Assessing Risk and Uncertainty in Fisheries Rebuilding Plans

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Abstract

This paper deals with risk and uncertainties that are an inherent part of designing and implementing fisheries rebuilding plans. Such risk and uncertainties stem from a variety of sources, biological, economic and/or political factors, and are influenced by external factors like changing environmental conditions.
The aim of this paper is to characterize such risks and uncertainties and to assess the importance of it in relation to the performance of fisheries rebuilding plans, to give some examples where uncertainties have negatively affected the ability of rebuilding plans to reach their intended targets and to give some guidelines how to deal with risk and uncertainties.

The conclusion is that when designing fisheries rebuilding plans, it should be taken into account the availability of relevant information, such that progress is (indisputable) measurable, and causes of potential failure can be clarified. Rebuilding plans need to consider biological, economic and distributional consequences in order to reduce uncertainties and to ensure successful implementation of the plan. Risk communication is also valuable in the process, since it gives transparency of the objectives and means to meet these objectives, elucidates crucial information from stakeholders and legitimates the whole process of designing and implementing the rebuilding plans, which is essential for the success of these plans. To that end the plans should be as simple and realistic as possible. It is recommended to apply risk analysis and to use the precautionary principle only in cases where large uncertainties exists and/or potentially high costs exits of ignoring the uncertainty cannot be resolved. Two fisheries rebuilding plans are analysed and how they address risk and uncertainties are evaluated.

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Contents

1. Introduction

This paper is concerned with fisheries rebuilding plans and the risks and uncertainties attached to them. Fisheries rebuilding plans are now in place for many fisheries, where fish stocks are at risk or even might collapse without adequate actions.[1]

A fishery rebuilding plan differs from ordinary regulation/management of fisheries in a number of respects. It formulates a target, typically that the stock should be above a certain reference level, where the stock is at minimum risk, formulated in terms of target biomass and target fishing mortality. But is also formulates a roadmap how to end there, including what regulatory instruments to use, how to monitor and enforce the plan, and how to deal with possible divergence from the planned path. The management part transforms the assessment into management actions, e.g. Total Allowable Catches (TAC), technical measures or number of fishing days, while the implementation of the plan and monitoring of the fishery determines the actual catches, revenues and cost and hence the profit. The design is based on assessments of stock biomass and fishing mortality and of economic parameters and outlooks.

Fisheries rebuilding plans must both be designed and must perform under a variety of risks and uncertainties, including e.g. inherent biological uncertainty, influence by external factors (e.g. changing environmental conditions or changes in demand or technological development) and under the interaction of many players (fishermen or countries), but also uncertainties related to economic and market factors.

1 There exist different definitions of what constitutes a collapse. According to Cooke (1984), a collapse is a sustained period of very low catch values after a period of high catch values. Mullon et al. (2005) identify three types of collapse, a smooth collapse, e.g., a long regular decline of caches, an erratic collapse where a large fall is experienced after several ups and downs, and a plateau shaped that implies a sudden fall after a long relatively stable period. According to their estimates, almost half of the collapses are of an erratic type, while the most unpredictable, the plateau shaped accounts for almost one out of four cases.

The aim of this paper is to characterize and define such risks and uncertainties, to analyze their importance in relation to the performance of the rebuilding plan, to give some examples where uncertainties have negatively affected the ability of rebuilding plans to deliver as supposed and finally to give some guidelines how to deal with risk and uncertainties.

But before that, it is appropriate to define properly the terms risk and uncertainty. In decision making theory, there is a clear distinction between risk and uncertainties. Risk is the probability of the occurrence of an event multiplied by the consequence, if it occurs. The consequences have to be measurable, e.g., weight, money, composition of the fish stock etc. Decision making under risk implies that all the consequences of a decision are known and a distribution function over all possible consequences is known. In comparison, a situation where it is not possible to calculate the risk, such that no probabilities can be attached to the consequences, is denoted decision making under uncertainty. (If even less information is known, i.e., the consequences not known, is sometimes denoted decision making under ignorance). In the presence of uncertainty it is no longer possible to make decisions based upon calculating expected values. Other criteria, based upon maximin or precautionary principle are, however, admissible to apply to evaluate policies. However, the definition of and distinction between of risk and uncertainties are not universally agreed upon, and in the rest of this paper we will only make a distinction between those two concepts if it is needed. Risk and uncertainties will in the sequel denote any situation where the decision makers at the time they choose an action, cannot determine with certainty the consequence this action will imply.

Several types of risk and uncertainties are relevant when analyzing rebuilding plans. Economic risk comes partly from the demand side, via fluctuating market prices, due to either changes in consumer preferences or market conditions (changes in competition), or from the supply side through changes in factor prices, changes in technologies, and credit conditions. Risk from a biological or environmental perspective comes around partly due to an inherent uncertainty about the state of nature and its dynamics in itself, but partly also due to uncertainties in prediction the consequence of proposed regulation. Such uncertainties are related to difficulties in estimating recruitments and stock growth. In management advices as practiced by e.g. the International Council for the Exploitation of the Sea (ICES) and National Oceanic and Atmospheric Administration (NOAA), evaluation of risk and uncertainties is largely related to conservation reference points for the stock and fishing mortality in the fishery, which in turn, e.g., are assumed to represent states with increased probability of impaired recruitment. Risk and uncertainties also stems from the political/institutional reality and potentially changes herein. E.g., how changes in policy measures, or regulatory systems, affect the possibilities to achieve a specific target. Further, the uncertainties might impact the design of the management plan, e.g. the choice of instruments. There are uncertainties involved in implementation and monitoring of any rebuilding plan, e.g. how is the TACs transformed into actual harvest. Both economic, environmental, biological and political risk, therefore, have a potential influence on outcomes of rebuilding plans.

The paper presents and analyses two actual rebuilding plans in the context of risk and uncertainty. Focus is in partuicular on which types of uncertainties are present, how they have been handled in the design process, and how the uncertinaties involved have impacted on the success of the rebuilding plan. The first is the North Sea cod rebuilding plan and the second one involves fisheries rebuilding plans from USA using the Pacific Groundfish Fishery as an example.

A number of proposed guidelines emerge from the analysis. Fisheries rebuilding plans should be dealt with by applying a formal decision making process, in combination with a formal risk analysis. The benefits of such a process are that it elucidates the importance of risk and uncertainties, and gives valuable insights to how best to manage these risk and uncertainties. As an example, it could show how to reduce uncertainties by deliberate choice of regulatory instruments. Moreover the possibility of measurement of progress and the availability of relevant data should be considered explicitly already when designing the rebuilding plan. To reduce implementation uncertainties, it is warranted to consider both biological as well as economic consequences, and formal risk communication should be used. Finally, the precautionary approach should be applied in accordance with the level of uncertainty.

Overall, the relevance of incorporating economic consequences for the fish industry must be stressed. Otherwise, the implentation is compromised, because the likely reaction and adaptation of the fishermen to the plan is not foreseen. In the presence of uncertainties, and in order to get acceptance of the implication of the rebuilding plan from affected parties (the fishermen), risk communcation is, moreover, a necessary tool.

The paper is organized as follows. In section 2 risk and uncertainties are described for fisheries rebuilding plans followed by the definition and describtion of rebuilding plans in terms of design, implementation and monitoring in section 3. Section 4 discusses how risk and uncertainties can influence outcomes of rebuilding plans, while risk (and uncertainty) assessment and management and communication are covered in section 5. Two examples of rebuilding plans are in section 7 discussed and evaluated with respect to cases where risk and uncertainties have or have not been addressed. Section 7 contains conclusions and proposed guidelines.

2. Risk and uncertainty

This section aims at describing the risk and uncertainty present in fisheries and rebuilding plans. It provides the definition of risk, risk assessment and risk management, the distinction between risk and uncertainty and considers different types and sources of risk and uncertainties.

2.1. Definition of risk

Risk refers to the possibility that human actions or events lead to consequences that affect aspects of what humans' value (Fischhoff et al. 1984, Vlek 1996). Risk analysis is both a descriptive and a normative concept. It includes the analysis of cause-effect relationships, but it also signal implicitly to reduce undesirable effects through either appropriate modification of the causes or, though less desirable, mitigation of the consequences.

2.2. Distinction between risk and uncertainty

While risk generally refers to the possibility of suffering harm or a loss, in engineering and the physical sciences, for example, the term "risk" is taken to be probability multiplied with consequences. In psychology, risk is rather seen as a function of subjectively perceived utilities and probabilities of their occurrence (See. e.g., Slovic et al., 2004). But in decision making theory risk has yet another meaning, and most be distinguished from uncertainty and ignorance. Decision making under risk implies that all consequences of any action/decision is known, i.e. a value attached to it and a probability distribution over possibly consequences is known. Table 1 shows terms and implications. Broader, uncertainty refers to the incompleteness of knowledge about the states or processes in nature.

Table 1. The three basic elements in risk theory

Complexity ↓	Term	Definition	Possibility for decision making	Possibilities to make decisions
	Risk	Probabilities, consequences and their values known	Calculate expected values	Good
	Uncertainty	Probability not known, but consequences and their values known	Possible to rank consequences (apply e.g. maximin criterion)	Moderate
	Ignorance	Probability not known, not all consequences or their values known	Major problems for decision making	Bad

2.3. Risk assessment and risk management

In risk analysis, two distinct operations are identified as risk assessment and risk management. Risk assessment is the scientific process of defining the components of risk in precise, usually in quantitative terms. In technical risk assessments, this means specifying what is at stake, calculating the probabilities for (un)wanted consequences, and aggregating both components by multiplying the probabilities by the magnitude of the effects. Risk management refers to the process of reducing the risks to a level deemed tolerable by decision maker (e.g. society) and to assure control, monitoring, and public communication. Risk assessment has been discussed in a fisheries context. According to Hilborn et al. (2001), risk assessment aims primarily at evaluating the consequences of various harvest strategies in terms of probability statements about future trends in yield, biomass and collapse of the stock, while risk management involves finding and implementing management policies, strategies and tactics to reduce the risk to the communities exploiting them (Hilborn et al. 2001*)*. Therefore the concepts of risk assessment and risk management refer to situations of risk, uncertainty and ignorance.[2]

2.4. *Different type and sources of risk/uncertainties*

Risks and uncertainties can be grouped with respect to either type or source. The type relates to whether the risk and uncertainties come from economic, environmental, biological or political sphere. The second grouping relates to the underlying source of uncertainty.

The first type of risk can be identifiable as economic risk. Economic uncertainty relates to the fishing industry, demand and supply side (price effects) and behavioural assumptions about fishermen. Uncertain factors here are the profitability of the industry under various regulation regimes, which depends on market effects, via fluctuating market prices, due to either changes in consumer preferences or market conditions (changes in competition), and partly from the supply side through changes in factor prices, changes in technologies, and credit conditions. Another area of uncertainty relates to the behaviour of the fishermen /industry (conditioned on the development of profitability). Such behaviour influences relevant variables like overfishing, discard, illegal landing or

2 The combined operations of risk assessment and risk management can also be conceptualized in a DPSIR framework (DPSIR; Driving forces, pressure, state, impacts, response). Another model of this type is the OECD pressure-state-response (PSR) model. Even though these models are developed for analyzing environmental problems, it also can yield an appropriate framework for analyzing risk /rebuilding stock. See Caddy (2004), Page 1310, Figure 3 for an attempt to apply the DPSIR model to fisheries. Drivers could be human activities or environmental conditions which exert pressure in terms of overfishing or overcapacity on the resource/stock resulting in changes in the state of the resource, which in turn result in impacts. The impacts could e.g. be a decline of the profitability of the fishery, e.g. a decline in stock size or even collapse of fishery. Society's response to changes in pressure or state (or impact) is then with policies or programs intended to prevent, reduce or mitigate the pressure or the socio-economic damages/costs that occurred as a result of the original pressures. The link to risk assessment and management is obvious: Risk assessment is to evaluate the change in state and the resulting impact on human welfare. Risk management is to propose policy options that can mitigate the risk.

overcapacity (and hence, also the likelihood that the rebuilding plan turns out successful). Expectation about profitability/possibilities for the fishermen/industry also influences the process of determining the design of the rebuilding plan.

The second type of risk relates to the uncertainty about how climatic and environmental conditions affect the link between the changed efforts of the fishermen as described in the rebuilding plan and the resulting change in the biological variable that has to be recovered. As an example, whether observed hydrological condition can be attributed to either natural and hence temporal variation or climate change induced permanent trends has implication on whether the rebuilding should be revised or not.[3] These types of uncertainties influence the likelihood of achieving the stated goals, and affect how to handle divergence from an expected rebuilding path. For example, the main human threats to North and Baltic Seas marine environment are identified as effects of climate changes, fisheries, nutrient (eutrophication), and pollution inputs from a number of different sources (COM, 2005). Furthermore, the marine ecosystem is still being endangered by shipping, raw material encroachments, agriculture and tourism. In the future, pressure on marine ecosystems is likely to increase due to the offshore use of wind energy, but such effects are uncertain, too.

The third type of risk is biological risk related to the fish stock and its development. The risk and uncertainties attached relates to the lack of understanding or the lack of possibility of observing how the stock evolves in light of the changes in fishing activity implied by the rebuilding plan. This is in particular critical when there is a risk of collapse, which is the most severe biological risk. Moreover, there is uncertainty attached to the exact rebuilding of a stock, if the stock is below a certain threshold level. In the case of threshold stock levels, below which rebuilding is slow or impossible due to badly or wrongly understood biological factors, like year to year recruitment, the risk is that the planned

3 Another uncertainty is how the level of nitrogen influences stock size (eutrophication) (e,g, Baltic Sea cod). See also Salomon (2004).

changes by the invoking of the rebuilding plan do not increase the stock as desired. Evaluation of risk is largely related to conservation reference points for the stock and fishery, which in turn are assumed to represent states with increased probability of impaired recruitment.

Finally, political risk occurs from the political/institutional reality and changes herein. E.g., how changes in policy measures, or regulatory systems, affect the possibilities to achieve a specific target. As will be discussed in the next subsection, how fishermen or the fishing industry in general react to changes implied by the rebuilding plan is also uncertain. Both with respect to the pressure the industry puts on the decision makers (in terms of e.g., lobby pressure to increase TAC), or in terms of changes in actual fishing behaviour. This could be with respect to changes in discards or changes in entry and exit decisions. Such factors are uncertain, and might compromise the ability of the rebuilding plan to achieve its proposed target (the implementation issue).

2.5. Different sources of risk/uncertainties

We now turn to the grouping of risk and uncertainties with respect to different source of risk and uncertainties. This section builds heavily on Francis and Shotton (1997). According to the authors, the sources of uncertainties can be categorized into six groups, those associated with process, observation, model, estimation, implementation, and institutions.

Process uncertainty: Due to real uncertainties, as a result of random or chaotic processes. This type of uncertainty arises often from natural variability, not error. The most common example of process uncertainty in the fisheries risk literature is inter-annual variability in recruitment. But it can also include economic processes and processes describing e.g., behaviour of economic agents (fishermen). Unexpected reactions to rebuilding plans (e.g. increasing discards) can be seen as process uncertainty.

Observation uncertainty: Arises in the process of data collection, through measurement and sampling errors. Landings data and survey data forms together the data input to the stock assessment process. No assessment is better than the data and landings data do often not reflect the catch data. In ICES several stock assessments are supplemented by official data about discards. This initiative will reduce the observation uncertainty, all things equal.

Model uncertainty: The term "model" refers to the conceptual model that fisheries scientists, managers and economists use as an aid in making inferences and decisions. Biologists model fish populations and fisheries, and economists use models to describe the structural and behavioural drives of the economy. Risk and uncertainties in modelling has at least three different origins. First, the wrong model would be used, secondly, the model could be inadequate and finally, exhibit misperceived relationships. In biology, such failures could be caused by lack of information about the correct structure (e.g., is the stock–recruit relationship asymptotic or domed?). Another model uncertainty is the use of single-species models or multispecies models in the assessment. In many cases the models give different prediction of the stock development. Finally, model uncertainties are from an economic point of view related to correct modelling of market conditions (demand and supply), and of modelling behaviour of economic agents.

Estimation uncertainty: Relates to the process of parameter estimation. Even in the case where e.g., the right model has been proposed, parameters in the model must be estimated. An example here is the estimation of recruitments. Even if the recruitment of a species follows a Beverton-Holt function, the parameters in the model must be estimated on basic of incomplete knowledge (like the proliferation rate of the carrying capacity). Such estimation uncertainties appear whenever estimation requires data and a formula, or algorithm, which implies a model.

Implementation uncertainty: Relates to the uncertainty about the extent to which management policies will be successfully implemented. For example with unsuccessful implementation, the objectives stated in a rebuilding plan may not be achieved. The risk associated with various management rebuilding plans depends in part on how effectively they are likely to be implemented, which again is dependent on whether the objectives of the management and industry are aligned or differ substantially. It follows that if the incentives of the fishermen are not foreseen and very different from what the management has expected (the "incentives gap") the implementation uncertainty is high.

Institutional uncertainty: While implementation uncertainties relates to reaching effective plans, institutional uncertainties relates to uncertainty in the process of defining an effective plan in the first place. Institutional barriers like difficulties in proper risk communication from regulator to fishermen, or problems associated with the interaction of the individuals and groups (scientists, economists, fishermen, etc.) that compose the management process. One type of institutional uncertainty is associated with the lack of well-defined social, economic, and political objectives in fisheries management. Stephenson and Lane (1995) claim that part of the reason for many fishery failures in recent decades are that "objectives have been broad, ill-defined, and in many cases not operationally feasible." Finally, distributional issue also contribute to the uncertainty: A rebuilding plan normally implies a short term reduction of fisheries effort. If the industry initially is in a (close to) zero-profit situation (e.g., because of inability to control investments in capacity), such limitations will imply a short term loss, leading to exit from the industry. Once the stock is rebuild and properly managed, profitability increases, and pressure for entry increases, such that those who have to bear the costs not necessarily are those who reap the benefit of such investment. The uncertainty surrounding such dynamics is important to understand, in particular related to acceptance of the plan from the fish industry. As an example of how instrument choice can reduce uncertainty, is the system of individual transferable quotas, which secures that those who bear the costs also are those who reap the full benefit, reducing implementation uncertainty considerably.

Follow up: Finally, the stated uncertainties should not be looked at in isolation. A now classical example how economic, political and biological uncertainties can interplay and yield a worsening of the fisheries situation is given by Ludwig et al (1993). The driven forces are described as economic and political incentives (forces). The effect, labelled as a ratchet effect works as follows: Given natural fluctuations in the stock size, in “good” years additional investment will be made. However, when the stock decreases to a size smaller than “normal” size, the industry appeals to government for help. The response is subsidies (direct or indirect). The effect is to encourage overharvesting. The ratchet effect is that no (or insufficient) limits are put on harvest investment during high stock levels but political pressure not to disinvest during low stock levels are added. This reasoning has been used by Hennesey and Healey (2000) to explain the collapse of the stocks of the principal groundfish species off New England. Therefore, we add a phase called the follow-up phase, which essential is the situation where the recovery plan has succeeded, and how the fishery has to be managed so that it remains “well-managed”, with respect to economic and biological variables. Considerations of this phase also have implication on the achievement of the recovery plan, and examples are added in Table 2.

Table 2. Main types and sources of risk and uncertainties in fisheries[4]

	Types of risk and uncertainties				
	Uncertainty	**Economic**	**Biological**	**Environment**	**Political**
Sources of risk and uncertainties	**Process**	Price fluctuations Profitability	Recruitment Stock size	Variations in hydrological conditions, temperature	Shifts in the political arena or in political focus
	Observation	Landings Discards	Annual rate of fishing mortality	Temperature Salinity Oxygen Wind speed	Lobby activity of stakeholders
	Model	Behaviour of fishermen upon regulation Illegal landings	Stock size Recruitment	Connection between temperature and recruitment	Modelling of the political system
	Estimation	Prices Catches	Annual rate of fishing mortality	How environmental variables affect biological variables	Importance of lobby activity on outcome
	Implementa-tion	Relation between instrument choice and reaction of fishermen	How biological variables affects possibility of reaching the planned target	How environ-mental variables affects possibil-ity of reaching the planned target	Reaction of political sys-tem: Control, surveillance
	Follow-up	How a rebuilded fishery attacks new entry: Distri-bution of benefits between incum-bent and entrants	Considerations about the whole ecosystem which the fishery is a part of	Long term climate variations and man-made trends	Political will to withstand pressure for increases in catches

2.6. Combining different types and source of risk and uncertainty

We are now in the position to describe /categorize the risk and uncertainty inherent in the process of fisheries management using the tools from section 2.3 through 2.5. This is done in Table 2. In the risk assessment matrix of Table 2,

4 For ease of exposition, we have excluded institutional uncertainty.

we have summarized the sources and types of risk uncertainties that have been discussed in this section. The table is by no means comprehensive, but has two overall functions. First, it shows the many different sources of risk and uncertainties that potentially affects a fishery rebuilding plan. Second, it can be used to structure the risk assessment of actual rebuilding plans.

The table reads as follows. E.g., the first entry in the matrix considers the cell representing the economic process uncertainties. These uncertainties are caused mainly by difficulties in predicting fluctuating prices and profitability. The source to e.g. fluctuating prices is process uncertainties.

3. Describing rebuilding plans: Design, implementation and monitoring

In this chapter we develop a framework for rebuilding plans. We describe the necessary content of fisheries rebuilding plans and explore issues related to design, implementation and monitoring.

3.1. Rebuilding plans

Rebuilding plans typically (or ideally should) include

1. Specification of a target or targets of the plan.
2. A realistic timeframe and/or rebuilding path for reaching the target.
3. Implementation of the rebuilding plan (i.e. restricting fishing effort by reducing the TAC).
4. Monitoring, compliance and control of the fishery.
5. The level of observation with the development in the catches, stock, economic parameters etc.
6. A rule of adjustment of the plan.

Each of these points can be linked to the set-up of Table 2, to indicate the risks and uncertainties related to each of these points. As an example of this, consider the first point.

Rebuilding plans first of all must specify a target, a timeframe and an approach path. Targets can be specific stock sizes or fish mortality levels or can be formulated as threshold levels which the manager wants the fish stock to be above and the fishing mortality to be below. How the targets are specified, influences the level of uncertainties. In considering this, one could go back to Table 2, and consider, e.g., if targets are specified as number of fish, uncertainties might appear in all of the mentioned biological categories, if targets are specified in profits, uncertainties to measuring this has to be considered. However, in a proper analysis, all types of risks and uncertainties should be considered for all parts of the plan.

The limited reference point approach can be used for threshold or targets in the fisheries rebuilding plans. The following four are normally used:

B_{lim}: (Danger level) scientists have proposed it as the limit below which the stock must never be allowed to decline.
B_{pa}: (precautionary level) is set at a higher level which gives reasonable certainty for that in spite of year to year fluctuations the stock will stay above B_{lim}.
F_{lim}: the level of fishing mortality at which there is an unacceptably high risk that stocks will collapse.
F_{pa}: a lower level of fishing mortality which offers a high probability that (F_{lim}) will never be reached.

The starting point of the rebuilding plan is that the current fishery policy has lead to a degradation of the stock (with a high risk of going below a threshold level (B_{lim}), where the reproduction level is impaired). In this case, there will often be uncertainties about the actual size of the stock biomass,[5] and the level of B_{lim},[6] and the causes for the low size of the stock, e.g. too high fishing mortality, or natural variations, or changes in the climatic trend.

Once the target(s) and a timeframe have been set, several policy actions must be taken to get there. The choice and level of regulatory instruments must be decided. If TAC is used, then the reduction of TAC has to be decided together with decisions about how to allocate the fishing opportunities. Another option is to use number of fishing days as an instrument and hence the allocation of limited number of fishing days is the main policy measure. Given these choices which indirectly determine the expected level of compliance, the decision makers have to determine the level of control of the fishermen, together with the level of observations about development in stock and fish mortality. If observations show that the regulation differs from planned path, the plan most contains the possibilities of adjustment (subject to an assessment of the causes for divergence).

This can lead to the construction of a rebuilding plan as seen in several countries (Caddy and Agnew, 2004). In considering the feasibility of a plan to achieve the stated goal (s), a number of uncertainties must be dealt with. For this purpose, the framework specified in Table 2 can be applied, which we will do in section 4. Here we continue with a more detailed description of issues related to the issues of design, implementation and monitoring.

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5 In many cases the fishery has experienced yearly catches close to 100% indicating very tight regulations. This often leads to lower quality of the catch statistics. Therefore, assessment of the stock biomass can be very complicated and with high interval of confidence.

6 This is often an evaluation of scientists based on studies of stock-recruitment relationships and past observations of the biomass level.

3.2. *Design*

Basically, there are two fundamental different ways of thinking about the design issue. The first which is based on the approach of optimal control theory, treat fisheries as a rocket that can be steered to a given target. In this approach the policy variables or decision variables can be adjusted or fine-tuned so the fishery will end up at the steady-state target biomass with an annual constant exploitation rate and harvest. If outside the steady-state, the approach path is towards the steady-state point again. The second way of thinking is an approach where the policy continuously is changed based on updated information about the status of the fish stock and may be other parameters. None of these approaches are likely to function in practice. Management of fisheries is not an optimal control problem, as already seen in section 2, because of the inherent biological uncertainty, influence by external factors (e.g. changing environmental conditions or continuous changes in demand or technological development) and the numbers of players (fishermen or countries) involved. Further, the results of management plans are often long term, i.e. over at least 7-10 years, because it is typical long lived species that are managed by rebuilding plans. This will depend on how the species in question and the ecosystem in general will react and adjust to changes in fishing pattern. Overfishing can take several forms, including recruitment or/and growth overfishing and the applied means in the plan has to be appropriate with the type of overfishing.[7]

The design of a rebuilding fishery plan has to address these issues if it is going to be successful. A rebuilding fishery plan often has as the overall objective to increase the stock biomass above B_{lim}. There are several problems with such a goal. First, the fish stock is not measured exactly, but it is assessed based on survey data and catch data. Second, changes in the fish stock might be related to external environmental factors. This can change both the growth rate and the

7 Roughly speaking, recruitment overfishing is when the harvest level is too high leading the problems with the reproductivity of the stock, while growth overfishing is when the individuals of stock are harvested at a too small size.

carrying capacity and therefore also impact the level of stock biomass. Third, it might be difficult to define exactly what is meant by a recovered stock, i.e. to agree on a target level.

The decision variable in rebuilding plans is very often the exploitation ratio, normally defined as the fishing mortality rate. One has to be careful here, because the fishing mortality rate is an instantaneously rate, while the exploitation ratio often is the yearly removal of fish in percentage. There is, however, a relationship between them, e.g. fishing mortality rates at 0.1 or 1.0 correspond to removal ratio per year at 10% and 64% respectively.[8] It is clear that none of these variable is a real control variable because of two things. First, the fishing authorities do not control directly the exploitation. Secondly, the uncertain stock biomass is included in both variables. This means that if the aim is to have a removal ratio at 30% then if the stock biomass is negative impacted by external factors then the catch quantities have to be reduced even further to reach the target of a ratio at 30%.

In the literature several theoretical papers are published on optimal harvest level with uncertainty. Adding a simple uncertainty term to the growth function does not fundamentally change the functional form of the optimal harvest rate rule (Reed 1979), only the optimal escapement level increases and often only a little (Conrad and Clark 1987). The harvest rule is, as in the deterministic case, to set the harvest to zero below a certain stock level and above this stock level to keep the escapement constant, meaning that the harvest rate increases with the stock level. It is well known from the literature that the uncertainty has to be more complex in order to change the harvest rule. When there is uncertainty about the stock size, then the optimal policy change. The harvest rule is not a constant escapement rule and the harvest begins at lower levels of recruitment, while at higher recruitment levels optimal escapement is higher (Clark and Kirkwood 1986).

8 The exact relationship is $u = 1 – \exp(-F)$, where u is the yearly removal fraction and F is the instantaneous fishing mortality. This formulation can be extended to include natural mortality.

Roughgarden and Smith (1996) introduce three types of uncertainties; in the growth function, in the measurement of the stock and in the implementation of the harvest/quota. They show (by numerical simulation) that the optimal stock size increases with increasing uncertainties. Thereby and therefore they suggest a target stock size of ¾ of the carrying capacity *K*. They apply a model for a fishery without the marginal stock effect, i.e. where the harvest does not depend on the stock size.

In Sethi et al. (2005) these three uncertainties are modeling in a bio-economic framework where the trade-offs involved are explicitly included, not ad hoc as in Roughgarden and Smith (1996). They show that with low uncertainty in general or large growth uncertainty, the optimal policy does not change much compared to the deterministic case. The optimal policy is, however, not a constant escapement policy, but very close to, indeed. Harvest begins at around 45-50% of the carrying capacity in the numerical example. With large implementation uncertainty of the quota, the optimal policy is still very similar. However, the harvest begins at a little lower level of the measured stock than above and the escapement level increases with higher stock levels. But with large uncertainty in the measurement of the stock, the optimal policy changes a lot. The harvest begins at a much lower level of the measured stock (in the numerical example at about 30% of carrying capacity) and is increasing with higher stock level, but at a rate lower than one, meaning that the escapement level increases with increases in stock level and eventually becomes larger than the level from the constant escapement policy. This last effect is due to the situation where a large measurement of the stock has a high probability of being wrong and hence it pays to leave a higher portion in the ocean.

These results do not include a growth function with depensation, i.e. at low stock levels the growth in the stock is not sufficient for replacement. This increases the risk of collapse of the fisheries. In the models, the only way the fishery can collapse is with harvest levels above the stock size or continuing harvesting at levels above the growth rate of the stock. A growth function with depensation calls for a more conservative policy, see section 4.1 below).

Another part of the literature study cases where it is optimal for some species to let the fishery collapse (see e.g. Amundsen and Bjørndal 1999). We do not explore this issue further here, because such policies do not correspond with the objectives of most fishery plans and politics.

To sum up, the result from the literature is to have positive harvest rates at stock levels above 30% of the carrying capacity when confronted with measurement uncertainty. The harvest rate will increase at a rate lower than one with increases in stocks. This will ensure that the risk of a collapse is very small given the uncertainties in the growth rate, in the implementation of the quota and in the measurement of the stock size. This risk might increases for species which growth functions include depensation. This will call for a more conservative harvest policy.

3.3. Implementation

Implementation of the rebuilding plan involves a choice of management measures. Is quotas or input controls (or both) applied? And is it possible to use price regulation or landing taxes? As we will demonstrate latter (chapter 6) the issue of management measures is not a part of the two rebuilding plans we have investigated in detail.

Sutinen (1999) analyses a large number of management plans in OECD countries. He groups management measures into three, output control, input control and technical measures. Output control includes Total Allowable Catch (TAC), individual quotas and vessel catch limits. Input controls are in the form of limited licenses, individual effort quotas and other gear and vessel restrictions and finally technical measures including size and sex selectivity and time and area closures. Each of these measures was evaluated with respect to biological, economic, social, and administrative consequences. One of the conclusions in the analysis is that no single measure is superior in all respects. Most interesting is that TAC-regulation combined with technical measures, which is the backbone of many rebuilding plans, has shown to have serious flaws. Sutinen (1999, page 1056) concludes that "TAC management results in a race-to-fish with all its attendant effects and generally has not effectively prevented over-exploitation of resources. Effects of over-capitalization, shortened seasons, market gluts, and increased harvesting and processing costs are particularly evident." Individual Transferable Quotas (ITQs) have, however, also shortcomings, most problematic the initial allocation of quotas, but ITQs do otherwise outperform TAC-regulation, and seems to be the most effective measures to reduce overfishing (Costello et al. 2008).

Weitzman (2002) presents an important contribution in case of choice of instrument under uncertainties about recruitment. He compared taxes (in the form of landing fees) with quantity regulation (in form of auctioned ITQs), and concludes that taxes perform better (in terms of reaching the first-best result). This result comes about because the number of ITQs has to be determined before the fishermen fish. The tax is first paid when the fishermen land their catches. In this way the tax uses the information that is revealed to the fishermen. Therefore, Weitzman concludes that the tax mechanism is more flexible than ITQs. If there is economic uncertainty in form of unknown economic parameters the result is however not clear-cut, see Jensen and Vestergaard (2003) and Hannesson and Kennedy (2005).

3.4. Monitoring

A fishery rebuilding plan is based on implicitly division of the involved variables into target, decision and exogenous variables. Stock biomass and fishing mortality are examples of target variables (sometime also called outcome variables). An economic outcome variable is profit. Exogenous variables are environmental factors (climate changes) or other impacts which are outside the control of the manager or outside the boundaries of the plan. Decision variables are the variables that the manager can change to influence the outcome, in our case the fisheries management system, e.g. TACs combined by limited entry etc.

The overall performance of such a system is very depended of information about the target variables. These variables are latent variables, meaning that they cannot be observed directly and has to be inferred. The size of the stock biomass is determined in biological assessment models where catches of the fishermen is a very important input variable. In these models the actual fishing mortality is also determined. It seems therefore very important that the managers design the monitoring and enforcement system in such a way that the reported catches reflect the actual catches. As indicated below one of the main problems in the EU cod rebuilding plan has been that the reported catches (i.e. landings) did not reflect the actual catches. This makes it very difficult to do reliable biological assessment which is a prerequisite for fisheries rebuilding plans.

We will not elaborate more on the monitoring and enforcement issue, just emphasize that it is important that the variables, the plan is based on, can be inferred or observed.

4. How risks and uncertainties can influence outcomes of rebuilding plans

As specified in section 3.1, rebuilding plans ideally should consider a number of issues. Each such issue is relevant for the design of the fisheries rebuilding plan and each point has potential risk and uncertainties attached to it, which has to be considered. E.g., which target to choose influences the level of uncertainty? (or targets could be chosen so as to reduce the prevailing uncertainty). A stock target will be difficult exactly to reach if there is uncertainty about the stock/recruitment relationship. In such cases, other measures might contain less uncertainty, like fish mortality. It should also be considered how many resources is needed to provide the necessary information.

4.1. Risks and uncertainties related to design of the rebuilding plan

Roughgarden and Smith (1996) define a biological target as ecological stability, which is achieved if the target stock is above the level that produces maximum sustainable yield and the harvest level is less than the maximum sustainable yield. The benefit of such a relatively high target is “natural insurance”, which is relevant in cases with environmental fluctuations that could drive lower stock towards extinction. This approach builds upon the precautionary principle. According to Randall (2009), the precautionary principle is fundamentally a claim that acting to avoid and/or mitigate threats of serious harm should be accorded high priority in public policy. Moreover, Randall (2009) compares principle of precaution with ordinary risk management and finds that risk management not only has to consider means of reducing risk (to an acceptable level), but also to consider the costs and benefits of such risk reduction. As a consequence, in relation to application of precautionary principle/approach it seems to be that calling upon the principle imply a larger weighting on risk reduction. In conclusion, in cases of large uncertainties, and without possibilities to resolve these uncertainties, and with a non-zero probability that a very averse event could happen (e.g., extinction of the stock) then advocating for a “biological buffer” as defined by Roughgarden and Smith (1996) makes sense.

According to ICES (2001) a stock outside safe biological limits will suffer increased risk of low recruitment, i.e. average recruitment will be lower than if the stock were at its full reproductive capacity. This causes a reduction of the potential catch fisheries can take from the stock. A stock that suffers severely reduced productivity is considered to be "collapsed”. A stock "outside safe biological limits" is not, however, usually at risk of extinction. In ICES (2001), it is stated that ICES recognizes that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to change in the environment and human values (see also FAO, 1996). Therefore ICES agrees that a precautionary approach should be applied to fishery management. Reference points, stated in terms of fishing mortality rates or biomass and management plans are key concepts in implementing a precautionary approach (see also the UN Fish Stocks Agreement from 1982, where the precautionary approach is explicitly linked to reference points).

We should, however, note that the precautionary approach should only be used when uncertainties are large, and not resolvable and the risk of adverse effect sufficiently high. Otherwise, an ordinary risk management approach is preferable.

4.2. Risks and uncertainties related to implementation and monitoring of the rebuilding plan

The implementation phase covers the time span from having agreed upon a specific plan until the results materialize in terms of improvement of the resource. According to Table 2, a variety of risk and uncertainties are attached to this phase and may impact the rebuilding trajectory.

Both economic, biological, environmental and political risk and uncertainties have to be addressed. As an example of this, according to Horwood et al (2006), monitoring the progress of North Sea cod rebuilding is hampered by considerable uncertainties in stock assessments associated with low stock size, variable survey indices, and inaccurate catch data. In addition, questions arise as to whether rebuilding targets are achievable in a changing natural environment. Disentangling of the effects is important in relation to possible reactions. Therefore a mechanic adjustment rule under uncertainty is not adequate. If it can be verified with high confidence that deviations from the scheduled plans are caused mainly by temporal anomalies in the natural climate (e.g., due to an El Niño or an abnormal NAO[9]), and not due to too high fishery pressures, then

9 NOA stands for North Atlantic Oscillation.

adjustments need not to be made.[10] But if the change in the environment is permanent then the targets and the rebuilding trajectory has to be adjusted.

5. Risk (and uncertainty) assessment and management and communication

As a starting point in a formal decision process, one of the most important tasks is to find all possible alternatives and calculate /consider the consequences (in our case economic and biological). However, such a process is difficult when uncertainties are present.

5.1. Review the methods and mechanisms for assessing risk and uncertainties

The risk assessment matrix (Table 2) shows the whole range of risk and uncertainties that potentially has to be taken into account when considering the outcome of a fisheries rebuilding plan. The assessment of risk and uncertainties should not only serve as an input to risk management, but importantly it should be stressed that e.g. instrument choice also affects the level of uncertainty.

Francis and Shotton (1997) quote various authors' definition of risk assessment and extract a general definition of risk assessment as: "Using information on the status and dynamics of the fishery to present fishery managers with probabilistic descriptions the likely effects of alternative future management options". Such a description seems most used for risk assessment of the biological development. According to Francis and Shotton (1997), all the risk assessment comprises of three elements, inputs, models and outputs. (The authors present examples related to stock assessment). Inputs refer to data that has to be used, like

10 O'Brien et al., 2000 argue that for the North Sea, the precise form of any recruit-stock-temperature relationship is highly model-dependent. Nevertheless, it appears that two strong pressures are acting together to depress recruitment. According to the authors, separating these two effects is scientifically challenging, with no definitive solution at this time.

catch data or growth rate of the stock. Uncertainty is added by stochastic processes, and a model can be constructed /simulated. The output is a prediction /forecast of the likelihood of various outputs from a given rebuilding plan. An example of such an analysis is given in Horwood et al. (2006), where they estimate the probability of cod rebuilding in the North Sea as a function of fish mortality *F*. Such simulation e.g. showed that reducing *F* to 80 % of F_{pa}, gives a low probability of rebuilding, while cutting *F* to 60% gave a high probability of rebuilding within ten years. It is also noted that the results are not that robust, because they are sensitive to starting conditions and to the specification of the stock-recruitment function. The same type of reasoning has been used by the IPCC to describe temperature increases by means of probabilistic forecasts for a given socio-economic scenarios. Such an approach involves a series of potential uncertainties, both related to process, data and model uncertainties.

Assessing economic and political risk and uncertainties is normally not done in such a fashion on a micro level, e.g. assessing the effects that a specific fishery rebuilding plan has on the level of discard. Most microeconomic models provide qualitative, not probabilistic, statements. The same is valid for assessment of political uncertainties. Simulations of such models are possible, but needs parameter assumptions and model assumptions that make simulations less robust than biological risk assessments.

5.2. How to deal with imperfect and incomplete data

It is possible to identify several ways to deal with the issue of incomplete data. This can be handled by use of models or simulations, by improvement of the quality of information, by use of indicators, or by including uncertainty into decision making process. It should be noted that these points are not exclusively, and proper decision making includes all.[11]

11 Improving quality, should consider the cost of providing better information with the expected benefit of doing so. That is, not all information improvement is necessarily desirable.

One of the most common used ways to present information is by use of indicators. Garcia and Stables (2000) define fisheries indicators as "a variable, a pointer, an index related to criterion. Its fluctuations reveal the variations in those key attributes of sustainability in the ecosystem, the fishery resource or the sector and social and economic well being. The position and trend of the indicator in relation to the rebuilding plans or values indicate the present state and dynamics of the system". Ideally, indicators may measure productivity, biomass, exploitation rate, but also ecosystem, spatial, habitat and environmental together with socio-economic characteristics (Caddy, 2004).

Given the potential lack or imprecision of data and the need to measure progress in fishery rebuilding plans, the issue of finding and using appropriate indicators is a crucial exercise. In case of uncertainty, agreement on which indicators to use is a relevant and an important task, because it might circumvent the lack of data. As an example is the usage of landing data to describe the development in stock. In order to be used in a decision making process, it is, however, necessary that the attached uncertainty in such estimates is specified. The reason is obvious, as already discussed in previous sections; the amount of uncertainty will determine the optimal rebuilding strategy. E.g., the decision to apply a precautionary approach also depends on the level of uncertainties in the data.

5.3. Communication of risk and uncertainties

According to WHO (2009), risk communication is an interactive process of exchange of information and opinion on risk among risk assessors, risk managers, and other interested parties. It is a process to get mutual understanding between regulator and the regulated, and to get alignment of interests and targets. In part due to acceptance and implementation, in part because stakeholders might possess relevant information, or will get access to information (e.g., stock size due to experience at sea). Making the fishermen an integral parts of the risk analysis process might increase their willingness to share such information. It is therefore also a mean of reducing the risk. That the stakeholder fell that they are an integral part of the decision process is according to McColl et al. (2000) a necessity to get acceptance for the plan.

Risk communication is in this light first and foremost seen in relation to reducing the uncertainty with respect to implementation. Communication relates particularly to the interaction between assessments and decisions and between decisions and implementation. The basic purpose is to make the rebuilding plan understandable for the relevant stakeholders by specifying its target, and the choice of instrument choice. It is important that the whole decision process can be specified including all the considered alternatives. Also important is to communicate the uncertainties present, and the measurement/indicators that will be used, as already discussed in section 5.2. It can be argued that the applied indicators translated into monetary terms, or something that is meaningful for the fishery managers, fishermen and other interested parties, are preferable. Therefore, proper risk communication between the scientific community and the decision makers must also be well functioning.

However, risk communication also relates to the design phase, used to elucidate valuable information about relevant issues. Stakeholder may bring information and perspectives on the table that are critical to the decision process. Fishermen may hold information about economic variables, knowledge about catch/discard/by-catches, ideas about expected reactions upon specific regulation measures. All this might provide information about the cost of being subjected to various regulation instruments.

6. Examples of cases where risk and uncertainties have not been addressed

We have selected two cases where rebuilding plans have been used, namely in EU and USA. The choice was based on the range of knowledge we had about rebuilding plans at the time we wrote the report.

6.1. North Sea cod

The first cod rebuilding plan was implemented primo 2004, one year after it was made possible in the Common Fishery Policy (CFP) from ultimo 2002, and over 21 years after the spawning stock biomass (SSB) was lower than B_{pa} the first time. The formulation of B_{pa} and B_{lim} followed the implementation of the precautionary approach in EU fisheries in the second part of the 1990'ties. Since then ICES has recommended huge reductions in fishing mortality, because the SSB was way below the B_{pa} and also B_{lim}, which is the level where there is a high probability of low or impaired recruitment and equal to the lowest observed SSB level (in 1999). However since then, the SSB has been lower than B_{lim}, but since 2006 the SSB has been increasing, see Table 3.

The rebuilding plan from 2004 (EC 2004) stipulated a harvest control rule and regulations to limit the fishing effort. The harvest rule was based on a target biomass of 150,000, the B_{pa} level. So, if the biomass is lower than B_{pa} then the TAC has to be set so it allows for an increase at minimum 30% of SSB and the fishing mortality rate cannot be higher than 0.65, which corresponds to the level for F_{pa}. Finally, except for 2005 the changes of the TAC cannot be more than 15% each year. If the SSB level is lower than 70,000 - the B_{lim} level - then the Council shall determine a TAC which is lower than what the above described rule says. The effect of the plan on the size of the TAC was basically nothing, because the Council – even though the SSB was lower than B_{lim} – kept a TAC level at 27,300 tons like the years 2003 and 2004. The TAC was reduced in 2006 and 2007 by 15% which was the normal rule, but because the SSB was below B_{lim} a more strengthen rule should have be followed according to the rebuilding plan. The rebuilding plan did also contain regulation with respect to limitations of fishing effort. Further, the plan included new measures on monitoring and inspection of vessels. The limitation of fishing effort was defined as maximum number of sea-at-sea per month depending on the gear type and the mesh size.

In 2008, a new rebuilding plan was implemented and in force from 2009. The plan again formulates a target, a harvest control rule and a transition period. The target is not expressed in terms of stock biomass. Now the target is a fishing mortality rate at 0.4, which is estimated to correspond to the MSY-level. This rate is much lower than F_{pa} (from 2004). Climate changes were one of the reasons for leaving the stock biomass as a target variable, because it has an uncontrolled impact on the biomass. In the transition period, the fishing mortality rate in 2009 is 75% of the level in 2008, in 2010 65% of the level in 2008, continuing with a decrease of 10%-point each year. The long-term harvest control rule says that fishing mortality has to be reduced below 0.4 when the SSB is between B_{pa} and B_{lim} according to the formula: $F = 0.4 - 0.2*(B_{pa}-B)/(B_{pa}-B_{lim})$. When SSB is less than B_{lim} then the fishing mortality has be less than 0.2. However, the changes in TAC from year to year have to be less than 20%. The transition period ends when the TAC calculated following the transition rules is less than the TAC obtained from following the long term rules. The rules limiting the fishing effort were changed to a system based on kilo-watt-days. These days were made permanent transferable between vessels. Another change was that the basis of the fishing effort system is a maximum allowable number of fishing days to each vessel group in the member states. By this the overall number of fishing days applied in the fishery is limited.

The ICES Advice for 2010 is to follow the rebuilding plan, i.e. a fishing mortality level at 65% of the F in 2008 leading to catches less than 66,400 tons. Assuming discards rates at a level as observed in 2008, this implies landings of less than 40,300 tons in 2010. The rebuilding plan from 2004 did not explicitly address the involved risk and uncertainties, so no formal overall risk analysis and/or risk assessment was executed. Implicitly, however, the uncertainties were addressed by ICES using the precautionary approach.[12] By introducing limitations on the use of inputs in the fishery, one can argue that the implementation uncertainty created by the lack of compliance with the TAC was addressed, because effort control would reduce the fishing mortality all things equal. The rebuilding plan from 2008 recognises that the stock is influenced by environmental factors and therefore a stock biomass target is not appropriate. It is too early to assess the results of this 2008 plan, but again a formal and coherent risk assessment was not executed. The regulations of use of inputs were further tightening reflecting that the fishing mortality has not adjusted enough. In general, both plans are relatively complicated and with respect to risk communication the plans do not take the socio-economic impacts in fishery sector of e.g. closure into consideration. The 2004 plan did not specify clearly what to do in cases where the stock biomass was assessed to be lower than B_{lim}.

12 ICES implemented generally the precautionary approach in 1998, where the first reference point occurred (González-Laxe, 2004).

Table 3. Development in SSB, F, landings and discards since 1999, North Sea cod, Tons (ICES 2009)

	SSB	F	Landings	Discards	Catches[1]	Agreed TAC	ICES advice
1999	74,317	1.167	96,2	14,2	138,457	132,000	F=0.60
2000	49,052	1.074	71,4	13,7	96,179	81,000	F<0.81
2001	38,830	0.801	49,7	13,9	75,895	48,600	Lowest possible catch
2002	47,150	0.790	54,9	5,7	81,559	49,300	Lowest possible catch
2003	43,644	0.930	30,9	6,4	76,695	27,300	Closure
2004	40,050	0.903	28,2	5,8	53,925	27,300	Zero catch
2005	36,564	0.725	28,7	6,3	51,858	27,300	Zero catch
2006	34,475	0.694	26,6	8,1	53,268	23,200	Zero catch
2007	42,313	0.619	24,4	23,6	70,102	20,000	Zero catch
2008	57,282	0.788	26,8	21,8	90,687	22,200	Total removals < 22,000
2009	60,139					28,800	Zero catch

[1] The catch figure is estimated by ICES.

According to Horwood et al (2006), monitoring the progress of North Sea cod rebuilding is hampered by considerable uncertainties in stock assessments associated with low stock size, variable survey indices, and inaccurate catch data. This observation is confirmed by looking at the disparity between landings plus discards and catches in the Table 3. In addition, questions arise as to whether rebuilding targets are achievable in a changing natural environment. There are therefore significant uncertainties with the assessment of North Sea cod. These uncertainties appear particularly in estimates of the most recent annual rate of fishing mortality (*F*). The current assessment relies upon three sets of research surveys to calibrate the assessment: a spring international bottom trawl survey and autumn Scottish and English surveys. Since the current landings figures do not reflect the actual catches the assessment is not based on these figures. This point to considerable biological uncertainty about the cod stock (growth and stock size) and therefore the use of the precautionary approach seems appropriate in this case.

There has been significant political uncertainty involved, because the setting of TACs in several years didn’t follow the rebuilding plan. This does not allow the fishermen to make longer term planning. Combined these two types of uncertainties leads to a myopic behaviour where the fishermen prefer sure short run catches instead of longer term uncertain higher catches. In that sense, the rebuilding plan is not creating the necessary medium and long term planning possibilities and incentives. The revision in 2008 of the rebuilding plan did not address neither the incentives of the fishermen, so the considerable implementation uncertainty was maintained. The biological uncertainties are mainly due to lack of reliable catch data making the assessment of fishing mortalities and stock biomass to be more an art than science. Since the rebuilding plan is based on these variables, the scientific foundation tends to be unreliable. The lack of improvement in the size of the stock biomass also points to more fundamental problems with the plan. In a market economy overfishing is due to wrong economic incentives and reducing fishing mortality will mean that it has to be less profitable to catch cod today and more profitable to investment in the fish stock. Rebuilding plans need goals and targets, but the tools or means to achieve the targets have to be better chosen. To sum up, solving or reducing the economic and political uncertainties may therefore all things equal lead to a smaller the biological uncertainty.

6.2. US fisheries rebuilding plans

In 1996 the Sustainable Fisheries Act (SFA) was approved and implemented into US fisheries policy. It allows NOAA[13] to formulate fisheries with the primary goal of preventing overfishing, rebuilding overfished stocks and protecting essential fish habitat.[14] In particular, the SFA changed the requirements to prevent overfishing and to rebuild overfished fisheries. Each fishery management plan (FMP) was required to specify measurable objective for determining, when a stock is overfished or when overfishing is going on. The overall definitions of overfishing and overfished are based on fishing mortality and stock

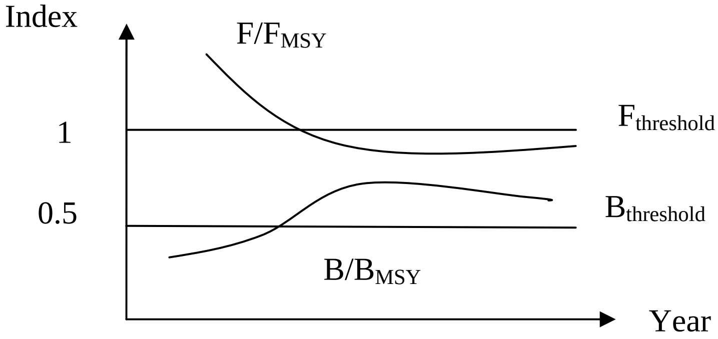
13 National Oceanic and Atmospheric Administration.

14 And also minimizing bycatch, enhanced research and improved monitoring.

biomass, respectively. The definitions are: “A stock that is subject to overfishing has a fishing mortality (harvest) rate above the level that provides for the maximum sustainable yield. A stock that is overfished has a biomass level below a biological threshold specified in its fishery management plan”. (The two levels correspond to $F_{threshold}$, and $B_{threshold}$ in Figure 1, respectively). Included in the plans is in many cases four reference points, two threshold and two target points. The threshold points for fishing mortality are either F_{MSY} or a lower value if the stock biomass is very low. So most often, if the ratio F_{actual}/F_{MSY} is higher than 1 ($F_{threhold}$) then there is overfishing. The threshold points for stock biomass are the maximum of either $B_{MSY}*0.5$ or a stock level where it will take up to 10 years to rebuild the stock to B_{MSY} applying F_{MSY}. So for many stocks, if the ratio between actual biomass and B_{MSY} (B_{actual}/B_{MSY}) is less than 0.5 ($B_{threshold}$) then the fish stock is overfished. The target points for the biomass is B_{MSY}, while for fishing mortality the target point is normally F_{MSY}, se Figure 1. Note that the precautionary threshold will be the B_{MSY} level if known. The default precautionary threshold will be 40% of the estimated unfished biomass level.

This gives very straight forward measures of overfishing and overfished. The main issue in these plans is to formulate and implement management initiatives to secure that fishing mortality and stock biomass stay within safe limits, i.e. away from passing the thresholds. In Figure 1 a case is shown with overfishing and where the stock is overfished in the first years. The rebuilding plans have as the goal to move fishing mortality below F_{MSY} and the stock above B_{MSY}*0.5 within 10 years. Applying the logistic growth function the threshold for the stock biomass is ¼ of the carrying capacity. If the biomass is below ¼ of the carrying capacity then the stock is overfished. This threshold is a little bit lower than the threshold (around 30%) proposed by Sethi et al. (2004) when there is uncertainty in the stock measurement.

Figure 1. Reference points in the US fisheries rebuilding plans



Based on the status with respect to overfishing and overfished, fisheries management plans are formulated included management measures. As an example, for the Pacific Groundfish fishery this involves a whole range of technical measures, seasonal limitations and limited entry programs based on gear types. These measures are further restricted or adjusted yearly in order to fulfill the goals of the fishery management plan.

The SFA was approved in 1996 and shortly hereafter in function. In 2006 Rosenberg et al. published a study which showed that nine years later overfishing and overfished stocks are still a major problem in US Fisheries. They find that overfishing continued in 45% of the stocks managed by rebuilding plans, while over 70% of the stocks were still overfished. While over 45% of the stocks under rebuilding have experienced increasing biomass, only 3 stocks have been rebuilt to B_{MSY}.[15] They conclude that the main cause of slow progress is the failure in many cases to reduce the fishing mortality sufficient. The goal

15 Every year NOAA published an index showing the aggregate development in the health of the stocks. The Fish Stock Sustainability Index (FSSI) is a performance measure for the sustainability of 230 U.S. fish stocks selected for their importance to commercial and recreational fisheries. This index has been growing since 2000 by around 55%. This index can however also change if the stock previously not assessed becomes assessed, but the main part of the increase in the index is due to overfishing not happening and that the stock is not overfished. So, the overall conclusion is that in general the health of the fish stocks is improving in the US (Worms et al 2009), but the assessment in 2009 was that overfishing still happens for around 20% of the US stocks, while 25% of the stocks are overfished.

of rebuilding in 10 years is therefore rarely meet. While there may be biological and environmental reasons for this, the mean reason is, as pointed out by Rosenberg et al. (2006), difficulties in reducing fishing mortality, i.e. economic and management reason. The guidelines at the NOAA web-site do not, as we see it, include this aspect in the design phase of the rebuilding plan.

7. Conclusion and guidelines

A number of guidelines emerge from the analysis

- Fisheries rebuilding plans should be dealt inside a formal decision making process.
- Fisheries rebuilding plans should be as simple, realistic and credible as possible.
- Fisheries rebuilding plans should consider both biological as well as economic consequences.
- The possibility of measurement should be considered in all phases of the process.
- Risk communication should be used to improve the probability of implementation success.
- A formal risk analysis should be performed.
- The precautionary approach should be applied in accordance with the level of uncertainty.

First of all, since deciding upon fisheries rebuilding plans essentially is a decision problem, application of a (rational) decision making process (model) is warranted (See Figure 2 for a schematic overview of this process. see also Clemen, 1992). In such a process, first the problem is recognized, and analyzed, where after the objective is specified, possible actions (instruments, plans) are considered of how to reach the proposed objective. It is argued in e.g. Clemen (1992) that considering the precise objectives is all-important. However, also a very important part is that for each of these actions the consequences are assessed, and finally the action is chosen that best reaches the targets given some criteria. This could be reaching the objectives in a least-cost way or in a least-risky way. Hereafter the plan is implemented and progress assessed. The key to this framework is that all the stages are interconnected, in the sense that in the process of working with the decision making model, as new information and insights are gained, adjustments in the plan should be considered.

Consequences should consist of both economic and biological variables. Understanding the economic reality surrounding the fishery that has to be rebuilt is essential with respect to considering implementation success: How will fishermen or the industry reacts to the proposed plan, and what are the consequences in terms of profitability, entry, exit and so on? The potential drawback of not including economic and behavioral consideration cannot be exaggerated.

Figure 2. The stages in a decision process model

1. Identification of the problem (e.g. low stock, falling catches).
2. Stating the objectives.
3. Identify alternatives (type of rebuilding plans: instruments, timeframe, adjustment, observations, monitoring).
4. Consider the consequences of each plan (both with respect to biological and socio-economic consequences).
5. Is further analysis needed? (If yes, go back to 2 and/or 3 and /or 4).
6. Choosing the best alternative.
7. Implement the chosen alternative.
8. Monitoring and feed-back.

Even though it might be difficult to compare economic and biological consequences, the process of evaluating them will often help prioritizing. Moreover, under uncertainties, there might be problems in assessing the consequences and efforts should be made to assess these. The mere process of assessing risk and uncertainties will yield valuable information (using the risk assessment approach as done in Table 1 could serve helpful). Since different plans result in different types and levels of uncertainties, a formal risk analysis at this point may yield important insights. Each potential rebuilding plan should also be evaluated with respect to the possibilities of measuring or assessing progress in the essential variables stated in the objective. If a plan turns out to be difficult to measure, or data is expected to be lacking, then it might be useful to consider other plans. As an example of this, consider the choice of instrument to regulate the fishermen. A plan containing one overall instrument (e.g., ITQ) presumably provides less uncertainty than a multi instrument plan containing, e.g. a TAC combined with a range of input restrictions. Furthermore, it is essential to stress the importance of the implementation phase. A plan that is not assessed likely to be successfully implementable has to be revised. One way to increase the likelihood of implementation success is to include the stakeholders like fishermen into the process. In an advanced risk communication process this is relevant both because participation increases willingness to do as required, and because it can be a tool to gather information. As discussed in this paper, there need to be objective reasons for applying the precautionary principle. One such reason is a positive probability that a non-precautionary approach will end in a collapse of the fishery, or that processes of uncertain due to e.g. climatic changes have a potential negative impact on the stock. Finally, the continued process of monitoring and feed-back is also important: If the plan does not work as planned, then this creates a new problem, for which the decision making model can be applied once more.

8. References

Amundsen, Eirik S. and T. Bjørndal (1999). 'Optimal Exploitation of a Biomass Confronted with the threat of collapse'. *Land Economics*, 75, 185-202.

Caddy, J.F. (2004). 'Current Usage of Fisheries Indicators and Reference Points, and their Potential Application to Management of Fisheries for Marine Invertebrates', **Canadian Journal of Fisheries** *and* **Aquatic** *Sciences*, **61**, 1307-1324.

Caddy, J.F. and D.J. Agnew (2004). 'An overview of Recent Global Experience with Recovery Plans for Depleted Marine Resources and Suggested Guidelines for Recovery Planning', *Reviews in Fish Biology and Fisheries*, **14,** 43-112.

Clark, C.W. and G.P. Kirkwood (1986). 'On Uncertain Renewable Resource Stocks: Optimal Harvest Policies and the Value of Stock Surveys', *Journal of Environmental Economics and Management*, **13,** 235–244.

Clemen, R.T. (1992). Making Hard Decisions: An Introduction to Decision Making, PWS, Lancashire, UK.

Conrad, J. M. and C. W. Clark (1988). *Natural Resource Economics: Notes and Problems*. Cambridge University Press.

Commission of European Communities (2005). Communication from the Commission to the Council and the European Parliament, Thematic Strategy on the Protection and Conservation of the Marine Environment. COM(2005)504 final.

Cooke, J.G. (1984). *Glossary of Technical Terms*. In May, R.M (ed.), *Exploitation of Marine Communities*. Springer-Verlag, New York.

Costello, C., S. Gaines, and S. Lynham (2008). Can Catch Shares Prevent Fisheries Collapse? *Science* 321: 1678-1681.

EC (2004). Council regulation No 423/2004 of 26. February 2004. Establishing measures for the recovery of cod stocks.

FAO (1996). Precautionary Approach to Capture Fisheries and Species Introductions. FAO Technical Guidelines for Responsible Fisheries, *FAO Fisheries Technical Paper*, No. 350, Part 2, Rome.

Fischhoff, B., Watson, S.R. and Hope, C. (1984). 'Defining Risk', *Policy Sciences*, **17**, 123-129.

Francis R.I.C.C. and R. Shotton (1997). '"Risk" in Fisheries Management: a Review', **Canadian Journal of Fisheries** *and* **Aquatic** *Sciences*, **54**, 1699-1715.

Garcia, S.M. and D.J. Stables (2000). 'Sustainable Reference Systems and Indicators for Responsible Marine Capture Fisheries: A Review of Concepts and Elements for a Set of Guidelines', *Marine Freshwater Research*, **51**, 385-426.

González-Laxe, F. (2004). 'The Precautionary Principle in Fisheries Management', *Marine Policy*, **29**, 495-505.

Hannesson, R. and J. Kennedy (2005). 'Landing Fees versus Landing Quotas', *Land Economics*, 81(4), 518-529.

Hennessey, T. and M. Healey (2000). 'Ludwig's Ratchet and the Collapse of New England Groundfish Stocks', *Coastal Management*, **28**, 187-213.

Hilborn, R., J-J Maquire, A. M. Perma and A. A. Rosenberg (2001). ‘The Precautionary Approach and Risk Management: Can they Increase the Probability of Successes in Fishery Management’, *Canadian Journal of Fisheries and Aquatic Sciences*, **58**, 99-107.

Horwood, J., C. O’Brien and C. Darby (2006).’ North Sea Cod Recovery?’, *ICES Journal of Marine Science*, **63**, 961-968.

ICES (2000). Report of the ICES Advisory Committee on Fishery Management, ICES Cooperative Research Report No. 242, Copenhagen.

Jensen, F. and N. Vestergaard (2003). ‘Price versus Quantities in Fisheries Models’, *Land Economics*, 79(3), 415-425.

Lane, D. E. and R. L. Stephanson (1995). ‘Fisheries Co-management: Organization, Process, and Decision Support’, *Journal of Northwest Atlantic Fisheries Science*, **23**, 251-265.

Ludwig, D., R. Hilborn and C. Walters (1993). ‘Uncertainty, Resource Exploitation and Conservation: Lessons from History’, *Science*, **260**, 36-37.

O’Brien, C. M., C. J. Fox, B. Planque and J. Casey (2000). ‘Climate Variability and North Sea Cod’, *Nature*, **404**, 142.

McColl, S., J. Hicks, L. Craig and J. Shortreed (2000). *Environmental Health Risk Management: A Primer for Canadians*. NERAM, Institute for Risk Research, University of Waterloo, Canada.

Mullon, C., P. Fréon, and P. Cury (2005). ’The Dynamics of Collapse in World Fisheries’, *Fish and Fisheries*, **6**, 111-120.

Randall, A. (2009). ’We Already have Risk Management – Do We Really Need the Precautionary Principle?’, *International Review of Environmental and Resource Economics*, **3**, 39-74.

Reed, W. J. (1979). ‘Optimal Escapement Levels in Stochastic and Deterministic Harvesting Models’, *Journal of Environmental Economics and Management*, **6**, 350-363.

Rosenberg, A.A., J.H. Swasey and M. Bowman (2006). ‘Rebuilding US Fisheries: Progress and Problems’, *Frontiers in Ecology and the Environment*, **4**, 303-308.

Roughgarden, J. and F. Smith (1996). ’Why Fisheries Collapse and What We Do About it’, *Proceedings of the National Academy of Science*, **93**, 5078-5083.

Salomon, M. (2004). **‘**Marine Environment Protection for the North and Baltic Seas’, *Marine Pollution Bulletin*, **49**, 1127-1128).

Sethi G., C. Costello, A. Fisher, M. Hanemann and L. Karp (2005). Fishery Management under Multiple Uncertainty. *Journal of Environmental Economics and Management*, **50**, 300-318.

Slovic, P., M.L Finucane, E. Peters, and D. G. MacGregor (2004).’Risk as Analysis and Risk as Feelings: Some Thoughts about Affect, Reason, Risk and Rationality’, *Risk Analysis*, **24**, 311-322.

Sutinen, J. G. (1999). ‘What Works Well and Why: Evidence from Fishery-Management Experiences in OECD Countries’, *ICES Journal of Marine Science*, **56**, 1051–1058.

Vlek, C.A. (1996). ‘A Multi-Level, Multi-Stage and Multi-Attribute Perspective on Risk Assessment, Decision-Making, and Risk Control’, *Risk, Decision, and Policy*, **1**, 9-31.

Weitzman, M. (2002). ‘Landing Fees vs Harvest Quotas with Uncertain Fish Stocks’, *Journal of Environmental Economics and Management*’, **43**, 325-338.

Worm, B., R.Hilborn, J. K. Baum, T. A. Branch, J. S. Collie, C. Costello, M. J. Fogarty, E. A. Fulton, J. A. Hutchings, S. Jennings, O. P. Jensen, H. K. Lotze, P. M. Mace, T. R. McClanahan, C. Minto, S. R. Palumbi, A. M. Parma, D. Ricard, A. A. Rosenberg, R. Watson and D. Zeller (2009). “Rebuilding Global Fisheries”, *Science*, **325**, 578.

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