Northwest Atlantic Fisheries Organization

Serial No. N2732

NAFO SCR Doc. 96/56

SCIENTIFIC COUNCIL MEETING - JUNE 1996

# Declining Weight-at-age in Northern Cod and the Potential Importance of the Early-years and Size-selective Fishing Mortality

by

Martha Krohn and Steve Kerr

Biology Department, Dalhousie University
Halifax, Nova Scotia, Canada B3H 4J1

**Abstract**

Weight–at–age of northern cod has been declining since 1979 for all age–classes, while the greatest reduction in size–specific growth has been before age 3. To what extent could the declining weight–at–age 3 be responsible for smaller weights in older age–classes, and to what extent are size–specific growth rates of the older age–classes declining? The among year variability in weight–at–age 3 explained 54% of the variability in weight–at–age of older age–classes of the same cohorts, and differences in weight–at–age among cohorts suggest that cohorts that are small early in life tend to stay small. According to our simulations, over 50 % of the decline in weight–at–age of 4 to 8 year–olds can be attributed to a decline in weight–at–age 3. These results suggest that size in early years greatly influences future production but also that weights–at–age are lower than one would expect purely from small sizes at age 3, and therefore that the environment for growth in the older age–classes has worsened. Because cod are recruited to the fishery at age 3, it is possible that some of the decline in weight–at–age 3 may not be due to reduced growth rate, but may be a result of size–selective fishing mortality.

## Introduction

Weight–at–age of northern cod has been declining in 2J3K over the last 15 years (Bishop et al. 1995); on average a cod of a given age in 1979 weighed about twice as much as a cod of the same age in 1993 (Fig.1). These small weights–at–age are not unprecedented, they were also low through the early and mid 70's. The recent decline in weight–at–age in 2J3K has been coincident with declines in temperature and capelin biomass. Water temperature and capelin biomass are correlated to both northern cod condition factor and northern cod size–at–age (Millar and Myers 1990; Bishop and Baird 1993; de Cardenas 1994; Shelton and Lilly, 1995; Krohn et al. in press) as well as size–at–age of cod on the Scotian shelf (Campana et al. 1995). During this same period fishing mortality has been increasing (Baird et al 1992), and so it is possible that some of the reduction in weight–at–age is not due to reduced growth rates but to the selective removal of larger fish by the fishery. Even if the size–selection is strongest on the first age–class that is recruited to the fishing gear, the effects on weight–at–age may be expected to persist through the later year–classes because smaller fish grow more slowly. To identify which age–classes of northern cod have experienced the biggest declines in growth we calculated size–specific growth rates (rather than growth increments) which correct for the effect of size at the beginning of a given year on growth rate through the year. The use of size–specific growth rates allowed us to identify which age–classes have experienced the most dramatic changes in growth and in which age–classes declining weight–at–age was a result of smaller initial size.

After identifying that specific-growth rates declined to the greatest extent before age 3 (Fig.2) we

(1) determined the proportion of variance in weight-at-age of older year-classes that can be explained by weight-at-age 3 of the corresponding cohorts.

(2) examined the difference in weight-at-age among cohorts to determine whether differences in weight-at-age track through the age-classes of a given cohort.

(3) simulated the proportion of the decline in weight-at-age of older age-classes that can be attributed to weight-at-age 3.

**Methods**

*Weight-at-age and size-specific growth*

We used mean weights-at-age from the annual autumn groundfish surveys as reported by Bishop et al. 1995. For the time series (Fig. 1 and 2) we averaged mean weights-at-age and size-specific growth rates for 2J and 3K. Size-specific growth (G) was estimated using weights-at-age (W(1) and W(2); kg) in two consecutive years (t(1) and t(2); days):

$$(1)\ G = ([\ln W(2) - \ln W(1)] / [t(2) - t(1)]) \times 100$$

We limited our analysis to the period 1979 to 1993 (the period over which the decline in weight-at-age was observed) and age-classes 3 to 8. We omitted any weights at-age from the analysis for years in which a mean of 0.05 cod or fewer were caught per tow (see Table 20 and 21 Bishop et al. 1995). This criterion resulted in the elimination of age 7's in 1993 and age 8's in 1992 and 1993 from the analysis.

*Relative weights-at-age*

To allow us to include weight-at-age of age 3 to age 8 cod in the same analyses we corrected for age. Relative weights-at-age were calculated by dividing weight-at-age for a given age-class in a given year by the mean weight-at-age of the given age class over the period 1979 to 1993. For example if the weight-at-age for age 3 cod in 1979 was 0.65 kg, and the mean weight of 3 year old cod over the period 1979 to 1993 was .5 kg, the relative weight of age three cod in 1979 would be 1.3. Each age-class therefore had an overall mean weight-at-age equal to 1.

*Detrended weight-at-age*

It was necessary to detrend the weights-at-age to remove environmental effects that could be confounded with cohort effects. One can divide the influences on the growth into two categories, one category that includes environmental influences that vary annually (such as food supply or temperature) and act on all age-classes in a given year, and the second being cohort effects, most importantly the size of the fish at the beginning of the year. Size-selective fishing could be considered a cohort effect; if the largest fish are removed from a given age-class, then the smaller individuals of that cohort are left to grow in the following year. If we wish to trace the effects of cohorts through time it is important to remove annual effects. For example, the decline in weight-at-age could be due to in part to the annual and in part to cohort effects, the annual effects being deteriorating environmental conditions for growth, and the cohort effects causing a decline in weight-at-age through the age-classes that resulted either from the removal of the largest fish by the fishery or from changing environmental conditions at a young age, in either case small weight-at-age may have been established at a young age and persisted through to the older year-classes.

To detrend the data we took the mean of the relative weight-at-age of all age-classes in a given year, and then divided each relative weight-at-age by the mean for the year. For example if the mean relative weight of all age-classes in 1979 was 1.4 kg then we would divide the weight-at-age for each age-class in 1979 by 1.4.

*Differences in weights-at-age among cohorts*

To determine whether differences in weights-at-age persist through cohorts we compared relative weights-at-age among cohorts using a bootstrapping or resampling program (Krohn and Boisclair 1994).

*Proportion of the decline weight-at-age due to the decline in weight-at-age three*

We ran simulations to determine the proportion of the decline in weight-at-age of older year-classes that could be due simply to smaller weights-at-age 3. For all pairs of years in which there was a reduction in weight-at-age for a given age-class, we simulated the growth, using the same size-specific growth rate of the two cohorts starting at their observed weights-at-age three. We used size-specific growth rates from the appropriate division, 2J or 3K (Fig.3). We then divided the difference in the two modelled weights-at-age (for age 4 to age 8) by the difference in the two observed weights-at-age to get a proportion of the observed reduction in weights-at-age that, given equal growth rates, could have been due to solely to smaller initial weights.

*Relationship between size-specific growth and weight*

To simulate appropriate growth rates for cod in the 2J 3K area, we modelled specific growth (G) as an function of weight (W(2)):

$$G = a \cdot W(2)^b \qquad (2)$$

We used modelled growth as a function of weight at the end of the growth interval (W(2)) rather than at the beginning (W(1)) to avoid creating a spurious negative correlation between specific growth ($[\ln W(2) - \ln W(1)] / [t(2) - t(1)] \times 100$) and initial weight (W1), because specific growth decreases with weight. We included age 3 through age 12 cod to extend the weight range.

## Results and Discussion

*Size-specific growth rates*

Size-specific growth rates declined significantly ($p<0.01$) only for the 3 year olds, the first year that cod are recruited to the fishery (Fig.2). Growth rates are calculated from changes in weight between consecutive years, so the decline in growth rate for the 3 year-olds represents a decrease in the difference in weight-at-age of 2 and 3 year-olds through time, or more specifically reflects a decrease in the weight-at-age 3 relative to a more stable weight-at-age 2. It is possible, however, that weight-at-age 2 has also decreased but that the sampling gear only catches the largest 2 year olds. The interpretation therefore should be limited to a decline in specific growth rate somewhere before age 3, not necessarily between age 2 and 3.

*Relationship between weight-at-age 3 and weight-at-age in following years.*

Is it possible that these changes in weight-at-age 3 lead to the declines in the older year-classes? If so one would expect that weight-at-age three would explain a significant proportion of the among year variance in weight-at-age of the older age-classes. Relative weight-at-age 3 explained 54 % of the variance in relative weights-at-age of the 4 to 8 year olds ($p < 0.001$), although when we used the detrended weights-at-age there was no significant relationship. Weights-at-age were detrended to remove the effects of annual environmental conditions, however it may be that detrending the data removed most of the range in the weights-at-age, and therefore that the cohort effects were no longer detectable.

*Relationship between weight-at-age of the same cohort in two consecutive years*

To quantify the importance of size in one year on size of the same fish in the following year, we regressed relative weights-at-age in year X against relative weights-at-age of the same cohort in year X + 1, and found that 70% of the among year variability in weight-at-age can be explained by weight in the previous year, suggesting that once fish are small, they stay small (Fig. 4). This relationship was weaker, but still held with the detrended relative weights-at-age ($r^2 = 0.35$, $p < 0.001$, Fig.5).

*Differences in weights-at-age among cohorts*

If once fish are small they remain small through their lives, then we would expect to find significant differences in weights-at-age through the age-classes among cohorts. Relative weights-at-age did differ significantly among cohorts, the largest cohorts being as much as 84 % bigger than the smallest ones in 2J ($p < 0.001$; Fig. 6), and 50% bigger in 3K ($p < 0.001$; Fig.7) with the earlier cohorts being bigger than the more recent ones. This decrease in cohort size is not necessarily due to a cohort effect, but may be due to changing environmental conditions, as discussed earlier. After detrending the weights-at-age, the range in relative weights among cohorts was greatly reduced, but the differences in relative weights among cohorts were significant ($p < 0.004$; and $p < 0.02$ in 2J (Fig. 8) and 3K (Fig.9) respectively). Therefore even after removing most of the variability in weights-at-age among cohorts, cohort effects were still detectable in both divisions.

*Proportion of the decline weight-at-age due to the decline in weight-at-age 3.*

According to the simulations, the decline in weight-at-age 3 explained, on average across age-classes, 55 and 59 % of the declines in weight-at-age in the older year-classes, in 2J (Fig. 10) and 3K (Fig.11) respectively. This trend in this proportion declines with age in 3K, and there is no clear trend in 2J.

A mean of 1 across the age-classes would have suggested that the whole reduction in weight-at-age of age 4 to 8 year olds could have been explained by reduced weight-at-age 3, and that after age 3 cod have not experienced reduced growth rates but are smaller only because of smaller initial sizes. The mean of 55 to 59% suggests that smaller weight-at-age 3 is not entirely responsible for the decline in size-at-age in later age-classes, the specific growth rates themselves must have also declined, but it does suggest that over half of the decline in weight-at-age may be a direct result of smaller sizes at or before age 3.

This analysis points to the importance of the decline in size-at-age of young fish, 3 years-old or less. They have experienced the greatest decline in growth rate, and this small size has propagated through the older age-classes, explaining over 50% of the reduction in size-age of the 4-8 year olds. It is also possible that some of the decline in weight-at-age 3 is not due to reduced growth rate, but is due to the selective removal of the largest 3 year-olds by the fishery (3 year-olds are the first age-class recruited to the fishery). To cause a decline in weight-at-age 3 through time fishing mortality on 3 year-olds would have to have increased over this period. Fishing mortality on 7 to 9 year-olds has increased steadily over this period (Baird et al 1992) but is not clear whether fishing mortality has also increased on 3 year-olds.

It is not known whether fishing mortality on 3 year-olds has been increasing, or whether the size-selection would be strong enough to explain the observed decreases in size-at-age. However, if size selective fishing was a key factor in the decline size-at-age of age 3's, the simulations may underestimate the potential effect of size-selective fishing on weight-at-age in later years because removing the largest fish may also involve removing the fastest growers. The remaining fish may not only be smaller but may also have lower size-specific growth rates.

**References**


Baird, J.W., C.A. Bishop, W.P. Brodie and E.F. Murphy. 1992. An assessment of the cod stock in NAFO divisions 2J3KL. CAFSAC Res. Doc. 92/75.

Bishop, C.A., D.E. Stansbury and E.F. Murphy. 1995. An update of the stock status of Div. 2J3KL Cod. DFO Res. Doc. 95/34.

Bishop C.A. and J.W. Baird 1993. Spatial and temporal variability in condition factors of 2J3KL cod. DFO Res. Doc. 93/56.

Campana, S.E., R.K. Mohn, S.J. Smith, and G.A. Chouinard. Spatial implications of a temperature-based growth model for Atlantic cod (*Gadus morhua*) off the eastern coast of Canada.

de Cardenas, E. 1994. Some considerations about annual growth rate variations in cod stocks. NAFO SCR Doc. 94/64.

Krohn, M.M. and D. Boisclair. 1994. Use of a stereo-video method to estimate the energy expenditure of free-swimming fish. Can. J. Fish. Aquat. Sci. 51: 1119-1127.

Krohn, M.M., S.P. Reidy, and S.R. Kerr. In Press. Bioenergetic analysis of the effects of temperature and prey availability on growth and condition of northern cod (Gadus morhua).

Millar, R.B. and R.A. Myers. 1990. Modelling environmentally induced change in size-at-age for Atlantic Canada cod stocks. CAFSAC Res.Doc. 90/48.

Shelton, P. A. and G.R.Lilly. 1995. Factors influencing weight-at-age of cod off Newfoundland (NAFO Divisions 2J+3KL) ICES C.M. 1995/P14. 29 p.


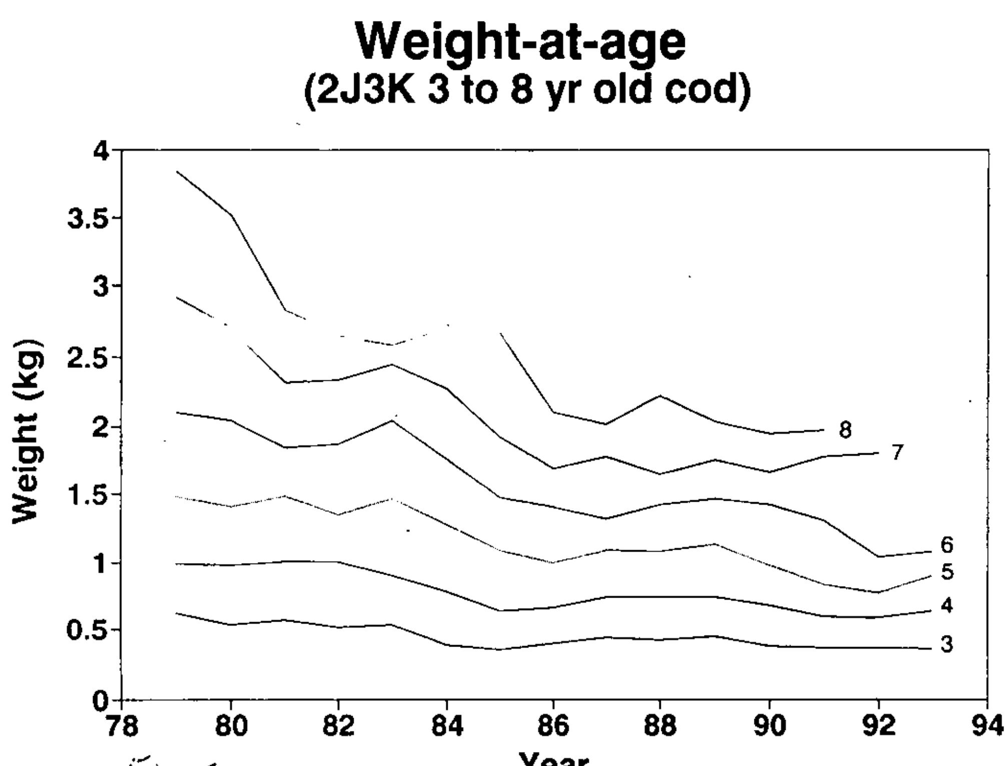


Fig 1

## Weight-specific growth
### (2J3K 3-8 yr old cod)

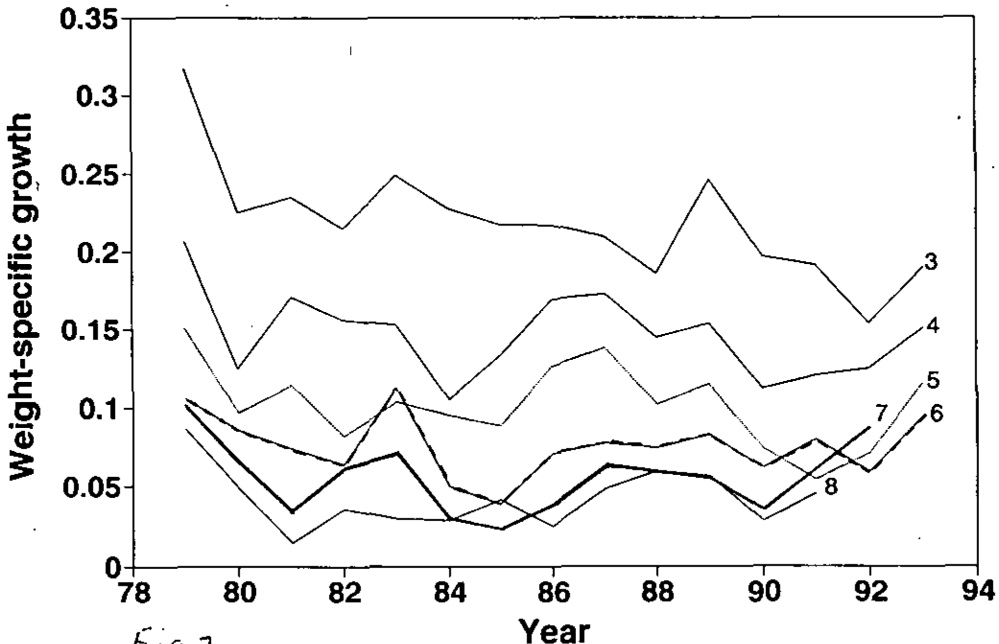


Fig 2.

## Weight-specific growth of 2J and 3K cod

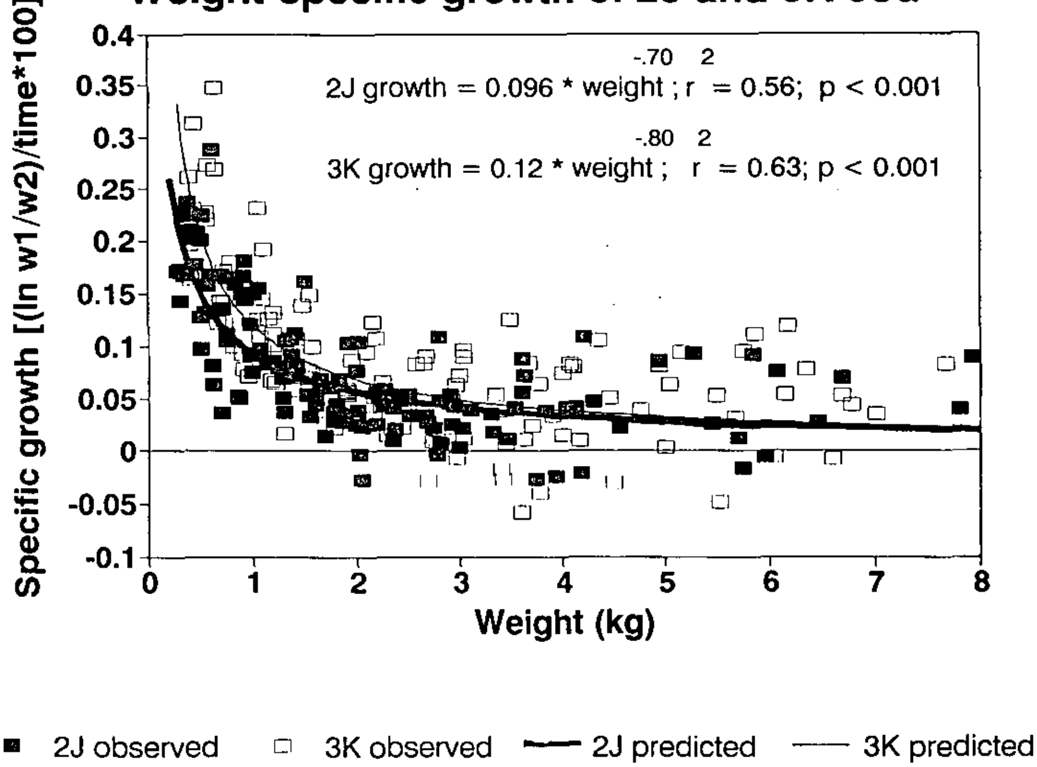


Fig 3.

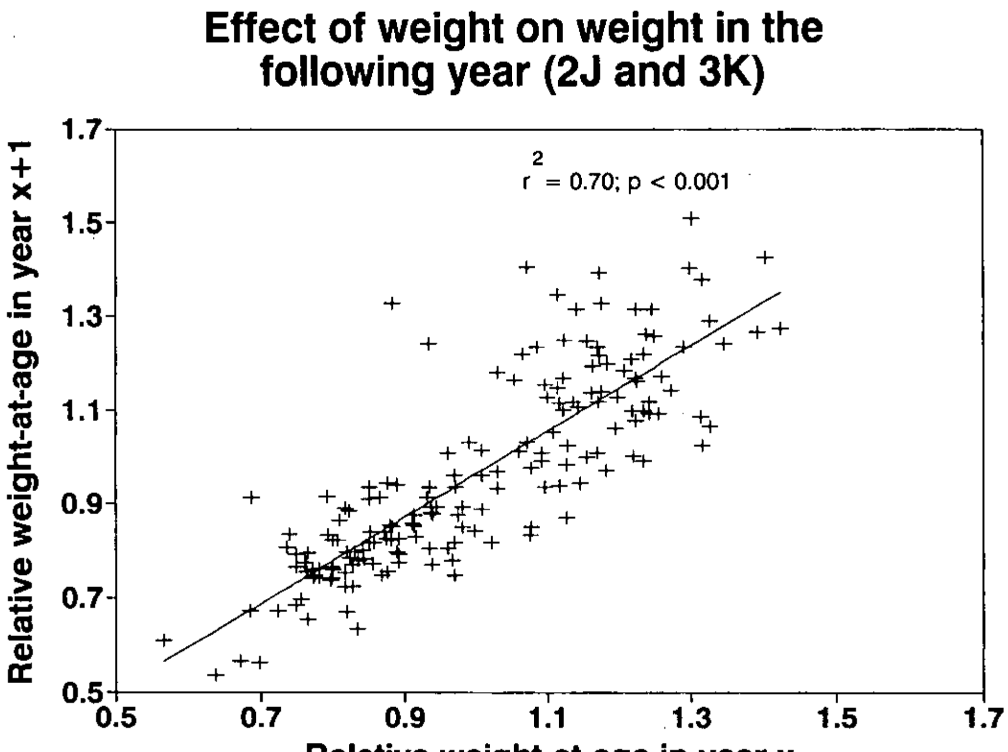
Effect of weight on weight in the following year (2J and 3K)
$r^2 = 0.70; p < 0.001$
Relative weight-at-age in year x+1
Relative weight-at-age in year x
0.5 0.7 0.9 1.1 1.3 1.5 1.7

Fig. 4.

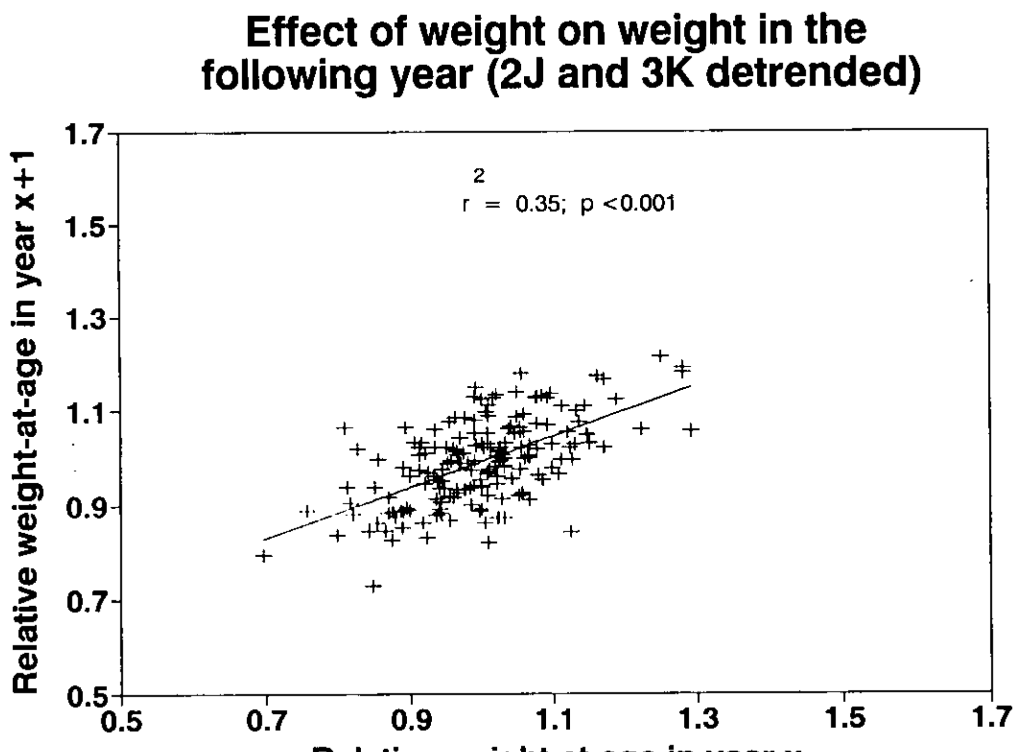
Effect of weight on weight in the following year (2J and 3K detrended)
$r^2 = 0.35; p < 0.001$
Relative weight-at-age in year x+1
Relative weight-at-age in year x
0.5 0.7 0.9 1.1 1.3 1.5 1.7

Fig. 5.

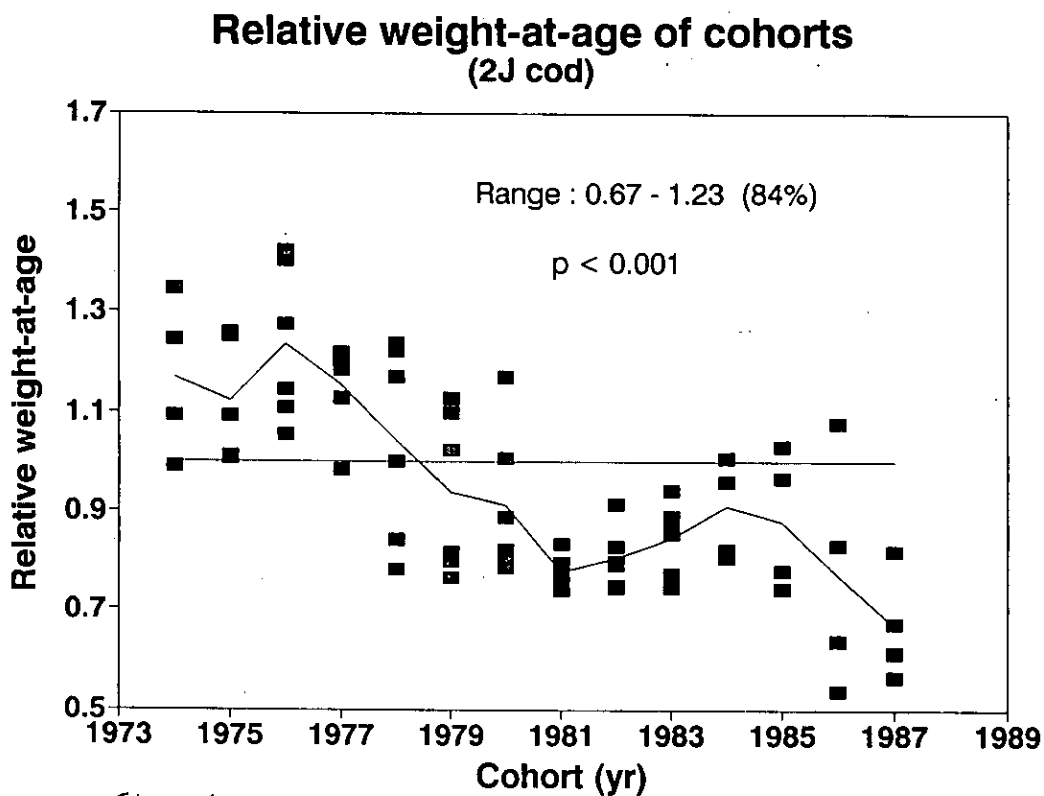
Relative weight-at-age of cohorts
(2J cod)
Range : 0.67 - 1.23 (84%)
p < 0.001
Relative weight-at-age
Cohort (yr)
1.7
1.5
1.3
1.1
0.9
0.7
0.5
1973
1975
1977
1979
1981
1983
1985
1987
1989

Fig. 6.

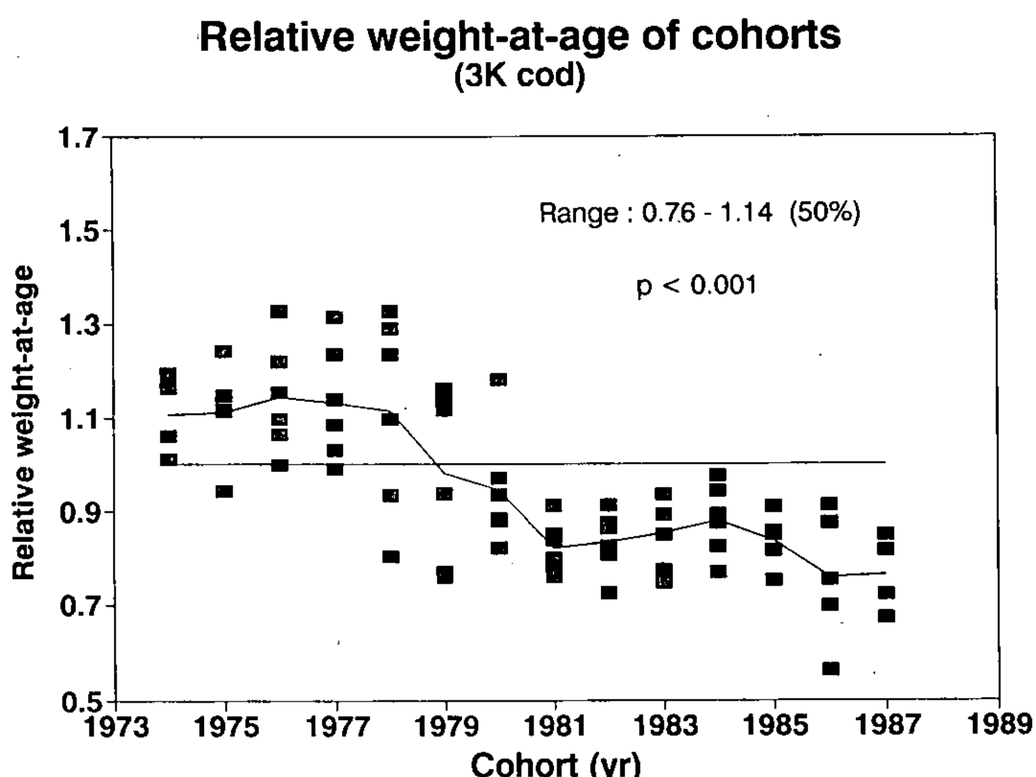
Relative weight-at-age of cohorts
(3K cod)
Range : 0.76 - 1.14 (50%)
p < 0.001
Relative weight-at-age
Cohort (yr)
1.7
1.5
1.3
1.1
0.9
0.7
0.5
1973
1975
1977
1979
1981
1983
1985
1987
1989

Fig. 7.

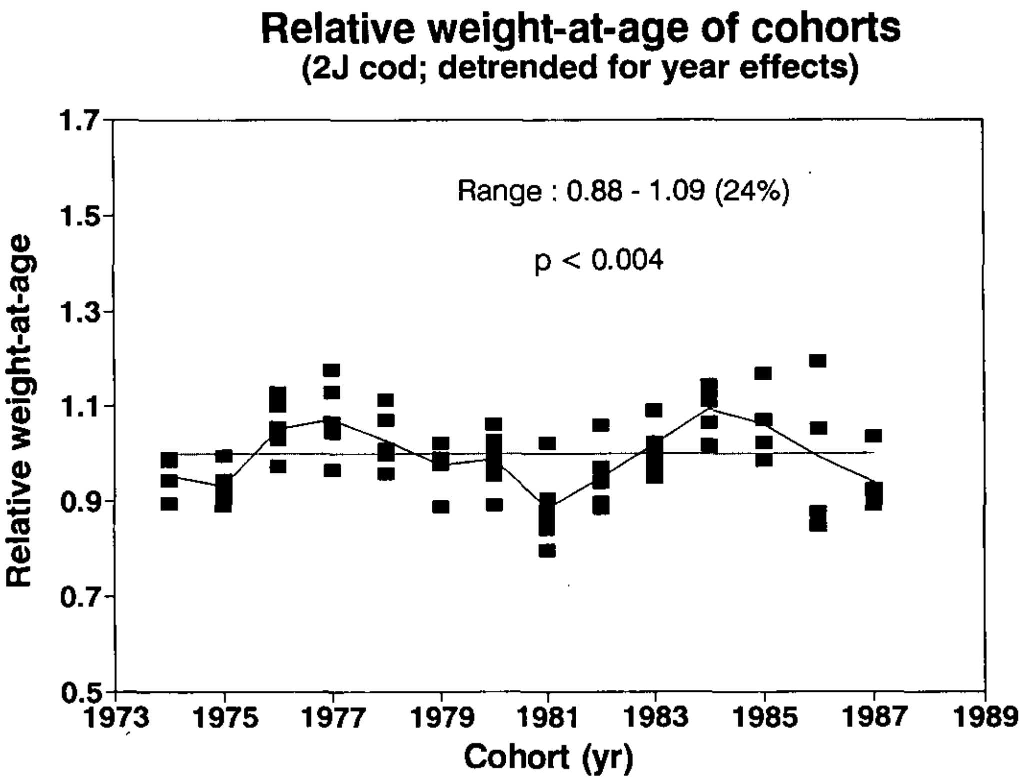
Relative weight-at-age of cohorts
(2J cod; detrended for year effects)
Range : 0.88 - 1.09 (24%)
p < 0.004
Relative weight-at-age
1.7
1.5
1.3
1.1
0.9
0.7
0.5
1973 1975 1977 1979 1981 1983 1985 1987 1989
Cohort (yr)

Fig. 8.

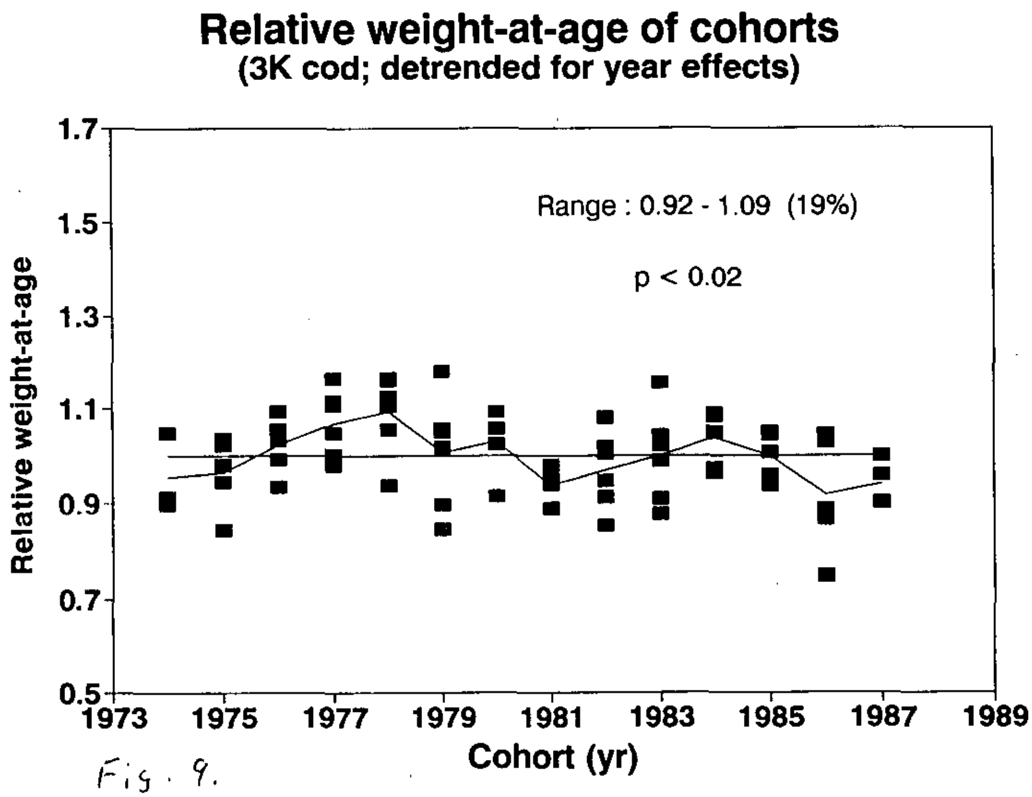
Relative weight-at-age of cohorts
(3K cod; detrended for year effects)
Range : 0.92 - 1.09 (19%)
p < 0.02
Relative weight-at-age
1.7
1.5
1.3
1.1
0.9
0.7
0.5
1973 1975 1977 1979 1981 1983 1985 1987 1989
Cohort (yr)

Fig. 9.

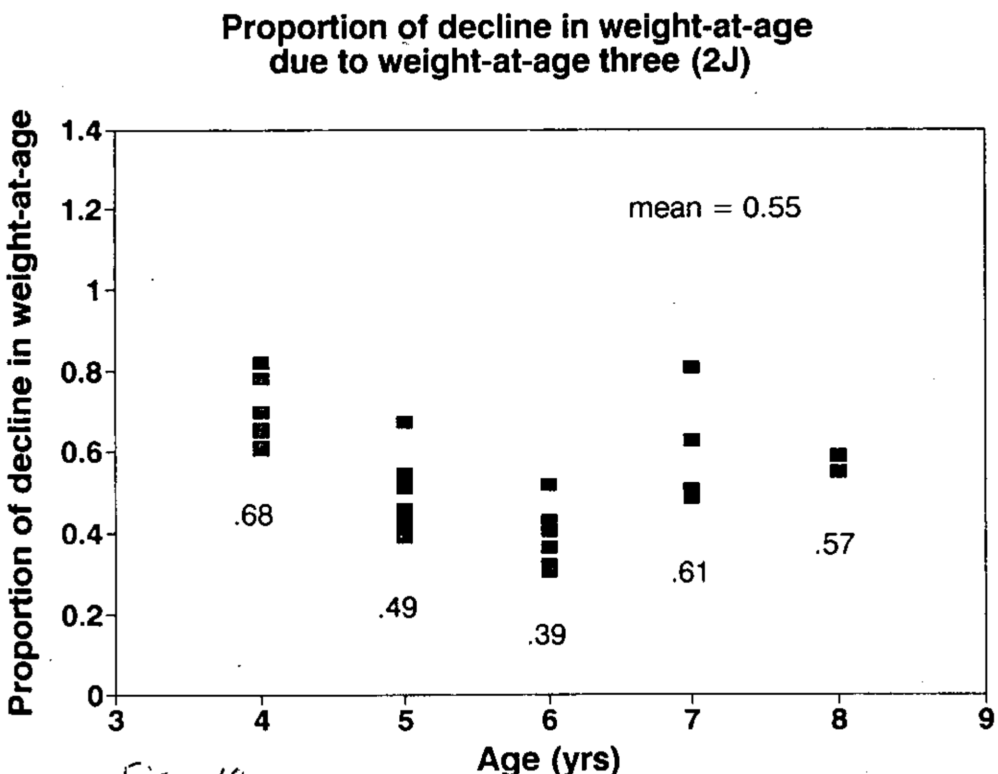
Proportion of decline in weight-at-age
due to weight-at-age three (2J)
Proportion of decline in weight-at-age
mean = 0.55
.68
.49
.39
.61
.57
Age (yrs)

Fig. 10.

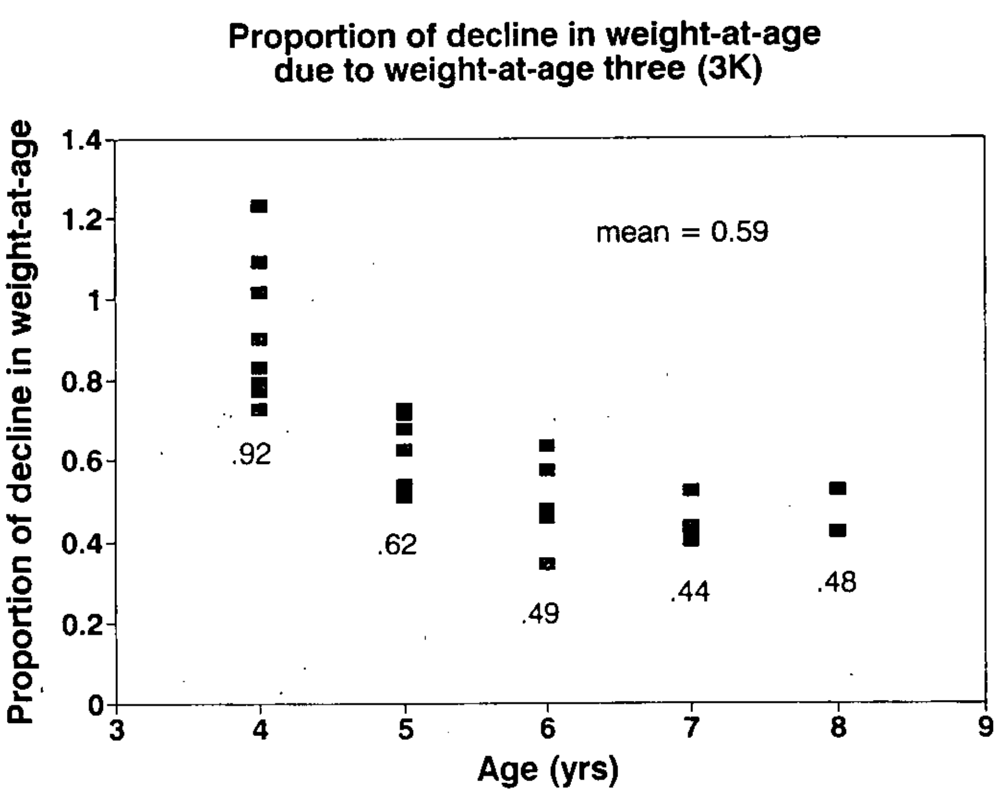
Proportion of decline in weight-at-age
due to weight-at-age three (3K)
Proportion of decline in weight-at-age
mean = 0.59
.92
.62
.49
.44
.48
Age (yrs)

Fig. 11.