Prost Users Guide

Morten N. Åsnes *
Bjarte Bogstad <bjarte.bogstad@imr.no>
IMR, Bergen, Norway

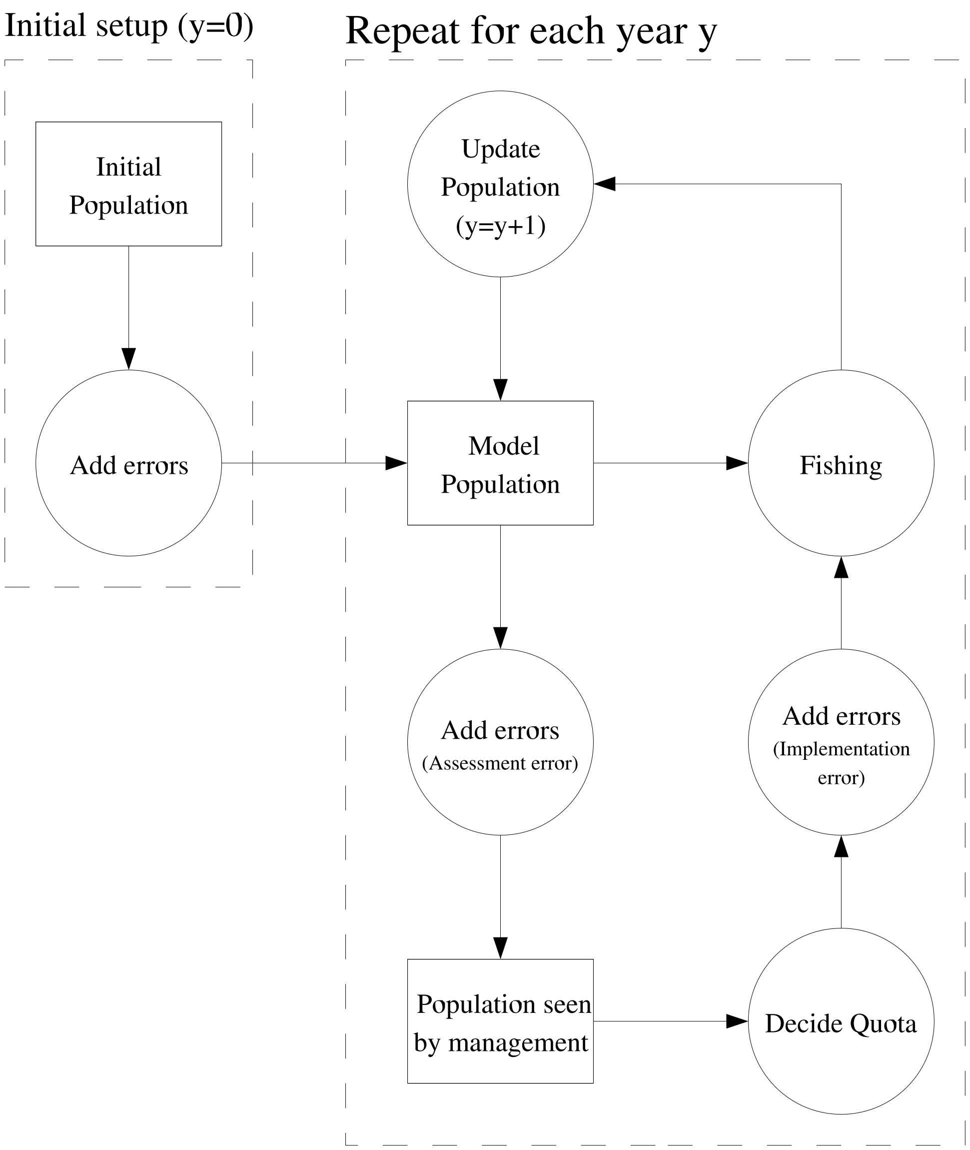
January 14, 2014

Contents

*No longer at IMR, please contact bjarte.bogstad@imr.no for questions regarding Prost

1 Introduction

This document describes the prognosis program Prost (Projections Stochastic), version 0.1. The purpose of the program is to perform stochastic projections using an age structured population model, for given management rules. The program starts with a given population, which is then projected into the future and subjected to natural mortality and fishing. Fishing level is given by a management rule. Stochastic errors can be added to the initial starting population (numbers, weight, maturity, etc.), and to the recruitment. In addition errors can be added to the population before it is seen by the management rule (assessment error), and to the decided quota (implementation error). Each model simulation will thus give a different realization of the projection. The model works as described in Skagen et al. (2003). A yearly time step is used. The following figure illustrates a single realization of the model.



The program was developed for use in the evaluation of the proposed harvest control rule for Northeast Arctic cod (Bogstad et al. 2004), but is generally applicable for making single-species, single-fleet, single-area stochastic projections using an age-structured population model. Weight at age and maturity at age can be density-dependent, and a variety of harvest control rules can be applied. It is easy to add more options for density-dependent weight/maturity at age as well as additional harvest control rules.

The ICES Study group on Long term Advice (ICES 2004a) as well as the ICES Methods Working group (ICES 2004b) have discussed existing tools similar to Prost. Such tools include WGMTERM, ICP, STPR and CS5.

The model does not assume any specific unit in the input and output files. It is up to the user to make sure that units for numbers and weight match up. In the manual we assume that numbers are in thousands and weights are in tons.

2 Installation

Prost is written in Java, and can therefore run on any platform where a Java runtime version is available.

If you're not developing Java software yourself, it is sufficient to download the JRE (Java Runtime Environment). Verify that you have a suitable Java installation by typing `java -version` in a Dos or Terminal window. The output should be something like this:

```
java version "1.7.0_45"
Java(TM) SE Runtime Environment (build 1.7.0_45-b18)
Java HotSpot(TM) 64-Bit Server VM (build 24.45-b08, mixed mode)
```

Please notice that the Java Browser Plugin is not sufficient for running Java Applications like Prost.

An up to date JRE can be downloaded at http://www.oracle.com/technetwork/java/javase/downloads/jre7-downloads-1880261.html. The download should be named *jre-7u45-windows-i586.exe* or similar for the 32 bit version, or *jre-7u45-windows-x64.exe* or similar for the 64 bit version. The download consists of a setup program, which must then be run to install Java on your computer.

After running the installer try to run `java -version` from a DOS windows again to verify that the correct Java version is found.

If for some reason Windows can still not find the installed Java version, you will have to configure your the windows *Path* environment variable to include the path where `java.exe` is installed. First, locate directory where `java.exe` is in installed. It should typically be something like `c:\Program Files\Java\jre7\bin`. Now, to add this directory to the system path, click *Start*, then *Control Panel*, then *System*. Then click *Advanced* and *Environment Variables*. Now edit the *Path* under *System Variables*, and add the java directory to the end, separated from the previous entry by a semicolon. The new path should be in effect when you open a new command window.

As an alternative, it is possible to change the path temporarily in a single command window. In a command windows, type the following: `set path=%path%;c:\Program Files\Java\jre7\bin` (but change the path to reflect where Java is installed on your machine). Now the new path will be in effect only in the current window until it is closed.

Prost comes packaged as a single file called `prost.jar`. It is most convenient to place this file together with the input files in the directory where you intend to run the program.

3 Running Prost

To run Prost, type `java -jar prost.jar`. This will read the file `stock.dat`, and start a run. Output will appear in various text files (`.csv` files which can be read into Excel). See Section 5 for more detail on the output files.

3.1 Command Line Options

To control how many simulations to perform, add the command line option `-i nr_of_simulations`. For example; to run 1000 simulations you type: `java -jar prost.jar -i 1000`. The default is 100 simulations. The option `-o` produces very detailed output to the file `out.csv`. When doing many simulations this file will become very large. It is usually only needed for debugging.

To specify a seed for the random number generator, use the option `-r seed` where seed is an integer.

The option `-v` will print some more information to the screen as the input files are read in. This will be helpful in tracking down any mistakes in the input files.

It is possible to set the fishing level on the command line with the option `-f flevel`. If this option is used, the given value will override the `FaboveBpa` parameter from the management file (Section 4.4).

When this option is used, all output files will have a prefix added to their name, to distinguish output files from different runs. For instance; if the option `-f 0.4` is used the summary file will be named `F0.4-summary.csv`.

This option can be useful when one wants to automate the task of running Prost with different fishing levels. The script `prost.js` can do this on Windows. See Section 3.2 for details on how to use the `Prost.js` script.

The option `-s portnr` specifies that Prost should communicate with an external program on the specified port. During the simulation Prost will then read data from this socket each year,

The data read from the socket is weight in stock, weight in catch, maturity, and natural mortality. Prost will then write the number of the start of the next year back over the socket.

3.2 Scripting

A script is provided with the Prost distribution, for doing multiple runs, with different fishing levels. The script will accept all the usual Prost arguments, but the `-f` option is handled differently. This option is now followed by three values: The smallest fishing level to use, the largest fishing level, and a step-value. The script will run Gadget multiple times, starting with the smallest fishing level, increasing the level by the step value each time, up to and including the given max level. The script is called `prost.js`, and it will only work on the Windows platform. The complete syntax is as follows:

```
prost.js -f minf maxf stepf <ordinary prost options>
```

The script expects the Prost program (`prost.jar`) to be in the same directory as the script is running from, or the directory above it. If `prost.jar` can not be found, the script will exit with an error message.

4 Prost Input Files

All input files are pure text files. They generally consist of keyword – value pairs, in a predefined order. Comments can be introduced with a semicolon. The rest of the line following the semicolon is treated as a comment.

4.1 Control file

The control file must reside in the directory where Prost is started, and it must be named `stock.dat`. This file specifies the age range and time span to run the model for. It also lists all the other input files. An example of the file:

```
name                Torsk
firstyear           2003          ; intermediate year
lastyear            2028          ; last prediction year
extrayears          5             ; extra years after lastyear
minage              3             ; recruitment age
maxage              13            ; +group
fbarmin             5
fbarmax             10
bpa                 460000
blim                220000
flim                0.49
maxthreshold        20
minthreshold        20
maxf                0.9
summarystart        2004
summaryend          2028
population          pop.dat
recruitment         rec.dat
management          manage.dat
weightandmaturity   density
file                density.dat
```

The keywords are explained in Table 1.

The model will start some years before the intermediate year because data from earlier years might be needed for the recruitment function. And because the management rule may look several years into the future when setting the quota, the model may also run for several years after the last year.

The numbers of years to run before $firstyear$ is determined by the minimum age in the model. Thus if $minage = 2$, the program will require data for two years before $startyear$. The number of years to run after $lasteyear$ depends on several things. Firstly, the model must run at least $minage$ years after $lastyears$, this is because of the way the recruitment function is implemented. Then, if the *lookahead* management rule is used, the model must run as many years after *lastyear* as the *lookahead* management rule is set to look into the future. Lastly, there is the keyword *extrayears* in the control file, where the user can specify how many years after *lastyear* of data are in certain input

Table 1: Keywords in control file

Keyword	**Type**	**Description**
name	string	Name of the stock
firstyear	integer	Intermediate year (assessment year)
lastyear	integer	Last year that a quota will be given for
extrayears	integer	Extra years needed (for management rule) after *lastyear* **(optional)**
minage	integer	Minimum age
maxage	integer	Maximum age
fbarmin	integer	Minimum age for reference F calculation
fbarmax	integer	Maximum age for reference F calculation
bpa	double	B_{pa} value
blim	double	B_{lim} value
flim	double	F_{lim} value
maxthreshold	double	Threshold for counting a year as having a big increase in quota
minthreshold	double	Threshold for counting a year as having a big decrease in quota
maxf	double	Maximum fishing mortality
summarystart	integer	First year in summary output
summaryend	integer	Last year in summary output
population	string	Filename for population data
recruitment	string	Filename for recruitment function definition
management	string	Filename for management rule definition
weightandmaturity	string	Option for weight and maturity
file	string	Filename for density dependent, or historic weight and maturity **(optional)**

files. Thus the number of years to run after *lastyear* will be the largest value of *minage*, *extrayears*, and *years* (in the *lookahead* rule). We will call this last year of the model Y_N in the discussion below.

The B_{pa} value is used only as a trigger point in the constant F rule (Section 4.4.1) and the lookahead rule (Section 4.4.2). The B_{lim} value is only used for calculating $P(SSB < B_{lim})$ in the summary output. The values F_{lim}, *maxthreshold*, and *minthreshold* are also used only for printing.

4.1.1 Weight And Maturity option

The keyword *weightandmaturity* indicates how weights and maturity are modeled. The option must be one of *initial*, *density*, or *historic*. If the option is *initial*, the weight and maturity comes from the population file, in the format specified below. If the option *density* or *historic* is given, the next line of the file must give a filename where these options are further specified. The format for the *density* option is specified in Section 4.5 The *historic* option is described in Section 4.6. Note that even if the *density* or *historic* option is given, the initial population file must still contain weight and maturity.

4.2 Population File

The name of the population file is given in the control file. As mentioned above, all data given here must start in the year $firstyear - minage$, but depending on which recruitment function is used, the data before *firstyear* might not be used. The following sets of data must be given (Table 2). Y_i is the intermediate year (*firstyear*), Y_0 is $firstyear - minage$, and Y_N is the last year of the model run as defined above.

Table 2: Input data type keywords and ranges

Keyword	**Range**	**Description**
[numbers]	$Y_0 \to Y_i$	Population numbers up to and including intermediate year
[fishingmortality]	$Y_0 \to Y_i$	Fishing mortality up to and including intermediate year
[naturalmortality]	$Y_0 \to Y_N$	Natural mortality for the whole time period
[stockweight]	$Y_0 \to Y_N$	Stock weight for the whole time period
[catchweight]	$Y_0 \to Y_N$	Catch weight for the whole time period
[maturity]	$Y_0 \to Y_N$	Maturity for the whole time period

Each set of data has the following general format:

```
[keyword]
expected
<age vector of expected values 1>
...
<age vector of expected values N>
distortion <distortion 1>
...
distortion <distortion N>
```

The keyword identifies the type of data. Each age vector gives the expected value for each age in a given year. Each distortion then specifies how to draw a random value around the expected. The distortion format can be one of the following:

4.2.1 No distortion

```
distortion none
```

This will use the expected value directly, no error is added.

4.2.2 Normally distributed distortion

```
distortion normal
cv <cv age vector>
[bias <Optional bias age vector>]
trunk <truncation>
```

This will draw from a normal distribution with expected value as above, and standard deviation $sd = cv\hat{X}$ where $\hat{X}$ is the expected value.

Optionally bias can be included. This will give a normal distribution with mean $\hat{X} + \hat{X} \cdot \text{bias}$.

4.2.3 Multivariate lognormally distributed distortion

```
distortion multivariate
covariance <covariance matrix>
```

This will draw from a multivariate lognormal distribution with expected value as above, and the given covariance matrix with dimension $(maxage - minage + 1) * (maxage - minage + 1)$.

4.3 Recruitment File

The recruitment functions are defined in a file given by the control file. Several recruitment functions can be listed, so that for example a fixed recruitment can be used for the years where data on recruits are available, and a stock-recruit relationship can be used for other years. Here is an example of such a file.

```
[Recruitment]
generators 2

[RecruitmentGenerator]
firstyear 2004
type fixed
years 2
;       2004    2005
numbers 308000  664000
error   none

[RecruitmentGenerator]
firstyear 2006
type  ockham
a     529104
b     224482
error normal
sd    0.2
trunk 2.0
```

The keyword generators gives the number of recruitment functions. The recruitment functions are then listed in order. The format is as follows:

```
[RecruitmentGenerator]
firstyear <year>
type <function type>
<function specific input>
<error distribution>
```

4.3.1 Recruitment Functions

The recruitment type can be one of the following:

Fixed recruitment

This reads the recruitment numbers from a file. The recruitment is then:

$$R_y = N_y$$

The file format is:

```
type fixed
years <nr of years>
numbers <n_1 n_2 ... n_N>
```

Here N is the number of years that this recruitment function applies to (see above).

Beverton-Holt

Beverton-Holt gives recruitment according to the following function:

$$R = \frac{a \cdot SSB}{b + SSB}$$

where *SSB* is the spawning stock biomass. The file format for this function is:

```
type bevertonholt
a    <parameter a>
b    <parameter b>
```

Cyclic Beverton-Holt

The cyclic beverton-holt function has this format:

```
type      bevertonholt-cyclic
a         <parameter a>
b         <parameter b>
amplitude 0.43
period    6.57
phase     -1.92
k         0.19
w         4.29
```

This gives the same recruitment as the beverton-holt function above, but with a cyclic term included. The recruitment function is thus:

$$R = f(SSB)e^{amplitude \cdot \sin(\frac{2\pi(year-1946+phase)}{period})+k(\bar{w}-w)}$$

where $f(SSB)$ is the normal beverton-holt function:

$$R = \frac{a \cdot SSB}{b + SSB}$$

Ricker

The Ricker recruitment function gives recruitment according to the following function:

$$R = a \cdot SSB \cdot e^{-b \cdot SSB}$$

The file format is as follows:

```
type ricker
a    <parameter a>
b    <parameter b>
[ssb-cutoff <optional parameter ssb-cutoff>]
```

The parameter `ssb-cutoff` is optional. If this parameter is given, it is used as a maximum SSB. If the stock SSB is higher than `ssb-cutoff`, the value of `ssb-cutoff` will be used instead of SSB in the recruitment formula above.

Ockham

The ockham recruitment function gives recruitment according to the following function:

$$R = \begin{cases} a & \text{if} \quad SSB \geq b \\ \frac{a \cdot SSB}{b} & \text{if} \quad SSB < b \end{cases}$$

The file format is then:

```
type ockham
a    <parameter a>
b    <parameter b>
```

Cyclic Ockham

The cyclic ockham function has the following format:

```
type      ockham-cyclic
a         <parameter a>
b         <parameter b>
amplitude 0.43
period    6.57
phase    -1.92
k         0.19
w         4.29
```

This gives the same recruitment function as Ockham, with a cyclic term included.

$$R = f(SSB) e^{amplitude \cdot \sin(\frac{2\pi(year-1946+phase)}{period}) + k(\bar{w}-w)}$$

Where $f(SSB)$ is the same as the standard Ockham function.

$$f(SSB) = \begin{cases} a & \text{if} \quad SSB \geq b \\ \frac{a \cdot SSB}{b} & \text{if} \quad SSB < b \end{cases}$$

$\bar{w}$ is here the mean weight in the spawning stock.

This recruitment function is further described in Bogstad et al. (2004).

4.3.2 Recruitment Error

For all recruitment functions an error distribution must be specified (it can be set as *none* if no error is to be added). The error distribution is specified using one of the following formats.

Normal distribution

```
error normal
cv    <coefficient of variance>
[bias <Optional bias age vector>]
trunk <truncation>
```

This gives an error (ε) drawn from a normal distribution with $mean = 0.0$ and $sd = cv$. ε is truncated to be in the range $[-trunk \cdot cv \rightarrow trunk \cdot cv]$. If R is one of the recruitment functions in Section 4.3.1 the number of recruits is then $R' = R + R \cdot \varepsilon$.

Optionally bias can be included. This gives the number of recruits as $R' = R + R \cdot \text{bias} + R \cdot \varepsilon$.

Lognormal distribution

```
error lognormal
cv    <cv on a log scale>
[bias <Optional bias age vector>]
trunk <truncation>
```

This gives an error (ε) drawn from a lognormal distribution with $mean = 0.0$ and $sd = cv$. ε is truncated to be in the range $[-trunk \cdot cv \rightarrow trunk \cdot cv]$. The number of recruits is then $R' = R{\cdot}e^{\varepsilon}$.

Optionally bias can be included. This gives the number of recruits as $R' = R \cdot \text{bias} + R{\cdot}e^{\varepsilon}$.

No error

```
error none
```

This gives no error added to the recruitment. $R' = R$.

4.3.3 Special recruitment functions

In this section we list ad-hock recruitment functions which have been added for specific situations. They are not meant to be general.

Cyclic Haddock

This is a special recruitment function intended used for haddock. It gives recruitment according to the following 7-year cycle:

- Four years with *low* recruitment.

- One year with *good* recruitment.
- Probability p of a year with *outstanding* recruitment,
  or a year with *good* recruitment with probability $1 - p$.
- One year with *good* recruitment.

For the years with low recruitment a Ricker function is used. A ricker function is also used for the good years, and an Ockham function is used for the outstanding year. Thus three sets of recruitment parameters must be given; for the Ricker function in low years, for the ricker function in good years, and for the Ockham function in Outstanding years. In addition and error function must be specified after each of these recruitment functions. The Input formats are the same as described for the Ricker function, Ockham function, and error functions described in the previous sections. The complete format for the cyclic haddock recruitment is thus as follows:

```
type haddock-cyclic
low-recruitment
  a <parameter a for ricker>
  b <parameter b for ricker>
  [ssb-cutoff <optional parameter ssb-cutoff for ricker>]
  error <error type>
  <parameters for error>
good-recruitment
  a <parameter a for ricker>
  b <parameter b for ricker>
  [ssb-cutoff <optional parameter ssb-cutoff for ricker>]
  error <error type>
  <parameters for error>
outstanding-recruitment
  p <probability of outstanding recruitment>
  a <parameter a for ockham>
  b <parameter b for ockham>
  error <error type>
  <parameters for error>
```

4.4 Management File

The management file defines the management rule to use for setting the fishing quota. It also specifies how the real model is distorted before the managers see it, and how the decided quota is distorted before it is fed back to the real model. The format is as follows:

```
[ManagementDistortions]
ImplementationError distortion none
InputNumbers        distortion none
InputFishing        distortion none
Recruitment         distortion none
```

```
[ManagementRule]
type <management rule>
<input for management rule>
```

The format for distortion is the same as for the population file (Section 4.2). The rule type can be one of *constantf*, *tac*, or *lookahead*. Let F be the *reference* F (arithmetic average over the age range $fbarmin - fbarmax$) and S_a the selection age vector. The *fishing mortality* for age a is then given by:

$$F_a = F \cdot S_a \cdot \frac{\sum_{a=\text{fbarmin}}^{\text{fbarmax}} S_a}{(\text{fbarmax} - \text{fbarmin} + 1)}$$

All the rules will calculate a quota in tons for year $y + 1$. We then use the selection pattern (from the input file) to find the appropriate fishing level that gives this quota. We then use this fishing level to calculate catch in numbers for year $y + 1$. This catch in numbers is then fed back to the model and used for fishing in year $y+1$ after possibly being distorted. The ImplementationError above decides how the quota is distorted before it is fed back into the model as fishing mortality.

4.4.1 Constant F Rule

For the *constant F rule* the format is:

```
type         constantF
Selection    <selection age vector>
FaboveBpa    <F level above Bpa>
[Fmin        <Optional minimum F level>]
[FlowRec     Optional keyword enable adjustment of F at low recruitment>]
[LowRec      <LowRec> Recruitment belowe this number is considerd poor.]
[LowYears    <years> How many years of recruitment to consider]
[Freduction  <factor> At low recruitment multiply F by this factor]
[HistoricRec <recruitment vector> Historic recruitment before first year]
Maxinc       <Max increase in quota from last year>
Maxdec       <Max decrease in quota from last year>
MaxTAC       <Max allowed catch in weight>
FirstYearTAC <quota for intermediate year>
FbelowBpa    <function type>
```

The *fbelowpa* function is one of the keyword *flat*, *low*, or *linear*. The formats are:

```
flat
```

Which gives $F = F_{target}$ when $SSB < B_{pa}$

```
low
Flow <flevel>
```

Which gives $F = F_{low}$ when $SSB < B_{pa}$

```
linear
Bzero <Bzero>
```

Which gives $F = \frac{(SSB - B_{zero}) \cdot F_{aboveBpa}}{B_{pa} - B_{zero}}$ when $B_{zero} < SSB < B_{pa}$ and $F = 0$ when $SSB < B_{zero}$.

If $SSB(y+1) > B_{pa}$ and $SSB(y) > B_{pa}$, the quota is constrained by the limits on year-to-year change indicated by the keywords *maxinc* and *maxdec*: If the quota is more than *maxinc* percent larger than last years quota, or more than *maxdec* percent less, we adjust the quota to be within *maxdec* and *maxinc* percent of last years quota.

If *firstyeartac* is -1 the *maxinc* and *maxdec* values are not used for setting the quota in year $y+1$. If *firstyeartac* is positive the value is used when applying the *maxinc* and *maxdec* check in year $y+1$.

The $MaxTAC$ parameter makes it possible to use this option to apply a constant F rule with a catch ceiling.

If the *FlowRec* is present, the following keywords must also be present in this exact order:

```
FlowRec
LowRec      <LowRec>
LowYears    <years>
Freduction  <factor>
HistoricRec <recruitment vector>
```

This option will reduce F when the stock goes through several consecutive years with poor recruitment. The value Lowrec gives the level the average recruitment has to fall below to be considered poor. The value LowYears specifies over how many years this average recruitment is calculated.' The value *Freduction* gives a factor by which the target F level will be multiplied in case of poor recruitment. The recruitment vector gives recruitment values for the years before the intermidiate year in the model. There must be $LowYears - 1$ values given.

If the optional *Fmin* is given, it must be followed by an F value. Whenever there is a year where the fishing level is below this *Fmin* level, except in years where $SSB < Bpa$, F will be adjusted up to the Fmin level. Because the *constantF* rule applies a constant F level, the *Fmin* option is only useful if some other constrains that can potentially reduce F are also in use.

It is not advised to use both the FlowRec *and* Fmin *options at the same time. A warning will be given if you do so.*

4.4.2 Lookahead Rule

The Lookahead rule is a generalization of the 3-year rule. The 3-year rule was suggested by the Joint Norwegian-Russian Fisheries Commission in 2002, as a way of stabilizing the quota for the Northeast Arctic cod and haddock stocks by looking more than one year into the future.

The format for the lookahead rule is similar to the format for the *constantF* rule (4.4.1) with a few changes:

```
type         lookahead
[years       <N> Optional specification of how many years to simulate]
selection    <selection age vector>
FaboveBpa    <F level above Bpa>
[Fmin        <Optional minimum F level>]
[FlowRec     Optional keyword enable adjustment of F at low recruitment>]
[LowRec      <LowRec> Recruitment below this number is considered poor.]
[LowYears    <years> How many years of recruitment to consider]
[Freduction  <factor> At low recruitment multiply F by this factor]
[HistoricRec <recruitment vector> Historic recruitment before first year]
Maxinc       <max increase in quota from last year in percent>
Maxdec       <max decrease in quota from last year in percent>
MaxTAC       <max allowed catch in weight>
Firstyeartac <quota for intermediate year>
[MaxChangeRuleVariant <Optional keyword>]
Fbelowpa     <function type>
```

The Optional keyword *years* specifies how many years to simulate forward when deciding on the quota. If this keyword is omitted, it will be set to 3 years.

When the *Lookahead Rule* is used in year y to set the fishing quota for year $y+1$, we first simulate N years forward from these starting values, with a fishing level dependent on SSB(y+1) in the same way as in the *constant F rule*.

We set the quota for year $y+1$ as the average of the catch in tons in the years $y+1$, $y+2$, ... ,$y+n$ from the simulation we did.

If $SSB(y+1) > B_{pa}$ and $SSB(y) > B_{pa}$, the quota is constrained by the limits on year-to-year change in the same way as for the *constant F rule*. But if the optional keyword *MaxChangeRuleVariant* is specified, the year-to-year change is only constrained if $SSB(y') > B_{pa}$ for all the years y, $y+1$, $y+2$ and $y+n$.

If weight in catch is density-dependent (4.5) and the *3-year rule* is used, The *weight at age in the catch* used by the rule in year $y+1$ is also used int the remaining years.

The options *Fmin* and *FlowRec* work as for the *constantF* rule, and are described in section 4.4.1

4.4.3 3-year Rule

The 3-year rule has been deprecated, please use the lookahead rule instead.

The 3-year rule is a way of stabilizing the quota by looking more than one year ahead. It was suggested by the Joint Norwegian-Russian Fisheries Commission in 2002, for the Northeast Arctic cod and haddock stocks.

The format for the 3-year rule is:

```
type         3year
selection    <selection age vector>
```

```
FaboveBpa     <F level above Bpa>
Maxinc        <max increase in quota from last year in percent>
Maxdec        <max decrease in quota from last year in percent>
MaxTAC        <max allowed catch in weight>
Firstyeartac <quota for intermediate year>
[MaxChangeRuleVariant <Optional keyword>]
Fbelowpa      <function type>
```

When the *3-year Rule* is used in year y to set the fishing quota for year $y+1$, we first simulate 3 years forward from these starting values, with a fishing level dependent on SSB(y+1) in the same way as in the 3-year rule.

We set the quota for year $y+1$ as the average of the catch in tons in year $y+1$,$y+2$, and $y+3$ from the simulation we did.

If $SSB(y+1) > B_{pa}$ and $SSB(y) > B_{pa}$, the quota is constrained by the limits on year-to-year change in the same way as for the *constant F rule*. But if the optional keyword *MaxChangeRuleVariant* is specified, the year-to-year change is only constrained if $SSB(y') > B_{pa}$ for all the years y, $y+1$, $y+2$ and $y+3$.

If weight in catch is density-dependent (4.5) and the *3-year rule* is used, The *weight at age in the catch* used by the rule in year $y+1$ is also used for the years $y+2$ and $y+3$.

4.4.4 Tac Rule

For the *Tac Rule* the format is:

```
type tac
Selection <selection age vector>
maxF      <maximum F level>
TAC
<y_1> <Tac_1>
<y_2> <Tac_2>
.     .
.     .
.     .
<y_n> <Tac_n>
```

With this rule you simply specify in the input file the quota in tons for each year. The *maxF* parameter makes it possible to use this option to apply a fixed F rule with a catch ceiling.

4.5 Density dependent processes

In this file, you can specify that various processes in the model will be density dependent. The processes are growth (stock weights and catch weights), maturity, and cannibalism. In all cases the age range the process will apply to can be restricted to a subrange of the full age range in the stock. There is also an option to give minimum and maximum values for each age group.

The functional forms for growth, and the first maturity variant are described in Bogstad et al. (2004). All the functions are further described below.

The format for density dependent processes is:

```
stockweight <yes or no>
<if yes, additional input for stockweight>

catchweight <yes or no>
<if yes, additional input for catchweight>

maturity <yes or no>
<if yes, additional input for maturity>

cannibalism <yes or no>
<if yes, additional input for cannibalism>
```

4.5.1 Growth (stockweight and catchweight)

The following function is used for weight in the stock:

$$ws_{a,y} = \alpha_a TSB_{y-1} + \beta_a$$

For weight in the catch this function is used:

$$wc_{a,y} = \alpha_a ws_{a,y} + \beta_a$$

Both *stockweight* and *catchweight* uses the following format:

```
minage      <minage>
maxage      <maxage>
alpha       <alpha parameter age vector>
beta        <beta parameter age vector>

limit                          ; optional limit
  min  x1 ... xn               ; minimum value for each age (optional)
  max  y1 ... yn               ; maximum value for each age (optional)
```

4.5.2 Maturity

The maturation process can use one of two different functions. The *function* keyword followed by *densitydependent* or *weightdependent* selects which function to use.

The *densitydependent* function is:

$$P_{a,y}(TSB) = \frac{1}{1 + e^{-\alpha(\gamma a - \kappa - TSB_{y-1})}}$$

Where TSB denotes total stock biomass.

The *weightdependent* function is:

$$P_{a,y}(ws_{a,y}) = \frac{1}{1 + e^{-\lambda_a(ws_{a,y} - w_{50,a})}}$$

The format for the *densitydependent* function is:

```
function    densitydependent
minage      <minage>
maxage      <maxage>
alpha       <alpha parameter>
kappa       <kappa parameter>
gamma       <gamma parameter>

limit                          ; optional limit
  min  x1 ... xn               ; minimum value for each age (optional)
  max  y1 ... yn               ; maximum value for each age (optional)
```

The format for the *weightdependent* function is:

```
function    weightdependent
minage      <minage>
maxage      <maxage>
lambda      <lambda parameter age vector>
w50         <w50 parameter age vector>

limit                          ; optional limit
  min  x1 ... xn               ; minimum value for each age (optional)
  max  y1 ... yn               ; maximum value for each age (optional)
```

4.5.3 Cannibalism

The cannibalism process can use one of two different functions. The *function* keyword followed by *ssblag3* or *biomass6and7* selects which function to use. The *ssblag3* function is:

$$M2_{y,a} = \alpha_a SSB_{y-3} + \beta_a$$

Where SSB denotes spawning stock biomass. The *biomass6and7* function is:

$$M2_{y,a} = \alpha_a(N_{y,6}W_{y,6} + N_{y,7}W_{y,7}) + \beta_a$$

Both the *ssblag3* and *biomass6and7* function uses the following input format:

```
function    <ssblag3 or biomass6and7>
minage      <minage>
maxage      <maxage>
alpha       <alpha age vector>
beta        <beta age vector>

limit                          ; optional limit
  min  x1 ... xn               ; minimum value for each age (optional)
  max  y1 ... yn               ; maximum value for each age (optional)
```

4.6 Historic weight and maturity

In this file, you can specify how stock weights, catch weights, and maturity are drawn from historic time series. The format is:

```
numberofyears <n>

stockweight <yes or no>
file <file with historic stockweights>

catchweight <yes or no>
file <file with historic catchweights>

maturity <yes or no>
file <file with historic maturities>
```

Each of these files has the following format:

```
historicdata
d1,1 ... d1,a
 ...
dy,1 ... dy,a
```

where y is the number of years with historic data, and a is the number of age groups.

5 Prost Output Files

Summary output is written to the file `summary.csv`. More detailed output for individual variables can be found in `fishing.csv`, `distortedfishing.csv`, `recruit.csv`, `catch.csv`, `ssb.csv`, and `tsb.csv`. On the file `rule.csv` it is indicated how often the various segments of a HCR are activated.

The file `out.csv` gives very detailed output, and can become quite large. It is most useful for diagnostic purposes. All the output files are written as comma separated values (`.csv`) and can thus be imported into *Excel* or other spreadsheets for further processing.

6 Suggested extensions

- Extend the *linear* option in the *fbelowpa* function with a new parameter $Fzero$. The formula for F will then be: $F = Fzero + \frac{(SSB - B_{zero}) \cdot F_{aboveBpa}}{B_{pa} - B_{zero}}$ when $B_{zero} < SSB < B_{pa}$ and $F = Fzero$ when $SSB < B_{zero}$.
- Extending the historic option so that fishing pattern and natural mortality also can be drawn from historic times series.
- Allow for a non-zero proportion of F and M before spawning.
- Allow for the maximum increase/decrease in TAC from year to year to be given in biomass in addition to as a percentage.

7 References

Bogstad, B., Aglen, A., Skagen, D. W., Åsnes, M.N., Kovalev, Y., Yaragina, N. A. 2004. *Evaluation of the proposed harvest control rule for Northeast Arctic cod.* Pp. 396-417 in Report of the ICES Arctic Fisheries Working Group, Copenhagen 4-13 May 2004. ICES C.M. 2004/ACFM:28, 483 pp.

ICES 2004a. *Report of the ICES Study Group for Long Term Advice*, Copenhagen 23-27 February 2004. ICES C.M. 2004/ACFM:16, 38 pp.

ICES 2004b. *Report of the ICES Working Group on Fish Stock Assessment Methods*, Lisbon 11-18 February 2004. ICES C.M. 2004/D:03, 232 pp.

Skagen, D. W., Bogstad, B., Sandberg, P., and Røttingen, I. 2003. *Evaluation of candidate management plans, with references to North-east Arctic cod.* ICES C.M. 2003/Y:03, 19pp.