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The Fragility of Precautionary Reference Points

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A basic idea in fisheries management is that a fishery should be managed so that there is sufficient spawning stock biomass left to reproduce after the following year's fishing. An essential task for the scientists has thus been to predict spawning stock one to two years ahead. The focus on precautionary approach in fisheries management is an expression of a will to be careful with the marine resources by taking into account the uncertainty in science. The fisheries science community has responded by designing precautionary reference points to reflect the state of the stock and the uncertainty in the predicted spawning stock biomass and fishing mortality rate. However, experience has shown that this has not become the intended success. In this paper I argue that the precautionary reference points do not communicate uncertainty adequately. The system of reference points is static regarding the communication of uncertainty, it is an inefficient way of communicating uncertainty, it only reflects part of the total uncertainty in advice and it is value-laden as it is not transparent regarding underlying assumptions. In addition, the ACFM advice on catch options communicates an incorrect precision level and contradicts the precision level reflected by the reference points. ICES should therefore rethink the concept on how to communicate fisheries related advice that is more robust and more in accordance with the precautionary approach. The solution to the mismatch between quantified uncertainty and the total uncertainty could be to partly move the focus from quantified uncertainty to qualitative perspectives of the uncertainty. I include some suggestions that can be further explored.

Keywords: Precautionary Reference Points, Uncertainty, Uncertainty Characteristics

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Introduction on Uncertainty

It is claimed that Lord Kelvin, the British physicist who developed the Kelvin temperature scale, once said (Hacking 1983):

> "I often say that when you can measure what you are speaking about, you know something about it; when you cannot measure it … your knowledge is of a meager and unsatisfactory kind."

This quote is a reminder of the importance of measurements and numbers in science. Precise knowledge has been valued while uncertain knowledge has been associated with knowledge of low quality or of no value. Strict criteria have been necessary to follow in order to get scientific claims accepted. The introduction of the precautionary principle has been a turning point in this sense. The idea behind this principle is that uncertain scientific knowledge must not postpone the action of protecting from potential dangers. The principle thus reverses the burden of proof giving the polluter the responsibility of proving that it is not dangerous. The principle implies that more caution should be taken the more uncertainty associated with the scientific knowledge. In statistical terms, one should avoid type two error instead of type one. Crucial for implementing the principle is thus a proper assessment of the uncertainty accompanied with a proper communication of it and a robust management strategy in relation to the policy issue in question.

The precautionary principle may be difficult to make operational because precaution is a relative measure, making decisions under uncertainty is difficult and often there are conflicting interests. In fisheries management the term *the precautionary approach* is preferred to *the precautionary principle* because it is a weaker formulation.

Communicating uncertainty may be difficult as well. The first introduction to uncertainty in school, and the communication of it, is significant figures. The definition of significant figures is according to Webster: "figures of a number that begin with the last figure to the left that is not zero and that end with the last figure to the right that is not zero or is a zero that is considered to be correct." Most people would say that there is a difference in precision of the expressions "100.00", "100" and the word "hundred". In the sentence: "there are hundreds of possibilities", "hundreds" is just an expression meaning "many", maybe from 5 to 50, thus indicating no significant figures. "100.00", on the other hand, has five significant figures and "100" may have two or three, depending on the context. The next introduction to uncertainty in numbers is standard deviation, but not everyone has courses in statistics. Researchers that have applied statistics or mathematical models know that quantitative knowledge is built on subjective judgments like simplifications, extrapolations and underlying assumptions. How sensitive the scientific knowledge, the result or the advice is to these judgments may not be communicated or in some cases not even tested.

In fisheries science, and other sciences where there are conflicting interests, the communication of uncertainty is necessary both because of scientific decency and of ethical/political concerns. Different ways of dealing with the uncertainty in a political decision will have different impacts on the stakeholders. Withholding uncertainty, intentionally or not, may benefit one party and the scientific advice becomes value-laden (not neutral).

Precautionary reference points in fisheries management

A basic idea in fisheries management is that a fishery should be managed so that there is sufficient spawning stock biomass left to reproduce after the following year's fishing. This is a simple and logic idea, easy to grasp for anyone. An essential task for the scientists has thus been to predict spawning stock one to two years ahead. Experience has shown that this has been difficult regarding the precision level required by the fisheries managers.

The introduction of the precautionary approach implies that a) there is a common understanding that the dangers of overfishing and collapse must be avoided and b) that we need to take the uncertainty in the assessments and predictions into account. The ICES has responded by defining a suite of reference points: B_{lim} and F_{lim}, representing the danger of recruitment overfishing, and B_{pa} and F_{pa}, defining a buffer zone aiming at controlling the risks of recruitment overfishing. These reference points are defined for most stocks in the ICES area. The purpose of the precautionary reference points is thus to take the uncertainty in science into account for management purposes, but also to reflect the uncertainty in the predictions in the catch forecasts table in ACFM advice (ICES 2003a).

There are several points about the precautionary reference points that need consideration in evaluating their quality and usefulness. The uncertainty in ACFM advice is represented by the precautionary reference points and eventually statements in the text and/or error bars in long term predictions. Neither the catch forecast tables in the 2003 ACFM report (ICES 2003a) nor the time series include uncertainty measures. Blue whiting is an exception. The precautionary reference points build on several assumptions: historic measures of spawning stock biomass, recruitment and fishing mortality are of sufficient precision, the danger of recruitment overfishing is not dependent on fluctuations in environmental conditions or biological conditions of the stock. In some cases there are multi-species considerations in the stock estimates/predictions (like the northeast Arctic cod and the Barents Sea capelin), but still the reference points are constant. One should expect that the environment influences the danger level, and that the ecosystem can be more vulnerable in some situations. In this case a danger might be irreversibility (like the case of the Northern cod stock might be).

The calculations of B_{pa} and F_{pa} is meant to represent the expected uncertainty. If the uncertainty in stock numbers is thought to be much higher (or lower) a certain year, the system of reference points does not reflect this. In the decision/calculation of B_{lim} and F_{lim}, we assume that the estimates of historic stock numbers are precise enough to decide B_{lim} with 2-3 significant figures and F_{lim} with 2.

Maybe the most serious problem with ACFM advice is that the precision level in advice contradicts the actual uncertainty and may thus be a reason for neglecting the uncertainty. Precise "answers" may make life easier for the manager, but the precautionary principle or approach necessitates a proper assessment of the uncertainties and its communication. Keeping in mind the precision level in ACFM reports (see e.g. ICES 2003a), one can wonder whether Kelvin's attitude (see above) is still dominant in fisheries science in spite of the production of precautionary reference points.

The 2003 Advice on Northeast Arctic Cod

In this section I will have a look at how uncertainty is communicated in ACFM advice (Advisory Committee on Fisheries Management) on Northeast Arctic cod (ICES 2003a). This stock is chosen because it is the economically most important stock for Norway, the ICES has had a series of "revisions" of the stock and the scientists' credibility has continuously been questioned in the fisheries press.

The 2003 ACFM advice on Northeast arctic cod consists of

- a description of the state of the stock related to reference points
- management objectives for this stock
- A background paragraph on reference points
- A technical description of the reference points including proposed reference points
- A general advice statement
- A table with catch forecasts for 2004
- Paragraphs on the fisheries, catch control and comments on biology and managment
- A suite of tables and figures, quite standard for ACFM advice

The uncertainty is communicated through the precautionary reference points and some considerations in the text.

I consider the main parts of the ACFM report for giving the advice is the statement on the state of the stock, the general advice, the values of the reference points and the table with the catch forecast for 2004. The main text on the state of the stock today is: ' .. *ICES classifies the stock as being harvested outside safe biological limits. The current stock is above* $\boldsymbol{B}_{pa}$*, but the stock is harvested above* $\boldsymbol{F}_{pa}$.' The advice for 2004 is: "*Advice on management: In order to harvest the stock within safe biological limits, ICES recommends a considerable reduction in fishing mortality to less than Fpa (0.40). This corresponds to catches in 2004 of less than 398 000 t.*" The values of the reference points are: $\mathbf{B}_{\text{lim}}$ = 220 000t, $\mathbf{B}_{\text{pa}}$ = 460 000 t, $\mathbf{F}_{\text{lim}}$ = 0.74 and $\mathbf{F}_{\text{pa}}$ = 0.40. These were revised in 2003. The catch forecast table is shown in Table 1.

Table 1 *Forecast for 2004 (ICES 2003a)*

Basis: F(2003)=$\mathbf{F}_{\text{sq}}$=0.70; Catch=578; SSB(2004)=652.			
F(2004)	Basis	Landings (2004)	SSB (2005)
0.00	0	0	1189
0.25	0.36*$\mathbf{F}_{\text{sq}}$	266	965
0.40	$\mathbf{F}_{\text{pa}}$ (=0.57*$\mathbf{F}_{\text{sq}}$)	398	858
0.44	Catch rule 2 (=0.63*$\mathbf{F}_{\text{sq}}$):1.1*2003TAC	435	830
0.50	Catch rule 1 (=0.73*$\mathbf{F}_{\text{sq}}$)	486	788
0.70	1.0*$\mathbf{F}_{\text{sq}}$	623	682
Weights in '000t. Shaded scenarios considered inconsistent with the precautionary approach.			

The intention with the catch forecast table is to indicate the size of the total catch and the level of the remaining spawning stock biomass, given a set of fishing mortalities. Some of the fishing mortalities in the table are chosen by ICES for illustration purposes, like the first three and the last. The last row is a prediction of landings and spawning stock biomass is the fishing mortality is kept at the same level as estimated for 2003. The two other options are answers on a request from the Joint Norwegian-Russian

Fisheries Commission on northeast Arctic cod and haddock. According to the text in the ACFM report, Norway and Russia have agreed upon catch control rule from 2004 based on an average TAC level from 3 years' predictions based on $\mathbf{F}_{pa}$. (See ICES 2003a p. 68 for further details.) Catch rule 1 and 2 in the above table correspond to two different interpretations of the agreement, but are not important for the discussion in this paper.

A quick glance at the catch forecast table, considering the number of non-zero digits in the predicted spawning stock biomass indicates three significant figures. This suggests an uncertainty between 0.1 and 2%. Keeping in mind the yearly revisions of stock numbers tells us that this uncertainty is too low. In the next section I will give alternatives on the catch forecast table trying to present the uncertainty in a more adequate way.

Alternative Catch Forecast Tables

I here present a catch forecast table (*Table 2*) with numbers reflecting a lower precision level that the ACFM report (ICES 2003a). I define significant digits as above, but adding that in order to call the last figure significant, the correct figure is somewhere between one unit above and one below the value presented in the number. I here assume that we are able to predict spawning stock biomass levels on a precision level of 100 000 tons. This indicates one significant digit (or two on the first option in the table), thus an uncertainty of about 10%. Due to the uncertainty in predicted stock levels, I find it appropriate to present the catch options with the same precision level and to present the fishing mortality rate with only one decimal. Table 2 is the same as table 1 except that I have decreased the number of decimals and put zeros in figures that are not considered significant.

Table 2 *Catch forecast for 2004 with correct number of significant figures(?)*

Basis: F(2003)=$\mathbf{F}_{sq}$=0.7; Catch=600; SSB(2004)=700.			
F(2004)	Basis	Landings (2004)	SSB (2005)
0.0	0	0	1200
0.3	0.4*$\mathbf{F}_{sq}$	300	1000
0.4	$\mathbf{F}_{pa}$ (=0.6*$\mathbf{F}_{sq}$)	400	900
0.4	Catch rule 2 (=0.6*$\mathbf{F}_{sq}$):1.1*2003TAC	400	800
0.5	Catch rule 1 (=0.7*$\mathbf{F}_{sq}$)	500	800
0.7	1.0*$\mathbf{F}_{sq}$	600	700
Weights in '000t. Shaded scenarios considered inconsistent with the precautionary approach.			

Appropriate presentations of figures and numbers communicate uncertainty a lot clearer. A particular feature that appears clear in table 2 is that some of the options are chosen too close to each other according to the uncertainty. Rows number 3, 4 and 5 cannot be distinguished properly and should be replaced by two options only. Note also that the shaded area is reduced due to the reduction of decimals in the fishing mortality. $\mathbf{F}_{pa}$ (=0.44) can be chosen as a precise number, but it is too optimistic to expect the predicted fishing mortality to be of the same precision level.

A study carried out by Sparholt (2002) suggests that the predicted spawning stock biomass was overestimated by an average of 59% in the years 1990 to 1999. In calculating the average historic estimation error, Sparholt had added up the errors including their sign (plus or minus). The average error had been 80% if only the values had been taken into account.
The calculations by Sparholt are based on the assumption that the 2001 assessment gave the correct stock numbers.

Although we cannot know what the "true" numbers are, the study gives an indication of the uncertainty. At least we should expect the uncertainty to be higher than 10% as what was suggested for table 2. This implies that there are no significant figures. My next step is therefore to present the spawning stock biomass in the catch forecast table by intervals. I have based the interval on a moderate interpretation of Sparholt's results and chosen an expected error of 50%. Note that Sparholt had the "correct" numbers so that the error percentage is related to the correct number and not the earlier estimate. We still don't know the "correct" number for 2002, 2003 or 2004. I have therefore used a formula that relates the 50% error to the boundaries:
upper = 2 X and
lower = 2/3 X,
where *upper* is the upper boundary of the interval, *lower* is the lower boundary of the interval and *X* is the estimated spawning stock biomass. The estimate is thus not in the center of the interval. Table 3 shows the catch forecast table with intervals. As with table 2, only the presentation of numbers are changed except that I have based the intervals on an expected error of 50% related to a "correct" estimate.

Table 3 *Catch forecast for 2004 with suggested intervals (50% reversed uncertainty)*

Basis: F(2003)=$\mathbf{F}_{sq}$=0.7; Catch=600; SSB(2004)=700.			
F(2004)	Basis	Landings (2004)	SSB (2005)
0.0	0	0	800-2400
0.3	0.4*$\mathbf{F}_{sq}$	300	700-2000
0.4	$\mathbf{F}_{pa}$ (=0.6*$\mathbf{F}_{sq}$)	400	600-1800
0.4	Catch rule 2 (=0.6*$\mathbf{F}_{sq}$):1.1*2003TAC	400	500-1600
0.5	Catch rule 1 (=0.7*$\mathbf{F}_{sq}$)	500	500-1600
0.7	1.0*$\mathbf{F}_{sq}$	600	500-1400
Weights in '000t. Shaded scenarios considered inconsistent with the precautionary approach.			

Again, the shaded area of the table is reduced and the consequences of the different fishing mortality options are even more difficult to separate.

In table 4 I have presented the uncertainty by an expected error of 300 000t. This was a little less than the average error in Sparholts' study.

Table 4 *Forecast for 2004 (ICES 2003a)with an expected error of 300 000t*

Basis: F(2003)=$\mathbf{F}_{sq}$=0.70; Catch=600; SSB(2004)=700.			
F(2004)	Basis	Landings (2004)	SSB (2005)
0.0	0	0	800-1500
0.3	0.4*$\mathbf{F}_{sq}$	300	600-1300

0.4	$\mathbf{F}_{pa}$ (=0.6*$\mathbf{F}_{sq}$)	400	500-1200
0.4	Catch rule 2 (=0.6*$\mathbf{F}_{sq}$):1.1*2003TAC	400	500-1200
0.5	Catch rule 1 (=0.7*$\mathbf{F}_{sq}$)	500	500-1100
0.7	1.0*$\mathbf{F}_{sq}$	600	400-1000
Weights in '000t. Shaded scenarios considered inconsistent with the precautionary approach.			

Table 3 and table 4 look different because table 3 presents relative error and 4 an absolute error. Relative errors result in high values for the upper boundaries when the estimates are high. Absolute errors result in low values for the lower boundary when the estimates are low. There are many ways of calculating and presenting uncertainty. The predictions in Table 3 and 4 both give the impression of being more uncertain than in Table 2. The estimated uncertainty from the stock assessment in the working group is not discussed in this paper as it is not presented in the ACFM report.

Discussion

The number of significant figures presented in the ACFM report on northeast Arctic cod (ICES 2003a) is clearly in contrast with the assessment and prediction uncertainties. This concerns the catch forecast table (Table 1) and stock estimates presented in other tables. A quick glance at other stocks in the ACFM report (ICES 2003a) indicates that the northeast arctic cod is not a unique case. The stocks that include predictions and/or estimations of stock numbers tend to exaggerate the number of significant figures. Three questions emerge from this observation:

i. What will the catch forecast table look like if the number of significant figures were taken into account?
ii. Is it possible to give scientific advice that enables the managers to decide quotas with annual adjustments?
iii. What are the likely consequences of presenting stock numbers with the existing precision level?

I addressed the first question in the last section. I presented a catch forecast table indicating a precision level of 100 000 tons in the predicted spawning stock biomass (Table 2). This implies one single significant figure in all but one prediction and an uncertainty of about 10%. The predictions of spawning stock biomass are considered to be more uncertain than that, indicating no significant figures. If predictions are too uncertain to be communicated decently with one single number, an interval is a better alternative. One could of course present the prediction by a number with confidence intervals, but there are two concerns associated with this in my opinion. Confidence intervals demand estimation of statistical uncertainty. Stock estimates build on numerous assumptions on non-scientific choices of model functions, parameters, weighting and data so that it is unlikely that quantified confidence will reflect the uncertainty in the estimate. My other concern is that people will read the estimate as more certain than it is simply because grasping uncertainty is difficult. Still of course, I would prefer estimates/predictions with uncertainty measures to estimates/predictions without. In this paper I have presented two catch forecast tables (Table 3 and 4) with plain intervals as biomass predictions. I think this gives a more appropriate picture of the uncertainty. I have also been careful about introducing too many significant figures in the borders of the intervals. There are many different ways of calculating/estimating uncertainty and I have suggested two ways. The span of the intervals varies with different ways of calculating uncertainty. In either case the uncertainty is too high to separate all the options in the catch forecast table (Table 1); some of the options overlap somewhat.

There is one immediate consequence of the uncertainty that appears clearer with the alternative ways of presenting the table: the uncertainty is too high to give advice on detailed quotas or fishing mortalities. The next consequence follows: the uncertainty is too high to give reason to alter the quota with small changes from year to year. That is actually the purpose with the annual advice: to adjust quotas annually. In my opinion, that demands a piece of advice that we, the scientists, cannot produce in general. A problem that we have seen with the assessments of northeast Arctic cod, and which probably is a quite common problem with dynamic stocks, is that when the development in stock numbers changes from increasing to decreasing, and the opposite, it may take a few years to discover this change. Another dominant uncertainty feature, characteristic for this stock is that its condition, or average individual weight, may vary substantially and is hard to predict. Predictions are based on the number of fish while quotas are set in weights. This supports my suggestion of a more stable quota. Still caution must be taken when there are signs of a decreasing stock.

A consequence of introducing intervals in the catch forecast table is that it makes the comparison to precautionary reference points more difficult. On the other hand, an advice based on a comparison of the forecast to reference points builds on several assumptions. One is that the uncertainty in estimates and predictions is sufficiently represented by the precautionary reference points. It may well be so on average, but this is an indirect way of communicating uncertainty and does not communicate uncertainty well. Besides, risk considerations reflected in reference points and prediction uncertainties are two different aspects of the uncertainty. If the uncertainty in stock numbers is thought to be much higher (or lower) a certain year, the system of reference points does not reflect this. As pointed to earlier, withholding uncertainty, intentionally or not, makes advice value-laden.

I have argued that the combination of precautionary reference points and the catch forecast table is confusing and misleading. Fisheries management is based on a precision level in scientific advice that I argue cannot be given. There are several critical voices to management based on reference points. Hilborn (2002) points to several weaknesses of the reference points in general: they are almost impossible to find, they depend on knowledge that is very uncertain and they make us neglect the more important issues of fisheries management. He recommends data based management rules rather than the existing model based because the latter is too complicated. Koeller (2003) supports this view. Degnbol (2001) suggests that indicators for management purposes should have the following properties: observable (also by stake holders), understandable, acceptable (also by fishers and the public) and they should be related to management. Froese and Kesner-Reyes (2002) support this view and suggest mean length in commercial landings in relation to the length at first maturity as an indicator, with values at and above 1.0 indicating sustainable fisheries. Shepherd (2003) suggests a system in which he argues that direct control of fishing effort can be effective. A discussion on the efficiency of these suggestions is beyond the scope of this paper. I would suggest however that we look for alternative management measures and rules that satisfy Degnbol's list; measures that are not associated with such uncertainties as the estimated levels of spawning stock biomass and the precautionary reference points.

Getting to my last question posed earlier in the discussion I would like to point to some possible consequences of continuing the present way of giving advice. The precision level in estimates and predictions contradicts the uncertainty reflected in the precautionary reference points and is confusing. I expect the most efficient communication of uncertainty is through significant figures, and that we (the ICES community) therefore should be worried about how the uncertainty is perceived. Re-estimates of stock numbers, because of the precision level, make previous estimates/predictions look like mistakes. If the uncertainty had been adequately communicated the estimate and the re-estimate of the same stock number would (hopefully) look the same. The natural question arises: what will the revisions, or perceived mistakes, do to the credibility of fisheries science? A study (ICES 2003b) suggests that for stocks in the OSPAR-defined North Sea area, there has been a 47% success in giving "correct" advice, relating estimated/predicted spawning stock biomass and fishing mortality to precautionary reference levels ("correct" depending on what is known afterwards, in 2002). This is perhaps not so alarming for the resource situation as long as B_{lim} and F_{lim} have not been crossed. However, there may be another side to it. Imagine the attention we will get from the public if the criteria of eco-labeling of fish will follow the ACFM advice on precaution. A stock that is labeled a certain color at some time will have a good chance of getting relabeled to another color after the release of the ACFM report. What will this do to the credibility of fisheries science? And a follow-up question would be: With decreasing credibility because of our, the scientists', choice in communicating advice, are we part of the marine resource problem?

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