Invited Plenary Lecture

Recovery plans for depleted fish stocks: an overview of global experience

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1. EXTENDED ABSTRACT

1. The primary and grey literature as well as the WWW were searched for information on recovery plans implemented for marine fish stocks globally. Although information sources are generally incomplete, especially on the managerial aspects, 9 examples are focussed on here that provide some information on details of the plan followed, and.fragmentary information was located for other stocks, but it is clear that a full review of the subject will require international cooperation. Evidence of success or otherwise was not always provided by these reports, and in some cases it was clear that a reversal of preliminary results may have occurred subsequently. Experience with recovery plans mostly stems from the1990's onwards, so that results presented in this review are still inconclusive. Nonetheless, the present study could provide a starting point for an internationally-coordinated attempt to build a data base of recovery plans, which is recommended to ICES as a high priority objective. The present paper provides a broad-brush overview of scientific and managerial issues involved. A second paper by Caddy and Agnew to be presented at this meeting provides more complete documentation on sources, and discusses issues relative to the duration of recovery plans.

2. We recall that the concept of a recovery plan first originated for rare terrestrial organisms, and an example of a recovery plan for an endangered wetland bird is briefly reviewed. This shows that broad multidisciplinary approaches are required, and it is believed this applies for marine finfish recovery plans also. Given the increasing number of marine fish stocks in difficulty due to overexploitation documented by FAO, the distinction between endangered and common (but now depleted) marine resources is disappearing, and the CITES process is now more frequently being invoked for conservation of formerly commercial species. Transitional examples are low fecundity, slow-growing depleted stocks such as rays, sawfish and sharks, which with depleted marine mammal and turtle stocks, include the growing number of protected species, often of low commercial value, which are affected incidentally by fishing operations. Also transitional to finfish recovery plans are relict populations impacted by anthropogenic environmental change such as the endangered Atlantic whitefish, an example showing the importance of public outreach and stakeholder participation.

3. The first fishery recovery plans historically were fisheries closures, principally for herring stocks, and the success of many of these single-species fisheries led to misplaced optimism that recovery of groundfish could similarly be achieved. Closures have rarely been implemented for groundfish taken in multispecies trawl fisheries, and this approach is reluctantly adopted and often treated as a last resort. The collapse of Canadian groundfish stocks made closure inevitable, but revealed that this measure is not inevitably successful, and the suggestion followed up in the companion paper that regime shifts are in part

responsible for slow recovery. The problem of technical and multispecies interactions for recovery of trawl fished resources remains difficult or intractable without involving the whole species complex harvested.

4. Early experience following extension of jurisdiction, suggests that quota management without regulation of access/capacity is unlikely to be successful. Some key features of the better-documented recovery efforts are briefly reviewed, and some common features extracted to form a draft set of Guidelines for recovery planning included in an annex. Single-species approaches have generally been followed, using COMFIE-type[1] decision rules, with fishing mortality control often implemented through quotas, though doubts are raised that approaches using quotas to fine tune fishing mortality targets will be successful at low stock sizes. In a few cases a constant low quota was used, and the characteristics of different approaches are compared in the light of increasing uncertainty and variance in stock and fishery indicators, and the chaotic behaviour and poor performance of retrospective analysis and surveys at low stock sizes.

5. It is usually supposed that a return to a 'normal' exploitation strategy will follow once the recovery 'target' has been achieved, but experience shows that growing disputes over stock status between stakeholders occur as some recovery becomes evident. Experience also suggests that in order to avoid continual repetition of earlier stock collapses, a more precautionary approach to 'routine' management will be needed which incorporates some features of the recovery plan.

6. Multispecies and technical interactions have been given little consideration in most finfish recovery plans, although there is some evidence that 'spontaneous' recovery of a number of overfished invertebrate stocks can be linked to declines in finfish predators. Placing a priority on conserving long-lived top predators or 'keystone' species (e.g. Pacific halibut) may be an effective multispecies strategy. A review of biological criteria for initiating stock recovery plans focuses mainly on %SPR considerations, and reveals an apparent paradox, in that species with low natural mortality rates may have recovered from very low stock sizes relative to shorter-lived, and pelagic species; presumably under favourable environmental conditions. This suggests that longevity in large demersal fishes is a strategy for surviving periodically unfavourable regimes, and that 'fishing down the age structure' does not equip populations to survive subsequent and perhaps prolonged unfavourable recruitment conditions. A tentative conclusion for most groundfish is that it is precautionary to avoid %SPR levels falling below 30-40+% of virgin stock size, and similar high values also seem limiting for small pelagics, cephalopods, abalone, and large crab populations. Restoring age structure as well as stock biomass is suggested as an appropriate rebuilding approach for groundfish, using the refugium approach or MPAs supplementary to conventional controls on exploitation rate and technical measures. It is warned that focussing solely on improving juvenile survival through supplementary mesh size increases or minimum sizes in a recovery plan based on quotas, may increase pressure on the few remaining large spawners. Ensuring that a significant proportion of older spawners survive in the population, and that source populations and critical habitats are protected, become important supplementary objectives of recovery plans. Area closures are suggested as an important supplementary measures to protect critical habitats, nursery areas and spawning refugia, and the need to protect metapopulation structure is emphasized, since it is suggested that simplification of metapopulation structure may not be easily reversible.

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[1] **ICES Working Group on Comprehensive Fishery Evaluation**

7. Experience suggests that successful recovery depends more on management infrastructure and socio-economic context than on stock calculations, whose accuracy has often been overestimated, especially where there has been a heavy reliance on retrospective analysis of age structure. The cooperation of industry and stakeholders in co-management approaches seems indicated, and consultation within co-management and rights-based approaches in setting up the recovery plan is essential. In contrast to this, once a stock is declared overfished or depleted, decision-making within a formal recovery plan must be rapid, and rapidly implemented. Apparently relevant here is that a majority of the small number of successful recoveries documented world-wide, occurred in United States waters under the jurisdiction of the Magnuson-Stevens Act. This suggests that overriding non-discretionary legislation is of critical importance, and should incorporate overfishing definitions and reference points. It should also require recovery to MSY conditions or their equivalent when these limit reference points for biomass and fishing mortality are infringed. At the same time, the inclusion of a broader range of fisheries indicators in the decision process, especially those measuring the environment and changing productivity of the ecosystem, seems important. The traffic light approach is suggested as one way of monitoring regime change and avoiding the erroneous assumption that future recruitment will remain at the levels observed during past favourable regimes. From our analysis, we have derived a draft set of principles and working procedures for further discussion that may assist in formulating future recovery plans. These deal with aspects of resource biology and stock assessment, but also discuss socio-economic considerations, and the appropriate management frameworks which have proved important for several successful stock recoveries. These are appended to the paper as a set of draft guidelines for future discussion of best practices in fisheries recovery planning.

2. INTRODUCTION

Few can now doubt that an alarming decline in global fish stocks, especially shelf demersal finfish, has been going on over recent decades. Starting with FAO concern over the high percentage of stocks fully and overexploited, (SOFIA??ADD), Caddy et. al. (1998) showed that despite different responses to exploitation in different FAO statistical areas, the decline in landings by area was staggered in time, beginning in developed, and spreading later to developing, country waters, through the export of capacity from the former to the latter. Pauly et.al. (1998) documented general declines in mean trophic levels in world fisheries, and Myers and Worm (2003) have suggesting that groundfish populations are now only at around 10% of pre-industrial levels. For multi-age spawners such as long-lived groundfish which are the main focus of this study, 'fishing down of age classes' has gone on in parallel with trophic truncation, and the occasional occurrence of good year classes may have reduced awareness of serious problems until few mature age groups remain in the population. As a result, management measures in response to stock declines have tended to be slight modifications to 'business as usual' and the perception that there is a completely new situation to be faced requiring much more serious and coordinated efforts, is only now dawning. This MS and its companion hope to initiate a data base on stock recovery efforts, and from it to extract some guidelines for stock rebuilding by fishery management authorities. A draft set of possible guidelines are attached as an annex to this paper, and referred to throughout the text.

A global review of stock recovery plans located will be presented in a companion paper, giving some preliminary indications of their success or failure, as well as discussing environmental issues affecting the timing and duration of successful recovery plans[2]. Other operational aspects of recovery planning are dealt with in this paper, largely based on a selected number of case studies located in the above-mentioned study. The approach adopted here paralleled that leading up to the Code of Conduct for Responsible Fisheries, in that the use of case studies are used to arrive at a first draft for a possible set of guidelines for stock recovery processes, given in the Annex to this paper.

Historically, the earliest recovery plans were fishery closures, particularly for herring stocks fished to dangerously low levels. Closures were applied in the Northeast Atlantic for herring (Bailey and Steele 1992, Jennings 2001, and also for herring in British Columbia and on Georges Bank. Not all closures resulted in recovery (see for example the Icelandic herring, Jakobsson 1980) , but the majority did, with recovery times generally of the order of a decade or less.

Those that have been better documented (North Sea herring (Bailey 1991, Steele 1992, Jennings 2001), some Icelandic herring and Atlanto-Scandian spring-spawning herring (Bakken 1983 reference not located) and Barents Sea capelin (ICES 1990, 94) show that pelagic stocks may recover rapidly if environmental conditions are favourable.

Extrapolating from experience with highly-fecund, early maturing herring populations to groundfish stocks, is however, risky. When herring stocks are depleted and closed, bycatch in other fisheries is minimal, unlike multi-age, late-maturing groundfish which continue to be taken incidentally in other trawl fisheries. Thus, there is no automatic assurance that reducing quotas for long-lived demersal species will show similar responses to herring closures. For Canadian Northern cod stocks, more than a decade after an effective moratorium began, the populations of cod and other groundfish are still low and showing few signs of convincing recovery. Despite a long closure and a subsequently very restrictive fishing regime, recovery is not evident here. This may reflect

[2] *The degree to which a stock is supposed to have recovered or not, as indicated in the last-cited companion report, can only be judged from the last publication cited – subsequent events may have reversed apparent stock recoveries, or vice versa. This and the companion paper, can only be tentative, and are inevitably out of date, in monitoring a continually changing situation. For this reason, errors of fact and interpretation may inevitably occur and the authors would appreciate receiving information where this has occurred*

lower-than-average temperatures and high predator (seal) populations (Zwanenburg, et. al. 2002), but also sounds the alarm for recovery programmes elsewhere, suggesting that long-lived repeat-spawners have evolved in an environment which is frequently hostile to successful recruitment, and need to maintain their older cohorts to survive to the next favourable recovery period.

The second type of recovery strategy attempted was to reduce fishing mortality to at or below the level providing optimal yield. There seems evidence that fishing at $F_{0.1}$ in Eastern Canada (Parsons and Beckett 1995) was initially successful in rebuilding depleted groundfish stocks after Canada's declaration of a 200 mile EEZ. Subsequent application of $F_{0.1}$ criteria under routine management however, does not support the contention that 'business as usual' management, i.e. simply reducing slightly the target fishing rate, will inevitably restore stocks that have been strongly depleted. Reducing quotas and often as a last resort, capacity, to some fraction of recent historical levels, and institute a 'stock rebuilding' strategy aimed at restoring the stock to equilibrium levels capable of yielding the historical MSY is the strategy specified in the FAO Code of Conduct and the UN Fish Stock Agreement. When the resource reaches some 'restoration level' higher than the limit reference point for (mature) biomass that the stock dropped below during its decline, it is often assumed that 'normal' fisheries management provisions can then be resumed. The implicit assumption in many recent approaches relies on the 'equilibrium assumption' and in particular, an assumption that the stock recruit relationship based on previous favourable production years will still provide compensatory behaviour, and that the stock is above the level where depensatory effects come into play. By leaving some surplus yield unharvested, it is assumed that restoration is inevitable, and that the ecosystem, food web and species dominance have not changed since periods of favourable production. From recent experience these 'equilibrium assumptions' are not safe ones to make. As noted by FRCC (2000) we have now entered 'uncharted waters' as far as stock management is concerned. Continued application of 'business as usual' fishery management approaches with discretionary management decisions and long time lags between advice and action, are not preconditions for rebuilding, especially if a regime or ecosystem change has occurred (see companion paper for further information on this aspect).

The origin of recovery plans

The concept of a "recovery plan" as an emergency and holistic response to a deteriorating situation arose first for endangered or protected mammal or bird populations. These recovery plans were invoked when populations had declined to some few hundreds to tens of thousands of individuals, or confined to a small part of their former range, and special efforts were needed to restore populations. The international context for plans seeking to prevent extinction as opposed to commercial recovery, is the Biodiversity Convention and CITES, and a number of papers (e.g. Musik 1999, Roberts and Hawkins 1999, Powles et. al. 2000, Musik et. al. 2000 and Hutchins 2001) review the probability of extinction of marine finfish resources. In the marine environment, plans for whales (Kirkwood 1997), monk seals (Forcada et. al. 1999), marine turtles (NMFS 1998), etc were developed early on. For long-lived low fecundity fish, such as sturgeons (Secor et. al. 2000) and elasmobranchs recovery plans also exist, since rare species occur in all ecosystems (e.g.Swaby and Potts 1990). Although the emphasis in these approaches for critically endangered species (where habitat loss and the level of threat is most important to the success of recovery plans; Abbitt and Scott 2001), is different from the different case of overfished commercial stocks it seems worthwhile briefly examining the approach for protected species other than finfish before considering fish stock recovery plans. Such plans take more into account habitat and social considerations, and often aim at protecting much smaller numbers of endangered species than fishery plans, though we discuss briefly the first category of plans in the following section.

A terrestrial recovery plan: the Canadian piping plover plan

This is a good example of a terrestrial plan (Anon 2002) which takes into account the biology and bird population dynamics as well as habitat considerations, land and water conflicts with other users, pollution, human recreation and management activities.

The 22nd Canadian National recovery plan for the Canadian Piping Plover (*Charadrius melodus*) takes into account the biology and population dynamics of an endangered wetlands species. It proceeds by setting up recovery teams with all interest groups represented, who decide feasible, cost-effective actions, most likely to lead to fast recovery. Under the Piping Plover plan there is a discussion of strategies for achieving recovery goals and objectives, and the following proposed actions:

- Set up teams of experts to take responsibility for recovery plans
- Define habitat requirements and draft habitat guidelines
- Manage/protect breeding sites, determine their productivity and search for new ones.
- Monitor and evaluate effectiveness of management actions
- Monitor and evaluate effectiveness of recovery actions
- Provide managers with current population, productivity and habitat data
- Develop and implement public information and education programmes
- Census population annually to determine regional trends and determine prey at feeding sites
- Identify options to restore natural habitat and coordinate recovery actions across species range
- Data exchange internationally/nationally- formally share goals/strategies between jurisdictions.

Table 1: Proposed template for recovery actions in the piping plover plan

Priority	Broad approach / strategy	Specific steps	Anticipated (measurable) effect	Cost estimates
Urgent	Habitat protection	Conservation easement	Increase breeding success	$20K
Urgent	Habitat mapping	Establish Recovery Action Groups	Improve understanding of critical habitat and its characteristics	$8K
Urgent	Enforce legal protection	Negotiate with province	Reduce mortalities due to hunting	In-kind
Necessary	Breeding / wintering surveys	Integrate with other planned surveys	Ongoing assessment of popl'n status	$10K/yr
Necessary	Public outreach	Provide brochure: give talks	Improve understanding among public, hunters and community support for recovery	$6K
Beneficial	Habitat restoration	Plant upland cover along riparian habitat	Increased population density	$5K
Beneficial	Demographic and genetic studies	Develop DNA markers	Identification of management units, life history attributes	$20K

All of the items in the above table should appear in fishery recovery plans, but in few cases do.

Standardised headings given in Table 1 illustrate the scope of this type of plan, and it would be worthwhile considering what criteria and procedures applied that would be useful in marine fish recovery plans and the above tables offer food for thought. Few items would be considered irrelevant, although not much could be said for most groundfish on essential habitat, behaviour or population genetics; illustrating the serious lack of research on these aspects for most marine resources.

Other useful considerations for marine species are provided in IUCN (2002) and in a 'Working draft Recovery operations manual' from the Canadian 'Recovery Secretariat' (see RENEW-ESCAPE@ec.gc.ca). This apparently was submitted in 2002 for approval by Canadian Wildlife Ministers and notes that funding for the recovery effort will need to be identified in which both governmental, local jurisdictional and private sector contributions are included. The manual suggests a template for recovery actions will have to be developed (see Table 1 and the above box for examples).

Extracting some principles for stock recovery of marine resources

When describing a limited number of case studies in the following sections, we have assembled what appear to be important considerations in a draft set of guidelines given in the Annex. Descriptors such as [D12] cross reference to items in these guidelines.

Recovery plans for endangered fish species

Examples of considerations relevant to low fecundity species such as elasmobranchs (Smith et. al. 1998), the nurse shark Plan (www.ea.gov.au/coasts/species/sharks/greynurse/plan/index.html), and considerations relevant to recovery of sawfish resemble more terrestrial plans using life table analysis. The Atlantic Whitefish Plan (Anon 2000) deals with endangered species incorporating more elements of habitat restoration, but also socio-economic and environmental implications are evident. Such plans may be administered by a Ministry of the Environment, not necessarily to restore commercial exploitation, but to protect biodiversity. In fact, in Canada, the term 'recovery plan' is reserved for resources in danger of extinction, while the term 'rebuilding plan' is used where a stock, though low, is not in imminent danger of extinction. In this document however, both types of plan are considered as 'recovery plans', even if extinction is unlikely, which cannot be taken for granted, at least as far as genetically distinct stocks is concerned. In fact, the recent closure by the Government of Canada of cod stocks in the Gulf of St Lawrence, Newfoundland and Labrador (see www.dfo-mpo.gc.ca/focus-une/20030424e.htm) suggests that this distinction is becoming academic, as previously commercially valuable species are risking to appear on the IUCN Red List (IUCN 1996).

Relatively few recovery plans were located for critically endangered marine resources, but several plans for endangered freshwater fish and anadromous species, notably sturgeons and salmons, were found which are not listed, often involving hatchery techniques: an approach not dealt with in detail here. An example is the National Recovery Strategy for the Atlantic whitefish (*Coregonus* *huntsmani*), a species formerly used for sport and consumption, of Environment Canada (Anon 2001). This species is only found in two watersheds in Nova Scotia, and was declared endangered by COSEWIC in 1984. Some features of this plan for are transitional between the terrestrial wildlife type of plan above and the conventional fisheries approach to recovery planning. The species once had anadromous (sea run) and lake components, though persistence of the former is now equivocal. Local non-migratory populations remain where there is a protected watershed area providing a town drinking supply. Species risks here seem to be largely environmental: acid rain, exotic predators (smallmouth bass) and pollution. Sport and commercial fishing are not seen as the primary problem though both are prohibited. Recommended objectives of the plan are:

	Objectives	Recommended actions
1	Conserve and restore whitefish popl'ns	Implement a fish culture program
2	Conserve, protect, manage the species and its habitat [A16]	Habitat protection including lakes on the upper Petit Riviere river where populations are most stable
3	Monitor and research existing populations	Assess threats by predators and predator control methods
4	Foster public education [A6]	Implement public communication and education activities

'The Atlantic Whitefish Conservation and Recovery Team' supervising recovery efforts, consists of federal/provincial managers, municipal staff, aboriginal peoples, fishermen and NGOs, and agreed terms of reference and specific funding resources for recovery. [A16]. CITES and IUCN criteria developed for threatened terrestrial and freshwater organisms are now being applied to commercial fish stocks. Hence issues formerly confined to fisheries are entering the competence of organizations such as CITES aimed at protecting rare, endangered or 'charismatic' species. When categorizing marine organisms by risk of extinction, authors often refer to 'classical' marine species, having high fecundity, pelagic larvae and wide distributions. Many of these (e.g. cod, whiting, *Nephrops*, scallops etc) are also multi-annual, hence more than one spawning occurs after maturity if the female survives. One axiom following Charnov (1993), is that a stable population must replace a mature female by one of the next generation. Since finfish fecundity is high and spawning is repeated every 5-10+ years after maturity, it follows that the probability of individual egg survival is very low for 'classical' marine species, hence the limited importance given earlier to stock fecundity. The heavy focus on SRRs developed using stock biomass and recruitment data from retrospective analysis may provide a misleading picture however: From DNA recovered from archived North Sea cod material, it seems that significant reductions in genetic diversity of North Sea cod occurred as early as between 1954 and 1970 (Hutchinson et. al. MS).

Performance measures for 'classical marine species' should not depend exclusively on VPA results, biomass estimates and SRRs, but also on more general criteria such as changes in stock range, condition, growth rate and age at maturity. One depletion criterion suggested by CITES is to avoid comparison with recent stock sizes, and use Extent-of-Decline' criteria, comparing the current state ofdepletion with that early in exploitation. A tabular approach categorizing the state of depletion is useful in planning recovery strategies and an example scored for North Sea cod comes from O'Brien et.al. 2000) where the population seems to be in a chronic decline.

Table 2: Evaluation (first table) Impacts of past exploitation and (second table) relevance of biological characteristics to risk of extinction for North Sea cod (From O'Brien et. al. 2000).

Possible impact?	**Yes**	**No**
Reduction in number of spawning populations/sites?		No
Change in sex ratio for mature fish?	Yes. (Due to fishing)	
Has there been an effective change in life history traits (e.g. age/size at maturity, sex ratio)?		No. small change in size at maturity
Is there a critical density for spawning success?		No. depensation shown
Is distribution patchy ?		No. Continuous

The possibility of extinction or irreversible biological damage will depend on a range of biological characteristics:

Risk of extinction	**Yes**	**No**
A/ Genetic and evolutionary legacy:		
1) Does the population have high genetic divergence?	*	
2)Does the population exist in an unusual habitat?		*
3) Does the population have an unusual life history trait?		*
4) Does the population have unusual morphological traits with genetic basis?		*
5)Has the population been isolated genetically for a long time?		*
6)Has the population avoided severe bottlenecks in the past?	*	
7) Does the population occur at the extreme range of the species?		*
B/ Ecological legacy:		
8) Is the population member of a native assemblage that is unusual or rare?		*
9)Does the population occur in an unusual or unique biogeographical province?		*
10) Are adjacent populations of the same species extinct, declining or relictual?	*	
11) Are numerous other species in the area extinct, declining or relictual?	*	
12) Would protecting the species (its habitat, or by reducing exploitation) encourage recovery of other imperilled populations in the same area?	*	

Tables 2 confirm that the criteria described for terrestrial recovery plans are relevant here also.

2. CASE STUDIES: KEY FEATURES OF SEVERAL FISHERY RECOVERY PLANS

Partial information was located in the companion paper on more than 20 recovery plans. Some key themes from the better-documented of these are extracted below. For the US case studies, a common context of recent plans is provided by the Magnuson-Stevens Act of Congress [A2]. This triggers mandatory recovery when the stock falls below a specified critical level, or when fishing mortality rate exceeds a specified limit reference point for F, and is required to continue until the stock can once more provide the historical MSY. One visualization of this type of management control measure is provided in Fig 1, following a Traffic Light colour convention (Caddy 1999) incorporating precautionary reference points (F_{PR} and B_{PR} and F_{LIM} and B_{LIM}), and similar overriding legislation is suggested as an essential basis for any recovery approach.

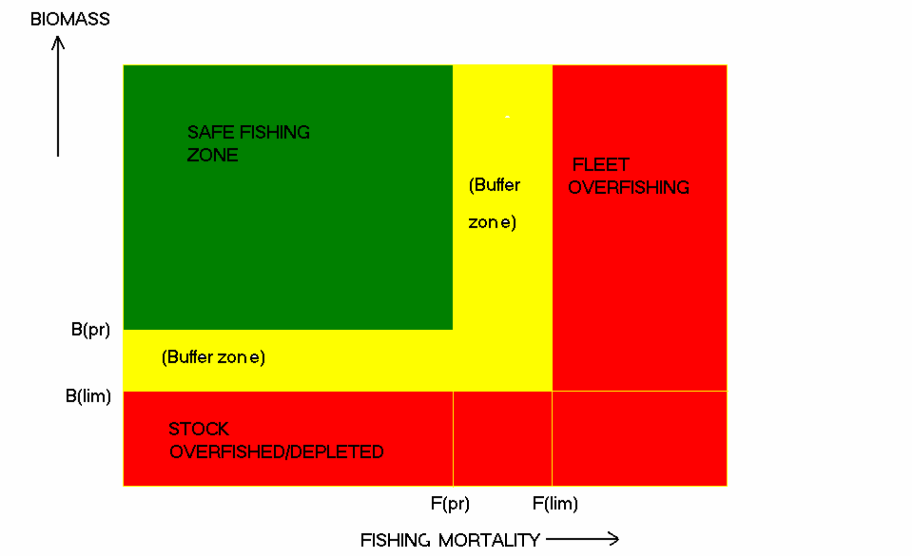


Fig 1. Visualization of a control rule specifying when a rebuilding plan is mandatory in terms of precautionary and limit reference points for spawning biomass and fishing mortality rate.

1) Pacific halibut (*Hippoglossus stenolepis*). <u>Successful recovery</u>

An early attempt was made at recovery of the halibut stock (Quinn et.al. 1984; Hoag et. al. 1993), which was aided by Pacific halibut being the subject of a special fisheries commission with powers to overrule other groundfish management measures in the area taking this top predator incidentally. Stock recovery in the favourable regime conditions that occurred in the 1970's to 80's was supposedly assisted by bycatch restraint legislated for other groundfish fisheries, and by limiting removals in the directed fishery to 75% of estimated surplus production (Quinn et.al. 1984). Recovery was also significantly assisted by favourable environmental conditions leading to productivity increases (Clark W.G. pers. comm.) (Anticipating the discussion in the companion paper, Jurado-Molina and Livingstone (2002) provide evidence of linkages between trophic considerations and climate change). Subsequently, recruitment declined: probably largely for the same reason [D15]. Parma (2002) warned that changes in assessment methodology had undermined the ability to correctly interpret trends in stock condition however [A3]. In her opinion, a robust harvest rule should be able to operate with only occasional interventions arising from new or revised assessments [B2]

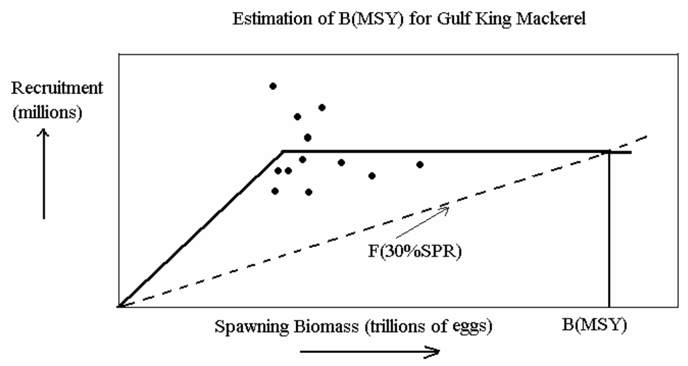
2) King mackerel (*Scomberomorus cavalla*). <u>Successful recovery</u>

Fig 2. Estimation of a proxy for B_{MSY} for Gulf King Mackerel marking the obligatory onset of a stock rebuilding programme as specified by the Magnuson-Stevens Act.

Evidence of the initial success in this plan, though not its completion, is given in Fig 3.

Key themes:
The stock was heavily exploited in the 1970's-80's, falling below 1000 mt in 1987/88. Powers (1996) describes provisions for a stock rebuilding programme to be implemented by regional fishery management councils in order to meet provisions of the Magnuson–Stevens Act, when stock biomass fell below a BMSY proxy. This was estimated based on the intersection of a SRR and the F(30%SPR) line for the stock (Fig 2) and formed the basis for a formal recovery strategy [C3]. A degree of recovery was achieved (Fig 3).

a) Following NOAA (2001), the '% Spawning Potential Ratio' is defined as:
b) *(spawn produced in year t)/ (lifetime reproductive potential with no fishing)*100%].* According to Powers (1996) the stock had dropped as low as 10% of virgin reproductive



capacity by the mid-1980's before a formal recovery plan was implemented [C3].

c) The determination that the above fishing mortality limit has been exceeded and rebuilding provisions should be invoked, depends on the degree of risk accepted by the Council. F should not exceed the above limit was established not to exceed a value of %SPR corresponding to 30% (NOAA 2001).

c) Recovery was effected by aiming for an agreed fixed fishing mortality level through an ABC (Allowed Biological Catch) with a low probability of exceeding F = F(40%SPR), but probably a control of gillnet fisheries in Florida State waters (M.Ortiz, pers. com.) also provided a major impetus for recovery [A7].

In general, conclusions drawn by Powers (1996) from this example were:

d) Reference points estimated while the stock is being overfished are not precautionary since density-dependent effects are not incorporated: stocks frequently exhibit large compensatory increases in growth, maturity and fecundity at low stock sizes.

e) Redeployment of effort to other fisheries would be impossible for many depleted stocks, given that all stocks in an area are fully exploited, hence achieving even moderate reductions in F would be noteworthy.

f) It was implied that F would be reduced to very low levels initially and then raised when target LRPs are reached at the end of the plan. However, Powers (1996) feared that unless precautionary caps on capacity were introduced and strictly enforced, an increase in allowable F could attract additional capacity, and would send the stock back to the overfished condition again [A12]. Thus, as F_{pa} is approached, care needs to be taken that there is not simply an oscillation around (production) P_{pa} or (biomass) B_{pa} levels [B4].

g)MSY and related reference points should be conditioned by environmental factors [D15].

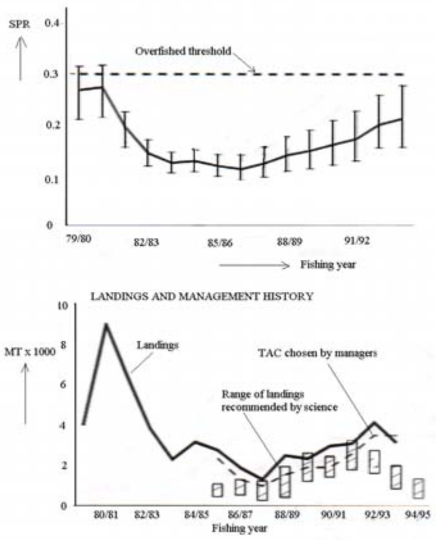


Fig 3. The recovery trajectory for King Mackerel (After Powers 1996).

According to Powers (1996), assuming that the fishery is not to be closed, and a quota or effort control regime is in place during the recovery period, stock recovery strategies should include the following components:

1) A threshold measure of the overfished state [A1]
2) Periodic monitoring relative to that measure [A3]
3) A specified recovery period [see however A5]
4) A proposed recovery trajectory relative to the overfished state [A5,B6].
5) A transition from a recovery strategy to an ‘optimal yield’ strategy [E].

Powers (1996) suggests the best estimate of current stock status (age composition) as the starting point for projections of possible recovery strategies using the geometric mean of (past) recruitments, or other realistic estimates of possible future recruitment levels. He assumes that ‘mid-course corrections’ will be needed to adjust between projected and realized stock status during recovery to keep the recovery programme on track and maintain the proposed recovery duration [but see C6]. This implies a further tightening of quotas if a recruitment shortfall occurs, or if recruitment is better than expected, that a decision must be made either to shorten the period of recovery, or increase quotas. He feels that a constant fishing mortality rate policy based on standard benchmarks should theoretically be adequate for stock recovery even if there are stochastic fluctuations in recruitment [A19]. He notes that a constant harvest policy is another option [A20], although this may require a threshold of stock size below which it should be abandoned, it has the advantage that 'windfalls' from better-than-expected recruitment will speed the realization of the recovery programme, whereas under a constant F approach, recovery allows yields to increase prematurely, which leads to unrealistic expectations [A12]. Allowing very good recruitment years to provide a temporary 'windfall' for industry during the recovery plan may be unrealistic, since there is no assurance that a TAC can be revised downwards when the inevitable succession of poor yc's occur.

In fact, we comment that implementation of a constant F policy is inevitably imperfect at low stock sizes [B3], especially if based on retrospective analyses, although for king mackerel these were tuned by 7 independent data sources. Attempting to maintain an agreed recovery trajectory was seen as essential, but mid-course corrections would be needed to keep the recovery trajectory on course, but this requirement is very vulnerable to recruitment variations, especially if the age structure is truncated. As noted, the minimum time frame set for recovery to the proposed benchmark inevitably requires flexibility in application, but prolonging the plan after a provisional plan duration was set, will cause industry unrest.

3) Striped Bass (*Morone saxatilis*). <u>Successful recovery</u>

This recovery plan aimed at protecting 1 or two fairly good cohorts, and as well as spawning stock size an improve estuarine environment for juveniles was seen as essential for good recruitment (Rago 1991). Size limits were set very high, so that the fishery was effectively closed until the target cohort(s) reach spawning age, which virtually phased out the commercial fishery. Chesapeake Bay is a key nursery area for the species, and suffered from water quality problems, but Richards and Rago (1999) suggested that recruitment overfishing was the key to former reduced survival of juvenile striped bass. A decisive management plan was adopted by the Atlantic States Marine Fisheries Commission in 1991/1995 which imposed a major increase in age at entry to the fishery from age 2 to age 8, with the intention that 95% of females could spawn at least once before capture [D1]. Size limits imposed by States differed, and were in the range 25-41 cm before the plan, but through successive increases, were intended to reach a uniform 97 cm by 1990. This strong provision effectively constituted a moratorium in the early years of the plan, and imposed a 'no-kill' policy on sports fishermen in the early days of the plan. A number of key themes make this a particularly useful example. Key themes:

a) The strongest year classes in the 44-year time series were in 1993 and 1996 when spawning biomass was high, so fishery management can claim some credit for recovery of juvenile production (ref). However, environmental factors and estuarine degradation strongly influenced recruitment, and environmental improvements in nursery areas may have contributed to the good recruitments in 1989, '93 and '96 [D15]. Hence, stock recovery was not guaranteed by spawning stock recovery alone. The R/SSB ratio was highest in 1982 & 1989 when SSB was rather low, suggesting an environmental contribution in those years.
b) Rebuilding F was established at 0.? instead of a maintenance F, estimated at .
c) Although some restocking from hatcheries occurred, success depended to a large extent on management of the wild stock.
d) Effectiveness of the plan depended heavily on public acceptance by fishers (Healy 1985) and evidently recreational fishers were strongly motivated to support conservation [A6]. A strong conservation ethic developed around the plan and voluntary compliance was high, (especially by sports fishers). Fishers were involved in the decision process [A8].
e) A clearly defined endpoint to restrictive management was crucial to acceptance of the plan by fishers. This stipulated that a 3-year average of the Maryland juvenile index should exceed 8.0. Despite the apparently unambiguous nature of this 'endpoint decision rule', reopening of the fishery was triggered prematurely by one very large sample of juveniles

[D14]. Care is evidently needed to define a recovery plan end point in a statistically valid fashion.

f) Despite doubts as to full recovery at the time of reopening, further delay was politically untenable, even though the endpoint decision rule was flawed [D14]. Further amendments to 'routine management' were made however, to restrict exploitation after opening [E1].
g) Thus, after recovery, the ASMFC and the States adopted a new management regime with some of the restrictive features of the recovery regime [E2].

Management can claim credit for rebuilding the striped bass stock of the US East coast even though even here, environmental quality and climatic fluctuations strongly influenced recruitment (the latter might have led to v. good recruitments in 1989, '93 and '96) [D15]. Hence, stock recovery was not guaranteed by recovery of the spawning stock alone, though the strongest yc's in the 44 year time series were in 1993 and 1996 when spawning biomass was high, allowing management to claim credit for recovery of juvenile production. In the striped bass case, despite scientific doubts as to the full recovery of the stock, it was politically untenable to delay reopening even though the endpoint decision rule based on a single criterion was flawed, (leading to reopening based on a single, very large sample of juveniles). This required further restrictions to exploitation in the first years of 'normal' fishing [E2].

Hatchery stocking programmes are a popular response to depressed stocks, and although recovery may be enhanced by hatchery production, an analysis of tradeoffs shows that stocking should not be used as an excuse to avoid conservation, since gains from reducing fishing mortality were much higher without accompanying effects of genetic selectivity often associated with hatcheries [B9].

4) Summer flounder (*Paralichthys dentatus*): (Partially successful: some recovery but target not fully met after 10 years)

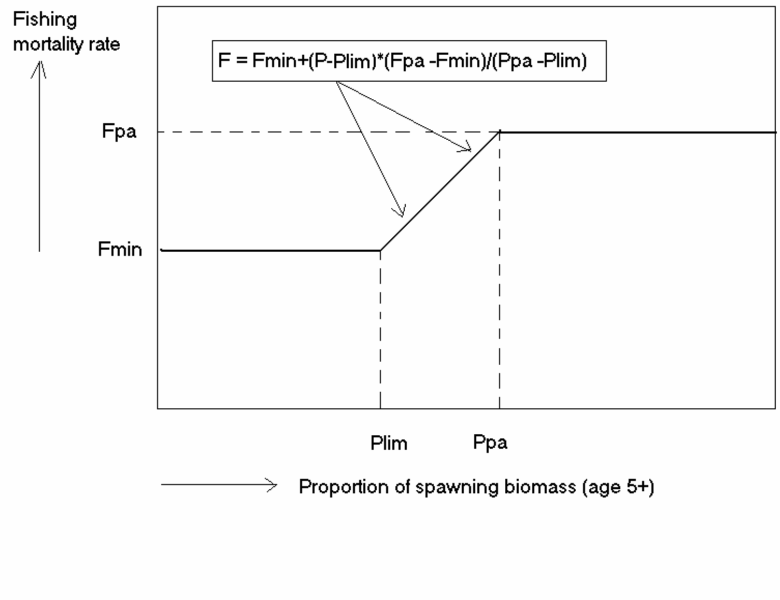


Fig 4. A fishery control law specifying fishing mortality rates between limit and precautionary levels, as a function of the proportion of spawning biomass consisting of age 5+ fish.

Key themes:

a) The rebuilding strategy centred on reducing fishing mortality to a long-term fishing mortality rate, F_{max}, derived from Y/R analysis. This was originally considered the fishing mortality rate at which a rebuilt stock should be exploited, but controversy on this developed later. There was apparently no explicit decision prior to rebuilding on the F trajectory with time, or on the duration of the rebuilding strategy.

b) A slowing in rebuilding, and changes to the target F_{max} and the ideal F trajectory, and reanalysis of biomass targets (as proxies for MSY) also occurred during rebuilding. This led to litigation, which, in turn, provoked further re-analysis [A10].
c) A central theme of the very complete review of Terceiro (2002) dealt with retrospective errors in tuned VPA/ADAPT procedures, as revealed by successive estimates [A10]. 'Earlier year Fs' were later found to be underestimated by between 23 and 123%, with unreported discard deaths and catch under-reporting revealed as the major sources of bias. Progressive revisions to the assessment procedure during rebuilding radically changed the early values of F and population size. This contributed to distrust by industry of scientific advice, and led to heavy scrutiny in the courts of the data and methodologies used in assessments. In societies where recourse to the courts by stakeholders is possible, one can expect legal scrutiny of the rebuilding plan if a loss of equity or severe drops in quotas occur for methodological reasons. Retrospective errors were in part due to tuning the VPA with commercial data, and although the retrospective bias was largely eliminated later by using only survey data for tuning, in general, retrospective analyses are less reliable in more recent years, when stock size is low, and for older age groups. Over-reliance on VPA/ADAPT may have also given an impression of spurious precision to stock estimates, and prompted industry outrage when major changes in retrospective stock sizes occurred with successive assessments [B1].
d) Controversy in later years centred on the abundance of older age groups in the population, believed by fishers to be underrepresented in the VPAs [C1, C7], and the feasibility of a rebuilding plan using abundance of older fish was discussed as a criterion (Fig 4).
e) Two opposing themes emerged which occur in other examples: the concern by fishers (and the courts) with the over-use by scientists of the precautionary approach in setting too-low quotas, and the tendency of managers to pick the highest of quota options offered by scientists. The chain of events seems to have confirmed the second problem, in that the target recovery biomass was not attained by the time the plan was apparently abandoned.
f) The frequent recourse to litigation, or arbitration in this case study (through the courts or by special technical review) was not entirely negative, since it led to the identification and correction of retrospective errors. All parties were involved in litigation, with commercial fishers and conservation groups providing the major polarity of views.
g) In a real sense, the summer flounder is a shared stock in that states have inshore jurisdiction (within 3 miles) and the federal government outside. Procedures were set up in the management infrastructure to ensure representation of all levels of government within a common management framework [B5,D13]. This seems to have worked initially, but controversies developed later on in stock rebuilding between State and Federal jurisdictions.
h) The frequency of legal challenges to the plan appeared to increase as rebuilding proceeded, such that a complete rebuilding of the stock was not yet completed by 2001. Later, there was scientific controversy over what constituted a rebuilt stock in spawner-recruit terms.
i) Differential treatment of user groups (commercial and sports fishers) especially involving quota overruns was a source of controversy, especially since commercial fishers bore the brunt of quota overages, and where the unreliability of data sources for sports fishers led to them apparently being excluded from corrective actions [C10].

In conclusion: classification of summer flounder stocks as "overfished" led initially to desirable actions, namely, a reduction of F and mandatory rebuilding of SSB and age structure, and subsequent restrictive harvests and mesh sizes initially led to some recovery. The failure to rebuild the stock by 2001 to more than 50% of the target B_{MSY} was due less to defects of the plan, and more to an increased readiness to move to litigation as rebuilding proceeded. For opposite motives, commercial fishers and the green movement engaged in civil actions in which assessment scientists were called to justify assumptions and methods as rebuilding progressed. Revisions to assessment methodologies during rebuilding usually had the effect of reducing apparent progress towards the rebuilding objective, such as by reducing apparent stock size or increasing apparent fishing mortality: actions that risked placing a partially recovered stock back within the terms of reference of the Magnuson-Stevens Act as a stock in need of urgent rebuilding [A3].

5) Pacific Ocean Perch (POP) - *Sebastes alutus*. (not yet successful)

POP offers as examples of a long-lived species caught in a mixed trawl fishery, for which recovery times of greater than 20-30 years may be required if age structure is to be restored (Gunderson 1977; Ianelli and Ito 1992). Little recovery has yet been observed in most stocks, probably due to slow population growth or regime change. Target biomass B_{MSY} in the plan was set to correspond to 'MSY conditions' and a post-recovery $F = F_{0.1}$ was envisaged. During recovery, a COMFIE-type rule set F at $F_{0.1}*B_{NOW}/B_{MSY}$.

Key themes:

a) The probability of detecting a 10% biomass change with slow population growth or regime change using estimation methods with CV's ??CHECK THIS of 30% or more is about 35% over three successive surveys. In contrast, the increases in POP biomass under a recovery plan is only expected to be of the order of 5-8% per year (Ianelli and Ito 1992). This will be difficult to detect, illustrating the problem of monitoring recovery where small population increases occur in plans for long-lived species [A4].
b) Long times to rebuilding for relatively low value species in a mixed fishery will be difficult to sustain given impacts on other resource harvests.
c) On the West coast of North America there is little observer coverage, hence discards may be significant, and landings much smaller than removals.
d) The mixed-species assemblages in which POP is fished with non-selective trawls contain species more valuable than POP, and make it difficult for fishermen to engage in recovery programs without suffering significant economic losses, hence for slow-growing and lower-value species such as POP, the economic incentives to rebuild are not great [C10, D10].
e) Much longer rebuilding durations will be required for long-lived species under long term environmental variability (MacCall 2002).

Conclusion: Recovery programs for rockfish (including Pacific Ocean perch) have only been in place since the early 1990s. Although they have not failed yet, neither could they have achieved their rebuilding targets. Their occurrence in multispecies assemblages leads to largely insoluble control and bycatch/discard problems unless more selective gear or procedures are developed [D8]. Wide statistical confidence intervals on stock size and slow rebuilding will lead to major difficulties in monitoring the success of rebuilding plans. Given the relatively low commercial value of POP compared with higher unit value 'bycatch' species (such as sablefish or Pacific cod), the sacrifices required from the multi-species trawl fishery are unlikely to be compensated once the POP stock is rebuilt [D9]. Economic criteria should be used with care however, since if recovery rates are lower than the discount rates that apply, fishing to commercial extinction may constitute an economic optimum.

6) Canadian Cod (*Gadus morhua*) and Haddock (*Melanogramus aeglifinus*) in NAFO Area 4X5Y. Recovery plan not yet effective

Considerable comment has focused on the collapse of the Canadian northern cod stock, which is proving a milestone where fisheries science and management has been entering new territory over the last decade (FRCC 2000), and this has prompted a number of retrospective analyses (e.g. Hutchings and Myers (1994), Hutchings (1996), and overall reviews of policy (e.g. Harris 1996) and the serious implications of a loss of metapopulation structure are emerging (See Smedbol and Wroblewski 2000). A wider suite of groundfish stocks have also shown declines which are not yet reversed, and the first signs of recovery occur to the SW of Canadian waters, suggesting a climatic linkage.

A conventional COMFIE harvest rule is used, although a quota change rule is also contemplated which does not allow catch increases from a very low quota until individual growth/condition factor/ recruitment - all improve. Directed catches and bycatches in other fisheries are closely controlled, with the quota minimum = bycatch in other fisheries to avoid closing all groundfish fisheries in the area. One approach to allowing increases of (cod) quota discussed, is to allow limited increments of 2000t/yr, and only if biomass indicator(s) are green, productivity indicator(s) are green, otherwise not (REF). Stocks are monitored by RV (stratified random) and by industry surveys (fixed stations). Poor regime conditions were improving slightly in S.W. Nova Scotia, Gulf of Maine, and Georges in 2002, but not further east and north.

Key themes:

a) Even the best recovery plan will be ineffective if regimes are unfavourable for growth and survival, and in recent months of 2003, Canadian authorities have closed two other cod fisheries to exploitation.
b) The 2002 situation for 4X5Y cod (ref), while still poor, was one of the more favourable Canadian stock units, especially for haddock. A very limited fishery was opened after a long moratorium, under a cautious harvesting plan where a quota control rule [D4] preventing rapid rebuilding of catches was proposed (see above). The division of responsibilities between management (the FRCC) and science is being actively discussed, and efforts are being made on both sides to clarify their respective roles. A 'Consideration Matrix' is one option suggested by the FRCC as providing an interface for the scientific advice they seek (Fig 5). Under this, scientific advisors should place the stock in one of 12 'boxes' classified in terms of two variables; stock condition and productivity regime. Management is constrained to accept the general advice, compatible with the traffic light (TL) colour indicated.
c) Observations suggest that SRRs are unreliable for predicting the likely size of recruiting ycs, and Mohn (1992 MS) showed that SRRs differ in good and poor regimes – i.e. 'depensation' risks being confounded with effects of a poor regime, and using historical data in a SRR risks overestimating likely recruitment in coming seasons [A9].
d) Experimentation with a wider series of fishery indicators is ongoing (Halliday et. al. 2001), which measure fisheries productivity and not just biomass and fishing mortality [B3]. Other indicators such as condition factor and growth rate have proven to vary, and provide a measure of environmental conditions which can be included as components of a 'production characteristic' within an empirical monitoring system, the traffic light (TL) approach. Comparisons are being made with the conventional VPA/ADAPT approaches described in other Case Studies. Both systems can link advice to the consideration matrix: the TL approach through a series of fuzzy logic conditional statements which simply indicate the direction of advised TAC change (but not the quantity) in response to the net 'colour' of biomass, fishing mortality and production 'Characteristics' or indicators (See Fig 2 and Halliday et. al. 2001) [D4]; leaving strictly circumscribed decisions on TACs to management. The VPA/ADAPT approach uses a COMFIE style harvest rule, which is supplemented by a quota change rule described above [B8].
e) The approach emphasizes recovery of older age groups as a specific recovery target [C7].
f) Tying continued exploitation of a more rapidly recovering haddock stock, and limiting catch of cod to bycatch in the haddock fishery, seems to have led to more discrimination by industry, seeking to avoid taking the cod quota and automatically closing that for haddock [C10, D7].
g) Involving industry in data gathering activities and monitoring helps convince them that scientific advice essentially represents the state of the resource, and that recovery has not yet occurred [D11]. Demands from industry for advice on broader ecological and life history

issues appears to reflect their deep concerns that the ecosystem itself is in trouble, and supports a conservationist approach by industry.

CONSIDERATION MATRIX

Stock condition: → Productivity regime ↓	Healthy	Moderate	Poor	Collapse
High	TAC MAY BE RAISED	TAC MAY BE RAISED	TAC TO REMAIN STABLE	BYCATCH ONLY
Intermediate	TAC MAY BE RAISED	TAC TO REMAIN STABLE	TAC SHOULD DECREASE	MORATORIUM
Low	TAC TO REMAIN STABLE	TAC SHOULD DECREASE	MORATORIUM	MORATORIUM

Fig 5. One possible interface between assessments and management authority suggested by (Lane name?) of the Canadian FRCC, is for 'science' to place the current position of the stock in one of 12 boxes, judging from stock condition and current productivity level; each box linking to a rule for action, without infringing on management discretion.

Conclusion: Restrictive recovery measures have been in place for NW Atlantic cod and haddock stocks starting with a moratorium, but only the latter species shows encouraging signs of rebuilding some years after closure, and only at the southern end of the range (Georges Bank and NAFO areas 4X5Y). Sampling of the closed population involved limited 'sentinel' fisheries [B7], and strict by-catch regulations using observers [A22]. Despite considerable restrictions, the lack of success seems due to unfavourable environmental conditions. Uncertainties with the use of age-structured methodologies at low stock size have lead to the development of a parallel "traffic-light" approach monitoring a wider range of stock health indicators [A27]. (Table 3 gives numerical estimates for colour zones used in a traffic light scheme).

Table 3. An example of the choice of indicator boundaries for 4X? cod using the traffic light (TL) approach. (From O'Boyle 2002 (ed) revised by D. Clark):

Indicator	Green-yellow boundary	Yellow-red boundary	Character-istic	weight
Summer RV. mean wt./tow	18: Consistent with highest values	10: Consistent with low abundance years of 1990s	Abundance	1
ITQ survey, mean catch/tow	55: A short time series, hence range is uncertain: (green value set a little above highest observed value to make uncertainty explicit)	15: Lowest value in this time series)	Abundance	1
VPA SSB (3+)	45,000: Target SSB specified in FRCP*	25,000. Unacceptable limit of SSB	Abundance	1
Above average yc (VPA)	4: As specified in FRCP*	2 : Set at half the FRCP target	Abundance	0.5
Area occupied by 75% of survey number (**)	0.45: Consistent with widest distribution observed.	0.35: Consistent with narrowest distribution.	Abundance	0.5
Density where caught	2: Consistent with highest density.	1.5. Consistent with lowest density.	Abundance	0.5
RV.: Recruits	1.0 : Consistent with largest	0.4 : Consistent with	Production	1

(< 33 cm)	observed recruitment pulses.	smallest observed values		
R.V.: mean wt at age 4.	3.0: consistent with the largest observed mean sizes	1.5 : Consistent with the smallest observed sizes	Production	1
VPA recruits	16,000 : consistent with largest recruitment pulses	10,000: Consistent with smallest observed R. pulses	Production	1
Condition factor (Fultons K)	1.0 : Consistent with largest observed.	0.9 : Set to ensure no red conditions in this indicator	Production	0.5
R.V. survey Z (age 4-8): (smoothed).	0.4: (FRCP Limit F + M=0.2)	0.6 : (Twice FRCP limit F +M)	Production	1
Relative F (4-8)	0.2: Boundary consistent with VPA F in 1990s	0.8: Chosen for consistency with F's from VPA (near F_{MAX} for cod?).	Fishing Mortality	1
Shelf area with 6-10 C water (**)	80 (represents a plateau from early 70's to early 80's)	50 (low end data series in early 70's-80's)	Environment	1

(* *Units not given in O'Boyle 2003).*

Lessons were drawn by Charles (1998) during the moratorium from the Canadian cod experience, suggesting that the following aspects required correction:

a) Changes to the 'burden of proof' from requiring scientists to 'prove' why a lower quota is necessary rather than for industry to 'prove' there is a surplus to take through industry-sponsored surveys and data gathering using observers, and 'sentinel fisheries'.

b) The desire of managers to avoid disrupting harvesting activity by frequent and large changes in quotas, unfortunately conflicts with the strategy of management by constant exploitation in a variable environment – (see also Walters and Parma 1996).

c) Charles mentions the '50% rule' as a non-precautionary decision rule used in Canada until at least the 1980's, whereby to avoid rapid drops in quota, the quota would be reduced by 50% of the difference between the last quota and the scientific recommendation. Similar approaches to 'averaging out' the large quota changes that seem inevitable with fixed exploitation recovery plans under high variance of control data, apparently also occurred in other jurisdictions. An opposite and precautionary approach to the usual 'ratchet rule' could be suggested: a decision rule to be applied in conditions of high uncertainty. This would allow only small increments in quotas if indicators show sustained improvement into green conditions, but larger cuts if they do not.

d) Management of cod quotas was formerly non-adaptive, in that quotas were set and allocated a year in advance; not necessarily taking the latest surveys into account. The revision of quotas (or the partial allocation of quota twice yearly) would allow unfavourable surprises to be taken into account.

e) Charles (1998) points to the relative success of fisheries not based on quotas such as the Canadian lobster fishery in which effort/access control is the key approach, with focus on the 'how, when and where' questions of fishing rather than the 'how much'. Walters and Parma (1996) note that 'pure' effort control is impractical as the sole approach given technological advances which continuously increase the catchability coefficient. Requiring the use of 'obsolete' technologies (such as certain shellfish fisheries where 'tonging' by hand or sail power are obligatory) could be a possibility but has not yet been considered in finfish fisheries, although if trawling were banned, longlining might be less disruptive.

f) Reopening the Canadian fisheries for stocks showing signs of recovery has been accompanied by a package of supplementary measures, such as relatively low harvest levels, protection for sub-stocks, spawning ground closures, and effort/access controls.

7) New Zealand lobster: use of a stochastic modelling approach. <u>Successful recovery</u>.

This example illustrates the use of decision rules within recovery plans based on yield, catch rate, and other commercial data rather than SRR or %SPR indicators; an indicator-based approach recommended for adoption for other New Zealand fisheries (Gilbert et.al. 2000). The New Zealand lobster plan was implemented through a "National rock lobster management group" [A8] and management actions were based on extensive (Bayesian) simulation analyses, which led to agreed decision rules [A10].

Some useful themes that emerged were:

a) Checking a recovery plan using a population model is sensitive to the assumptions made in the simulation, but gives managers an idea of the importance of different factors in setting up their decision rule.

b) Simulations showed that average fishery performance was not much improved by a decision rule rather than a constant (low) quota benchmark. A strong tradeoff occurred between early detection of poor recruitment and obtaining good recovery.

c) Catch reductions in the initial years of a rebuilding period have 'great leverage on the outcome' [A20].

d) If CPUE varies to some extent independently of biomass, an unnecessarily sensitive decision rule and random fluctuations in the index of abundance, 'led to pointless fluctuations or even unstable, coupled oscillations in catch and biomass', a conclusion also reached by Sanders and Beinssen (1989) from simulation of abalone life histories [C4]. This appears to cast doubts on the efficiency of quota adjustment as a means of controlling fishing mortality at low stock sizes.

8) Proposals for cod recovery plans in the NE Atlantic

The urgent need for stock recovery plans in the NE Atlantic follows from the diagnosis in EEA(2003) which suggested for the NE Atlantic waters of the EC, 69-91% of commercial stocks are outside safe biological limits (depending on the marine area involved), and that almost all round fish have declined and catches are currently not sustainable. It seems useful to discuss the underlying approaches to stock recovery planning in the NE Atlantic, which still remain to be fully implemented and hence do not constitute an implemented recovery plan. Of the considerable number of NE Atlantic stocks currently depleted mentioned above, the most significant (and widely acknowledged) are the cod stocks of the North Sea, West of Scotland, Irish Sea and Celtic Sea.

As an example, Irish Sea cod displayed signs of stress beginning in the early 1980s, when fishing mortality started to rise, initially from F_{pa} to F_{lim} and then from 1989, F exceeded F_{lim} (ICES Coop. R.R. No. 246). Spawning stock biomass responded by declining from above B_{pa} (10,000 t) in the 1980s to at or below B_{lim} (6000 t) from 1994 onwards (Table 4). Thus, although stock status was poor from the1980s, only in 2000 was the stock classed as critical. The current set of recovery efforts were initiated when the European Commission closed the spawning grounds for Irish Sea cod from 14 February to the end of April (Commission regl'n 304/2000). Derogations allowed *Nephrops* otter trawl, and shrimp/flatfish beam trawl fisheries to continue, with mesh regulations.

Similar measures followed for North Sea and West of Scotland cod (Commission regl'ns 259/2001, and 456/2001), implying considerable concern, but not yet a formal recovery plan. North Sea cod stocks are subject to joint agreement between the EU and Norway, and in meetings between the parties in Nov. 2000, ICES advice that this cod stock was far outside safe biological limits. The need for a recovery plan was accepted, and the North Sea TAC was reduced from 81,000 tonnes in 2000 to 48,600 tonnes in 2001 and 49,300 t in 2002. In 24 January 2001, agreement was reached between parties on emergency measures. For North Sea and W. Scotland cod, these included closure of spawning areas, with derogations for pelagic, shrimp/*Nephrops* and scallop fisheries to continue with mesh size restrictions and observers to monitor cod bycatch. An effective minimum mesh size for cod of 120 mm was agreed, and a restriction on cod bycatch to be retained in other fisheries operating with smaller meshes.

Table 4: Limit (and Target in parenthesis) reference points defined by ICES for selected NW Atlantic cod and hake stocks. The year in which the limit reference points were met or exceeded (indicating that the stock was in danger of collapse) are indicated.

Stock	B_{lim} (B_{pa})	F_{lim} (F_{pa})	Year that F first >= F_{lim}	Year that B first >= B_{lim}
Irish Sea cod	6000 (10000)	1.0 (0.72)	1989	1994
N. Sea cod	70000 (150000)	0.86 (0.65)	1984	1992
West of Scotland cod	14000 (22000)	0.8 (0.6)	1986	1992
Divisions VIIe-k cod	5400 (10000)	0.9 (0.68)	1991	2001
Northern hake	120000 (165000)	0.28 (0.2)	1988	1989

The provisions above are best described as ‘emergency measures’ rather than a ‘recovery plan’, and it was acknowledged that alone they would not lead to recovery (ACFM 2001) Acknowledging that these measures would be insufficient for rebuilding, the Council of Fisheries Ministers requested the Commission to develop a long-term plan to rebuild cod in the North Sea and West of Scotland. So in December 2001 the Commission proposed a Council Regulation to establish measures for the recovery of fish stocks threatened with collapse, which provided for a multi-annual recovery plan for cod and hake stocks (COM (2001) 724 final, 11 December 2001). This was quite a radical plan, in that for the first time it explicitly attempted to define long-term objectives and a decision rule. This development was consistent with the ideas being put forward by the Commission and other EU parties during the development of the revised CFP, which now includes an obligation to implement multi-annual management plans.

Acting on directions from the Council, the Commission requested specific advice from both the International Council for the Exploration of the Seas (ICES) and the Commission’s Scientific, Technical and Economic Committee for Fisheries (STECF) on the likely success of rebuilding plans based on the proposed regulation. ICES and ACFM concluded that in order to effect a recovery F would have to be significantly below F_{PA}, and that recovery in 5 years was unlikely, although recovery in 10 years had a relatively high probability. However, as a result of its simulations, reported that the implementation error, both due to the lack of reliable information on catches (including discards), and the over-estimation of stock size, appeared substantial, and retrospective studies of ICES forecasts (Hilden 1988) seem to confirm that wide confidence limits for assessments could severely compromise the success of proposed recovery plans if not taken into account by an adequately precautionary approach. It was further highlighted that the overriding success of any recovery plan would depend on the ability of managers to:

- monitor catches and discards,
- adhere to the effort reduction schemes, and
- achieve reductions in fishing mortality, despite assessment uncertainties.

From this evaluation, ICES concluded that “the proposed rebuilding plan cannot be accepted as likely to lead to a safe and rapid rebuilding of this cod stock”.

In spite of this advice from ICES, the Commission did not close the fisheries, but did amend the proposed recovery plan (COM 2002, 773 final, 20 December 2002). The most significant change to the recovery plan in December 2002 was the introduction of Article 5, which allowed for much lower maximum F levels for stocks with SSB lower than B_{LIM}, and a modification of the “change rule” (Article 3 paras 3 and 4) in the December 2001 proposal. The latter restricted TAC movements to 50% between years, whereas in 2002 this was reduced to 30%. A further important change was made to the method of calculating effort reductions.

Further to Council Regulation proposals put forward in 2001 and 2002, the Commission made a further proposal in May 2003, to ensure "the safe recovery of the cod stocks to the precautionary stock sizes advised by scientists within the time frame of five to ten years" (COM (2003) 237 final; 6 May 2003). This was directed specifically at cod. The 2003 proposal differed considerably from the 2001 and 2002 proposals. Possibly the most important changes were to the recovery trajectory. Instead of maximum annual TAC changes of 30%, the new regulation stipulates a maximum of a 15% change (up or down) each year**.** Secondly, instead of moving to a low fixed F when SSB is below B_{LIM}, the proposal now develops an explicit target of B_{LIM} irrespective of stock size. A new Article 7 allows the potential to set a zero TAC, and the calculation of effort reductions has been simplified. Note however, that the reference period for effort reductions has changed, and is now 2000-2002.

- The proposed regulation of May 2003 has improved upon the existing emergency measures and went a long way to providing the protection and management required to rebuild cod stocks to within safe limits. The EC plan meets many of the pre-requisites our review has identified as necessary for a successful plan. It proposed:
- Target reference points B_{LIM} (minimum safe biomass) and B_{PA} (target safe biomass) are to be used within a set of pre-defined decision rules;
- A rebuilding trajectory – firstly to get SSB up to B_{LIM} as fast as possible, then to rebuild the stock to B_{PA} with a target 30% increase in SSB each year. Constraints on TACs are set equal to an annual change of not more than 15% and an upper fishing mortality limit;
- Fishing effort (days at sea) must be consistent with required changes in TAC
- Financial assistance schemes to assist fishermen during tie-ups or decommissioning;
- Increased control measures, using a system of defined landing ports.
- A defined recovery period – 5-10 years, until SSB has been assessed to be at or above the B_{PA} for two successive years;

Some areas where this recovery plan seems inconsistent with others proposed may be mentioned. Probably the most significant of these is that there is no guarantee that such a short recovery period will be effective if environmental and/or depensatory effects depress recruitment, nor is it clear that the recovery plan will be protected by overriding legislation from political interference. Annual TAC decisions, and especially the TACs required to rebuild the stock to B_{LIM}, are presumably still subject to the annual decisions of the Council of Ministers, as for routine stock management. Stock rebuilding appears to be treated as an extension of normal 'business as usual' resource management, and not as an emergency procedure requiring streamlined and non-discretionary decision making. A clear sequence of events that will be followed should recruitment not be adequate also needs to be envisaged. One reason advanced for why cod and hake stocks now need a recovery plan was the inability of the extensive 'management cycle' of consultations within the EC and its member countries to take difficult decisions, and drastically reduce TACs early enough to prevent stock declines. From experience described in the summer flounder case study, political and social pressures are likely to be high towards the end of the recovery programme, when industry is again realizing high catch rates but is restricted by effort and catch limits. The incentive to jeopardise a recovery plans ability to meet its recovery targets will always exist, and seems to require an overriding legislation. The social pressures are of particular concern since apparently lacking is a consensus between management and industry on the status of the stocks.

All told, there was ample warning of the alarming resource situation from ICES in the late 1990s, and ICES in its 20 July 2003 advice noted that the North Sea cod stock was in such a bad way that the most effective plan would be a 5-year closure, and the emergency technical measures agreed to date have not effected stock recovery. Although workable models for a recovery plan were available since early 2002 they have not been fully implemented, suggesting that the problem is operational and not due to the failure of scientific advice.

One scientific query for European cod stocks is whether nature will allow the 'trajectories' specified in the plan can be achieved, even with severe effort restrictions. As for the Canadian cod stocks, and the summer flounder case, underestimation of F and overestimation of biomass by age-structured methodologies has emerged as a key factor in the NE Atlantic also, especially when stock size is low. van Beek and Pastoors (1999), and ACFM/ICES (1999), showed that for cod, haddock and whiting, F was much higher than originally estimated, and this problem and an associated overestimation of biomass, was identified as early as 1977. Hence, the practical question must be asked as to whether the assessments available will be robust at the unprecedented low stock sizes which now apply? Experience in the West Atlantic shows that much longer recovery periods than envisaged in the EC proposals may not be effective, even with much lower fishing mortality rates than those considered here. To aim for a 30% per year rebuilding of adult biomass also appears optimistic, and seem to assume that average-good recruitment is expected annually, when it is clear (e.g. Cushing 1980) that favourable and unfavourable periods for cod recruitment have occurred in the past, and seem inversely related to abundance of herring.

Nevertheless, the major problem with the recovery plans in European waters is that they have not yet been implemented. Reluctance of some member states to accept effort reduction appears to have been the major obstacle to the Commission's proposal. The continued allowance for political intervention, even should the plan be adopted, is probably the single factor that is most likely to jeopardise the success of the plan. But, in the absence of a plan, allowing current effort levels to continue will result in higher levels of discarding, high-grading, misreporting and declarations of black fish, and the diversion of effort to stocks not currently over-exploited, and onto the remnants of older age groups, if either category still exists. The longer the situation continues, the more difficult it will be to effect recoveries.

A summary of some common themes in the case studies

The following table summarises briefly some key factors that appear to have contributed to recovery success, and others which prevented it, for the eight main case studies mentioned. Since quantitative comparison is impossible, and information sources fragmentary, Table 5 should be seen as an incomplete attempt at an overview, using the concept of overall 'Themes': a 'theme' being an aspect of a plan that is most evident to an outside observer:

Table 5. A very incomplete scoring of the 8 case studies by recurrent themes.

Themes in recovery plans	1	2	3	4	5	6	7	8	9
Environmental changes important for rebuilding/declines?	Y	Y	Y			Y		?	
Was an effort made to protect/ improve critical habitats?			Y					Y	
Did changes in assessment methodologies during plan lead to parameter changes/ cause problems in interpreting stock condition?	Y			Y				N	
Was SSB proposed as the control indicator?								Y	
Was recruitment irregular before or during the plan?	Y		Y		Y			Y	
Was a constant quota (Q) or constant effort (F) specified? Were there year-by-year attempts to compensate for changes in recruitment?(C)							Q? ? Y	C	
Were there major (potential) sources of bias in the assessments?				Y	Y			Y	
Was a recovered age structure considered in the plan?		Y		Y				N	
Were target (T) & limit (L) reference points used?	T							T,L	
Were gear restrictions/size limits changed before/in the plan?		Y	Y					y	
Were multispecies problems (M) technical interactions (T) considered?	Y	N?	N?	?	Y			Y	
Were bycatch considerations taken into account?	Y	?	?	?	Y	Y		Y	
Was a robust stock rebuilding rule followed?	N	Y						?	
Was there overriding legislation specifying criteria for initiating a non-discretionary recovery plan?	?	Y	Y	Y	Y	Y		Y?	
Were spatial closures specified?						Y		Y	
Were problems with implementation error considered?	?	Y						Y	
Were hatcheries used to augment recruitment?	N	N	Y					N	
Were there conflicts between stakeholder groups?				Y				Y	
Were fishers consulted (C)? Was the Plan accepted by fishers (A)? Are they actively represented on a recovery team (T)?			Spor ts Y					Y/?/ N	
Was a plan duration specified?								Y	
Was an attempt made to reduce capacity before/during plan?								Y	
Is effort likely to be diverted to other fisheries during the plan?	Y		Y	Y	Y	Y	?	Y	
Was a fishing mortality (vector) specified?								Y	
Was there a formal end point to the rebuilding plan?			Y				Y		
Was there litigation before (B)/during (D) the plan/ Was there an external review (E)?				D, E				B	
Was the management regime changed after recovery?			Y	Y				?	
Did problems increase during the implementation of the plan?				Y		Y			
Was the management infrastructure suitable for timely action?	Y					Y		N?	
Has the rebuilding effort been successful? (P = partly)	Y	Y	Y	P	N	N	Y	N	

1 : Pacific halibut 2: Spanish mackerel
3: Striped bass 4: Summer flounder
5: Pacific Ocean Perch 6: Canadian cod in 4X5Y
7: New Zealand lobster 8: North/Irish Sea cod

3. GENERAL CONSIDERATIONS ARISING FROM RECOVERY PLANS PRESENTED

A broader basis for an appropriate rebuilding framework?

The existence of favourable or unfavourable environmental conditions, the possibility of depensatory problems with the stocks, and the appropriate management response in the presence of shortfalls or windfalls in recruitment, all remain open questions. A considerable amount of scenario modelling has been undertaken to investigate the effect of different recruitment assumptions and assessment bias, but it is arguable that the key issues have not been modelled. As an example, the complicated political and administrative reporting system between national and super-national levels within the EU risks leading to a slow response time for consultative decision-making. Charles (1998) highlights this issue from experience with Northern Cod in Canada, and finds that uncertainties in fisheries arise in 3 principal forms:

- Random fluctuations
- Uncertainty in parameter estimates and states of nature
- Structural uncertainty, reflecting a lack of knowledge about the fishery system

The third in his opinion, has proven immune to analytical treatment, and must be addressed through redesign of the management system, to ensure that it is robust, adaptive and precautionary. He refers to 8 categories of uncertainty:

1) Spatial complexity 2) Multi-species interactions
3) Environmental effects 4) Technological change
5) Management objectives 6) Fishermen's objectives
7) Fishermen's response to regulations 8) Institutional arrangements

All of these sources of uncertainty have been mentioned in the various Case Studies. Though no ranking by importance can be given, we discuss 3) and 4) in the companion paper. It also seems obvious that reconciling items 5) to 8) through some form of co-management approach is essential. Given the growing use of Bayesian methods for fish stock analysis and setting management rules (see e.g. Butterworth et al. 1997), it is assumed that we have a good idea of the correct underlying parametrisation of a model for an exploited resource. One may ask if a Bayesian framework could incorporate all of factors 1) to 8) above into a management model? Our conclusion is that although management decisions can be aided by simulation, 'surprises' resulting from a misunderstanding of the relative importance especially of factors 3) to 8) above will inevitably occur, and suggest that the interface between resource advice, stakeholders and managers needs to be streamlined for implementation of effective recovery plans.

Some general considerations for planning stock recovery

In discussing recovery plans, two concepts can be mentioned with important practical applications; recruitment shortfalls, and windfalls. Making explicit decisions before the plan begins, about what to do when these two situations occur, seems essential to the success of the plan.

CONCEPT	MEANING	POSSIBLE MANAGEMENT ACTIONS
A/ shortfall	Recruitment falls below expectation in the plan	1) Reduce quota still further attempting to keep recovery period on track. 2) Keep same quota but prolong recovery plan.
B/ windfall	Recruitment exceeds expectation	1) Allow higher quota to keep recovery plan 'on track'. 2) Keep the same quota so as to shorten the recovery period

Recovery strategies, *sensu strictu* involve attempting to predict trajectories of biomass and fishing mortality, but there are significant problems in achieving this realistically. Apart from the technical obstacle of the low precision and significant chance of bias in analyses of data for depleted stocks, and the effect of shrinking ranges on the precision of pre-stratified cruise surveys, stock recovery may also be affected by changes in ecosystems and their productivity. Simulation results show that many small changes in strategy from year to year are likely to be counterproductive. The choice of an initial (low) exploitation rate during recovery, assuming fishing is allowed, seems crucial, and will require a precautionary approach. It also appears desirable to initiate a recovery regime with severe restrictions, aiming for a short recovery period, and taking advantage of windfalls in the form of good yc's, to shorten recovery time.

Effects of stock size on assessment precision

A trial using a log-normal distribution of recruitments to create an age structure and fishing it with constant F, shows, as expected, that catch variance (lower line in Fig 6) rises with fishing mortality as older age classes are depleted, and the catch becomes progressively dependent on incoming year classes. Under these circumstances, the ability to estimate accurately fishing mortality rate and biomass from catch statistics will inevitably deteriorate. This would appear to make the calculation of effective population F from catch sampling uncertain at low stock sizes, and hence we may question whether 'adjustments' for shortfalls or windfalls can be effectively accomplished under these conditions.

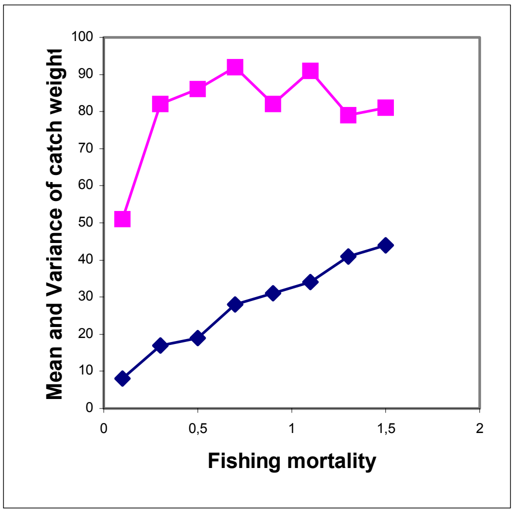


Fig 6. Mean catch (above) and its variance (below) calculated for a time series simulated with fishing mortality at different constant rates on an age structure created using a log-normal recruitment distribution.

Obviously the two approaches compared in Fig 6 have advantages and drawbacks, but a constant low quota in 'sentinel fishing mode' (Fréchet 1998) seems more precautionary, at least until there is unambiguous evidence that recovery is underway, when a return to an F-based strategy should be considered when assessments suggest that adequate precision in measuring stock parameters is being achieved.

Recovery trajectories

There are several obvious ways in which a recovery trajectory can be defined, and Deriso (MS) notes that 'a constant catch policy requires the fish stock to absorb all the natural stochasticity' in the system, and hence the success of a constant catch strategy rides on the precautionary choice of the catch level. Once a moderate year class is recruited, a constant low quota should lead to a rapid increase in biomass taking the stock out of immediate danger, while a constant F, if chosen in a precautionary fashion, should also allow a rapid initial recovery, but this will be followed by a slow-down as quotas as well as biomasses increase. We do not have enough data yet to judge which type of trajectory is most likely to be successful, but the issue is discussed in Table 6 and Figs 8 and 10. Defining a recovery strategy using a low fishing mortality rate and benchmarks in terms of spawning biomass, may restore a stock towards the recovery criterion according to a fixed schedule (see Fig 7), but in practice, environment and recruitment variability will result in deviations from this. We should also recognize the considerable errors and biases likely in judging attainment of target F's with a depleted stock. This tends to suggest that a concave trajectory is more favourable, based on a constant restricted catch until the recovery condition is met, or at least the first few 'way-stations' to recovery have been attained, before allowing a constant exploitation strategy to be safely resumed.

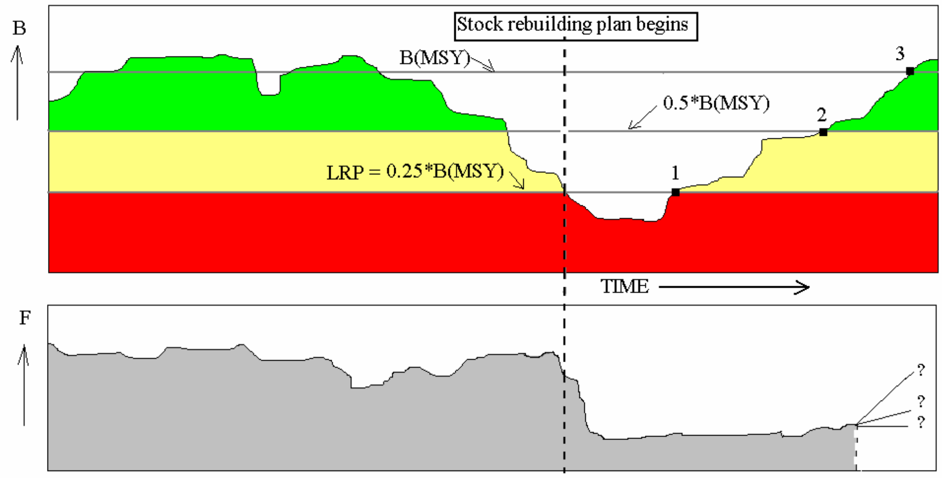


Fig 7. Schematic time line for a rebuilding plan triggered by biomass dropping below an LRP hypothetically set at $0.25B_{MSY}$. Sequential biomass recovery points 1, 2 and 3 are set, without specifying a rigid scheduling. Opening of the fishery on arrival at B_{MSY} may lead to several options: continuation of the current level of fishing, a slight increase in F, or, for those who are in favour of recapitulation, a restoration of previous exploitation rates.

Table 6. A comparison of two methods of stock rebuilding. (Note: in both cases bycatches in other fisheries need to be incorporated in quota calculations, and in mixed fisheries a failure of recruitment will require closure of fisheries, including those taking the recovery species as bycatch).

A/ A Fixed low fishing mortality		**B/ A constant low quota**	
Advantages	**Drawbacks**	**Advantages**	**Drawbacks**
Harvest rate in theory is set at a low level initially, but rises as the stock recovers (COMFIE).	Calculating quotas based on retrospective analysis is uncertain at low stock sizes	As long as the initial quota is set at a low rate of exploitation, the need for (uncertain) annual quota recalculation is reduced. Scientific resources can be devoted to monitoring.	The recovery quota must be set at a precautionary level, since effective exploitation rate with a fixed quota will rise if stock declines further.
This strategy allows industry to profit from the recovering stock before the recovery	Since recruits make a significant component of yield, and are difficult to estimate, this adds to errors in current F, B estimates used to	Any good recruitment is rapidly translated into recovered stock size.	As catch rate increases during recovery, the fishery remains open for progressively briefer

plan is over.	set quotas.		intervals.
Good recruitment should lead to increased catches, but poor year classes require a drop in quota.	Increasing quotas will be welcome but may lead to capacity increases, but quota cuts will be resisted.	As long as the recovery rule is maintained and occasional good recruitment occurs, this strategy should accelerate stock recovery.	Industry unrest later in a (successful) plan, is likely, given ever-shorter open seasons, despite improved catch rates.
	Changing quotas annually adds to the uncertainty of indicators monitoring catch rate, F and biomass.	Using the limited quota either for bycatch, or for a 'sentinel fishery' with recovery monitoring is advisable.	A switch to a fixed exploitation rate strategy may be advisable when CVs of population parameters improve.
	Survey stratifications used when the stock was abundant may be less valid at low stock sizes, hence biomass estimates used in calculating quota may be biased.		
	Recovery rate later in the plan will slow, and a long recovery time may lead to dropping the plan before recovery.		

From issues mentioned in the case studies, Figs 8 and 10 suggest there will be problems in implementing a COMFIE type rule for stock rebuilding at very low sizes, suggesting that fixed low exploitation rates or fixed low quotas should be used at least until rebuilding has restored the stock to 'safe' levels above B_{LIM}. In fact, two target levels may be required; the first requiring a fast return to above B_{LIM}, by closure or a very low constant quota by a Sentinel fishery as a way of escaping immediate danger, (and allowing monitoring of changes, aided by a constant exploitation strategy), followed by a constant low exploitation strategy when the stock is within historical stock levels aiming at B_{PA} levels or above.

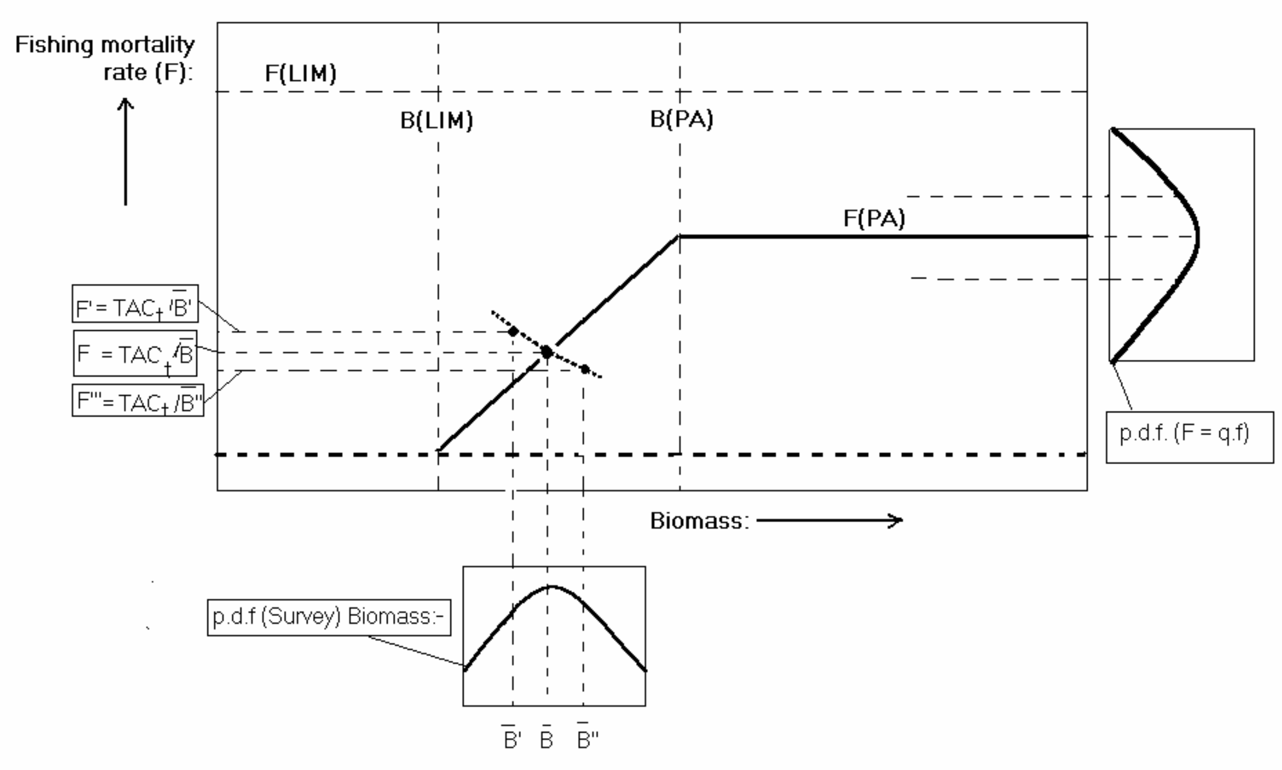


Fig 8. Illustrating 2 problems with the standard COMFIE 'generic form of harvest control law' (ICES 1997) when used for stock rebuilding of depleted stocks: 1) where a TAC is used to realize a safe fishing mortality from a survey biomass whose high variance (and likely bias) suggests a range of F values depending on whether biomass is believed to be B' or B''. For B', this could lead to an excessive TAC. 2) Unexpectedly high values for the catchability coefficient, q when stock range is restricted, could occur, especially if catchability is density-dependent.

Some criteria for management actions during rebuilding

1) Especially in mixed species fisheries, a first estimate of minimum catch of the species to be recovered should not exceed the summed bycatches in fisheries for other species.

2) If this summed bycatch is below the safe recovery quota, a small directed fishery may be allowed, but if the summed bycatch still exceeds the precautionary rebuilding quota, other fisheries must also be regulated to allow rebuilding of the species being rebuilt.

3) Discarding or highgrading must be severely controlled during rebuilding.

4) If a constant (low) exploitation rate is aimed for, this should be defined in terms of the number of vessel-days allowed on the grounds per category: when stocks are critically low, quotas calculated from estimates of biomass, and fishing mortality from retrospective analysis of catch age structure, are liable to serious errors.

5) For this reason, it appears precautionary to impose either a constant low quota that should lead to rebuilding even with below-average recruitment, at least until significant rebuilding is evident. If this strategy is ineffective after several years, closure of the trawl fisheries of the area seems inevitable. A constant low quota as long as recruitment leads to rebuilding, is likely to give the most rapid recovery compatible with some fishing on the stock, but could be dangerous if the stock drops too far, (Fig 9) when the fishery should be closed.

6) It is suggested that priority allocation of this low quota be in the form of 'sentinel' fishery, such that specific stations of previous high abundance be fished by commercial vessels with observers on board, so as to collect data in cooperation with industry that illustrate that the stock is still not recovered.

7) One possibility where control of exploitation rate is uncertain, involves confining harvesting to small ‘windows’ in space and time (e.g.Walters and Parma 1996). Thus, only a small fraction of the stock is available to exploitation, and increased fishing power simply means that what is available is caught sooner in the season. Another spatial approach might involve setting up a large harvest refugia. Less restrictive is the possibility of incorporating such ‘harvest windows’ sequentially into a rotating harvest framework (Caddy 1993, Botsford et al. 1993; Caddy and Seijo 1998, Myers et.al. 2000). Rotating harvesting of unit areas for trawling during a short open season could be designed around the depleted stock such that the overall exploitation rate remains at a safe rebuilding level. Special derogations for harvesting other species using selective gears and fishing areas where the recovery stock is not abundant should be considered with care, and with observers on board.

Spawner-per-recruit theory: one basis for judging when recovery plans are needed?
Defining critical stock levels using stock-recruit relationships (SRR) has been the subject of considerable theoretical development, but serious problems occur in practice due to so-called ‘depensatory effects’, discussed in the companion paper.

In absence of suitable data to define SRRs, spawner-per-recruit theory formalized by Gabriel et al. (1989), is widely used in specifying RPs for recovery plans in the US. Mace and Sissenwine (1993) follow earlier authors (summarised in Charnov 1993), in noting that “population persistence requires that successive generations produce sufficient ‘spawning units per recruit’ (expressed in biomass or eggs) over their lifespan to correspond to the average number of recruits (R) produced by a unit of spawners, (S). They remark that in the early 1990’s, application of %SPR reference points in management plans was sporadic in the USA, and the first usage they report was in July 1989. The impetus for using these criteria in management came with the requirement that Fishery Management Councils, charged with management under the Magnuson-Stevens Act, establish measurable definitions of overfishing for all managed stocks in their fishery management plans (FMPs), and to: “Specify to the maximum extent possible, an objective and measurable definition of overfishing for each stock or stock complex covered by the FMP…and how it relates to the reproductive potential”.

Mace and Sissenwine (1993) in fact note that it is surprising that the SPR approach has been adopted so widely, since “few critical levels of SPR have been calculated from actual S-R data”. Nonetheless, the minimum values they derive for a number of species are given in Table 7.

Table 7. Mean values of the %SPR for 2 or more stocks of species judged to correspond to exploitation at species replacement were provided by Mace and Sissenwine (1993), and are ranked by increasing value of %SPR. (Indicative values for natural mortality rate shown are obtained from FISHBASE).

Species	Recovery %SPR	Category	Adult M	No. stocks
Scallop		Shellfish	0.1	1
Sole	6.99	Flatfish	0.25	6
Cod	7.29	Gadoid	0.14	14
Plaice	8.46	Flatfish	0.17	6
Greenland halibut	15.05	Flatfish	0.1?	2
Saithe	19.48	Gadoid	0.14	5
Haddock	22.68	Gadoid	0.2	6
Summer flounder	23.05	Flatfish	0.2	2
Herring	25.61	Pelagic	0.26	16
Whiting	29.66	Semi-pelagic	?	5
Sprat	40.75	Pelagic	0.76	2

Mackerel	41.75	Pelagic	0.22	2
Hake	42.80	Semi-pelagic	0.35?	2

Precautionary levels of stock size for short-lived invertebrates such as cephalopods, penaeid shrimps, king crabs and abalones may have to be similar to those for pelagic fish stocks, i.e. not dropping below 30-60% of virgin stock size, and for sharks, even higher values will probably be needed**.**. Minimum spawning stock sizes for lobsters and small crabs may be of the order of 10% SPR, but perhaps from precautionary considerations these should also be kept above the 30+% of virgin stock size now considered precautionary for groundfish.

Some tentative conclusions on limiting levels of %SPR for stock rebuilding

The values in Table 7 are assumed as default estimates of recruitment overfishing thresholds with some reserve, as explained below. Species such as small pelagics with smaller adult body weight (and size at maturity) seem to have high %SPR's. Walters and Parma (1996) refer to Patterson's (1992) finding that pelagic stocks are unable to sustain exploitation rates greater than F = 0.5M -> F=M, and note that this may apply to demersal stocks also. If so, the $F_{0.1}$ level may not be as precautionary as once thought for some species. Strangely enough, low values for %SPR in Table 7, appear associated with low M values: a counter-intuitive result, but which may simply represent the time lag over which 'fishing down of the older age groups' (associated with low M) took place, or that small refugia of mature individuals existed that were not vulnerable to fishing (Abella et.al.1997). The removal of up to 70% of a virgin stocks reproductive potential is often considered (perhaps erroneously?) as fairly risk-averse, since populations vary in terms of the degree of compensation they show to stock depletion. A stock boundary of 30% virgin population fecundity for an Australian abalone stock was estimated by Sanders and Beinssen (1996), below which stock recovery could not be assured, and Shepherd et. al. (2001) suggested even higher thresholds were precautionary for abalones.

From the above considerations, it may be questioned if the low values for %SPR at the top of Table should be regarded as precautionary for species with low values of M. Waiting for their recurrence before triggering a rebuilding programme may not be a good idea. A tentative conclusion from Table 7, might be that 20%SPR is a relatively high risk threshold, but 30-40% seems more reasonable for 80% of the stocks considered, but may be too low for some. Based on theoretical considerations Clark (1991) preferred a limiting management target of 35% SPR, and most overfishing thresholds used by FMCs are reported to be in the range 20-35%. Myers et. al. (1994) show that it is no longer safe to make the assumption that spawning population can be reduced by more than 60-70%, and even that these levels may be dangerously optimistic if metapopulation structure is not taken into account. Walters and Kitchell (2000) suggest that stock abundance goals should not fall below 50% of the unfished spawning biomass, which as they note, should not produce yields much less than the 30% unfished spawning biomass level often recommended as a lower limit for exploitation., unless other measures protect the spawning stock

Restoring older age groups

A supplementary stock recovery criterion associated with the above (see also Fig 4) is to restore the wider range of mature age groups in the population, and without this it may be questioned if stock rebuilding has been achieved. Certainly relying on the first maturing cohort for population replenishment as suggested under the current paradigm seems inadequate (see: Wigley 1999, Stephenson and Kenchington 2000, Caddy and Seijo 2002 and Longhurst 2002).

Indicators, reference points and control laws for stock recovery

During the last decade, the emphasis on biological reference points has shifted from target reference points (TRPs) to limit reference points (LRPs) and from optimising yield to preventing overfishing (e.g. Caddy and Mahon 1995). Once overfishing and depletion has occurred, the need for other reference points and recovery control laws is evident. By the early-mid 1990s, the new international norms, the FAO Code and the UN Fish Stock Agreement were applied, and procedures changed from the use of MSY (or F-based TRPs such as F_{MSY}) as fishery objectives, to using B_{MSY} or spawning stock equivalents as precautionary limits, below which the fishery should not fall. For many fishery administrations and commissions, restoring the 'ability of a stock to produce MSY' (as defined by experience previous to the decline) is a biomass-based TRP criterion that signals the end of rebuilding. As previously, reference points form integral 'action points' within fisheries control laws, but the emphasis is now on defining the limits of fish biomass below which depensatory effects reduce the possibility of stock recovery. As noted by Collie and Gislason (2001) "the formal definition of overfishing reference levels has been instrumental for recognizing and reversing overfishing".

Attaining B_{MSY} or its proxies, marks the end of the recovery plan by attainment of a sufficiently large 'recovery biomass'. As such it differs from TRPs for yield which are to be implemented. and the fishing mortality rate acceptable for continued harvesting is going to be much less than F_{MSY}, such as $F_{0.1}$ or lower, and such a 'recovery fishing rate' needs to be defined in advance. It has been suggested (e.g. Gilbert et.al. 2000), that indicators other than SRRs, derived more directly from fisheries data may be more robust and of more practical value in rebuilding strategies. For the majority of world fishery resources, this hopefully is the case, since data to construct SRRs are not generally available, and may be misleading if regime shifts occur. Collaboration between FAO/CITES (FAO 2001) suggests that 'Historical extent-of-decline' should be the criterion both for judging stock declines and setting recovery targets, rather than comparison with more recent catch rates or biomasses (which minimizes the significance of historical stock levels). If a single figure is sought for the state of decline of most stocks, Myers and Worm (2003) find from meta-analysis that stocks are now at around 10% of pre-industrial levels. If this is the case, and assuming that a 'safe' spawning stock size is in the range 30-50% of virgin stock size for most demersal species, then a stock rebuilding of between 3 and 5x current stock levels should be aimed for.

With an 'expert system' such as the Traffic Light System, expert opinion also includes industry and non-governmental inputs, and a recovery team potentially allows for faster implementation in response to changes in indicator values in an automatic quota rule. Control points on the indicator series could correspond to useful but agreed conditions such as the state of the fishery in a specified year prior to stock collapse, the stock size in the early 70's, etc. or other bench marks that are not derived from population models but are agreed to correspond to either desirable (TRPs) or undesirable (LRPs) conditions.

Prior to stock rebuilding, rules may specify the biomass and/or fishing mortality trajectories in terms of 'way points' through the projected recovery process (Fig 7). Given that the rate of recovery depends on annual recruitment levels and cannot be predicted, a succession of TRPs may be specified in the recovery plan (Fig 7), and attempts made by sampling and surveys to determine the probability that these have been attained. Thus we may consider five phases in a rebuilding plan:

1) The plan is prenegotiated with stakeholders
2) Once the stock has dropped below a biomass-based LRP the recovery plan is initiated.
3) A (succession of) recovery TRPs formulated as biomasses are defined (Fig 7). When the last is attained with a predefined probability, the recovery plan will be complete. The final biomass target should be significantly higher stock size than the LRP, and preferably should be B_{MSY}, and contain a significant proportion of several mature age classes.
4) A recovery trajectory may be defined in terms of a series of TRPs of biomass, but not be precisely defined in terms of duration. Of course, ideally, when a shortfall in a biomass target

occurs in rebuilding, the exploitation rate should be reduced, but the generally low precision of assessment data and methods at low stock sizes makes it difficult to 'steer' onto the precise fishing mortality needed (Fig 7), requiring precautionary approaches. Windfalls in better-than-expected recruitment should anyway ideally be 'banked' to shorten the recovery period rather than be harvested, while shortfalls, in practice, would require difficult reductions in quotas that may be politically impracticable.

5) When biomass has recovered to the TRP defined in 3), 'management for optimal yield' may be resumed, but some precautionary elements of the recovery plan should be retained, otherwise the stock risks soon returning to a dangerous condition.

The rebuilding procedure and decision-making bodies should be specified in binding legislation to allow rapid responses without time-consuming consultation during plan execution.

A traffic light approach to stock rebuilding

A precautionary management framework proposed by Caddy (1999a,b) for data-poor situations, has been subsequently developed further and applied in Eastern Canada for depleted groundfish stocks (see especially Halliday, Fanning and Mohn (2001) and recent research documents available on the DFO Government of Canada web site).The method as originally proposed, was seen as a development of the limit reference point approach based on multiple measures of stock status, productivity, performance etc, each measured by one or more indicator values. A traffic light stock status index was used by Koeller et al. (2000) to show historical trends in shrimp stocks, but the approach can be adapted as a Control Rule for stock rebuilding. Elements of a fishery are conceptualised by Halliday et al. (2001), as having 'attributes', such as biomass, growth rate and the mortality due to fishing. 'Attributes' are monitored by one or more indicators: (e.g., mean weight per tow of a RV survey is a 'relative' indicator of population biomass). Conventional estimates from VPA are often thought of as providing 'absolute' estimates, but due to sampling and retrospective errors, these are also measuring relative change, but shatter the common illusion of managers that retrospective analysis yields absolute numbers This together with 'Equilibrium thinking' may have led to insufficient precaution by managers, and inevitably, over time, to scepticism by stakeholders with the scientific process (e.g. Terceiro 2001).

Each indicator value can assume one of three colours, separated by what Halliday et al. (2001) as 'traffic light boundary points', falling close to the lowest value of an indicator believed to represent 'safe' conditions; and the red boundary at the onset of clearly unsafe conditions, however measured. This approach is directly analogous to the definitions of 'decision points' in a fisheries law. Similarly, a boundary point in a TL approach can be based on expert judgement or experience, (as well as) analysis or modelling, but may also represent a previous historical state which common opinion agrees marked the onset of unfavourable conditions, such as B_{1966}, (where 1966 might be the year when stock decline began).

Halliday et al. (2001) point out that the assignment of boundary points to indicators in the TL approach is precautionary, in that a wide range of indicators can be incorporated, in what is an 'objective-based' management approach. Whether this is controlling fishing under 'normal' stock conditions, or results in stock rebuilding, depends less on the definition of boundary points and indicator weightings than on the likelihood that action will be taken once these points are reached or passed. An advantage of the TL system is its ease of understanding, the sense of urgency and immediacy the colour coding provides once boundary points have been established, especially in discussions with industry and stakeholders. As they noted:

- It is only possible to apply conventional methods on stocks for which there is a lot of data
- This requires assumptions on the relationship of recruitment to spawning stock size, on which there is no consensus.

- Single species models generally assume that future environmental/ecological conditions will mirror those in the past.
- Most decision rules depend on only two attributes, B and F, and it is questionable that the SPA/catch projection method used for monitoring and feedback provides sufficiently accurate information to support such rules.
- The framework usually described refers only to decision making at the scientific/political interface and not to the entire fisheries system, which as he notes, could be incorporated into a broader TL framework, (incorporating economics, MCS, ecosystems, etc).

With the TL system, managers might use a formal 'quota change protocol' that only allows slow rebuilding of fishing mortality as indicators move into the 'green' range, and larger downward moves to either the base quota, with at the limit, a general fishery closure, of all fisheries taking the target stock, if indicators remain in or return to, red or yellow conditions. This may be called 'wasteful' in terms of landings foregone, but reduces the risk of serious errors in the early crucial stages of rebuilding without requiring too many assumptions in the modelling framework. This procedure makes explicit what is already the case, namely, the role of judgment by managers and scientists in setting reference or cut-off points for any control law. In general, an assessment of the performance of an indicator and its boundary points over a time series should be checked periodically against what we know about the resource status from other multiple data sources.

2) A quota control rule

Where information on the stock condition and mortalities experienced is unreliable, the use of a quota decision rule seems to become necessary. Contrary to the usual 'ratchet effect' (Caddy 1985) whereby fishing effort/capacity tends to increase unidirectionally upwards, a 'counter-ratchet' strategy seems necessary, such that larger declines in quota occur under unfavourable indicator values than when these are favourable.

Halliday et al. (2001) provide an illustration of how a set of fuzzy 'IF then DO' tests can be used to arrive at a suggested quota, and their illustration is modified below as a possible rebuilding rule. If the advice requested by management is only to characterise the position of the fishery within a Consideration Matrix (Fig 5), leaving management to implement a quota decision rule with respect to quota assigned the previous year, a set of rules of the following type might be proposed. These could presumably be tested by simulation using current values of characteristics under different assumptions as to colour boundaries as defined for example, in Table 3. The quota decision rule might consist of a series of conditional 'If' statements such as:

If production = green AND abundance = red, THEN TAC_t increment is –2X tonnes
If production = yellow AND abundance = green, THEN TAC_t increment is 'no change'
If production = green AND abundance = yellow, THEN TAC_t increment is 'no change'
If production = green AND abundance = green THEN TAC_t increment is +X tonnes
If production = yellow AND abundance = yellow, THEN TAC_t increment = - 2X tonnes(*)
If production = yellow AND abundance = red, THEN TAC_t increment = - 2X tonnes(*)
If production = red AND abundance = red, THEN all trawling in the area is closed.
(*) If (TAC_{t-1} – 2X) < Y tonnes, THEN all trawling in the area is closed.
(*) If (TAC_{t-1} – 2X) < Y tonnes, THEN all trawling in the area is closed.
(Where Y tonnes is the expected bycatch of the recovering species in other directed trawl fisheries).

Invertebrate stocks rebuild at low finfish stock sizes?

The most commercially evident (but poorly documented) impact of finfish reduction seems to be for invertebrate resources (e.g. shrimps, crabs and scallops), which seem to have increased production simultaneously with decimation of finfish predators, and without in many cases, a specific recovery plan. This is an issue that might have serious repercussions when assessing overall multispecies yield from an area. A review of successful invertebrate recovery plans is provided by Castilla and Defeo (2001). For some invertebrates however, stock recovery is not easily achieved: thus abalone stocks (Shepherd et.al. 2001) appear difficult to restore due to the local nature of populations and their low dispersal rates, and Orensanz et.al. (1998) recorded the difficulty of restoring stocks of Pacific crustaceans due to the contraction of stock range as a result of fishing, which maintains exploitation rates high even at low stock sizes. Local density appears more important than stock size for sedentary and territorial species, hence stock recovery may occur from relatively small populations as long as some dense local 'source' population remains. Restoration of scallop beds on Georges Bank ocurred as a result of enterprise allocations to the scallop industry on the Canadian side of the boundary, and closure of part of the US zone to trawling. This is apparently only beginning to restore the groundfish stocks aimed at by the measure (Overholtz et.al. 1986; Brown. et. al 1998), but has allowed scallops stocks to reach unprecedented levels (Hart 2003).

Bioeconomic criteria

The Pacific Ocean Perch rebuilding plan takes a bioeconomic approach, discriminating between 'directed' trips for various target species, while considering the value of target and/or bycatch species foregone. Rebuilding the cod/haddock stocks of S. Nova Scotia, and Irish sea groundfish presents similar problems. The Pacific halibut precedent simplifies the issue by setting strict bycatch limits on halibut catch in other groundfish fisheries and hence discouraging trawl fisheries for other flatfish whose potential economic yield may be sacrificed. Some of these issues are illustrated by the hypothetical example below, modelled on a possible 5-species fishery, without taking into account trophic interactions, as addressed by Brander and Bennett (1989) .

Technical interactions and multispecies complications in mixed species fisheries

It is assumed that we are trying to rebuild a cod stock taking into account a directed quota, and typical rates of bycatches of cod in other fisheries. An example of multispecies constraints is the priority given in the Canadian cod/haddock fishery example to rebuilding cod. Given that the allowable cod bycatch is supposed to be enforced strictly, there are only two options available:

- Improve selectivity of directed fisheries to avoid bycatch of cod
- Reduce the quotas for other species so as to reduce their overall effort and hence cod bycatch.

Choosing the second strategy will lead to substantial cuts to other species quotas, given that discarding is assumed to be unacceptable. Any solution would need to respect the equity of different fleet components by allowing cuts of equal economic importance for other species, which generally seems the strategy proposed by the EC in its rebuilding plans. Seeking a solution to this problem might require writing a set of equations for the total quota (QT_1) of species 1 of the following form:

$$QT_1 \geq QD_1 + \Sigma({}_1a_2{*}By_2 + {}_1a_3{*}By_3 \ldots {}_1a_n{*}By_n) \qquad \ldots\ldots A)$$

Where QD_1 is the quota of species 1 taken in a directed fishery for it, ${}_1a_2$ is the proportion of species 1 taken in a directed fishery for species 2, By_2 is the total bycatch of species 1 in fishery 2, and QT_1 the total quota (directed plus bycatches in all fisheries) for species 1. A set of equations of type A, one for each directed species under quota in the fishery assemblage can be envisaged, and could in theory, be solved for the whole assemblage under various constraints. Evidently, once the cod recovery plan TAC is exceeded by bycatches alone, preserving the cod recovery plan requires that other fisheries be restricted.

In the case of the mixed *Nephrops*-cod-whiting fishery in the Irish Sea, Brander and Bennett (1989) suggested that if the greater economic value of *Nephrops* and its consumption by the finfish were given weight, keeping finfish stocks low would tend to maximize total landed value of all resources from the area. They recognized that following this economic criterion is ecologically unacceptable, but it illustrates the dilemma faced in many recovery plans. (What would be the cost in terms of trawl catches of other species foregone by a rebuilding plan for Atlantic halibut?)

According to Murawski (2000), ecosystem considerations provide little basis for defining optimal fishing per se, but should be 'modifiers' to existing single species advice. The complications gear and species interractions cause for all mixed groundfish fisheries emerged from the Irish Sea cod story, and for POP and Canadian East coast trawl fisheries. It emerges that prioritisation by 'importance' or 'fragility' of resources must precede decisions on single species rebuilding plans in typically mixed fisheries, since implementing a rebuilding plan for one species in a multispecies complex poses serious problems that cannot be resolved practically or theoretically, without removing the bottom trawl (or other unselective fishing gears) from the equation.

The above considerations support the need for a sequence of actions as stocks decline (Fig 9). A low, fixed exploitation rate (e.g. Walters and Parma 1996) might be appropriate if stocks are below 20%SPR for example, but if it is judged that quota setting to meet a precautionary F is likely to be too imprecise, a small directed fishery with fixed quota on specified grounds with observers, may be more precautionary, or a sentinel fishery by a fixed fleet capacity with observer coverage might be used to regularly fish formerly productive grounds to follow changes in catch rate and recruitment. If allowed catches are equivalent to the allowed quota, then the fishery is for by catch only. However, if bycatches and discards of the regulated species in other fisheries are likely to exceed a very limited quota, their closure seems a logical step, if recovery is still to be pursued.

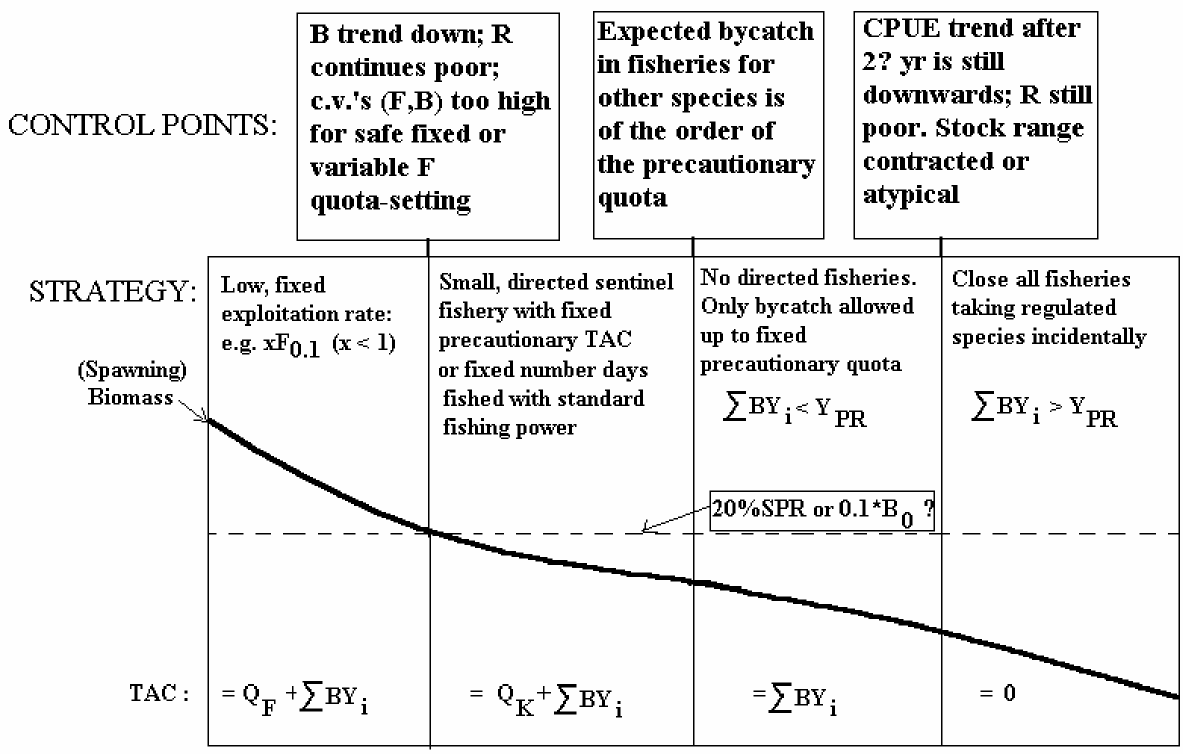


Fig 9. Illustrating a sequence of strategies for a declining stock and possible control points between strategies. [ΣBY_i = sum of bycatches + discards of managed species in fisheries i; Q_F is quota set to meet preset fishing mortality rate; Q_K is constant catch or effort quota; B_0 = virgin biomass]

Although varying exploitation rate to apply a COMFIE or other harvest control rule has strong support at 'normal' stock sizes, implementing a change in F through quotas may be suspect at low stock sizes (Figs 8 and 10), and various authors (e.g. Cook *et al.,* 1995) questioned for North Sea forecasts, whether a small (10%) reduction in F is really distinguishable from the *status quo*. In this connection, the simulation of rebuilding of an abalone stock by Sanders and Beinssen (1998) showed that using TACs alone to lead to rebuilding is an uncertain procedure unless catches are cut drastically (in which case, we are effectively dealing with a significant cut in capacity). The reason they give is that a given TAC may be associated with a wide range of Fs, and quotas leading by error to unexpectedly high fishing rates, may coincide with years of below-average recruitments. Sanders and Beinssen (1998) found moderate probabilities of recovery with various constant TACs after thirty years, but also a significant probability that recovery would not be achieved by catch limitation alone. Fig shows of course that a constant quota is hazardous if stocks continue to decline after the recovery plan is initiated, but the importance of this will presumably depend on level of precautionary quota chosen.

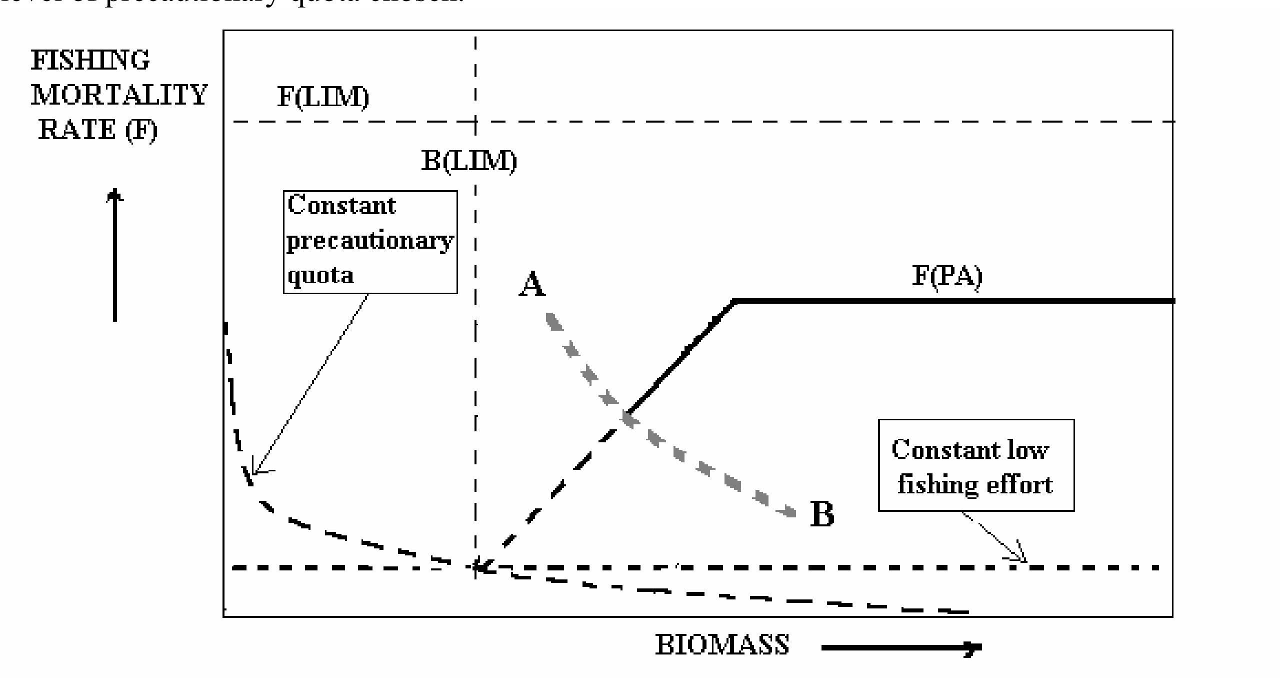


Fig 10. Comparing the COMFIE rule at low stock sizes with precautionary constant low catch or low effort strategies. There must be some level to the left and below line A-B where using quotas based on biomass estimates to adjust annual target F values with a COMFIE rule becomes hazardous and precautionary approaches seem necessary.

Spatial considerations

a) Stock recovery strategies using marine protected areas (MPAs) and closures

The use of closed areas and MPAs has become a popular option for restoring biodiversity, and inevitably for stock recovery (see Jennings 2001 for a review). Typically, models of MPAs suggest that reserves increase S/R but have limited effects on either the net F value or the stock Y/R, unless the MPA is a large fraction of the stock range. Few success stories have resulted from relatively small closure areas: perhaps that by Bennett and Attwood (1991) dealing with a surf zone fish assemblage is one of the clearest examples reported, but Brown et. al.(1998) show that this approach may be effective at a larger scale.

Gains in spawning biomass within MPAs are greater when transfer rates are low, as for sedentary or territorial species such as invertebrates or coral reef fishes. Benefits are likely to accrue from increased egg production and export of larvae to adjacent areas and less from emigration of adults which is more difficult to estimate, despite a number of models of emigration/immigration processes out of and into MPAs (reported in Jennings 2001). When there is a 'metapopulation', the location of a reserve should ideally include 'hot spots' which act as 'sources' of recruits dispersed to 'sink' populations where reproduction is less likely. A knowledge of meta-population structure may be essential for the success of species recovery programmes involving reserves. Conversely, according to Hutchins (1996), the continuation of high catch rates from the few 'hot spots' with residual cod populations accelerated the rapid decline in stock numbers. Hence closure areas should, where possible, incorporate 'sources' of recruitment and refugia for adults. Empirical estimates of doubling times for tropical snappers and other predatory fish have resulted from experimental closure of reef systems. For these top predators, the doubling times reported by Jennings (2001) for populations inside reserves were as follows:

Species	Value of r	Doubling time	Author
Large reef predators	0.17	4 yr (7.1x in 11 yrs)	Russ and Alcala (1996)
Lutjanids/Haemulids	0.35/0.70	2yr/1 yr	Bohnsack (1990)*
Serranids + Lutjanids	-	1 yr	White (1988) **
Coracinus spp + *Diplodus* spp		CPUE increased 4x in 29x2 mo?	Bennett & Attwood (1991)***

Key: *Problems in calculating doubling times were found by the above authors. These included:*
* - *too high estimates due to diver avoidance during census in a spearfished area*
** - *aggregations of fish from outside the reserve*
*** - *new cohorts added to the population may have immigrated in from outside.*

b) Rotating harvest schemes?
An administratively simpler option for rebuilding cod would be to insist on the landing of all catches until the cod rebuilding target for the year was met, then close all trawl fisheries. In the case of 4X cod and haddock, the threat of closure of the haddock fishery once the small cod quota in NAFO area 4X5Y is taken, has made haddock fishing more selective in avoiding the capture of cod (ref). Selective fishing could be tightened still further by requiring other species quotas to be taken in gear-season-area-depth windows where target species under recovery are less abundant. A mandatory vessel satellite monitoring system and in-time reporting would make such a strategy feasible technically. In the case of the Irish Sea mixed bottom fishery, protecting Norway lobster from overfishing seems a simpler task given its relatively sedentary habits, than for groundfish. A rotating closure scheme designed for *Nephrops* for example, but applying to the entire bottomfish resource (treated as *Nephrops* bycatch, given that cod stocks might otherwise be closed for rebuilding), deserves further investigation, and might function as an effective closed area for other species; offering them some protection while recovering from overfishing.

The legislative and political context
The largest stumbling blocks to recovery plans appear to be socio-political and administrative – not scientific - due to the difficulty of achieving buy-in and inter-group confidence of the various stakeholders in the plan (e.g. Government, industry, science, NGOs, coastal communities), especially for transboundary stocks. The contrasting requirements of wide consultation, and rapid action in response to negative indicator values must be resolved before the plan is implemented. The science (as opposed to the data gathering needs) for a successful recovery plan are not

excessive, if there is a willingness to use a precautionary approach for the good of future users of the resource. There seems to have been a reluctance to move to implementation in the north-eastern Atlantic even though objective evidence of the deteriorating resource situation continues to accumulate.

From US experience, it seems that to be successful, a stock recovery strategy requires an overriding legislation that defines what constitutes overfishing, and an overfished stock, and incorporates technical criteria for recognizing these conditions. Objectively, the majority of recovery plans implemented with some success have been in the United States, where such overriding legislation is based on the provisions of the UN Fish Stock Agreement. Despite possible criticisms that might be directed at the rather restrictive fisheries indicators (fishing mortality and biomass), this experience confirms the primary importance of overriding legislation, and a speedy move to implementation as a result. Non-discretionary management plans must be implemented should precautionary RPs be triggered, but if productivity is reduced for environmental reasons, or genetic selectivity has occurred, the situation becomes more complex.

Rights-based approaches

After closures had led to some successful recoveries in Icelandic fisheries (Jakobsson 1980) a rights-based approach was implemented for those remaining in the fishery. In this connection, Cochrane et. al. (1998), noted that in recent years it has become widely accepted that the key interest groups should be involved in fisheries management. Pikitich et al. (1997) reported that 'Australia, Canada, Chile, New Zealand and the USA have...begun to develop mechanisms to consult with their users', and Laurec and Armstrong (1997) and Pope and Symes (2000) described the need to promote dialogue amongst different interest groups within the European Union. The underlying rationale is that fishers will only voluntarily heed fishing regulations if they support them. This mechanism becomes still more necessary for stock rebuilding plans which require substantial sacrifices and restraint from stakeholders. Greater integration with stakeholders, and some regionalisation of action are necessary, as unsuccessful attempts to impose reductions in effort world-wide illustrate.

Changes in environmental regimes cause wide fluctuations in recruitment, but except for 'irregular' or 'spasmodic' stocks (Spencer and Collie 1997a ?), stock collapses are generally due to overoptimistic fisheries management. Once a stock collapse has occurred, we have reviewed a variety of recovery strategies used to assist in recovery. At the same time is a return to 'business as usual' after stock recovery the way to go? I.e. what should be the last step in the following sequence (if it is not to be A)?:

Inappropriate management measures/framework (modulated by environmental changes) ->
B) stock depletion -> C) recovery strategy successfully applied -> A) ? ?

Given that the ability of the stock to support harvesting is greatly reduced, and is likely to be so for a number of years, a decision will have to be made between two approaches at the political level. This decision will have to be followed up over a long time horizon and be bipartisan in nature:

A. If it is decided to give continued priority to the industrial fishery, this will have to involve a drastic reduction in capacity and restriction of the area of operation. A move to some sort of ITQ system will probably be required, as occurred in Iceland; with more recent approaches from England (Hatcher and Reed 2000) and Holland (Davidse 2000) of what are effectively ITQ systems. Regionalisation of fisheries management authority and formation of local management measures for inshore marine areas with participation of all local stakeholders will probably also be required.

B. Precedence may be given to small-scale fishing not using towed bottom gear, or trawling be restricted to specified corridors. Some form of co-management by national or supernational government with local communities, involving bottom-up consultation procedures should be considered. Integral to this approach could be the allocation of an increased proportion of a very much reduced quota to local management entities that could be shared out to the small-scale fishing industry especially for coastal resources, can be managed through local associations, as for the co-management and TURF approaches adopted for inshore resources in South America (Castilla and Defeo, 2001).

In deciding between these two options, socio-economic considerations suggest the need to decide which option maintains the maximum number of livelihoods and requires the minimum level of compensation over the short or long term consistent with conservation requirements? Whichever strategy is followed, it must be consistent with ecosystem management (see Pope and Symes 2000).

4. DISCUSSION

The concept of a "recovery plan" as an emergency and holistic response to a deteriorating situation appears to have arisen first in the terrestrial context of endangered mammal or bird populations rather than in fisheries. These plans of necessity take into account habitat and social considerations, and are therefore similar to environmental restoration plans. Practical experience in the marine environment, as judged from this study, is rather limited, and not many successful case studies can be cited, despite theoretical and practical considerations being currently under intensive discussion.

The review has identified a number of features of the design of recovery plans that seem appropriate for marine living resources. Only since the early 1990s have recovery plans been formalised, whereas before stocks were "managed" primarily by closure when they were seen to be in terminal decline. Various herring closures may be cited as examples, but it seems to be emerging that groundfish stocks are more vulnerable; largely perhaps because trawl fisheries are expected to operate even during a single species recovery plan, thus imposing significant stock impacts even at low fishing mortalities. Additional to this, the likelihood that environmental change may be moving northern shelf resources into unfavourable territory is discussed in the companion paper.

Recovery plans sensu strictu usually seem to assume that: a) access control has already been tightened, b) a radical reduction in fishing mortality is required to meet biomass recovery targets, and/or c) that an expected time for recovery can be realistically set. d) Supplementary objectives in terms of the ideal age structure and proportion of older fish in the population may also have been defined. e) More generally, no less important criteria such as human impacts on ecosystems and prey abundance, on critical habitats, population genotypes and metapopulation structure evidently need to be taken into account, but few case studies were located which gave these factors the priority in practice suggested from terrestrial recovery plans.

Most classical approaches to fisheries management have tended to be 'top down' and certainly overriding legislation dictating when and how recovery plans should be initiated is essential, and implementation should be non-discretionary. At the same time industry needs to buy into the plan since they may avoid compliance with regulations they had no hand in developing, so consultation on the basis for the plan is needed, plus some form of participation in implementation overview. Referring to the NE Atlantic, Gascuel et. al. (1998) noted that conventional management systems impose a serious lag between data gathering and analysis, and between the provision of advice and subsequent action, and rapid stock declines expose the weakness in such approaches. The classical 'top down' approach has government monopolizing the collection and analysis of data and formulating Limit Reference Points, and although fishermen consultations may occur, when industry-government disagreements arise, industry has few options but to take the political or legal route in search of alternatives to 'imposed' solutions. Devolving responsibility for implementing a fishery law to a 'recovery team' where industry is represented, and works within strict decisional confines set by overriding legislation, seems the only way to ensure rapid and decisive management action. Perhaps most important, is to realize from the outset that a recovery plan cannot lead to stock revival and provide employment to the capacity surplus that has accumulated under previous lax management regimes. Attempting to satisfy both conservation and the requirement for a return on investment, will inevitably lead to failure of the stock recovery plan.

Conservation of rare or endangered species

In Canada, bill (C-5) considered by the Federal Government aimed at the protection of wildlife species at risk, and conferred regulatory powers to the 'Committee on the Status of Endangered Wildlife in Canada' (COSEWIC). Regional fisheries departments now work with COSEWIC and its recovery programme, RENEW. Under this legislation, formal listing on a recovery plan is followed by annual status reports. After listing, catching, killing and selling is prohibited, and strong habitat conservation measures applied. Atlantic cod, Bering wolfish, whitefish, sturgeon species, and Pacific sardine were reported on the list of the draft bill for C-5. If groundfish recovery does not occur, COSEWC risks becoming the lead agency for conservation of commercial species such as cod, and would encroach on the mandate of the department responsible for fisheries if conventional fishery conservation measures are judged to have failed. This provides a strong incentive here and elsewhere for considering more radical solutions to the depleted groundfish problem.

Such a shift in jurisdictional authority is likely to continue globally if sufficiently rigorous measures are not introduced and further stock declines continue to occur, and de facto is occurring at the international level, where UNEP has effectively taken a lead role with respect to conservation of marine mammals, and CITES is moving into the marine fishery arena to block trade in species (such as sturgeons) whose existence is at risk under current fisheries legislation and management practice. Recovery plans for wildlife species in danger of extinction can provide impetus and a format for fish stock recovery plans in the fisheries sector, where although a species may not be currently in danger of extinction, the fishery for it may be. This specialized type of recovery plan is a relatively recent innovation in fisheries, and efforts so far have tended to focus on a relatively narrow range of actions. It would be desirable to consider a broader range of information than has been customary so far in conventional fishery management plans, and to use a wider range of indicators in planning and implementation.

'Historical precedence' is often invoked as a reason to continue unwise management practices, but the striped bass example show that it will be necessary to break long-established patterns before the stock is driven almost to extinction. Throughout the 1990s, several international initiatives based around responsible fisheries and the precautionary approach changed the way rebuilding fish stocks has come to be considered. Before 1995, stock rebuilding was considered feasible using a continuation of "business as usual" procedures but with lower fishing mortality rates. As this study shows, this had minimal success, prompting the consideration of more structured and holistic approaches.

For reasons that follow from the chronic uncertainty of recruitment and the high uncertainty of stock assessments for seriously depleted stocks, a form of 'Heisenberg's uncertainty principle' seems to apply, in that hoping to specify in advance both plan duration, and the fishing mortality and quotas to be applied in the plan, seems overoptimistic. It seems to follow that if fishing mortality control is the modality chosen under a COMFIE type of rule, that adjustments during the course of the plan would be needed to correct fishing mortality for typically irregular recruitment, but here the problem of uncertainty arises. Probably deviations of catchability and natural mortality rate of juveniles from earlier levels will also occur, and must inevitably reduce the scientific ability to specify the current situation of the stock: its biomass, and if fishing is occurring, the effective fishing mortality rate that applies. This lack of information increases the risk of continued exploitation. Hence, COMFIE type rules may become inoperable or risky at low stock sizes, and a fixed precautionary catch or effort quota seems advisable, short of closure of the fishery. Simulations show that short of closure, a very cautious initial level of harvest is the best strategy to speed recovery, and it seems generally agreed that catch restraints should be accompanied by supplementary measures, of which spatial closures of critical areas seem most likely to be effective.

The main debate then, seems to be between (i) that fishing mortality rate can be adjusted from year to year to accommodate changes in recruitment and keep predicted recovery time constant, or whether (ii) a constant very low catch or effort quota should be set, with the understanding that the time before recovery criteria are met, is essentially undefinable in advance. The authors' impression from reviewing the case studies is that strategy type (i) reflects an assumption of 'sustainability' or a constant compensation rate for the depleted resource, as well as overestimating our ability to measure rates of recovery for now uncommon resources, subject to wide and unknown sampling errors. A constant precautionary quota of catch or effort, although imposing the usual MCS problems, short of total closure, should allow scientists to concentrate more resources on estimating stock trends, but probably the key debate for very depleted stocks should be whether the risk of any continued fishing is acceptable, as opposed to a complete closure.

Assuming that good fortune allows a 'surplus recruitment' over the average expected level to occur during rebuilding, we believe that TACs should not be allowed to increase, but better-than-average yc's used to shorten the recovery period. This is because there is more resistance from stakeholders to reducing TACs when recruitment (inevitably) falls below average, and that this resistance builds once some small increase in biomass has been achieved and a semblance of normality returns to the fishery. Given this reluctance to see the TAC further reduced once a better-than-average yc has been inevitably replaced by a series of poorer-than-average yc's, social pressures inevitably add to a lengthening of the projected recovery period. In the US, controversy resulting from changes in rebuilding plans while underway, have required the scientific basis for the assessment to be explained by assessment scientists themselves in response to civil actions by stakeholders. This process has not been entirely negative since it revealed serious weaknesses in assessment procedures such as the prevalence of retrospective effects in VPA-type analyses. The long and painful experience with fisheries closures in Atlantic Canada has led to a much broader range of biological data being monitored to gain a handle on productivity changes, rather than the current preoccupation mainly with stock size and F imposed by conventional quota management (O'Boyle 2003).

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ANNEX: TENTATIVE GUIDELINES FOR BEST PRACTICE IN FISHERY RECOVERY PLANS

From our review, the following types of considerations seem relevant when planning a stock recovery process for a depleted population and are presented under 5 major headings:

A./ Actions prior to the recovery process:

A1. The recovery objectives and strategies should be spelled out in overriding legislation which should specify indicators, and associated values of indicators corresponding to limit reference points marking a dangerously depleted stock and/or one being overfished.

A2. The overriding legislation should specify obligatory actions when these conditions occur, including the reference points to be met during rebuilding

A3. Associated monitoring procedures should specify the precision required from population indicators in order to establish whether the recovery is on track, or has a high probability of meeting its target. Changes to assessment methodologies during the plan may undermine an ability to monitor the stock.

A4. A statistically verifiable end point defined as an unambiguous ‘endpoint decision rule’ is needed, or statistical error may lead to a legal requirement to reopen the fishery under under-optimal conditions. Care is therefore required to define the recovery target in a statistically valid fashion.

A5. Estimate a likely range of recovery periods and trajectories, but avoid stipulating in advance a fixed recovery duration. Preferably incorporate formal reviews at intervals to assess the plan’s progress.

A6. The plan should be a public document, for which consensus has been sought through negotiation with stakeholders, with input from all interested parties. The fishing industry needs to be incorporated into decision-making, planning and monitoring activities to ensure they are aware of the objectives and progress of the plan.

A7. Define any area/gear/interactions and supplementary technical measures such as closed areas in legislation prior to the plan. Area restrictions, such as closing critical habitats, nursery or spawning areas or rotating harvest schemes will provide necessary redundancy to a plan centred on effort or catch control.

A8. A recovery team made up of interest groups, scientists and managers is needed to decide on a programmed approach and oversee implementation of the recovery plan.

A9. Ensure the target and strategy for rebuilding are achievable, including the effects of possible changes in climatic regime and accompanying levels of recruitment to the stock.

A10. Be aware of errors in retrospective analysis at low stock size, and possible biases in survey biomass estimates resulting from changes in stock range with depletion. Model rebuilding under a range of reasonable scenarios, especially for recruitment and environmental conditions. Explore the likely outcomes and risks involved with various decision strategies using realistic estimates of survey, assessment and indicator precision and/or bias.

A11. Spell out the mechanisms by which the recovery trajectory will be achieved (reductions in quota, effort, bycatch and area restrictions, gear/vessel restrictions etc), so as to ensure a necessary redundancy of measures (i.e., capacity control, closed areas, quotas and relevant technical and economic measures).

A12. The importance of incoming year class strength increases for depleted stocks, places a high priority on assessing recruitment strength. However, softening plan restrictions in light of good recruitment ‘windfalls’ is not recommended, since good yearclasses are infrequent and improved

catch rates may attract new entrants and compromise completion of the plan. Corresponding reductions on fishing after poorer-than-expected recruitment years will be resisted.
A13. Protecting concentrations of recruits and pre-recruits from exploitation becomes highly important, but in a way that discourages discarding, and avoids juvenile concentrations and undue damage to juveniles and critical habitats from repetitively passing over of the net.
A14. Priority for the recovery process must also constrain harvests of associated resources which take the depleted resource incidentally as a bycatch, and should aim to recreate a multi-age spawning stock.
A15. Long time lags typically occur before assessments are translated into management action, but rebuilding procedures require rapid, non-discretionary responses to changes in indicator values.
A16. Set aside adequate funding for all aspects of the recovery plan, including a monitoring control and surveillance programme, and as appropriate, special funding for retraining fishers displaced from the fishery by the recovery plan, and for vessel repurchase and scrapping costs as appropriate
A17. Discouraging misreporting of catches, quota overruns and juvenile discarding or high grading needs priority from MCS. These processes add bias to existing methods of analysis, and leads to a deterioration in the precision of assessment advice which should be taken into account in modelling.
A18. Habitat requirements, breeding and nursery seasons and critical habitats, and environmental/ anthropogenic impacts on the target resource need to be established, and the carrying capacity of critical habitats protected or enhanced where this is feasible. Is rebuilding of critical habitats or the closure of nursery areas and spawning refugia, a pre-requirement for rebuilding?
A19. Bear in mind that attempts to manage by actively changing quota or effort/mortality are likely to have low precision, given well-documented errors and biases in survey and retrospective estimates of stock size or year class strength. The plan should be precautionary with respect to errors and biases in indicators, analyses and modelling approaches.
A20. If biomass and/or fishing mortality can only be estimated with low confidence, targeting a fishing mortality rate by quota control is a risky strategy. A low fishing effort level or a constant low TAC including all bycatches, should be set, such that the fishing mortality rate has a low risk of exceeding the natural mortality rate.
A21. Given that controlling fishing mortality rate indirectly through a quota is an imprecise mechanism at low stock size, another option is to aim for a low, constant fishing mortality directly. This may consist of a limited 'sentinel fishery' limited to a specified number of fishing days on agreed fishing grounds by vessels of known fishing power and gear characteristics. If after a few years a recovery strategy is unsuccessful, all fisheries taking the depleted stock should be closed.
A22.Observers should be present on all fishing boats, and a requirement to land all catches of the recovery species should be imposed.
A23. Collect background information and conduct research to establish the impact of changing environmental conditions and fluctuations on stock-recruit relationships, including possible mechanisms for depensation.
A24.Investigate the ecological and genetic status of the stock, and the stock status of other associated resources, including predators and preys.
A25. A programme of public outreach and education must explain the need for stock recovery.
A26. establish protocols for intensive data collection, sampling and indicators of stock condition.
A27. Multiple indicators (such as condition factor, mean age in the population, SPR, distributional extent etc) should be monitored as measures of variable resource productivity, allowing the following questions to be answered:
A28. Condition of the environment: are we in a favourable or unfavourable regime? Ecological status: has there been a radical change in the ecosystem that might lead to a change in carrying capacity of the ecosystem for the species in question?
A29. Stock status: compare current stock status not just with recent stock trajectories, recruitments and the stock-recruit relationship, but also with historical biomass levels prior to industrial exploitation.

B/ Issues to be considered by the recovery team:
In developing a recovery plan the recovery team should take into consideration the following:

B1. Ensure that surveys or other sources of fishery-independent information on stock size and productivity changes are adequate, rather than just using retrospective analysis from catch data for making management decisions. Given the low precision possible with retrospective analysis on depleted stocks, surveys need to be intensified and ideally should be semi-annual.
B2. A pre-negotiated management procedure should ideally be applied, requiring non-discretionary actions when pre-established limit reference points in the recovery rule are approached. As noted, management procedures, and where data are poor, quota change rules, must be built into the underlying legislation, management infrastructure and the annual (or better, semi-annual) decisional cycle.
B3. It should be recognized that assessment methods become less precise as a stock declines, and this is a major problem in monitoring depleted stocks. This requires a redundancy in stock indicators and a wider range of indicators as inputs to management than normally used for retrospective age-structure analysis. Indicators should contain information on ecosystem, habitat, spatial distribution, condition factor, environment and productivity, as well as relevant socio-economic and data, as for the terrestrial plans mentioned.
B4. The plan should be very restrictive until the stock has recovered to well above the level B_{LIM} and continue until the level B_{PA}, B_{MSY} or equivalent safe stock levels have been reached, in order to avoid oscillation of stock size between these two reference points.
B5. The global case studies presented suggest the key importance of an appropriate, timely decision-making and consultation infrastructure to implement the rebuilding plan. This seems to require cooperation between stakeholders, managers and industry within a recovery team charged with developing the recovery plan, with scientific advice on management options and their likely consequences, but minimal changes to the plan during implementation, other than closure.
B6. A major problem is in defining recovery trajectories of achievable duration, and designing indicators and assessments that inform managers where they are on the recovery trajectory, since assessments will be subject to increasing bias and/or imprecision as stocks decline. Most analysis-based indicators will be subject to a lag time of 1-2 years, requiring a precautionary approach.
B7. Whatever small quota is allocated should ideally incorporate industry test fishing, and also yield indicators based on contraction or expansion of species ranges and hot spots.
B8. Especially where indicator data are imprecise and possibly biased, a quota management rule (for catches or days fished) may be necessary, incorporating an 'inverse ratchet': such that quota increments are small when conditions are 'green' or favourable, but more radical cuts are made when poor conditions and 'yellow or red' indicators are registered.
B9. Avoid complete dependence on hatcheries for restocking: be aware of the risk of genetic contamination to the wild stock if hatchery broodstock is not selected carefully.

C/. Recovery objectives:
C1. Establish an 'end-point' for completion in terms of spawning biomass and possibly age composition, that takes into account estimation error, and data bias. This should be well above the biomass-based LRP that triggered the recovery plan, and should ideally relate to pre-exploitation levels.
C2. The impact of environmental and ecological uncertainties on recovery should be taken into account at the start of the plan in suggesting a recovery period, which can only be tentative.
C3. Define a strategy for arriving at the recovery target: whether constant F or constant catch or some other approach should be taken. Define what approach to take to inevitable deviations from the most probable trajectory. Recall that 'tuning' fishing mortality rate is very vulnerable to changes in availability and recruitment.

C4. Experience and simulations show that speedy recovery depends on choosing a low initial exploitation rate, and that frequent 're-tuning' of the exploitation strategy can be counterproductive.
C5. Avoid assuming that compensation for low stock size will always occur, and that future recruitment levels will resemble those in the immediate past. Hence, defining a time period for recovery to the biomass target can only be uncertain, since it depends on recruitment, which is an (uncertain) function of environmental and ecological conditions as well as biomass. In addition to setting a final target biomass, it may be wise to set a series of progressively larger interim biomass targets for each phase of the rebuilding plan with flexible timing.
C6. Under constant exploitation strategies, using 'windfalls' from better-than-average recruitment to allow temporary increases in catch during rebuilding is shortsighted, since these will occur infrequently. Rapid rebuilding requires making best use of them. Contrariwise, it will be politically difficult to reduce a small quota below the summed bycatch in other fisheries when inevitable 'shortfalls' arise, since this will require closing or restricting other fisheries.
C7. In addition to a primary target of rebuilding spawning biomass, the plan should give priority to rebuilding older age groups. A broadening of mature year classes in the population should be aimed for using a variety of tools, and not just better survival of recruits, but this may not be easy given irregularities in recruitment.
C8. The companion paper shows that with potential ages of demersal fish in the stock of up to 12 years, expecting more than two good year classes to consistently occur in a restored population is optimistic, given typically irregular recruitment, and not only at low stock size. One consequence of this is that there is never a justification for a return to 'routine' equilibrium production strategies: the stock will always face the risk of further collapses.
C9. For intermittent or spasmodic stocks, yc variations are strongly tied to environment as much or more as stock size – here, the stability hypothesis should be avoided. Recognize that duration of recovery is largely environmentally determined and hence uncertain.
C10. In mixed species fisheries, rebuilding one stock inevitably affects others, providing a strong incentive for selective fishing, but also requiring consultation with users of other resources on the impacts of the rebuilding plan on the utilization of other resources.

D/. Recovery management:
D1. Necessary actions must be specified if recruitment varies from predicted conditions. As in the Striped Bass case, if a very good year class enters the population during rebuilding, ideally, its survival should be improved by special measures until it has been in the spawning population for several years.
D2. Ensure that decisions required by the recovery plan as indicator values approach target RPs for biomass, are not delayed by consultation. Once the plan is agreed, streamlined implementation by the recovery team with authority to apply the decision rules with minimal interference.
D3. Ensure that all concerned understand the criteria for assessing progress along the recovery trajectory, and what should happen when the plan reaches its end point.
D4. The importance of appropriate and accurate data for management decisions has been emphasized and ideally should be linked to a decision rule on quotas which translates greater uncertainty on stock status into lower quotas, and ensures through a formal quota rule, that annual quota increases due to improved conditions are more contained than decreases due to poor conditions.
D6. Consideration must be given to multi-species and multi-gear interactions that may undermine the effectiveness of the plan and its ability to meet targets: bycatch and discarding, especially if unreported, may severely compromise any attempt to follow a recovery trajectory.
D7. However, multispecies considerations, low gear selectivity and technical interactions all confound stock recovery plans in trawl fisheries, making rebuilding especially difficult to implement.

D8. Attempting to recover a single species in a mixed fishery on an exclusively short-run economic basis may lead to ecologically unacceptable consequences, and biodiversity and ecosystem restoration considerations should predominate.
D9. Recovery of long-lived, especially low-value species means inevitable sacrifices in catches of more valuable by-catch species that are unlikely to be recovered given long rebuilding periods.
D10. A rebuilding plan involving multi-gear fisheries and multi-national fleets for mixed species poses complex problems. This requires prior agreement on how the inevitable restrictions on landings of species not the target of recovery are apportioned between users.
D11. Design a monitoring, control and surveillance programme that is easy to implement, involves industry, and provides incentives rather than disincentives. MCS and data gathering must be coordinated, and voluntary compliance encouraged by involving fishers and industry in survey and monitoring.
D12. An overriding and as yet unsolved issue, especially for shared, straddling and highly migratory stocks, are the conflictual (or often non-existent) allocation processes whereby different fleets/countries harvest a common stock.
D13. The chance of effective stock rebuilding is minimal in the case of straddling or highly migratory resources in international waters, shared resources under split jurisdictions, where multiple fleets fish a common resource, as well as situations where there is a lack of entry restrictions and fishing power control, unless there is prior agreement on allocations and acceptance of necessary cutbacks involving all parties.
D14. The conclusion of the recovery plan should require more than one test statistic to be satisfied, expressed in both spawning biomass, the abundance of older fish, and preferably evidence that recruitment is satisfactory in the year that the other two criteria are satisfied.
D15. Do not underestimate the role of environmental conditions in determining the success or otherwise of rebuilding plans, or overestimate the ability of management measures to return stocks to historical levels once they have been heavily overexploited!

E/. After recovery:
E1. Before the stock approaches its recovery target, consider all post-recovery issues, because this is when the political pressure to resume large-scale fishing will be greatest. Problems that led to past overfishing during 'routine management' need to be corrected before the end of the plan. When rebuilding is almost accomplished, decisions should already have been made on the following 'routine' exploitation strategy, to ensure that depletion is not repeated in the future.
E2. Aspects of the rebuilding plan should be incorporated into a precautionary framework for the rebuilt stock, recognizing that irregular recruitment, and possibilities of overshooting sustainable harvests after years of poor recruitment, will still occur.
E3. For some stocks with notably irregular recruitment (and for most depleted stocks) good year classes are few and far between, and this leads to the prospect of an indefinitely repeated series of recovery plans. This suggests that the recovery plan for irregular species should be incorporated into the routine management plan for the stock, and that a return to 'fishing as usual' may not be the optimal strategy. A reduced fleet capacity should apply in the recovery period and when stocks are low.
E4. A revised approach to management should be considered before the end of the recovery plan, such as the move to an ITQ system, or a change to a more selective fishing strategy.