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# Fishing Mortality of Cod in Flemish Cap Calculated from Survey Results

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## Introduction

Stock abundance-at-age calculated in survey are abundance indices. But total mortality coefficients (Z), as a way to measure changes in abundance, are independent of whether abundance is expressed in either absolute or relative scales.

The common method to calculate total mortality (Z) from survey results includes: to calculate individual Z values for each cohort at each age and to average all Z results of the same year or age. It lack of a global test on the goodness of fit because each class is independently resolved. Survey results on abundance-at-age are highly correlated data, and they can be better considered in a whole approach.

## Material and methods

The ratio between survey indices of stock abundance-at-age and the corresponding real abundance at sea is called survey-catchability. It changes with the age of the fish due to survey differential efficiency, so let be $q_a$ the survey-catchability for age **a**, assumed to remain unchanged along survey years.

Stock abundance can be expressed as a function of fishing mortalities:

$$N_{y+1,a+1} = N_{y,a} \cdot \exp(-F_{y,a} - M)$$

being $N_{y,a}$ and $F_{y,a}$ abundance and fishing mortality at age **a** on year **y**, and being M the natural mortality, assumed constant.

Let $F_{y,a}$, the fishing mortality at age **a** on year **y**, be the product of an fishing mortality index for that year (also call $F_y$) and a partial recruitment factor for that age ($PR_a$):

$$F_{y,a} = F_y \cdot PR_a$$

Starting with some value for the abundance of each cohort occurring in survey time period, stock abundance at each year and all ages can be calculated with these relationships. Survey indices of abundance-at-age ($S_{y,a}$) can be compared with stock abundance-at-age times the survey catchability ($N_{y,a} \cdot q_a$). If comparison is made by a sum of squares of differences, a log-transformation of values may contribute to a better homoscedastic behaviour. The Marquardt method (Bard 1974) can now be used to calculate a minimum square solution for all parameters in this framework:

- Abundance of each cohort in the first age and year
- fishing mortality at year
- survey catchability at age
- partial recruitment at age in the fishery

Indices of cod abundance-at-age were taken from the EU survey on Flemish Cap (NAFO Division 3M) (Vázquez at al. 1998). Cohort with only one year presence were excluded: those cohorts appearing as the oldest age of the first year and the youngest age of the last year. So, in a n years case, only n-1 parameters for abundance at the youngest age are necessary. Also, for n ages, only n-1 parameters for abundance at the first year are necessary. The parameter for the first year and youngest age must be not counted twice. For fishing mortality at year, n-1 parameters are needed for n years. For both survey catchability and fishery partial recruitment, n-1 parameters are in use for n ages, but some of them must be predetermined, i.e. equalling to 1, to prevent multiple solutions.

To analyse the variability associated to the above procedure to calculate parameters, a bootstrap on the survey indices of abundance-at-age were carried out, using the method described by Vázquez and Cerviño (1998).

## Results

A description of all parameters used is presented in Table 1. Original estimates for all parameters and average value after bootstrap are presented in Table 2. Average of all parameters, both original and log-transformed, is presented. The suitability of the log-transformation depends of the skew of each parameter distribution. Parameters 1 to 11 have a noticeable skewed distribution, so log-transformed mean (when back-transformed to the original scale) are smaller than non-transformed mean. However most of the parameters exhibit a close to normal distribution, i.e.: parameters 16 to 24, where both non- and log-transformed bootstrap results have roughly the same mean and standard error, being skew worse for log-transformed.

Covariance among bootstrap estimates are presented by groups in Table 3. Covariance among both original and log-transformed parameters were analysed, but no important differences were observed, so only original parameters are presented.

## Discussion

The sum of squares of the Marquardt fit (SS) was also included as a parameter in the bootstrap to identify non convergence situations and, consequently, spurious results. In fact, there is a mean SS greater that the original value. Their distribution is also bimodal, indicating that, probably, lack of convergence was produced in same cases. Filters were included to discard those cases, but some of them seems to remain. Further analysis is needed on that point.

The bootstrap results produce annual fishing mortality estimates with less inter-annual changes that de original estimates, particularly in 1988 to 1993 period, where highest changes were observed in original estimates. The smoothing effect of the bootstrap is clear.

From table 3, it is clear the high positive correlation among all parameters corresponding to abundance at the beginning of each cohort, particularly for those cohort with the largest presence in the table and those of the latest years. It means that this group of parameters deviates as a group, maintaining their relative position, a good property for an abundance indices. The abundance of cohorts having more than two years in the first year are poorly correlated.

Table 3 also shows that among parameters 16 to 24, those of annual fishing mortalities, there is a noticeable negative correlation between consecutive years, but they seems to be independent out of that case. This means that an overestimation of one parameter must be balanced with an underestimation of both previous and following annual parameters. As a consequence, the moving average of these parameters should results in less disperse variables.

Parameters of the annual fishing mortality are compared with annual fishing mortality results from a VPA analysis (Vázquez and Motos 1998) (Table 4). It is necessary to take into account that both series correspond to different time intervals: VPA annual mortality correspond to a calendar year. but these annual parameters correspond to a year interval between consecutive surveys, usually made in July. So, a better agreement between both series must be obtained between data of one series and the moving average of the other.

According to the conclusions of the two previous paragraphs, the moving average of the annual parameters are compared with the fishing mortality F 3-5 VPA estimates (Figure 1). The agreement seems to be poor because both variables peak at different years. But taking not into account the inter-annual variability of both series, they coincide in pointing to an increase of fishing mortality from 1988, that peaks around 1992/1994, and then declines. Annual fishing mortality calculated with survey data are in general higher than VPA estimates, particularly in the last years. Decreasing of cod abundance observed in the surveys imply fishing mortalities higher than the one estimated by VPA.

## Acknowledgements

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Table 1 - Parameters denomination and scheme of their relationships.

N1988 - N1996 : abundance of 1987 to 1995 cohorts at age 1 in 1988 to 1996, respectively.
N 2 - N 7 : abundance of those cohorts that in the first year have 2 to 7 years old.
F1988 - F1996 : annual fishing mortality parameters for years 1998 to 1996
F 1, F 2, F 3 : Partial recruitment for ages 1 to 3. Partial recruitment at all other ages was set equal 1.
S 1, S 2, S 3 : Survey catchability at ages 1 to 3. Catchability at all other ages was set equal 1.
SS : Sum of squares in the Marquardt solution.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| N1988 | N1989 | N1990 | N1991 | N1992 | N1992 | N1994 | N1995 | N1996 | . |
| N2 | . | . | . | . | . | . | . | . | . |
| N3 | . | . | . | . | . | . | . | . | . |
| N4 | . | . | . | . | . | . | . | . | . |
| N5 | . | . | . | . | . | . | . | . | . |
| N6 | . | . | . | . | . | . | . | . | . |
| N7 | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . |

| | |
|---|---|
| F1 | S1 |
| F2 | S2 |
| F3 | S3 |
| 1 | 1 |
| 1 | 1 |
| 1 | 1 |
| 1 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| F1988 | F1989 | F1990 | F1991 | F1992 | F1992 | F1994 | F1995 | F1996 |

SS

Table 2 - Original estimates for all parameters and average value after 1001 runs bootstrap, both non- and log-transformed.

| | | | bootstrap-estimates --> | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | original | non-transformed | | | log-transformed | | |
| parameter | : | estimate | mean | s.e. | skew | mean | s.e. | skew |
| 1 | N1988 : | 20111.195 | 36208.149 | 36803.694 | 10.530 | 29576.348 | 18217.534 | 0.652 |
| 2 | N1989 : | 39624.542 | 92471.397 | 130820.869 | 9.122 | 65136.434 | 54782.197 | 0.541 |
| 3 | N1990 : | 12739.208 | 32837.019 | 46863.886 | 7.379 | 22168.148 | 20246.993 | 0.424 |
| 4 | N1991 : | 112450.901 | 345217.410 | 675368.544 | 5.997 | 202419.330 | 194521.322 | 1.143 |
| 5 | N1992 : | 132929.496 | 355271.369 | 622863.408 | 12.191 | 241410.549 | 204004.460 | 0.766 |
| 6 | N1993 : | 9116.747 | 29124.002 | 77418.773 | 10.584 | 14737.953 | 16635.364 | 0.808 |
| 7 | N1994 : | 18947.021 | 34540.193 | 42727.383 | 4.463 | 22014.614 | 24668.154 | -0.198 |
| 8 | N1995 : | 5328.299 | 10558.945 | 11233.860 | 5.508 | 7961.233 | 6265.955 | 0.085 |
| 9 | N1996 : | 140.653 | 358.761 | 478.067 | 6.977 | 238.549 | 242.845 | -0.155 |
| 10 | N 2 : | 98797.422 | 154246.871 | 95693.281 | 8.334 | 137462.839 | 65707.266 | 0.391 |
| 11 | N 3 : | 44509.778 | 51843.096 | 18855.725 | 2.017 | 49000.019 | 16482.111 | 0.261 |
| 12 | N 4 : | 6794.287 | 7135.468 | 1524.525 | 0.513 | 6975.097 | 1507.033 | -0.140 |
| 13 | N 5 : | 1180.665 | 1226.524 | 233.982 | 0.299 | 1203.905 | 237.098 | -0.467 |
| 14 | N 6 : | 317.312 | 323.670 | 70.724 | 0.118 | 315.333 | 75.750 | -1.156 |
| 15 | N 7 : | 196.067 | 189.765 | 38.086 | -0.125 | 185.580 | 41.379 | -1.457 |
| 16 | F1988 : | 0.699 | 0.638 | 0.169 | -0.286 | 0.629 | 0.174 | -0.670 |
| 17 | F1989 : | 0.179 | 0.428 | 0.316 | 1.141 | 0.396 | 0.295 | 0.379 |
| 18 | F1990 : | 1.613 | 1.545 | 0.346 | -0.343 | 1.520 | 0.364 | -1.000 |
| 19 | F1991 : | 1.934 | 2.087 | 0.513 | 0.670 | 2.046 | 0.501 | 0.077 |
| 20 | F1992 : | 0.497 | 0.729 | 0.575 | 0.946 | 0.641 | 0.538 | 0.135 |
| 21 | F1993 : | 2.291 | 2.354 | 0.594 | -0.025 | 2.297 | 0.638 | -1.347 |
| 22 | F1994 : | 1.864 | 1.941 | 0.543 | -0.165 | 1.885 | 0.591 | -1.363 |
| 23 | F1995 : | 0.945 | 0.926 | 0.500 | 0.032 | 0.857 | 0.523 | -0.561 |
| 24 | F1996 : | 1.009 | 0.953 | 0.383 | 0.218 | 0.915 | 0.390 | -0.465 |
| 25 | F 1 : | 0.217 | 0.307 | 0.351 | 1.232 | 0.266 | 0.313 | 0.752 |
| 26 | F 2 : | 0.258 | 0.435 | 0.294 | 0.981 | 0.407 | 0.278 | 0.323 |
| 27 | F 3 : | 0.916 | 0.957 | 0.267 | 0.450 | 0.939 | 0.264 | 0.030 |
| 28 | S 1 : | 0.365 | 0.253 | 0.189 | 1.295 | 0.240 | 0.175 | 0.934 |
| 29 | S 2 : | 1.149 | 0.898 | 0.474 | 1.197 | 0.845 | 0.434 | 0.504 |
| 30 | S 3 : | 0.809 | 0.755 | 0.244 | 0.668 | 0.738 | 0.237 | 0.238 |
| 31 | SS : | 21.492 | 42.835 | 21.058 | 1.489 | 38.976 | 16.804 | 0.816 |

Table 3 - Correlation coefficients among parameters estimated by bootstrap.

| R1\R2: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1: | 1.000 | | | | | | | | | | | | | | |
| 2: | 0.931 | 1.000 | | | | | | | | | | | | | |
| 3: | 0.868 | 0.906 | 1.000 | | | | | | | | | | | | |
| 4: | 0.629 | 0.727 | 0.788 | 1.000 | | | | | | | | | | | |
| 5: | 0.938 | 0.945 | 0.900 | 0.688 | 1.000 | | | | | | | | | | |
| 6: | 0.553 | 0.669 | 0.618 | 0.835 | 0.612 | 1.000 | | | | | | | | | |
| 7: | 0.452 | 0.420 | 0.552 | 0.662 | 0.411 | 0.492 | 1.000 | | | | | | | | |
| 8: | -0.802 | 0.841 | 0.794 | 0.785 | 0.805 | 0.711 | 0.496 | 1.000 | | | | | | | |
| 9: | 0.828 | 0.819 | 0.827 | 0.693 | 0.821 | 0.602 | 0.462 | 0.684 | 1.000 | | | | | | |
| 10: | 0.834 | 0.756 | 0.680 | 0.361 | 0.773 | 0.291 | 0.181 | 0.609 | 0.706 | 1.000 | | | | | |
| 11: | 0.346 | 0.298 | 0.188 | 0.119 | 0.262 | 0.126 | -0.004 | 0.296 | 0.234 | 0.439 | 1.000 | | | | |
| 12: | 0.168 | 0.155 | -0.119 | 0.141 | 0.143 | 0.120 | 0.092 | 0.146 | 0.129 | 0.185 | 0.149 | 1.000 | | | |
| 13: | 0.256 | 0.214 | 0.154 | 0.148 | 0.169 | 0.103 | 0.074 | 0.209 | 0.201 | 0.329 | 0.293 | 0.360 | 1.000 | | |
| 14: | 0.117 | 0.048 | 0.055 | 0.000 | 0.031 | -0.073 | -0.017 | 0.012 | 0.114 | 0.193 | 0.205 | 0.290 | 0.530 | 1.000 | |
| 15: | -0.006 | -0.065 | -0.091 | -0.080 | -0.062 | -0.080 | -0.071 | -0.076 | -0.030 | 0.049 | 0.248 | 0.334 | 0.503 | 0.512 | 1.000 |

| R1\R2: | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|
| 16: | 1.000 | | | | | | | | |
| 17: | -0.349 | 1.000 | | | | | | | |
| 18: | 0.393 | -0.638 | 1.000 | | | | | | |
| 19: | -0.204 | 0.170 | -0.473 | 1.000 | | | | | |
| 20: | 0.064 | 0.189 | 0.087 | -0.367 | 1.000 | | | | |
| 21: | -0.060 | 0.081 | -0.093 | 0.035 | -0.506 | 1.000 | | | |
| 22: | 0.176 | -0.235 | 0.204 | -0.030 | 0.025 | -0.486 | 1.000 | | |
| 23: | 0.104 | -0.182 | 0.043 | 0.176 | -0.033 | 0.038 | -0.347 | 1.000 | |
| 24: | 0.085 | -0.038 | 0.033 | -0.002 | 0.043 | -0.035 | 0.078 | -0.380 | 1.000 |

| R1\R2: | 25 | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|---|
| 25: | 1.000 | | | | | |
| 26: | 0.179 | 1.000 | | | | |
| 27: | -0.280 | 0.207 | 1.000 | | | |
| 28: | -0.297 | -0.636 | -0.495 | 1.000 | | |
| 29: | 0.030 | -0.619 | -0.653 | 0.834 | 1.000 | |
| 30: | 0.279 | -0.065 | -0.806 | 0.517 | 0.740 | 1.000 |

Table 4 - Mortality parameters compared with the annual fishing mortality calculated in a VPA analysis (F 3-5) for the same years (Vázquez and Motos 1998).

| | parameter | original estimate | -- bootstrap -- mean | moving average | VPA F 3-5 |
|---|---|---|---|---|---|
| 16 | F1988 : | 0.699 | 0.638 | 0.638 | 0.471 |
| 17 | F1989 : | 0.179 | 0.428 | 0.533 | 0.820 |
| 18 | F1990 : | 1.613 | 1.545 | 0.987 | 0.849 |
| 19 | F1991 : | 1.934 | 2.087 | 1.816 | 0.458 |
| 20 | F1992 : | 0.497 | 0.729 | 1.408 | 1.555 |
| 21 | F1993 : | 2.291 | 2.354 | 1.542 | 1.018 |
| 21 | F1994 : | 1.864 | 1.941 | 2.148 | 0.882 |
| 22 | F1995 : | 0.945 | 0.926 | 1.434 | 1.241 |
| 23 | F1996 : | 1.009 | 0.953 | 0.940 | 0.234 |
| | | | | | 0.208 |

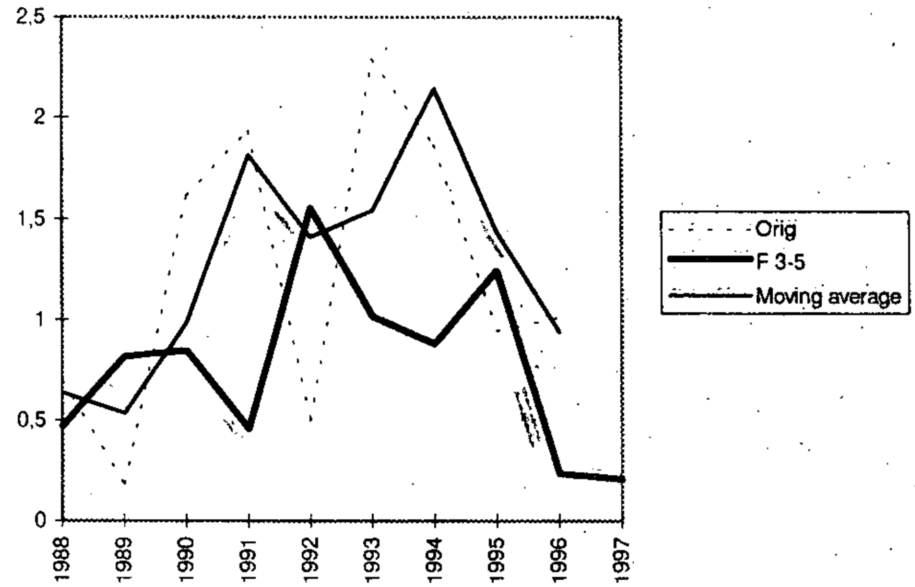


Figure 1 - Original estimates, bootstrap moving average and VPA estimates of annual fishing mortality on cod.