Theme Session 3: RETROSPECTIVE ANALYSES OF ASSESSMENTS AND MANAGEMENT ADVICE FOR BARENTS SEA FISH STOCK

AN EVALUATION OF THE METHODOLOGY FOR PREDICTION OF CAPELIN BIOMASS

by

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Abstract

The one-year prediction of capelin made as part of the assessment after the annual joint acoustic capelin survey during the autumn, is evaluated. Such predictions were made for the period from 1981 till present, and compared to observed stock sizes. The results show that the predictions underestimate the stock size in about half of the years and overestimate the stock size in the others, but in 18 out of the 23 years the observed stock sizes are within the 90% confidence interval of the predictions. It is found that there is a tendency for overestimating stock size in periods when the stock decreases and vice versa. The ratio between predicted and observed stock sizes is variable and some times quite high for stock sizes below one million tonnes (collapsed stock size) but varies between about 0.5 and 1.5 and is unrelated to stock size for larger stock sizes. These results are discussed in light of the various components of the models involved in the predictions.

1. Introduction

The capelin (*Mallotus villosus*) stock in the Barents Sea is surveyed by an annual acoustic survey in September/October (Gjøsæter *et al*., 1998). Almost all capelin die after spawning, and the capelin stock is managed by a target escapement strategy. The quota (TAC) is calculated based on a ½-year prediction of spawning stock size 1 April the year after. The quota is set so that there is a 95% probability for the SSB to be above 200 000 tonnes (ICES, 2005). The Joint Norwegian-Russian Fishery Commission accepted this harvest control rule in 2003.

The capelin stock, as well as the capelin catches, has fluctuated strongly (ICES 2005, Fig. 1). The stock abundance has varied between 0.1 and 7 million tonnes. The maximum annual catch recorded is close to 3 million tonnes, but the fishery has been closed in several periods (1987-1990, 1994-1998, 2004-present).

The current methodology for assessment of the Barents Sea capelin stock, using a combination of the multispecies model Bifrost (Tjelmeland, 2002) and the spreadsheet model CapTool (Gjøsæter et al., 2002) run in the @RISK add-in to MS Excel, has been applied since 1997. Up to 1998 the models served the purpose of giving a ½-year prediction of spawning biomass from the survey in autumn to the spawning next spring, for use in the quota calculations for the winter fishery. The models have been steadily enhanced, and from 1999 a one-year prediction of biomass of 1+ capelin from the autumn survey to the time of the next autumn survey was included. Such predictions include many sources of uncertainty. However, even an uncertain prediction might be of value for some purposes, e.g. for giving a first

prediction of the amount of capelin available as food for cod (*Gadus morhua*) and other predators during the coming year (see e.g. Bogstad *et al.* 2000 for a description of predator-prey interactions in the Barents Sea). The amount of capelin available for cod may affect both individual cod growth and cod cannibalism. Another use of the one-year prediction might be to give the management authorities an early indication of the expectances for the capelin fishery one-and-a-half year ahead of time.
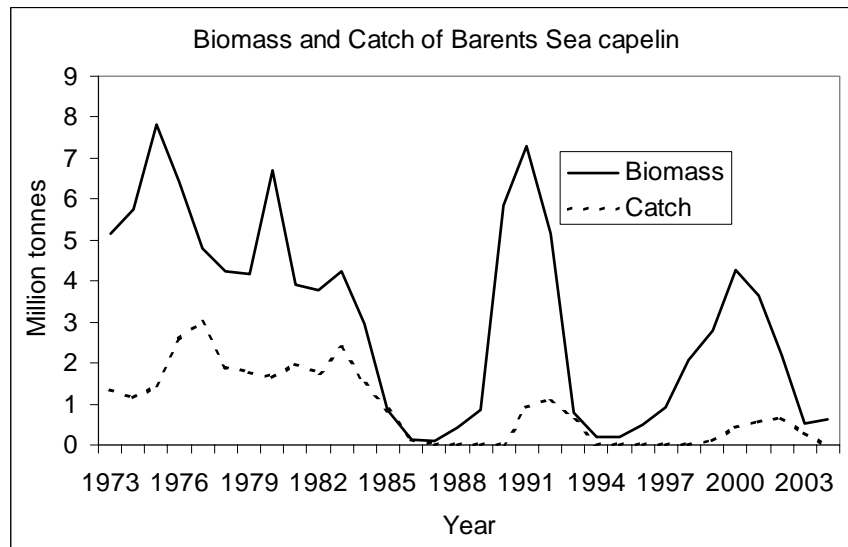

Figure 1. Biomass and catch of the Barents Sea capelin

The aim of this paper is to evaluate the current methodology for one-year-predictions of capelin biomass by comparing them to observed stock sizes, and to discuss the goodness of the predictions in light of the total information about the stock. We will not review the actual one-year predictions made during the period 1998-2004, when varying methodologies were used. We also outline how more biological knowledge could be taken into account in the predictions.

2. Material and methods

The period 1981-2004 was chosen. The reason for this is that before 1981, the coverage of 1-group capelin during the acoustic survey was incomplete (Gjøsæter *et al.*, 1998).

The calculations were performed using Excel spreadsheets with the @RISK add-in. Five thousand simulations were made for each year.

2.1. Input data:
- Capelin abundance and size at age (number by age and length group, mean weight and length at age) measured by an acoustic survey in September (Gjøsæter *et al.*, 1998, updated numbers given in ICES (2005). The uncertainty in the capelin stock estimates is based on resampling the September estimates (both total acoustic abundance and biological samples), as described by Tjelmeland (2002). A CV of 0.2 is used for all years; this is close to the long-term average. The same CV is applied for all age groups, and the CV for the various age groups are assumed to be uncorrelated.

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- Capelin 0-group abundance from the annual 0-group survey in August-September (ICES, 2005).

2.2. Models for population dynamics

The following population dynamics processes are modeled: Mortality-Maturation-Recruitment-Growth.

When making the sub-models for these population dynamics processes, we assume that current knowledge (time series from 1981-2004) is available when making the predictions.

2.2.1. Mortality

Two kinds of mortality are modeled: Spawning mortality and residual mortality. Fishing mortality on immature capelin is ignored, and since total spawning mortality on mature capelin is assumed, the fishing mortality on mature capelin is not of interest for the 1-year prediction.

2.2.1.1. Spawning mortality

All mature capelin are assumed to die on April 1, due to spawning mortality. The calculation of the proportion mature is described in Section 2.2.2.

2.2.1.2. Residual mortality

The residual mortality was drawn from the historical time series of natural mortality of immature capelin from the period 1983 till present, calculated as described in Section 2.2.2. Predation by cod on mature capelin in the period January-March is modeled in Bifrost. However, the development of the immature capelin stock from year *y* to year *y+1* is independent of this predation mortality.

2.2.2. Maturation

The proportion mature, *PM(l),* is modeled in the following way:

$$PM(l) = \frac{1}{1 + e^{4P_1(P_2-l)}} \; , \tag{1}$$

where *l* is the fish length.

The maturation function is applied on the acoustic stock estimate in autumn (October 1), in order to separate the modeled stock into a mature and an immature part. The parameters P_1 and P_2 are estimated with uncertainty using the model Bifrost (Gjøsæter et al. 2002, see also www.assessment.imr.no). The estimations are done by simulating one year ahead using the model, assuming total spawning mortality, and comparing the number of modeled fish at ages 3 and 4 with the observations from the survey one year later. The estimations were made using data from 1972-1980, and an M-value for this period was also estimated. The reason for not using the full time series is that during the chosen time range the population dynamics was stable, with relatively constant M-values. Later there were large variations in M as herring (*Clupea harengus*) re-entered the Barents Sea, and possibly also connected to large

fluctuations in the harp seal (*Phoca groenlandica*) stock. For years after 1980, annual mortality parameters are estimated using the estimated maturation parameters for the period 1972-1980. P_1 was set to 3.5, which makes the maturation function close to a step-function in compliance with earlier treatment of maturation. The mean value of P_2 is 13.89, which is close to the value estimated by Tjelmeland and Bogstad (1993).

2.2.3. Recruitment

Gundersen and Gjøsæter (1998) established a linear regression between the logarithm of the 0-group area based indices and the logarithm of the 1-group acoustic abundance 1 year later.

This regression has been annually updated with new data, and used in the predictions of capelin stock size. Revised 0-group indices calculated using the method described by Dingsør (2005) and Anon. (2005) are now available (ICES, 2005). Using those indices without correction for length-dependent selectivity in the trawl, we found that a linear regression gave better fit than a log-log regression. The new regression, using data from the 1981-2003 year classes, is shown in Fig. 2.
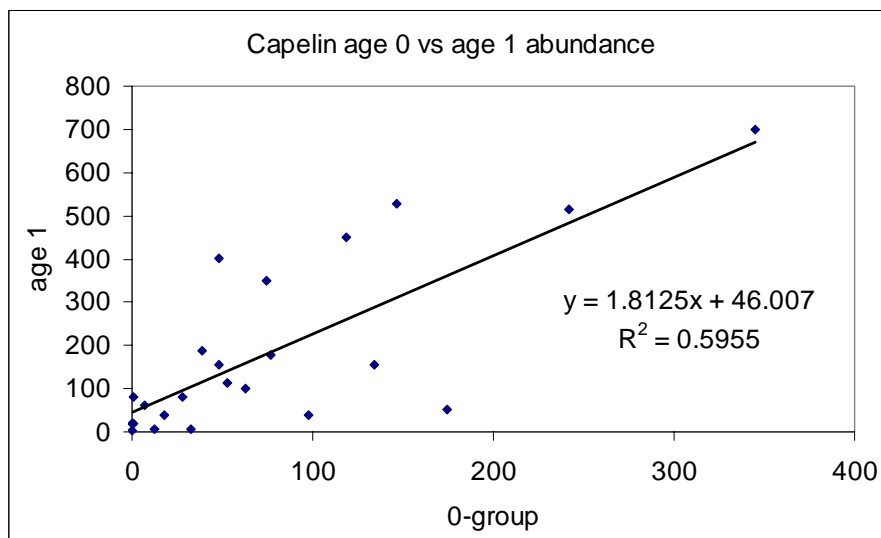

Figure 2. Regression of abundance of capelin at age 0 and age 1

2.2.4. Individual growth

The individual growth in length (cm/year) for each age group can be calculated from values obtained by comparing the mean length at age of immature capelin one year with the mean length at age of the total stock next year, for the period 1981-2004. The individual growth (in cm/year) for age 1 and older fish, i.e. for age groups (1-2, 2-3, 3-4) is drawn randomly from the time series. The length distribution of age 1 fish is drawn from the historical time series.The growth of fish from age 4 to 5 is assumed to be the same as for ages 3-4. The draws from the time series are made separately for each age group, i.e. we do not draw the same year's growth for all ages. However, it might be more logical to change this into drawing one year and use that year's growth for all age groups.

The length growth is implemented by shifting the distribution of immature capelin upwards with the number of 0.5cm length intervals, which corresponds to the growth in length, for each age group and year.

The capelin length-weight relationship for use in the 1-year prediction is drawn randomly from historical data for the period 1981-2004.

3. Results

3.1. Prediction of total stock size

Table 1 shows the results of the simulations for the total stock.

Table 1. Comparison of predicted (with confidence limits) and observed total capelin stock size during the period 1981 to 2003

Year	Stock abundance (1+) in year y (million tonnes)	Predicted stock abundance (1+) in year y+1 (million tonnes)	Lower Confidence Limit (5%)	Upper Confidence Limit (95%)	Observed stock abundance(1+) in year y+1 (million tonnes)	Ratio predicted/ observed	Residual/ observed
1981	3.90	4.15	1.35	9.64	3.78	1.10	0.10
1982	3.78	4.63	1.76	9.88	4.23	1.09	0.09
1983	4.23	4.59	1.37	10.50	2.96	1.55	0.55
1984	2.96	2.73	0.98	5.35	0.86	3.18	2.18
1985	0.86	1.05	0.39	2.15	0.12	8.73	7.73
1986	0.12	0.35	0.18	0.58	0.10	3.45	2.45
1987	0.10	0.29	0.10	0.58	0.43	0.69	-0.31
1988	0.43	0.66	0.34	1.17	0.86	0.76	-0.24
1989	0.86	3.37	1.75	5.62	5.83	0.58	-0.42
1990	5.83	4.84	1.00	12.56	7.29	0.66	-0.34
1991	7.29	6.47	1.37	16.46	5.15	1.26	0.26
1992	5.15	3.73	0.60	9.84	0.80	4.69	3.69
1993	0.80	0.64	0.18	1.55	0.20	3.19	2.19
1994	0.20	0.38	0.16	0.68	0.19	1.95	0.95
1995	0.19	0.26	0.09	0.51	0.50	0.52	-0.48
1996	0.50	0.95	0.47	1.69	0.91	1.04	0.04
1997	0.91	1.39	0.62	2.66	2.06	0.68	-0.32
1998	2.06	1.82	0.58	4.01	2.78	0.66	-0.34
1999	2.78	2.24	0.92	4.48	4.27	0.52	-0.48
2000	4.27	2.96	0.78	6.96	3.63	0.82	-0.18
2001	3.63	2.06	0.42	5.13	2.21	0.93	-0.07
2002	2.21	1.32	0.42	2.91	0.53	2.47	1.47
2003	0.53	1.64	0.93	2.55	0.63	2.61	1.61

In 18 out of the 23 years, the observed stock size is within the 90% confidence interval of the predicted stock size (Figure 3). However, the confidence intervals are rather wide in most years, and the difference between predicted and observed values is quite large in many of the years. In half of the years the stock sizes are underestimated, in the other years they are overestimated. However, the sign of the residuals is not randomly distributed along the time

series; it is evident that there is a trend in the data, where periods of overestimation alternate with periods of underestimation. With a few exceptions, the stock size is underestimated in periods when the stock is increasing, and overestimated in periods when it is decreasing (Figure 3). When the ratio between predicted and observed stock sizes are plotted versus observed stock size during the period, it is seen that the positive ratios (overestimation) are larger than the negative ratios, and there is seemingly a tendency for the highest ratios to occur when the stock size is at a minimum (Figure 4). This tendency is confirmed when the ratios are plotted versus observed stock size (Figure 5), but above an observed stock size of about 1 million tonnes, the relationship between the ratio and the observed stock size flattens out (linear regression, b=-0.03, R^2=0.02).
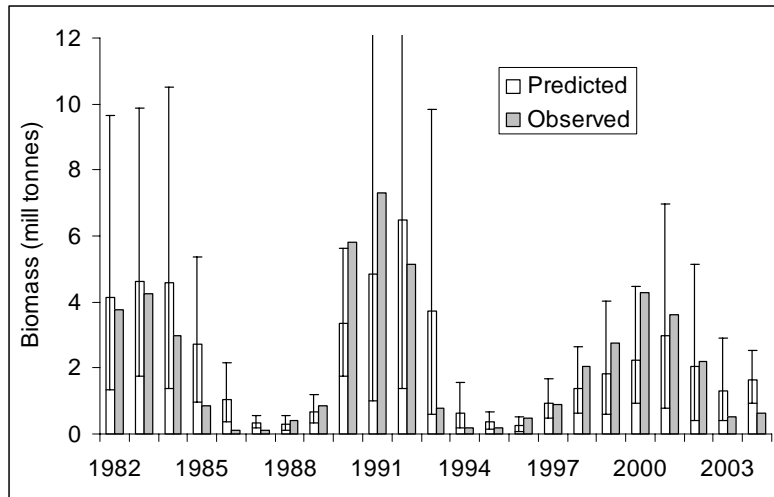
Figure 3. Predicted (with 90% confidence interval) and observed total stock sizes during the period 1982 to 2004
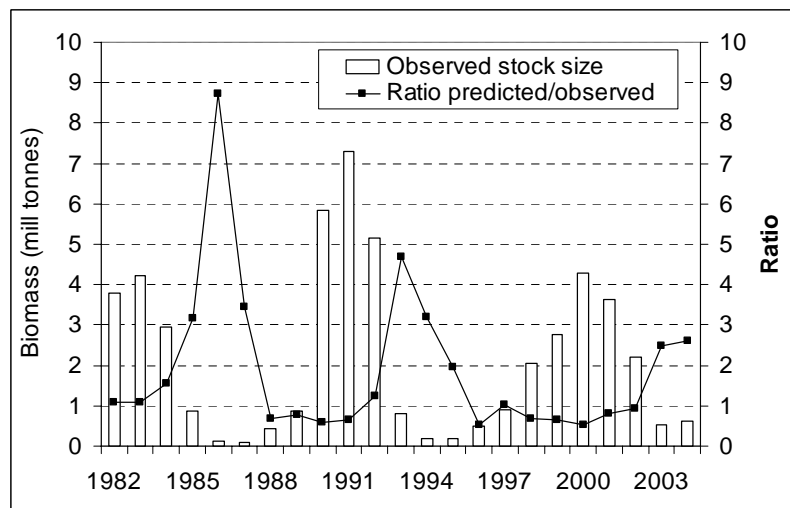
Figure 4. Time series of observed stock size and corresponding ratio between predicted and observed stock size during the period 1982 to 2004
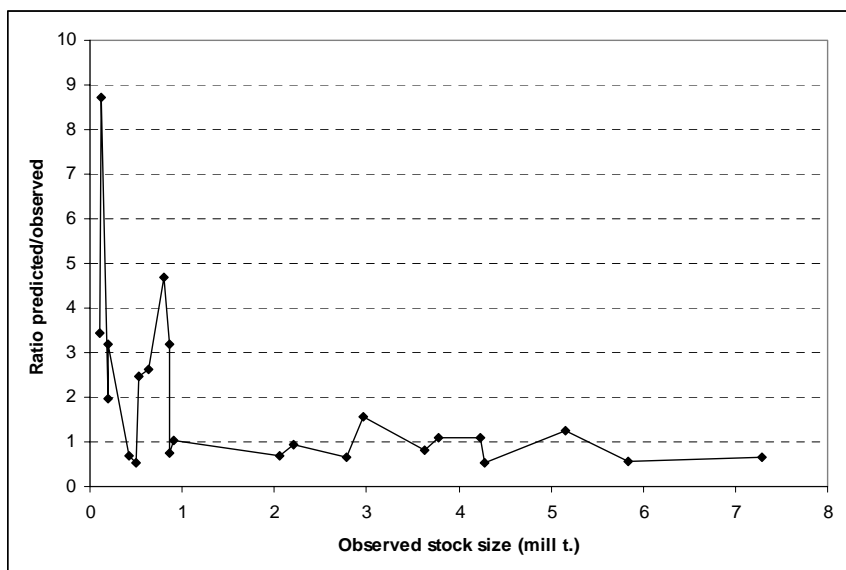
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Figure 5. Ratio between predicted and observed stock size plotted versus observed stock size

There is no clear trend in the relative residuals ((predicted – observed)/observed) when plotted versus the observed stock size (Figure 6). The residual for the year 1985 is more than twice as large as any of the other residuals. That year, the stock collapsed and the predicted stock size for 1986 was almost 9 times as large as the observed stock size.
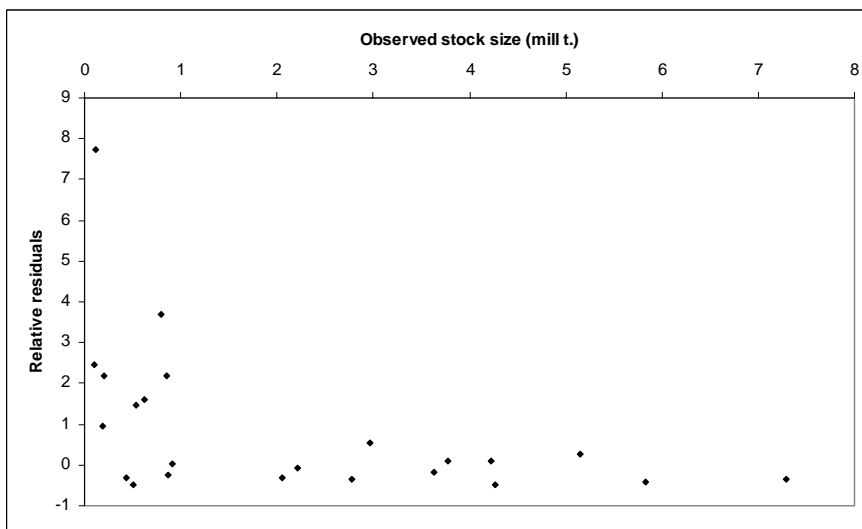

Figure 6. Relative residuals plotted versus observed stock size

3.2. Year class strength of the 1-year-olds

In addition to the simulations of total stock size of one-year-olds and older capelin, the part of the prediction constituting the one-year-olds was analyzed separately. The results are given in Table 2.

Table 2. Comparison of predicted (with confidence limits) and observed biomass of 1-year-old capelin during the period 1981-2003

Year	Predicted abundance of age 1 in year y+1 (million tonnes)	Lower Confidence Limit (5%)	Upper Confidence Limit (95%)	Observed abundance of age 1 in year y+1 (million tonnes)	Ratio predicted/ observed	Residual/ observed
1981	1.11	0.64	1.65	1.22	0.91	-0.09
1982	1.73	1.00	2.60	1.60	1.08	0.08
1983	1.04	0.61	1.55	0.57	1.81	0.81
1984	0.80	0.47	1.19	0.17	4.59	3.59
1985	0.38	0.21	0.60	0.02	16.23	15.23
1986	0.28	0.13	0.48	0.08	3.60	2.60
1987	0.17	0.03	0.36	0.07	2.40	1.40
1988	0.42	0.24	0.65	0.61	0.68	-0.32
1989	2.40	1.33	3.57	2.66	0.90	-0.10
1990	0.48	0.28	0.72	1.52	0.31	-0.69
1991	0.65	0.39	0.96	1.25	0.52	-0.48
1992	0.17	0.04	0.35	0.01	22.08	21.08
1993	0.18	0.03	0.37	0.09	2.04	1.04
1994	0.25	0.10	0.45	0.05	5.23	4.23
1995	0.18	0.04	0.36	0.24	0.75	-0.25
1996	0.58	0.33	0.86	0.42	1.38	0.38
1997	0.67	0.39	0.99	0.81	0.83	-0.17
1998	0.48	0.27	0.72	0.65	0.73	-0.27
1999	0.94	0.54	1.38	1.70	0.55	-0.45
2000	0.51	0.29	0.77	0.37	1.36	0.36
2001	0.22	0.08	0.41	0.23	0.92	-0.08
2002	0.35	0.18	0.56	0.20	1.74	0.74
2003	1.29	0.73	1.93	0.20	6.61	5.61

For the one-year-olds, the observed values are within the confidence limits of the predicted values in only 13 out of the 23 years (Figure 7). That means that the prediction of one-year-olds constitutes a "weak part" of the prediction of total stock size. Similarly to the predictions of total (1+) biomass there is also in this case a trend of overestimation in cases of an increasing stock and underestimation when the stock is declining. However, the trend is not as systematic as found for the total predictions. On average, there is an annual overestimation of about 21 thousand tonnes of one-year-olds during this period.
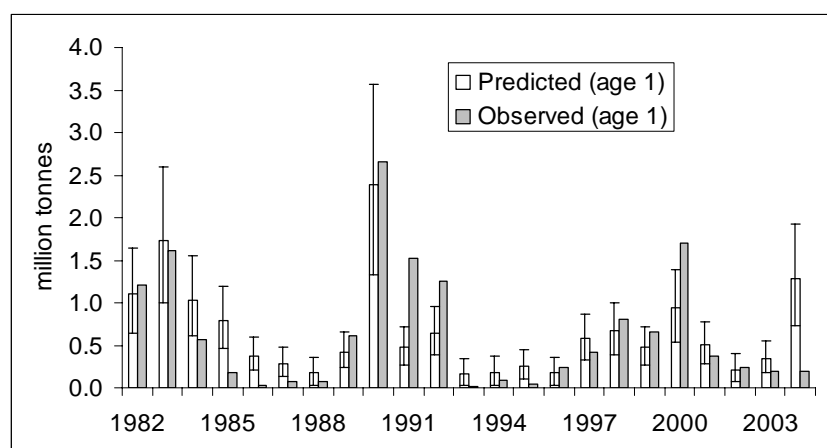

Figure 7. Predicted (with 90% confidence limit) and observed biomass of one-year-old capelin during the period 1982 to 2004

4. Discussion

4.1. Precision of predictions and time lag

The average overestimation of stock size is 96 thousand tonnes, out of which 21 thousand tonnes stem from the one-year-olds, showing that the model has had a slight tendency to overestimate stock size compared to observed values in this period. The predictions obviously "lags behind" the development of the stock, since the model overestimates the stock size when it is declining and underestimates the stock when it is increasing.

4.2. Effect of ignoring catch of immature capelin

Ignoring catch of immature capelin in 1981-1986, 1991-1993 and 2000-2003 leads to overestimation in prediction for these years. The amount of immature fish taken during these periods has varied considerably, but especially for the first of these catch periods catch of immature capelin was quite high, amounting to between 131 and 435 thousand tonnes annually. For 1981 and 1982, the catch of immatures was in fact 118% and 33% of the difference between predicted and observed stock size respectively. For the other years the catch of immatures makes up less than 15% of the difference. This clearly shows the need to take account of these catches, at least when analyzing historical data. Because it is quite time consuming to implement this in the model, it was not possible to do before this symposium. This is a task for the near future.

4.3. Year class strength of the 1-year-olds

The analysis of one-year-olds separately shows that there is a slight tendency for overestimation, but the sign and value of the residuals are less related to stock situation than those for the total predictions. It has not been possible to check the various components of the predictions of one-year-olds, so it is unknown whether it is the natural mortality or the growth that constitutes most of the residuals. Since the mortality is large and variable during this phase (see Figure 2), it seems probable that the rather low accuracy and precision in the predictions of one-year-olds mostly stem from the regression of one-year-olds on the 0-group index. The regression of one-year-olds on 0-group index has a positive intercept. This will inevitably cause a relative increase in overestimation for smaller stock sizes, and may partly explain the increase in ratio between predicted and observed stock sizes seen for smaller stock sizes in figure 5. Further work will include implementation of a regression through the origin, to avoid this effect.

4.4. Natural mortality

One possible reason that the predictions lags behind the stock development is the way the natural mortality is handled, by drawing at random a natural mortality (as observed by the decrease of one year class from one year to the next when fishing and spawning mortality is accounted for) observed during previous years. The rationale behind this method is that the natural mortality is unknown, but may vary randomly within the observed limits. However, it is observed that in periods of stock decline, the natural mortality is increasing and vice versa. If this could be taken into account, a better prediction for natural mortality could be made. However, it is not a straightforward task to implement this in the model, since it is unknown

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whether the stock will increase or decrease during the next year. One possibility would be to draw the natural mortality at random from e.g. the last 2-3 years, since the trends in stock size normally changes in a cyclic manner, and recent years would better reflect current level of natural mortalities.

An even better idea would be to model the natural mortalities with external factors as driving forces. The most obvious factors to try would be density dependence, predation pressure from cod, or rather, a combination of these. The most probable mechanism for an increased natural mortality when the capelin stock is decreasing is that a high predation pressure will exert a galloping mortality (M) as the capelin stock gets smaller. When the capelin stock is above a certain level, one may suppose that M would be inversely proportional to the cod/capelin ratio. When the capelin stock falls below this critical level, the cod may have problems with encountering capelin, and may even actively switch to other food sources. The hypothesized relationship would then break down. Unfortunately time has not allowed us to pursue these ideas further, so this is for the future.

4.5. Growth

The growth from year y to $y+1$ is implemented in an analogous way to the natural mortality. Assuming the actual growth is unknown, the growth rate is drawn at random from previously observed growth rates independently for each age group. In the future, this might be changed into drawing one year and use that year's growth for all age groups. It would be possible to compare the length frequencies in the predictions with those observed, but this is a quite laborious task and has not been done. However, if trends in these residuals could be demonstrated, a logical enhancement would be to model how individual growth from year y to year $y+1$ would depend on some or all of the following factors:

Mean length at age of immature capelin in year y
Total stock abundance in year y
Oceanographic variables in year y
Plankton abundance in year y

This was studied by Bogstad et al. (2005), who found that individual growth from age 1 to 2 was density-dependent, i.e. negatively correlated with the biomass of capelin in year y. They also found how the individual growth from year y to $y+1$ was correlated with the mean length at age of immature capelin in year y. These relationships will be built into the CapTool model.

1.6. Additional possible improvements:

- Use annual estimates of uncertainty of number at age in surveys (including how these numbers are correlated), to get more appropriate measure of uncertainty in survey estimate.
- Try to account for other uncertainties in survey estimate than those modeled by Tjelmeland (2002)

5. Acknowledgements

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