ATP Working Paper: D 6.1

Project document on the use of indicators in HCR, adaptive management, fuzzy logic and prognosis by the use of cellular automata

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1. Introduction

The aim of this working paper is to clarify how the work within Task 6.1 (*Harvest control rules based on indicators capable of handling major ecosystem perturbations*) should be carried out. The scope of the work is to set up a simulation model useful in testing out the robustness and performance of different management strategies and principles under unpredictable environmental changes, including abrupt changes in fish biomass localisation and densities. The simulation model will include a scenario model of the Barents Sea ecosystem which will be employed to test out different management strategies for the cod fishery in this area. The scenario model will follow the principles explained by Schweder (2006), though no stochastic processes will be involved. The scenario model is constructed on the basis of cellular automata modelling principles with pseudo random outputs. The cod stock biomass in the scenario model may be assessed by employing conventional assessment principles or by assuming perfect or biased information. Stock assessment today is vital for feeding the harvest control rules with its predefined indicators.

2. The concept of Harvest Control Rules (HCR) and current use

By the introduction of precautionary approach to fishing, indicator based Harvest Control Rules (HCR) were implemented in most developed fisheries where the stock are assed by working groups within the International Council of the Exploitation of the Sea (ICES). It was a rather smooth transition from the former reference points, though the new control paradigm represents a rather big change from a theoretical point of view. Harvest Control Rules are implemented as predefined rules where indicator values are inputs and quota value

(TAC) is output. Quota setting may then become automated on the basis of the predefined rules of action; if this, then that. The direct reason of implementing *HCR* was to operationalise precautionary approach, but also other considerations, including social and economic objectives could be included.

In many ways this ideas represent a paradigm shift in fisheries management, as the focus shifts from the direct stock-catch relations based on crude assumptions on how the two dynamic systems interrelates, to a indicator based system where current level of understanding is implemented in a set of rules defining precautionary actions. The first is based on the assumption of perfect knowledge on system functionalities; the latter is a way to operationalise the best knowledge available, uncertainty and possibly learning the system from previously experienced effects.

The new concept of *HCR* also opens for new ways to include other ecosystem effects which may not be fully understood today. Examples are the within and between year fluctuations, multispecies relations, ecosystem dynamics, but also economic dynamics as fisher's behaviour, fleet dynamics, effects of skills, technological differences, etc. In addition the rates by which different participants adapt to changing conditions, natural fluctuations in age structures and other properties of stocks, cost compositions, stock output elasticises, differences in future evaluation, etc., may contribute in understanding phenomena as the diverse fleet structures and other observations which are not easily explained by currently available analytical tools.

The current HCR system implemented in the Northeast Arctic Cod fishery (hereafter labelled CodHCR) is probably the most complex HCR-system in use. Yet it is simple compared with the complexity of a system including some of the above mentioned indicators. The CodHCR is, as pointed out previously, based on two indicators linking directly to the previous reference points. In addition to these two indicators a 10% rula and a 3-year-rule have been implemented. The current CodHCR is described below (quotation from Anon, 2009).

The two indicators are spawning biomass (SSB) and fishing mortality rate (F), which really are outputs from the current XSA procedure (see Anon., 2009). The 3-year-rule introduced a prognostic model (PROST, see Eide, 2007) based on monte carlo runs. Finally the 10% rule aims to stabilise the TACs from year to year, the main rule being not change last year's TAC by more than +/- 10% when setting a new TAC.

3.6.3 Adopted harvest control rule

At the 31st session of The Joint Norwegian-Russian Fishery Commission (JRNFC) in autumn 2002, the Parties agreed on a new harvest control rule. This rule was applied for the first time when setting quotas for 2004. The rule was somewhat amended at the 33rd session of The Joint Norwegian-Russian Fishery Commission in autumn 2004.The amended rule was evaluated by ICES in 2005 and found to be precautionary.

"The Parties agreed that the management strategies for cod and haddock should take into account the following:

- *conditions for high long-term yield from the stocks*
- *achievement of year-to-year stability in TACs*
- *full utilization of all available information on stock development*

On this basis, the Parties determined the following decision rules for setting the annual fishing quota (TAC) for Northeast Arctic cod (NEA cod):

- *estimate the average TAC level for the coming 3 years based on F_{pa}. TAC for the next year will be set to this level as a starting value for the 3-year period.*
- *the year after, the TAC calculation for the next 3 years is repeated based on the updated information about the stock development, however the TAC should not be changed by more than +/- 10% compared with the previous year's TAC.*
- *if the spawning stock falls below Bpa, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from F_{pa} at B_{pa}, to F= 0 at SSB equal to zero. At SSB-levels below B_{pa} in any of the operational years (current year, a year before and 3 years of prediction) there should be no limitations on the year-to-year variations in TAC.*

A review and discussion of this and other harvest control rule was made by the ICES SGMAS (ICES 2007c). They discovered that this HCR may give unexpected and possibly unwanted results if the assessment changes much from year to year in a situation when SSB is close to B_{pa}. This problem has, however, so far not been encountered in the application of the HCR.

(Quoted from Anon, 2009; page 131)

The problem of using model outputs (SSB and F from XSA and future TACs from PROST) is not within the scope of this report. There are however both tautological and problems related to this way of introducing the use of indicators. New indicators are needed, also indicators covering fluctuating behaviour and economic and social components.

The current indicators are easily presented in a graph referred to as the traffic light (Figure 1). The traffic light reflects no- and go-zones (respectively the red and green zone in Figure 1). Figure 1 also shows the history of the two indicators, reflecting the problem of a static approach to indicator use, as critical and precautionary limits of the indicator values are fixed. Critical limits are $F_{lim} = 0.74$ and $B_{lim} = 220$ thousand tonnes, while the precautionary limits are $F_{pa} = 0.4$ and $B_{pa} = 460$ thousand tonnes. As seen from the time series presented in Figure 1 most years after the Second World War the spawning biomass has been below the precautionary level, including those years of high production and huge catches during the 1960ies and 1970ies. When it comes to the fishing mortality rates (F), the picture is even clearer, as this value has almost always been above 0.4. Only recently (2007 and 2008) the sets of indicators have been found in the green go-zone (after a short visit in 1991 following a significant catch reduction in 1990).

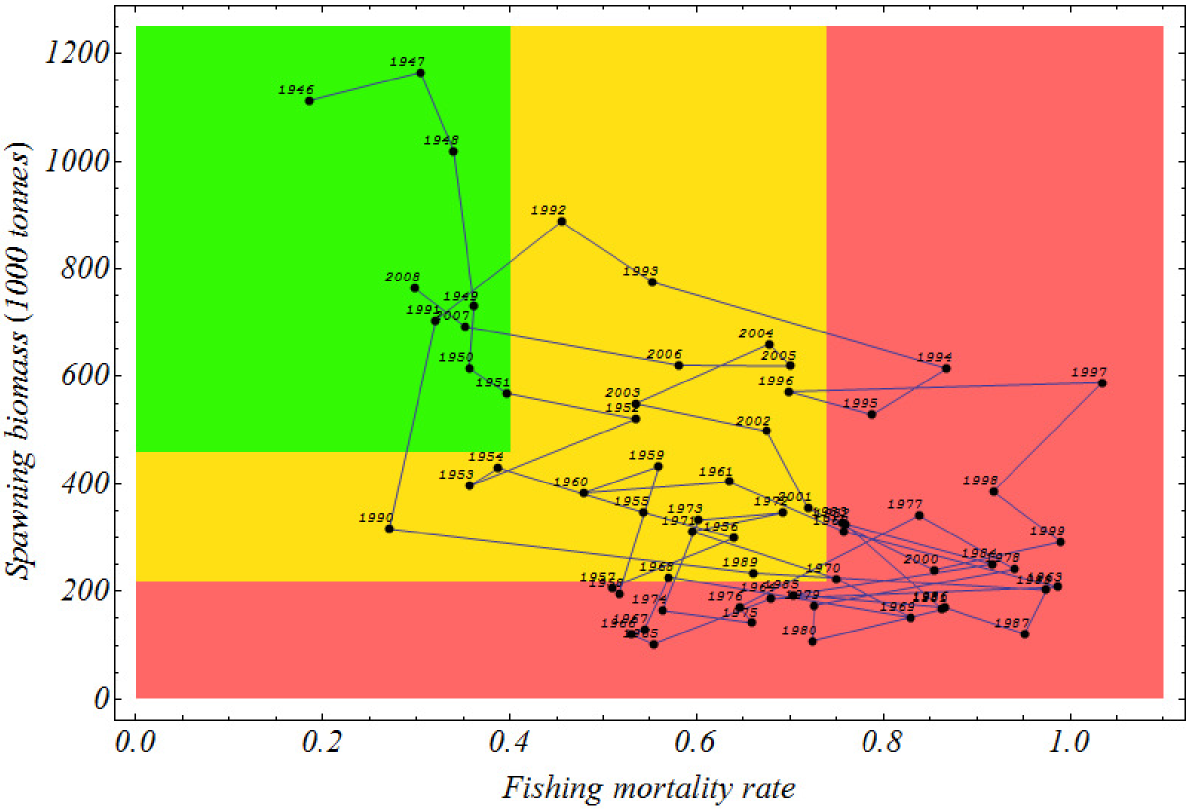

Figure 1. *The traffic light of cod management, displaying the green go-zone and the red no-zone, limited by precautionary and critical limits of the indicator values, spawning biomass (SSB) and fishing mortality rate (F). Data from Anon. (2009).*

The basic HCR for the Barents Sea cod fishery is illustrated in Figure 2. The 10% rule is active in the non-red area, while the 3-year rule goes beyond what is possible to express in the two dimensional graph.

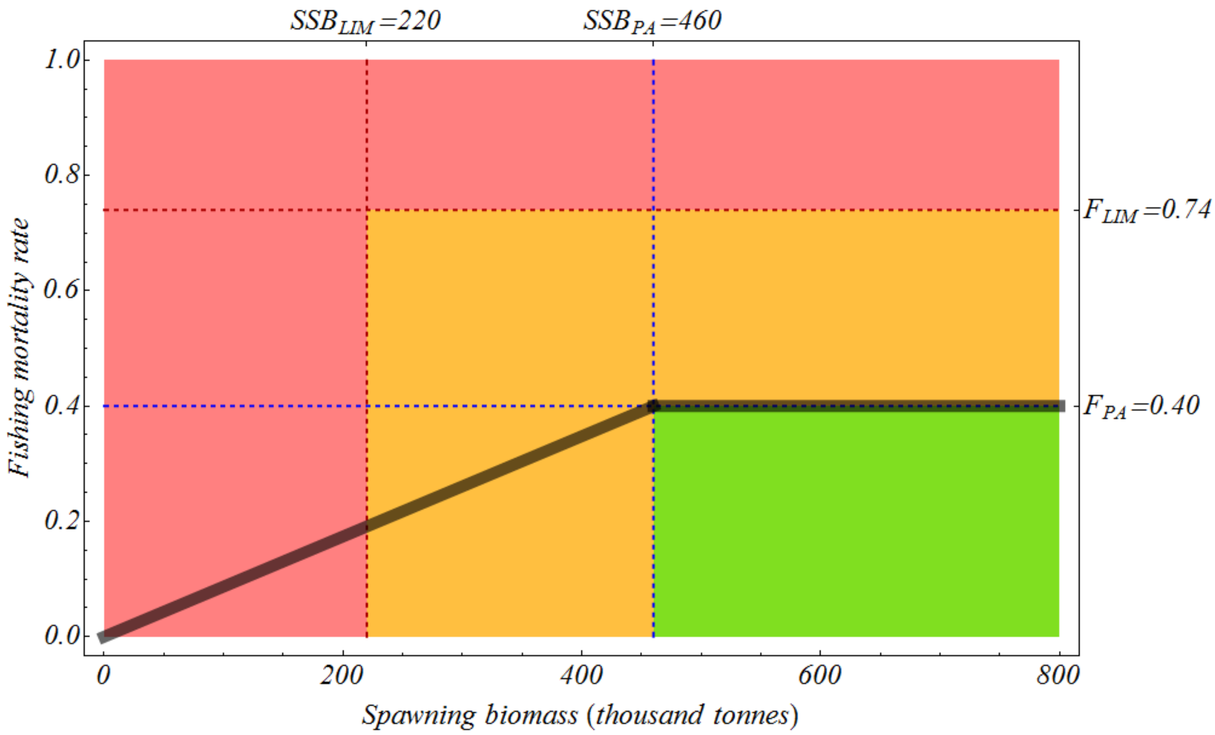

Figure 2. *The traffic light of cod management, showing the basic harvest control rule of the Barents Sea cod fishery. The thick line is the rule of total allowable catch (TAC) expressed as fishing mortality rate as a function of spawning biomass. In the red area the rule is not restricted by the 10% rule, stating that TAC could not be changed by more than 10% from the TAC of previous year. Data from Anon. (2009).*

3. Choice of Indicators

The static use of indicators may represent a more severe problem in the Barents Sea cod fishery than in most other fisheries. The reason of this is the highly fluctuating property of the cod stock, including many year classes but always dominated by one or two large year class biomasses. Figure 3 show how the largest year class in terms of biomass each year makes up for more than 20% of the total biomass, sometimes almost half the total biomass. The average for the period 1946-2008 is 27%.

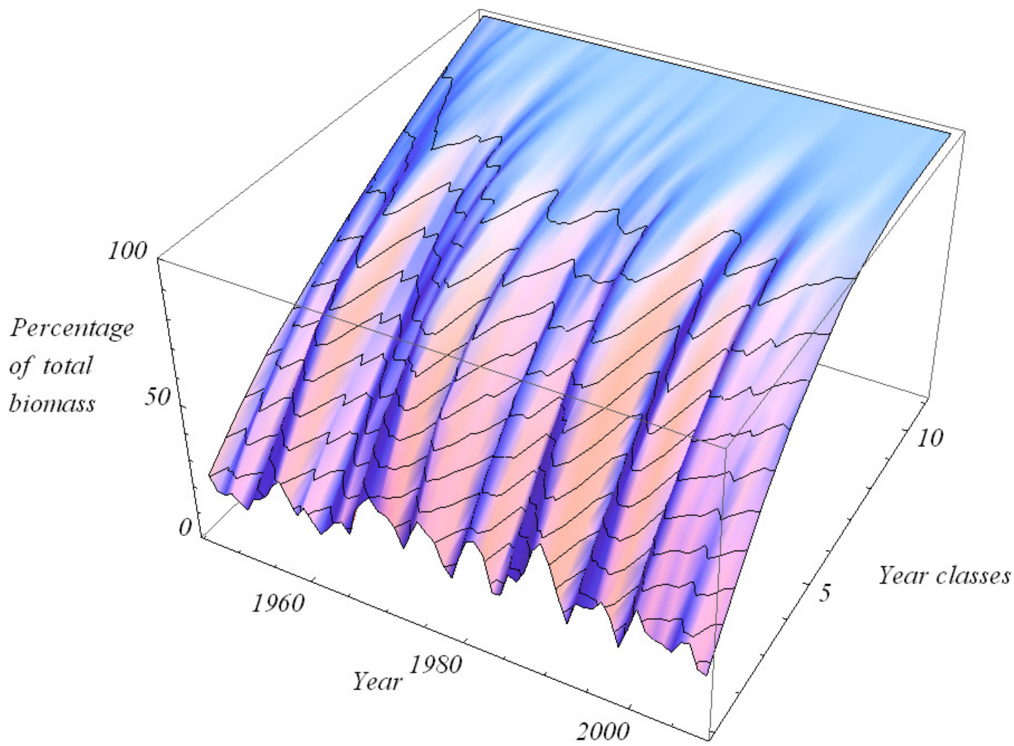

Figure 3. *Cumulative fractions one and more biomasses makes of total cod stock biomass, while year class biomasses of each year are sorted on the basis of biomass size. Data from Anon. (2009).*

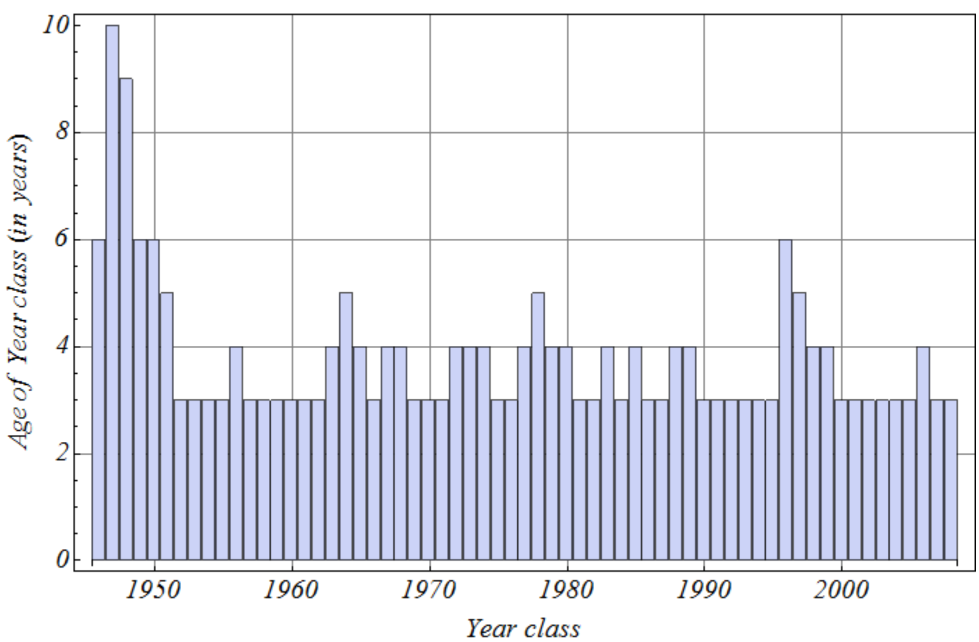

Figure 4. *Age of year class with largest biomass 1946-2008. Data from Anon. (2009).*

In most years after 1946 the year class constituting the largest biomass have been three year old cod (see Figure 4). The pattern in the early years is slightly different, which may be related to the low fishing activity during the Second World War or lower data quality the years before ICES initiated the VPA stock assessments. The pattern reflected in Figure 3, showing that 2 or 3 year classes each year constitute more 50% of the cod biomass, indicates a constantly fluctuating age composition, also affecting the spawning biomass. No indicators reflecting long and short term variations in the stock have so far been proposed.

Further there exist no indicators reflecting economic or social conditions in the cod fishery. Some linkage to other parts of the ecosystem was introduced in the early 1990ies when the management of the capelin stock was made dependent of the cod stock situation as well as the state of the capelin stock. This is however a one way direction management, as the state of the capelin stock has no influence on the cod stock management.

4. Fuzzy logic and Fisheries Management

A set of relevant indicators is needed and control system involving a set of rules based on combinations of indicator values, could be implemented as fuzzy logic control (Zadeh, 1973). Evaluation of the effects of previous decisions could be utilised in refining the predefined rules, adding a dimension of adaptive management to the rule based control system.

Fuzzy logic is often referred to as *a suitable extension of classical logic* (Bayesian logic assuming a statement to be either *True* or *False*). Functional forms are obtained in classical logic in the Boolean algebra, where any formula is translated into {*True, False*} subsets. In fuzzy logic such subsets may have many, or even infinitely many values, for example {*Completely True, Almost True, Partly True, Almost False, Completely False*} or similar sets. Fuzzy control is obtained by rules based on input of fuzzy sets, expressed by if-then algorithms. How this could be used to implement partly known or fuzzy functions is shown in Figure 5. The granulation of the function identifies overlapping areas (in Figure 5 *S*, *M* and *L*) which are associated with *if-then* rules.

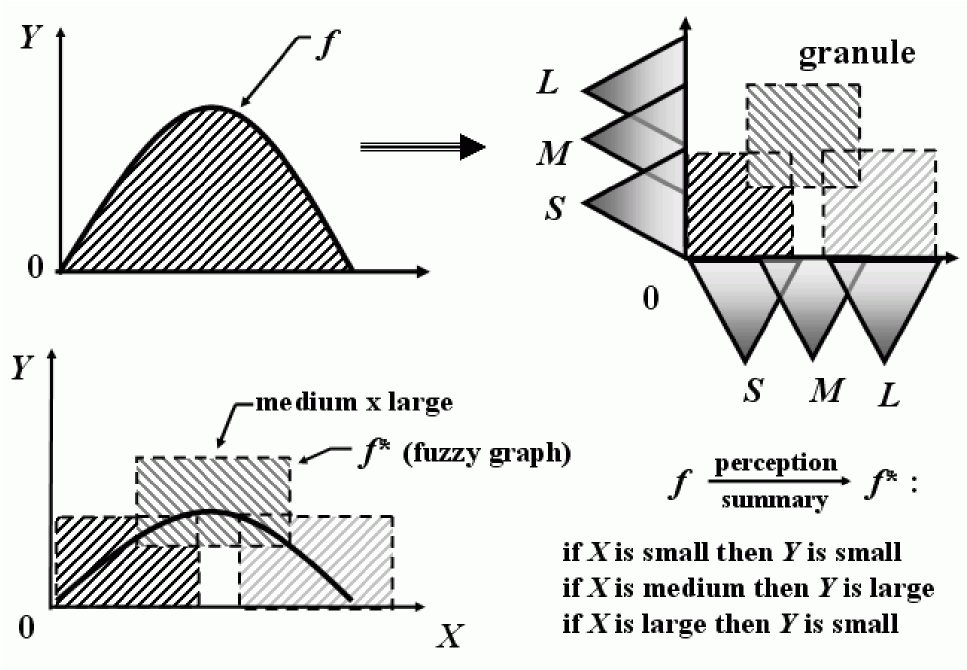

Figure 5. *Granulation of a function. S (small), M (medium) and L (large) are fuzzy sets. f* may be viewed as a summary of f. (From Zadeh, 2008).*

Figure 5 shows how a crisp value function (which may be assumed to exist) could be fyzzified or granulated into a fuzzy system including the basic assumptions, reflecting uncertainty related to the exact values of the function. Any measured data which are vague or perturbed by noise may be converted into a fuzzy number trough a process of fuzzification. The fuzzy number may

5. Prognosis utilising stochastic or pseudo random models, the possible role of cellular automata

Cellular automata (CA) approach to modelling derived from the works of Stanislaw Ulam and John von Neumann (Neumann, 1966) during their stay at the Los Alamos National Laboratory in the 1940ies. In the early 1980ies Stephen Wolfram published a number of papers on the topic, systematically investigating simple cellular automata rules and finally publishing the seminal work "A New Kind of Science" in 2002 (Wolfram, 2002).

Eide (submitted 2010) refers to several works where cellular automata modelling techniques have been used in ecosystem modelling and develops a simple bioeconomic cellular automata model aiming to discuss economic and biological impact of marine protected areas. This model is developed further into a 2D continuous CA model as a part of the ATP project and will serve as a scenario model for testing out different effects of different management strategies in the Barents Sea cod fishery.

6. The use of statistical scenario modelling techniques in testing out robustness of automated HCRs

Scenario modelling to evaluate management strategies was originally developed for whaling, but has also been applied in fisheries (Schweder, 2006). The basic idea is to establish structures and interdependences which are not easily explained by currently available analytical tools and use this model as a test bed varying management strategies. The manager has ideas and assumptions but limited knowledge about the dynamics behind the scenario model. This knowledge may increase by adding new observations of measurable state variables over time. The increased knowledge may be implemented by employing a management approach capable of utilising new information. This can be obtained by defining HCRs as meta-rules, or dynamic HCRs changing as the information of the system dynamics is increasing. In the terminology of fuzzy logics the fuzzification process is a function of the knowledge of functional relationship between measureable input values and measurable output values. Dynamic HCR then represents a possible implementation and automation of adaptive management.

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