ICES CM 2007/O:22

Management with sparse data

Dankert W. Skagen and Dorothy J. Dankel
Institute of Marine Research
PO box 1870 - Nordnes
Bergen, Norway

Abstract

We consider a management that aims at controlling the removal from the stock, guided by a perception of the state of the stock derived from limited data that does not allow an ordinary analytic assessment.

In simulation modeling, there is a 'real' stock and 'real' removals, and the stock develops according to these removals. The management part creates a feed back loop through a noisy link between the state of the true stock and the actual removals. The performance of the management will depend on how the real removal responds to the stock, and how the stock responds to the removals. Structurally, this is a quite simple feed-back system. The interior of the building blocks is complex and diverse, however, and include obstacles like time lags and stochastic terms. When an analytical assessment is not available, the link between the real stock and the management decisions is harder to understand and model, and it may be noisier.

The main emphasis in this paper is finding decision rules that rely on sparse and noisy data. A simulation tool runs as a bootstrap and was made to cover a variety of stocks, decision rules and noise in a versatile way, but on a quite generic level. The link between state of the stock and the basis of the decision was modeled as SSB (or alternatively total stock biomass TSB) derived from the real stock numbers at age, but with random noise and a random year factor. Several types of harvest rules were explored, and pros and cons of various types are highlighted.

Contact author: Dankert W. Skagen, Institute of Marine Research, Postboks 1870 Nordnes, 5817 Bergen, Norway; (+47) 55238419; dankert@imr.no

Introduction

The routine procedure in ICES fisheries advice is to translate a target fishing mortality into a TAC by predicting the stock abundance at age from an estimate of current stock numbers at age obtained through an analytical assessment. Very often, this procedure is not possible, because the data are insufficient to provide a reliable analytic assessment. This may be due to lack of reliable age information, unreliable catch statistics or the lack of appropriate tuning data.

In such cases, two questions emerge immediately:

1. How can the fishery still be regulated in a presumably safe way?
2. What kind of advice can be provided that is applicable to such a regulatory scheme?

In this presentation, these questions are addressed in rather general terms. We try to address aspects which may be regarded as more or less generic and relevant to a wide range of stocks and fisheries.

Outline of the general problem of regulating the exploitation of a stock.

Any fisheries regulation can be outlined as a simple feedback system: There is a stock with a dynamic behavior that is partly caused by internal dynamics (stock-recruitment relations, density dependent growth and maturity), partly by external influences (natural mortality, survival of offspring causing recruitment variation, environmental influence on growth and maturity) and partly by removals through the fishery. The removal by the fishery is the implementation (more or less accurate) of managers' decisions, which in turn should be based on a perception of the state of the stock. With sparse data, this perception is uncertain and may even be quite misleading.

Dynamically, the performance of this feedback system depends on:

1. How the harvest extraction levels respond to the state of the stock (via observation, the harvest decision-making and implementation of the decision)
2. How the state of the stock responds to the removals given the additional internal and external forces.

How the removals depend on the state of the stock depends on the signal from the stock, the signal/noise ratio and the specification of the management arrangement. The response of the stock to removals is more complex, because it has important time lags and cumulative effects and may be heavily influenced by other processes.

The management objectives usually ensure a near maximum removal, also in the long term. There may also be an incentive to stabilize the annual catches, and perhaps a willingness to sacrifice some catch for stability. Obviously, to meet such objectives, severe depletion of the stock has to be avoided. This is also the obligation for the advisors according to the precautionary approach.

Designing and simulating management regimes with sparse data.

The basic difference between a 'normal' data rich situation and a data poor situation is that in the data poor situation, the basis for managers decisions is less firmly related to the state of the stock, and that the dynamic properties of the stock are less well known. The less information, the less scope there is for micro-management. A different paradigm, where management actions are initiated by an 'out of control' signal in the system rather than a direct response to the resource productivity, seems more promising (ICES 2007). Hence, we concentrate on rules that aim at keeping something constant unless there is a good reason for change. The 'something' can be either the exploitation rate (i.e. fishing mortality) or the volume of fish removed. Both strategies have advantages and disadvantages, and are discussed further below.

Simulations have become a major tool in evaluating management strategies in data rich situations (ICES 2007). Furthermore, there is ample theory about feedback systems and their performance, which can add to the insight in the performance of management strategies. However, most of this theory, at least on the elementary level, assumes linearity, random noise and no delay effects. Hence, although general feed-back theory may provide guidance, simulation studies remain a natural choice as a direct way to get insight in the performance of a management arrangement.

Simulation of fisheries management in general has an underlying stock model which is artificial, but known. Hence, the 'true' effects of regulations can be followed. Furthermore, there is an observation model which generates the basis for decisions, a management rule and an implementation model that generate the removals that are applied to the model stock. Figure 1 outlines the main building blocks in a simulation framework.

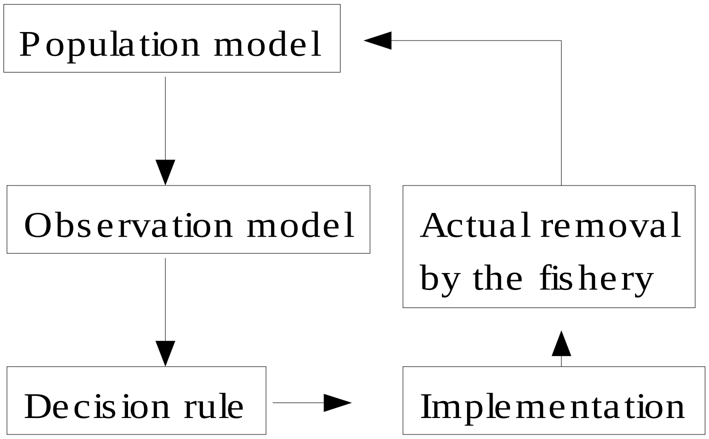

Figure 1. *Outline of a standard simulation framework.*

To compensate for the shortcomings in data poor stocks, one should strive at designing management rules that function for a wide range of the unknown properties. The rule cannot rely on precise monitoring of the stock, but it has to have elements that allow responding in time to signals that are strong and persistent enough to show through the smokescreen of noise. Furthermore, it should perform satisfactorily for a realistic range of alternative stock dynamics. This approach is somewhat different from what is commonly encountered, when simulations are done for just one set of stock dynamic parameters, which are assumed to be exactly the right one for the stock in question. Given the sparse knowledge, robustness is more important than exact specifications.

In the following, we discuss some types of management strategies, and some kinds of signals that can be used as guidance. We use a simulation framework to outline the range of conditions where such strategies can function. We have designed a simulation program that can be used as an example of how simulations may be done. The program is an extension of one used previously to study fixed quota regimes (Skagen 2007). The idea is to cover a range of dynamics and decision rules, to allow studies of decision rules on a relatively generic basis. The elements in this program are further discussed here.

Simulation tool

Population model

The population model was designed to simulate a variety of biological properties such as growth rate, maturity ogive, recruitment regime and natural mortality. Growth according to the von Bertalanffy equation was used to derive weights at age. For the maturity at age a logistic function was used. Natural mortality was fixed. Hence, a range of basic biological properties can be explored by varying a small number of parameters.

Recruitment model:

- Hockey-stick stock-recruitment relation
- Periodic fluctuations in recruitment
- Spikes with regular intervals
- Step response at a given time
- Random noise on top of the other variation.

A population model could also include variations due to:

- random variation in weight at age
- density dependence in growth
- density dependence in maturity.
- fluctuations in natural mortality

The fishery is characterized by selection at age according to a logistic function.

Possible measures of the stock (observation models).

In data poor stocks the lack conventional analytic assessments, other measures relating to the stock abundance and/or trends in stock abundance have to be considered. The choice of measures depends of course on the stock and fishery in question. Indicators, which broadly may be regarded as indirect measures of the stock abundance or exploitation rate, are emerging as possible sources of information Rice and Rochet, 2005, Codling and Kelly, 2006). From a performance perspective, the important thing is that the measures can be used to respond timely and strongly enough to changes in the stock. In a simulation context, this comes down to the link between signal and the stock abundance. This link will include noise, non-linear effects and delays. In our simulation framework, we used the following procedure:

- Start with a measure S of stock abundance from the operating model
- Modify the signal with a non-linear relation between actual abundance and signal, we used $S' = S*\exp(\alpha S)$, where α is a gain factor.
- Modify further with a time trend, which might represent a creeping in catchability, i.e. $S'' = S'*(1+\beta t)$
- Add random noise: $S''' = S''*\varepsilon$.

- For each years' management decision, take either the average S''' or the trend over the years (y-y1) - (y-y2).

It should be possible to establish similar links between the population state and other kinds of signal, for example length distributions, but that would require more elaborate population models.

Possible management strategies (decision rules).

Constant F regimes

Aiming at keeping the fishing mortality constant, without being able to directly estimate the fishing mortality, leads naturally towards maintaining a constant effort. In practice, even though the nominal effort may be constrained by direct regulation, licensing etc., some important obstacles remain.

For example, the fishing mortality applied to a stock may not be proportional to the effort, since fishermen must be expected to direct the effort towards the highest concentrations of fish. Technological improvements may increase the effective effort compared to the nominal effort. In fisheries for schooling pelagic fish, the relation between effort and fishing mortality is weak, but even in demersal fisheries such effects may be encountered. One may also foresee that with a declining stock and limitations to their total effort, fishermen will become especially particular to optimize their fishing operations for efficiency. Hence, when simulating effort regimes it may be worth considering a compensatory increase in the fishing mortality when the stock goes down. Likewise, robustness to this effort-creeping needs to be considered and also measures to compensate for effort-creeping should be part of the management plan.

There are some management measures that may complement direct regulations of nominal effort. Changes in mesh size will change the cumulated mortality over ages, even if it does not affect ages that normally go into the overall average F. Measures to reduce discards, in particular of undersized fish will have the same effect. Closed areas may contribute to reducing the total effort, but the effect depends on the migrations into and out of the protected areas and the effort occurring outside the closed area.

The main advantage of a fixed F regime is its robustness if it can be implemented properly. As long as the F is maintained below the F_{crash} there is always an equilibrium catch and biomass. Also, keeping F near F_{MSY} gives a long-term yield near the maximum that can be achieved with any regime.

Fixed quotas

Fixed catch quotas is another alternative, which can be used alone or in combination with constraints on effort. Fixed quotas are conceptually a simple way of managing a stock and at least in theory they are simple to implement and they allow some stability and predictability that may be attractive for the industry. Such quotas will have to be set without knowing the absolute size of the stock. The main obstacle is that unless a fixed quota is set extremely low, there is some risk that the stock sooner or later will be too small for the quota. If the fleet is able to increase the fishing mortality in such a situation, the stock will be trapped in a vicious circle leading to severe depletion. The trigger for such a development is that the stock becomes small, which may be due to a sequence of unusually small year classes, overfishing of the quotas or poorer growth and/or increased mortality from external causes. Figure 2 shows an example of a bundle of trajectories from a simulation of an artificial population which illustrates the trapping effect when the stock becomes too small. Hence, this kind of regime must have sufficient precautionary and protective measures in place.

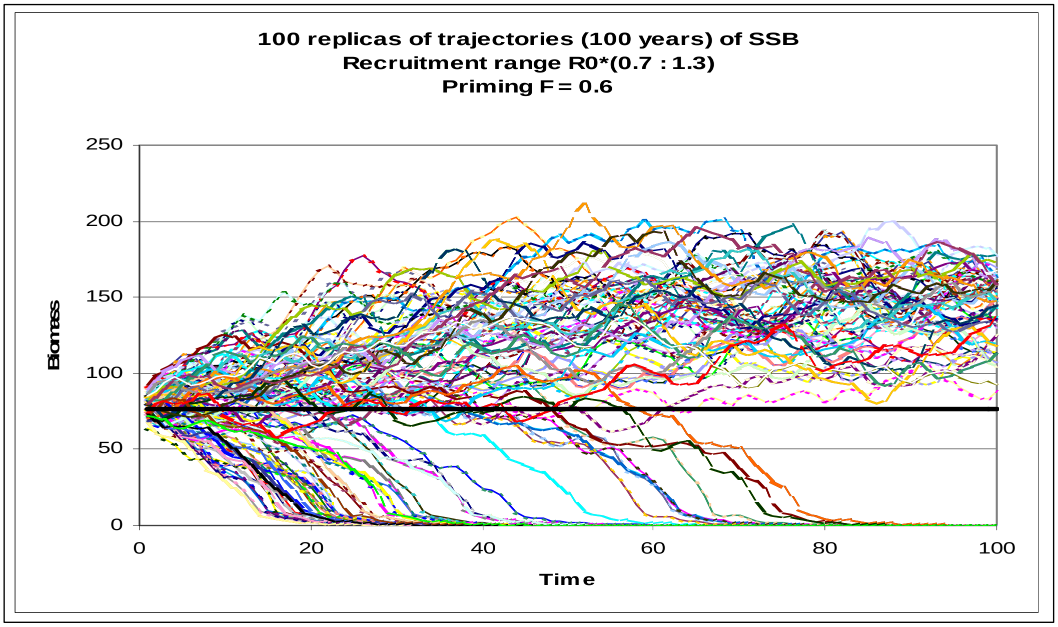

Figure 1. *An example of trajectories (100 years) in a simulation of an artificial population with a fixed quota regime. Each trajectory has one color. Recruitment is random within the range indicated, but not dependent on the stock. The TAC was assumed to be taken if at all possible. Before the simulation period, the model was primed with fixed F and stochastic recruitment.*

Examples of case studies

We here give two examples with artificial populations of possible management rules and how strengths and limitations can be outlined through simulations.

In both cases, the population model included ages 0-10+. Weights at age were derived by applying a condition factor of $80*L^3*10^5$ to lengths at age. The lengths at age were derived from the von Bertalanffy equation with $L_{infinity} = 70$ and k=0.2. Recruitment followed a hockey stick function with breakpoint at SSB = 400 and a standard value of 1000 above the breakpoint. The recruitment was assumed to vary periodically, with a period of 7 years and amplitude of 0.4. Finally, a random multiplier was applied with CV = 0.5. Maturity at age and selection at age in the fishery both were specified by logistic functions, with A_{50} = 3.0 and 1.5 respectively.

With these specifications, the population has an F_{max} = 0.24, with a corresponding SSB = 889 and a yield of 202. The breakpoint in the recruitment function corresponds to F = 0.46 (F_{crash}), which has an equilibrium yield of 181.

The basis for decisions was a biomass measure (S) derived as outlined above from the fishable biomass (FSB), assuming proportionality between S and FSB. The catchability of the measurement of the FSB was either assumed to be constant or increasing linearly, with a yearly rate of 5%. A random noise multiplier was applied with a CV = 0.5. The managers decisions were based on the average of these values over the years y-1 to y-3. No implementation error was included.
The simulations started with a priming phase of 30 years with fixed F = 0.4. The rule was then applied for years 31 - 60. Simulations were done with 1000 bootstrap replications.

Example 1

This a harvest rule where the TAC is set directly, aiming at keeping the TAC at a standard level unless the stock becomes small or very large. It has three reference points related to the biomass measure S described above. S1 = 300, S2 = 800 and S3 = 1500. The rule was:

$S < S1$: TAC = 0
$S1 < S < S2$: TAC = StdTAC*(S-S1)/(S2-S1)
$S2 < S < S3$: StdTAC
$S > S3$: StdTAC * (1+α *(S-S3)/S3), with α= 0.2.

Two scenarios are shown in Figure 3: with and without a trend in the catchability of the biomass measure used for decisions.

Without this trend (blue lines), the regime behaves quite well, even with a standard catch that is close to the peak of the yield per recruit curve. If there is a trend in the catchability, leading to an increasing overestimate of the state of the stock, the regime breaks down, and already after 30 years the stock has collapsed in more than half the cases. The protection rule, which should reduce the TAC when the stock becomes small does not work because of a too optimistic measure of the stock.

The biomass measure used for making decisions is quite noisy, and the decisions are based on an average over the 3 years preceding the TAC year. Still, the regime seems to work. The critical issue is the stability of the measure used for deciding the TAC. This measure could be something related to CPUE or a survey index, and illustrates how dangerous unaccounted improvements in measuring a stock can be with this kind of regime.

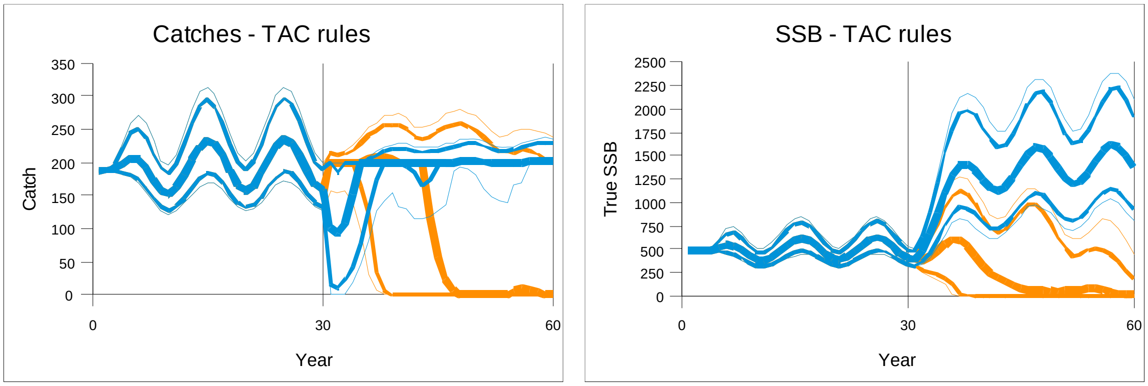

Figure 3. *Results of simulations with TAC regimes. Lines are 5, 10, 50, 90 and 95 percentiles. Left: Catches. Right: SSB. Blue lines: Without trend in observations catchability. Orange lines: With 5% per year linear trend in observation catchabilities. Years 1-30 are priming with fixed F, years 31 - 60 with applying the harvest rule. For details of model specifications, see text.*

Example 2

This is a rule for setting a fishing mortality. The rule uses the same breakpoints as in Example 1 above, but decides on a fishing mortality instead of a TAC. This may correspond to an effort-regime, with no attempt to translate the effort into a TAC. The standard F applicable in the interval $S2 < S < S3$ was 0.4, which is close to F_{crash}. Selected results are shown in Figure 4.

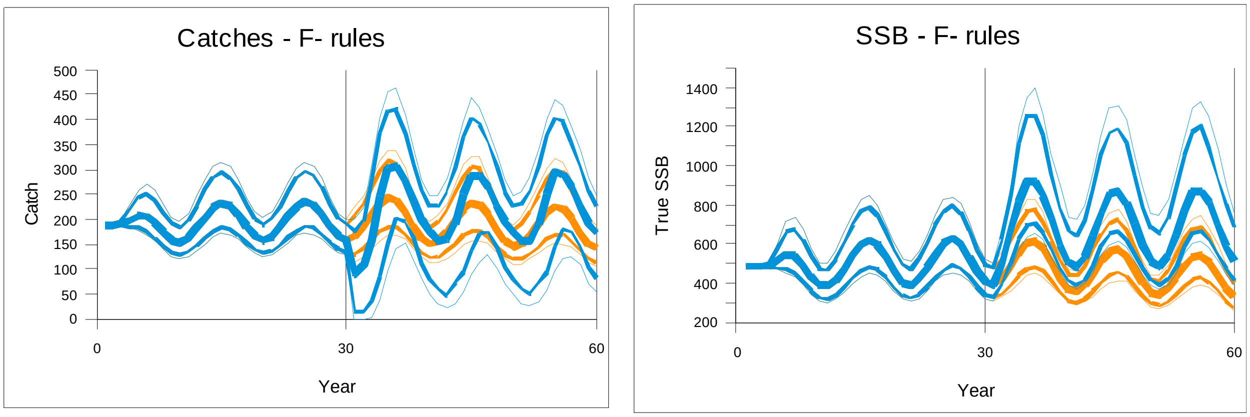

Figure 4. *Results of simulations with F regimes. Lines are 5, 10, 50, 90 and 95 percentiles.*
Left: Catches. Right: SSB. Blue lines: Without trend in observations catchability. Orange lines: With 5% per year linear trend in observation catchabilities. Years 1-30 are priming with fixed F, years 31 - 60 with applying the harvest rule. For details of model specifications, see text.

The results in this case indicate that an F-rule should function rather well. A trend in catchability in the measure, used for deciding the F, leads to a gradual reduction in both SSB and in the catches, as the optimistic measure leads to F-values above what they should have been.

The more serious concern with such regimes is that they rely on a stable link between effort and fishing mortality. Figure 5 shows an example where, in addition to the trend in catchability of the abundance measure, there also is a trend of 2% per year in the actual F compared to the decided F. Even with this very weak effort-creeping, the stock declines markedly due to higher realized fishing mortality, and the protection rule here does not seem to be sufficient to prevent the stock from dropping well below the breakpoint of the of the recruitment function.

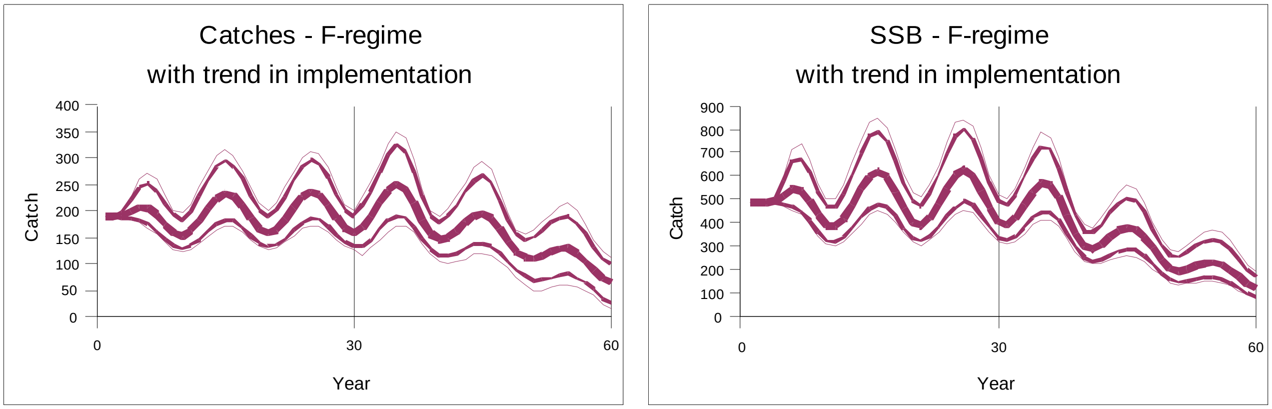

Figure 5. *Results of simulations with F regimes, with a trend in the relation between decided and realized F. Lines are 5, 10, 50, 90 and 95 percentiles.*
Left: Catches. Right: SSB. Years 1-30 are priming with fixed F, years 31 - 60 with applying the harvest rule. For details of model specifications, see text.

Conclusions

The purpose of this study was to indicate that even when an analytic stock assessment cannot be obtained as basis for management decisions, management strategies are still possible. They will have to be adapted to the poorer basis for decisions, however, and such stocks are hardly good candidates for micro-management. Management strategies can still be evaluated through simulation, the main difference from the 'normal' situation being that the link between the stock and the information that is used to take decisions is weaker and that the dynamics of the stock is less known. Hence, it is more important to test the robustness of a rule than attempting to model the dynamics of the stock in question precisely. A framework for simple simulations is presented, with some examples of its use. These examples emphasize the importance of stability in both the measures used to monitor the stock and in the implementation of management measures.

References

ICES(2007) Report of the Study group on Management Strategies (SGMAS). ICES CM 2007/ACFM:04

Codling, E.A., and Kelly, C.J. (2006a) “Cheap and dirty” fisheries science part II: An example of fisheries management using simple indicators. 62-68pp, in Codling, E.A., and Kelly, C.J.(Eds), Reports from the FSS mini-symposia 2004-2005. Marine Institute, Rinville Ireland. ISSN 0578-7476. (http://privatewww.essex.ac.uk/~ecodling/FSS%20Mini%20symposium%20report%20-%20Codling%20&%20Kelly%202006.pdf)

Rice, JC and Rochet, M-J. 2005. A framework for selecting a suite of indicators for fisheries management. ICES Journal of Marine Science, 62: 516-527.

Skagen, D. W. 2007. Management strategies for reducing variation in annual yield: when can they work? ICES Journal of Marine Science, 64: 698-701, 2007