Estimation of parameters in Bifrost

Parameters governing capelin maturation, consumption by cod and the recruits (cod as 0 years, capelin as 1 year) and parameters in the spawning stock - recruitment relations are estimated separately, because parameters in the latter group do not influence parameters in the former group.

Estimation of parameters governing capelin maturation and consumption by cod, estimation of recruits

As a rule, these parameters are estimated simultaneously, but it is also possible to invoke a stepo-wise procedure, see below.

The parameters governing the consumption of cod are influenced by the parameters governing maturation of capelin, since the amount of mature pre-spawning capelin is an important source of food for the cod. The converse is also true, since the parameters governing maturation must be estimated using data from the capelin stock after maturation has taken place. Such data are not available immediately after maturation is assumed to take place (October 1) and during the time period from maturation until the effect of maturation is detected the capelin is subjected to predation by cod.

Previous modelling exercises have shown that the period from the first trawl-acoustic measurement of capelin in 1972 until the first collapse caused by the 1983 year class of Norwegian spring spawning herring was stable in terms of the population dynamics of capelin, with little variation in natural mortality. This period is used to estimate the parameters governing the maturation of capelin, using a scalar parameter for the natural mortality. With these parameters fixed, the parameters governing consumption by cod are estimated in a separate step using - among other data - consumption per cod data calculated from stomach content samples.

In one estimation session the steps below can be made in succession several times for each historic replicate.However, all parameters can also be estimated simultaneously. The stepwise procedure is useful initially to arrive at good initial parameter values to feed the simultaneous procedure. When the parameters are estimated simultaneously, no assumption on constant capelin mortality in the "calm" period is made.

Data on maturation based on visual inspection of eggs or gonads exist for the September surveys. However, it is unclear which maturation stage corresponds to spawning the following winter. These data can later be of importance, however.

- ### Parameters governing capelin maturation

The parameters in the capelin maturation function are estimated by establishing a likelihood function from the immature stock as calculated from the survey estimate by October 1 and the maturation model and then simulated forward one year, and the total stock as measured by October 1. This makes the maturation parameters confounded with e.g. parameters governing predation on capelin. In order to minimize this problem, the period for estimation may be restricted to the 1970s, which was a calm period with regards to the population dynamics. Several types of error function are possible. The likelihood is constructed from number at age or from number at sex and age.

- ### Parameters in the cod consumption model

The likelihood function is based on the modelled and empirically calculated consumption of capelin by cod of different ages. The range of cod age used in the likelihood function can be selected, and several error functions are possible. It is also possible to use only empirically calculated consumption in quarters 1 and 3, for which the stomach content data are the most abundant.

Recruits of cod and capelin, and capelin residual mortality

The recruits of capelin are estimated at age 1. In the past it happened in several years that the number of 2 year old capelin measured in the September survey was higher than the number of 1 year old capelin the year before. The 1 year old capelin was more likely to be wrongly estimated than the 2 year old capelin, because the 1 year old capelin often stayed somewhat geographically distinctly from the older capelin, and these areas had poorer coverage during the surveys. Therefore, the measurements of the 2 year old capelin are taken to be the data for recruitment during the whole historic time series. Before the capelin is 2 years, however, it will be subjected of predation by cod. Therefore, the number of capelin as 1 year old by October 1 is estimated to be the number of capelin required to yield the number of 2 year old capelin by October 1 the following year, having been subjected to predation by cod.

The recruits of capelin are forced to be non-negative.

The recruits of cod are estimated at age 0 as the number required to yield the number of 3 year old cod from the assessment made by the ICES Arctic Fisheries WG. Thus, cannibalism is an inherent part of the model and the estimation process and shall not be modelled seperately in the recruitment function.

The recruits of cod are forced to be non-negative.

The residual mortality of capelin is estimated as the mortality required for the amount of simulated capelin of age 3 and older to equal the measured capelin of age 3 and older at October 1. The residual mortality is also applied to capelin of age 1 and 2.

The residual mortality of capelin is forced to be non-negative.

■ Algorithm for estimating capelin maturation and consumption by cod parameters

The estimation is based on the Nelder-Mead method, which by experimentation has been found to perform well on this very intricate estimation problem. The objective value is calculated on a N + 1 grid, where N is the number of parameters. The core of the algorithm is to reflect the worst point through the centre and if the new point is better, replace it with the original point. The parameter range must be specified, and the global optimum may be outside of the parameter range. Therefore, a series of estimation procedures are conducted initially, each time using the result of the previous estimation as starting point. Simulated annealing and gradient methods have been tested, but have performed poorer on this etsimation problem.

■ Estimation for different historic replicates of data

The basic input data to Bifrost are in the form of historic replicates with equal probability, calculated by resampling. Thus, drawing at random from each year gives several different equally plausible perceptions of the history. In Bifrost, the model parameters are estimated using several of the plausible historic data series, each giving rise to different recruitment models and different prognostic simulations and contributing to a more correct picture of the uncertainty in conclusions drawn regarding which harvest rule to chose.

Estimation of parameters governing recruitment

Recruitment is the single most important process governing the outcome of long term simulations and conclusions drawn about harvest rules can be strongly dependent on the choice of recruitment model form. Therefore, for each historic replicate, a wide variety of recruitment models are estimated. For each model the value of the Akaike Information Criterion (AIC) is calculated and stored along with the parameter estimates, see the sections on recruitment models for details. During prognostic simulations, first one historic replicate is drawn. Then one recruitment model is drawn among those estimated for that historic replicate, with a probability proportional to the Akaike weight. This ensures a balance between an overfit due to many parameters and an underfit because the model does not capture the most essential biological processes.