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A Simple Method to Project Catches, in the Absence of VPA

by

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Summary

The information available about exploited fish stocks is often restricted to catches and an abundance index of numbers-at-age from direct surveys or commercial data (CPUE). In these cases, analytical assessment (VPA) is not possible. This paper presents a simple method to project catches and to define biological reference points for stocks where information is restricted to total catch in weight, mean weight at age, and an at least one abundance index by age. This method permits the estimate of reference points defined by the levels of effort maximising yield-per-recruit function as well as the 0.1 level for this function. The whole family of Biological Reference Points would be defined, if: a) the abundance index were representative of the spawning biomass level and b) a reliable stock recruitment relationship could be defined.

The method is a modification of the equations to estimate M proposed by several authors (see, for example, Paloheimo, 1961). The approach relies on the assumed relationship between the Z-at-age vector and the total effort applied to the fishery each year defined as the ratio between total catch in the year and the biomass index.

In order to be able to apply this method, it is necessary to have at least one series of indices of abundance-at-age, mean weight-at-age and the series of catches (weight) for the stock. Neither data on the level of natural mortality are needed, nor data on the exploitation pattern.

The application of this method to the Greenland halibut population, in the NAFO Regulatory Area (NAFO Div. 2J3KLMNO), is presented as a case example. In order to assess the sensitivity of this method, to the variability of the input parameters, a risk analysis was set up and performed. The year effect was proven to be the most sensitive input when estimating yearly Z values along cohorts.

The model residuals present temporal trends. Such a correlation could be utilised to provide more precise forecasts of catches.

1. Introduction

The information available about exploited fish stocks is often restricted to catches and an abundance index of numbers-at-age from direct surveys or commercial data (CPUE). In these cases, analytical assessment (VPA) is not possible. This paper presents a simple method to project catches and to define biological reference points for stocks where information is restricted to total catch in weight, mean weight at age, and an at least one abundance index by age. This method permits the estimate of reference points defined by the levels of effort maximising yield-per-recruit function as well as the 0.1 level for this function. The whole family of Biological Reference Points would be defined, if: a) the abundance index were representative of the spawning biomass level and b) a reliable stock recruitment relationship could be defined.

2. Data

Age composition of the fall Canadian survey and mean weight-at-age was obtained from Brodie et al. (1998). Selectivity at age was derived from de Cárdenas et al. (1995). Data on maturity-at-age was calculated as the average of the maturity ogive for NAFO Division 3M obtained by Junquera and Saborido-Rey (1995) for the years 1990 and 1994 (Table 1).

Table 1: Selectivity, mean weight and maturity at age vectors used in the analysis.

Age	Selectivity at age	Mean Weight	Maturity at age
1	0.00		0.00
2	0.00		0.00
3	0.13	0.126	0.01
4	0.26	0.222	0.02
5	0.41	0.383	0.03
6	0.58	0.581	0.05
7	0.90	0.909	0.08
8	1.00	1.264	0.18
9	1.00	1.85	0.32
10	1.00	2.427	0.48
11	1.00	3.104	0.62
12	1.00	3.996	0.74
13	1.00	5.141	0.82
14	1.00	5.943	0.89
15	1.00	6.658	0.92

3. Methods

The method is a modification of the equations proposed by several authors to estimate M (see, for example, Paloheimo, 1961). The approach relies on the assumed relationship between the Z-at-age vector and the total effort applied to the fishery each year defined as the ratio between total catch in the year and the biomass index.

In order to be able to apply this method, it is necessary to have at least one series of indices of abundance-at-age, mean weight-at-age and the series of catches (weight) for the stock. Neither data on the level of natural mortality are needed, nor data on the exploitation pattern.

If an abundance-at-age is available, we can calculate the total mortality for a specific age as:

$$Z_{y,a} = \ln\left(q_a NI_{y,a} \big/ q_{a+1} NI_{y+1,a+1}\right)$$

where,

$Z_{y,a}$ = The total mortality observed for the age a in year y
$q_{,a}$ and q_{a+1} cathabilities in the survey for ages a and $a+1$, respectively.
$NI_{y,a}$ = Number of individuals at age a in the abundance index of year y
$NI_{y+1,a+1}$ = Number of individuals at age $a+1$ in the abundance index of year $y+1$

As the catchability of the survey is not known, the (log) ratio of numbers in a cohort at age a in year y over numbers at age $a+1$ in year $y+1$ will estimate the total apparent mortality affecting that cohort:

$$Z_{y,a} - \ln(q_a / q_{a+1}) = \ln\left(NI_{y,a} \big/ NI_{y+1,a+1}\right) \qquad \text{Equation 1}$$

Where $Z_{y,a}$ - $\ln(q_{,a/} q_{a+1})$ = The total **apparent** mortality observed for the age a in year y

Taking into account that the annual catch in weight can be estimate as a function of the biomass in the sea and the mortality exerted to the stock:

$$C_y = F_y \times \overline{B}_y \qquad \text{Equation 2}$$

Since $\overline{B}_y$ can be estimated from directed surveys as the survey-derived index times a catchability factor $q_s \times BI_y$,

$$C_y = F_y q_s BI_y$$

$$F_y = 1/q_s \times C_y / BI_y \qquad \text{Equation 3}$$

where:

q_s = Average survey catchability.
F_y = Average fishing mortality for year y
C_y = Catch in weight for year y
BI_y = Biomass index for year y, $BI_y = \sum N_{y,a} w_{y,a}$, where $w_{y,a}$ is mean weight at age a in year y.

So, C_y / BI_y is the **annual effort** given in biomass index units.

Paloheimo (1961) relates the annual effort with the annual total mortality to estimate catchability and natural mortality (M). Z_y is the total mortality affecting the stock one given year:

$$Z_y = F_y + M$$

Z_y = Total mortality for the year y
M = Natural mortality of the stock, assumed constant for years and ages.

Z-at-age can be also estimated applying an age related selection factor (s_a) to the overall F in the year y:

$$Z_{y,a} = s_a F_y + M$$

On the other hand, since what we get from the survey indices is the apparent natural mortality, the equation above becomes:

$$\left[Z_{y,a} - \ln(q_a / q_{a+1})\right] = s_a F_y + \left[M - \ln(q_a / q_{a+1})\right] \qquad \text{Equation 4}$$

$\boldsymbol{F_y}$ can be substituted in this equation by the value derived in equation 3 above:

$$\left[Z_{y,a} - \ln(q_a / q_{a+1})\right] = \left[s_a / q_s\right]\left(C_y / BI_y\right) + \left[M - \ln(q_a / q_{a+1})\right]$$

This equation relates the total apparent mortality with the annual effort for a given year. The coefficients for the equation are:

The slope (s_a/q_s) is a constant equal to the ratio between the partial recruitment at age of the fishery and the catchability of the survey.

The intercept (M_a **-** $ln\ (q_a/\ q_{a+1})$) is the apparent natural mortality at age *a*, i.e. the natural mortality corrected by the subtraction of the log ratio of catchabilities at age *a* and age *a+1*. The magnitude of this ratio will largely depend on partial recruitment for the age under consideration and on other factors as migration/availability on the survey/fishery area.

These regressions can be used to estimate apparent *Z*-at-age for a range of *C/BI* ratio as can be seen in figure 1. In order to make these variables comparable, the survey biomass index should be converted in fishable biomass by applying the selectivity of the current gear in the fishery, i.e. the 130 mm mesh size for the trawl fishery in RNA.

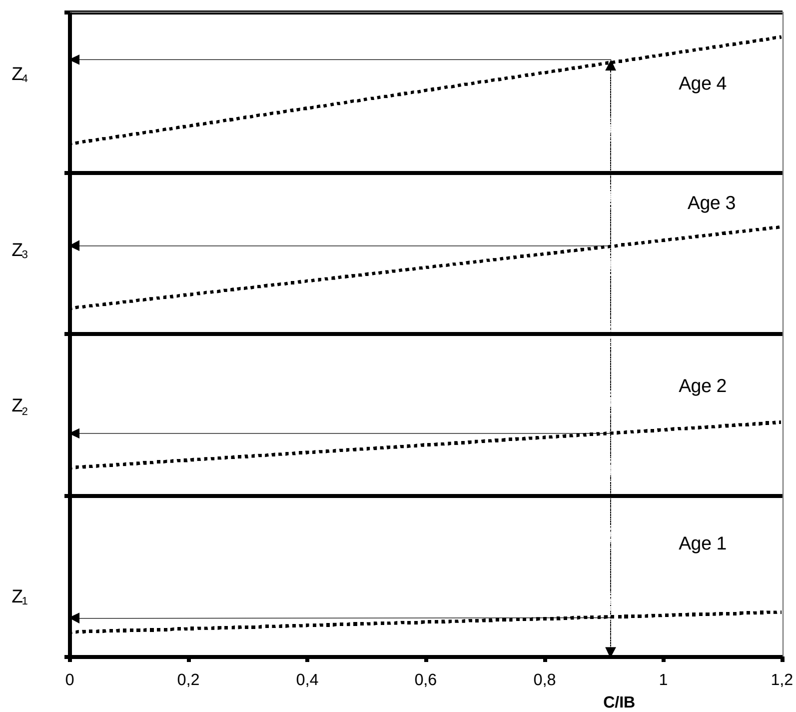

Fig. 1. Estimation of apparent Z vector for a particular **C/BI** level

Furthermore, once obtained in this way, these *Z*-at-age vectors can be used together with mean weight-at-age to calculate the biomass in which *BI* will stabilise for a situation of equilibrium with constant recruitment of a unit fish. As the *C/BI* ratio and the *BI* are known, it can be obtained the catch in equilibrium, the yield per recruit and estimates of reference points based on *C/BI* ratio, i.e. $C/BI_{0.1}$ and C/BI_{max}.

The model can provide short-term catch projections by applying the *Z* vector for specific *C/BI* levels to the biomass index-at-age vector of last year.

The method is applied to the 2+3KLMNO Greenland halibut stock. Stock abundance indices are derived from the Canadian fall survey series (1978-96) in Div 2J3KL (Brodie et al., 1998). An index of the fishable stock abundance for each survey can be obtained by using the selectivity of 130 mm mesh, which is transformed into a fishable biomass index by multiplying each resultant number-at-age by the corresponding weight-at-age. Since this particular survey is made during the 4th quarter of the year, the average fishable biomass during a given year was calculated as the mean of the biomass index that year and the biomass index of the preceding year.

This method largely depends on the precision of the numbers-at-age estimated by the surveys. To check the sensitivity of the output parameters to the accuracy of numbers at age estimated in the cruise, a resampling exercise was made. The numbers-at-age in the cruises were bootstrapped using Montecarlo replicates. The year effect and the age effect on numbers-at-age variability were computed separately and they were common for the whole historical series, i.e. one vector through years for the year effect and one vector through ages for the age effect. Normal errors of 0 mean and se = 0.2 were used in both cases. Similarly, errors for weights-at-age used to raise numbers to biomass were bootstrapped assuming a lognormal error with a s.e. of 0.4 for the weights. Finally, both the maturity ogive and the selectivity pattern were bootstrapped assuming normal errors after logit transformation for both parameters (se = 0.4 and 0.2, respectively). It should be noted that the overall error in numbers-at-age from the combined year and age effect assuming a se = 0.2 in both effects is about 0.29 (se).

3. Results

The historical series of fishable biomass as derived from the indices shows a period of relatively high values above 150,000 tonnes up to 1987 (Figure 2). Afterwards, a decreasing trend is evidenced, first to a slightly lower level between 1988 and 1990 and thereafter to the lowest level recorded in 1995. Since this year the fishable biomass is steadily increasing, although in 1997 it was still below the levels recorded prior to 1991.

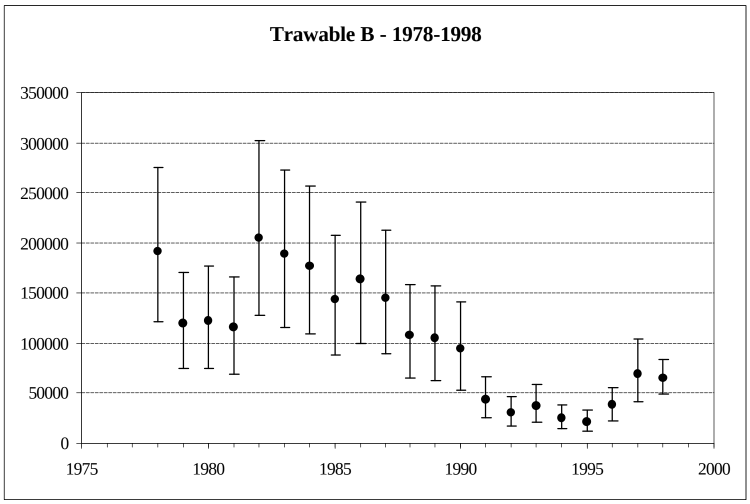

Fig. 2. Time series of fishable biomass derived from Canadian Autumn surveys. 95% confidence level bars are shown as derived from a risk analysis.

The trend in effort (C/B ratio) shows a first period of stable effort below 0.5 from 1978 to 1989 (Figure 3). A sudden increase in the effort level was recorded in 1991, when the estimates of C/B increased by a factor of eight from the period 1978-1989 to the period 1991-1994. The level of effort was dramatically reduced since 1995 to reach a level close to the low, stable effort level of the historical period prior to 1990.

The time series of total mortality (Z) shows a time development of the mortality similar to that shown by the C/B ratio (Figure 4). However, the increase between the two periods defined above (1978-1989 and 1991-1994) is by a factor of 4 in comparison to a factor of 8 as mentioned in the case of C/B ratio. The value in 1978 is very different in both series, being one of the historical lowest in the C/B ratio and one of the historical highest in the Z series. This could be an effect of miss reporting of catches in 1978 or, alternatively, a year effect in the 1978 survey leading to very high numbers that year. Last year's estimate show an increase in apparent Z.

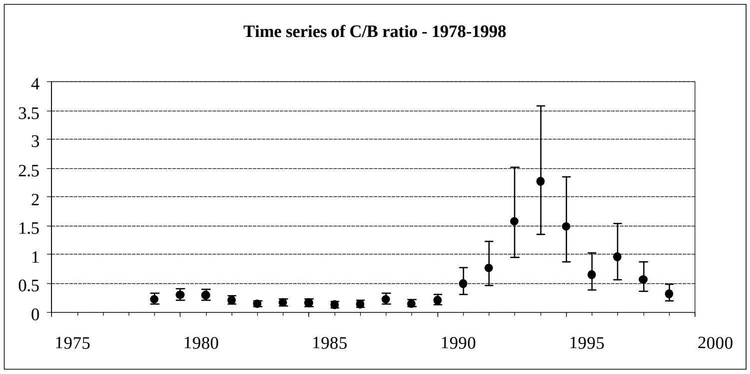

Fig. 3. Time series of C/B ratio. 95% confidence level bars are shown as derived from a risk analysis.

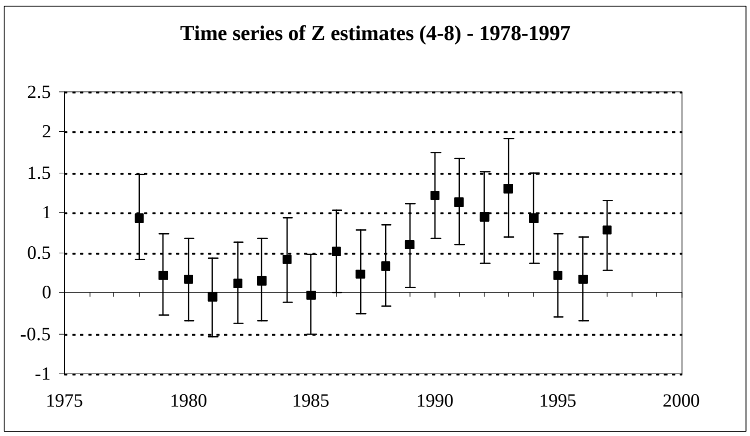

Fig. 4. Time series of total mortality (Z) estimates derived from Canadian Autumn surveys. 95% confidence level bars are shown as derived from a risk analysis.

Figure 1 in Annex 1 shows the the C/B vs Z-at-age regressions for ages 2 to 11+. Figures 5 and 6 shows the intercepts and slopes of the regression lines respectively as derived from the risk analysis.

The intercepts of the C/B vs Z-at-age regressions, a proxy for the natural mortality, though influenced by factors like recruitment to the fishery, migrations and related phenomena, is at a mean level of about 0.2 for ages 2 to 6 (Figure 5). Afterwards, a sudden increase of the intercept value is recorded to a mean level of about 0.8 for ages 7 and older. This pattern of natural mortality is consistent with previous works showing a seven-fold increase of natural mortality for males in Greenland halibut populations (De Cárdenas, 1996).

The slope of the C/B vs Z-at-age is related with catchability-at-age both in the fishery and in the survey. The general expectation of increasing Z as C/B increases is observed in all ages except for age 2, where it is practically 0 (Figure 6). The slope steadily increases from age 2 to age 4 and it reaches a plateau around 0.5 for ages 4 to 10. The slope of the regression for individuals 11-year-old and older shows a value is not significantly different from 0. This means that the influence of the commercial fishery does not have a significant effect on the bulk of the female spawning stock, i.e. females older than 10 year old (Junquera and Saborido-Rey, 1995).

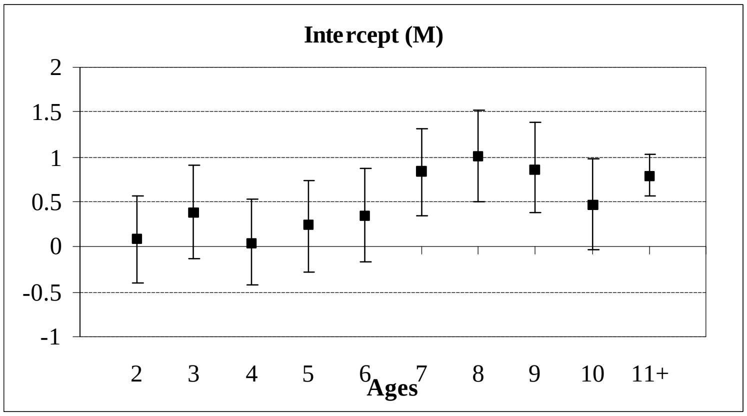

Fig. 5. Plot of the intercept of the Z vs C/BI regressions for ages 2 to 11+. The estimate for the combined 4-8 age group is also shown. 95% confidence level bars are shown as derived from a risk analysis.

The analysis of the slope values through ages show that the fully recruitment age to the fishery appear to be a little earlier that the age expected from selectivity curves (De Cárdenas et al, 1995) for 130 mm trawl mesh size. On the other hand, the analysis shows that this method does reflect the evolution of the female spawning stock in this case and, therefore, it can not be used for SSB projections in the 2J3KLMN Greenland halibut population. Since the abundance index appears not to be representative of the spawning biomass level it will not be possible to obtain any reliable stock recruitment relationship. Consequently, no reference points based on this relationship can be estimated in the case of this Greenland halibut population.

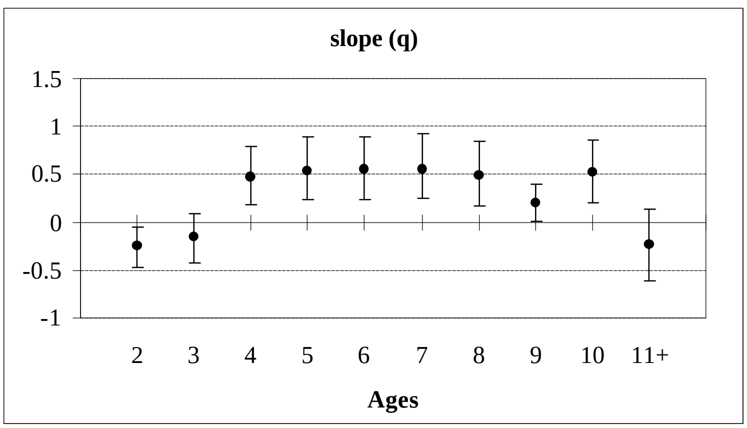

Fig. 6. Plot of the slopes of the Z vs C/BI regressions for ages 2 to 11+. The estimate for the combined 4-8 age group is also shown. 95% confidence level bars are shown as derived from a risk analysis.

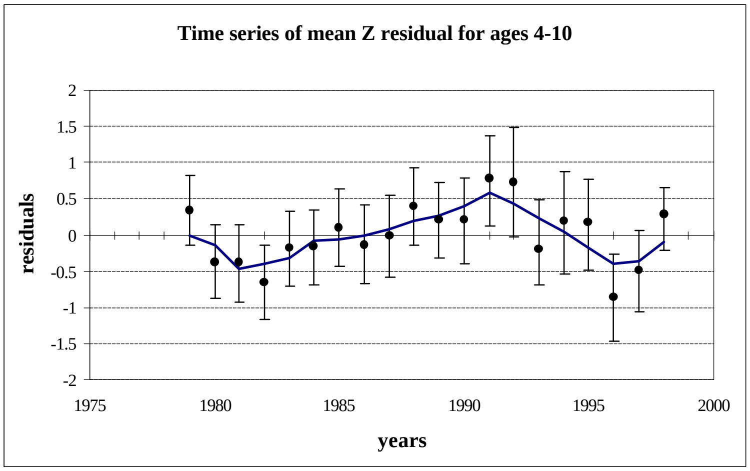

Fig. 7. Time series of Z residuals (mean residuals for ages 4 to 8). 95% confidence level bars are shown as derived from a risk analysis.

The residuals of Z from the regressions for different ages appear associated along years and show a characteristic pattern in the time series (Figure 7). Although starting with a high positive residual in 1978, residuals are negative for the period 1979 to 1984 and become positive for the period 1987 to 1992. They became negative again in the last period since 1994. Positive residuals means higher observed Z than that expected from the C/B ratio and the model. They can be due to changes in catchability of either the survey or the fishery, or both, as well as to miss-reporting of catches or to changes in natural mortality. Higher catchabilities, higher M or missreporting of catches can lead to positive residuals. On the contrary, lower catchabilities, lower M or overreporting of catches can lead to negative residuals. However, the temporal trends observed in the time series of residuals seems to be more related to changes in either catchability or M or both than to patterns in catch reporting. Changes in distribution, as reported by Bowering and Power (1998), could have affected either catchability or M, or both in the time series.

The pattern observed in the Z residuals could be used to restrict the variation of the short-term forecast. However, a partial autocorrelation analysis performed on the time series of mean Z residuals for ages 4 to 9, did not show any significant correlation with those of the next year

The yield per recruit curve is presented in figure 9. $C/B_{max}$was estimated around 0.74 and C/B_{01} around 0.46.

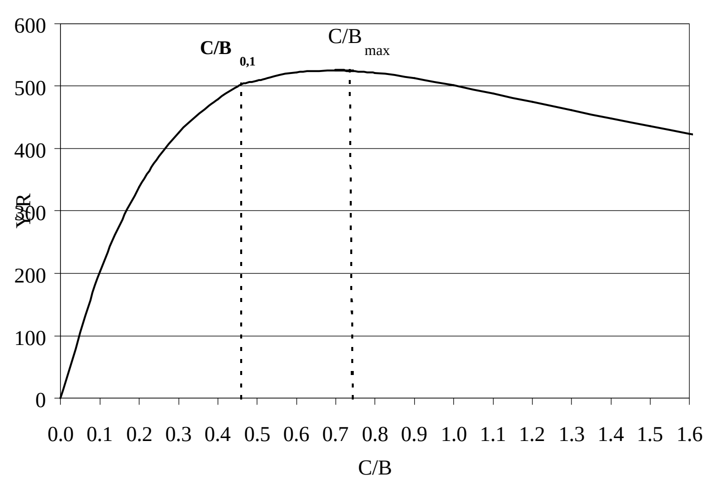

Fig. 9. Yield per recruit plot relative to C/B ratio levels.

5.- References.

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ANNEX 1

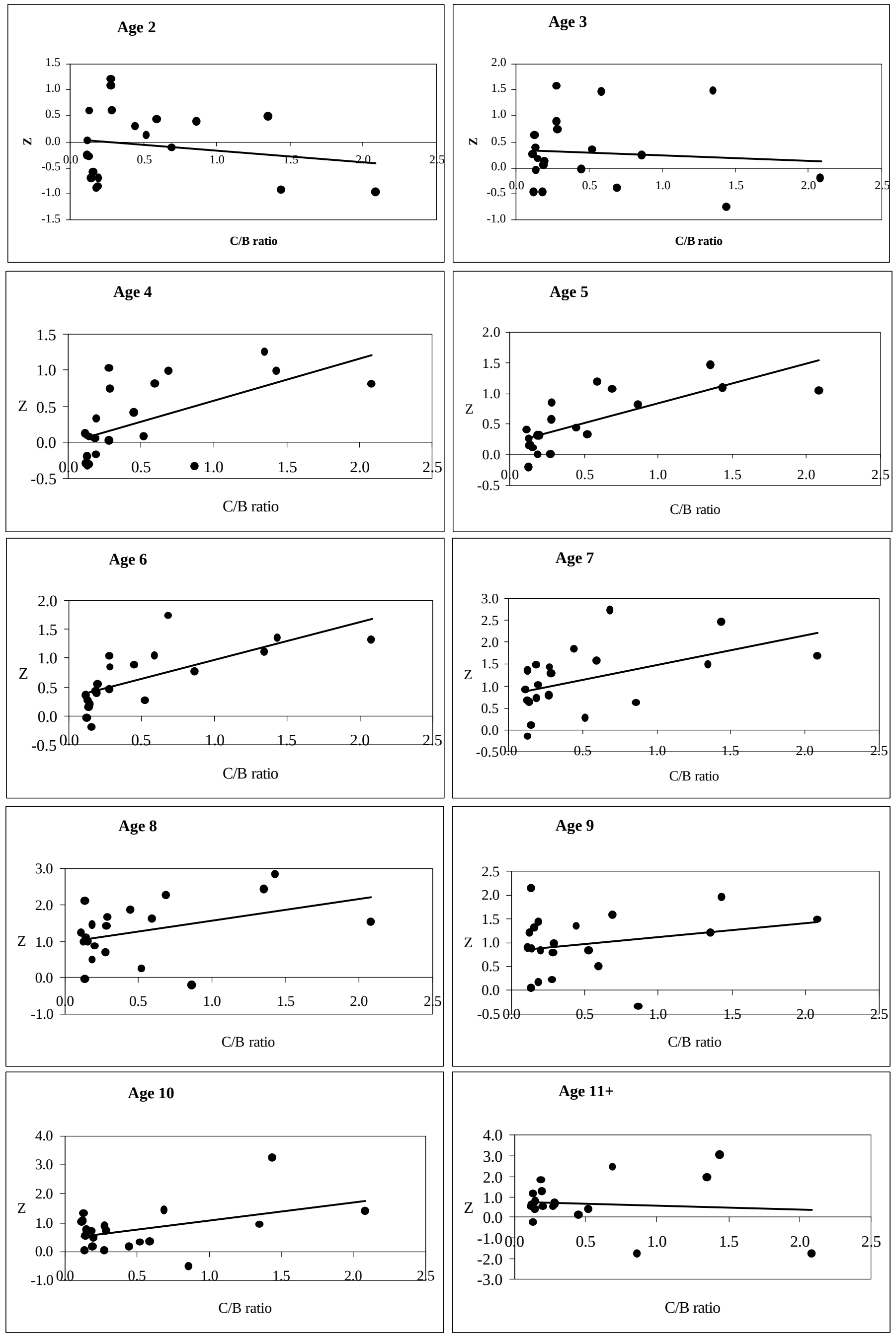

Fig. 1. Plots of C/B ratio vs Z for ages 2 to 11 plus for the Greenland halibut 2J3KLMN. Each plot presents the corresponding linear regression with the equation and coefficient of determination given in the top right hand side.