Working document to the ICES
Multispecies Working Group
meeting, December 1990.

CEC — a VPA for cod in the Barents Sea with cod-cod cannibalism

Dankert W. Skagen, Bjarte Bogstad and Sigbjørn Mehl
Institute of Marine Research
P.O.Box 1870 Nordnes
5024 Bergen
Norway

Introduction

In the Barents Sea, it is commonly assumed that the interaction between fish species is strongly dependent on highly variable environmental factors, which not only are important for the recruitment, but also for the geographical overlap between predator and prey.

In the North Sea, on the other hand, modelling the predator - prey interactions under the simple assumption of constant suitabilities has been quite successful. This assumption implies that the predator selects its diet in accordance with the amounts of available prey. The available prey is the modeled biomass of the prey in the North Sea, multiplied by a factor termed suitability, which is constant from year to year and can be computed from a single year's stomach data.

In the Bergen meeting of the MSWG (Anon., 1990) , the question was put forward if this simple assumption would hold also in the Barents Sea. To elucidate this question, we have constructed a simple VPA for cod, where the mortality of younger cod caused by predation from older cod is taken into account. The program is termed CEC (cod eats cod).

Outline of the model.

Cod is the dominating predator among the fish species in the Barents Sea. At the Institute of Marine Research, Bergen, and PINRO, Murmansk, cod stomach data have been collected systematically back to 1984. For these years, it is therefore possible to run a VPA where the M2 for the younger cod is computed directly by summing up the amount eaten by the older ages of cod. This strategy is here termed DVPA. (Direct VPA).

Suitabilities can be computed based on each of these years's stomach data, and applied to the other years. The suitabilities and M2's by this approach are computed the same way as in the MSVPA, using the Helgason-Gislason functional feeding relationship (Gislason and Sparre, 1987). An option for combining the stomach data for all years is also included. As suggested by Sparholt (pers.comm, 1990), this is done by using the mean fractions in the stomach and the mean biomasses over the years, when computing the suitabilities. The only difference from the MSVPA is in the treatment of the 'other food' compartment. Since capelin is an important prey whose biomass can be estimated from survey data, it is entered in the model as a prey biomass, which can be assigned suitabilities, but which is not assessed within the model. In addition, there is an 'other' other food compartment, which may be varied from year to year in the present model. Three options are possible for the treatment of capelin: 1. Not included. 2. Included as a single compartment. 3. Mature and immature capelin treated separately.

Technical details about the program, its operation and the input files are included in the appendix.

Input data.

Cod catch data.

Data on cod catch-at-age and weight-at-age were taken from the latest report of the Arctic Fisheries Working Group (Anon., 1991) . The catch in numbers in each quarter is set to 1/4 of the yearly catch for all age groups. The weight at age in each quarter was set such that the average of the weights for the four quarters is equal to the weight in catch during the year. For the 10+ group, the weight at age for 10-year-old fish was used. For the age groups 1 and 2, weight at age is calculated using survey data for the period 1984–1989 (Anon., 1991). For age 0, the weight was set to 3g in the third quarter and 9g in the fourth quarter, based on unpublished survey data. For the other years, the average for the period 1984–1989 was used. The quarterly M1 was set to 0.2 for age 0, 0.1 for age 1, 0.075 for age 2 and 0.05 for ages 3 and older. As a M2 "guesstimate", 0.01 is used for age 0, 0.0075 for age 1 and 0.005 for age 2. M2 is set to 0 for ages 3 and older. The terminal F's were also taken from (Anon., 1991) . For ages 0,1 and 2 in 1990, dummy terminal F's and catch numbers were set selected to give

numbers at age in the fourth quarter in 1990 in accordance with the numbers at age January 1,1991 given in the working group report.

Stomach data.

The total rations and the ration of capelin consumed per predator age group per quarter were estimated by multiplying the mean stomach content weight by the rate of gastric evacuation, weighted by the distribution of the different cod agegroups in 3 main areas of the Barents Sea (Mehl, 1989). A preliminary version of an exponential evacuation model based on experiments in Northern Norway was used in the calculations (Bogstad and Mehl, 1990). For cod (as prey), the amount consumed of different 5-cm sizegroups was converted to the amount consumed of different agegroups, using data on mean weight and and age composition within each sizegroup. The cannibalism on 0–group cod will be underestimated because most of the stomachs sampled in the autumn are sampled before the 0-group cod has settled to the bottom.

Capelin and other food data.

The capelin biomass available was calculated in the following way: The available biomass in the first quarter was set equal to the biomass of the mature stock January 1, calculated using the natural mortalities and maturation lengths used by the working group (Anon., 1989). For 1989 and 1990 we used the same natural mortalities and maturation lengths as in 1988. The biomass available in the second quarter was set equal to the biomass of the immature (3+) stock April 1 calculated in the same way (assuming equal natural mortality for mature and immature fish). The biomass in the third and fourth quarter was taken to be the biomass estimated from the yearly acoustic estimate in the autumn.

The biomass of other food was arbitrarily set to 5 million tonnes for all years and quarters.

Preliminary results.

Tables 1-5 show the biomass eaten by cod in each of the years 1984-88 as estimated directly from the stomach data (DVPA) and as estimated by applying suitabilities based on each of the stomach years 1984-88. The DVPA results may here be taken as the 'correct' ones. The slight difference between this and

the suitability based estimate for the stomach year itself, is due to the different population numbers obtained when the assessment for the later years is based on the suitabilities.

It is clear that the estimates of the consumption of both cod and capelin based on other year's stomach data, are of limited value. In this respect, the MSVPA concept is too simple for the Barents Sea system. The main reason for this may be that the year to year variations in stock sizes and geographical overlap in this system are far more pronounced than in the North Sea. Nevertheless, this model may be a useful framework for considering also other features of the system. Possible extensions may include corrections for the geographical overlap between old and young cod, other sources of food, and other functional feeding relationships.

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Table 1. Consumption by cod in 1984 (1000 tonnes), estimated directly and by using stomach data for each of the years 1984-1988.

		cod0	cod1	cod2	cod3	cap	other
Quarter= 1							
DVPA		0.0	5.3	3.6	0.2	787.1	488.0
Stom.year	1984	0.0	5.3	3.6	0.2	781.2	480.0
	1985	0.0	0.2	6.8	2.7	1067.2	223.4
	1986	0.0	0.8	5.6	6.3	1192.6	161.9
	1987	0.0	2.3	18.7	4.2	523.4	814.5
	1988	0.0	4.1	0.1	0.0	1183.5	52.3
Quarter= 2							
DVPA		0.0	4.7	2.9	0.1	690.8	434.4
Stom.year	1984	0.0	4.7	2.9	0.1	685.4	427.2
	1985	0.0	0.1	2.6	0.7	1041.7	100.5
	1986	0.0	0.3	2.1	1.0	1151.0	53.2
	1987	0.0	0.5	32.2	1.1	861.5	272.5
	1988	0.0	0.2	0.0	0.0	1098.0	2.3
Quarter= 3							
DVPA		0.0	15.9	3.5	0.1	67.1	846.5
Stom.year	1984	0.0	15.9	3.5	0.1	65.9	817.7
	1985	0.6	31.8	6.7	0.0	113.4	801.4
	1986	0.1	2.9	50.9	2.2	130.7	832.1
	1987	0.9	16.0	3.4	0.0	527.2	431.0
	1988	0.1	2.9	2.3	0.3	134.7	727.6
Quarter= 4							
DVPA		0.0	12.9	2.7	0.0	61.5	736.3
Stom.year	1984	0.0	12.9	2.7	0.0	60.5	710.2
	1985	0.4	26.9	4.7	0.0	232.1	552.1
	1986	0.0	1.1	29.4	0.6	138.7	692.0
	1987	0.8	7.9	1.6	0.0	590.4	256.8
	1988	0.0	1.7	1.4	0.2	216.8	546.7

Table 2. Consumption by cod in 1985(1000 tonnes), estimated directly and by using stomach data for each of the years 1984-1988.

		cod0	cod1	cod2	cod3	cap	other
Quarter=	1						
DVPA		0.0	0.3	20.8	5.7	2003.7	490.7
Stom.year	1984	0.0	4.6	10.0	0.3	1335.8	1028.2
	1985	0.0	0.3	20.8	5.7	1988.6	437.7
	1986	0.0	1.6	18.1	14.2	2232.3	346.1
	1987	0.0	1.6	56.1	8.8	1095.1	1377.8
	1988	0.0	2.8	0.2	0.0	2207.8	121.0
Quarter=	2						
DVPA		0.0	0.3	16.9	4.6	1769.1	433.6
Stom.year	1984	0.0	5.9	11.4	0.5	665.5	1426.0
	1985	0.0	0.3	16.9	4.6	1755.2	385.5
	1986	0.0	1.3	14.5	6.6	2033.2	250.0
	1987	0.0	0.8	73.0	5.2	1689.3	398.6
	1988	0.0	0.4	0.0	0.0	2071.3	15.5
Quarter=	3						
DVPA		3.5	21.1	13.6	0.0	175.0	1246.1
Stom.year	1984	0.0	7.6	6.1	0.2	88.1	1165.3
	1985	3.0	21.1	13.6	0.0	161.2	1142.1
	1986	0.1	3.0	79.7	4.4	182.2	1256.1
	1987	2.3	9.4	7.2	0.0	779.8	501.9
	1988	0.2	1.4	3.7	0.5	201.7	1042.8
Quarter=	4						
DVPA		3.0	17.3	9.7	0.0	154.7	1075.9
Stom.year	1984	0.0	5.6	4.5	0.1	28.2	1071.2
	1985	2.6	17.3	9.7	0.0	142.2	981.6
	1986	0.1	1.3	44.4	1.4	88.1	1141.2
	1987	3.5	6.9	5.5	0.0	695.1	425.9
	1988	0.2	1.2	3.2	0.5	165.4	932.4

Table 3. Consumption by cod in 1986(1000 tonnes), estimated directly and by using stomach data for each of the years 1984-1988.

		cod0	cod1	cod2	cod3	cap	other
Quarter=	1						
DVPA		0.0	2.8	21.4	18.2	807.0	566.4
Stom.year	1984	0.0	8.3	2.8	0.3	235.7	1009.8
	1985	0.0	2.6	13.0	8.7	639.8	634.7
	1986	0.0	2.9	21.4	18.2	810.6	570.3
	1987	0.0	2.4	9.0	4.0	192.8	1076.8
	1988	0.0	9.4	0.3	0.0	966.6	275.2
Quarter=	2						
DVPA		0.0	2.4	17.5	14.7	703.6	494.8
Stom.year	1984	0.0	6.9	1.9	0.4	64.8	1041.9
	1985	0.0	2.5	9.5	11.2	486.3	629.0
	1986	0.0	2.5	17.5	14.7	707.0	498.4
	1987	0.0	2.3	14.3	7.0	660.3	445.2
	1988	0.0	1.6	0.0	0.0	1054.3	57.9
Quarter=	3						
DVPA		0.2	5.6	79.2	11.1	45.2	1401.8
Stom.year	1984	0.0	22.5	2.8	0.4	6.7	1449.8
	1985	1.1	114.2	5.4	0.0	17.3	1428.1
	1986	0.2	5.6	79.2	11.1	45.2	1426.1
	1987	7.6	28.0	4.4	0.5	316.2	1143.8
	1988	0.5	2.9	2.4	1.8	55.0	1403.2
Quarter=	4						
DVPA		0.2	4.6	58.4	8.2	41.3	1163.8
Stom.year	1984	0.0	25.5	4.5	0.8	4.8	1218.8
	1985	2.2	113.1	8.0	0.0	35.4	1124.7
	1986	0.2	4.6	58.4	8.2	41.3	1186.0
	1987	12.9	30.9	6.1	0.6	462.3	754.8
	1988	1.0	4.7	4.3	4.2	97.4	1137.5

Table 4. Consumption by cod in 1987(1000 tonnes), estimated directly and by using stomach data for each of the years 1984-1988.

		cod0	cod1	cod2	cod3	cap	other
Quarter=	1						
DVPA		0.0	1.1	16.4	3.3	90.1	747.6
Stom.year	1984	0.0	7.0	4.1	0.1	116.4	720.0
	1985	0.0	0.7	19.8	4.7	344.4	555.2
	1986	0.0	3.4	27.3	11.9	402.3	515.5
	1987	0.0	1.1	16.4	3.3	90.2	753.7
	1988	0.0	14.6	0.3	0.0	551.4	276.1
Quarter=	2						
DVPA		0.0	0.9	13.6	2.6	80.4	634.4
Stom.year	1984	0.0	2.2	1.1	0.1	2.8	725.6
	1985	0.0	0.4	9.9	4.2	36.0	740.9
	1986	0.0	2.1	14.5	5.6	55.5	733.4
	1987	0.0	0.9	13.6	2.6	80.4	639.9
	1988	0.0	4.5	0.1	0.0	371.1	348.5
Quarter=	3						
DVPA		8.4	4.2	2.1	0.2	82.9	1202.8
Stom.year	1984	0.0	8.5	1.6	0.1	1.1	1290.3
	1985	1.4	45.1	1.5	0.0	4.2	1266.8
	1986	0.1	5.2	38.5	2.7	5.8	1295.6
	1987	8.4	4.2	2.1	0.2	82.9	1205.6
	1988	0.1	1.9	2.0	0.5	11.4	1283.8
Quarter=	4						
DVPA		6.9	3.0	1.5	0.2	65.6	1007.9
Stom.year	1984	0.0	5.0	1.1	0.1	0.3	1078.8
	1985	1.3	23.6	1.1	0.0	3.7	1062.5
	1986	0.0	1.8	13.5	0.8	2.1	1090.4
	1987	6.9	3.0	1.5	0.2	65.6	1010.4
	1988	0.1	1.4	1.5	0.5	9.0	1072.4

Table 5. Consumption by cod in 1988 (1000 tonnes), estimated directly and by using stomach data for each of the years 1984-1988.

		cod0	cod1	cod2	cod3	cap	other
Quarter=	1						
DVPA		0.0	2.0	0.2	0.0	72.6	285.7
Stom.year	1984	0.0	1.0	0.8	0.0	6.8	355.1
	1985	0.0	0.2	6.0	2.5	30.4	367.7
	1986	0.0	1.6	10.9	4.9	31.8	370.6
	1987	0.0	0.2	2.0	0.9	2.9	364.2
	1988	0.0	2.0	0.2	0.0	72.6	285.8
Quarter=	2						
DVPA		0.0	1.7	0.1	0.0	63.3	245.5
Stom.year	1984	0.0	1.1	0.6	0.0	0.3	311.7
	1985	0.0	0.2	5.3	1.7	3.9	339.6
	1986	0.0	2.3	12.3	2.3	5.3	337.9
	1987	0.0	0.7	6.4	1.2	5.0	305.2
	1988	0.0	1.7	0.1	0.0	63.4	245.5
Quarter=	3						
DVPA		0.1	0.8	2.3	0.4	201.0	1096.8
Stom.year	1984	0.0	11.7	2.4	0.1	15.5	1276.7
	1985	0.2	152.0	2.6	0.0	45.4	1162.6
	1986	0.0	21.5	64.8	1.8	86.4	1223.0
	1987	23.7	10.0	2.2	0.0	512.7	768.3
	1988	0.1	0.8	2.3	0.4	201.0	1097.0
Quarter=	4						
DVPA		0.1	0.7	1.9	0.3	158.4	912.3
Stom.year	1984	0.0	5.8	1.8	0.0	4.4	1063.5
	1985	0.1	64.6	1.9	0.0	39.6	986.1
	1986	0.0	8.5	23.8	0.5	32.9	1074.9
	1987	16.1	7.1	1.7	0.0	426.5	633.9
	1988	0.1	0.7	1.9	0.3	158.4	912.5

Appendix The CEC program.

The program is written in Fortran. The present version is running under UNIX on a SUN Sparcstation, but should be transferrable to other computers with minor changes. The VPA is run on a quarterly basis. Room has been made for including a separable VPA instead of entering terminal f's, this option has not been implemented yet.

The program is distributed on 4 files.

cecmain: Main program

cecfilin: Reading of input files

cecalc: Calculations

cecprint: Output

In addition, there is a file termed cecommon which contains common variables and parameters. This is entered in most subroutines by include statements.

The names of input and output files, and options for running the program are read from an 'options file'. Only the name of this file is given interactively.

All input files are supposed to be read in free format, one line being treated as one record. Lines with ! in column 1 are taken as comment lines and skipped at reading.

Input files:

1. Catch file (catches and biological data for cod)

Record format: year age quarter catch-(numbers*1000) weight-(kg) m1 m2

The value for m2 is only used if no stomach data are available.

2. Stomach file (Stomach contents data)

Record format: year predator-age no-of-stomachs cod0 cod1 cod2 cod3 cap1 cap2

where cod0..cod3 and cap1..cap2 is the fraction (in o/oo) of these prey cathegories in the predators diet (stomach content corrected for digestion rate) .

3. Rations file (Predators rations in kg/quarter)

Record format: year age quarter ration

4. Terminal f file (terminal f's)

Record format: year age f-value

These f-values refer to the fourth quarter and are needed at the oldest non-plus group for previous years and for all ages the last year. If no catches are taken for the youngest ages, dummy catches and f's must be given, which give correct starting values for the numbers at age.

5. Capelin file: (Biomass of capelin (tonnes))

Record format: year quarter cap1 cap2

cap1 and cap2 permits division of the capelin biomass into two compartments, e.g. immature and mature.

6. Others file (Biomass of other food)

Record format: year quarter biomass (tonnes)

Options file: The possible options are shown in the printout below. (file cecinit)

```
! File containing options for running the cod-eats-cod programs
!
! All lines containing ! in the first column are comment lines
! These lines are skipped when reading the file.
! Actual values should be filled in in the line below the
! corresponding comment line
!
! (1) name of the file containing catches, mortalities and weights
catch-file
! (2) name of file containing stomach data
stomach-file
! (3) name of file containing rations data
rations-file
! (4) (sepopt) separable option =1, ordinary vpa=0
! NB. Only option 0 is implemented at present
0
! (4) reference age for sep. vpa            These lines can be given
4
! (6-9) quarter  ref f   term s (4 lines)   dummy values if not used
1   0.3     1.5
2   0.5     1.0
3   0.3     1.0
4   0.3     1.0
```

```
! (10) file name for terminal f's (only opened if sepopt=0)
termf-file
! (11) (vpaopt) single vpa =0, d-option =1, suit-option=2, rev. othfood=3
2
! (12) year for computation of suitabilities (99 = all) dummy if not used
1984
! (13) (inclcap) include capelin as prey: 0=no,1=one class,2=each class
0
! (14) file name for capelin data (only openend if vpaopt=2 and inclcap=1)
capelin-file
! (15) file name for other food
others-file
! output files: give file name, not wanted = -
!
! (16) copy of the catch,mortality and weight file with updated m2's
cecinnew
! (17) output file
cecout
! (18) criteria for convergence (difference in (z-zold)**2) at levels 0,1,2,3
0.0001 0.0001 0.0001 0.0001
! (19) options for who eats who tables 0: reduced, 1: by numbers, 2: by biomass
0
```

Parameters:

Some standard parameters are given in the cecommon file. The input data must conform with these. The parameters and their present values are given below:

ia1=0,ia2=10: youngest and oldest age. ia2 is a plus group.

ipa1=0,ipa2=3: youngest and oldest age at which cod can act as prey. Should be within the limits of ia1,ia2, and ipa2 should be less than ia2-1, i.e. the oldest pure age class should not be prey.

iapcap=2: Number of capelin cathegories. Other prey, which is only entered by biomass, is treated like capelin

iapc=6: iapc-iap1+1 is the number of prey categories. Capelin is referenced as iap2+1 to iap2+iapcap, other food as iapc

iy1=1972,iy2=1990: first and last year: Since all years are referred to within these limits, they can be 'meaningful' numbers. The years in the input files must keep the same standard.

inquart=3: first quarter for the youngest age.

iys1=1984: first year with stomach samples.