fishing must cease or be restricted to bycatch only. The option of closing down a fishery when stocks become severely depleted should always be retained. One way of incorporating such an absolute biomass limit would be to set it arbitrarily low (e.g., 10% of current biomass) to be used as a safeguard only in extreme situations of failed management, poor stock assessment or continuing adverse environmental conditions that place the stock in jeopardy.

If a control law that reduces the fishing mortality rate gradually as biomass is reduced below some designated precautionary level is used: (1) It affords additional protection for the resource when stock condition is apparently poorer; (2) the consequences of mistakes in the specification or estimation of reference points are not as serious; (3) relating F to biomass over some intermediate range of biomass should allow more time and flexibility for evaluating whether the stock is in a transition phase from one stationary state to another; (4) temporary reductions in biomass can be accompanied by temporary reductions in F that need not result unnecessarily in permanent changes in the composition or operation of the fishing fleet; and (5) small or gradual reductions (or increases) in F will be less controversial, and therefore less subject to litigation.

3. THE ROLE OF UNCERTAINTY

There are three principal sources of uncertainty with respect to the precautionary application of limit reference points for fisheries. The first is the difficulty of adequately accounting for some life history features in choosing the reference points. This means that there is uncertainty about the dynamics of the stock. In effect the determination of a precautionary limit is uncertain because of the difficulty of describing the relationship between stock and recruitment. As noted in the introduction, the choice of a null hypothesis is crucial in dealing with uncertain stock dynamics. To be cautious, it should be assumed that there is a linear relationship between stock and recruitment, such that reductions in spawner abundance (increases in fishing pressure) will reduce stock productivity directly. However, there will still be uncertainty about all parameters used to calculate the reference points, e.g., growth and maturation rates, an that uncertainty needs to be accounted for in application of any precautionary strategy.

A second major source of uncertainty that affects the use of precautionary reference points is measurement error in the determination of the current state of the stock. For many stock assessments, estimates of measurement errors are available and these should be used directly in advising managers on the probability that a stock is overfished relative to a given reference point. Such uncertainty is generally reduced with longer time series and more accurate and precise data. e.g. for relative abundance indices. The benefits of reduced uncertainty when managing a stock under a given harvest strategy show up most clearly in the expected variability of yield (Powers and Restrepo 1993) and the power and Type I error for detecting the probability of recruitment overfishing (Rosenberg and Restrepo 1993)(here, Type I error refers to erroneously concluding that overfishing is taking place). As would be expected, the statistical power of detecting overfishing is higher in more precise assesments having a longer time series and higher contrast in abundance levels. Similarly, the Type I error is lower for longer time series and higher contrast in abundance.

Assessment methods are subject to errors due to variability in input data and to model mis-specifications. In some cases, errors tend to cancel. For example, the natural mortality rate M is rarely known accurately, and errors in M result in systematic errors in assessments. However, if a reference point is based on models using the same erroneous value of M, performance of the limit reference point may prove to be robust.

A more disturbing possibility is the so-called "retrospective problem" (ICES 1991). Experience has shown that assessment methods in some cases consistently overestimate or consistently underestimate current abundance for a given stock, as compared with estimates based on subsequent information. Causes for this phenomenon are many, including mis-specification of natural mortality values, biased trends in relative abundance data, and other forms of model mis-specification such as ignoring sexually-dimorphic growth. As stocks approach a condition of being overfished, assessment methods may be prone to Type I and Type II errors (falsely indicating recruitment overfishing when it is not occurring or failing to indicate overfishing when it is occurring), due to the "retrospective problem." The error may be recognized only after passage of several years. This leads to the question of how management should address such retrospective errors, especially when there is reason to believe the error is an ongoing phenomenon.

A third source of uncertainty relates to possibly changing environmental conditions that affect stock productivity. Such environmental changes may mean that the value of the limit reference point must be changed, but it is difficult to detect and forecast environmental trends and their impacts. Most stock assessment models and overfishing definitions assume that life history characteristics are constant and that long-term changes in stock abundance are determined principally through a stationary stock-recruitment relationship. Short-term fluctuations in the environment introduce variability into the stock-recruitment relationship, but do not create a fundamental problem for the analysis. However, long-term trends in the environment and changes in the density-dependent nature of individual growth and egg production can change the shape and scale of the stock-recruitment curve. The short duration of most time series hinders unambiguous detection of these trends and changes. In a short time series, the stock is typically observed over only a narrow range of abundance. The resulting lack of contrast in stock-recruitment data can lead to large measurement error in estimates of biological reference points, and to estimates of biological reference points that may not be applicable to other levels of stock abundance or environmental conditions. While extending the time series can alleviate problems caused by lack of data contrast, it can exacerbate problems caused by long-term trends in the environment.

Limit reference points based on an absolute minimum biomass level differ from definitions based on a maximum fishing mortality rate in terms of their ability to protect a stock during prolonged periods of adverse environmental conditions. A minimum biomass threshold may be preferable, because it can protect a stock until there is sufficient information on production capacity. However, if the environmental carrying capacity for new recruits alone has changed (i.e., if the slope at the origin of the stock-recruitment curve is unchanged), then the new climate regime may not change the appropriate fishing mortality rate. In this case, a reference point based on maximum fishing mortality rate would be robust; the corresponding yield and biomass levels would simply be scaled up or down by the change in recruitment potential.

All assessment methodologies contain some amount of error and/or bias. One aspect of the performance of a methodology for setting a limit reference point is its ability to identify accurately a condition of overfishing, even when implemented according to imprecise or inaccurate stock assessments. This property can be called robustness. It is important to evaluate the robustness of not just the method for setting a limit reference point, but the performance of the entire management procedure used for the stock, meaning everything from data collection and analysis, to the assessment results and their use in combination with target and limit reference points in harvest control laws. The reason for this is that there is feedback between all parts of the system (stock-management) over time: today's decisions affect tomorrow's outcomes and, therefore, tomorrow's decisions. The robustness of a management procedure can be best evaluated through simulation experiments, as advocated by, e.g., de la Mare (1986), Rosenberg and Restrepo (1993), and Restrepo and Rosenberg (1994).

Because all of the various sources of uncertainty interact, managers should choose a "decision rule" that sets an acceptable probability of recruitment overfishing, given the uncertainty in knowledge of the true dynamics of the stock, the estimates of current stock status, and the possibility of environmental trends. The acceptable probability of overfishing is related to the time frame considered, the consequences of crossing the limit reference point, and the action to be taken if it is concluded the stock is overfished. For example, a given probability of overfishing might be acceptable if the only consequence is a slightly increased risk of poor recruitment in one year. However, the same probability might not be acceptable if there was thought to be a high chance of recruitment failure that would affect the fishery for several years to come. Similarly, if the actions taken upon crossing the threshold are likely to redress the situation quickly (e.g., if crossing a maximum F threshold is followed by corresponding quota reductions), then the decision rule may allow a higher probability of overfishing than if the action is merely to begin a 20 year gradual decrease in fishing.

Thus, an important consideration is that all limit reference points are not created equal in terms of their inherent degree of cautiousness. As shown by Rosenberg and Restrepo (1993), there is little to be gained by setting a very low allowable probability of overfishing if a very cautious limit reference point is being used. On the other hand, overfishing could be avoided by setting a low allowable probability of overfishing when the limit reference point is not very cautious.

These types of uncertainties and the need for a decision rule on the acceptable probability of overfishing apply to both F-based and biomass-based thresholds. A control law that reduces the fishing mortality rate gradually as biomass is reduced below some designated precautionary level, as advocated in the previous section, can incorporate decisions based on the perceived uncertainty in stock status and the reference point (Restrepo and Rosenberg, 1994). For instance, the control law may reduce F in inverse proportion to the estimated probability that the stock is below a precautionary biomass-based threshold.

Estimates of stock status and the appropriate limit reference level to prevent recruitment overfishing will always be uncertain and engender substantial argument in management fora. Because of this, the management actions to be taken if the overfishing definition threshold is crossed should be explicitly stated in conjunction with the chosen decision rule. It is important that the determination of management actions be made prior to reaching the limit, so that action to protect the stock is not delayed. If this is done, and the reference point is chosen conservatively, then the time for the stock to recover from any short period of overfishing should be short. It is recommended that the expected time for a stock to recover from the limit level to the target level be considered in developing limit reference points. Calculations should be done to estimate how rapidly recovery could occur with high probability if the fishery were closed. For example, in the event of recruitment overfishing a rebuilding program could be designed to result in a high probability of recovery in not more than one generation longer than the time needed under a complete closure.

CONCLUSIONS

Precautionary management reference points are those intended to prevent recruitment overfishing, even if a direct link between spawning stock size and subsequent recruitment cannot be established statistically.

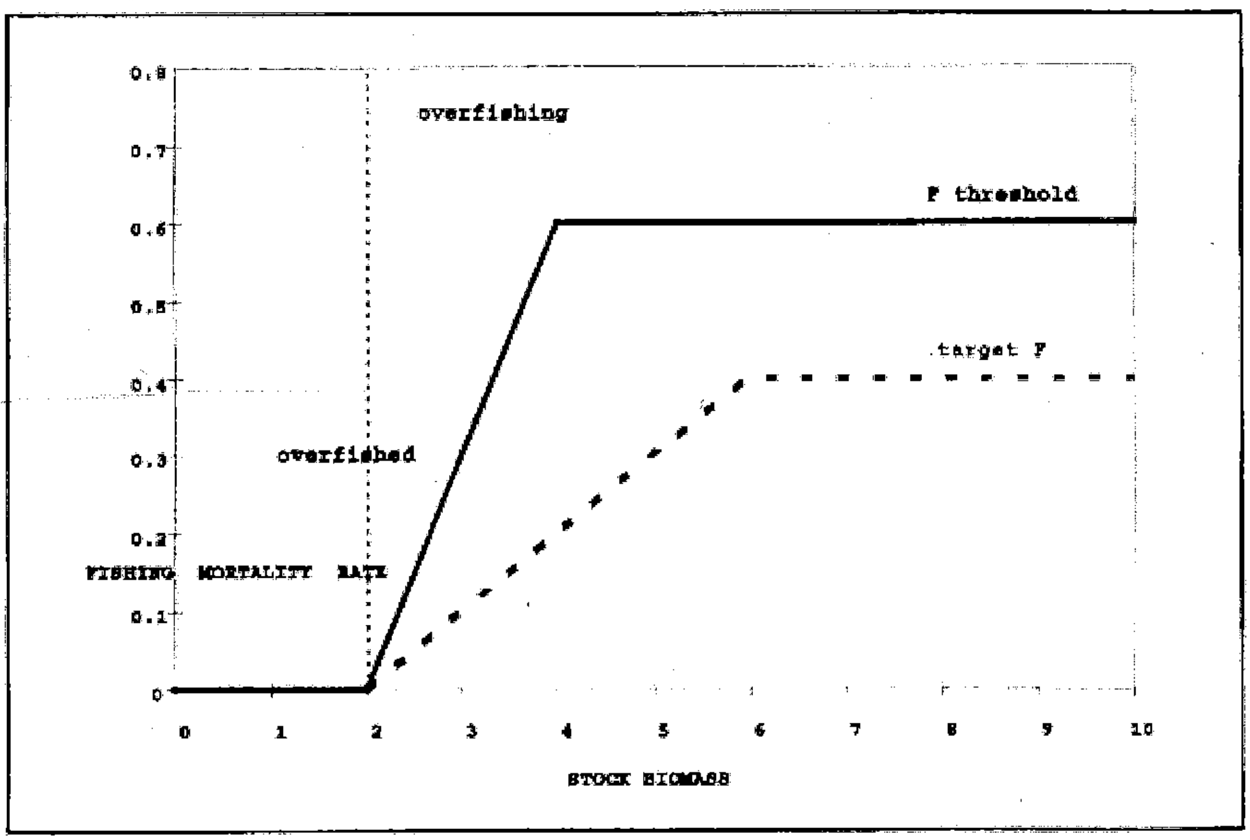
In order to be precautionary, the appropriate null hypothesis is that spawning biomass or egg production is linearly related to recruitment, i.e., that the stock does not compensate for reduced abundance by increasing productivity. A null hypothesis of average constant recruitment at all stock sizes (slope = 0), prevalent in the minds of many scientists and managers, can result in continued harvesting until a major decline in recruitment at low adult biomass occurs, the antithesis of precaution.

Limit reference points for biological conservation should set the constraints within which a management strategy must operate. A number of limit reference points related to recruitment overfishing have been developed based on theoretical or empirical work, or both, as detailed in the second section above. In some cases these are expressed in terms of fishing mortality rates and in other cases in terms of biomass. Both ways of expressing limits have advantages and disadvantages and how a particular limit definition performs could be case-specific. However, it is unlikely that a single limit reference point can provide protection for the resource under all foreseeable circumstances and, thus, it is useful to define harvest control laws which combine several thresholds. For instance, using a combination of a maximum fishing mortality rate, a precautionary biomass level below which the maximum allowable fishing mortality rate is reduced, and an absolute minimum biomass limit (Figure 1) may provide good protection for the resource.

Figure 1

A schematic harvest control law

In this example, the dashed line represents a target fishing mortality rate which may vary as a function of stock size. A stock biomass value of 2 corresponds to an absolute biomass threshold. Biomass levels below this value indicate that the stock is overfished. The solid line represents a threshold fishing mortality, or the maximum allowable F. F values above this line indicate overfishing. A stock biomass value of 4 corresponds to a precautionary biomass level below which the maximum allowable F is reduced.



A precautionary management strategy should contain, in addition to limit reference points, a priori decision rules on the acceptable probability (risk) that recruitment overfishing will take place, given the target harvest and the estimated stock status. If the acceptable probability of overfishing is not defined a priori, or if it is redefined with every new assessment, it becomes inevitable that higher risks will be taken at low stock sizes in order to maintain stable catches. What constitutes a reasonable decision on the acceptable probability of overfishing is likely to be case-specific, depending on the life-history characteristics of the stock in question, in particular on its resilience to fishing.

All of this can - and should - be investigated from available data and simulation studies. The choice for a particular definition should also be tied to uncertainty and precautionary management dictates that more uncertain situations require more conservative measures.

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ASSESSING THE PRECAUTIONARY NATURE OF FISHERY MANAGEMENT STRATEGIES

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Abstract

A fishery management strategy has three essential components: data pertaining to the fishery (e.g. catch at age data), a method for analyzing the data to produce a stock assessment (e.g. VPA), and a decision rule taking the output from the assessment and translating it into a specification of a technical management measure (e.g. an $F_{0.1}$ TAC). Even though a management strategy may incorporate elements that are intended to make it precautionary, so that it may be deemed precautionary in principle, it does not necessarily follow that it will actually be precautionary in practice. This can arise through deficiencies or uncertainties in any one of the components of the strategy. In this paper, we discuss how the degree of precaution in a management strategy can be assessed quantitatively.

The first step in evaluation of a management strategy is to identify appropriate performance criteria for determining how well it meets the management objectives for the fishery. In a precautionary setting, these will include, but not be restricted to, its performance in maintaining the stock (or stocks) above critical biological reference points, such as spawning stock threshold levels. Evaluation then proceeds by repeatedly simulating the application of the management strategy to a fishery, where the underlying dynamics of the stocks are governed by a variety of specified operating models, and the simulated data for use in the assessment part of the strategy have specified statistical properties. The operating models will normally be much more complex than the dynamics models implicitly or explicitly assumed in the assessment method, and the different operating models used should reflect the full range of plausible hypotheses about the true dynamics of the stocks. The degree of precaution in the management strategy can then be assessed through examination of how well it meets the performance criteria.

Use of this methodology is illustrated with two examples. The first describes the approach adopted by the International Whaling Commission (IWC) during the development of its Revised Management Procedure. The second describes how these methods have been used in an ecosystem setting by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) for determining precautionary catch limits.

INTRODUCTION

Recent reviews by FAO of the state of the world's fishery resources have amply shown that most stocks either are fully or over-exploited, and that a number of fisheries have collapsed, either biologically or economically. Much of the blame for the parlous state of the fisheries must be laid at the door of either inefficient or over-optimistic management. Rectifying the situation requires modification of current management practices, in the direction of making them more cautious.

Developed originally in the early 1970's in West German legislation as the "Vorsorgeprinzip" in the context of controlling pollution, the precautionary principle has been widely endorsed in a number of international fora. While there is no single accepted definition of the precautionary principle, it generally is taken to have two main attributes: (i) where there are risks of serious or irreversible environmental damage, regulatory action to alleviate this risk is required even in the absence of full scientific certainty that it will occur; and (ii) reversal of the burden of proof, that burden being placed on those who contend that there will be little or no environmental impact.

Although the applicability of this principle to potential pollution problems is fairly clear-cut, its strict applicability to fishery management has been rather more controversial. As discussed by Garcia (1994), the precautionary approach introduced in the UNCED RIO declaration softened the strong requirements of the precautionary principle by recognising differences in local capabilities and the need for alleviatory measures to be cost-effective. These ideas were developed further by Garcia (1994), who proposed a set of characteristics that a precautionary approach to management should have.

One of the tasks of this meeting is to amplify these ideas and to further develop practical guidelines for a precautionary approach to management. These, of necessity, will take the form of general principles. However, even if they are followed, and a management strategy may be deemed to be precautionary in principle, there remains the question of whether it is actually precautionary in practice. In this paper, we address the issue of how the degree of precaution in a management strategy can be assessed. For the most part, we restrict our attention to precaution in respect to biological conservation. In the discussion we suggest a wider view of what it means to be precautionary.

The structure of the paper is as follows. In section 2, we discuss a number of general issues related to the identification and selection of criteria for assessing the degree of precaution. Section 3 outlines the characteristics of management strategies. In section 4, the procedures needed to evaluate the performance of a management strategy are described. Section 5 contains two practical examples. The first of these briefly describes how the procedures for evaluating the performance of a management strategy were applied by the International Whaling Commission (IWC) in the development of its Revised Management Procedure. In the second, the approach taken by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) to ecosystem management is briefly outlined. In the final discussion, we draw some general conclusions from the approaches we have presented, suggest a wider view on precautionary management, and briefly allude to how this wider approach could be evaluated.

1. CRITERIA FOR ASSESSING THE DEGREE OF PRECAUTION

In seeking criteria and methods for assessing how well a fishery management strategy performs in managing a fishery, it is essential to look first to the management objectives, for it was to meet these objectives that the management strategy should have been designed. It follows immediately, therefore, that the first place to seek evidence on the precautionary nature of a management strategy is in the management objectives themselves. Making any judgement at this level requires at the very least that the objectives are explicitly stated. Objective assessment of performance of strategies in meeting the objectives requires further that the objectives are also stated or subsequently interpreted in a sufficiently quantitative way that the extent to which they are being met can be determined unambiguously.

In practice, it is difficult enough to extract from managers any explicit statement of objectives, and in most cases where they are available, the objectives take the form of motherhood statements such as "ensure the long term conservation of the stocks". No analysis of objectives like these can discern whether a management strategy designed to meet them is precautionary or not. The first step, therefore, in seeking to encourage a precautionary approach to management is to advocate incorporation of an explicit recognition of the approach into revised management objectives. An example of objectives that contain aspects of a precautionary approach is found in the convention governing the operations of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), where the ideas of reversibility over fixed time scales and biological reference points are explicit. The approach taken by CCAMLR is discussed further in a later section of this paper. Note that mere insertion of the words "precautionary approach" into a statement of objectives is not sufficient to ensure precautionary management.

Evaluation of how well a management strategy performs in meeting the management objectives and how precautionary it is also requires the identification of performance criteria. These can be either qualitative or quantitative. Considering first qualitative criteria, one useful approach is to assess the management strategies against a checklist of desirable and undesirable properties. For example, on the positive side a properly precautionary management strategy must at least incorporate continuing collection of appropriate monitoring data and it must have sufficient flexibility to allow a quick reaction to any signs that something is going wrong. On the negative side, in most cases a strategy that controls a fishery solely by setting total allowable catches and that has no mechanisms for controlling fishing capacity is not precautionary. A very useful first attempt to develop practical guidelines for precautionary management was included in Garcia (1994), and one of the aims of this meeting is to progress further with that approach.

While it is possible to progress quite a long way in defining characteristics of a precautionary fishery management strategy by using qualitative criteria, the extent to which they actually succeed in being precautionary can only be properly assessed quantitatively, and this requires identification of quantitative criteria. A good example of this process is that adopted by the International Whaling Commission (IWC) during the development of its revised management procedure. As discussed further below, this included quantitative interpretation of general management objectives and identification of a range of statistics that allowed measurement of the performance of a management strategy in meeting each objective in a simulation study.

A key step in identifying performance criteria for assessing degrees of precaution is to establish both targets and threshold levels. For many years, there was only one management target: MSY. Fortunately, this target, expressed in terms of catches, has largely gone out of fashion (Larkin, 1977), although its ill-defined cousin, the "optimal" sustainable yield, apparently still persists. Nearly all management objectives retain the goal of seeking high sustainable catches, and the extent to which this is achieved is obviously one criterion for judging the performance of a management strategy.

Recent attention, however, has focused more on thresholds or biological reference points, usually expressed in terms of population levels, below which there is an unacceptably high risk of stock collapse. With these, an additional management constraint is imposed, in that exploitation is allowed only to the extent that the probability of the population falling below the threshold levels is acceptably low. Identification of biological reference points has received considerable attention in the recent literature, and it has been the subject of a major international conference (Smith *et al*, 1993). The connection between biological reference points and management strategies has been further discussed by Mace (1994), and in the context of a precautionary approach to management, the topic is discussed in detail in a separate background paper (Rosenberg and Restrepo, 1995).

A familiar application of this approach has been to set a threshold level on spawning stock biomass. For example, an oft-quoted rule of thumb sets this threshold at 20% of the unexploited spawning stock biomass. The degree of precaution may then be assessed in terms of the probability that the spawning stock falls below the 20% threshold in a fixed period. One may also look for specific remedial action to be triggered by a precautionary management strategy (e.g. immediate cessation of catches or at least substantial reductions in them) if the threshold is inadvertently crossed. The difficulty with this approach when it is applied across a range of species or stocks is that it can be largely arbitrary. For some species, the 20% threshold may involve far too much risk of stock collapse, while for others, it may be more cautious than is necessary, thereby leading to lower catches than could safely have been taken. It is far better, of course, if the threshold can be determined directly from historical data for the stock being managed, e.g. from historical stock-recruitment data.

Intimately associated with the idea of thresholds is that of risk[1]. Continuing with the theme of a spawning stock threshold, obviously the lower the probability of the spawning stock falling to below a critical threshold, the lower is the risk of stock collapse and the greater is the degree of precaution. It is important, however, to realise that the probability of exceeding a threshold is not the same as the risk of stock collapse, other than in the exceptional case when the threshold corresponds to a point of critical depensation, below which stock collapse is certain.

This distinction becomes important when a threshold is explicitly included in a management strategy, such that the size of (say) the spawning stock is assessed regularly, with pre-determined remedial actions to be triggered if the threshold is crossed. In such cases, the true risk of stock collapse can only be determined properly on a stock-by-stock and a strategy-by-strategy basis, since the risk depends heavily on the dynamics of the stock, the variability in recruitment, the information content of the past and likely future data, the types of triggering action to be taken, and the timescales involved.

The approach adopted by the IWC in its revised management procedure provides an interesting example of this: the threshold for stock numbers was set at the essentially arbitrary level of 54%, and catch limits were to be set to zero by the management strategy whenever the stock numbers were assessed to fall below this threshold. Simulation studies were then used to determine that there was an acceptably low probability of inadvertently continuing to allow catches when the stock was actually below the threshold but assessed to be above it. With such a high threshold, this approach clearly is strongly precautionary, but it is also highly conservative. That may be appropriate for whales, where the present climate of opinion would probably favour no commercial catches to be taken at all, but it would be much less so for many fish stocks. Balancing risks, thresholds and commercially acceptable catch levels is rather more difficult.

This last comment leads to our final point in this discussion of criteria for assessing degrees of precaution. In many fisheries, biological thresholds will be set at relatively low stock levels, and there may be little argument that if these thresholds are crossed, then drastic action is needed to allow the population to recover. What is less clear, however, is the role that precaution should play when a stock is assessed to be overexploited, in the sense that higher catches could be taken sustainably if the stock were allowed to increase, but where the stock is not at so low a level that a biological threshold has been crossed. In the earlier case, the interests of the stock should obviously be paramount, but in the latter case there is a need also to take account of the welfare of the fishermen, who would inevitably suffer in the short term from the reduction in catches needed to achieve long-term increases. Many management strategies attempt to take partial account of this by incorporating restrictions on the speed at which allowable catches can change. These additional restrictions, however, themselves have implications for the risks associated with breaching a threshold: if only small changes are allowed each year, it may not be possible to react quickly enough in the face of a declining stock to prevent it from reaching unacceptably low levels.

[1] In this paper, we use the term "risk" to denote the probability of something bad happening. It is not used in its technical sense in a decision theoretic framework as meaning expected loss. Detailed discussion of risk in its technical sense is given in Huppert (1995)

2. MANAGEMENT STRATEGIES[2]

In identifying, and later evaluating, fishery management strategies, the first problem is to decide how broadly or how narrowly to define the problem. In most western industrialized fisheries, there is a management system already in place with a well, defined and highly regulated fishing fleet, regular collection of fishery data, and so on. In many of these fisheries, the fishery management problem is conceived quite narrowly, generally revolving around issues of limiting fishing mortality (e.g. via quotas or other technical measures) to protect stocks while at the same time attempting to maximize economic returns from fishing. At the other extreme perhaps are artisanal fisheries in developing countries, where the fishery management problem is inextricably linked with much broader socioeconomic processes and changes in the country as a whole. In this paper, the main focus will be on the former situation rather than the latter, though application of the methods and approaches discussed here to the broader socioeconomic problems will be discussed briefly in general terms.

Taking for the moment the narrower focus on typical western industrialized fisheries, a management strategy or management procedure may be thought of as a set of rules that specifies the technical measures that will be adopted (over time) in managing the fishery. Technical measures here refer to the sets of management regulations on the fishery, such as limits on entry to the fishery, catch quotas, gear restrictions, size limits, and closed seasons and areas. An example of a management strategy for a quota managed fishery might be to set the catch quota in each year to try to achieve a reference fishing mortality rate (e.g. $F_{0.1}$). This in turn requires information on stock abundance and selectivity, which might be obtained from analysis of catch at age data, using for example virtual population analysis (VPA).

The preceding example illustrates that there are usually three ingredients to a management strategy, namely data (e.g. catch at age), a model or method to analyse the data (e.g. VPA), and a decision rule for taking the output of the data analysis and translating it into the specification of a technical measure (in this case application of $F_{0.1}$ to derive a catch quota)[3]. Another example might be use of growth and mortality data in a yield per recruit analysis to set a minimum size limit. Thus, the general pattern is

[2] Throughout the literature, the terms "management strategy" and "management procedure" have been used synonymously. In this paper, while we mainly use the term "management strategy", we revert to the alternative when not to do so would be awkward (e.g. when discussing the IWC's revised management procedure)

[3] Some management strategies effectively use only data and a decision rule, with no formal assessment model in between. An example is the management procedure for South African anchovy described by Butterworth and Bergh (1993), where results from a biomass survey are fed directly into the decision rule

strategy = data + model + decision rule -- > technical measure

Choice of different combinations of data, model and decision rule quickly generates a potentially very large number of strategies for managing fisheries. In practice, most of the variety has come from developments of stock assessment methods that use different combinations of models and data, and rather less attention has been paid to developing new decision rules. The latter may be categorized in various ways and a brief typology follows, with a particular eye on issues relating to precautionary management.

One categorization of decision rules is by the extent to which they use future information. Those that do not use future information may be called non-feedback or non-adaptive strategies. They use data up to the present combined with a model to generate decisions into the future that will not be altered by future data or analysis. For example Francis (1992) considered a series of TAC scenarios for management of an orange roughy stock over 10 years[4]. Each scenario involved a fixed schedule of TACs over the period considered. By virtue of their inability to take account of future data or analyses, such non-feedback strategies are intrinsically non precautionary. They are also quite rare in modern fishery management.

Strategies based on decision rules that use future information are called feedback or adaptive strategies. In the above example, incorporation of feedback would involve simply setting a TAC for the next year, then updating the assessment with the new information collected during that year and setting the following year's TAC on the basis of the revised assessment, and so on into the future. In general, such feedback strategies ought to be more precautionary than non-feedback strategies, to the extent that they will be better able to respond to changing circumstances (such as evidence of overfishing).

The class of feedback or adaptive strategies may be further categorized by whether they take active account of future learning. The above example fits into the category of passive adaptive strategies, in that while it is adaptive to the extent to which assessments are updated as new information comes in, no specific account is taken in the current year that further learning opportunities will arise in later years. Walters (1986) has dealt at considerable length with active adaptive or experimental fishery management strategies. These strategies recognize that in many circumstances there is a relationship between the way a stock is managed and how well its dynamics are understood. There can therefore be a (longer term) value in deliberately "perturbing" the stock away from its current level (which may appear to be optimal given current information) to test its productive potential at either a higher or lower stock size. In most instances such strategies have been evaluated with respect to their performance in maximizing long term catches, and not in relation to risk of overfishing. Clearly, strategies that call for increased exploitation rates in the short term will be less precautionary. However, experimental strategies need not in general be less precautionary, and in the longer term they may lead to better performance with regard to overfishing.

An important subset of control laws in fisheries management are those that are stock-size-dependent. These strategies prescribe catch quotas as a function of current estimates of stock size. Three examples of such control laws are the constant catch, constant harvest rate and constant escapement strategies (Hilborn and Walters, 1992). In terms of maximizing catches over time, the constant escapement strategy can be shown to be optimal under some restricted sets of conditions, and it generally performs better with regard to minimizing the risk of low stock sizes. However these performance attributes come at the expense of very high inter-temporal fluctuations in catch, which can lead to poor economic performance. The range of strategies based on the fishing mortality rate (e.g. $F_{0.1}$, F_{med} etc.) which have been proposed and used in fisheries management fall into the class of constant harvest rate strategies. The comparative performance of these types of control laws in the presence of uncertainty has been examined further by Frederick and Peterman (1995), who found that appropriate adjustments to the harvest policies to take account of uncertainties in estimates of stock abundance and biological parameters can vary widely with the stock and harvest policy considered.

[4] Although these 10 year fixed schedules were used for evaluation purposes, in this case there was no intention that they were to be set in place without the ability to revise them based on future information

More complex variants of the stock-size-dependent strategies are easily established. One variant is to apply one of the basic strategies described above, but to limit either the absolute or proportional changes in catch quota from one period to the next. As noted earlier, to the extent that this limits the flexibility to reduce catches quickly in the face of declines in stock size, such variants might be regarded as inherently less precautionary.

Another variant is to make the decision (the catch limit to be applied) a function not only of the current estimated stock size, but also of the degree of uncertainty in that estimate. A strategy that is definitely precautionary is one that deliberately sets lower catch limits in the face of higher uncertainty. Note, however, that the appropriate extent of downward adjustment of catch quotas in the face of uncertainty will vary from case to case (Frederick and Peterman, 1995).

3. EVALUATING MANAGEMENT STRATEGIES

As noted above, there are several prerequisites to a quantitative assessment of how precautionary a particular management strategy might be. This assessment is no different in kind to an assessment of how well a particular strategy achieves any of its objectives. The steps involved include (i) obtaining a clear statement of objectives, (ii) identifying one or more performance criteria related to each objective, and (iii) clearly specifying the management strategy to be evaluated. The specification of the management strategy must include the stock assessment method to be used (a combination of model and data) and the control law or decision rule that specifies the technical measure to be chosen at each decision point. Once this information is available, the performance of the management strategy can then be evaluated.

The only really reliable way of evaluating a fishery management strategy is to apply it in practice to the real fishery for which it was intended. Where, however, there is a range of potential strategies to be evaluated, for example, this obviously is completely impractical. The only alternative is to seek a "laboratory world" in which to test the strategies. This usually involves developing a computer simulation model of the fish stock and fishery, which not only allows the consequences of management actions specified by the management strategy to be determined, but also simulates the "data" used in the stock assessment part of the management strategy. This underlying simulation model used for the evaluation is often called the operating model.

The operating model should not be confused with the dynamics model implicitly or explicitly contained in the stock assessment. Normally, the operating model will be far more complex than the stock assessment model, as it is designed to mimic the real world as far as possible and to allow examination of the consequences of failures of the assumptions in the stock assessment model. Thorough evaluation of a management strategy will usually require testing it with a range of operating models in order to cover the full extent of uncertainties about the real world in which the management strategy will be applied. Inevitably, this will mean that in some cases the dynamics of the simulated fish stock and the associated biological parameters may be quite different from those assumed by the stock assessment.

The issue of uncertainty is intimately linked to the notion of precaution and risk. In predicting the consequences of a management strategy using the above approach, a number of sources of uncertainty must be recognized and dealt with. One of these uncertainties is data error or observation error. All fisheries data, be they catch, effort, survey abundance, or age and length data, have measurement error associated with them. Random error in such data is relatively easy to deal with, through specification of an appropriate observation equation. Systematic error or bias is generally harder to detect and deal with. In contrast to measurement error in data, process error is used to represent uncertainty in the underlying dynamics of the resource. For example, recruitment is frequently represented as a stochastic process, although an underlying relationship with parental stock size is often assumed.

Both observation and process error have been considered fairly extensively in the fisheries literature in relation to parameter estimation and stock assessment. Much less attention has been paid to the more general issue of model uncertainty. This may take the form of uncertainty about parameters of the model, or more generally of uncertainty in the form of functional relationships or major structural assumptions of the model.

Sainsbury (1991) has gone further than most in explicitly dealing with model uncertainty in the context of evaluating fishery management strategies. The example he investigated involved the assessment and management of a tropical multi-species fishery where the exploitation history had resulted in considerable changes in species composition of the catch over time. Sainsbury identified four alternative hypotheses or models that could account for the observations, and then designed and evaluated a number of experimental management regimes to distinguish between the alternative models. The evaluation dealt not only with model uncertainty, but also with process and observation error and parameter estimation within each model. The experimental approach used spatial contrasts in the fishery effected through spatial closures.

One of the principal benefits of evaluating management strategies using simulation testing lies in the ability to quantify the sensitivity of the results to the various sources of uncertainty identified above. This generally involves testing the performance of the strategy in a series of robustness trials. This approach is more fully described in section 5.1 below, and further examples may be found in Punt (1992) and Butterworth and Bergh (1993). The robustness trials are essentially alternative specifications of the operating model. However, one of the judgements to be made in using this approach to evaluate the performance of management strategies lies in the selection of an appropriate set of robustness trials. This is because it will almost always be possible to identify some hypothesis for an underlying "reality" that will cause any management strategy to fail. The question then becomes one of assessing how credible such a hypothesis might be.

Punt and Smith (1995) offer some qualitative guidelines for the selection of hypotheses for testing robustness. They note first that hypotheses should be framed in a way that allows them to be tested through data analysis, at least in principle. They then suggest four criteria for ranking a set of alternative hypotheses:

1. How well do the data support each hypothesis for the species and region under consideration?
2. How well do the data support each hypothesis for a similar species or another region?
3. How well do the data support each hypothesis for any species?
4. How strong or appropriate is the theoretical basis for each hypothesis?

In general, those hypotheses that are supported higher up the list should be given higher weight or credibility. Clearly there is still scope for subjective judgement in this approach. For example, what criteria are used to judge similarity between species (life history characteristics, taxonomic proximity, functional ecological similarity)? Nevertheless, the idea of a hierarchy of support for ranking hypotheses seems to be a useful step forward.

The output from an evaluation of management strategies using simulation testing can take various forms, but it is often usefully summarized as a decision table (see, for example, Hilborn and Peterman, 1995). For the evaluation of a single harvest strategy, such a table might present the performance for each criterion against each of a set of selected robustness trials. For those performance criteria that seek to measure or represent precautionary performance, this provides a measure of how well the strategy achieves precautionary objectives (for example, how often critical thresholds are exceeded). The performance across robustness trials also helps to identify critical uncertainties.

Where several alternative management strategies are being considered, an alternative form for a decision table presents a summary (across robustness trials) of performance for each strategy against each key objective. This may be a much more useful table for decision makers as it allows a ranking of alternative strategies for any one objective (such as a conservation objective) and therefore provides a basis for decision making irrespective of the absolute level of performance. More particularly, it also provides a basis for quantifying the tradeoff to be made between alternative and conflicting objectives. This will be particularly important in developing a practical approach to precaution, where often there will be a clear tradeoff between conservation and economic objectives. This approach allows a quantitative assessment of that tradeoff. Decision makers can assign their own subjective rankings to different objectives, and choose the strategy that best (or adequately) addresses their primary objectives. Note that this approach (evaluating alternative strategies against a range of objectives) is quite different from an optimization approach that seeks the single strategy that performs best for an explicitly weighted set of objectives.

4. EXAMPLES

In this section we discuss two examples. The first, dealing with the revised management procedure of the IWC, illustrates how the methodology of the previous section has been applied to evaluate the performance of a set of alternative management strategies. The second, rather different, example shows how precautionary aspects have been explicitly incorporated into the management objectives of CCAMLR and describes the approach that body has taken towards setting precautionary catch limits.

The revised management procedure of the IWC

Before its decision in 1982 to declare a moratorium on commercial whaling, the catch limits set by the IWC were based on stock assessments, developed by its scientific committee, which were very similar in nature to standard fishery assessments at the time. In essence, for each stock all the available data were used to obtain best estimates of current and historical stock sizes and of the productivity of the stock. Catch limits were then set with the aim of keeping the stock at or above the level at which the MSY could be taken, or moving it towards that level. One of the major reasons for deciding to impose the moratorium was the difficulty experienced by the scientific committee in reaching consensus on the status of stocks, given the prevailing uncertainties in the data and in their interpretation.

During the late 1980's and early 1990's, the scientific committee of the IWC developed a revised management procedure designed to resolve these difficulties. The development process involved a reexamination of management objectives, taking a realistic view of the uncertainties inherent in current and likely future data and in the baleen whale dynamics, and a very thorough testing of the robustness of proposed procedures to these uncertainties. Although a precautionary approach was not explicitly considered, the way in which the revised management procedure was developed and tested gives an ideal illustration of the methodology described in the preceding section of this paper.

The first step in the process involved identification and quantification of the IWC's management objectives. After much discussion, the following (brief) statement of its objectives was agreed:

i. stability of catch limits;
ii. acceptably low risk of stock depletion to below 54% of carrying capacity;
iii. making possible the highest continuing yield from the stock.

The IWC agreed that a management procedure must first satisfy objective (ii). Subject to that, it was then free to maximise catches under (iii), while performing satisfactorily in (i). A stock assessed to be below 54% of its carrying capacity (i.e. below the protection level in the previous IWC management procedure) should have a zero catch limit. Acceptable risk was then to be judged in terms of the likelihood of inadvertently setting non-zero catch limits when the stock was actually below the protection level, but was assessed to be above it.

For a revised management procedure to be acceptable, it must be able to meet the above objectives, regardless of existing and continuing uncertainties in the basic data, stock structure and dynamics of whale populations. Whether or not a procedure is robust to these uncertainties can only be decided by examining its performance across a wide range of plausible situations. Development of a revised management procedure therefore proceeded on two fronts: identification and refinement of potential procedures, and specification of means for testing the performance and robustness of these procedures in meeting the objectives. The procedures themselves are not relevant to this paper; interested readers are referred to IWC (1992, pp 93–103), in which descriptions are provided of the five procedures as they stood at the time a choice was made between them. Rather, we shall concentrate on the methods used to test their performance.

Simulation trials of management procedures

Since experimental application to management of actual whale stocks was out of the question, the approach taken was to simulate the management of whale stocks. An initially unexploited whale population was set up and subjected to a series of historical catches before the onset of management. The dynamics of the simulated stock were governed by specified operating models. Estimates of abundance, which in addition to the historical catches formed the primary input data source for whale stock assessments, were simulated so that they had the same nature and properties believed to occur in real data of those types. Computer programs implementing potential management procedures were then applied to this simulated stock.

A lengthy series of computer-based trials was then conducted. Each trial examined management of a simulated whale stock over a 100 year period. This was repeated at least 100 times for each trial scenario. Summary statistics monitoring the performance of the procedure in relation to the three management objectives were collected for each trial.

Two categories of trials were identified: "base case" trials and "robustness" trials. The base case trials consisted of a short series of relatively mild trials. These examined the ability of procedures to manage both unexploited, moderately depleted and heavily depleted stocks of whales with different levels of productivity, in cases where the dynamics of the stocks followed conventional models and the abundance data were unbiased. The scenarios covered in these trials were typical of those now often examined in sensitivity tests carried out in association with fish stock assessments, though such tests rarely include future application of a management procedure.

The key to the performance evaluation lay in the additional robustness trials, which examined a much wider range of possible departures from assumptions than is normally considered in sensitivity tests. Each trial was repeated for a selected subset of the base case scenarios on initial abundance and stock productivity. The robustness trials included the following (for a full list, see IWC 1993, p. 224a).

i. Incorrect assumptions about the dynamics of the true stock. This formed the largest category. Cases examined included widely differing forms of density dependent responses, differing biological parameters, trends and cycles in the carrying capacity of the population, and cyclic changes in productivity.

ii. A wide range of initial abundance levels.

iii. Upward and downward bias in the abundance data, and trends in that bias, as well as differing frequencies of collection and levels of precision.

iv. Uncertain or inaccurate catch histories before exploitation, and long periods of protection before management starts.

v. Irregular episodic events (e.g. occasional occurrence of epidemics).

vi. Deterioration of the environment, with declining trends in both carrying capacity and productivity.

A further set of trials examining interactions between a subset of these factors (those that were most important on their own) was also carried out.

Statistics for evaluation of performance in meeting management objectives

For each trial, statistics allowing evaluation of the performance of management procedures in meeting the three management objectives were collected. The primary statistics and the management objectives to which they referred were:

Objective (i): the average inter-annual variability in catch limits;

Objective (ii): percentiles of the lowest population size during the 100 years of management;

Objective (iii): percentiles of the total catch over 100 years, and of a measure of "continuing" catch, which in most cases was the average catch over the final 10 years.

Similar statistics were also collected for the final population size after 100 years. This was effectively used as a proxy for a target population size.

To assess the probability of whaling being inadvertently allowed when stock levels were below the protection level of 54% of carrying capacity, two further sets of statistics were used. These were percentiles of the "realised protection level", which was the lowest population size in a trial at which non-zero catches were set, and of the relative degree of recovery, which compared the time it took to recover to the protection level under the management procedure being tested with the time it would have taken had zero catches been set. These last two statistics, or slight modifications of them, would be ideal for evaluating performance in the presence of a biological reference point or threshold. They are complementary in nature, because while a management procedure may inadvertently set non-zero catch limits at stock levels below the protection level, they may be so small that any delay in stock recovery is also very minor.

Selection of the revised management procedure

By 1991, the development and testing process for management procedures applicable to single stocks of baleen whales was completed. At its 1991 meeting, the Scientific Committee reviewed the large set of performance statistics on the trials of each of the five procedures (IWC, 1992b). All procedures considered were found to have performed satisfactorily on the simulation trials. The best performing procedure (developed by Dr Justin Cooke) was subsequently adopted by the IWC.

Implications for assessing degrees of precaution

The two key features of the process adopted by the IWC were that all elements of the management strategy were tested simultaneously and that robustness was examined to a much wider range of uncertainties than is normally considered.

The results of the trials showed clear interactions between the precision and quantity of data and the degree of conservatism needed to meet the objectives. These proved to be quite nonlinear, further amplifying the findings of Frederick and Peterman (1995). A valuable aspect of the best-performing procedure was that it incorporated a mechanism for automatically adjusting the catch limit in line with the apparent precision of the assessment. This is not a new suggestion, but the important role it played in ensuring good performance suggests that this may be a design feature that should be included among the characteristics of a precautionary management strategy.

The equivalent of the stock assessment method used in the best-performing management strategy involved fitting a simplified production model by Bayes-like techniques. By itself, this carries no particular connotations for other fisheries, since whales have rather different dynamics to fish, but in this case it was found that increasing the apparent realism of the underlying dynamics of the model would not necessarily improve the performance (cf. Ludwig and Walters, 1985). This is good news for fisheries for which data availability is relatively low, since it provides an example where robust precautionary management can be achieved without having to rely on the data-hungry types of stock assessment typically used for temperate western industrialised fisheries.

The results of the robustness trials strongly emphasised the distinction brought out in an earlier section between a strategy that was precautionary by design and one that was precautionary in performance. Both the final and earlier versions of each of the five potential whale management procedures were precautionary by design. They clearly differed, however, in the degree to which they exhibited precautionary (conservative) performance. Futhermore, this difference in performance itself varied across the robustness trials. In particular, most performed relatively well when faced with the base case trials, in which the dynamics and the data satisfied most of the usual assumptions made in previous whale assessments. Not surprisingly, much greater differences were observed in robustness trials where the assumed properties of the data differed substantially from what was expected, and where the underlying dynamics was quite different from that implicitly assumed by the procedures. The clear lesson was that the true degree of precaution of a management strategy cannot be determined just from an analysis of the management objectives and the structure of the management strategy alone.

Precaution in an ecosystem setting - CCAMLR

Two important steps identified for increasing the precautionary nature of fishery management are incorporation of explicit precautionary elements into the management objectives for a fishery, and taking proper account of the ecosystems affected by capture fisheries. In our second example, we briefly outline the steps taken by CCAMLR to address these issues. In particular, we highlight the incorporation of precautionary aspects into the CCAMLR convention and the ways these have been translated into management strategies, particularly for management of lower trophic level species.

The CCAMLR convention is unique, in that it explicitly attempts to address ecosystem management. Paragraph 3 of Article II of the convention states:

"Any harvesting and associated activities in the area to which this Convention applies shall be conducted in accordance with the provisions of this Convention and with the following principles of conservation:

a. prevention of decrease in the size of any harvested population to levels below those which ensure its stable recruitment. For this purpose its size should not be allowed to fall below a level close to that which ensures the greatest net annual recruitment;

b. maintenance of ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels defined in sub-paragraph (a) above; and

c. prevention of changes or minimization of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, taking into account the state of available knowledge of the direct and indirect impact of harvesting, the effect of the introduction of alien species, the effects of associated activities on the marine ecosystem and of the effects of environmental changes, with the aim of making possible the sustained conservation of Antarctic marine living resources."

When interpreting this Article, it should be noted that Article II of the Convention includes rational use among the meanings of the term "conservation".

This statement of objectives explicitly includes the idea of biological reference points, the concepts of risk and of reversibility of changes over a specific time span, and a requirement to take account of the state of available knowledge in assessing risks and reversibility. It furthermore requires account to be taken of effects of harvesting on both the population being harvested and on dependent and related populations. By any measure, these objectives have strongly precautionary aspects, though the term "precautionary" does not appear specifically.

The need to address conservation of the whole Antarctic marine ecosystem, rather than of just the species that would be harvested directly, arose because of the nature of the Antarctic ecosystem and of the potential fisheries. Around the time the CCAMLR Convention was being negotiated, there was a popular view that a potentially huge harvestable surplus of krill (*Euphausia superba*) existed in the Antarctic, resulting from the heavy overexploitation of baleen whale stocks there. Consequently, there was strong interest in developing a substantial krill fishery.

Fortunately, the more extreme versions of the krill surplus theory soon lost currency and wiser views prevailed (e.g. May *et al*, 1979). Krill, near the base of the Antarctic food chain, is the key species in the ecosystem on which nearly all other species are either dependent or related. Clearly, if a major krill fishery did develop, there was a considerable risk that it could have a substantial effect on these other species.

One of the major thrusts in response to this by CCAMLR has been the setting up of a comprehensive ecosystem monitoring programme, concentrating on key krill predators, to which most member governments contribute. In this programme, selected biological parameters are monitored using standardised methods at sites around the Antarctic. A number of species of penguins, flying birds and seals are monitored in this programme. Individual member governments also conduct research programmes aimed at evaluating and improving the utility of the biological parameters being monitored, and providing the background information needed to interpret changes in the monitored parameters.

Such monitoring programmes take considerable time to set up, and often quite long time series are needed before any apparent changes can be properly interpreted. It is therefore perhaps fortunate that technical and other marketing difficulties have so far delayed the anticipated development of a large krill fishery. Current krill catch levels are believed to be much lower than those that may have deleterious effects on the ecosystem. Despite this, CCAMLR has taken the step of imposing a series of precautionary catch limits for krill, which are much larger than current catch levels, in preparation for any future increase in krill fishing.

The precautionary catch limits for krill were based on application of a krill management strategy. This strategy incorporates an explicit single species biological reference point and an additional ecosystem constraint, with precautionary TACs being determined using simulation studies, based on a krill yield model, that were similar to those conducted by the IWC described above. The management strategy is designed for use with previously unexploited (or very lightly exploited) stocks, for which an estimate of pre-exploitation biomass is available. Details of the computational and simulation methods in the krill yield model are given in Butterworth *et al* (1994). This approach has also recently been adapted by Constable and de la Mare (1994) to calculate precautionary TACs for the myctophid *Electrona carlsbergi*.

In the management strategy, if B_0 is the estimated pre-exploitation biomass, then the precautionary TAC is set as:

TAC = &agr; B_0

The value of &agr; to be used is the minimum of &agr;$_1$ and &agr;$_2$, where, based on simulation studies using plausible operating models,

i. &agr;$_1$ is the value such that under a constant TAC of &agr;$_1$ B_0, the probability of the spawning biomass falling below 20% of its pre-exploitation level over a 20 year period is 0.1; and

ii. &agr;$_2$ is the value such that under a constant TAC of &agr;$_2$ B_0, the median escapement over a 20 year period is 75% of B_0.

The first constraint is the now-common single species constraint on the probability of falling below a biological reference point in a given time span. The second is quite different; it is aimed to leave at least some of the prey for other predators. The biological reasoning for this is as follows. A standard single species production model that completely ignores the interests of the prey, such as the Schaefer model, suggests that the population level at which MSY can be taken is around 50% of the pre-exploitation level, so that the "optimal" single species escapement from the fishery would be 50% of B_0. If all the prey were to be reserved for the predators, than the appropriate escapement from the fishery would be 100% of B_0. The figure chosen, 75% is halfway between these.

Clearly, the 75% figure chosen is largely arbitrary and the biological underpinnings are not strong. As further information is accumulated on the dynamics of both the prey and predator species, the ecosystem constraint will be refined. However, the principle by which account can be taken explicitly of dependent species seems a very good one and well worthy of consideration under the umbrella of a precautionary approach to management of harvested prey species in a marine ecosystem.

CONCLUSIONS

A strong distinction has been made in this paper between management strategies that are "precautionary in principle" and "precautionary in practice". The former can often be judged quite qualitatively, for example using guidelines similar to those outlined by Garcia (1994). For a management strategy to be precautionary in practice, it is probably necessary for it to be precautionary in principle, but it is definitely not sufficient.

The results of simulation testing of baleen whale management strategies described earlier provided very clear examples of this distinction. In addition, recent simulation testing of management strategies for developing fisheries has further emphasised the distinction between precaution in principle and in practice (R.I.C.C. Francis, A.D.M. Smith and S.E. Wayte, unpublished data). This study evaluated a feedback management strategy for a new fishery which was deliberately precautionary in nature. In particular, an explicit element of the feedback decision rule was to select, as the maximum current catch, that catch which resulted in less than a 10% chance of reducing the stock to less than 20% of virgin biomass across a series of projected future catch trajectories. Despite the clear precautionary nature of this element in the decision rule, simulation tests revealed that this strategy resulted in frequent reductions in stock below the 20% biomass threshold. This decision rule clearly did not meet its own (inbuilt) performance criteria.

As noted in section 3, most quantitative evaluations of fishery management strategies to date have been concerned with quota management systems. One aspect of such systems not often considered in such evaluations is the allocation of the catch limit for the stock (equivalent to a TAC) among the fishing fleet(s) and the likely effects of different ways of doing this. Arguably, this is at least as important as the other processes leading up to it. Few would argue, for example, that a completely open access fishery management policy was likely to be precautionary. While it is not axiomatic that open access will lead to overcapacity in the fishing sector, it very frequently seems to be the case. As overcapacity increases, this is likely to lead to increased pressure on the managers to raise catch limits, or at least not to reduce them in cases where that becomes necessary.

A number of alternative technical management measures to open access have been proposed and used in different fisheries around the world, ranging from limited licensing to individual transferable quotas, with varying degrees of success. What is extremely difficult, however, is to disentangle the contributions to this success of the management measure *per se* from the degree of precaution (or otherwise) of the remainder of the management strategy. In principle, this can be addressed by simulation, only now the behaviour of the fishermen needs also to be included in the operating models. If one adds the further complication of imperfect compliance with management measures (cf. Rosenberg and Brault, 1993), the task of carrying out a full quantitative assessment of the degree of precaution of a management strategy becomes truly formidable.

Evaluation of management procedures using the methods described in this paper is undeniably computationally intensive, though it is only for complex industrialised fisheries that really extensive research on the scale of that conducted by the IWC would normally be necessary or appropriate. It is equally important to realise that, no matter how exhaustive the evaluations by simulation are, there can still be no guarantee that the management strategy studied will turn out in real application to exhibit the same degree of precaution as the simulation studies suggest. That accepted, however, current evidence suggests that even only modestly sized evaluations can provide valuable insights into the degree of precaution in a proposed management strategy that are very difficult to obtain by other means.

Much of the discussion of the precautionary approach to management has focused on a narrow definition of precaution, where the aim is essentially to prevent overfishing leading to stock collapse. A broader view of precaution sees the aim being to maintain a flexible, resilient fishery system, where that system is taken to include the fish stock, the ecosystem of which it is a part, the fishing fleet, and the management agency which regulates it. This view is closely tied to the notion of reversibility, where for example the management system is sufficiently flexible that previous decisions can be reversed without undue delay or cost (both economic and political), where fishermen do not become economically locked into a position where they cannot afford to reduce effort even temporarily, and where the biological system is maintained in a state where irreversible changes are not triggered by overfishing.

This broader definition makes it clear that the precautionary approach does include non-biological considerations. This may be particularly true for artisanal fisheries in developing countries, where the fish may provide the only source of protein and employment for substantial communities. In such circumstances, precautionary management should also be concerned with conserving the fishery and fishermen, as well as the fish stock. This should be reflected by incorporation of socioeconomic aims, as well as biological aims, in the management objectives for that fishery. In principle, methods for assessing the degree of socioeconomic precaution similar to those described above can be developed, but they do require that the operating models for the fishery system have a much wider scope than most that have been used to date.

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PRECAUTIONARY APPROACH TO THE INTRODUCTION AND TRANSFER OF AQUATIC SPECIES

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Abstract

Introduced aquatic species are an established means to increase productivity and generate income in aquaculture and capture fisheries. Introduced species are also an inadvertent by-product of modern transportation, shipping and international trade. Both the intentional and inadvertent introductions are recognised as serious threats to aquatic biological diversity. Therefore, management must address both beneficial and negative aspects of species introductions. However, there is often an inadequate knowledge base on which to base policy and management decisions. Two basic unknowns exist concerning an introduced species: i) its impact on the receiving ecosystem and ii) its performance in the new ecosystem. Related to these unknowns are three general levels of uncertainty: i) uncertainty that arises from a lack of basic information; ii) uncertainty that arises from unknown interactions within a given system; iii) uncertainty that arises from shifts and interactions in physical, biological, social and political systems. Activities to reduce uncertainty and reduce the chance of adverse impacts are considered part of a precautionary approach to species introductions. There are several precautionary approaches that may help minimise adverse effects from exotic species. These range from getting resource managers to think about an introduction through education and use of a code of practice, documenting native resources that may be affected, maintaining registries of exotic species and their effects, up to incorporation of protocols and guidelines for implementing codes of practice and environmental impact assessments in legislation. Guidelines and codes of practice represent one of the best precautionary activities available for species introductions. However, several recommendations to minimise the chance of adverse impacts are controversial in that they may not be scientifically nor economically justifiable,

may be difficult to implement, or may compromise human safety. Genetically modified organisms (GMOs) are recognized as an exotic organism, even if they may be conspecific with native organisms and derived by conventional breeding techniques. The product of the genetic modification, i.e. the change in phenotype, should be assessed rather than the process that lead to the modification in order to assess accurately the level of risk associated with GMOs.

INTRODUCTION

The use of exotic species has been demonstrated to be an effective means to increase food production and generate income. The introduction[1] of Kapenta, *Limnothrissa miodon*, into Lake Kariba in southern Africa created a fishery worth millions of dollars (Marshall, 1991, Bartley, 1993), exotic salmonids in Chile form the basis for a growing and internationally successful aquaculture industry (FAO, 1994). Grass carp, *Ctenopharygodon idella*, and the mosquito fish, *Gambusia affinis*, have been widely introduced as biological control of aquatic weeds and mosquitoes (Welcomme, 1988). However, bio-control and the development of fisheries and aquaculture based on exotic species poses risks to native aquatic resources and can significantly change the socio-economic structure of local human communities (Reynolds and Greboval, 1989).

Species are also introduced unintentionally through the aquarium trade, ships' ballast, on ships' hulls, in packing material, and even on fishing gear. The movement of exotic species by shipping has been reviewed (Carlton, 1985, 1987, 1989, 1992a,b; Carlton and Geller, 1993; Carlton et al., 1990; Williams et al., 1988 and Omori et al., 1994). Because of the limited survival time of many species most introductions have been to either side of the same ocean (Carlton et al., 1990; Hallegraeff and Bolch, 1991; Mills et al., 1993). Because of the large volumes of water used in ballast discharges, a variety of viruses, bacteria, single celled organisms and metazoa may become moved to a new locality and inoculated into a new ecosystem. It is likely that ports in partially enclosed bays with poor water exchange may be more likely to enable new populations to develop. Areas such the Baltic Sea, the Black Sea and the Mediterranean Sea, as well as ports situated close to tidal nodes are particularly at risk.

Introduced species are now regarded as a leading threat to native aquatic biodiversity (Williams et al., 1989). European crayfish, *Astacus astacus*, were adversely affected by a fungal disease inadvertently introduced to Europe with American crayfish, *Orconectes limosus* (Furst, 1984). The introduction of the Nile perch, *Lates niloctica*, to Lake Victoria may have caused, or contributed to, the extinction of nearly 200 species (Barel et al., 1985; Gophen et al., 1995). Fisheries in the Black Sea have been decimated by, *inter alia*, the introduction of an introduced ctenophore, *Mnemiopsis leidyi* (Travis, 1993). Epizootic ulcerative syndrome has expanded its range through Southeast Asia with fish movements and poor quarantine controls, and may be introduced elsewhere with further aquaculture species movements or aquarium fishes. This disease has resulted in a serious loss of cultured fish production through most of Asia (Roberts et al., 1994; M. Shariff, pers. comm.). Transfers of Atlantic salmon from the Baltic Sea to stock enhancement programmes in Norway, introduced a monogenean ectoparasite, *Gyrodactylis salaris*, that now threatens native stocks (Bakke, 1991). Although successful treatment using rotenone has eliminated the infected salmon in one catchment (Johnsen and Jensen, 1986), eradication of an introduced species once it is established is usually difficult or impossible (Carlton and Mann, 1981).

Introduced species may affect native resources *via* ecological, genetic, pathogenic, and socio-economic pathways. Ecological interactions include predation (Barel et al., 1985), competition (Chew, 1990; de Iongh and van Zon, 1993) and habitat modification (Chilton and Muoneke, 1992). Genetic impacts include hybridisation and introgression, loss of co-adapted gene complexes, reduction in fitness, and loss of genetic diversity (Bartley and Gall, 1991; Hindar et al., 1991; Waples, 1991). Pathogenic impacts include the transmission of disease and parasites (Bakke, 1991; Furst, 1991; Stewart, 1991) and socio-economic impacts include the changes in fishing methods, markets, price, labour force and activity patterns (Reynolds and Greboval, 1989). These effects may arise out of developments intended for aquaculture and fisheries, shipping, or by other sources. Once a species has been exported, i.e. introduced, transfer back to its native range may also cause impacts. For example the flat oyster, *Ostrea edulis*, introduced to north-east America, and from there to the Pacific coast, were subsequently transferred to France. The oysters carried a previously undescribed haplosporidian, *Bonamia ostreae*, which has resulted in a changes in oyster farming practice in affected areas of Northern Europe (Chew, 1990).

[1] Introduction has been defined as the movement of a species to an area outside of its natural range, transfer has been defined as the movement of a species within its range (Welcomme 1988). To increase readability and to acknowledge that transfers of genetically differentiated populations and genetically modified organisms may be nearly equivalent to the introduction of a new species, in this paper introduction refers to both the introduction and transfer of organisms, including genetically modified organisms

Movements of species which are closely related may result in very different effects. For example the Chinese hat limpet, *Calyptraea chinensis*, was probably introduced with oysters to the west coast of Ireland from France, have little effect on benthic communities (Minchin et al., 1987). Whereas the related slipper limpet, *Crepidula fornicata*, introduced to northern Europe from the east coast of the USA, has modified the environment in several sea inlets and bays and can locally produce a biomass significantly greater than many commercial species (Minchin et al., 1995a). In the Baie de Granville the population biomass is calculated as 750,000 tonnes (Blanchard, 1995).

For a number of introduced species the full effects on its host or new environment remain unknown. For example, the introduction of half-grown Japanese oysters, *Crassostrea gigas*, to Europe (Grizel and Heral, 1991) has resulted in the recent expansion of the range of populations of the copepod gut-parasite, *Mytilicola orientalis*, from France to Ireland (Minchin and Holmes, 1995) and the Netherlands (Stock, 1993) and may affect the condition of its host if badly managed in culture.

1. UNCERTAINTY

The management of exotic species must address both beneficial and negative impacts resulting from their introduction. However, there is often an inadequate knowledge base on which to base policy and management decisions. Baltz (1991) states "... Our present understanding of how coastal marine communities function is poor. Until we understand the factors that regulate communities, the effects of species introductions will remain unpredictable...". A similar situation is likely to exist in many freshwater systems (Ross, 1991).

There are two basic unknowns associated with the use of exotic species in fisheries:

i. the impact of the new species on the receiving ecosystem and
ii. the performance of the new species in its new environment.

Knowledge of the nature and extent of the impact will be crucial for protecting local resources, biological diversity and evaluating risk, whereas, the performance evaluation will be necessary for evaluating benefits. Although evaluation of impact and performance may only be possible following the introduction of the species, some indications may be obtained from information in areas where the species occurs naturally or at other introduced sites that have similar characteristics.

There are three areas of uncertainty that form a continuum from simple easily addressed uncertainties to complex uncertainties arising from interaction of physical, social and political systems (Costanza, 1993). The use and management of exotic species involve all of these:

i. Uncertainty that arises from a lack of basic information.

   For example, the uncertainty of the composition of a lake's fish community could be addressed by faunistic surveys. Fishery biologists or systematists could address this uncertainty.

ii. Uncertainty that arises from unknown interactions within a given system. For example, how an introduced fish will evolve in its new environment. Several hypotheses could be modelled or estimated based on previous introductions of similar organisms into similar environments. For this procedure to be effective a large volume of information is often necessary.

Specialists, such as systems ecologists, could address this uncertainty where information gaps may be compensated for by informed judgement using a collection of data sets.

iii. Uncertainty that arises from shifts and interactions in physical, biological, social and political systems. The effects that arise from such circumstances are often unpredictable. The introduction of the Nile perch into Lake Victoria was an example of this type of uncertainty where changes occurred in the physical and biological composition of the Lake, in the character of the fishing industry, in the community surrounding the Lake, and in the economic structure of the Lake's bordering countries. Changes even occurred in the forest community surrounding the Lake because timber was removed to smoke Nile perch flesh to make it more transportable and palatable. Uncertainty as to the causes of the changes to the lake continues because the introduction of the Nile perch was not the only perturbation to the system; overfishing, pollution and sedimentation also affect the Lake (Reynolds and Greboval, 1989).

2. PRECAUTIONARY APPROACH

Uncertainty is recognised and accepted in science, but policy, legislation and regulations require more certainty. In trying to maximize benefits of aquatic species introductions for human populations, the third and most complex form of uncertainty is often generated. However, as Costanza (1993) states, a scientific method of experimentation and observation can still be applied here to determine the level of our understanding. Thus, the management of exotic species becomes adaptive, based on the results and assessments of previous or ongoing introductions. This approach appears similar to the precautionary approach of adaptive management or internalized feedback (Hilborn and Peterman, this volume).

When uncertainty is acknowledged, it is necessary to install mechanisms or policies to safeguard against harmful effects. Such is the basis of the precautionary approach. That is, policy and commitment of resources should be established in anticipation of potential adverse impacts of a management decision that may relate to a detrimental effect of an introduction. The approach could be extended to the monitoring and evaluation of introductions to comply with Costanza's "experimentation and observation" as a means to reduce our uncertainty.

Within fisheries management there are two broad categories of exotic species, those that are introduced into the wild purposefully for fisheries, biological control, etc. and those that are introduced passively or by mistake, such as in ship's ballast, escapes from aquaculture facilities and from petfish tanks (Carlton, 1992a,b). Pathogens and parasites may occur with either type of introduction and are not treated separately as introductions. Precautionary measures will require different application depending on the vector involved and the biological characteristics of the introduced species. For example, many significant introductions have been associated with oysters, and some of these have been harmful. Oysters may carry many taxa as epifauna or epiflora on the often rough surface of the shell. In addition, parasites and diseases, of which there are many, can be associated with the living tissues, and within the shells of oysters that have died; algal cysts or infaunal invertebrates may be contained in sediments (Minchin, in press). Oysters are often transported in large numbers, and because of this, may contain a sufficient population of the associated exotic to provide an effective innoculum for a new locality.

However, the precautionary approach must be reasonable and should not unduly hinder potential development. Several recent international gatherings of experts in aquatic resource development and management have stressed the need for practical guidelines on the responsible use of introduced aquatic species, as well as the need for easily understood information on ecology, genetics, and fish health (FAO, 1993; Coates, 1995; Aquaculture for Local Community Development Programme (ALCOM) and FAO, unpub. reports). Precautionary guidelines that require extensive research, technology or intensive management may only be feasible in developed countries, and may leave developing countries and rural areas marginalized and unwilling to adopt any level of precaution (Coates, 1995; ALCOM unpub. report).

Precaution can, in theory, extend to the depths of our lack of understanding of aquatic systems. This depth can be extensive, especially in the areas of genetic resources, introduced species and their value to the continued existence of a fishery resource. Therefore, the precautionary approach must be associated with a risk:benefit analysis or a comparative risk analysis (Pullin, 1994; Shrader-Frechette, 1995). The risks and benefits must be evaluated in relation to local priorities and national sovereignty.

The management of introduced species will involve research, technology, and actual management. However, many previously proposed precautionary activities for introductions are controversial or involve an element of increased cost that may not be scientifically nor economically justifiable. The purposes of this paper are to examine how a range of precautionary approaches can be applied to research, technology and management of exotic species in the aquatic environment and to assess some previous recommendations concerning introduced species.

3. INTENTIONAL INTRODUCTIONS

Fisheries and aquaculture

Aquatic species have been introduced to establish fisheries (commercial and sport), for aquaculture, as bait for fishing, and as forage for other important species (Welcomme 1988). The use of bait fishes can result in their establishment in new localities. This generally applies to freshwater species (Welcome, 1991), but also to marine species. The goldspot herring, *Herklotsicthys quadrimaculatus*, native to the Marshall Islands appeared in Hawaii, and may have been introduced there when used as a bait fish for tuna (Randall, 1987).

An introduction for aquaculture is considered to be similar to an introduction into the wild. Experience has shown that complete containment of exotic species in aquaculture facilities is nearly impossible and that an introduction to an aquaculture facility should be considered a step towards its eventual introduction into the wild (Welcomme, 1988, Coates, 1995). Furthermore, many extensive aquaculture impoundments are similar to intensively managed small water bodies and therefore difficult to distinguish from natural waterbodies.

Biological control

Biological control methods, particularly in the management of aquatic plants and mosquitoes. (Bennett, 1984; Welcomme, 1991) have been partially successful. The success of these methods encourages the further use of this option in the control of invasive species. Some important exotic pest species for which biological control is being researched include:

1. *Mnemiopsis leidyi*, introduced to the Black Sea in ballast water from the Western Atlantic, this ctenophore occurs in high densities and feeds on several phyla of plankton, including larval fishes that formerly sustained important commercial fisheries (Travis, 1993). Teleosts, such as sockeye, *Oncorhynchus nerka*, and chum salmon, *O. keta*, which feed on ctenophores and are commercially valuable are being considered as biological control (John Caddy, FAO, pers. comm.)

2. *Carcinus maenas*, the shore crab of European waters, has now become widely distributed beyond its natural range, probably as a result of ballast water transport. The shore crab is a significant predator of bivalves. Natural parasites of this species, such as *Sacculina carcini*, are being considered as a means for control. The parasites reduce the mechanical capabilities of the hosts chelae and in addition reduce the reproductive output (Lafferty and Kuris, 1994).

3. *Dressina polymorpha* and *D. Bugensis*, zebra mussels, are fresh water bivalves that have been introduced from the Black Sea to the Great Lakes of North America. Their abundance in the new environment has resulted in serious trophic changes and fouling. Studies for their control include research on predators from the zebra mussels' home range.

Biocontrol programmes, especially those that involve exotic species, should be weighted carefully against other control methodologies, such as physical and chemical techniques (ICES unpublished report). It is likely biological control techniques will take some time to evaluate, e.g. through establishment of field trials. However, the pressing need to manage some invasive species may conflict with the normal precautions and protocols observed for an introduction. The addition of further non-native species must be considered as having the potential to give rise to further and more complex management difficulties. Much may be learned by the studies on biological control in other disciplines such as entomology.

Research

Research and a basic understanding of an organism's biology and ecological requirements will be necessary to evaluate potential impacts and performance in a new environment. The study of a species within its normal range has been suggested as a means to evaluate its impact in a new environment. However, a species' performance in its natural environment may be very different from its performance in a new setting which may have different physical and ecological constraints. The golden apple snail, *Pomacea* spp., and zebra mussel have proliferated to pest status in the Philippines and Great Lakes of North America, respectively, because of favourable environmental conditions and an absence of natural predators (Acosta and Pullin, 1991; May and Marsden, 1992). Ruffe, *Gymnocephalus cernuus*, switched from a zoobenthos feeder to a zooplantivore when introduced to a Norwegian lake with a different community structure from lakes in the ruffe's natural range (Kålås, 1995).

The US Government subscribes to a precautionary approach in the use of exotic species by establishing research guidelines and performance standards for researchers using genetically modified organisms (ABRAC, 1995). These guidelines, however, do not go as far as they might because these standards do not apply to organisms that are " ... modified solely by intraspecific selective breeding or captive breeding... " (ABRAC, 1995). They consist of flow charts , decision trees, and worksheets to help researchers reduce environmental risk. Performance standards, that is, the level of precaution researchers must follow, are based on the type of genetic modification, the accessibility of natural ecosystems surrounding the research facility and the status of the natural resources of the adjacent ecosystem.

Pilot scale introductions for research have been proposed as a precautionary approach to species introductions (Turner, 1988; Tiedje et al., 1989). However, the validity of research results from pilot scale introductions has been questioned (World Aquaculture ad hoc Working Group on Hatchery Enhancement; ALCOM/FAO, unpublished report; DMB pers ob.). Ecological interactions at the population and community levels, as well as effects, of an introduction, are often the result of numbers of organisms (Lande, 1991); reducing the numbers may reduce the effect and reduce the probability of success of an introduction. Pilot scale introductions may lead to no effects, neither good nor bad. Pilot scale introductions for research purposes, in order to be of value, should involve large numbers of organisms and become nearly equivalent to full scale introductions.

The use of pilot scale introductions to a confined area has also been proposed as a means to assess adverse impacts (Turner, 1988; Tiedje et al., 1989). However, due to the interconnectedness of all things (Adams, 1985), especially in the brackish and marine environments, confinement may be difficult. Precaution would dictate that a species should be considered suitable for introduction well in advance of the implementation of a pilot scale research programme. A pilot scale programme may be seen by entrepreneurs and some agencies as an unnecessary delay and financial burden.

Reviews which have condensed research results so as to aid in selection of 'new' species (Bardach et al., 1972; Korringa, 1976a, b,c; Lutz 1980; New, 1982; Tucker, 1985; Manzi and Castagna, 1986) form a useful precautionary tool in the selection of species for aquaculture introductions. Lee and Wickens (1992) have compared the growth, productivity, stocking densities for a wide range of crustacea adapted for different habitats. General summaries of commercially important species or of those with potential are also of value such as the account on oysters by Arakawa (1990). There are synopses on diseases of organisms used in aquaculture (Bower et al., 1994) and disease transfers are summarised by Sindermann (1993). Sinderman outlines the importance of "transfer networks" of species in aquaculture along which pathogens move. In the case of shrimp these networks are extensive throughout tropical regions of the world (Lightner, 1990).

Technology

Technological aspects of managing an established fishery are discussed elsewhere in this volume and are not treated here. Because the use of introduced species requires active intervention by developers, technological intervention can be applied during the period of introduction. In this case the preferred use of technology is to prevent adverse impacts, but it may also be used to correct negative impacts should they occur.

Technologies with hypersensitive analytical tools such as disease diagnostics through enzyme-linked immunosorbent assay (ELISA) and DNA-fingerprinting are becoming applied more to fishery management to reduce the chance of disease introduction and to select appropriate genetic populations (Wirgin and Waldman, 1995). Pathogens and genetic polymorphisms are widespread, but the importance of these to aquatic populations is often unclear. Aquatic organisms that were once considered to be disease free, have now been shown to contain specific pathogens (R. Pascho USFWS in FAO, unpub. report). It is likely that most aquatic organisms carry low numbers of pathogens which will not normally result in problems should its environment remain suitable. Disease can be induced in healthy animals through improper husbandry or through environmental stress.

Researchers in the USA have produced and promoted a Specific Pathogen Free (SPF) strain of shrimp for aquaculture (Wyban et al., 1993). In areas where specific pathogens would be a serious threat, for example BKD in salmon producing areas, other SPF strains of introduced fish could be produced as a precautionary measure. The use of SPF organisms would be only to reduce the chance of the pathogen being introduced; the organism would not be resistant to the pathogen if it were encountered.

The use of marine hatcheries to enhance fisheries is an established practice in many parts of the world and some have utilised introduced species (Bartley, 1995). The use of hatcheries has also generated controversy and there are potentially adverse effects that could arise from this technology (MacCall, 1988; Hilborn, 1992; Bartley, 1995a). The dependence of a fishery on a hatchery provides a level of control should adverse impacts arise. Hatcheries may also provide a useful tool for the management of exotic species in environments which are unsuitable for spawning. Species such as the Pacific oyster and the Manila clam *Tapes philippinarum* seldom spawn in Britain and Ireland and the culture activities depend on hatchery spat for their production. Spawning does occur in warm summers but recruitment is normally small (Eno, 1995; Minchin, 1993). Hatcheries may release only sterilised fish, thus preventing their establishment in natural waters. However, it is often the desire of a hatchery supported introduction to create self sustaining populations or to contribute to natural recruitment through interbreeding with natural stocks (Bartley et al., 1995).

The ICES/EIFAC protocols (Turner 1988) recommended the use of sterilised individuals to minimise risk of adverse effects from introductions. Triploidization and inter-specific hybridization are two common technologies capable of producing sterile organisms (Khan et al., 1990; Mair, 1993). Using sterile animals gives the importer or hatchery a measure of control over the introduced group of organisms such that if problems arise, releases or further introductions can be stopped. Grass carp used for aquatic weed control are often made sterile by triploidization (Winn 1992); Atlantic salmon cultured in Nova Scotia, Canada must be triploid (therefore sterile) to reduce their genetic impact on natural stocks (McGeachy et al., 1994). Triploid animals should be inspected and certified to be triploid before their use is permitted. The introduction of monosex populations of fish will also reduce the chance of establishing self-sustaining populations in the wild, provided of course that the 'other' sex is not present. Groups of fish of a single sex can be produced through combinations of chromosome manipulation, hormone treatment, gamete manipulation, and hybridization (Mair, 1993). However, the use of triploids, hybrids, or mono-sex groups requires either their continuous importation, and therefore continuous inspection and quarantine, or the maintenance of fertile broodstock in country to provide sterile offspring.

Management

Codes of practice governing the use of introduced species have been produced and are probably the single best precaution against the adverse effects of exotic species (Turner, 1988). Codes of practice, such as ICES[2](Turner, 1988; ICES, 1995) and NASCO (Porter, 1992) represent a precautionary approach in that they are an a *priori* policy that forces importers to submit a proposal to use an introduced species and forces managers to evaluate the proposal. The ICES code also calls for a commitment of resources in the form of an advisory panel, quarantine, disease screening, environmental impact assessments, species documentation, monitoring etc., before an introduction is allowed. Codes of practice or guidelines that deal with specialised topics within the broad category of "introductions" have also been created. The North Atlantic Salmon Conservation Organization (NASCO) has promoted guidelines on management of the Atlantic salmon (Porter, 1992). The Office International des Épizooties (OIE, 1995) has developed a prototype aquatic animal health code that contains guidelines for risk assessment, evaluation by competent authorities, and zoning in order to reduce the chance of spreading pathogens when transporting fish.

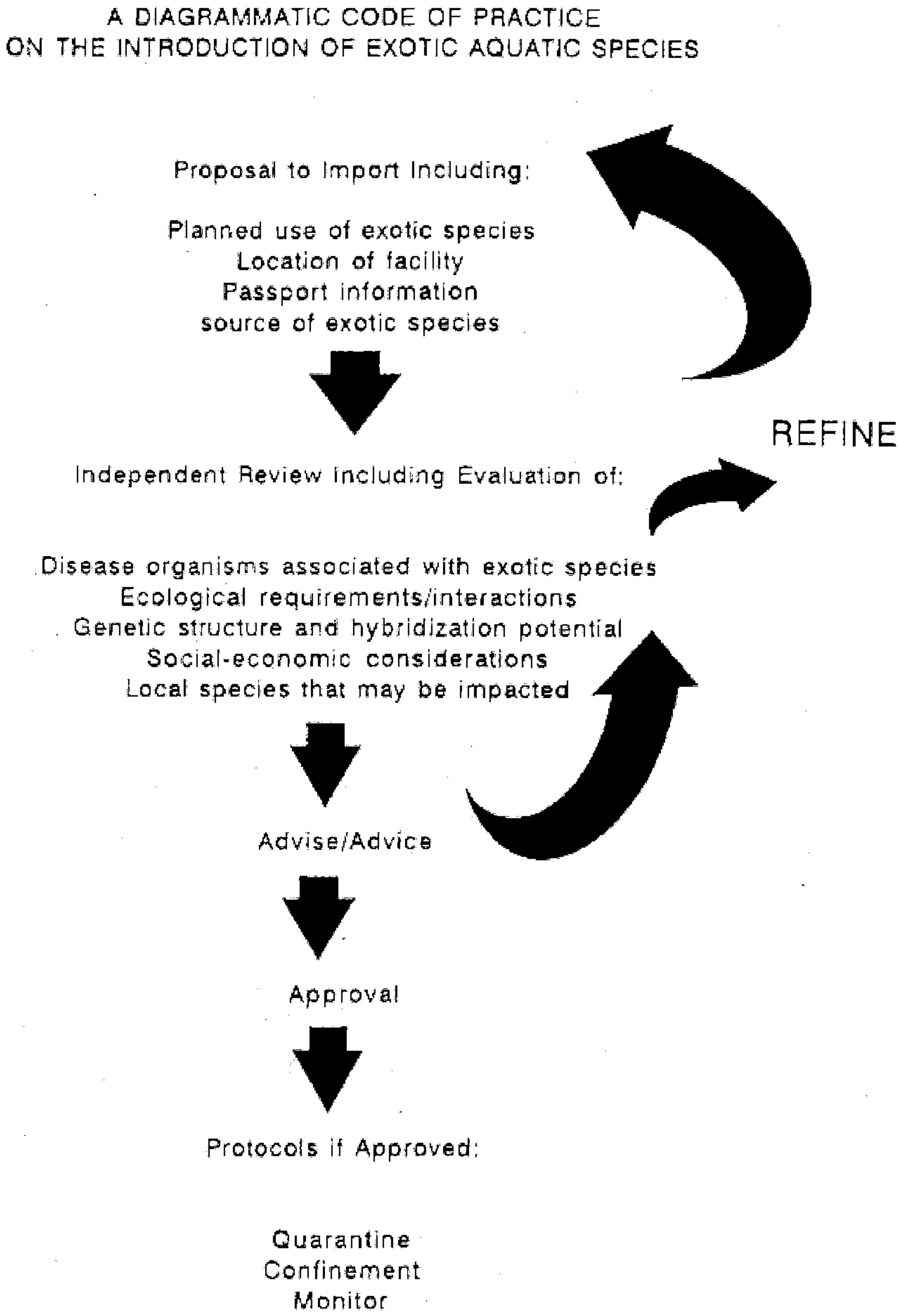

Figure 1. Main elements of a code of practice for the introduction of aquatic species (Truner, 1988; Bartley, 1995; ICES, 1995)

[2] The currently available ICES Code (ICES 1995) is modified from the previous ICES/EIFAC Code in Turner (1988). EIFAC is expected to incorporate further modifications before finalizing their version

The main elements of the ICES Code are summarized in Figure 1 and its historical roots are discussed in Courtenay and Robins (1989). Principle activities to implement the element of the ICES code include, *inter alia:*

1. Conduct comprehensive disease and ecological studies in the native habitat in advance of the introduction.

2. Transfer the introduced species to a secure system within the recipient area

3. Maintain and regularly sample the contained population, and the water quality therein.

4. Develop a broodstock in quarantine.

5. Grow isolated F1 individuals in quarantine

6. Introduce small numbers to natural waters and continue disease and ecological studies (but see previous Research section).

7. Implement a monitoring plan to evaluate the introduction.

The ICES Code also recommends with normal trade that regular inspections of live consignments take place. Should unwanted species be found, trade should discontinue until the problem is rectified. Similar approaches should also be taken outside of ICES areas.

Although the elements of the ICES Code appear simple, they may be difficult to carry out. Therefore, protocols and guidelines have been created (ICES, 1984; Turner, 1988;ANSTF, 1994) to facilitate implementation. Practical guidelines must present a range of options that can be utilised depending on available finances, materials, personnel, the state of knowledge on native resources and the introduced species, as acknowledged in Article 15 of the Rio Declaration. This will be especially important in rural and developing areas where facilities, finances and baseline biological information may be scarce.

In the case of temperate marine bivalves, Utting and Spencer (1992) have concluded that there is little requirement for the introduction of further marine species to Britain. This is because of the availability of a wide range of temperate species, including exotics already introduced, for successful management and development of shellfish aquaculture programmes for the foreseeable future. Grizel (1994) considers that with the expansion of aquaculture careful management and continued studies of shellfish must include protective strategies in relation to possible epizootic diseases. Recently in China, production of the bay scallop, *Argopecten irradians*, has been affected by a haplosporidian disease (Chu et al., 1995). It is not clear whether the parasite came with the original transfer of 26 individuals used as broodstock in 1982, or arose due to adaptations by an opportunistic native species.

In the interest of free trade, some local areas may become subjected to introduced species, as has taken place under the EC Council Directive 91/67/EEC. This Directive permitted transfers of Pacific oysters which previous Irish legislation had controlled (Minchin et al. , 1993). The pacific oysters in cultivation in Ireland before the Directive had been introduced via a quarantine station, Conwy North, Wales and consequently no associated organisms were introduced with them. However, large scale movements of unquarantined oysters are high risk vectors for algal cysts, pests and parasites (O' Mahony , 1993;Dijkema, 1992). The movement of spat, results in a smaller biomass being transferred and consequently a reduced risk of introducing attached organisms, but this may not be adequate in control of the spread of disease causing organisms.

To reduce potential ecological impacts, the use of native species has been proposed, as has the importation of a species into a "vacant niche" in the receiving ecosystem (Coates, 1995). Clearly the use of native species would not be an introduction unless the species was genetically modified prior to release (see following section). However, native species may not be considered as suitable for exploitation because of unknown culture or performance data (Marshall, unpublished report). In addition, local species may be undervalued because they are too common or they are not internationally marketable (Bartley, 1993).

Codes of practice and guidelines that aid implementation should acknowledge uncertainty and avoid making excessive recommendations that require absolute certainty. For example, many conservation geneticists strive to preserve the "evolutionary potential" of a species (Waples, 1991a; FAO, 1993). such a recommendation is a worthy goal, but nearly intractable for policy makers, because of our ignorance of the value of specific genetic resources, how they change over short periods of time, and how they change on an evolutionary time-scale.

Legislation has been enacted in many areas to help control the use and spread of introduced species (Wingate, 1991; Thys van den Audenaerde, 1992; ANSTF, 1994; Anon., 1994a; Windsor and Hutchinson, 1994; S. Sen, unpub. report). The European Union has also established Directives aimed at governing fish movements within the Union (Howarth and McGillivray, 1994). The recently ratified Convention on Biological Diversity (UNCED, 1992) contains articles that specifically address the use of exotic species. Article 8 (g) on in situ conservation states that " ... Each party shall ... Establish or maintain means to regulate, manage or control the risks associated with the use and release of living modified organisms resulting from biotechnology..." and 8 (h) states, " ... Prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species...".

Coates stated that in regards to introduced species, "... educationis better than legislation..." (ALCOM Technical Consultation, Zambia, November 1994). The U.S. Office of Technology Assessment suggested that Congress, *inter alia*, expand environmental education on the use and dangers of exotic species (Anon., 1994b; ANSTF, 1994). We could perhaps expand Coates' statement to, "... education and information are better than legislation...". Toward that end, documentation and dissemination of information on introduced species have been undertaken by FAO (Welcomme, 1988) and are continuing(Bartley and Subasinghe, unpub.) in collaboration with the International Center for Living Aquatic Resource Management (ICLARM) on a relational database on important fishes, FishBase (1995).

Although our knowledge of most aquatic systems is poor or incomplete, the interactions of past introductions may provide information on what might be expected with future introductions and would provide a valuable tool for resource managers and potential importers. The first global coverage of international introductions of inland fishes (Welcomme, 1988) is being augmented to include marine and invertebrate species by means of an internationally distributed questionnaire (Bartley and Subasinghe, unpub.); records of introductions are also being complied by H.Rosenthal (in prep.). Many past introductions have not been adequately studied making it difficult to evaluate impacts on ecological or socio-economic systems (Fernando and Holcik, 1991; Bartley and subasinghe, unpub.). Because the use of exotic species will continue, resource managers could help increase the usefulness of these databases by reporting all introductions and their success/failures to international organisations that maintain registries, such as FAO and ICLARM.

The precautionary approach to fishery management as described in FAO's Code of Conduct for Responsible Fisheries has been criticised by the fishing industry as being overly restrictive and placing undue burden of proof on the industry (Anon., 1994c). The International Coalition of Fisheries Associations (ICFA) in raising this criticism stated that a lack of scientific information on fisheries targeting undeveloped or under-utilised species is insufficient reason for setting conservation harvest levels (Anon., 1994c). The precautionary approach with intended introductions must be distinguished from natural capture fisheries because the act of introduction bears some costs in both time and money.

A fishery based on a newly introduced species must be given time to develop and conservative harvest goals are needed, at least initially. The criticism of the ICFA that the precautionary approach should not set conservative quotas on under-utilised or new fisheries (Anon., 1994c) can not be extended to newly created fisheries. In hatchery enhancement or culture based fisheries fishers may expect to increase pressure on a population in light of the large amounts of fish/larvae released from hatcheries. Management must be based on actual contribution of hatcheries to the fishery and not on numbers of fish released. Furthermore, in mixed stock fisheries management needs to set quotas based on the least abundant or most critical stock. Otherwise, the rare stock may be eliminated by fishing regulations that are based on more abundant components of the mixed stock fishery.

In capture fisheries the resource users (fishers) and the resource managers may oppose each other on management issues. However in regards to introductions, there may not be this antagonism as government agencies accounted for approximately 40% of the documented introductions, whereas private individuals and industry account for 15 and 18%, respectively (Bartley and Subasinghe, unpublished data). International organizations were responsible for 7% and 20% of the introductions were made by unknown sources. Resource managers should not be exempt from applying existing codes of practice and guidelines.

A private importer may choose to be very precautious because of legislation, legal responsibilities and the loss of production from choosing the wrong species to import. A common philosophy in environmental management is "the polluter pays". Exotic species that adversely affect the environment could be considered a form of pollution. The precautionary approach, as defined by Garcia (1994), would seem to dictate that exotic species were pollutants until proven otherwise. Therefore, the importer would be financially responsible for correcting adverse impacts. An importer of exotic species that is financially liable for mistakes should be motivated to make good decisions.

Genetically Modified Organisms

Genetically modified organisms (GMOs) may be considered a special category of exotic species. The underlying difference among all species is their genetic makeup. Therefore, organisms that have had their genome modified by humans, could be considered exotic in relation to the original population. There are a variety of methods available to modify the genomes of aquatic species that include hybridization, chromosome manipulation, selective breeding and gene transfer (Okada and Nagahama, 1993); each has advantages and risks (Hallerman and Kapuscinski, 1992).

There is no universally accepted definition of a GMO. The European Economic Community defines a GMO as "...an organism in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination..." (EEC, 1990). This is elegant in its simplicity and generality, but the EEC goes on to cloud the issue by excluding polyploid induction; the products of selective breeding are not mentioned, neither as a technique that results in a GMO nor as one that does not result in a GMO. ICES has adopted a narrow definition of GMO that refers to basically modern gene transfer techniques in their Codes of Practice (ICES, 1995) and have not included products of conventional selective breeding (J. Carlton, ICES Working Group, personal communication, unpublished report of the EIFAC working group on introductions, Rome, 1994). The Convention on Biological Diversity also adopted a broad definition similar to the EEC's, but then exempts the products of traditional selective breeding. Although the Ecological Society of America suggests regulating GMOs based on their "...biological properties (phenotypes), rather that according to the genetic techniques used to produce them..." (Tiedje et al., 1989), the US Department of Agriculture appears to exclude products of selective breeding from their performance standards (see Research section; ABRAC, 1995). In the United Kingdom GMOs refer to organisms that have genetic material transferred from other species, i.e. transgenic organisms (Woodwark et al., 1994).

Based on the history of animal and plant selective breeding programmes, the Convention on Biological Diversity (UNCED, 1992) wishes to exclude products of conventional technology from excessive regulation (Krattinger and Lesser, 1994). However, terrestrial breeding programmes may not be appropriate models upon which to base regulations for the aquatic sector, partly because so much of aquatic biological diversity is found in wild populations. Norway leads the world in Atlantic salmon production (FAO, 1994), but now farmed salmon may threaten natural runs of salmon through escapes and accidental releases (Gausen and Moen, 1991).

The reasons for the exclusions an ddefinitions of limited scope are fear of consumer rejection of fishery products should they be associated with a 'mysterious' scientific technique and fear of excessive regulatory and bureaucratic oversight of such technologies. The precautionary approach to GMOs should require that all genetic modifications be subject to examination and assessment for introduction, regardless of the technology used to create the modification. There may be more uncertainty associated with the production of transgenic organisms, e.g. how and where the new genetic material is incorporated in the genome, how it is inherited, if it is sterile, how it's expressed, and traits that are affected (J. Beardmore, pers. comm.). However, these uncertainties require a thorough examination of the transgenics phenotype. No organism, whether it is transgenic, polyploid, hybrid, or the product of selective breeding, should be released without answering these fundamental questions concerning the phenotype. Simply because a fish is a transgenic, it should not evoke fear; because a fish is the result of conventional breeding should not evoke complacency. Scientists, farmers, resource managers and administrators must look at the end product, not the process that created the product.

4. INADVERTENT INTRODUCTIONS

Shipping

In the 1800's ballast was normally in the form of sand or stone. This required special ballasting and deballasting points in order to maintain clear shipping fairways. The process was labour intensive and the first usage of water as ballast provided an immediate advantage as it was less labour intensive and consequently economically more effective. However, the use of water resulted in the movement of species across distinct biological provinces.

Some of the introduced species became invasive. For example, the diatom, *Odontella (Biddulphia) sinensis*, a tropical species appeared in 1903 in the North Sea forming a dense bloom. This species today inhabits the Baltic Sea (Leppäkoski, 1984) and may have been introduced in ballast water. Similarly, in 1912 the Chinese mitten crab, *Eriochir sinensis* was introduced to Germany in ballast and subsequently spread its range. In the new environment the crab caused damage to river banks in brackish water areas and siltation in rivers and estuaries, thus contributing to the cost of maintaining shipping channels (Jansson, 1995).

Introductions are taking place throughout the world on a regular basis. Although some notable catastrophes have resulted (see below), the majority of species introduced in ballast water have little major impact on their new environment. For example, the American razor-fish, *Ensis directus*, is now expanding its range in the southern North Sea (Essink, 1985; Beukema and Dekker, 1995). Those that become established may not become apparent for some time, either because they have little effect in the new environment or because of their size are overlooked. Additionally, the inadvertent or unknown movement of organisms may make determination of their natural range difficult. For example, *Cryptonemia hibernica*, principally found in the Pacific, has been described from Cork Harbour, Ireland (Guiry et al., 1973); its presence in Ireland is difficult to explain by means other than shipping.

The widespread occurrence of algal blooms throughout the world may in part be due to ship movements. In Australia studies on ballast water by Hallegraeff and Bolch (1991) have revealed 31 viable dinoflagellate species. Five of these were toxic, and included *Alexandrium catanella* and *A. tamarense* with estimates of 300 million cysts present in the sediment of some ships. Recent investigations on high liquid performance chromatography of toxins, bioluminescence capacity, morphology and mating compatibility of *Alexandrium* species in the north-west Atlantic Ocean suggests that there are several strains that can be distinguished according to their geography (Anderson et al., 1994). Similar studies of dinoflagellate bloom species elsewhere may enable the identification of likely transport routes.

Ballast water introductions have been responsible for two recent and notably destructive cases; the introduction of the zebra mussels, *Dreissena polymorpha* and *D. bugensis* from the Black Sea to the Great Lakes (Carlton, 1992a). These species have resulted in trophic competition in the Great Lakes, with modification of the abundance of the organisms in the normal food chain. Zebra mussels can remove up to 6.4 million tonnes of phytoplanton, about 26% of the primary production in western Lake Erie (Madenjian, 1995) and occur in sufficient numbers that the dead shells accumulate and stagnate on beaches. The zebra mussels are small, have a high reproductive capability, have few predators in their new environment and can, therefore, spread rapidly. They can sustain some desiccation and hence can be readily transferred among river systems on boats and fishing equipment; their spread is aided by seasonal flooding. The species fouls drinking and industrial water pipes, which require extensive servicing and new management methods . The species still continues to expand and the public is generally aware of its expansion in a well publicised series of messages in newsletters, broadcasts and posters. This species resulted in damages of an estimated $5 billion, primarily through clogging water pipes (Kiernan, 1993).

North Americas 'exchange gift' to the Black Sea has been a ctenophore, *Mnemiopsis leidyi*, introduced in 1982. The ctenophore ranges from Cape Cod, USA to Brazil and consists of a complex of at least six forms, generally considered to be one species (Harbison and Volovik, 1994).In its native habitat it is a voracious consumer of zooplankton and the abundance of copepods is at times negatively correlated with increasing concentration of ctenophores. In The Black Sea and particularly in the Sea of Azov the anchovy, *Engraulis encrasicolus* and the pilchard, *Clupeonella cultriventris*, fisheries declined to low levels by 1994 resulting in serious economic and social difficulties and additional pressures on other resources. There have been trophic changes in the normal plankton assemblages (Zaitev, 1993) with a wet ctenophore biomass exceeding 50g/m^3 during July to September over large areas of the Sea of Azov (Volovik, et al., 1993). This ctenophore has spread into the eastern Mediterranean since 1992; it is extending its range westwards by natural dispersion, and perhaps in ballast water, and may spread into the Indian and Atlantic Oceans. Sufficient are these problems that the United Nations Environmental Programme (UNEP) have a Working Group including all effected countries to determine how this species may be managed.

Ships with large ballast capacity and fast transit times provide greatest risk for inoculation of exotic species and may even include organisms that affect human health. For example, *Vibrio cholerae*, the causative agent for cholera, has been transferred from South America to Alabama (McCarthy and Khambaty, 1994) *and Clostridium botulinum* has been found in ballast water in the United States, Australia and Japan (Anderson, 1992). Harmful species continue to be described such as, *pfeisteria piscimorte*, a 'phantom' dinoflagellate which hatches from a cyst and releases a toxin that kills fish. They feed on fish then re-encyst and have a very complex set of life-history stages (Burkholder et al., 1992). Species such as this and those that cause amnesic shellfish poisoning may be transported in ships' ballast.

Many species have been spread as fouling organisms within and on ships' hulls. Wooden hulls have distributed gribbles, *Limnoria spp*. and the shipworm, a mollusc, *Toredo navalis*, throughout most parts of the world in the early years of regular sailing transportation (carlton, 1992a). Following the Second World War the New Zealand barnacle, *Elminius modestus*, introduced to the south coast of England, has spread to much of northern Europe. Although abundant in several harbours and bays, it does not impinge on local resources significantly .It can beabundant in estuarine regions where it may displace native barnacles. However, the introduction of the Koran sea squirt, *Styela clava*, to Europe following the Korean War has had some impact on localised industry particularly in port and oyster growing areas (Minchin and Duggan, 1988).

Ships may be capable of transporting organisms in other ways, such as within chain lockers or within other water holding facilities on board. Specialized vessels such as well boats, designed for carrying sea products in trade or for culture, may also facilitate species movements. The transport of oil platforms (Carlton, 1987) or flying boats (Eno, 1995) may also be implicated.

With increased knowledge of ballast movements and the harmful effects that some species can inflict in a new area, a precautionary approach to ballast discharge should be developed. The difficulty is that there is insufficient research undertaken to determine what species are most likely to become invasive or cause adverse impacts, except for the known exceptions mentioned above. It is therefore, prudent to assume that all ballast water will have potential to carry harmful species. Biocides, concentrating and collecting mechanisms, and ballast replacement are methods that, once effectively implemented, will reduce establishment of exotic species introduced via ballast.

Research and Technology

The general concern over the transmittal of exotic species in ballast water and sediment has resulted in several suggestions for their control. However, because of the wide range of taxa and varying resistance of these to different treatment methods, further research is required to determine the most cost effective and practical treatment, or combination of treatments. Current studies into treatment measures include: heat (Anon. 1992), a cooper/silver electrode system (K. Müller, pers. comm.), uv light, hydrogen peroxide, sodium hypochlorite, salt, ozone, reduction in oxygen (Rigby et al., 1993). Mid-ocean exchange for freshwater ballast enables dilution and a change of physical conditions. This will have an effect on the planktonic organisms, but the biota in sediments may not be affected. Apart from removal of sediments in dry-dock and reballasting at sea; there are no other generally accepted or applied control techniques.

Apart from tankers, most vessels are unable to pump their ballast ashore. For most ships the treatment of ballast water is not feasible. Because of difficulty of access, even sampling of ballast is difficult. Bulk carriers are the easiest to sample and the majority of studies to date have been on this type of vessel. It is not known whether studies on bulk carriers will reflect the patterns of diversity and survival found in vessels with more sealed ballast units. Studies of organisms in ballast water, where they may be deprived of light, with consequent changes in their rate of assimilation of food and behaviour may provide useful information that would aid new vessel design, either of continuously flushed ballast while in transit or positioning of equipment to make treatments more effective.

Dinoflagellates are of particular concern, their resistant cysts accumulate in sediments, and may remain viable for some years. The ballasting of dinoflagellate contaminated water may lead to inoculations in ports in succeeding years. Consequently the removal of ballast sediment of ships when dry-docked is a wise precaution. It would also be prudent to enable settlement of ballast sediments should ballast discharges in port be inevitable. The turnover of these cysts in sediments either by bioturbation or resuspension as a result of ballasting or poor sea state remains unstudied. Research projects involving ballast water and sediment need to be expanded. The early studies conducted on bulk carriers arriving in Australia from Japan demonstrated that significant numbers of toxic dinoflagellate cysts were indeed carried by this means (Hutchings, 1992). The Smithsonian Environmental Research Center has a current programme which includes work between the USA and Germany examining the prevalence of various taxa, including algal cysts, and application of IMO guidelines (see following section). This follows the work of the United States National Biological Invasions Shipping Study.

It would appear that those countries most affected by ballast water discharges are currently the most concerned. In northern Europe and North America there are a number of desk studies undertaken to quantify the diversity of introduced species, likely introduction sites and relative risk of different introduction vectors (Carlton, 1992a, b; Mills et al., 1993: Jansson, 1995: Eno, 1995; Minchin and Sheehan, 1995; Carlton, 1993; Mac Donald, 1995). The EU are likely to support studies in this area as a result of the serious economic consequences of introductions elsewhere.

Ballast may require different treatments depending on where the ship originated. However, research within this area is still needed. Little is known on the biological effects of light deprivation, ship vibration, duration within ballast tanks of marine organisms. Certain taxa will predominate within ballast water on account of their behaviour and whether they have planktonic stages may be more prone to being removed in ballast (Carlton, 1993). The survival of organisms in ballast water will depend on voyage duration, with few species expected to survive journeys of 24 days (Williams et al., 1988). Dinoflagellate cysts, may be capable of resting several years and some have a required dormancy period before hatching (Anderson, 1980). Studies by Locke et al. (1991) demonstrate that re-ballasting at sea of vessels due to enter the Great Lakes in about 67% effective in eliminating freshwater organisms despite compliance of re-ballasting at sea by 90% of vessels.

Those areas most likely for establishment of an introduced species are lagoons and port areas (Boudouresque, 1994). Care must be taken to find suitable ways of reducing the overall impact of ballast water in areas of partial containment which may enable a small innoculum to establish an exotic population.

The utilisation of effective antifouling applications, such as the use of organotins have reduced the overall biomass of fouling organisms. Such substances are sufficiently toxic that they can also result in species eradication near ports. The use of these substances is being reviewed and several alternative methods are being investigated so that a similarly effective antifouling substance can be produced that will deter fouling yet be more acceptable environmentally. Future antifouling applications will need to be equally as effective as organotin preparations.

Management

The International Maritime Organisation (IMO) has produced "...Guidelines for preventing the introduction of unwanted aquatic organisms and pathogens from ships' ballast water and sediment discharges..." (Anon., 1993). It is generally accepted that prevention is unrealistic and efforts should stress "...**minimizing** the introduction of unwanted organisms..." (Anon., 1994a,d). These guidelines are actively pursued in Australia and New Zealand and are endorsed by the United States and Canadian Coast Guard for vessels entering the Great Lakes (Anon., 1991).

The first control measures on ballast water were introduced by the Canadian Coast Guard in 1989 based on voluntary management of ballast water in ships entering Canadian waters. These procedures resulted from the introduction of a number of invasive species into the Great lakes, principally imported from Europe (Mills et al., 1993). The voluntary requirement was that ships entering the Great Lakes would flush their tanks at sea before entry into the St Lawrence Seaway. Legislation was enacted in the United States under the Non-indigenous Aquatic Nuisance Prevention and Control Act in 1990.

Formalization of present guidelines into legislation or a code of practice for ballast water, is urgently required, but is hindered by the lack of research information on which to base useful decisions and the knowledge that ballast tank or ship design for most vessels will not change for several years, except perhaps in the commissioning of new vessels. In Australia, Canada, and the USA there are measures for the control of ballast water by shipping. Due to difficulties in the mid-ocean exchange of ballast compliance may be difficult because of structural limitations and the dangers to the ship and crew. Secondary deballasting areas exist for those vessels entering the Great Lakes that have these difficulties.

A code for the management of ballast water needs to evolve from scientific studies on control of durable and potentially harmful species likely to be carried in ballast water and discharged in recipient ports. Control mechanisms may require studies of the resting stages of diverse phyla that may respond to different stimuli or be subject to different chemotheraputic techniques. The present guidelines are based on dilution of the numbers of organisms by the recommended mid-ocean exchange, or by flusing the tanks with water with properties unsuited for the organisms contained in the ballast. These methods probably reduce the potential of an innoculum establishing populations in a new locality. Future control methods may be greatly aided by changes in the design of ships ballast tanks that facilitate access and treatment methods.

As a result of finding viable cysts of toxic dinoflagellates and other non-native species in ballast waters and sediments, the Australian Quarantine and Inspection Service developed special quarantine measures in February 1990 which requested shipping to comply with one of the following options (Hallegraeff and Bolch, 1991);

1. Have a certificate to indicate that the port of origin is free from toxic dinoflagellates, (this is difficult because such events are often sporadic and can occur within hours, ballast water and in particular sediments may have accumulated as a result of previous re-ballasting in other ports. Dredging activities may result in suspension of cysts, which otherwise may have remained unavailable to ballasting.).

2. Provide evidence that they have reballasted at sea (this may not result in the purging of ballast sediment).

3. Provide evidence that they have treated the ballast water (no single treatment method is currently recognized).

4. Discharged their sediment in designated and 'safe' areas (this assumes that this practice reduces the risk of a successful inoculation).

5. That ballast does not contain sediment and was not loaded during a toxic bloom (sediment inevitably will collect in ballast tanks).

6. That ballast will not be discharged in Australian waters.

Similar guidelines have been adopted by the IMO (Anon., 1991, 1993).

Because effective management still requires much research, according to ships port origin, duration at sea, volume of ballast, deballasting provisions etc., a precautionary approach considers that the following measures would reduce the chance of a successful inoculation:

i. Intake of ballast water should be avoided when "coloured" water is present because this may contain algal blooms or organisms associated with sediments.

ii. Dilution of the organisms in the ballast.

iii. Changes, such as temperature and salinity, in ballast water may create unfavourable conditions for the contained organisms. This, together with the effect of dilution is the principle involved in mid-ocean exchange.

iv. De-ballasting before entering port.

v. Treatment of the ballast

vi. Special ballasting facilities ashore.

vii. Do not de-ballast.

The establishment of a database of harmful, toxic or potentially nuisance species would aid the management of ballast water. The International Oceanographic Commission has established a reporting structure of Harmful Algal Blooms. This database could be entered into a global shipping network register so that port authorities may be alerted of ballast posing potential risk in advance of a ship entering port. A computer alarm system based on the port of origin, or ship track, could be used to provide a warning system in advance of the ship arriving in port so that appropriate methods for dealing with the ballast water might be considered and employed.

The physical conditions of ports could be registered in a database. When a ship leaves one port for another, these physical characters could be compared between the two ports. Close similarities between the two would indicate a higher probability of ballast water discharge producing a new population in the recipient port. Harmful species known to occur in some port areas should be entered into a similar database, together with recent account of any algal blooms. Such information, if it were made readily available, would aid in the management of ballast water. However, at present, this information is not generally available.

Although not intended to prevent introductions of species the application of biocidal films have reduced fouling in order to reduce the costs incurred by hydrodynamic drag. The economic savings by utilising an efficient biocide will mean faster ship travel and reduced fuel consumption. Effective antifouling applications, such as the use of tributyl-tin have reduced overall biomass of fouling organisms and approximately 69% of ships are being painted with TBT antifouling (Ambrose, 1994).

Such substances, however, are sufficiently toxic to result in environmentally toxic conditions for a wide spectrum of organisms within some estuaries and bays. The IMO have proposed a ban on the use of TBT on all vessels less than 50m (Anon., 1994d). Legislation in many countries has controlled its use, with a general ban on vessels, most usually, below 25m. Shipping port areas continue to have environmentally high levels of TBT (Davies and Bailey, 1991; Uhler et al., 1993; Minchin et al., 1995a,b,c) and this may have some effect on the suppression of biotic innocula. The IMO are anxious to find a practical alternative for the replacement of this substance because of its toxic nature and several alternative methods are being investigated so that a similarly effective antifouling substance can be produced that will deter fouling and will be more environmentally acceptable.

Other introductions

Other vectors for the inadvertent introduction of aquatic species into nature are associated with the careless actions of many individuals, such as boaters, recreational fishermen, and pet-fish owners. For example, the range of the crayfish plague within Europe may have been extended, in part, by transferral of contaminated fishing gear. There is an extensive trade in freshwater and marine aquarium species throughout the world which may result in the introduction of organisms and diseases (Courtney and Stauffer, 1990). Establishment of the benthic alga *Caulerpa taxifolia*, in the Mediterranean probably resulted from fragments being released from a public aquarium facility, where it had been on display for some years (Meinesz and Hesse, 1991; Boudouresque, et al., 1992). This Pacific species has become invasive within the western Mediterranean and appears to have mutated to produce a more tolerant cold water form (Sabatini, pers. comm.).

Disposal of live packing materials may have lead to the establishment of the exotic shore crab *Carcinus maenas* in San Francisco Bay (Cohen et al., 1995). It may have arrived there within ballast water transfers, or with seaweed packing used in shellfish shipments from the Atlantic coast. The algae *Fucus spp.* and knotted wrack, *Ascophyllum nodosum* are used for this purpose and small shore crabs are common within these materials. These Atlantic algae have also been found in San Francisco Bay. The careless disposal of materials considered to be waste may be a frequent; the disposal of unwanted food items which were considered unfit as food or dead, but were in fact alive, may also be common.

Thus, the application of codes or guidelines is difficult and enforcement of controlling legislation, if any exists, is difficult or impractical. Public education and awareness campaigns are probably the best means to reduce these types of inadvertent introductions and promote responsible actions by the many individuals using the aquatic environment. Some pet-fish retailers are already distributing pamphlets on the dangers of escaping or released aquarium fish. Sterilisation of fishing equipment and boat hulls is being undertaken to help restrict the movement of zebra mussels (J. Carlton, pers. comm.). Now that we understand that animals can be introduced in algae used in packing, research on practical disposal and treatment, such as immersion of algae packing material in hypo-osmotic water, or replacing algae with biodegradable material may help avoid future inadvertent introductions.

CONCLUSION

The purposeful introduction of aquatic species is a management strategy to increase production and profits from fisheries. There are research and technological aspects of this strategy to which the precautionary approach can be applied. Implementation of Codes of Practice such as ICES represent the single best form of precaution in the purposeful import of exotic species. The codes require planning, approval, containment and both ecological and social evaluation. The methods and level of implementation will depend on local circumstances and resources. The documentation of the impacts of species introductions will also provide an increasing store of information that should be readily available through international organisations. By following the principles in the code, updating databases and other sources of information and then referring to these information sources, uncertainty can be reduced and the use of exotic species can proceed in a responsible manner.

Unintended introductions continue, the vectors by which these take place are known and measures to reduce the impact via these sources will require careful management to identify precisely how these risks may be minimised. A positive approach is to advise the public generally about the likely methods and consequences of introductions so that responsible action from the public is possible, recommendations to the trade and codes of practice should help to reduce unwanted introductions. The highest risk would appear to be from ballast water and sediments, further research into control methods and the biology of taxa contained in ballast water is needed to aid in ultimate recommendations for treatment. The use of the IMO Code, which recommends re-ballasting in the ocean may significantly reduce the viability of a ballast inoculation. If actions are not taken there will be a continuing trend toward cosmopolitan flora and fauna which will continue to impact human activities.

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TECHNOLOGY AND FISHERIES LEGISLATION

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Abstract

This document reviews technology adopted by the fishing industry. It explains how technology required to comply with international conventions has been further developed and adopted, on a voluntary basis, by the industry. It is suggested that in order to assess risks and reduce uncertainty, a thorough analysis should be made of the world's fleets of fishing vessels and fishing gear; that there should be a standard method for the measurement and classification of fishing vessels and gear; and, that fleet restructuring policies should be elaborated on the basis of a full understanding of technology required for the implementation of conservation and management measures (if they are to be effective) as well as to benefit industry. The document conclude that requirements for the adoption of technology, or development thereof, should be incorporated in legislation.

INTRODUCTION

Research and Development are expensive and those investing in such activities seek to capitalize on their work and look to the law to protect their interest. In this respect, the export or import of technology is often controlled by government decree and there are many examples associated with trans-national corporations, classified(military) technology and where its importation may give an unfair advantage to one or a limited number of local manufactures. Likewise, whilst patent laws, protect the interest of an inventor, they also provide a vehicle for control over its use as well as further development of the invention.

However, research and development is also concentrated to a great extent in developed countries. In fact, conservative estimates by UNIDO put the contribution of developing countries in this respect at no more than 6 percent (less if china is excluded). Consequently, many developing countries see a growing need for a new approach to international transfer of technology, particularly in the course of implementation of UNCED's Agenda 21. Recent trends have shown a greater interest in technology acquisition by developing countries and some have elaborated acts in this regard in response to their desire to promote and stimulate scientific development, research and technological capabilities, the precautionary aspects of which need consideration.

The following sections will address first the general issue of regulating fishing technology for management purposes and then present some thoughts about precautionary approach to such regulation, before offering, in conclusion, some guidelines about implementation.

1. THE REGULATION OF FISHERY TECHNOLOGY

Sources of technology

In general, capture fisheries benefit greatly from developments in technology arising from non-fisheries based industries. This is the case, for example, with regard to research and development in naval architecture, marine engineering, electronics and textiles without which there would have been little development in fisheries. Thus, laws promulgated for the purpose of fisheries conservation and management intended to restrict the transfer or development of technology, would not influence basic industrial research and development in the above mentioned disciplines. On the other hand, the fisheries sector does influence research and development to be directed towards aspects of capture technology by virtue of the market potential of the industry. Finally, the fisheries sector also causes applied research to be carried out, for example in the case of fishing gear design and properties (e.g., fuel efficiency, selectivity). A prime example of this being the development of Turtle Exclusion Devices (TEDs) in shrimp trawls; once the technology had been proven. legislation followed requiring its use.

Technology regulation

Subject to the provisions of UNCLOS 1982, each State may set conditions for the exploitation of stocks occurring in waters over which it has jurisdiction. Such conditions may also be applied to fishing methods and fishing materials. There is, therefore, ample license for a State to regulate the level of technology to be associated with the harvesting process.

In practice, many attempts have been made through fisheries legislation to restrict the importation of technology or to set limits within which a technology may be used, although these attempts have not always given the desired results. In fact efforts to restrict vessel sizes or power led to the development of "rule beaters" by the industry and some manufacturers simply rewrote their specifications to suit the law[1]. There are also many examples of technology having been held at a low level due to the general state of the development of the country concerned or for reasons of national security, trade agreements or labour considerations. However, given that the massive rate of increase in landings from the 1950' was attributed to the development of new technology and geographical expansion of fisheries facilitated by such development, few countries would appear to have placed too many restrictions on its adoption. This fact, combined with the growth rate of the world's fleets, led to the present situation where the overall fishing capacity is clearly out of proportion to the available living resources of the seas and inland waters.

Given also that future trends could reflect a decrease in landings from capture fisheries if management fails to improve, fisheries managers should take into consideration technical developments in fleet restructuring exercises and in doing so, they should evaluate the *risks* associated with the adoption or non-adoption of new technology, as the case may be.

[1] Regulations should include reference to specific internationally accepted standards for the measurement of performance. Those charged with the responsibility to implement regulations should have an understanding of such performance standards and their inter-relationship

Technology, safety and risk

Fisheries managers and legislators must first of all consider the risks associated with using the law to control the adoption and use of technology as a tool for the application of the precautionary approach to management of fisheries. Such risks arise, *inter alia*, from the fact that technology is developed and adopted not only to improve fishing efficiency but also to improve safety in maritime traffic, to comply with international conventions and laws on labour, and to enhance the well being of fishing communities. Regulations aiming at controlling or limiting the use of technology may also be in contravention with wider laws related to technology transfer, where, for example, a government has introduced basic acts to enhance the technological capability of the country.

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The inherent risks associated with maritime traffic have led to the development and availability of technology on the basis of which it has been possible to elaborate international conventions. Those countries ratifying such conventions legislate accordingly, requiring vessels to carry certain types of equipment and to carry out procedures that depend on associated hardware (and software). In such cases, the associated technical specifications for equipment are also internationally agreed. Furthermore, the time frame for the adoption of the technology under a convention, may take into consideration the age of ships, their size, area of operation, as well as the special needs of developing countries. For this reason, at any given moment in time, there is not a levelling out of technology in use world wide.

Within such international conventions, the safety of life at sea and protection of the marine environment play an important part and they set standards and regulations that can often only be met through **the adoption of new technology** and the bigger the fishing vessel, the more this is the case[2]. In addition, with respect to fishing vessels, such technology usually can be put to good use as an aid to fishing operations as in the case of the echosounder and navigation equipment, adding fishing efficiency to vessel safety (see Annex 1). In addition, many technological developments have been brought about through the need for increased efficiency, less crew, easier and safer working conditions and as a means to prevent marine pollution. Consequently, attempts to fishing vessels of some of their technical aids with the view to reduce fishing efficiency and capacity, may effectively render them uneconomic to operate and it could be illegal to do so with respect to national laws of those States that have ratified various international or regional conventions.

Technology and fisheries management

Traditionally, fisheries legislation sets out types of gear and methods that are permitted and where these may be deployed. In some cases, even the details of the type of materials allowed or banned are contained in the regulations. Furthermore, as mentioned above, legislation may also be enacted with respect to the selectivity of fishing gear and methods and this is clearly an area for further consideration. However, perhaps less attention has been given, in legislation, to matching gear to vessel types and power as well as matching investment in potential fishing effort with the level of available living aquatic resources. Indeed these are perhaps the main factors neglected in the past with respect to fleet development in general and the introduction of technology in particular.

It may be pertinent, therefore, to look at each type of fishery and associated technology (vessels, fishing gear and methods) in order to differentiate between the technology: (a) required by legislation in response to internationally agreed legal instruments; (b) freely adopted by the fishing industry, identifying the reasons for adoption; and (c) required to ensure sustainable use of fishery resources. Thereafter, the extent to which technology regulations could contribute to responsible management measures and precautionary approach to fisheries, could be assessed to ensure that they would not inadvertently decrease safety of life at sea while reducing threat to the resource or the environment. At the same time, the level of investment required from the fishers should be considered, with the associated commercial and social risks.

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[2] See protocol of 1993 to the Torremolinos International Convention on the Safety of Fishing Vessels, 1977

In this respect and given the general state of fisheries world wide, there are already identifiable situations where fisheries managers may have to resort to legislation and in which technology would play an important part.

Artisanal and small scale fisheries are already under severe pressure due to the generally high levels of fishing effort within inshore areas as well as competition with recreational, commercial and industrial fishers and other non-fishery resource users. As a result, the use of certain types of fishing gear is being restricted while commercial and industrial operations are being pushed farther offshore. The actual effects of legislation enacted in this respect vary according to the geography and demography of region, the availability of stocks as well as the capability of the vessels affected by the re-location measures to use other gear and move safely offshore. From experience gained to date, relocation of vessels to farther and deeper grounds and resources usually creates a need to refit them, update the technology they use, and even develop new types of craft in cases where the well-being of fishing communities and the continuation of their way of life is considered to be important. There are, however, instances where government policies are not so favourable towards fisheries and the law has effectively put fishers out of the business of fishing.

Past experience has also shown that there must be sufficient investment in credit and transfer of technology by governments as well as other incentives to the artisanal sector to get it to move part of his effort farther offshore, reducing pressure on coastal resources. There is of course a cost to both management and fishers and the latter have to recover such cost by earning more/greater efficiency.

Moving part, or all of the small scale fishing fleets away from inshore waters would also add to the complications arising from interaction with regard to larger vessels already operating within the contiguous zone and from the need to decide on overall levels of offshore effort and on theiur allocation among competing sub-sectors. Many of these larger are subject to regulations concerning their construction, manning and operation. High levels of competition among them have lead to the adoption of “borrowed” technology to increase efficiency. Thus the multiple use of electronics as well as communication systems and hydraulic transmission for which machinery is prevalent. Since care of the catch is usually crucial to their economic survival, the levels of technology in use in this respect may also be high. Without effort regulations to stabilize their incomes, the added competition for resources with re-located vessels would also increase the race towards improved technology that would decrease operational costs and increase efficiency. Managing fisheries through regulation of technology will therefore require: (a) matching fishing capacity and fishing effort with resources available, reducing fleet sizes where appropriate; (b) assessment of appropriate technology, satisfying both industries' and resources requirements; (c) the provision of access to investment/credit in new technology and training; (d) revision (and often simplification) of fisheries laws and regulations, and; (e) effort monitoring and control.

Larger vessels operating in EEZs and on the high seas are often purpose-built for specific fishing methods and although they may differ in configuration one to the other as may their target species, they must all be high earners to break even (subsidies not being encouraged in most cases). Many of the new entrants to this category are using state of the art technology, without it, they would not have attracted the necessary finance to build the vessels. Older vessels do not meet the same standards and have a lower technology co-efficient, consequently they look for alternative solutions to reduce high operational costs, some of which are in direct conflict with agreed conservation and management measures and some contrary to international labour agreements. This last category probably lends itself to the adoption of a higher level of technology as well as incorporating the requirements in legislation. However, to legislate for this sector, attention would have to be given, *inter-alia*, to: (a) improved financing arrangements for ship building (including vessel registration); (b) the trend towards increased automation; (c) provision of shore-to-ship services including weather prediction, satellite imagery related to upwelling, surface temperatures, chlorophyll concentrations and other productivity-related parameters; (d) education, training and certification[3] as well as compliance with labour laws, and; (e) effective MCS.

In general, using legislation for the diversification of fishing effort places a responsibility on fisheries managers to ensure that the numbers of those authorized to fish and their gear, are compatible with the available resources. Furthermore, management should take into consideration the probable fishing effort of those so authorized as well as their estimated break even point in terms of catch which means that management must have knowledge of the technical details of the vessels and gear to be deployed and of their performance under given management regimes.

2. APPLICATION OF THE PRECAUTIONARY APPROACH

From the above, a prerequisite for precautionary decision-making by fisheries managers would be a full understanding of fleet sizes and their composition together with knowledge of resources and their disposition as well an understanding of the impact of fishing gear, methods and practices on the environment.

With regard to vessels, such understanding would depend on records being as complete as possible and should include details of any improvements made during the life of a vessel. Many administrations do keep suitable records and maintain qualified technical staff to verify the information and to provide appropriate advice in the decision making process. What is lacking, however, is a uniform method of fishing vessel measurement and classification[4] through which the apparent fishing effort could be readily assessed for various fishing methods. In this respect, although many countries are beginning to keep records, these records do not always follows the same standards and fall short of the minimum requirements for the purpose of assessing: (a) potential fishing effort; (b) numbers and sizes of single gear vessels; (c) numbers and sizes of multi purpose vessels, and; (d) the fleet age/replacement curve/technology co-efficient[5].

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[3] In July 1995, IMO will convene an International Conference on the Standards of Training, Certification and Watchkeeping for Fishing Vessel Personnel; commonly referred to as the STCW-F Convention

[4] With a fleet of vessels of different ages, many even built under different regulations for the measurement of ships and certainly most with varying levels of efficiency, there would be a need to introduce an efficiency of technology factor in the classification process; to achieve this may take a considerable length of time

[5] In most restructuring exercises, the fleet sizes would have to be reduced. Furthermore, for each new vessel entering a fishery, more than one vessel would have to be taken out. The actual ratio would reflect the apparent increase in efficiency of the new unit compared to the fleet profile. This ratio, or technology coefficient, could vary from 1.5 : 1 to 4 : 1 or even 5 : 1 (see Annex 1)

Such information is only part of management requirements since it is equally important to be aware of the actual movement of fleets or even individual vessels. In this respect, the development and adoption of appropriate technology is essential to assure that managers have access to intelligence systems in support of rapid assessment mechanisms within the concept of the precautionary approach; it follows that historical fleets and technology records must be maintained and reference levels corresponding to dangerous situation estblished[6] while ensuring that the best scientific advice is available and used. It also follows that there must be effective monitoring, control and surveillance systems in place for which state of the art technology should be adopted in order to ensure:

- a two way flow of information from and to fishermen;
- more accurate reporting of catch (and discards) data;
- that the data collected through remote sensing and image processing systems concerning vessel operations are admissible as evidence in court.

With regard to fishing gear, methods and practices, and in addition to aspects of selectivity already mentioned, there would also be a need for a greater understanding of the effects of fishing activities on the environment. In this respect, it is probably premature to set generic and globally applicable indices of "friendliness" for gear and methods, related to their potential impact since much more research must be carried out with different types of gear, on the various species assemblages in distinct locations with particular bottom types and configurations before available gears and practices can be classified objectively in relation to ecosystems, stocks and local conditions.

However, in broad terms, the concept of classifying gears, methods and practices is reasonable with regard to their impact on the environment. The practice of dynamite fishing (or cyanide fishing) is already widely prohibited (equally widely used illegally) and the negative effects of bottom trawling on seabed ecosystems under certain severe conditions gives rise for concern even though there may also be positive effects; and in some places the common hook and line is blamed for damage to coral reefs. Certain types of gear are also prone to damage leading to loss and/or abandonment at sea and these contribute in no small measure to ghost fishing and environmental damage[7].

The gear technology presently available, may not be sufficiently developed to provide managers with a definitive planning management tool to allow then to readily assess all risks. but in general, there is suffient knowledge available, for them to react within a regime based on the precautionary approach and to use regulating in align gear and method " environmental indices" with authorised fishing areas(in space and time). Further there would always be the probability of uncertainly even if fishing effors were to be kept under strict control, early warning systems aould gives managers enough time to put in place contigency plans before disaster strikes a fishery.

[6] Such reference points could be established following accepted engineering principles to raise a warning sign prior to reaching danger levels in order to provide time to take appropriate remedial action

[7] The practice of incorporating biodegradable materials would be taken into consideration as would the likely effect of any increase in loss of gear or parts of gear due to the use of weaker materials. This subject is also referred to in the Report of the FAO Expert Consultation on the Marking of Fishing Gear, FAO Fisheries Report No. 485

With regard to a new fishery, or even the proposed introduction of new or different fishing gear and methods in an existing fishery, the level of uncertainty[8] should be assumed to be high *and the need for prior assessment of impacts and implications should be implicit*. Such assessment would most probably *require pilot operations to be conducted* simulating a limited commercial operation. Thereafter, should there be a decision to proceed on a commercial basis, the rate of expansion should be controlled and the results closely monitored.

CONCLUSIONS

The use of the "law" to limit the level of technology to be adopted for the purpose of applying the precautionary approach to fisheries, may not always be a straightforward and practical matter, particularly where vessels have been built with "state of the art" technology. Technology is not evil in itself and it is the way in which it is used (or misused) that gives rise to concern. Indeed many fishers rely on the adoption of recent technological developments to: (a) be cost effective; (b) secure a high level of safety, and; (c) make a real contribution to conservation measures (through the use of selective gear, predictive tools and techniques to reduce waste).

Fishermen are inventive by nature and stimulated by competition. They will always look for ways to ensure good returns for their efforts and ways to ensure that they can continue to fish in perpetuity. In order to ensure that fishing development is responsible, the following would be needed:

1. The law should be used to benefit both the resource and those engaged in fishing and the views of all concerned should be taken into consideration in promulgating legislation; the law should also hold all stake holders accountable.

2. A requirement should be incorporated in fisheries legislation, to adopt the technology, standards and administrative guidelines for the marking of fishing gear[9], as: (a) an aid to fisheries management; (b) a response to the recommendations set out in the guidelines for the implementation of Annex V of Marpol; and (c) a means to reduce the incidence of ghost fishing.

3. Legislation for the purpose of fisheries conservation and management should include regulations concerning fleet restructuring that would:

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[8] Much more research is required with regard to the incidential catch of birds, turtles and mammals. The kind of problem (with birds) which is closely related to longline fishing, is currently being studied and, in some cases, preventive measures have been successfully adopted and embodied in legislation.

In the case of turtles, considerable success has been achieved in relation to active gear. More research is required on the reaction of mammals to fishing gear with an emphasis on making full use of the natural means by which these animals communicate. In this respect, the use of acoustic technology and light reflection should be further developed

9 The report of the FAO Expert Consultation on the Marking of Fishing Gear, Victoria, British Columbia, 14– 19 July 1991. FAO Fisheries Report No. 485, may be used for reference although the system has not yet been adopted by the FAO Committee on Fisheries

a. Set the minimum standards for the construction of fishing vessels and performance standards for equipment related to the safety of life and property at sea as well as the protection of the environment;

b. Provide for the limitation of the growth in fishing effort by determining technology co-efficients for fishing vessels in order to arrive at ratios of new entrants to mandatory withdrawals from the fleet[10];

c. Give an internationally agreed definition of a fishing vessel by type, size and tonnage;

d. Classify fishing gear by selectivity ratios having regard to the maintenance of biodiversity, and by the allocation of environment indices, with regard to the protection of the environment;

e. Set upper and lower limits for the specification of fishing gears in relation to a fishing vessel as defined under para (c);

f. Regulate fishing gear, methods and practices to reduce discards;

g. Govern the conduct of fishing operations.

4. There should be a legal requirement for fishing vessels to be fitted with equipment that would facilitate vessel tracking systems[11].

5. In the case of new fisheries and/or the introduction of new fishing gears and methods in an existing fishery, there should be a requirement for prior assessment of the impact on habitat disturbance, biodiversity, as well as the socio-economic implications[12].

6. Requirements for the fishing industry to adopt technology to reduce the level of dangerous substances in exhaust gas emissions, as well as to phase out CFC's and to control the use of transitional substances (HCFC's), should be incorporated in legislation.

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10 Given that the average age of the fishing vessels of the world is in the order of 15 years, assessments could be made by taking 1980 for setting 1:1 bench marks; examples are given in Annex I. It being understood, that due consideration would be given to the level and periodicity of upgrading of individual vessels

11 It should be noted that this requirement is not limited to MCS functions. The requirements under "ship reporting" systems and vessel traffic separation schemes must also be incorporated in regulations

12 Provisions for impact assessments should be part of a statutory procedure and should include, inter-alia: (a) rules and specifications for the conduct of an impact assessment; (b) monitoring, control and review; (c) wide consultation with interested parties; (d) timely dissemination of information; and (e) appeal procedures

Annex I

TECHNOLOGY AND FLEET RESTRUCTURING

For the purpose of elaborating policies for restructuring fleets, a full analysis of the status of existing fleets and levels of technology in use should be made. The information so assembled could be used to determine vessel replacement ratios, establish decommissioning schemes and to calculate socio-economic effects of fleet restructuring policies. The introduction of "technology co-efficient" would greatly assist policy makers, with the co-operation of the industry, to arrive at agreed ratios of new entrants to withdrawals. Furthermore, it would also be possible to clearly identify technology and applications thereof for inclusion in legislation.

Estimated Technology Co-efficient By Vessel Types[13]

Vessel Type	Length (m)	Technology Co-Efficient		
		1965	1980	1995
Super Trawler	120	0.6	1	2.5
Tuna Seiner	65		1	1.6
Tuna Long Liner	65	0.5	1	2.3
Freeze Trawler	50	0.7	1	2.0
Purse Seiner	45	0.6	1	2.0
Stern Trawler	35	0.6	1	1.9
Long Liner	35	0.4	1	2.8
Multi-Purpose	25	0.6	1	2.5
Shrimp Trawler	25	0.5	1	2.2
Gillnetter	15	0.4	1	1.5
Trawler	13	0.5	1	1.8
Fast Potter	10	0.3	1	1.4
Pirogue	10	0.6	1	1.3

[13] As given in the text of the document, the year 1980 has been selected as the bench mark with 1:1 ratio. The table may be refined for specific fleets by taking into account operational patterns or tactics. Similarly, the bench marks (still on the basis of 1980) could be refined to compare vessel categories, provided that there exists an agreed classification of fishing vessels and fishing gear

Developments in materials of construction for fishing gear, fishing location and navigation equipment, catching methods, design and construction of fishing vessels as well as the development in post harvest conservation technology, were taken into account in assessing the "technology co-efficient[14]".

For the purpose of this paper, no attempt was made to compare efficiency between the various classes of fishing vessels since there would also be a need to analyze investment costs, economic and social factors. However this should not be neglected in the fleet restructuring process, just as, within the general classification given above, there would also be a need, in some fisheries to apply to the equation a factor relating to changes in operational patterns, but these must be done on a case by case basis.

[14] The Expert Consultation had access to an appendix entitled "Technology Development In Capture Fisheries" prepared by the author and is available from FAO

NOTE ON SOME LEGAL ASPECTS OF THE PRECAUTIONARY APPROACH TO FISHERY TECHNOLOGY: IMPACT ASSESSMENT, PILOT PROJECTS AND TECHNOLOGY CLASSIFICATIONS

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Abstract

This short note addresses there main aspects of a potential precautionary approach to fishery technology, namely Impact Assessemnt (IA), pilot projects and fishery technology classifications. These approaches could be used as part of procedures to be implemented before approval for new technologies, gears and practice is granted. The paper reviews the nature and scope of the IA, its control, and limitations. It looks at the contractual framework for pilot projects as well as their large scale appraisal. It also reviews the priniple and potential for using technology classifications as a means to facilitate agreements on the "friendliness" of fishing technology, as well as enforcement problems.

INTRODUCTION

The implementation of a precautionary approach to fisheries has still to be developed in practice. Some of the devices developed for environmental management could be used for fisheries management with the proper adaptation to take account of the particular nature of fisheries and of their impact. In particular, when considering the possibility to introduce a new technology, gear, of practice in an existing fishery or before authorizing the start of a new fishery, the precautionary approach foresees *inter alia:* (a) a mandatory requirement for a prior impact assessments (similar to the well known Environmental Impact Assessments, E.I.A.); (b) the implementation of pilot projects with adequate scientific analysis of the results through agreed analytical protocols; and (c) the reference to agreed fishery technology classifications elaborated at national or regional levels. These approaches are examined briefly below.

1. IMPACT ASSESSMENT

The following sections examine the legal bases and nature of impact assessment, the control and impact of its applications, its limitations and viability.

The Nature and Scope of Impact Assessment

Impact assessment is an important legal tool in environmental law and subordinates the implementation of any project to obtaining assurances that its repercussions on the environment can be appraised in advance and any necessary measures adopted to limit their scope to an acceptable level. As a preventive measure, this kind of assessment makes it possible to judge the viability of a project in terms of its environmental effects. Prior administrative authorization has to be obtained before planned activities can commence. The relevant authority takes its decision on the basis of the findings of the Environmental Impact Assessment. The project can then be either authorised or not, or if necessary modified, in order to take into account the conclusions of the environmental impact assessment. For an environmental impact assessment not only takes stock of a particular situation, but also proposes solutions to remedy any of the problems to which the scheduled work is likely to give rise.

It would be unrealistic to submit every project to an Environmental Impact Assessment, however. A preliminary selection may be made between the activities that require an impact assessment and those which are exempt. In the United States a prior appraisal is made to see whether a particular project should be subjected to an impact assessment in view of its importance and implications. Another method, such as the one used in France, is to draw up a list of the activities which require a prior impact assessment. A third way, combining the other two, also exists. This consists of drawing up a list of impact assessments to be carried out under certain circumstances. In cases for which no explicit provision is made a prior appraisal must be carried out to decide whether a scheduled activity should be subjected to impact assessment and added to the existing list. The fact that an impact assessment of a plan or a general programme has been carried out must not be used as a reason for not carrying out impact assessments for specific projects under that plan or programme.

Provision for the impact assessment must be made as part of a statutory procedure for granting authorization or issuing permits for specific activities (e.g. installing road furniture, industrial farming facilities, etc.). A specific authority or government department must be designated for this purpose with responsibility for commissioning and subsequently supervising the impact assessment. It should be empowered to make a decision subject to legal challenge on the basis of the conclusions of the assessment. Lastly, the administration must impose a set of specifications for the conduct of the assessment. They must set out a clear-cut but sufficiently broad and flexible framework to allow undetected aspects of the problem to emerge when the assessment is carried out.

Control and Impact Assessment

Four types of control are required over the conditions for conducting an impact assessment, and assessing its relevance and objectivity:

1. At all times the contractor must be able to appeal against an impact assessment which is not being conducted according to the statutory rules.

2. It must be possible to appeal against the licensing authority's final decision if it is in total contradiction to the conclusions of the impact assessment.

3. When the impact assessment is completed, the conclusions must be submitted to the authority which takes its decision after verifying its reliability. The authority ought to be able to control the whole performance of the assessment, thereby guaranteeing the best possible conduct of each phase.

4. The public must have the statutory right to be consulted during the performance of the impact assessment. The public should be given advance information in order to be able to take part in the impact assessment itself. Discussions should be organised to enable all the parties to debate their points of view, etc.

The petitioner and the government department concerned must give real and effective consideration to public opinion. The public must be given a right of appeal when they that the impact assessment in not being carried out in accordance with the law or when they wish to challenge its conclusions. The public must also be able to take legal action if the decision taken by the authorities appears totally in terms of the conclusion of the impact assessment.

The “public” comprises both individuals and corporations. With regard to impact assessment the right to challenge is sometimes subordinate to the existence of a real and proven stake. This is of vital importance because it is necessary to ensure transparency, even though the possibilities of appeal must be clearly defined. Appeals may sometimes be filed to obstruct the administration or the petitioners when studies are being carried out it measures are not taken to restrict litigation to the persons whose stakes are really affected by the project to be assessed. In the field of the marine environment, such parties may be associations of fishermen, environment protection movements, other users, etc. However it should not be forgotten that the environment, including the marine environment, is tending increasingly to become the “interest” or everybody, making it difficult to identify genuine stake holders.

The public can be informed through legal notices. This publicity should be adequately significant and not merely be a formal communication. All preliminary and specific information given to the public should enable it to submit relevant opinions and collect the broadest largest and most representative number of observations. To do this, facilities must be provided to collect options, and someone appointed to inform the public about the project. Prieur (1994) has put it this way: “In reality whoever actually carries out the impact assessment, the procedure should be such that the public is considered its co-author or the natural opponent if necessary, both to enlighten and assist the public administration's project promoter”.

Administration courts should be the normal fora for challenging impact assessment. The administrative courts generally have the power to issue penalties for non-compliance with the rules laid down for impact assessments or to irregularities committed in the course of conducting them. The civil and criminal courts should be used for cases in which the failure to implement or to properly conduct an impact assessment is deemed to have caused loss, damage or injury, e.g. such as the construction of chemical plant close to a residential area.

Individuals, corporations, associations, and petitioners considering that they have been harmed by acts or decisions taken by the authorities, or even by the public, should be able to take legal action. It must be possible for the parties to provide expert testimony to substantiate contrary opinions. Implementation must be halted while appeals are being examined. When examining appeals, the court should be able to issued interim orders suspending work until the final Judgment is issued, in order to preserve the environment and ensure that the sites, biotypes or landscapes that have been adversely affected can be restored or rehabilitated without incurring prohibitive costs.

Limitations of Impact Assessments

The cost and funding of impact assessments

The financial cost of an impact assessment should be related to the potential damage and represent a reasonable proportion of the cost of the project[1]. The contractor accept this cost as a supplementary assurance, like any other necessary preliminary survey or study, such as the resistance studies carried out by building construction firms, or market surveys before embarking on a commercial activity. The question is whether or not the contractor should be required to pay this supplementary financial charge. It is of course possible to claim that this cost, which is legally imposed by the State, is the responsibility of the contractor. However, it should not be forgotten that a measure of this kind might curb investment. With fisheries, it might seen reasonable to require private individuals to pay for the impact assessment prior to the installation of a fish culture farm or for harvesting a known stock using a new fishery technique. However, this might be unrealistic in the case of large geographical scale assessments on totally new and uncertain resources.

It would appear lawful for technical as well as financial public aid to be provided in certain cases such as when the State intends to promote exploitation of new resources involving an economic risk. However, when the private sector envisages new developments, it should bear the cost of the impact assessment. While it may seem logical to place the cost burden on the contractor, this approach must be nuance because it would tend to dissuade many entrepreneurs from investing in a preliminary survey which is often costly and fraught with uncertainty[2]. Government aid might therefore be necessary as a means to allow and indeed promote technical progress while supervising and controlling it.

Informing the public

Informing, consulting with and involving the participation of the public presupposes that both the contractors and the authorities must comply with certain democratic rules. Furthermore, this participation must satisfy two requirements. First it must be open and broadly based, but it must not be used deliberately by a minority to arbitrarily block a project. This is not always the case and the converse is still often true today, the contractor and the government having always a wide margin for manoeuvre. Secondly, confidentiality may need to be protected because future profitability may depend on keeping it a commercial secret at the outset and breaking into a narrow market very quickly (e.g. in the case of the culture of a particular species to met a targeted commercial demand). Solution to that problem may be found in other areas such as in the pharmaceutical industries where extensive tests are required before allowing a product on the market.

The reliability of and trust placed in impact assessments

it is essential to ensure that an impact assessment is reliable. If the contractor carries out its own impact assessment the results obtained will obviously be treated with some caution, which marks it important for the authorities, and if necessary the courts, to verify/assess its reliability. Even when the State is responsible for the project, the reliability of the impact assessment which the State has to impose upon itself must also be questioned. An alternative would be to commission a third party a research institution or a firm of experts, etc. to carry out ht impact assessment. However, total independence can never be fully guaranteed. (It should not the forgotten that employment can sometimes be used as a pressure in the case of negative conclusions of the assessment.)

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1 experience shows that the cost varies between 0.19 and 0.75% of the total cost, depending on the assessments

2 Unless this is an indirect way of preventing some form of development

There is a danger in "trivialisation" of the impact assessment and failure to lay down a specific set of specifications for it as such assessment would be worthless and just another bureaucratic procedure, to be carried out quickly and without substance. If this is repeated too often the procedure could soon be viewed with a certain mistrust both by the public and the authorities and result in a lax attitude.

2. PILOT PROJECTS

The Pilot Project: A contractual Framework

Pilot projects can also be viable in the framework of a precautionary approach to fisheries. They are not strictly speak a legal issue, but to ensure that they are effective, property specific rules must be laid down. Under a pilot project, the authorities have a wide margin of manoeuver in order to contractually impose the type of research, studies and experiments required when an innovation is introduced, or when new fishery zones are to be harvested, etc. The authority may also decide to have this kind of study carried out on its own account (e.g., in order to test a management measure). It could set out the programme for the pilot project by joint agreement with selected professionals. Moreover, the contractual relationship between the authority and the contractor provides the best possible guarantees to protest the economic interests (or "rights") of the "discoverer" of a particular stock, or the inventor of a particular technique. Lastly, in both financial technical and scientific terms, the direct participation of the authority in such cases facilitates the studies to be carried out.

Since the pilot project involves the partial implementation *in situ* of the planned activities, it goes much father than an impact assessment, which is not theoretically preceded by a specific activity on such a scale. In addition, the authority may directly carry it out or commission it. When the authorities are faced with a new technique, or an invention that they wish to test, the pilot project enables them to try out the innovation and measure its consequences.

With fisheries, the pilot project is more appropriate and more flexible that the impact assessment. It may be implemented by the authority on its own account. In terms of a third party, it certainly appears more consensual and less arbitrary than an impact assessment and establishes a contractual relationship. It may however be sometimes difficult to cancel a project when larger investments were made at pilot project level and it is therefore advisable to ensure that the probability of success is sufficiently high before allowing a pilot project to start.

Unlike the impact assessment, however, the pilot project does not from part of any statutory procedure that makes it a pre-requisite for authorising the implementation of a project. Neither does it create any legal constraints on relations with third parties, and it provides no specific means of appeal to the public.

Large—scale appraisal

The pilot project can therefore be likened to a " full—scale" experiment with a particular activity, gear, etc., controlled in terms of its timing and physical scope. The test monitored, the repercussions of the activity are studied and analyzed.

There are many advantages in such a full—scale appraisal. The pilot project does not run the risk of over—theorising, and its purpose must be to check predictions in the field. The pilot projects make up for the shortcomings of the impact assessment. An item of fishing gear or an innovation which brings about an improvement in terms of profitability might not be a threat to the environment *a priori*. Yet difficulties may arise when they are introduced on an industrial scale, which only come to light when tested on several ships: in other words, they may be revealed by the pilot project. Lastly, when an impact assessment is applied to fisheries, and is limited to a small scale, it does not easily allow to take account of the social environment. Various benchmarks based upon previous reactions of professionals to each of the problems that arise can, of course, be used. But the result will nevertheless always bean approximation. Conversely, because of its broad scope, an experimental trial can make it possible to analyze the social behaviour which is extremely important in fisheries. For instance, ITOs are a management strategy that may be considered innovative. While such a system may seem viable in theory, it was not until it was put into practice on a commercial scale that its limitations emerged mainly due to the social behaviour of the persons involved (high grading, concentration of individual quotas in a few hands, etc.).

Should the impact assessment and pilot project be viewed as two successive procedures? This may not always be necessary but, in view of a degree of uncertainty, it might sometimes be advisable to implement a pilot project after carrying out an impact assessment, provided of course that its results were favourable, in order to further refine the results. A group of fishermen could therefore request a pilot project to be implemented in order to verify the relevance of a particular type of gear in their fishery zone after it has successfully passed the impact assessment in another zone with the same features.

The pilot project can also be useful independently of the impact assessment. It is a system that can be used to compare the relevance of a particular fisheries management measure before bringing its application into general use. Thus the concept could be used to verify the relevance of a particular new fisheries management measure with the fisheries involved in the use of a particular fishing gear (e.g., a new mesh size regulation). This approach should, however, not be adopted by professionals as a means of challenging, delaying or preventing the adoption of a measure rendered necessary by the status of the fish stocks under consideration. It should also not be used by the sector to justify continuing tests with the sole purpose of protraction the commercial use of a particular item of fishing gear, or an innovation, on a limited scale serving only the interests of a small number of participants. If the gear or the innovation is hazardous on a larger scale, the small number of fishermen taking part in the pilot project that brings this hazard to light might find it financially to their advantage to protract the investigations, because that would enable them to continue harvesting. Conversely, when a pilot project demonstrates the viability of a particular technique, or the fact that no risks are associated with a new harvesting technique (deep water species) the fishermen taking part in that project will have every reason to ask for the investigations to continue because they fear competition. In either case, they skilfully create a monopoly position for themselves. Furthermore, the deadlines and the geographical scope of a pilot project must be clearly spelled out in advance so that there can be to complaints or pressures exerted to protract or expand it.

3. CLASSIFICATION OF FISHERY TECHNIQUES

The use of a system of lists is a technique used in many fields to regulate the trade in particular substances, and to govern certain activities. The design and the implementation of this approach varies in complexity according to the domain of application and adapting this system to fishery techniques may be more difficult than it seems.

The system of Lists in International Law

Using lists or classifications to govern the use of certain substances or techniques is extremely widespread even at the very highest level of the hierarchy of rules. Two international conventions provide good examples of the list system. One is the 1971 Convention on Psychotropic Substances which comprises four tables classifying psychotropic substances depending upon the threat they pose to public health. The Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and Their Destruction (signed in Paris by 130 governments between 13 and 15 January 1993) also has an annex containing three tables listing the toxic chemicals subject to controls. The products listed in Table 1 may not be transferred to States which are not parties to the Convention. Additionally, these products can only be used for scientific, medical or pharmaceutical purposes, or as protection against chemical or toxic products, or chemical weapons.

The last system is particularly common in environmental law. The "Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)" uses it. The species that are seriously endangered and threatened with extinction, or which are disappearing as a result of intensive trade are classified. This classification is coupled with specific conservation measures, such as a total ban on trade in all or some of these animals.

Very interesting examples of the system of lists to govern the use of products or substances are found in the Conventions on sea pollution. These Conventions set up a classification system (usually through lists, tables, or annexes) for the pollutants, whose dumping or incineration are regulated. Thus the Oslo Convention for the Prevention of Marine Pollution by Dumping form Ships and Aircraft, of 15 February 1975. Which applies to the Northeast Atlantic, contains two separate lists of products of substances for which prior authorization is required before dumping. The 1972 London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter follows the same procedure. Both Conventions provide that the substances or products which are not set out in the pre-established lists can only be dumped if the competent authorities approve (Article 7 of the Oslo Convention) or if a "general permit" is first obtained (Article 4(1) of the London Convention). These lists, sometimes known as "black lists" and "grey lists", are periodically updated.

Potential Application to Fisheries Law

Before this system can be applied to fishing operations, it is necessary to resolve the difficulties relating to the classification of fishing gear and to check the effectiveness of the lists. Both aspects are examined below.

A sensitive classification

It is tempting to set up a system which makes it possible to classify fishing gear in terms of its impact on the environment. The principle looks simple, and has the merit of being understood by all, particularly public opinion which would have an easy way of setting off the "good" against the "bad" fishing techniques classified, for example, in terms of a red list and blue list. There are some problems, however, related to the criteria to be adopted for classification, the diversity of environments and gears, and the process of updating. These three issues are addressed below.

First of all, it is necessary to define exactly what is to be classified and in particular whether one should only classify fishing gear or fishery techniques, or also the devices used to assist fishing in general (such as the use of satellites for tuna fishing). A second question relates to the procedures for classification and the benchmark elements by which to differentiate objectively between different types of fishing gear and technique. If the concern is responsible fishing and sustainable development, the classification of the fishing techniques and gear should be based on criteria that will guarantee them. Aspects such as the least possible impact on the biotope, selectivity, the best yield/energy consumption ratio, the nutritional quality of the catches, etc., could also be used. This makes it possible to object, for example, to the use of poison or explosives, or to favour otherwise more selective or environmentally friendly techniques, such as the harpoon or the hook. However, examining the issue more closely reveals other examples which show that this approach is not always that straightforward, as discussed below.

A given type of trawl differs in terms of selectivity as soon as its mesh is changed. The same applies to gillnets. Other minimal changes in one of the parameters of the fishing gear is enough to change trawling behaviour. Increasing the webbing of a gillnet on the type of otter-boards of a trawl or merely the propeller system of the trawler, or the size of the hooks on a long line, or the depth at which it is set, modify greatly the properties of a gear and complicates its classifications. In addition, the biotopes for which different harvesting techniques are used should also be considered. Bottom trawling has different effects in areas colonised by posidonia, seagrass, on muddy grounds. or on rocky seabeds. It is therefore vital to take account of all the different situations that might arise. For example, the 1973 International Convention for the Prevention of Pollution From Ships, signed in London on 2 November 1973 (Marpol Convention) laid down the maximum limits on the release of hydrocarbons from ships, depending upon the areas in which it takes place. Closed or semi-closed seas, for example, are more strictly controlled because of their particular situation (for example the low rate of water exchange. Drawing up lists of gear in terms of previously defined criteria (such as sustainable development or low bottom disturbance) is therefore only relevant if these lists also refer to such data as the biotopes and the species involved.

The 1961 Single Convention on Narcotic Drugs (see the report of the Permanent Central Committee for 1965 E/OB/21) was a failure because it only dealt with the "classical" drugs made from natural products and did not consider (or foresee) the arrival of synthetic drugs. Sufficiently broad definitions should be found to include all types of fishing gear or changes to fishing gear or techniques in this list system. Therefore, to prevent such a system from rapidly becoming obsolete, from a technological point of view, a continuing updating procedure must be designed to include new fishing techniques on the list, and make any other relevant changes to them.

A possible application

The adoption of a list system could lead to a total ban on certain techniques (e.g., poisons, explosives) or a partial ban depending upon the area concerned (e.g., banning bottom trawling in spawning zones) or for particular species (e.g., banning the tanglenet for harvesting shellfish). Other gear could then only be used if certain features were introduced to make them more selective and more biotope-friendly. Certain techniques would be encouraged because of their particular suitability to enhance catches, or because of better energy-use or lower pollution levels, etc. Because of the need for location-and stock-specific lists, their establishment should be best established at regional and sub-regional level even though international guidelines and generalized assessments could be usefully developed.

Evaluations of new gear and techniques, for the purpose of inclusion in the list should be carried out under the responsibility of the fishery resource management and conservation authorities.

A system of this kind has already been partly effective for a long time, even though as far as we know there is no general listing system anywhere. Fishing gear use is often regulated in terms of the fishing zones, and some types of gear are prohibited in certain zones or for harvesting certain species. Such regulations exist in many countries. Examples of their enforcement show how difficult it is to guarantee compliance with such a system, which could appear to be too rigid if based upon a list system.

Enforcement Difficulties

A list system may be more easily enforced in an EEZ, under the sovereign rights of a particular State. On a regional scale, it is only through international cooperation that such a system could possibly be brought into force. The establishment of a regional list will require debate and negotiations. The debate on the merits of each technique is likely to become heated depending upon the interests of the various users involved. In the fisheries field, disputes between different trades are extremely common. The effectiveness of the system will depend upon the effectiveness of the regional monitoring and control system set in place. There are dozens of parameters that can be used by fishermen to change the properties of fishing gear in relation to the resource or the environment and their cooperation would be essential to ensure the success of the system.

CONCLUSIONS

An impact assessment makes it possible to stand back objectively and examine a particular situation before deciding whether to implement a particular project. It enables both the authorities and the public to participate in designing a project. The human and financial investments involved make it possible to prevent dramatic repercussions on the environment with socio-economic repercussions that in many cases are out of all proportion to the initial cost of the assessment. If the assessment is set in a legal and administrative framework that is strictly adhered to, respecting the right to information and the right of appeal, it can be not only a legal but also a scientific tool of vital importance in the environmental field. The more objective and transparent the impact assessment is, the more easily will it be accepted by all the parties involved.

However, there are various obstacles to using the impact assessment. It must therefore form part of a specific legal framework, respecting the rights of all the parties concerned, requiring transparency in its drafting and the public disclosure of its results, while leaving the possibility open to the government, third parties or the contractor concerned to appeal in the event of failure to comply with these procedures.

A listing system to classify fishing gear might be an appropriate way of improving fisheries management. This system could take account of technological developments providing for their systematic appraisal. To cover all sources of efficiency they should ideally take account of the possibility to use such devices as satellite positioners, fish attractors, sophisticated sounders, computer assisted piloting systems, etc.

The procedures established to appraise new development will make use of impact assessment procedures described above or may require a pilot project. This illustrates the close linkage between pilot projects, impact assessment procedures and gear classifications. The combined use of these approaches in any management systems would make it possible to implement a truly preventive action and would introduce a clearly precautionary character in the system.

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