This is more difficult than we thought! The responsibility of scientists, managers and stakeholders to mitigate the unsustainability of marine fisheries

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The management of marine fisheries needs to undergo dramatic change in the new millennium, in response to the well-documented evidence of global overfishing and the general depletion of commercial fish stocks. The axioms of sustainable development and equilibrium productivity of wild ecosystems are identified as misleading concepts, which nonetheless underlie current approaches to the management of living marine resources. Current trends in marine fisheries landings worldwide provide little evidence of sustainability of marine resources under current management paradigms, where biological, economic and social aspects of fisheries are usually treated as different disciplines. While open-access conditions are less widespread than formerly, except for many straddling and highly migratory resources, fishers usually have access to the resource year-round throughout its range. Despite quotas, the nominal control of capacity and technical measures protecting juveniles, top-down management has generally been unable to prevent stock depletion, particularly of the older spawners that for demersal stocks often support recruitment.

An integrated solution to the complexity of managing wild resources seems not to have been achieved. Any new paradigm should assert the basic unpredictability of fisheries at the system level and require a broader range of performance indicators to be incorporated into the decisional framework. This must reflect the non-equilibrium nature of marine systems, and give greater importance to resource (as opposed to harvest) continuity in the face of regime shifts, and promote habitat restoration and conservation of genetic resources.

The new management framework requires co-management and collective decision-making to be incorporated within a precautionary and pre-negotiated management framework. This must explicitly recognize that decision-making occurs in conditions of model-based uncertainty and precautionary approaches should be incorporated at all levels, not least of which is to avoid the assumption that all resources can be harvested in a sustainable fashion through time. Redundancy in data inputs to management are needed to avoid the surprises that model-based sampling occasionally leads to, for example, when regime changes reduce productivity in response to climatic fluctuations. Emergency frameworks imposing non-discretionary rules must be invoked when overfishing and/or regime change trigger reference points indicating stock depletion. Non-discretionary recovery plans should then override rights-based systems and persist until fish populations recover to pre-established healthy levels, which may in turn need to await the return of a favourable regime.

In fact, some stocks may require periodic rebuilding after regime-induced collapses or because of a combination of ecological or economic impacts, hence a constant harvest policy may not always be possible. It will probably also be necessary to discard the axiom that a stock should be available to harvesting throughout its range and seasonal cycle. Technological advances mean that time- and area-specific access rights are now practical options, through satellite monitoring of vessel operations, even offshore.

More fundamentally, the basic axiom of 'enlightened self interest' underlying current methods of management will need to be tempered by an increased ethical concern for the fragility of natural ecosystems.

Keywords: non-sustainability; fisheries management; stock assessment; socio-economics

1. INTRODUCTION

(a) *The concept of sustainable development and fisheries management*

The implication of sustainability as a continuous train of benefits is not supported by experience with many world

fisheries (Caddy & Gulland 1983; Caddy *et al.* 1998; Garcia & De Leiva Moreno 2001). As data series for most well-established established fisheries approach or exceed a half century (see Grainger & Garcia 1996), it is evident that few single-species fisheries are stable production systems; in fact, a growing proportion are in decline (FAO 1995). Even when exploited 'optimally', evidence suggests that some species respond with pronounced stock-size fluctuations to long period climatic signals. Others are frankly intermittent

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Figure 1. Diagram to illustrate that many straddling and most highly migratory stocks require negotiation, not only between coastal States and DWFNs, but also between contiguous coastal States.

in production (Caddy & Gulland 1983; Spencer & Collie 1997), and for these, the yield is certainly not 'sustainable' in time in the conventional sense.

Spencer & Collie (1997) classified stocks into six categories, on the basis of their history of production. Apart from the categories I (steady state) and II (low variation and frequency), which can probably be managed by a modest 'steady state' approach, categories III (low frequency, cyclic), IV (irregular), V (high variation and frequency) and VI (spasmodic) would seem to require discontinuous management approaches. The emphasis should be on ensuring an adequate minimum population survives a poor recruitment regime until high productivity conditions return (Parma 1990; MacCall 2002). For the high frequency of stocks that are in categories III–VI, a constant catch regime unless maintained at very low levels is untenable, and a constant exploitation rate regime will be preferable, but will probably need to be adjusted in periods of poor recruitment. In fact, for resources that show very variable productivity, it would be ideal if exploitation rates slowed when stocks were in the 'trough' of the production cycle. Out of two frequently cited management paradigms, constant exploitation or constant escapement regimes, Walters & Parma (1996) opt for the former, urging the fishing industry to absorb the inevitable fluctuations in supply associated with this strategy under fluctuating resource productivity. They are less sanguine about the possibility of managing marine fisheries by the constant escapement criterion, although for spasmodic stocks such as Japanese sardine, this may be a more realistic possibility.

It also seems that overexploitation enhances recruitment variability, even for 'steady-state' stocks. By contrast, the axiom of 'sustainable development' followed at United Nations Conference on Environment and Development and embodied in other international agreements on living marine resources, is usually regarded as synonymous with steady or even increased exploitation. Various developments in the increasing efficiency of harvesting, transformation and transport of fish to markets are not compatible with this concept. Industrial-scale operations, a general

lack of access control and growing demand from efficient global markets for fish, mean that the growing proportion of yields coming from developing countries are diverted to hard currency areas (Caddy & Cochrane 2002). Apart from its management implications, this impacts (figure 1) upon the food security and earnings of developing country coastal States, calling for very careful access agreements (see Martin *et al.* 2001).

The definition of sustainable development followed by the World Commission on Environment and Development (1987) was: 'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.

This summarizes one of the fundamental axioms underlying current approaches to resource management, namely that it is expected that the resource will continue to sustain human needs into the future in a 'sustainable' fashion. Thus, it incorporates the idea of 'development', defined by the *Oxford Encyclopedic Dictionary* (1991) as 'a stage of growth or advancement' and 'sustainable development', which implies that such development is likely to continue. In practice, the idea is that countries, especially in the developing world, may expect to receive a train of benefits, sustained over time. This will tend to some form of equilibrium, and can be maintained at or around this level by enlightened management. At the time of negotiation of the Law of the Sea, the concept of a sustainable target level for managed fisheries was generally focused on the MSY, assumed to be sustainable at equilibrium by manipulating the level of fishing effort. Subsequent experience embodied in the 1995 UN Fish Stock Agreement and the 1995 FAO Code of Conduct for Responsible Fisheries, and spelled out by authors such as Larkin (1997), now implies that MSY is a dangerous target for fisheries management. This is owing both to the low precision of our knowledge of stock status, and because environmental change and spawning stock depletion accentuate fluctuations in productivity and cannot be tracked precisely by management using the limited and high-variance data available. In practice (e.g. Beddington & May 1977), resources are much slower to

return to equilibrium once MSY levels of fishing have been surpassed. Even if declines in resource productivity can occasionally be forecast, the immediate short-term reductions in exploitation rate after recruitment failure are large for a stock fished close to MSY with its heavy dependence on incoming-year class strength. This will be difficult to achieve through social consensus in real time, and management frameworks for single-species industrial fisheries are not adapted to rapid cutbacks in effort in response to sharp drops in ecosystem productivity. On the contrary, occasional good recruitment years inevitably promote further investment in fleet capacity.

Thus, we can say that so far, the ideal of sustainable development is not being realized. It would therefore seem useful to list some of the reasons why this is so, rather than simply continuing to assume that sustainable development is a realistic objective under present fishery management paradigms.

Issues about the lagged effect of unwise over-investment on fleet capacity are complex, but can be encapsulated under the heading of the 'ratchet effect' proposed by Caddy (1982). This concept summarizes the irreversibility of increases in fleet capacity over the medium-term, in part because of the potentially long lifetimes of industrial-scale vessels, which with maintenance, typically range from 20 to 50+ years (Caddy 1993a).

Market demand and prices have increased with scarcity in an elastic fashion over recent decades in response to the growing efficiency of international marketing of fish, thus increasing the incentive to invest in capacity. Because investment often follows the 'peak' of resource production, fisheries managers in effect have to deal with the after-effects of 'fossil' investment, and vessel owners who invested in a period of declining resources are left with inadequate returns to pay off their capital investments. Under these circumstances of evident imbalance between resource productivity and capacity, once catches are cut for conservation reasons, the call for subsidies becomes inevitable.

Formerly, artisanal fleets with generally shorter lifespans of approximately a decade (Caddy 1993a) showed a shorter response time to resource changes. In such 'primitive' or artisanal fisheries, as for most modern inshore fleets, polyvalence allows an easy change between targeted resources in response to changing relative abundances and market conditions, and access tends to be geographically delimited rather than fixed by quota. In contrast to this relatively more self-regulating system, single-species quotas taken by industrial vessels require that high capital investment continues to be deployed in the face of stock declines.

The above may be a partial explanation to the non-sustainability syndrome in both industrial and artisanal fisheries of the world, but the situation is undoubtedly more complex. Garcia (2000) points out that the main factors leading to non-sustainability are the lack of conservation of the resource base, and the inadequate orientation of technological and institutional changes. More recently, in the Bangkok meeting organized by the FAO in February 2002, the non-sustainability of fisheries was attributed by Greboval (2002) to five main factors.

- (i) Inadequate incentives and subsidies that stimulate overcapacity.
- (ii) Growing demand on limited fish resources.
- (iii) Poverty and lack of alternatives for coastal development.
- (iv) Fishery complexities, incomplete knowledge and the associated uncertainties.
- (v) Lack of solid governance structures.

The last factor includes the lack of a closed 'management cycle' (figure 2), through which governments, fisheries management institutions, stakeholders and scientific advisors can interact and implement in real time appropriate policies, plans and management strategies, to ensure that fish resources are used in a responsible manner. Despite theoretical advances in fish population dynamics, it is arguable that it is at the interface between scientific advice, stakeholder input, and management and political action that most failures in management arise.

It is still not always taken into account that apart from fishing, stocks also fluctuate owing to natural causes. For pelagic resources, major stock fluctuations occurred even before human exploitation (Soutar & Isaacs 1974). These fluctuations have been best documented in relation to the El Niño/Southern Oscillation climatic phenomenon, especially as it affects production of small pelagics in the eastern Pacific (see, for example, Lluch-Belda *et al.* 1989) but also occurs for other resources, and elsewhere (Cushing 1982; Southward *et al.* 1988). Similar climatic forcing factors have been affecting marine production systems at a global level (Kawasaki 1992; Klyashtorin 2001), and long-term fluctuations will be reinforced by climate change (Kelly 1983; Glanz 1990). Ice corings and tree rings confirm longer-term periodicities than those available from most fisheries data series. Thus, although 'decadal' periodicities are frequently mentioned in the fisheries literature (e.g. Zwanenberg *et al.* 2002), Klyashtorin (2001) suggests that natural cycles in productivity of *ca.* 50–60 years duration are likely to be dominant. Coastal fishery resources are also vulnerable to other human activities that may affect critical habitats and/or biological processes (Caddy 1993b; De Leiva Moreno *et al.* 2000). In fact, the role of environmental change has become more evident in recent years as fisheries data series of all but the longest-established fisheries exceed 50 years in duration. However, our ability to discriminate between natural environmental changes, the effects of fishing and other human activities remains poor.

2. KEY INTRACTABLE FACTORS CONTRIBUTING TO NON-SUSTAINABILITY AND APPROACHES TO THEIR MITIGATION

The ineffectiveness of management measures might be blamed on the unwillingness of managers to introduce and enforce adequate conservation measures, or the avidity of the fishing industry to maximize its profits, but it seems likely that the situation is a good deal more complex, with some key problematic issues also falling within the sphere of biological advice. A variety of problems are discussed separately in this text, but we are under no illusion that we can offer an improved integrated approach to fisheries management, though fishery managers have admitted that we will need to look at the problem with a completely new

Figure 2. A typical example of the 'closed management cycle' exemplifying 'rational management' by fishery commissions and national authorities. The smooth functioning of this mechanism often breaks down within the top left-hand box (catch negotiations), but also because the time-lag between establishing stock status and implementing a hopefully appropriate management decision over an annual cycle may be slow in reacting to significant population declines produced by high-capacity fleets.

perspective (FRCC 2000). Listing the various problems encountered with the concept of sustainability will not automatically lead to integrated solutions, but one must start somewhere. Some components of a solution are therefore proposed under the title 'mitigating factors', for a series of problem areas, which may compensate, in part, for the particular destabilizing mechanism described.

3. RECENT TRENDS IN WORLD FISHERIES

The FAO (1995) diagnosis of world fisheries trends was that an increasing proportion of marine fisheries are becoming overexploited or depleted, which seems to have been confirmed by subsequent analyses (Garcia & De Leiva Moreno 2001). The years when maximum landings were recorded in each FAO statistical area showed a progressive delay as industrial fisheries rapidly expanded from 'core' areas off developed countries to operate as distant water fleets, and developing countries also expanded their own levels of production over the 1970s and 1980s (Caddy *et al.* 1998). The niceties of fisheries management have followed more slowly, often arriving well after exploitation has depleted stocks. In fact the speedy growth of a global market for fish, and of new technologies of fish location, capture, processing, storage and transport, have all outstripped the capacity for management control, especially but not exclusively, in developing country regions.

Mean sizes of fishes have also declined owing to overfishing (Pope *et al.* 1988), in part because of fishing down marine food webs (Pauly *et al.* 1998), but in some areas nutrient enrichment by enhanced production of planktivores low in the food web has also reduced mean trophic level. Demersal production has also been particularly impacted because of hypoxic effects in eutrophic waters

(Caddy 1993a; De Leiva Moreno *et al.* 2000). Rapid developments in capture and processing technology have not been paralleled by similar increases in the efficiency of control measures (Caddy 1999a). In developing countries, rural poverty and the lack of government infrastructure generally means that it is hard to recover rent from national fisheries for use in MCS, data gathering and research. Hence, after international sources of aid have run out, licensing access by distant water fleets to the resources of the EEZs remains the main option for extracting rent from some developing country resources (Martin *et al.* 2001). This leads to 'drainage' overseas of fish products often needed for domestic food security, into a sophisticated global market in hard currency (figure 3).

4. NON-SUSTAINABILITY AND THE PRECAUTIONARY APPROACH

The most disturbing evidence of the non-sustainability of marine fisheries is from areas where the maximum densities of fisheries scientists operate: the North Atlantic, and where our understanding of the fisheries ecosystem, although still incomplete, is best developed. This argues that the solution to proper management, if it is to be found, will not be through improving science alone. In fact, further development of the conventional management approach which describes first the state of the resource, and only later decides how it is to be allocated, has been proven unsuccessful by the events of recent decades. The FAO (2003) refers to this approach as TROM, as opposed to the more favoured idea of EAF put forward at The Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem, 1–4 October 2001. A similar perspective to TROM, which also discourages new initiatives, was referred to by Henry Regier (personal communication) as

'based on sound science'; i.e. discouraging speculative thinking outside the permissible envelope. In the case of fisheries management, this risks being translated into 'sticking to the established paradigm'—even if this paradigm has been disproved by events as a useful guide to management. For some time, there has been a wide acknowledgement by marine fisheries science and management that the EAF is logical, but the contrast between the specifications for EAF laid out in FAO (2003) and reality is quite stark. Few practical approaches to ecosystem thinking seem to have been applied by management, other than the understanding in some fisheries that it is important to allocate a share of the TAC of forage fishes to top predators, or that overharvesting predators on sea urchins leads to the decline of kelp forests (Pinnegar *et al.* 2000). From the growing adoption of the precautionary approach in fisheries management, we deduce an implicit acknowledgement of our inability to predict events in a complex multi-species system and translate them into quantitative management advice. Hence, we cannot avoid uncertainty as to the current situation of the resource, but we are similarly uncertain as to the appropriate model to apply to quantify resource fluctuations, and hence also the appropriate EAF measures to apply. Although precautionary management (Anon. 1997) seems our best hope, it is worth noting that measures believed to be precautionary tend to reflect current perceptions as to what are the important factors influencing the state of the resource.

In other words, even 'precautionary responses' depend to a significant extent on the current paradigm influencing our thinking, and as noted, a key element of most current paradigms is the assumption that resource harvesting must be sustainable. Thus, our 'precautionary guesses' are still largely influenced by an existing world-view that is slow to change. Although a paradigm shift seems inevitable (Caddy 1999a), we have only imprecise ideas at this time where this will lead us, and as a consequence, must continue to place emphasis on empiricism supplemented by a wider range of data monitoring than with present model-driven approaches (Seijo & Caddy 2000).

5. OPERATIONALIZING THE PRECAUTIONARY APPROACH AND 'MANAGEMENT PROCEDURES'

Current management approaches tend to see data on resource status embedded in indicator series, which may assume specific values requiring action, referred to as LRPs (Caddy & Mahon 1995). The so-called 'management rules' now in operation appear to depend heavily on only a few fisheries indicators such as an estimate of the recent fishing mortality rate, the (spawner) biomass, and past data on the density dependence of recruitment on spawning stock size. Biomass estimates are often derived from analysis of landing data and/or fishery surveys. Fishing mortality estimates and SRRs come from retrospective analysis of catches and vessel surveys using best estimates of age and size composition, analysed retrospectively using constant parameter values of natural mortality rate. This low 'redundancy' in information sources and the use of constant parameter analyses may be inevitable, but means that it is impossible to track (except after a cohort has passed through the fishery) the impact of regime changes and the fluctuating (or declining) productivity of the ecosystem.

Thus while Monte Carlo or Bayesian methodologies may be applied to reintroduce variance into simple deterministic fishery models, the problem of model uncertainty remains. Most approaches currently used tend to support the existing paradigmatic structure of sustainability or continuity of production, through the implicit use, however heavily disguised, of the 'equilibrium assumption'. The paucity of indicator series in current use and the inflexibility of decision rules where these are applied therefore provide no guarantee that environmental 'surprises' will not 'upset the apple cart'. In fact, two recent decades of experience in the northwest Atlantic have shown that radical reductions in effort will not automatically lead to rapid stock restoration when regimes are unfavourable, nor can density-dependent 'compensation' by better recruitment always be relied upon after a stock declines.

(a) *Mitigating factors*

Management 'rules' such as the Magnuson–Stevens Act in the United States require that action be taken to restore stocks when either the biomass falls below some precautionary minimum or the fishing mortality applied exceeds an allowed maximum. Such an approach incorporating a 'management procedure' (Butterworth *et al.* 1997; Kirkwood 1997), into overriding legislation seems appropriate, with pre-negotiated responses agreed in advance to 'bad' events showing up as dangerous values of the fisheries indicators monitoring the stock, so that timely action may be taken. However, while a procedure (as specified in the upper section of figure 4) may be appropriate for a high productivity regime, it may not be so in a low productivity regime such as shown in the lower section of figure 4. Several authors (MacCall 2002; Parma 2002) have called for specific changes to fishing strategy during unfavourable regime conditions, mainly aimed at ensuring survival of some spawners until a favourable productivity regime returns. Experience begins to suggest that some index of the variable productivity of the system and its environmental driving functions needs to be incorporated into the management system, but this may need to be addressed empirically rather than waiting for an analytical framework.

'Operationalizing' the precautionary approach led to the idea of limit RPs (e.g. Caddy & Mahon 1995) as critical values of fisheries indicators that mark the onset of dangerous conditions. The switch from the over-confident identification of 'target RPs' such as MSY or $F_{0.1}$, to the less ambitious objective of attempting to trace uncertain boundaries to areas of sustainability, entered in 1995 with the UN Fish Stock Agreement and the FAO Code of Conduct for Responsible Fisheries. On approaching such boundary conditions, appropriate pre-negotiated responses are called for, but there is little evidence that this provision is often put into practice. LRPs are critical values of 'fisheries indicators', and are our best estimate of when the resource system, having left a 'safe' or 'green' condition, enters next an uncertain or 'yellow' stage, before the onset of 'red' conditions associated with overfishing, recruitment collapse and ecosystem change (figure 4). The Traffic Light System (Caddy 1999b) was originally suggested as a way of using multiple indicators and their critical RPs for managing populations of invertebrates where age structure information and SRR-based RPs were not available. The idea was to use a range of simple indicators measuring

Figure 3. Illustrating the problem for coastal developing States in satisfying both food security needs and hard currency requirements. Generally, the needs of the global market in high currency takes precedence over national markets satisfying local needs for protein.

Figure 4. Illustrating how a management regime supposedly based on controlling both fishing mortality and biomass, if appropriate for a high productivity regime (above), may require the minimum biomass to be raised and the fishing mortality reduced under low productivity (below) if the population is to persist until the environment returns to higher productivity: a period that may require a decade or more (see Klyashtorin 2001).

quantifiable life-history characteristics, scored initially into red or green if they fell on one side or the other of a value which analysis, past experience or biological studies suggested to be an appropriate LRP. The proportion of LRPs of a set of multiple indicators in the 'red' zone (figure 4) was proposed as a way of determining the increasing severity of management response. Halliday *et al.* (2001) developed this concept further, by considering several options including yellow as transitional between green and red to represent a precautionary or uncertain condition of the stock, and proposed various formulations for transitional situations, involving fuzzy logic, ramp functions, etc. Irrespective of the fact that these are options for handling multiple indicator series, the use of colour coding for indicating the status of a fishery (e.g.

figure 4) adds to the immediacy of the management measure proposed, and its urgency and ease of explanation. The need to somehow take regime changes into account remains largely an open issue, but one suggestion for addressing this is shown in figure 4.

6. AN ERRONEOUS BIOLOGICAL OR ECOLOGICAL PERSPECTIVE

(a) *Inappropriate equilibrium assumptions*

In the 1980s it was recognized that assuming equilibrium conditions in population models that specify constant parameter values without error terms was inappropriate for marine fisheries where year-to-year changes in recruitment, fishing effort and changes in ecosystem dominance all occur, especially when the ecosystem is stressed by heavy fishing effort. Therefore, equilibrium assumptions were supposed to have been abandoned in using the production modelling approach in the early 1980s (Hilborn & Walters 1992). The use of 'constant parameter' values in other fisheries calculations, such as in retrospective analysis and stock projection, is still widespread and, it must be said, inevitable, given the lack of precision in our knowledge of variations in parameter values and key variables. More recent modelling approaches incorporate Monte Carlo assumptions which allow parameter values to vary randomly, but very few (e.g. MacCall 1983, 2002) incorporate evidence for periodic changes in productivity (Cushing 1980). These are now seen as often involving so-called regime shifts (Steele 1996), whose reality is now being accepted in climate research, and they are dominant components of the so-called 'abiotic driving factors' of fishery production. In many cases, 'equilibrium assumptions' in stock assessment often pass unrecognized as such, and we assert that these are functionally equivalent to assuming that 'sustainable development' automatically occurs, at the management/socio-political level.

One example of an equilibrium assumption is the uncritical use of historical databases of SRRs for population projection. SRRs were generally fitted to data on stock size and

recruitment collected when fisheries were operating during favourable environmental regimes, and the points corresponding to years of good recruitment earlier in the fishery occurred when the ecosystem was largely intact and stock sizes were healthy. This tends to lead to exaggerated expectations when SRRs are used in prediction in poor regimes. Values for spawning stock size and recruitment in turn came largely from retrospective analysis using constant parameter values for natural mortality, and often constant values for growth or size-at-age. Thus, RPs based on SRRs constructed from historical SR data, such as F_{REP} (Sissenwine & Shepherd 1987) are only as good as the SRR generating them. It is not intended to criticize this particular RP, just to illustrate that RPs derived from models are not infallible or necessarily better than those obtained using judgement, historical experience and common sense. As implied above, there are potential problems in using SRRs to predict the speed of recovery of a stock in stock recovery plans. In many cases, the unfavourable nature of current climatic conditions for recruitment and survival, and not just the level of overfishing, is what is maintaining stocks at low levels. There are, for example, suggestions that the natural mortality rate of haddock in southwest Nova Scotia is considerably higher now than in the 1970s and 1980s, perhaps in part because of the dramatic increase in seal populations, but also to temperature change (Zwanenberg *et al.* 2002). Changes in the age at maturity, fish condition and slower growth rates of haddock have all been documented on the Scotian Shelf, and evidence suggests that the number of recruits produced by a given stock biomass is significantly lower (Mohn 2002). This would call for caution in using SRRs derived when the fishery was healthier, for predicting stock recovery and calculating RPs. Other empirical approaches to setting RPs can be suggested (e.g. Caddy 1999b).

Other equilibrium assumptions stem from the credo that the environment has maintained its productivity despite the indirect effects of fishing. The impact of trawls and dredges on the sea floor, including changes to epifauna and sediments, has just begun to be studied (see Jennings & Kaiser 1998; ICES/SCOR 1999; Rumohr & Kujawski 2000). A study of the long-term effects of intensive size-selective harvesting on the population genotype (Smith 1999; Law 2000; Kenchington 2001) is also at the beginning, but genetic selectivity has not begun to explicitly consider long-term management strategies, although results so far suggest that selecting for earlier maturing individuals should be avoided. The indications are that some older spawners with their higher specific fecundity and greater viability of gametes should remain in the population (Longhurst 2002; Conover & Munch 2002; Caddy & Seijo 2002), because first-time spawning fishes may not be as reproductively fit as repeat spawners (Wigley 1999).

(b) *Mitigating factors*

Providing advice to managers that takes the full dynamic range of control variables into account is likely to be impossible given the fragmentary information available, often rendered more so by limited or shrinking research budgets. A degree of redundancy should be aimed for however, so that decision making is not dependent on one or only a few data sources, or on a single model of reality, and the data used operationally may even be qualitative

and incorporate inputs from the fishing industry. Experience in eastern Canada has shown that cooperation by the commercial fleet in test fishing of commercial grounds by 'index fishermen programmes' and 'sentinel surveys', as opposed to relying solely on sampling commercial catches and/or stratified research surveys, adds needed redundancy to resource indicators. This helps persuade the industry of the reality of dangerous biomass trends (FRCC 1997). A more explicit focusing on fisheries indicators other than just fishing mortality and biomass seems required; in particular, predator and prey abundances, environmental changes and other factors essential to monitoring 'system productivity' such as growth rate, condition factor and recruitment. Given that modelling productivity changes is ambiguous, nonetheless the definition in Mohn (2002) suggests that biomass change can be expressed as:

$$B_{t+1} = B_t + R_t - Y_t, \quad (1.1)$$

where t is year R is biomass recruited, Y is yield, and B is stock biomass. A more detailed expression can be envisaged, where population estimates of growth (G), natural mortality (M) and fishing removals (F) may be annually varying such that:

$$B_{t+1} = B_t \times e^{(G_t - M_t - F_t)} + R_t. \quad (1.2)$$

Although it would be difficult to fit equation (1.2) with five new unknowns each year, indicators for each of the parameters may be sought, and combined in the Traffic Light approach to track changes in the population characteristic of productivity (Halliday *et al.* 2001).

What this line of argument suggests is that exclusive reliance on conclusions from a single modelling framework are liable to 'surprises' when the underlying assumptions of the model are overturned, as will inevitably be the case at some point in time. Modelling exercises, though essential, will need to be supplemented by empiricism (Seijo & Caddy 2000). In fact, several sets of indicators reflecting key population characteristics need to be maintained, with an emphasis on variables whose significance can be easily conceptualized by managers and stakeholders. Such a basic approach, placing high value on the data series does not preclude more sophisticated analysis, but does provide easily understandable trend information before and after modelling, to stakeholders and managers.

Currently, the need to operationalize the precautionary approach suggests we define critical values for fisheries indicators that correspond to the onset, respectively, of uncertain and of dangerous conditions, which for convenience can be called I_{PA} , and I_{LIM} , respectively, using the ICES (1997) notation. The close linkage between indicators and RPs for the same indicator series needs to be borne in mind, and can be expressed as a 'phase diagram' colour coded as in figure 4 using the 'traffic light' approach, and extended to multiple indicators (e.g. Caddy 1999b; Koeller *et al.* 2000; Halliday *et al.* 2001). Definition of boundary values may be established by consensus or based on experience with the fishery in previous years, rather than relying solely on critical values generated by population models. This process lends itself to cooperative decision making, and requires the managers and fishing industry to agree on what constitute risk-prone conditions in the light of past experience. In fact, this is an attempt to facilitate the interface between scientific advice,

managerial action and stakeholder consensus: an area we believe requires priority attention.

7. ATTEMPTING TO MANAGE COMPLEX ECOSYSTEMS BY SINGLE-SPECIES MODELS

Fisheries are still largely managed using single-species advice. Despite the proliferation of papers and models on multi-species issues, ecosystem considerations are rarely incorporated into management advice, except to suggest that top-down effects will occur from depleting apical predators (Pauly *et al.* 1998) or that eutrophication, as a bottom-up effect will change the productivity of the pelagic and demersal biomes (Caddy 2000; De Leiva Moreno *et al.* 2000). Common sense suggests that recruitment will often depend on the existence of critical habitats for life-history stages, but the issue of habitat conservation has hardly been addressed in the marine fisheries literature in comparison with inland waters (Cowx & Welcomme 1998). Trends suggested by food-web models are usually indicative, largely because of their complexity and the poor data sources available, and in practical terms, ecosystem considerations are often used in management advice either as a qualifier of single-species advice, or to take into account interactions between fisheries for different species in the same area (e.g. the Irish Sea fisheries for cod, *Nephrops* and whiting; Brander & Bennett 1989). In some cases, the relationship between the main predator and its main prey may be given consideration (such as the setting of quotas for capelin to avoid depleting the prime food source of cod). This seems a useful line of approach where keystone species are involved, but so-called 'trophic cascades' have so far been mainly documented in the field for rocky shore or coral reef ecosystems (Pinnegar *et al.* 2000).

8. RISK AND UNCERTAINTY IN FISHERIES MANAGEMENT

Another factor causing non-sustainability of fisheries has been the inability of management to cope with the inherent risk and uncertainty present in marine fisheries (Shotton & Francis 1997; Gabriel *et al.* 1997). Hilborn & Peterman (1996) identified different sources of uncertainty in marine fisheries; among which are: (i) uncertainty in resource abundance in space and time; (ii) uncertainty stemming from model structure and parameters used to assess the dynamics of the stock; (iii) uncertainty in representing the dynamics of fishing effort; and (iv) uncertainty concerning future environmental and economic conditions. The different sources of uncertainty in fisheries are rarely quantified and add to the complexity of fisheries management. Ways of estimating the risks of exceeding LRPs in fully or over-exploited fisheries (Prager *et al.* 2004) have been discussed as a way of mitigating the incomplete knowledge and the stochasticity characteristic of most fisheries data and analyses (Gascuel *et al.* 1998).

(a) *Mitigating factors*

One way to mitigate uncertainty is to develop fisheries management plans incorporating a precautionary approach, with components such as the following (Seijo *et al.* 2000).

- (i) Undertake biological/economic fishery assessment.
- (ii) Select biologic and economic performance variables.

- (iii) Collect data to estimate parameters.
- (iv) Construct fishery indicators to periodically re-assess the fishery.
- (v) Set limit and target RPs as values of these indicators.
- (vi) Estimate probabilities of exceeding limit RPs and/or achieving target RPs through the use of Monte Carlo methods.
- (vii) Identify non-discretionary management actions for when LRPs are reached.
- (viii) Design alternative mathematical models for the fishery and compare results.
- (ix) Identify states of nature.
- (x) Build decision tables and apply decision criteria with and without mathematical probabilities.

9. IMPACTS OF OVERCAPACITY ON FISHERIES IN DEVELOPING COUNTRY WATERS

The diffusion of surplus effort from 'core' oceanic areas adjacent to developed countries to developing country waters as 'distant water fleets' is associated with inappropriate fishing fleet capacity in developing country waters. This diffusion of capacity from core areas is reflected in the staggered peaks in maximum production (which inevitably seem to precede declines in overall yield). Peak landings in the 1970s and 1980s were in 'core' ocean areas such as the North Atlantic, followed by later peaks and declines in 'developing country' oceanic areas such as the western Indian Ocean (Caddy *et al.* 1998)

(a) *Mitigating factors*

There is no magic recipe that can be applied to managing a diversity of resources and users. Coastal fisheries ideally should be integrated into coastal area management, with co-management input from local government entities and communities (e.g. Berkes 1989). Larger offshore resources of the EEZ must be dealt with at the national level after consultation with national stakeholders. Unfortunately, a significant proportion of shared and SHMFSs involve multiple national users with different economies and hence different economic optima, but shared resource situations also prevail within and between EEZs. Resolving resource-sharing issues remains the most serious problem on the horizon, and fundamentally the key issue is one of reaching consensus, which may be eased once we abandon the assumption that resource continuity will inevitably continue.

10. ONCE A FISHERY COLLAPSES, IS THERE HOPE FOR RECOVERY?

It is inevitable that errors in even the best management system will lead to stock declines, and these will be accentuated (or even caused) by changes in system productivity or regime shifts. This makes it essential that specific recovery plans be introduced and implemented. Published records of recovery plans are sparse in the fisheries literature, and some 'recoveries' may in fact represent the re-emergence of favourable conditions rather than management success. This in turn points to the responsibility of managers to recognize conditions of low productivity and ensure that a suitable adult biomass is allowed to persist so that recovery *can* occur when conditions improve.

The UN fish stock agreement calls for depleted stocks to be restored to the level of biomass that could provide the

MSY, but when stock size falls below an established LRP roughly corresponding to less than 50% of this level, the sacrifices needed to restore the stock to health have rarely been addressed in a timely or convincing fashion. Earlier attempts at stock restoration in the east Atlantic generally involved complete moratoria on harvesting (Jakobsson 1980; Jennings 2001; Jennings & Kaiser 1998). Most positive experiences with closures have been with herring stocks, which in addition to high fecundity, are generally harvested by species-specific gear. Attempts to restore demersal stocks by complete closures are uncommon (Terceiro 2002), perhaps because this often requires a complete cessation of the multi-species trawl fishery in the area. Other factors such as compensatory effects on recruitment at low population size are rarely distinguished from the effects of regime change. Fishery interactions may also intervene; thus, where a former target species becomes rare, it often changes roles with its former bycatch species that has become the new 'target'. The recovery of the original target species may then be prevented through the so-called 'predator pit' mechanism (Liermann & Hilborn 1997). Suggestive confirmation of the difficulties of restoring depleted demersal stocks comes from Hutchings (2000), who used 90 datasets from 38 species taken from a SRR global database (Myers *et al.* 1995); his conclusions are that clupeids have a much higher potential for recovery than groundfish stocks. Many had recovered 5 years after the major decline, but for groundfish stocks, 15 years after the largest 15-year decline in catches in the database was over, 40% of stocks still continued to decline.

From an unpublished review of the literature, as mentioned earlier, it seems most successful attempts to restore stocks of demersal resources have occurred in the United States under the Magnuson-Stevens Act. In figure 4 (though this is not used in the USA), the different zones of a possible regulatory approach are colour-coded, which makes clearer the relationship between safe, risky and dangerous zones. The boundaries of dangerous zones are marked by the LRPs, B_{lim} and F_{lim} , and limits of safe zones by the RPs, F_{pa} and B_{pa} . The purpose of management is to avoid where possible, yellow and red zones, and to impose non-discretionary responses when dangerous zones are infringed.

Few demersal species off the Canadian east coast have shown much evidence of stock recovery over 15 years or more since the moratorium, despite considerable and sustained efforts at conservation, especially of east coast cod fisheries. However, the productivity of east coast Canadian invertebrate fisheries in the region (scallops, shrimp and lobster) is at close to historical highs, perhaps providing indirect evidence of the former controlling role of predation by ichthyofauna.

Specific recovery plans are needed to restore stocks to health, and from limited experience so far, closures or non-discretionary harvesting rules must be applied over a sustained period. The targets for recovery have to be high enough that the fishery does not immediately return to a depleted condition. Evidence suggests that sustainability will not be easily recovered, and that owing to future 'management accidents' combined with periods of low recruitment, an alternation between normal harvesting and recovery periods will persist into the future. As noted, this alternation between 'sustained' harvesting and periods of 'biological repose' may be especially called for where

resources are only abundant on an irregular basis, and calls into question the sustainability of their exploitation.

Long-lived species have fared less well than short-lived species, and require rebuilding periods of several decades. Regime shifts may have been in part responsible for fluctuations in North Pacific groundfish, and have become more frequently mentioned as important factors in recent decades. For most stocks, however, it is difficult to decide what has been the relative effect of environment and management, although the UN Fish Stock Agreement and Code of Conduct for Responsible Fisheries require protection of reduced populations whether the cause is overfishing or unfavourable environmental factors.

The cod and groundfish stocks of the eastern Atlantic are in crisis, and the European Community (EC 2002) admits that the current policy 'is incapable of reversing the situation increasing threats to important fish stocks...'. In fact, the Community (EC 2001) had proposed to the European Parliament a plan for 'rebuilding stocks of cod and hake in community and adjacent waters'. By early 2003, however, the search for consensus between member countries on drastic actions required for rebuilding decimated stocks in the East Atlantic appears not as yet to have been successful. In the case of Icelandic fisheries, following earlier stock declines (Jakobsson 1980), there was a movement to ITQ systems for the smaller number of fishers that the restored stock could sustain. ITQ and other rights-based fisheries approaches (Shotton 2000) are gradually being adopted, and appear to be sustainable and generate rent. It may be necessary even here, however, that overriding legislation be retained to restore a stock to safe levels if the sacrifices needed are not easily implemented under a rights-based management framework.

For some US coastal species of importance, either commercially or as sports fish (such as the striped bass, bonefish, kelp bass and other inshore sport fish of the United States inshore waters), recovery seems to have been achieved through confining fishing largely to the sports sector. Fishery closures employing marine parks and reserves (White 1988; Bohnsack 1990; Russ & Alcala 1996; Guenette *et al.* 2000) have apparently been locally successful, and have benefited adjacent areas where commercial fishing continues.

Once a special recovery regime has brought a depleted resource back from the edge, it is usually implied that 'normal' exploitation will be resumed. This presumably will be marked by a biomass-based RP well in excess of the LRP that triggered the recovery plan. The perception often arises during a prolonged recovery phase (Terceiro 2002) that to avoid a second collapse and recovery plan fundamental changes will be required to the management regime for the 'recovered' stock. Despite this, what has happened during at least some recovery plans, such as that for the summer flounder (Terceiro 2002), is that once evidence of partial recovery occurs, such as a good year class, increasingly strident calls soon go out for the fishery to be reopened. This scenario in part reflects the short social memory of what constitutes a healthy stock, but also the realistic understanding that given overcapacity and recent cutbacks in landings, the fishing industry has payments to make on substantial investments in production facilities. Other longer-term considerations that have intervened where a fishery was closed for a decade or more, is the loss of

employment in the production chain from catching to processing, and a possible loss of market opportunities and consumer acceptance for the species in question.

(a) *Mitigating factors*

The extreme situation for *r*-selected species, which show intermittent 'blooms' separated by years of low biomass, may be a controlled pulse fishing approach, with licences only issued in those years when apparent biological surpluses occur. For other years, strict conservation or closures should aim to maintain a minimum population until the next favourable 'production window' appears (MacCall 2002). Before their partial replacement by industrial-scale vessels, artisanal fleets were usually polyvalent, moving from one resource to another as seasonal fishing opportunities arose. The introduction of single species quota systems in the 1960s in North America was accompanied by increases in scale and specialization of industrial vessels, for which severe quota reduction in response to inevitable periodic declines in supply means economic disaster. One long-term response to stock fluctuations would therefore be to severely limit capacity, but favour reintroduction of small-medium polyvalent fishing vessels, where the option of a limited exploitation rate can be geographically and seasonally constrained without preventing sustainable harvesting of components of the local food web. Another possibility, given the introduction of low-cost satellite monitoring, is to make this mandatory for offshore vessels, allowing the auctioning of seasonal 'windows of opportunity' while still ensuring that a refuge for juveniles and the spawning stock is maintained.

11. MANAGING SHARED AND STRADDLING STOCKS

The Darwinian notion is that a stock can only be effectively managed 'subject to coordinated conservation measures throughout its range is central to ecosystem management', (Carr 1997); even though precisely how 'ecosystem management' is to be implemented is still not clear (Brodziak & Link 2002). Sharing the benefits from transboundary resources through multi-party agreements requires a mutually acceptable distribution of benefits and costs, and forms another weak link in the chain: management of shared and straddling stocks often falls down precisely through problems in operationalizing these questions.

12. APPLICATIONS OF GAME THEORY TO RESOURCE SHARING

The theory of games provides an approach to dealing with the complex issue of management of stocks shared between two or more groups of participants (Kaitala & Lindroos 1998). This body of theory predicts that fisheries exploited by two or more independent national fleets with inadequate exchange of information are liable to over-exploitation (Kaitala & Munro 1993, 1997; Munro 2002). What the rational response to this situation should be will depend on the extent of resource exchange across the boundary, and the tractability of the other participant(s) to negotiation (Walters 1998). Despite this qualification, at first sight, the management problem for shared stocks

seems more tractable than for the straddling and highly migratory stocks, because the number of national participants is limited if the resources remains within their combined EEZs. The problem of negotiating allocations between different parties still appears to be a major problem, however, because the valuation placed on a shared resource by each party is likely to differ. It is instructive to consider the probable size of the shared stock problem globally. Of the more than 500 EEZ boundary areas between adjacent maritime States determined from a global GIS survey (Caddy 1998), there is limited published evidence of the existence of bilateral fishery agreements. This suggests that for a significant proportion of global shelf resources that are in the 'shared' category, overall management frameworks subscribed to be all exploiting parties are uncommon.

The 1995 UN Fish Stock Agreement was an attempt to negotiate rules for management of SHMFSs, which could be accepted by coastal and distant water fishing countries, for those resources that extend from EEZs into the international waters beyond. Fisheries Commissions were given a key management role under this Agreement for managing SHMFSs, but Commissions are usually underfunded and have serious problems resolving differences over allocations and strategy between members. Only recently have some Commissions (ICCAT 2001) begun to revise allocations to developing country States that currently take only a small share of the large pelagic resources passing through or close to their EEZs. Because these developing States often do not have the technical resources for industrial-scale operation and because allocations outside EEZs still tend to be based on historical catch performance. Unfortunately, past high-catch performance may not have been compatible with proper stewardship of common resources, but is rewarded by 'historical criteria' under many allocation schemes. In both theory and practice, the management of SHMFSs is much more difficult than for EEZ or shared resources (Kaitala & Munro 2004), because of the essentially open-ended characteristic of fisheries outside EEZs. The UN Fish Stock Agreement, Article 11, requires new States showing an interest in a regional resource to become members of the appropriate Commission. However, the resulting 'new member problem' could have serious repercussions when Commissions embark on stock rebuilding plans, which for many SHMFSs are overdue. The needs of new members must then be absorbed within the seriously reduced TAC required for rebuilding. Thus, the 'free rider' problem is accentuated, especially if potential members take advantage of a rebuilt biomass to enter the fishery once sacrifices by 'founder members' of Commissions have allowed rebuilding to occur. Any mutual restraint between founder members is then likely to break down, and existing parties to the Commission will be tempted to abandon mutual restraint and compete to mop up the remaining stock.

Special problems are faced by developing coastal States, which are generally unable to extract revenue from their nationals harvesting EEZ resources. The funds available for MCS, data gathering and research, to pay Commission fees and attend meetings of Commissions, are thus very limited. Coastal States are therefore obliged to consider providing access to their EEZ resources to distant water fleets displaced from overfished 'developed' fishery waters,

Table 1. Conventional strategies for mitigating the effects of high exclusion, information and enforcement costs in fisheries, harvesting stocks with different degrees of mobility.

stock mobility	exclusion costs	information costs	enforcement costs
sedentary or low mobility	establish ITGs or leases assess the effectiveness of using ITQs	costs of stock assessment and bio-economic analysis are shared between those deriving resource rent and the government	emphasis on self-policing community-managed MCS co-management with government
mobile (transboundary or shared stocks)	limited entry agreed bilaterally or multilaterally, with allocation of shared TACs	bilateral/multilateral cooperation between parties and standardized data collection and stock assessment are essential, and MCS functions must be coordinated	bilateral/multilateral cooperation in management and enforcement of common or harmonized regulations
highly migratory (high seas)	harvest quotas are established by the Commission members of the Commission arrange negotiations on resource allocations, and establish harvest rules for the fishery	data collection and stock assessment are organized by the Commission. Satellite tracking schemes allow location of vessels and fishing areas. Remote telemetry of fishing operations allows for more efficient MCS operations	resource Commission members share enforcement costs proportional to annual harvest by individual countries

so as to extract some resource revenues. They are rarely in a position, however, to develop a precautionary management plan to cover operations of DWFNs and those of national fleets. Consequently (Garibaldi & Limongelli 2003), many straddling and highly migratory stocks are depleted and are being harvested unsustainably.

(a) *Mitigating factors*

Fisheries Commissions should be given a stronger operational role in managing SHMFS, including operational control of vessel monitoring systems. A rule requiring that the increased expenses of fisheries Commissions be covered by sale of a proportion of catches taken by accredited parties is suggested. Cooperation at the industrial level between harvesting and importing countries to ensure implementation of an eco-certification scheme requiring strict control of resource management would also be important. Some modifications to the provisions of the Fish Stock Agreement aimed at dealing with the problems of stock rebuilding, free riding and the new member problem seem essential if these resources are to recover. More effectively addressing the problems of deep-water resources is also an urgent priority because fishing operations outside 200 miles seem not to be effectively controlled.

13. FROM THE PERSPECTIVE OF ECONOMIC THEORY

To further understand management constraints, we now discuss the basic economic assumptions underlying the optimal allocation of natural resources, and the inherent characteristics of fisheries that prevent markets, under unrestricted access, from optimally allocating fishery resources. Although current literature invokes the allocation of property rights as a solution, even in those fisheries where rights have been allocated, the non-sustainability syndrome tends to remain. This leads us to ask what conditions are not being met which allow the market to optimally allocate fish resources once individual property rights have been established?

14. SOME BASIC ASSUMPTIONS UNDERLYING SUSTAINABLE ALLOCATION OF FISH RESOURCES

- (i) It is generally agreed that to ensure optimal allocation of natural resources, non-attenuated property rights should be in place. Those rights must be (Randall 1981; Schmid 1987; Seijo et al. 1998):
- (ii) *Completely specified*, including the restrictions on them, and the penalties that will result from the violation of common rules.

- (iii) *Exclusive*, so that persons holding these rights are responsible for any penalties resulting from infringing rules established governing harvesting of the resource.
- (iv) *Transferable*, to ensure that the rights enter the hands of those who will convey them to their highest use value.
- (v) *Effectively enforced*, because a non-policed right becomes an empty right.

In fisheries, the basic assumptions of the neoclassic market model mentioned above are usually violated. As we saw earlier in this document, the combination of overcapacity (Greboval 1999), overexploitation and non-sustainability is a syndrome common to many important fisheries. Fishery resources in fact have inherent characteristics that distinguish them from other natural renewable resources, and require further discussion to understand the importance of short- and long-term exploitation patterns (Seijo *et al.* 1998).

15. OBSTACLES TO PROPERTY RIGHT ALLOCATION IN FISHERIES

The violation of the basic assumptions of exclusivity and low information and enforcement costs (otherwise referred to as transaction costs) are serious obstacles to effective property rights allocation. The inherently high exclusion and transaction costs characteristic of fish resources require us to look beyond the simple solution of providing for 'proper allocation of individual rights'. Self-policing, questions related to numbers of fishers, and issues of education are discussed below as ways of mitigating these obstacles.

16. THE PROBLEM OF MULTIPLE STAKEHOLDERS AND DECISIONS BY CONSENSUS

As we have noted, the allocation of resources between stakeholders is the problem area where progress is most urgently required, both nationally and internationally. The strategic behaviour of fishermen and fleets sharing a trans-boundary stock is discussed using the framework of game theoretic analysis to better design management strategies in this complex situation, and the role of cooperation in avoiding resource collapse is also presented. Deliberate and unwitting free-rider behaviour is discussed, defined as the participation in the harvest without participation in the costs and constraints imposed by management of the stock. The roles of information on fish conservation and self-policing are presented as mitigating factors.

17. HIGH EXCLUSION COSTS IN FISHERIES

An inherent characteristic of exploited fish stocks is the high cost of excluding unauthorized fishers from exploiting the resource, and enforcing regulatory compliance on those authorized to fish. Although Charles (1998) urges us to live with uncertainty, the mobility and migratory nature of most fish resources, combined with high uncertainty as to stock magnitude, means that an individual fisher is unlikely to benefit from postponing the capture of a fish with the expectation of taking it at a larger and more valuable size later. Others are likely to have caught it in the meantime; that is, unless all or most fishers agree to abstain proportionately (Eckert 1979).

(a) *Mitigating factors*

Traditional approaches to avoiding high exclusion costs involve institutional structures such as: (i) resource privatization through allocation of ITQs; (ii) State intervention to regulate size and age composition of the catch, and the level of fishing effort; (iii) implementation of community-based management systems (Berkes 1989); or (iv) mixed strategies based on a combination of the above schemes (Seijo 1993; Castilla & Defeo 2001).

18. THE SOCIAL TRAP AND FREE-RIDER BEHAVIOUR IN FISHERIES

Without an agreement to limit catches, the main result of a single fisher's reduced catch rate is to lower the extraction cost of other fishers without necessarily increasing his own benefits. Using the terminology of Shelling (1978), this constitutes a social trap, because the micro-motives of an individual fisher in the short-run are not consistent with the macro-results he and other fishers desire in the long run. The short-run micro-motives consist of catching as many fish as possible to increase individual marginal benefits, while the long-run desired macro-results may involve reducing effort to achieve sustainable maximum economic yield. Uncertainty as to future stock availability in the face of the non-sustainability of resources, determines that long-run results are usually dominated by short-run marginal benefits. Allowing for temporal fluctuations in resource productivity and preferences of resource use, it seems that a sustainable yield will be attainable only when the number of fishers is limited, and act in concert to implement some form of effort regulation. However, if the group is large, a fisher may be an unintentional free rider or non-contributing user. This type of individual usually occurs when there is no collective action by the majority of the community to prevent resource depletion, or when uncertainty exists as to stock abundance (which is usually the case).

(a) *Mitigating factors*

The size of the fisher community exploiting a resource is relevant to avoiding this social trap. When the group is small, exclusion costs are not necessarily lower, but the non-contributing user can be more easily identified (Olson 1965; Schmid 1987).

19. HIGH TRANSACTION COSTS

Marine fisheries involve high transaction costs, which also diminish the efficiency of resource allocation over time. Transaction costs in most fisheries involve high information costs as well as high enforcement costs. These are discussed separately.

20. HIGH INFORMATION COSTS

The complexity of fishery management is increased by the major uncertainties inherent in natural systems, as well as by a range of other biological, social, political and economic factors (Hilborn & Peterman 1996). These increase the probability of non-contributing users emerging, and also deplete stocks and dissipate economic rent. Efficient fisheries management implies high information costs, but interdisciplinary research in biology, ecology, statistics and socio-economics is hampered by academic fragmentation. Unfortunately, an

overall increase in fishing intensity is not typically accompanied by a corresponding increase in scientific and fishery information. In fact, as MSY conditions are approached, the need for more accurate and real-time information increases, precisely at a time when system variance is increasing owing to less regular recruitment and a higher probability of ecosystem change. Thus effort overshoot, increases in harvesting costs and the elimination of economic rent from the fishery are almost inevitable consequences of fishing near MSY conditions.

21. HIGH ENFORCEMENT COSTS

Fisheries management involves high enforcement or policing costs if management schemes are to be implemented and allocated property rights protected. For oceanic (and many shelf) fisheries the areas to be policed are extensive, and conventional patrol vessel operations are ineffective and costly. Under these circumstances, a non-enforceable right risks becoming an empty right.

(a) *Mitigating factors*

Some strategies for mitigating the effects of high exclusion costs and high information and enforcement costs are summarized in table 1. Strategies are differentiated for varying degrees of resource mobility.

In addition to the above, market distortions are present in most world fisheries, and may foster the overcapacity problem. Principal among these distortions worth mentioning is the presence of subsidies (Milazzo 1998, 2000).

22. IMBALANCES CAUSED BY SUBSIDIES

In addition to the economic factors mentioned above which underlie the overcapacity problem, there is a growing awareness by governments and industry of the negative influence of subsidies on international trade, the environment and sustainable development (Milazzo 2000). Among subsidies fostering increases in fishing capacity the following may be included (Munro 1999; Seijo 2001).

- (i) Grants for the construction of new vessels, traps, aggregating devices, etc.
- (ii) Grants for the modernization of current fleets.
- (iii) Preferential credits and tax treatments for (i) and (ii).
- (iv) Reduced price or tax breaks for purchased inputs (e.g. fuel, bait and ice).
- (v) Market price supports.

The impact of subsidies on sustainability acts mostly through the dynamics of fleet capacity and fishing effort, and it is therefore fundamentally important to estimate their impact on cost-reduction and vessel profit margins; recognizing that at the margin, a subsidy allows profitable operation at lower stock levels than without subsidies.

(a) *Mitigating strategies*

The fact that subsidies artificially inflate profits of artisanal and industrial fleets at low stock sizes has serious conservation implications, and efforts should be made to eliminate them. Two scenarios occur: (i) vessel owners were granted subsidies at the start of the fishery to promote development; and (ii) subsidies arrived later to 'alleviate' short-run crises in fisheries sectors. The rationale for the first scenario has now ceased, because close to 47% of

global stocks are fully exploited, 18% overexploited and 10% notably exhausted (FAO 2002). This leaves only 25% of the stocks with some potential for effort expansion. If the second scenario applies, government is effectively perpetuating a *social trap* by artificially encouraging capacity to remain in the fishery, even though harvest returns cannot pay for variable costs of fishing, such as fuel, ice, etc. and for vessel replacement. The elimination of subsidies would result in negative quasi-rent of the variable costs (revenues above variable costs) and lead to substantial reductions in short-run effort for those vessels that are not covering their trip or daily variable costs.

23. FISHERIES IN THE POLITICAL ARENA

Management of fisheries is a complex process that requires the integration of resource biology and ecology with economic and institutional factors affecting the behaviour of both fishers and politicians. Agreement on an approved management plan signed off by all participants could be a positive objective of the political process as it relates to fisheries. A major problem relates to the mismatch of the time frames for management and political decisions. At least in democracies, the period of tenure of the party in power is invariably shorter than the necessary minimum duration of measures needed to restore stocks or ecosystems.

(a) *Mitigating factors*

An appropriate axiom for decision-makers preparing management plans would then be the question 'Will this decision allow future generations to also benefit from the resource?'. Some means needs to be found to ensure that decisions on ecosystem health are non-partisan in nature. Although this is an idealistic perspective and is perhaps unlikely to be realized in practice, its realization would address one of the major causes of non-sustainability. Where two or more nations are negotiating over a shared resource, political uncertainty is augmented, and achieving a common optimum for management is much more difficult.

24. THROUGH A FLAWED CRYSTAL BALL: FUTURE CURRENTS IN MARINE FISHERIES MANAGEMENT?

Given the multiple uncertainties in effectively coordinating the various mitigating factors mentioned in this paper, it would be unwise to try to propose an integrated management approach of general relevance. However, a summary of some of the key issues associated with non-sustainability discussed in this paper that cause difficulties in stock management and recovery is as follows.

- (i) Overcapacity of fleets.
- (ii) Increased demand and prices for fish on global markets.
- (iii) Political disagreement on the diagnosis of fleet overcapacity.
- (iv) Lack of political will to take necessary actions to restore stocks.
- (v) Lack of implementation of the precautionary approach.
- (vi) Short memories by stakeholders of what is a 'recovered' or 'normal' fish stock.
- (vii) Problems between parties sharing resources in deciding on allocations (or on shares of total fishing capacity).

- (viii) Inadequate funding of Commissions and the unwillingness of member States to cede management control to them.
- (ix) Absence of a management or recovery plan agreed to by all parties, leads to weak or conflictual management strategies.
- (x) Inadequate linkages between government and industry promotes illegal fishing and the evasion of regulations, if the rationale for regulations has not been explained to industry.
- (xi) 'Top-down' governmental decision-making ignores co-management with the fishing industry, but is proving unsuccessful in achieving industry consensus.
- (xii) Co-management is more effective, but time-consuming. Such 'rights-based' approaches as ITQs; or community-based quotas, allow coastal communities to decide management strategies for inshore/local resources.
- (xiii) There is a need for monitoring stock status by indicators not only of biomass and exploitation rate, but also of environmental/ecosystem change or regime shift.

How these pressing requirements can all be integrated into a management system is not clear to the authors. It seems, however, that looking ahead the following general tendencies are evident over two separate time horizons.

Over the short term of 5 years or so, one may expect the current impacts of effective open-access conditions and high demand for fish stocks to further drive demand and prices, especially as a large import market has arisen in China. Without strict controls, greater demand will further promote overcapitalization and further stock declines seem inevitable given a technologically sophisticated harvesting sector. With price rises, the shortages in supply already apparent will become more critical, and will particularly affect availability of protein for the poor.

National or regional fisheries organizations that have introduced precautionary and restrictive management regimes, based on the FAO Code and strict access control are likely to benefit greatly. However, the impression gained is that for many world areas and resources, a start on rational exploitation is not likely until stock collapse forces an agreement to effectively restrict access, so that stock recovery can be attempted.

Over the medium term of approximately a decade, a breakthrough in approaches to resource sharing and allocation will have to be found before some of the constraints outlined above can be overcome. While predicting landings is inherently uncertain, we can probably be more certain about the likely future species composition of landings. A continued downward move in trophic levels seems likely, with small pelagic fishes and invertebrates continuing to make up a growing share of harvests, and larger predators, and species dependent on special environments such as estuaries, coral reefs, sea mounts and the Antarctic, continuing to decline. Current unrestricted exploitation of slow-replenishing deep-water species will certainly be of short duration, hopefully representing a terminal phase for unrestricted fishing under the former 'freedom of the seas' axiom.

We could express a pious hope that anthropogenically impacted ecosystems will be restored, but Caddy (1999a) took the pessimistic view that stock and ecosystem replacement will prove difficult to achieve. Unfortunately, the

easiest option will be to harvest those organisms low in the food web that will probably remain once ecosystems have been drastically simplified by overfishing and environmental impacts. These can then be transformed into surimi-like products, and modified organoleptically to provide the palate with replacements for species high in the food web, whose remaining limited stocks will be reserved for the speciality seafood stores of the affluent.

25. DISCUSSION

It would be presumptuous to present simplistic solutions to the serious crisis now facing world fisheries, although any future fisheries management paradigm will have to address the problem areas we have mentioned using a precautionary approach, which admits, however, that we are incapable of predicting marine ecosystem changes. A new paradigm will have to be based on the admission that intensive exploitation regimes are unstable, and lead to chaotic ecosystem changes that are unpredictable. The as-yet-to-be-operationalized concept of 'ecosystem management', and the need to conserve critical habitats and genetic resources and the full span of age groups in a population, are all elements that are important from research so far. A greater role for spatial tools such as marine protected areas, spatio-temporal concession windows or rotating harvest schemes are likely to be made practical by low-cost satellite monitoring, which could drastically reduce costs of MCS functions.

Although advising on quotas has been rightly taken out of the hands of scientists, managers and stakeholders need to absorb the lessons of science and precaution to be effective. This calls for long-term education, but also an ethical concern for preserving ecosystem heritages in the marine environment.

We need to keep the spawning biomass high, and avoid the assumption that exploitation is necessarily sustainable or continuous for all resources. We should be aware of changes in productivity over time, and that not all areas of the stock should be available for production on a year-round basis. The Beverton & Holt (1957) approach suggesting that if a fish spawns once before capture, the population is sustainable, is not tenable in light of the major spawning contribution of older age groups. As stocks declined, this led to the preferred response of increasing mesh size and not reducing capacity. Combined with a quota system this means that the same quota is taken from the older population components, with direct impacts on population fecundity.

Even the relatively successful ITQ systems pursuing 'enlightened self-interest' do not seem particularly well adapted to stock recovery, and as we have seen, stock recovery plans, even when close to success can be sabotaged by civil action requiring the resource to be opened prematurely to exploitation. Perhaps the change required to the axiomatic underpinnings of our management system is the explicit incorporation of ethical considerations, that may (strangely enough) lead to a respect, and perhaps even veneration for natural systems, and a strong incentive to preserve the natural world, as embodied for example, in the Gaia concept (Lovelock 1990).

Although we hesitate to provide alternative solutions to the issues raised in this paper, we do propose a sequence of axiomatic criteria that should lead progressively to

sustainable global ecosystems, as follows.

priority	axiomatic criteria for use of natural resources
1	conserve ecosystem values—(education to install a conservation ethic)
2	conserve intergenerational equity
3	exercise enlightened self-interest

Obviously, we are currently attempting to implement (3) with the growing application of ITQ systems, co-management and community-based management approaches; it seems that actions guided by self-interest are not always enlightened at the whole-system level. Considering the needs of the next generation applies to the whole of civilization, but a specific parental motivation that only affects the declining numbers of self-employed individuals in the fishing industry will not be adequate. The teaching of an ethical basis for respect for natural systems, which evolved over millions of years, but can be extinguished in several fishing seasons, may be the only viable long-term approach.

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GLOSSARY

- DWFN: distant water fishing nation
 EAF: ecosystem approach to fisheries
 EEZ: exclusive economic zone
 GIS: geographical information system
 ITG: individual transferable ground
 ITQ: individual transferable quota
 LRP: limit reference point
 MCS: monitoring, control and surveillance
 MSY: maximum sustainable yield
 RP: reference point
 SHMFS: straddling and highly migratory fish stock
 SR: stock–recruit
 SRR: stock–recruit relationship
 TAC: total available catch
 TROM: target resources oriented management
 VMS: vehicle monitoring system