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A framework for qualitatively evaluating management plans in a results-based perspective

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Abstract

Currently many multi-year management plans are being developed either for rebuilding depleted stocks or for avoiding difficult negotiations when management decisions must be revisited on a regular basis. Management plans are commonly evaluated by intensive model simulations that describe the ecological and economic dynamics, and the management loop. Under the results-based management paradigm, the fishing industry or particular fishing sectors will develop their own management plans, potentially leading to a huge number of plans to be evaluated. Guidelines for evaluating the plans on a qualitative level before launching quantitative evaluations will be essential.

Here we propose a framework for evaluating management strategies in a qualitative way. A strategy is defined by i) an objective ii) a coordinated plan of actions to reach this objective. We evaluate i) under which assumptions the stated management objective is sustainable and ii) whether the proposed plan of actions can reach the objective, against theoretical criteria derived from general fishery models, and practical rules determining success of management plans from empirical review papers. We demonstrate this framework by analysing a series of management plans recently implemented in the EU.

Keywords

Management strategy, stock rebuilding, qualitative evaluation, sustainability, management plans.

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Introduction

Currently many management plans are being developed either for rebuilding depleted stocks or for avoiding difficult negotiations or lobbying when management decisions must be revisited on a regular basis. These management plans are commonly evaluated by model simulations that describe the ecological and economic dynamics, and the management loop from data acquisition to decision making and implementation. Unfortunately, many of the underlying processes and/or parameters are poorly known, especially in the case of depleted stocks. This incomplete knowledge makes the evaluation results uncertain. Some of the processes – both ecological and governance/ decision-making - are likely to be probabilistic and their distribution is not well documented, so evaluations of even well-described full systems may be highly uncertain. Besides, the simulations generally evaluate the management plans against the objectives included in the plans, and these may or may not be amenable for quantitative analyses. For example, ICES evaluates risk criteria such as the probability of spawning stock biomass being below reference points (B_{lim} and B_{pa}) after a given time period, but fails to give advice if the evaluated plan does not specify a target date for recovery and an acceptable level of risk (ICES, 2009).

In addition to the potential problems of uncertainty and incompleteness of many management plans, each evaluation exercise is fishery-specific. This poses challenges of both workload and generality of findings. Under the results-based management paradigm, the fishing industry or particular fishing sectors will develop their own management plans. If groups developing management plans are not responsible for the costs of their evaluation, potentially experts could be tasked to evaluate a huge number of plans. Moreover, during a recent symposium on rebuilding depleted fish stocks, it was pointed out that there is no general strategy for reducing fishing mortality when a stock is to be recovered (Hammer *et al.*, 2010). Reductions in F could be achieved by effort reduction, by Total Allowable Catch (TAC) reductions, a combination of both, or each or both with other technical measures. It is not known whether effective combinations of such tools are stock-specific, ecosystem-specific, or universal (Hammer *et al.*, 2010).

General results about the expected effects of management strategies, as well as guidelines for evaluating proposed plans on a qualitative level (or at least in a manner that is not too labour intensive) before launching full quantitative evaluations for a subset of promising management strategies, will be essential for addressing the workload demands. This analysis aims at providing a first approach to such tasks.

We propose a framework for evaluating management strategies in a qualitative way. A strategy is defined by i) an objective and ii) a coordinated plan of actions to reach this objective. Within the framework the sustainability implied by the way a management objective is defined is evaluated against sustainability categories defined by Quinn & Collie (2005). Whether the proposed plan of actions can reach the objective is then evaluated against both theoretical criteria derived from qualitative analysis of a general bio-economic model, and practical rules determining success or failure of management plans that have been listed in various empirical review papers.

We demonstrate this framework by analysing a series of management plans recently implemented in the EU to recover depleted stocks.

Evaluation framework

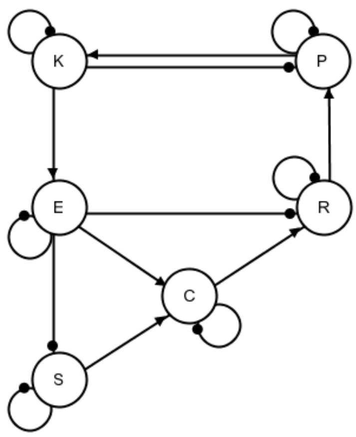
1. In what sense is the goal of the management plan sustainable?

To evaluate the sustainability implied by the way a management objective is defined, we refer to the sustainability categories defined by Quinn & Collie (2005). These authors reviewed the development of the concept of sustainability in fisheries science and identified four views which correspond to historic periods in fisheries science:

- The *classical* view was deterministic and the primary tool for achieving sustainability was the control of fishing mortality F; F_{msy} was a target, and a higher F-value F_{ext} (fishing mortality driving the population to extinction) was used as a limit.
- The *neo-classical* view acknowledged depensation and stochasticity, and thus considered both F- and stock biomass B-based reference points. F_{msy} was still considered a target but F-limits were lower than in the classical view, with the new limits F_{tresh} corresponding to fishing mortalities driving the populations below the biomass limits B_{tresh} .
- In the *modern* view the primary objective was to preserve spawning stock biomass SSB. Harvest control rules were defined, including more precautionary limit reference points (higher B, lower F); in that view F_{msy} was used as a limit.

- The *post-modern* view is more ecosystem-based and takes account of the economic and social dimensions of a fishery. This is still under development and the objectives are not well defined yet. Moreover, multiple objectives might have to be traded off. Thus, any strategy that considers something else than SSB and F in its goals can be classified as post-modern.

2. Are the planned actions adequate to achieve the goal, and/or to rebuild the stock?



S stock

C catch

R revenue

P profitability

K fishing capacity

E effort

Figure 1. A simple qualitative bio-economic model of a fishery. Arrow-ended links are positive, circle-ended links are negative. All variables are self-regulated, thus the negative self effects.

This evaluation is based on the qualitative analysis of a general bio-economic model of a fishery (Figure 1, see proxy-equations in Appendix 1) and some variants. Fishing capacity K describes capital invested in vessels and fishing gears. Here the technical capital capacity is approximated by the total engine power of the fleet (measured in kW). Economic performances are assessed by the return on Capital invested (Profitability). Net revenue is total earnings (Landings × Prices) less variable costs. Stock S is any consistent measure of stock abundance, either number or biomass or spawning stock biomass. This model has one positive feedback loop E-C-R-P-K-E (effort – catch – net revenue – profitability – capacity - effort), which would tend to destabilise the system. But this is counteracted by negative links from effort to net revenue (variables costs) and from capacity to profitability (fixed costs).

A qualitative analysis of this model predicts which changes at equilibrium are to be expected from a permanent change in model variables (see *e.g.*, Dambacher *et al.*, 2009). This approach can be used to evaluate management measures that can be translated as a permanent change in model variables (Table 1). For example, a reduced TAC would result in a permanently lower catch C, effort control would reduce E, additional taxes would decrease revenue R… The framework allows for multiple measures that is, permanent change in several variables (*e.g.* TAC + effort control). We use this approach to evaluate the adequateness of the proposed management measures

1. to achieve the management goal(s) as stated in the plan;
2. to rebuild the stock, that is, to permanently increase stock size S, and at the same time increase or not change profitability P and revenue R. The rationale is that a strategy that will decrease the economic variables will be opposed by fishers, who will pressure against the establishment and enforcement of the management plan, and/or not comply with it.

Table 1. Consequences on the fleet variables of the core bio-economic model (Figure 1) of various actions taken to rebuild stock S; all these actions are predicted to result in stock increase. d decrease, i increase, – no effect. Results in brackets are ambiguous, that is, depend on the relative strength of the links in Figure 1. For example, (i) means that the variable will increase in most instances, but might decrease if the links forming negative loops are stronger than the links contributing to positive loops; these conditions can be written explicitly (see text below).

Action to enhance stock S	Effect on			
	Effort E	Revenue R	Profitability P	Capacity K
Decrease C (TAC)	d	d	d	d
Decrease E (effort control)	d	(i)	(i)	(i)
Decrease R (remove subsidy/increase tax)	d	d	d	d
Decrease K (reduce fishing capacity)	d	(i)	(i)	d
Decrease E and K	d	(i)	(i)	–
Decrease C and E	d	–	–	–
Decrease C and K	d	(d)	(i)	d
Decrease C and R	d	d	d	d
Decrease C, E, and K	d	(i)	(i)	(d)

Thus with this core model, TAC-only strategies, and any strategy involving negative economic measures (taxes or decreased subsidies) are prone to failure owing to their detrimental effect on the economic variables revenue and profitability. If forced on the industry experiencing reduced profitability, effective implementation will require a near-constant management, control, and surveillance presence. This would add greatly to the costs of management; costs that would have to be borne by the public purse since fishery revenues are already being reduced. A combination of TAC reduction and effort control is more likely to be accepted for it is neutral to the economic variables. Under some conditions, effort control or capacity reduction or a combination of both will increase the economic variables. These conditions can be examined analytically (see Dambacher *et al.*, 2009).

All conditions for resolving ambiguous predictions (marked () in Table 1) related to a decrease in effort E, amount to the sign of $A = a_{ss}a_{cc}a_{re} - a_{ss}a_{rc}a_{ce} + a_{cs}a_{rc}a_{se}$, where a_{xy} denotes the coefficient of the link from *y* to *x*, with *x* and *y* as listed in Figure 1. If *A* is positive, R, P and K will increase when effort is decreased. The link a_{rc} from catch to revenue intervenes both in the positive and negative parts of *A*, thus will not make a difference. *A* will be higher (thus more likely positive) if effort is expensive (a_{re} high), the stock responds to effort reductions (a_{se} high, which might be enhanced in depleted stocks that contract their spatial distribution), or catch responds weakly to effort reductions (a_{ce} low, which might happen in the case of fishing overcapacity, with CPUE increasing when capacity and effort are reduced). The outcome is determined by the magnitudes of these coefficients, so is beyond a qualitative analysis, but any of these conditions or, of course, their combinations, is likely to make *A* positive hence lead to an increase in economic variables.

There is an additional condition related to predictions for the effect of changes in fishing capacity: if $a_{ek}a_{pr}A - a_{ss}a_{cc}a_{ee}a_{rr}a_{pk} < 0$ then decreasing K will increase profitability. This will happen if *A* is small (and even negative) and/or if boat and fishing gears are expensive (a_{pk} high). The "expense" of vessels and gears has to be expense to the fishers deploying the effort; subsidies to maintain or increase employment mean that a_{pk} will not be perceived as high by the fleet.

A needs to be positive for a decrease in E to have a positive impact on profitability, while it needs to be negative (or small) for a reduction in capacity to have a positive effect. Thus, when both effort and fishing capacity are reduced in combination, profitability will increase in less instances than when only effort is reduced.

In extreme cases some links are so weak that they can be considered absent; the core model does not hold and a separate analysis of a model variant is required.

Model variants (with some links absent)

1. No link from revenue to profitability (a_{pr} absent): this can happen if there are subsidies for fixed costs, or sources of income independent of fishing… In that case no closed loop links all model variables together – the only closed loop is the E-C-S triangle; thus variables are relatively independent. Most management actions are not going to impact profitability but only revenue (Table 2). TACs and economic measures are unable to rebuild the stock. Decreasing effort is neutral to the economic variables, while decreasing capacity will increase profitability.

Table 2. Model variant 1. Consequences of various actions when profitability is independent of revenue. d decrease, i increase, – no effect, results in brackets are ambiguous.

Action / Effect on	Stock S	Effort E	Revenue R	Profitability P	Capacity K
Decrease C	–	–	d	–	–
Decrease E	i	d	i	–	–
Decrease R	–	–	d	–	–
Decrease K	i	d	(i)	i	d

2. No link from effort to revenue (a_{re} absent), which happens when there are subsidies to variable costs, *e.g.* fuel. This cuts the economic loop P-K-E-R: the economic dynamics necessarily flows through catch, thus all single-measure strategies will increase the stock (Table 3). Decreasing effort is neutral to the economic variables, while decreasing capacity might increase profitability in certain circumstances. Decreasing catch decreases economic variables.

Table 3. Model variant 2. Consequences of various actions when variable costs are not significant. d decrease, i increase, – no effect, results in brackets are ambiguous.

Action / Effect on	Stock S	Effort E	Revenue R	Profitability P	Capacity K
Decrease C	i	d	d	d	d
Decrease E	i	d	–	–	–
Decrease R	i	d	d	d	d
Decrease K	i	d	–	(i)	d

3. No link from effort to revenue (a_{re} absent), *i.e.* subsidies to variable costs, *e.g.* fuel, AND no link from effort to catch (a_{ce} absent), *i.e.* overcapacity. This leaves one single long loop, and to

some extent re-establishes the balance between effort and revenue which was suppressed in variant 2. As with the core model (Table 1), a combination of TAC reduction, effort control and fishing capacity reduction is the most likely to be successful, since it may increase revenue and profitability and will increase stock (Table 4).

Table 4. Model variant 3. Consequences of various actions when variable costs are not significant and overcapacity implies that effort reduction will not result in increased catches. d decrease, i increase, – no effect, results in brackets are ambiguous.

Action / Effect on	Stock S	Effort E	Revenue R	Profitability P	Capacity K
Decrease C	i	d	d	d	d
Decrease C and E	i	d	–	–	–
Decrease C and K	i	d	(d)	(i)	d
Decrease C, E, and K	i	d	(i)	(i)	(d)

Review of published empirical rules

There have been several reviews of success and failure of stock rebuilding plans. Among the factors identified as favorable to stock recovery, some can be compared with the above framework, but others cannot be derived by qualitative analysis because they are essentially quantitative or deal with allocation between fleets or areas; and some are more related to the management process, not the plan itself. We discuss those three categories in turn.

Empirical rules that concern issues already considered in the present framework

- Reopening criteria have to be set early and based on stock properties (Rice *et al.*, 2003): this can be translated into sustainability of the management goals (first step of the qualitative evaluation), and is equivalent to goals being sustainable in a neo-classical or modern view.
- Highly depleted stocks have low productivity (Rice *et al.*, 2003), life history must be fast and fecund (Wakeford *et al.*, 2009), stock dynamics must be compensatory (Brodziak *et al.*, 2008), environment must be favorable (Powers, 2003; Wakeford *et al.*, 2009), habitat should be protected (Rosenberg and Morgensen, 2005; Brodziak *et al.*, 2008): all this has to do with the fact that stock dynamics should not be altered, that is, the self regulation and links from effort to stock and from stock to catch should be unchanged when the stock is depleted, if recovery is to be secure when TACs and/or effort are reduced.
- Reducing catch is not enough, it should be used in combination with closed areas and/or effort control and/or capacity reduction (Rosenberg and Morgensen, 2005): this is consistent with the results of the qualitative analysis above. While these authors thought the combination of measures would provide an insurance against uncertainty, we show that this is inherent to the fishery dynamics even in a deterministic view. However, we concur that uncertainty and variability certainly might compromise the efficiency of any particular management measure and strengthen the need for a combination of measures.
- Stability of markets (Powers, 2003), which means that the economic dynamics must not be changed.

Empirical rules dealing with issues that cannot be solved by qualitative analysis

Because they are essentially quantitative:

- A large and rapid initial reduction in fishing mortality is key to recovery plan success (Rosenberg and Morgensen, 2005; Rosenberg *et al.*, 2006; Brodziak *et al.*, 2008; Wakeford *et al.*, 2009)
- Degree of depletion matters: strongly depleted stocks are less likely to recover, and recover slowly (Powers, 2003; Rice *et al.*, 2003)

Both of these empirical rules are logically consistent with the qualitative framework. The large and rapid reduction is consistent with the framework because it functionally ensures that the fish and fishers behaviours reflected by the E-C link do not adapt at the same rate that effort is reduced. The initiation of recovery plans before depensation has set in is consistent because it ensures the S-C link maintains its characteristic strength.

Because they deal with allocation or variables not described in the model:

- Plans must be multi-species and take account of community structure (Rosenberg and Morgensen, 2005; Brodziak *et al.*, 2008)
- Also required are an equitable allocation of benefits (Brodziak *et al.*, 2008) or homogeneity of fisheries participating during recovery, and stability of future allocations (Powers, 2003)
- Plans should include bycatch reduction methods and monitoring of bycatch and discards (Rosenberg and Morgensen, 2005).

The first and third of these rules deal with ecosystem issues outside the scope of the framework. However, to the extent that protecting community structure directly, or indirectly through not allowing bycatch of other species to become excessive, is necessary to ensure healthy dynamics of the constituent species in the community, the measures again are consistent with maintaining the S – C link. Equity of allocation is a social and economic issue outside the framework, but if fisheries bearing the impacts of reduced catch or effort for recovery of the stock do not feel they have been treated fairly, their compliance with the plan may suffer, and lack of compliance with regulations can be addressed in the framework.

Rules related to the management process

This list is limited to rules mentioned in papers focusing explicitly on stock rebuilding plans, although many other, general rules would also apply. The plan must include:

- Unambiguous objectives and performance criteria (Rosenberg *et al.*, 2006; Wakeford *et al.*, 2009)
- A time horizon for recovery (Powers, 2003)
- Consistent monitoring, to ensure that plans showing no signs of progress are revised; or adaptive plans (Rosenberg *et al.*, 2006; Brodziak *et al.*, 2008).

Application

Recovery plans and management plans are considered as key measures to ensure the sustainability of fisheries resource exploitation in the European Common Fisheries Policy (European Union, 2002). As a consequence, several long-term management plans have been put into force over the last decade (Table 5). All of the plans analysed here concern depleted stocks and include a clause making them recovery plans for a fixed time period or until a condition related to the plan goal is fulfilled. In the EU vessels affected by recovery plans which permanently cease their activities receive public aid from the European Fisheries Fund (European Union, 2006).

The plans currently in force concerning cod stocks in the North Sea, Skagerrak and eastern Channel, in the Kattegat, to the west of Scotland and in the Irish Sea, and cod in the Baltic Sea have set their goals as fishing mortality (F) levels; depending on the stock, the target is either F_{msy} or a higher F level. These plans place themselves in a sustainability perspective that is, at best, classical (Table 5). The previous plan for the recovery of cod stocks and the plan for North sea plaice and sole set objectives either as a spawning stock biomass (SSB) level or a combination of SSB and F; the target Fs are F_{msy} or a higher F level. The plan for herring West of Scotland sets a control rule involving both measures, that is, the F target depends on the current SSB level, but the ultimate target F is still F_{msy}. Thus these plans can be termed neo-classical (Table 5).

All five plans combine TAC reduction with either effort or capacity control, or both. If implemented with high compliance, these management measures are qualitatively adequate in all cases to meet the goal(s) of the plans, that is, reduce effort (taken as a proxy for fishing mortality) in the case of the current cod stocks and Baltic cod management plans, and both measures reduce effort and increase the stock for the other plans. This holds with both the core model (Table 1) and variant 3 (Table 4) with subsidies to variable costs and overcapacity, which could be considered describing the typical EU fishery. Overcapacity and subsidies are two of the major failings of the Common Fisheries Policy (Commission of the European Communities, 2009), but also exist elsewhere (e.g. subsidies in the US, Sharp and Sumaila, 2009). This general statement might not hold for all EU fisheries, and/or might have been mitigated in recent years, *e.g.* by real capacity reduction (Villasante and Sumaila, 2010) and the prohibition of subsidies for vessel construction since 2006. Anyway, the management tools generally employed in Europe (TAC reduction combined with either effort or capacity control, or both) are robust to both links being weak or absent. Let us notice here that in a fishery with significant subsidies for both variable and fixed costs and overcapacity (that is, links a_{pr}, a_{re} and a_{ce} weak or absent), the system is no more a dynamical system as there is no loop left. So any intervention may only have implications on itself.

However, although all plans are adequate to meet their goals, the Baltic Sea cod and Western Scotland herring plans may not be adequate to rebuild the stocks, depending on the strength of certain links (Table 5). In the herring case with a decrease in C and K, the framework calls attention to the conditions required to make a reduction in fishing capacity and TAC an effective tool, *i.e.* resolve ambiguous predictions in Table 4 as explained above. Profitability might increase if fixed costs are high but variable costs low, or overcapacity is low, or response of stock to effort variation is weak. In the latter two cases revenue is predicted to decrease (Table 4). From an economic point of view decreased revenue might not be a problem provided profitability increases. But if fishers do not prefer greater profit margins on smaller total revenue to simply large revenues whether there is net profit being made or not, then this strategy would not be certain to succeed. So the success of this strategy in the European context is not guaranteed. As for Baltic Sea cod with a combination of three management measures (C, K and E), profitability and revenue increase for a larger range of parameter values hence the strategy has more chances for success.

Another important point is that these EU long-term management plans constrain annual TAC variations to be below 25% when the situation is critical, and most generally 15%. Empirical rules teach us that low initial reductions in F severely compromise the success of recovery plans, and our framework says that such measures, which weaken the link between stock and catch by buffering variation in the output (C) more than the input (S) varies also undermine success of recovery plans. These stabilizing measures might thus be a serious impediment to the EU plans. Besides, effort limitation in these plans is always closely related to catch limitation: effort variation is to be calculated every year so as to match TAC variation under the current assessment and projection model. So reduction in fishing effort is not and additional management measure, except perhaps in the case of the Baltic Sea cod plan which includes seasonal and area closures. If these closures are extensive enough, they may necessarily reduce annual effort rather than displace it in space and time, and bring about some desired reduction in catch. In none of these cases will it be a strong reduction in fishing effort since TAC variation is limited. Therefore the evaluations of adequateness to rebuild in Table 5 are likely rather optimistic, and the three "Yes" might be turned to question marks or "No", taking account of these quantitative considerations.

In summary, the qualitative evaluation of EU management plans suggests that the objectives of these plans are sustainable in a primitive way that do not take account of modern knowledge on the various sources of complexity and uncertainty. And, although the planned management measures are generally adequate to meet these goals, and in three out of five cases even to rebuild the stock (as defined above implying both increasing stock size while not reducing profitability and/or revenue), the stabilizing rules constraining TAC variations severely compromise their success.

Although most of these plans were implemented very recently, we can now turn to an early evaluation of their first outcomes (Table 6). Three stocks out of eight showed some evidence of an increasing trend in stock biomass: North Sea plaice and cod, and Baltic Sea cod in areas B & C. Obviously after three years of implementation of the management plans, the stocks are not rebuilt to their historical abundances, but show increasing biomasses over three years in a row. In the case of the Baltic Sea cod, the assessment is highly uncertain (ICES Advice 2010, Book 8) owing to underreporting, discarding and problems with age reading. Still the objective of the plan (F=0.3) was estimated to be met in 2009. North Sea plaice is the most easily understandable case: the stock was not severely depleted at the outset, and the plan succeeded in reducing fishing mortality in its early years. As a consequence, this plan with a neo-classical target and an appropriate combination of management measures seems to be working. The case of North Sea cod is the most surprising: despite a strong depletion and an inability to reduce fishing mortality after six years of implementation of two different management plans, still the stock shows some signs of increasing trend in biomass. This must be a case of "good luck" (Powers, 2003): favourable environmental conditions that overcome all weaknesses of the management plans.

All other stocks under long-term management plans examined showed no evidence of increasing biomass, or even, further decline. This is not surprising given all these plans were unable to reduce fishing mortality at the outset, although the stocks were severely depleted (Table 6). The major problem with the Common Fisheries Policy might be implementation and enforcement, a result that was already known (*e.g.*, Nielsen and Holm, 2007; Commission of the European Communities, 2009).

Discussion

We found that for rebuilding a depleted stock, a combination of management measures including both output and input control is required. This is a general result valid across several variants of the bio-economic model. Reduction of TACs alone is not sufficient because it reduces fishers' income and profitability if not accompanied by actions to reduce effort and/or capacity. Conversely, decreasing only effort or capacity should always rebuild the stock but in many instances, the effect on fisher's income and profitability is uncertain or null. Thus, although TACs can be criticized on many grounds (Cotter, 2009), they should be combined with, not replaced by (as advocated by Cotter, 2009), capacity and effort controls, at least as long as most EU stocks are depleted. This applies of course in a single stock perspective. In a broader view of fisheries taking account of stock interactions and environmental impacts, other management measures and/or qualitative analyses would be required.

The qualitative framework proves useful for a first, simple appraisal of a management plan. This approach is results-based because it links a plan to its expected results without looking at many intermediate steps. Qualitative analysis produces statements about expected results before implementation, thus allow us to screen expected outcomes. It also outlines which information stakeholders involved in a results-based management structure would have to provide. Once a management plan is agreed, fishers would have to deliver data on those variables that are expected to change: catch, effort, capacity, profitability. Of course to check that the stock is actually rebuilding, a combination of fishery-dependent and fishery-independent data is always required.

As with any modelling exercise, these results are highly dependent on model assumptions. Using a deterministic model does not mean ignoring variability and uncertainty. Rather, it means focusing on the main features of a system that should be valid across a broad range of fluctuating conditions. The qualitative analysis predicts changes in equilibrium that would be the consequence of a permanent change in drivers – here management measures. Everybody knows that fishery systems do not start at equilibrium and that changes in drivers, including management measures, are hardly permanent as illustrated by the example of the cod stocks management plans. We assume that, provided the model captures the major variables in the system, these predictions still apply to the direction of changes induced by a significant change in drivers. This alone suggests that in a varying world, timid measures such as constrained variations in TACs are not likely to have the expected consequences (as confirmed by empirical evidence). The model structure determines the outcome of the analysis – this is both the weakness and strength of the qualitative analysis. It helps focusing on the important variables and links in a given system, and identifies the key inequalities that are likely to determine the outcome of a plan. In this it can lead to relevant quantitative analyses.

The approach could simply be used to screen which plans deserve a thorough quantitative evaluation. The *Ad hoc* Group on Cod Recovery Management Plan (ICES, 2009) convened eight international experts for two days in Copenhagen and probably required some preparatory work by some of these experts; but in the end, the group could not give advice because the objectives were not framed in a way to allow a formal, quantitative evaluation. However, a fast examination of this cod recovery plan shows that i) the objective of the plan is not sustainable, and ii) the stabilizing rule that limits TAC variations would prevent the plan from being efficient. No specific simulation was required to come to these conclusions, the accumulated knowledge is sufficient. A worse case comes with the Baltic Sea cod management plan, which was evaluated as precautionary by ICES and further work (Bastardie *et al.*, 2010), while at first sight it appears that its objective is not sustainable. A more detailed examination of the relative strength of the links in this particular fishery system would be required to determine whether the planned actions are likely to rebuild the stock while not decreasing fishers' revenues and profitability – this is beyond the scope of this paper. In any case, a plan with a non-sustainable objective may not be adequate to rebuild the stock. Actually the plan is now deemed to have met its objective while there is a high uncertainty in the assessment and the true state of the stock is not known, and reference levels for biomass are not available (ICES, 2010).

A puzzling result is that the 2008 long-term plan for cod stocks has been substituted for the 2004 plan for the recovery of cod stocks, while the objectives of the 2008 plan are less sustainable than the objectives of the 2004 plan, since they are framed in fishing mortality only, while the 2004 one had a stock biomass target. The most recent plan allows for wider TAC variations (up to 25%

when stock size is lower than B_{lim}) and makes more explicit mention of discards and other causes of cod mortality caused by fishing. However, so far it was no more successful in reducing fishing mortality, so it is hard to see the progress here.

Advocates of management plans argue that agreed decision rules avoid annual debates of management actions following annual stock assessments (e.g., Butterworth and Punt, 1999). This neglects the fact that long-term management plans, just like annual decisions, are the output of a decision making process. In most jurisdictions stakeholders will be involved in the process, either formally by consultation and negotiation, or less transparently through lobbying. The resulting management plan will be a compromise between various interests, and for this reason, might not be the ideal management plan that would respect the general sustainability and precautionary principles of the given jurisdiction. The problem with long-term management plans lies in the "long-term" – if they are not well-designed (independently of the scientific background, as outcome of a decision process), they might do harm on the long-term – which an annual decision does not, or less – or at least defer actions that may do some good. Obviously the setting would be completely different in a results-based management structure, where those bound to demonstrate that the impacts of their fishing activities do not exceed specified constraints would design and implement their own management plan within these constraints. In that case the negotiations and trade-offs are about the constraints on impacts, not about the plan. There frameworks to evaluate sustainability of objectives and to evaluate the ability of a plan to reach a given objective would have to be developed and applied separately, at different levels.

Long-term management plans imply mechanization of scientific advice, which creates a deceptive appearance of certainty (Kraak *et al.*, 2010). To evaluate a management plan, probability distributions for many quantities are required. When the knowledge is not available, the need to evaluate a management plan creates temptation and/or pressure on scientists to transform ignorance and indeterminacy into assumed probability distributions (Wilson, 2009). Management methods that require a more humble and less technical approach to scientific advice than quantitatively evaluated long-term management plans might be more transparent and less deceptive. The qualitative evaluation framework was also developed in this perspective.

Acknowledgement

This study was carried out with financial support from the Commission of the European Communities under the DEEPFISHMAN project (Grant agreement no. 227390).

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Appendix: Equations of the model

The model does not need to be specified. However, the whole analysis relies on the assumption that the model can be linearised in the vicinity of equilibrium, according to the following equations:

$$\frac{dS}{Sdt} = -a_{ss} f_S(S) + k_s/S - a_{se}E$$

$$\frac{dC}{Cdt} = -a_{cc} f_c(C) + k_c/C + a_{cs}S + a_{ce}E$$

$$\frac{dR}{Rdt} = -a_{rr} f_r(R) + k_r/R + a_{rc}C - a_{re}E$$

$$\frac{dP}{Pdt} = -a_{pp} f_p(P) + k_p/P + a_{pr}P - a_{pk}F$$

$$\frac{dK}{Kdt} = -a_{kk} f_k(K) + k_k/K + a_{kp}P$$

$$\frac{dE}{Edt} = -a_{ee} f_e(E) + k_e/E + a_{ek}F$$

where the f_x are positive functions of X and the k_x are constants.

Table 5. Qualitative evaluation of recent EU long-term or recovery management plans. Y yes N no ? depends on model parameters. For description of model variants see text.

Stocks	Management plan	Year of implementation	Sustainability of objectives	Management measures	Weak links (model variant)	Adequate to rebuild?	Adequate to meet goal?
NS Plaice & Sole	676/2007 (European Union, 2007a)	2007	Neo-classical	TAC + effort	a_{re} and a_{ce} (3)	Y	Y
Herring West of Scotland	1300/2008 (European Union, 2008a)	2009	Neo-classical	TAC + capacity	a_{re} and a_c (3)	?	Y
Cod stocks[1]	423/2004 (European Union, 2004)	2004	Neo-classical	TAC + effort	a_{re} and a_{ce} (3)	Y	Y
Cod stocks[1]	1342/2008 (European Union, 2008b)	2008	Classical	TAC + effort	a_{re} and a_{ce} (3)	Y	Y
Baltic cod	1098/2007 (European Union, 2007b)	2007	Classical	TAC + effort + capacity	a_{re} and a_{ce} (3)	?	Y

[1] in the North Sea, Skagerrak and eastern Channel, in the Kattegat, to the west of Scotland and in the Irish Sea

Table 6. Early empirical assessment of the outcome of recent EU long-term or recovery management plans. Initial F reduction, initial stock depletion, and outcome, *i.e.* recent trends in stock biomass were assessed based on the most recent ICES advice (http://www.ices.dk/committe/acom/comwork/report/asp/advice.asp). 'Stock severely depleted' means that biomass or SSB just before plan implementation was lower than 10% maximum level in the assessment series. In the 'Outcome' column evidence is for increasing trend in stock biomass; assessment here was made by eye as the shortness of the time series in most cases precludes any statistical analysis.

Stock	Management plan	Period of evaluation	Initial F reduction	Stock severely depleted	Outcome
NS Plaice	676/2007	2007–2010	Y	N	Some evidence
NS Sole	676/2007	2007–2010	N	Y	No evidence
Cod Kattegat	423/2004 & 1342/2008	2004 –2010	N	Y	Further decline
Cod Irish Sea (VIIa)	423/2004 & 1342/2008	2004 –2010	N	Y	Further decline
Cod North Sea	423/2004 & 1342/2008	2004 –2010	N	Y	Some evidence
Cod West of Scotland (VIa)	423/2004 & 1342/2008	2004 –2010	N	Y	No evidence
Baltic cod area A (22-24)	1098/2007	2007–2010	N	N	No evidence
Baltic cod areas B-C (25-32)	1098/2007	2007–2010	Y	Y	Some evidence (uncertainty)