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Analysis of Mortality from Research Vessel Surveys for Cod and Flatfish in the Northwest Atlantic

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In this paper research trawl surveyes in the NAFO region are examined to estimate total mortality. We examine data for most of the cod stocks within the NAFO region, and all the flatfish around Newfoundland. The purpose is to detect overall trends that may be missed in the examination of individual stocks.

1 Mortality from Pairs of Abundance Estimates

Consider a population in which each cohort is surveyed at several ages. Let $r_{y,a,i}$ be the survey estimate of abundance for year y, age a, and survey i. A primitive estimate of total mortality, which includes the differences in catchability at age, is:

$$\hat{z}_{y,a} = r_{y,a,i} - r_{y+1,a+1,i}.$$

If the log catchability at age a is equal to that at age $a+1$, i.e. $q_{a,i} = q_{a+1,i}$, then this should provide an unbiased estimate of mortality. For younger ages, this method can only be used to detect trends in mortality, which may be contaminated by trends in catchability. The results across all years are displayed boxplots. The boxplots show the limits of the middle half of the data (the line inside the box represents the median). Extreme points are also highlighted. The amount of data is shown as the width of the boxes is *proportional* to the *square* root of the number of data points. Boxplots not only show the location and spread of data but indicate skewness, as well. The notches are the approximate 95% confidence intervals of the median. If the notches on two boxes do not overlap, this indicates a difference in a location at a rough 5% significance level. The upper quartile and lower quartile provide the outline of the box. Whiskers are drawn to the nearest value not beyond 1.5*(inter-quartile range) from the quartiles; points beyond are drawn individually as outliers. Outliers are plotted as points. For a *description of boxplots see* Hoaglin et al. (1983). *We present* the mortalities for each year, age combination, and smooth the resulting estimates. We use the "lowess" smooth for scatterplot data (Cleveland 1979). This is a robust, local smooth using locally linear fits. A window, dependent on the fraction of the data selected to be analyzed, is placed about each x value; points that are inside the window are weighted so that nearby points get the most weight. For the plots we used a fraction equal to $\frac{2}{3}$, which produces very smooth plots.

There are *considerable uncertainties* in an *analysis* such as this. It is difficult to know the selection of the trawl survey gear, i.e. when the fish are fully recruited to the gear. Older fish may be less vulnerable to the gear, but this could not be distinguished from an increase in mortality. If fish migrate between regions this would show up as a bias in the mortalities.

2 Results

We present mortalities for cod and flatfish stocks within the NAFO region. The results are as follows:

- For the 2J3KL cod stock, we see a clear upward trend in recent years for all ages over 2. These trends are clear in all surveys.
- 3NO cod. The estimate of total mortality for this stock is high at an earlier age than 2J3KL cod. There is not a clear trend in mortality for this stock, but total mortality has been about 1 for the entire time period.
- 3Ps cod. Total mortality is estimated to be about 1 for this stock as well. There appears to be an increase in mortality since the late 1980's.
- 4TVn cod. Mortality has increased in recent years for this stock. It appears that the total mortality has been close to about 1 or higher in recent years.
- 4VsW cod. Mortality has clearly been very high for this stock for many years. there is some indication that mortality has increased in recent years, particularly in the summer surveys.
- 4X cod. Mortality on the older ages appears to be high, e.g. around 1. There is no clear trend in mortality for this stock, but mortality appears to be increasing on the younger ages.
- 5Y cod. Mortality on the older ages appears to be around 1, with no clear trends.
- 5Z cod. Mortality on Georges Bank appears to have been increasing so that it is presently at a level of around 1.

Total mortality was also estimated for several flatfish stocks.

- 2J American Plaice. Mortality in this region appears to have been very high since the mid 1970's on the older ages. It may be possible that this "mortality" is actually migration to the south or due to senescence. There may have been an increase in mortality during the last few years in this stock.
- 3K American plaice. There is a clear progressive elimination of older ages in this stock.
- 3L American plaice. The estimated mortality for the older ages for the 3L region appears to be smaller than those for 2J and 3L. There are more older fish in 3L, there were 19 year old fish until 1985 in this region. This is consistent with the hypothesis that some fish from the north migrate to 3L. Mortality in recent years seems to have clearly increased.
- 3NO American plaice. There appears to be increasing trends in mortality for the younger ages for this stock, but little evidence of trends in the older ages except perhaps in the last year or so.
- 3Ps American plaice. There is increasing mortality at almost all ages above 3. The total mortality at the older ages appears to be very high.
- 2J3KL Greenland halibut. There is increasing mortality on all ages above age 3 for this stock. The mortalities on the older ages appear to be very high for such a slow growing fish.
- 2J3KL Witch flounder. Mortality appears to be high, almost 2 for the older ages of this stock.

- 3NO Witch flounder. Mortality appears to be increasing for the older ages on this stock.
- 3LNO Yellowtail flounder. There may be higher mortality on the younger ages for this stock. The mortality on age 8 appears to be relatively constant at around 2 for this stock in the Canadian spring survey. A similar pattern is seen in the juvenile survey, but there may be a downward trend in mortality in the older ages.

3 Conclusion

The high estimates of total mortality in all the cod stocks examined is extraordinary. The total mortalities appear to be around 1 for all stocks, and perhaps significantly higher in some. It is clear that these stocks cannot sustain such a high mortalities. Total mortalities has increased greatly for most of the Canadian stocks in the last few years.

There are clear differences in mortalities among the flatfish stocks. Mortality for yellowtail flounder appears to be very high by age 8; there are very few fish above this age. There are clear increasing trends for American plaice, and some of these trends appear to be consistent with migration. Total mortality also appears high for Greenland halibut and witch flounder. Again, it seems unlikely that these high mortalities can be sustained.

ACKNOWLEDGMENTS

Ray Bowering, Bill Brodie, G. Chouinard, Bob Mohn, Andy Rosenberg, D. Stansbury, and Steve Walsh provided the data and Nick Barrowman did most of the programming. This work was supported by the Northern Cod Science Program.

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Myers, R. A. and N. G. Cadigan. 1993b. Density-dependent juvenile mortality in marine demersal fish. Can. J. Fish. Aquat. Sci. 50: 1576-1590.

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4 Figure Legends.

For each survey we present two plots: (1) boxplots of the mortalities calculated for each pair of points for each cohort. These plots can be used to determine at what age the total mortality is maximum. (2) Plots of the year specific mortalities at each age. A lowess smooth is used on the data. These plots can be used to determine trends in mortality.

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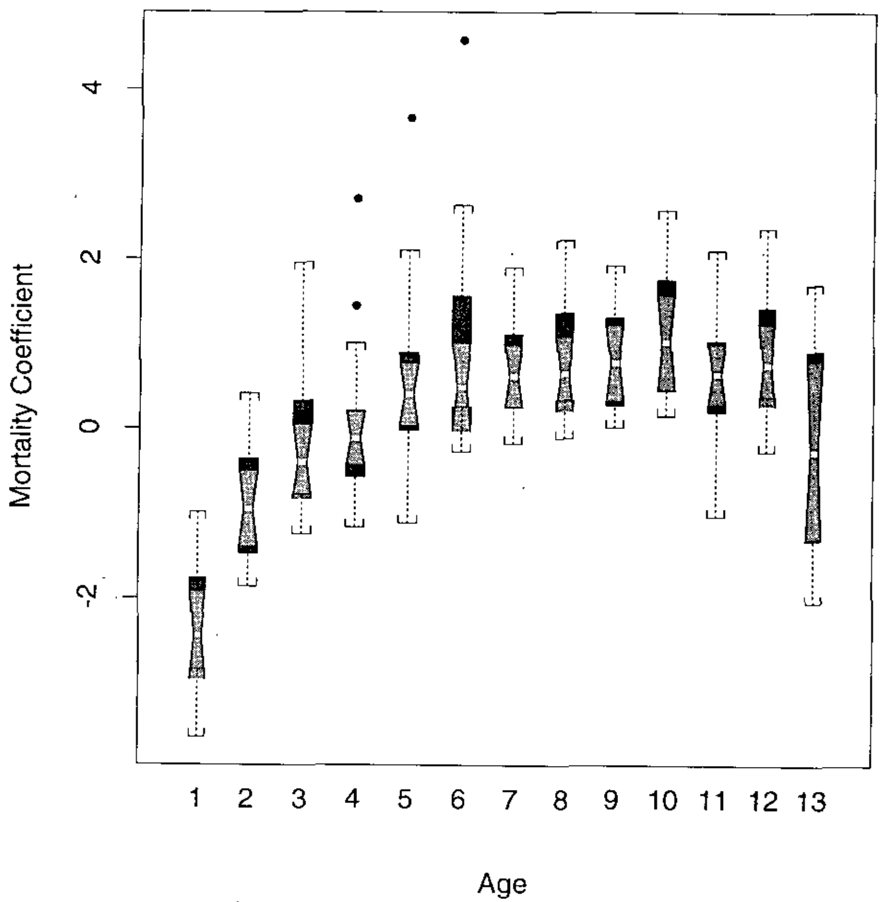

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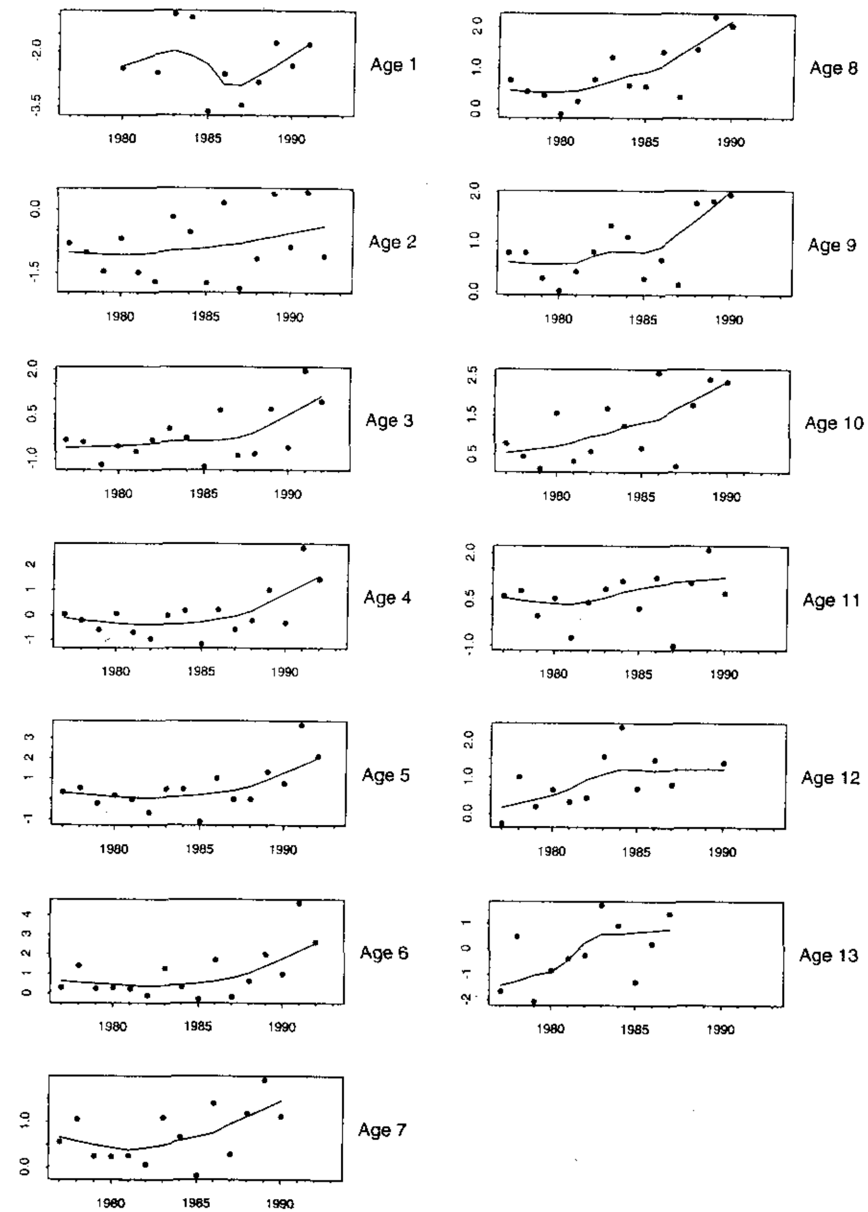

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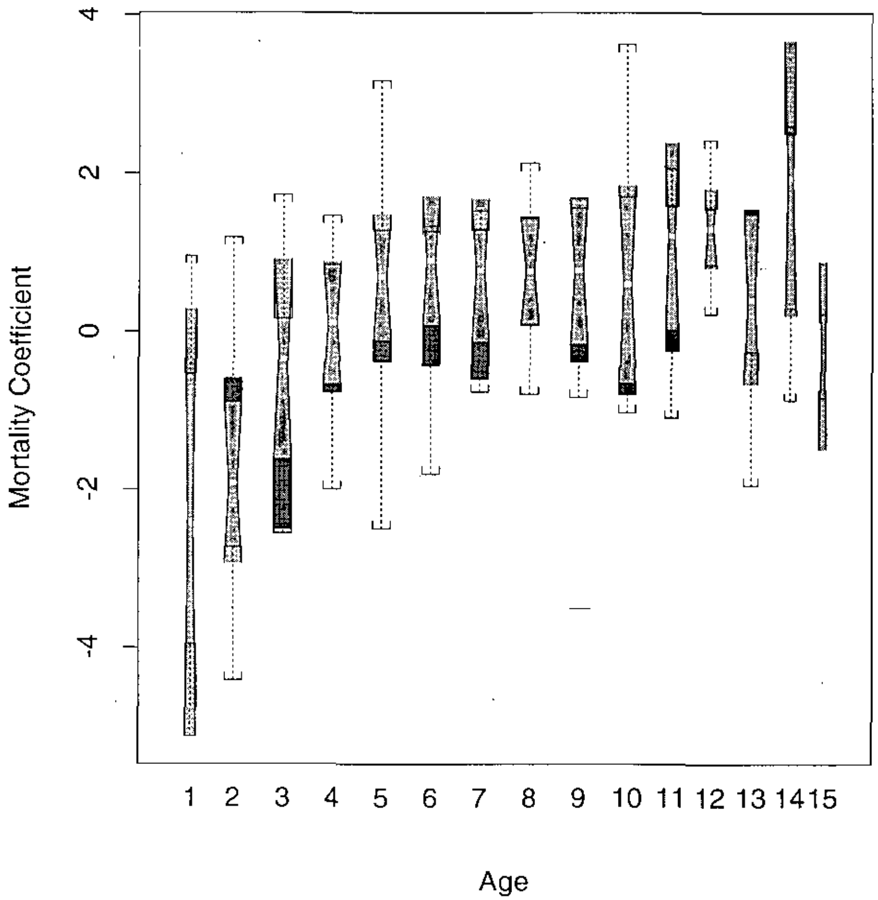

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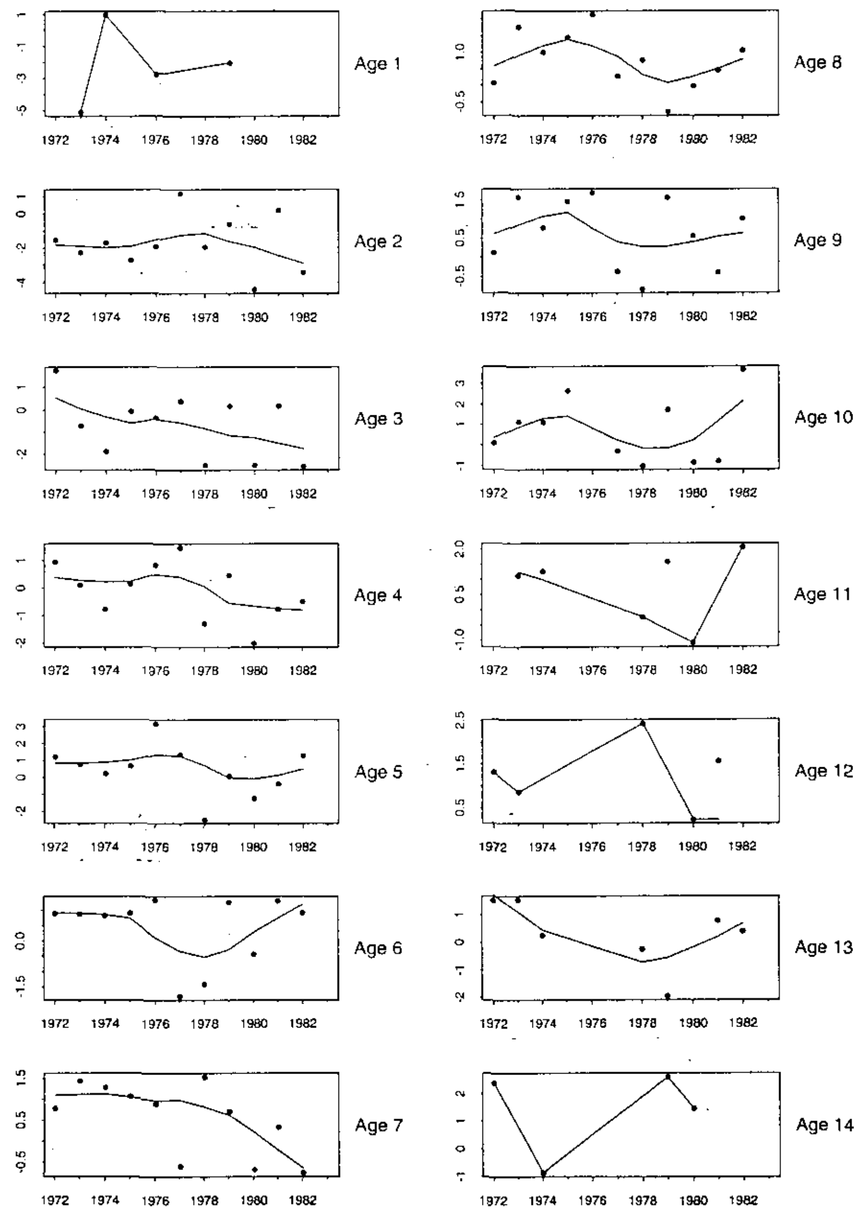

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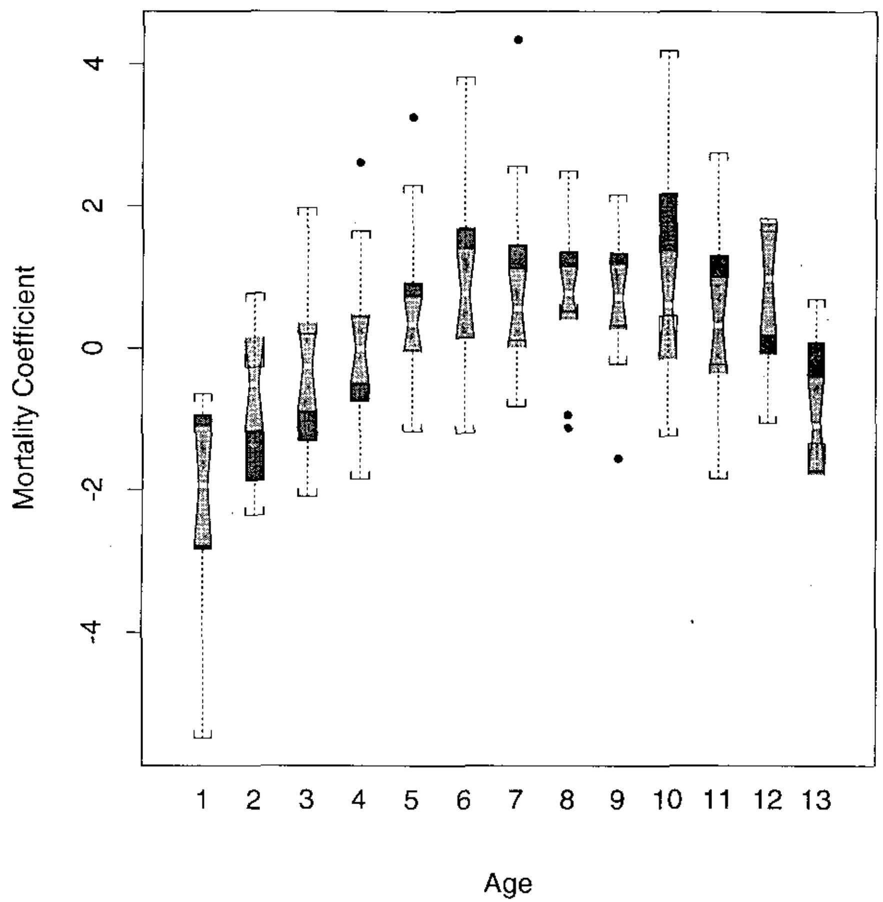

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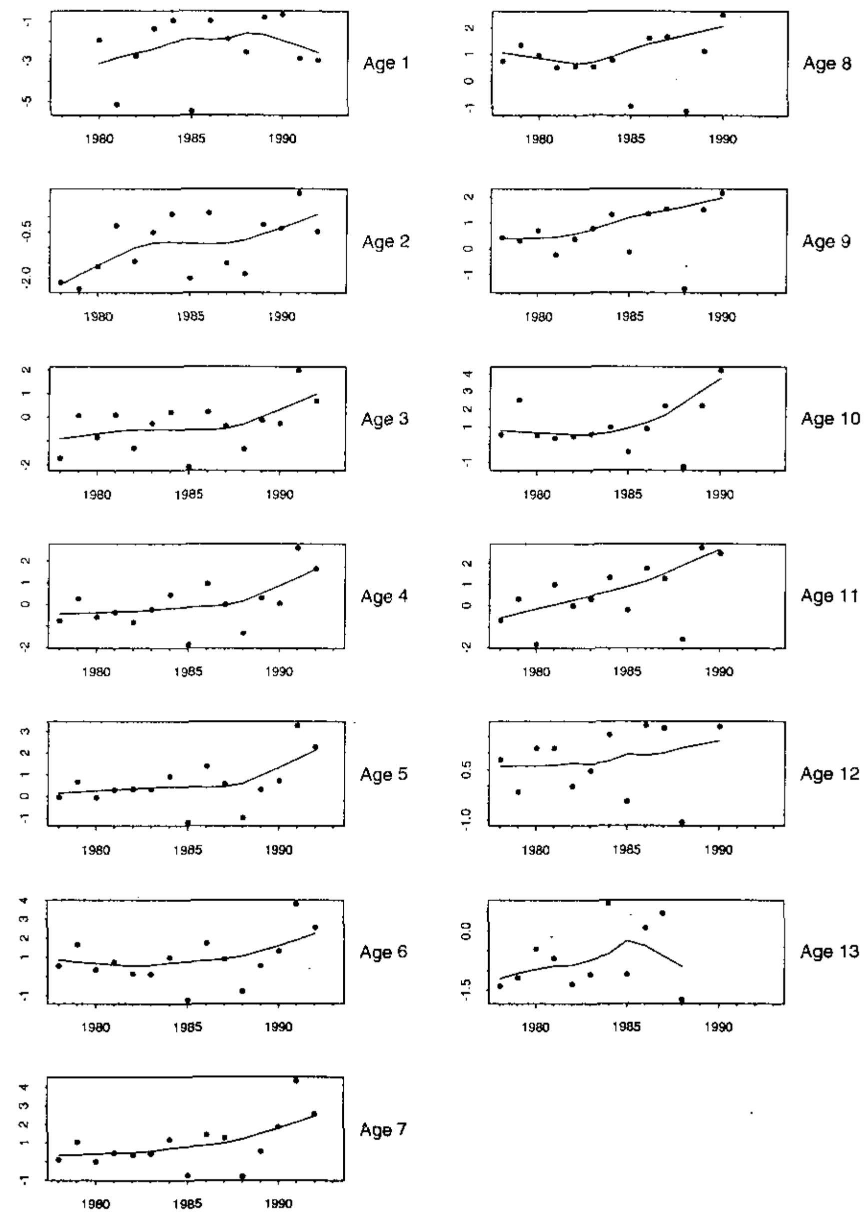

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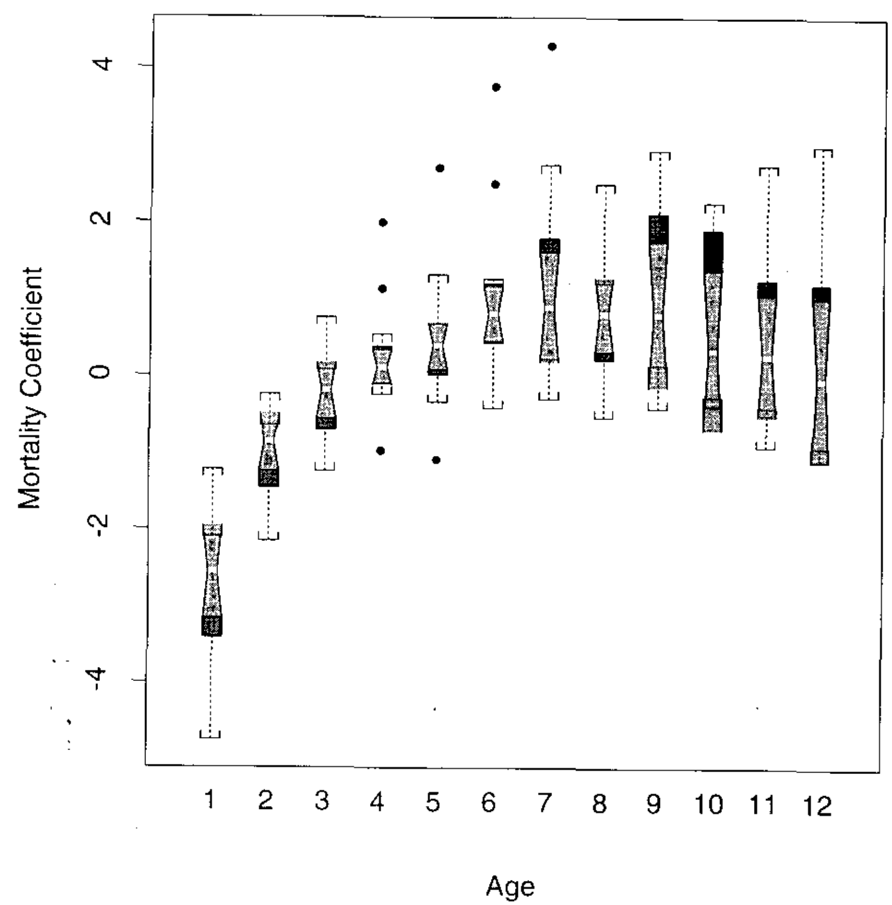

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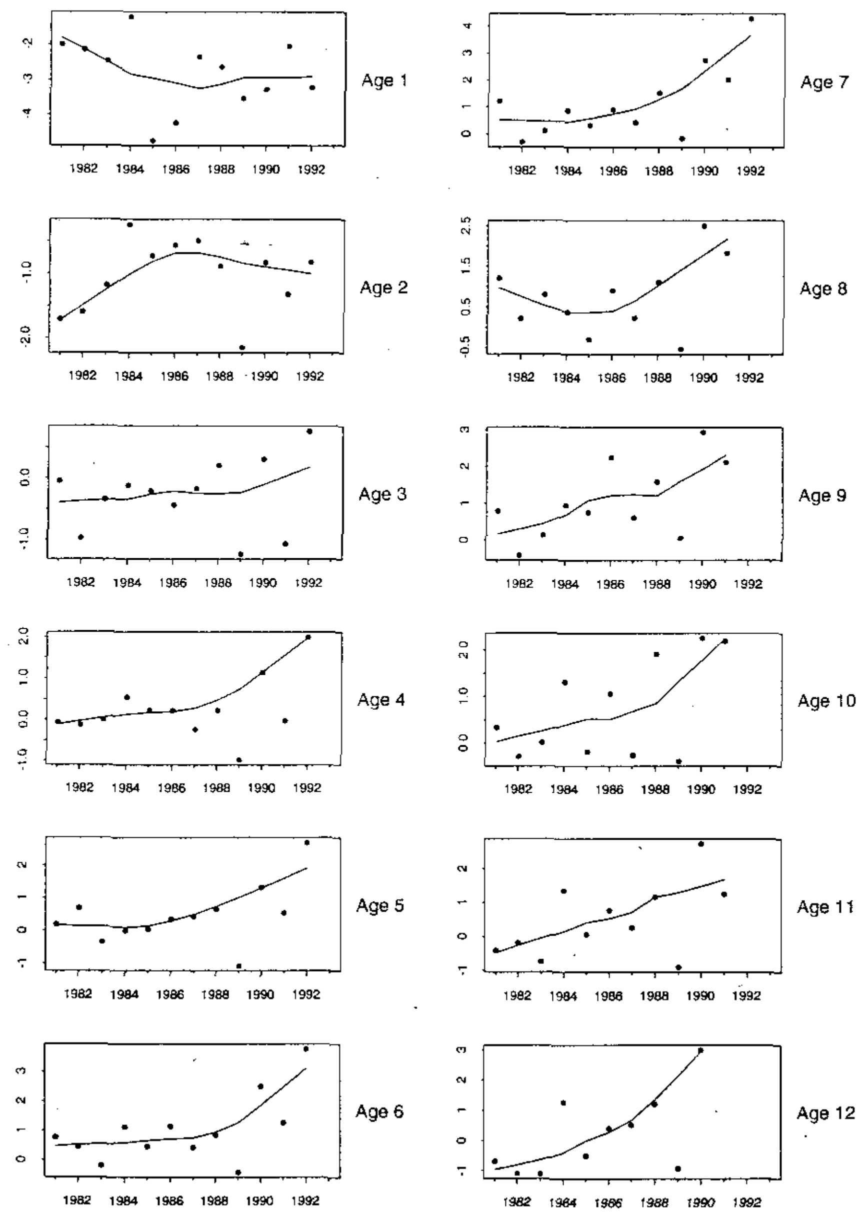

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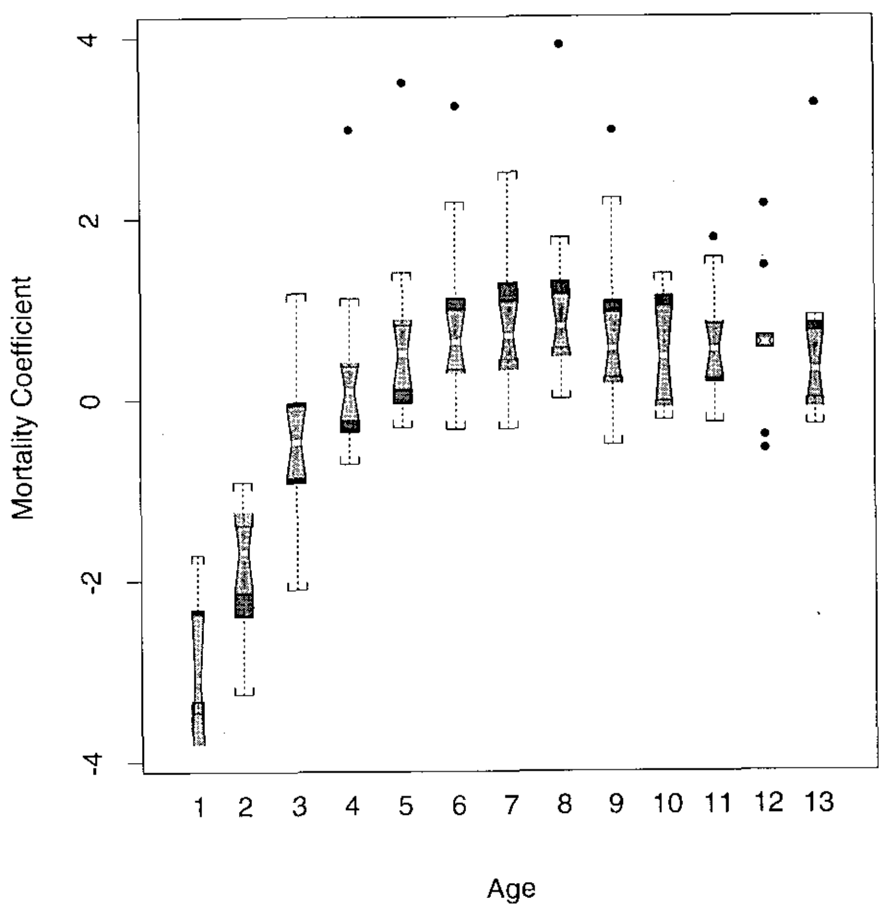

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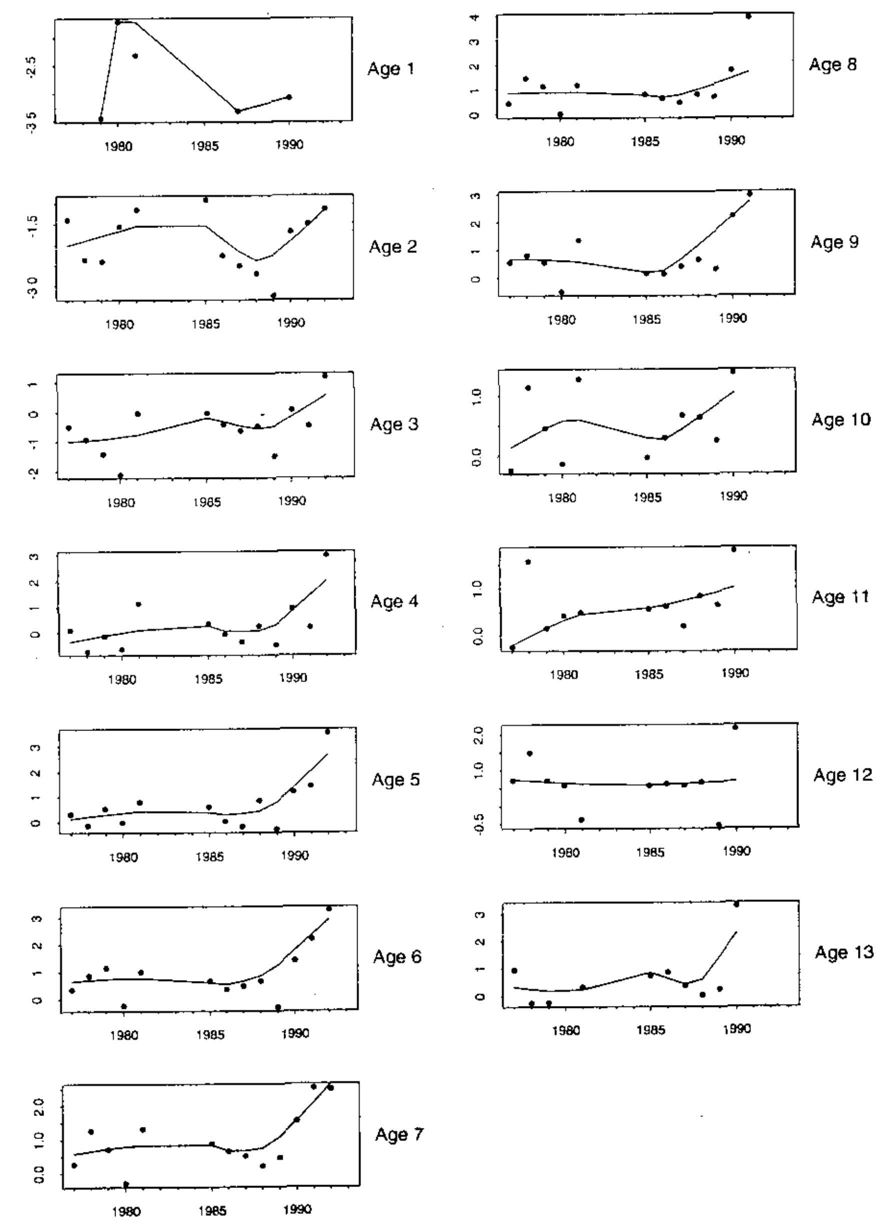

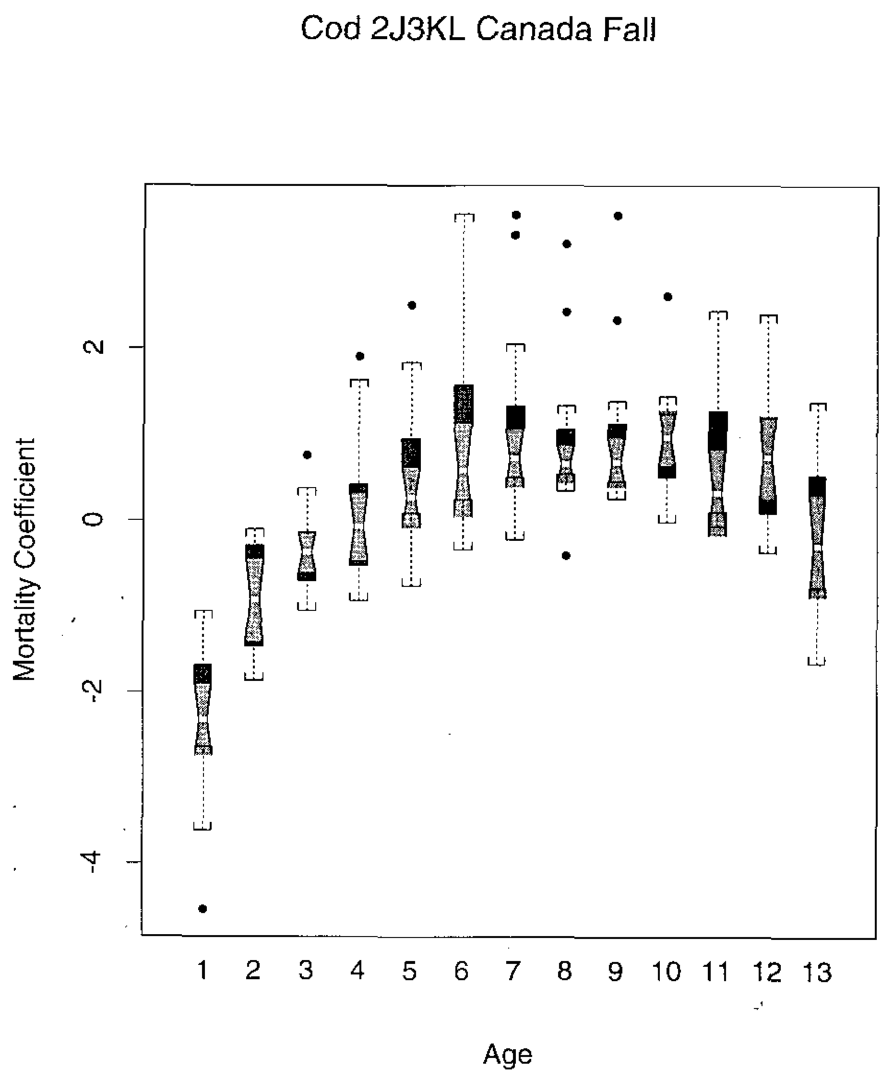
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Mortality Coefficient
Age
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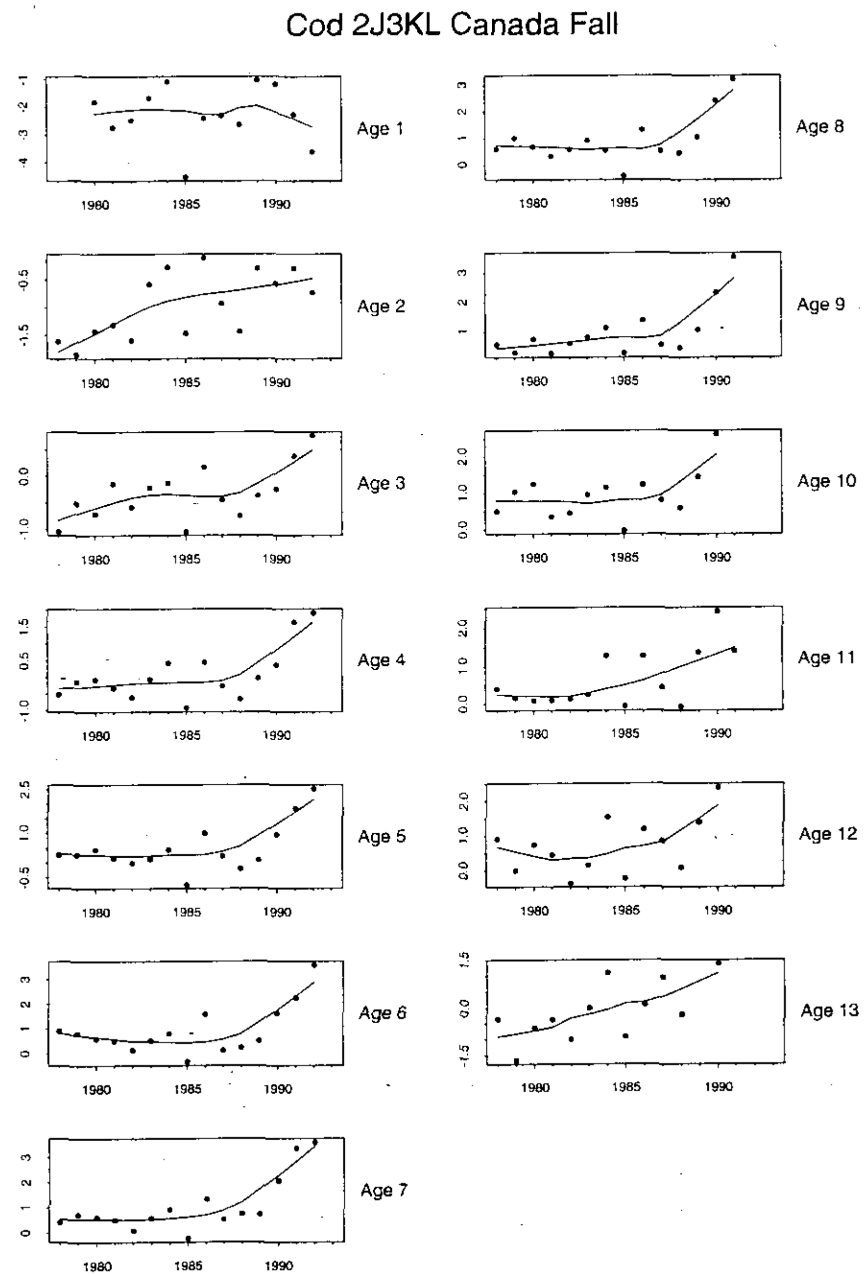
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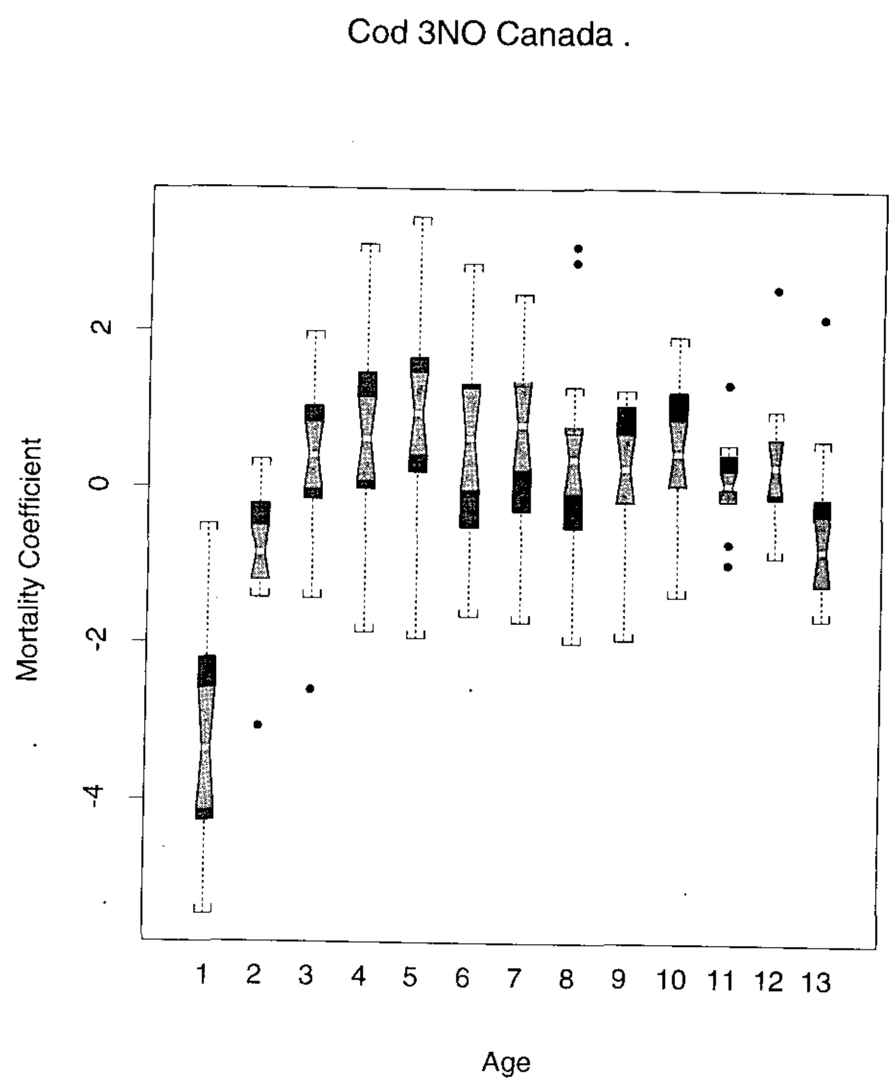
Age 2
Age 3
Age 4
Age 5
Age 6
Age 7
Age 8
Age 9
Age 10
Age 11
Age 12
Age 13



Cod 3NO Canada .
Mortality Coefficient
Age
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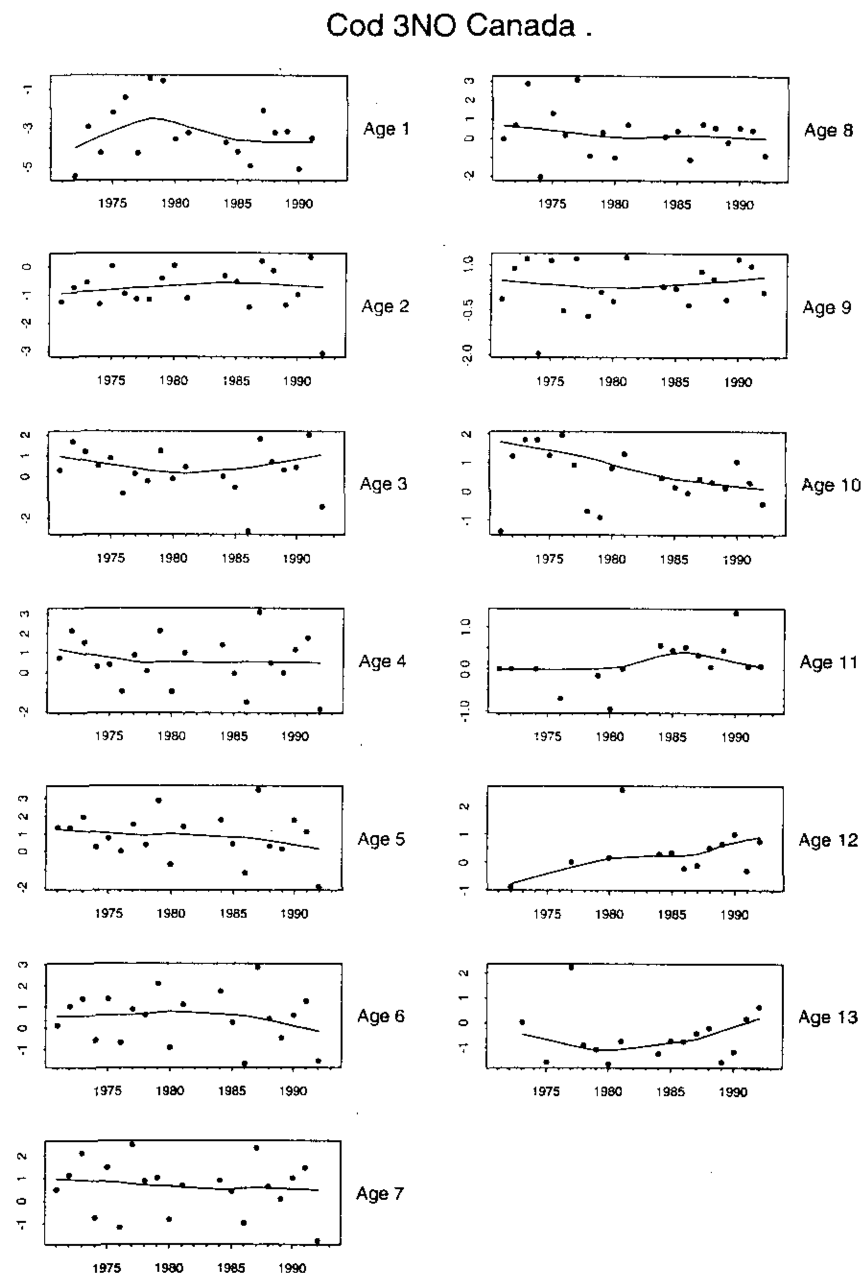
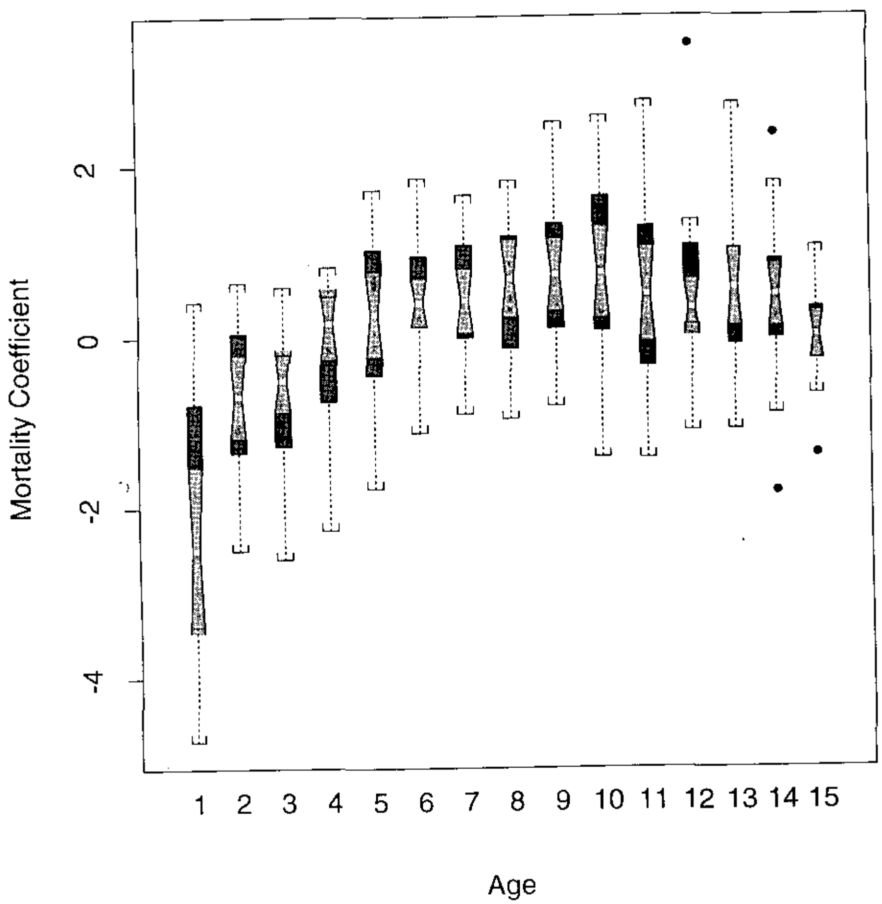
-2
-4
1
2
3
4
5
6
7
8
9
10
11
12
13



Cod 3NO Canada .
Age 1
Age 2
Age 3
Age 4
Age 5
Age 6
Age 7
Age 8
Age 9
Age 10
Age 11
Age 12
Age 13
1975
1980
1985
1990

Cod 3Ps Canada .



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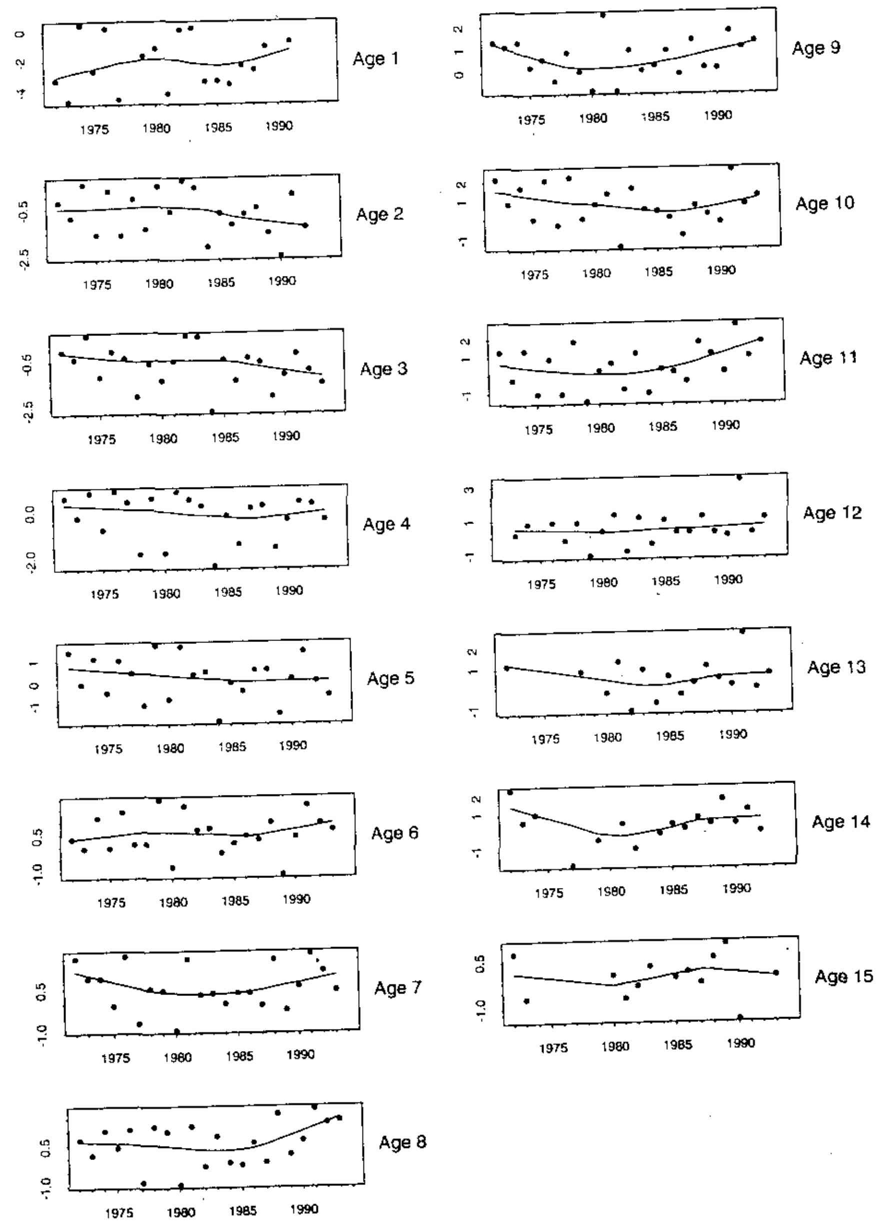

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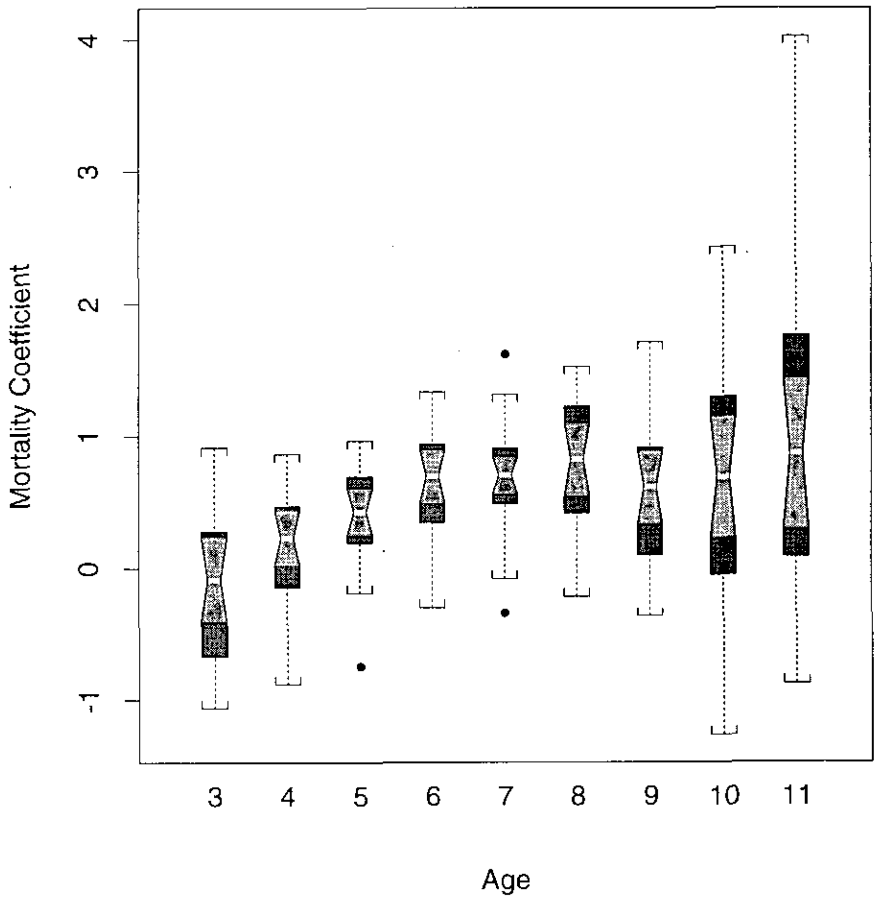

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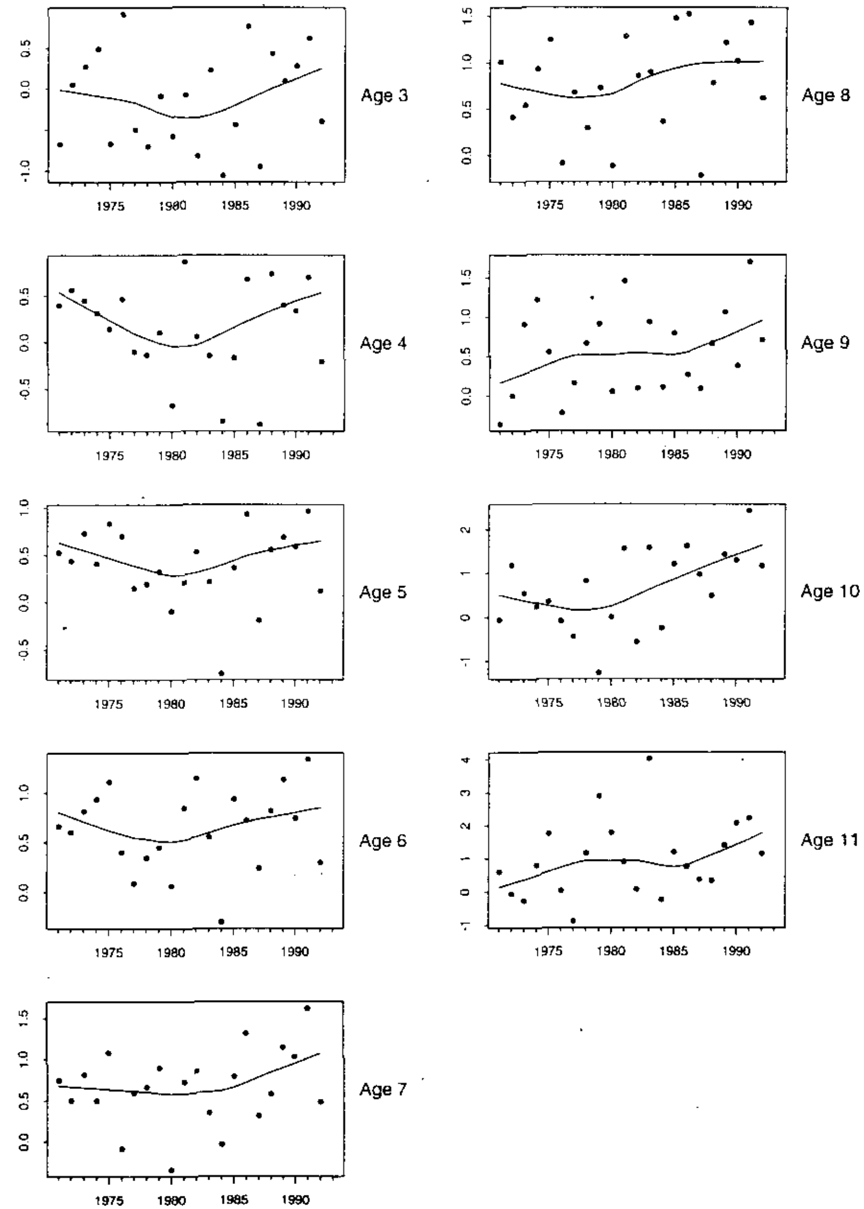

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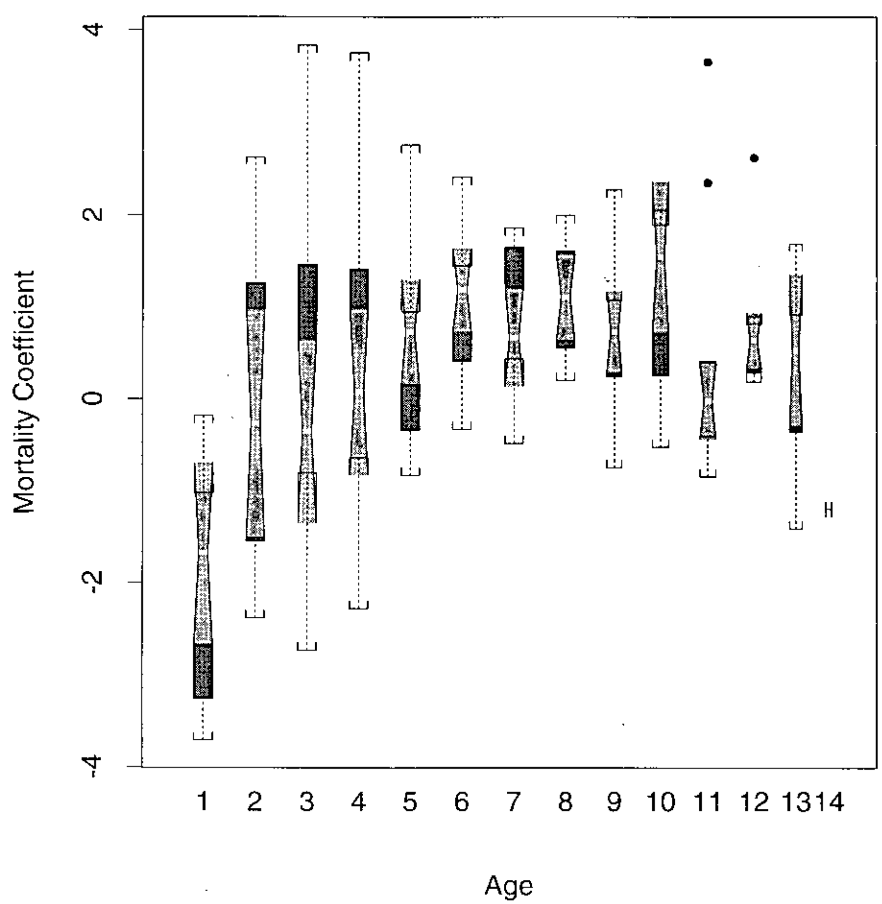

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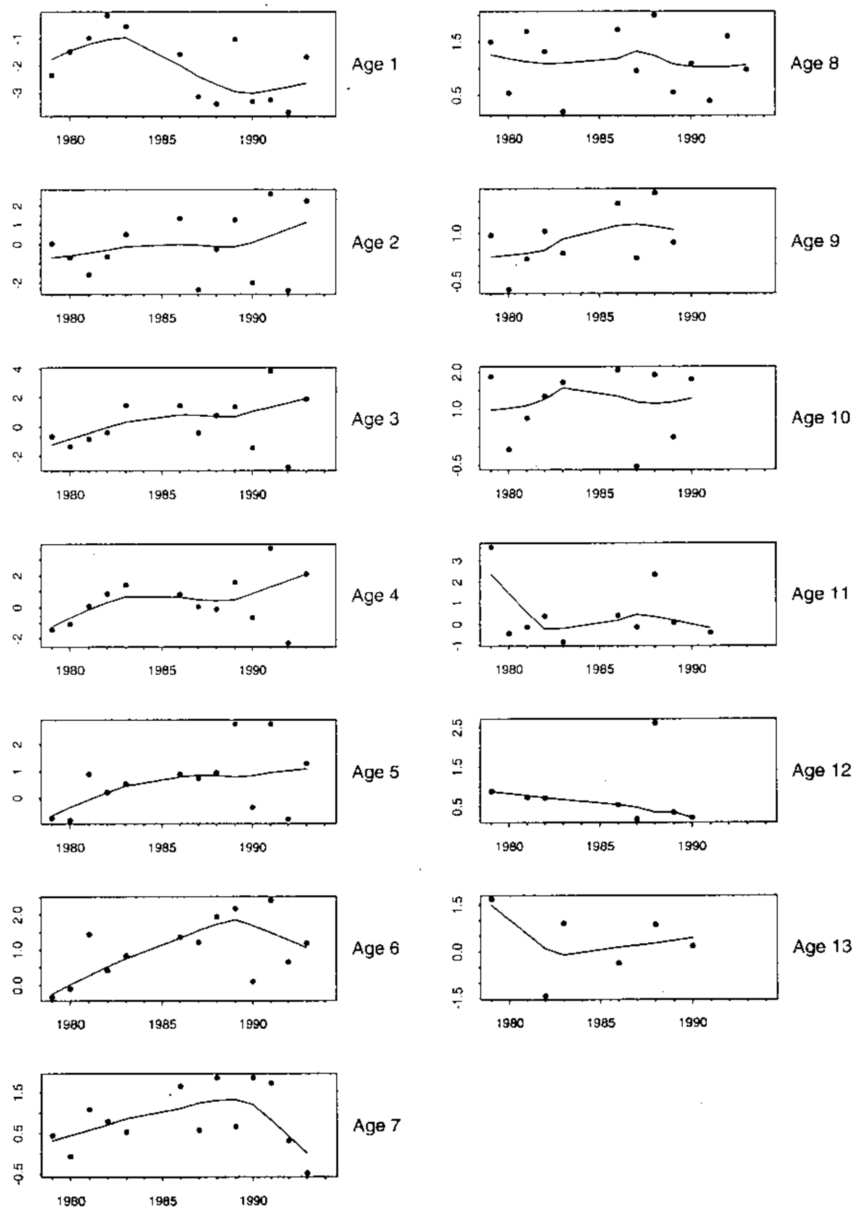
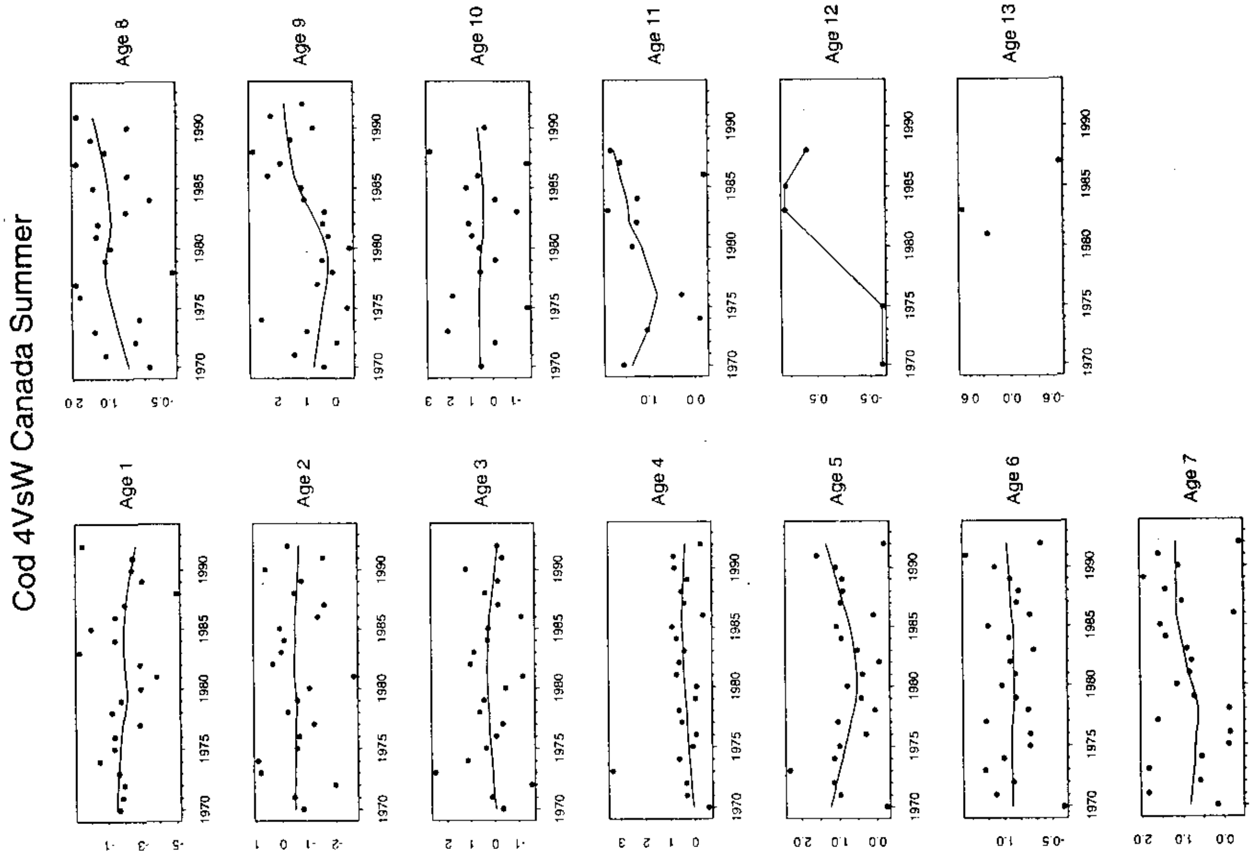
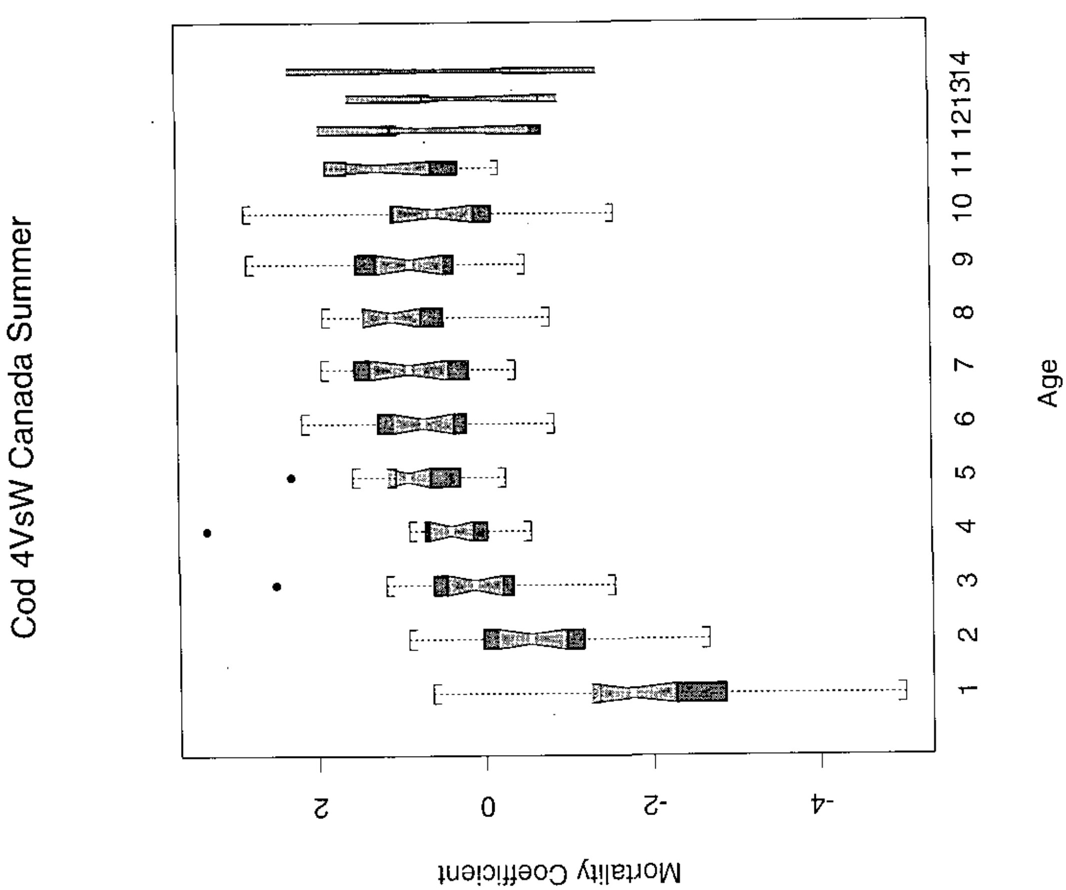
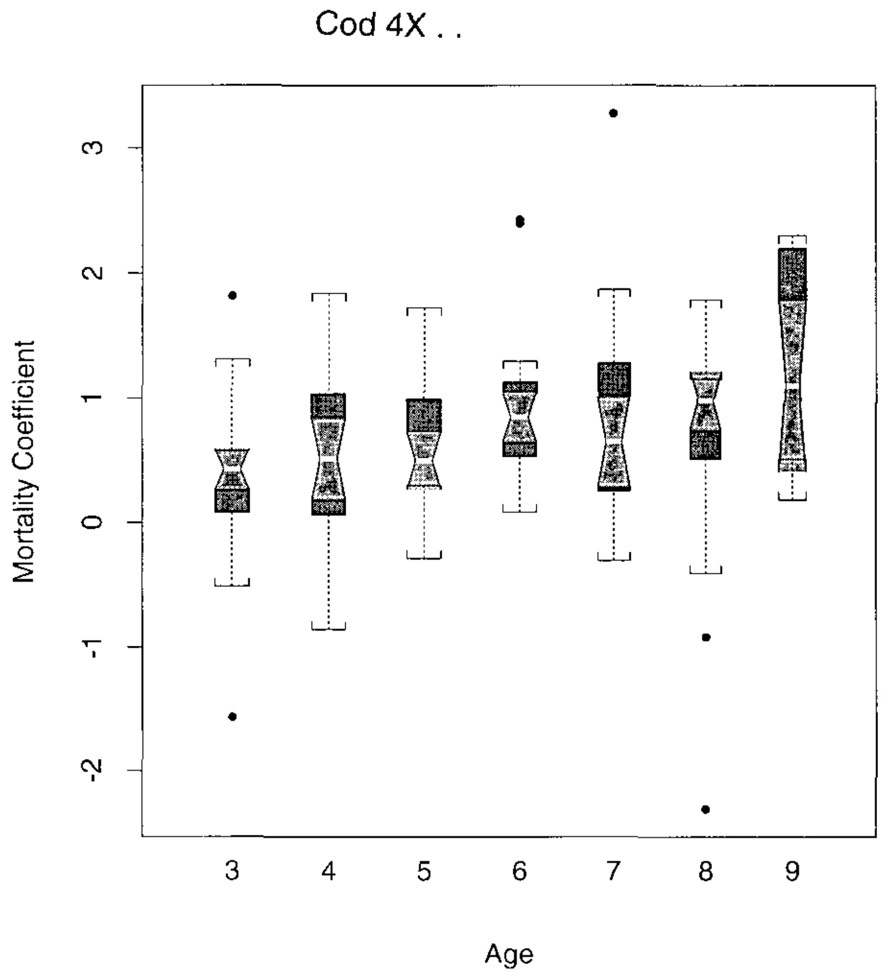
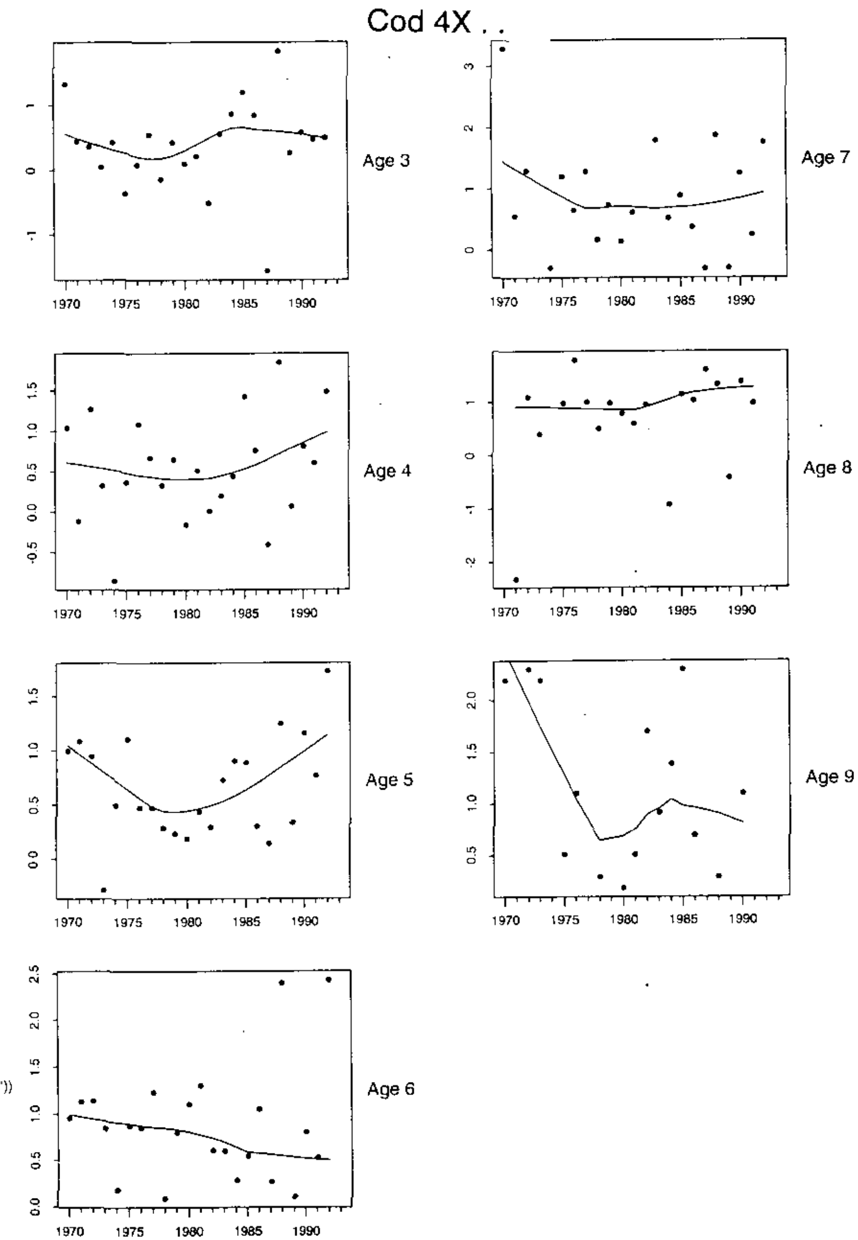



Cod 4VsW Canada Summer
Age 1
Age 2
Age 3
Age 4
Age 5
Age 6
Age 7
Age 8
Age 9
Age 10
Age 11
Age 12
Age 13


Cod 4VsW Canada Summer
Mortality Coefficient
Age





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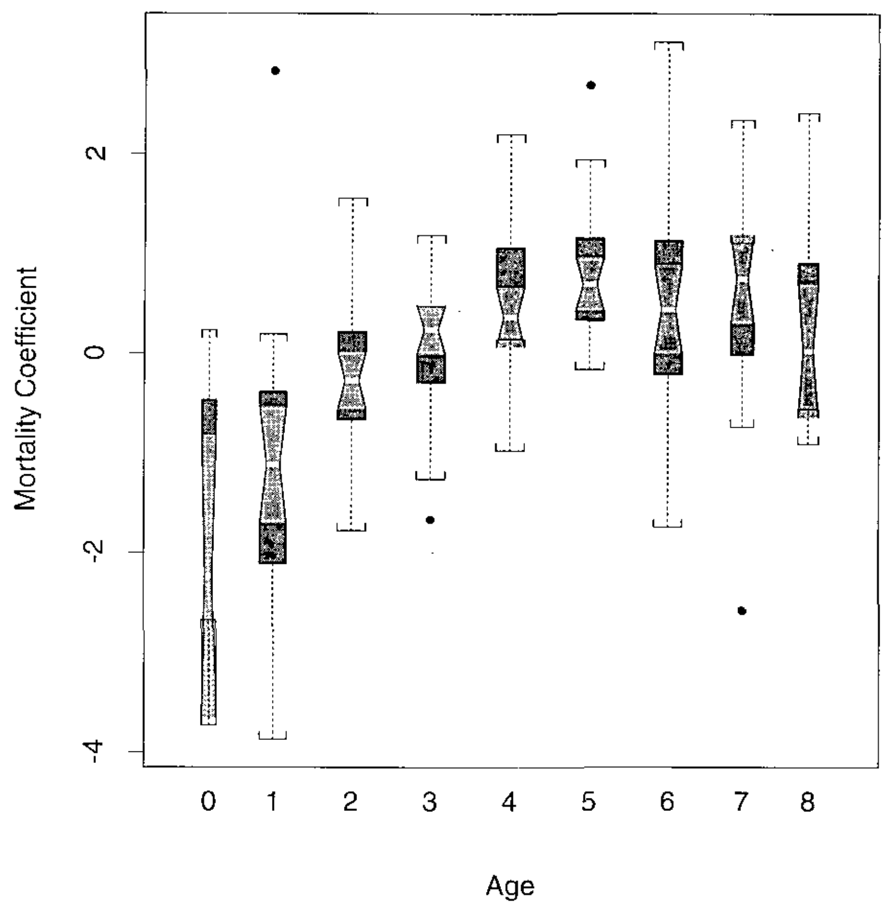

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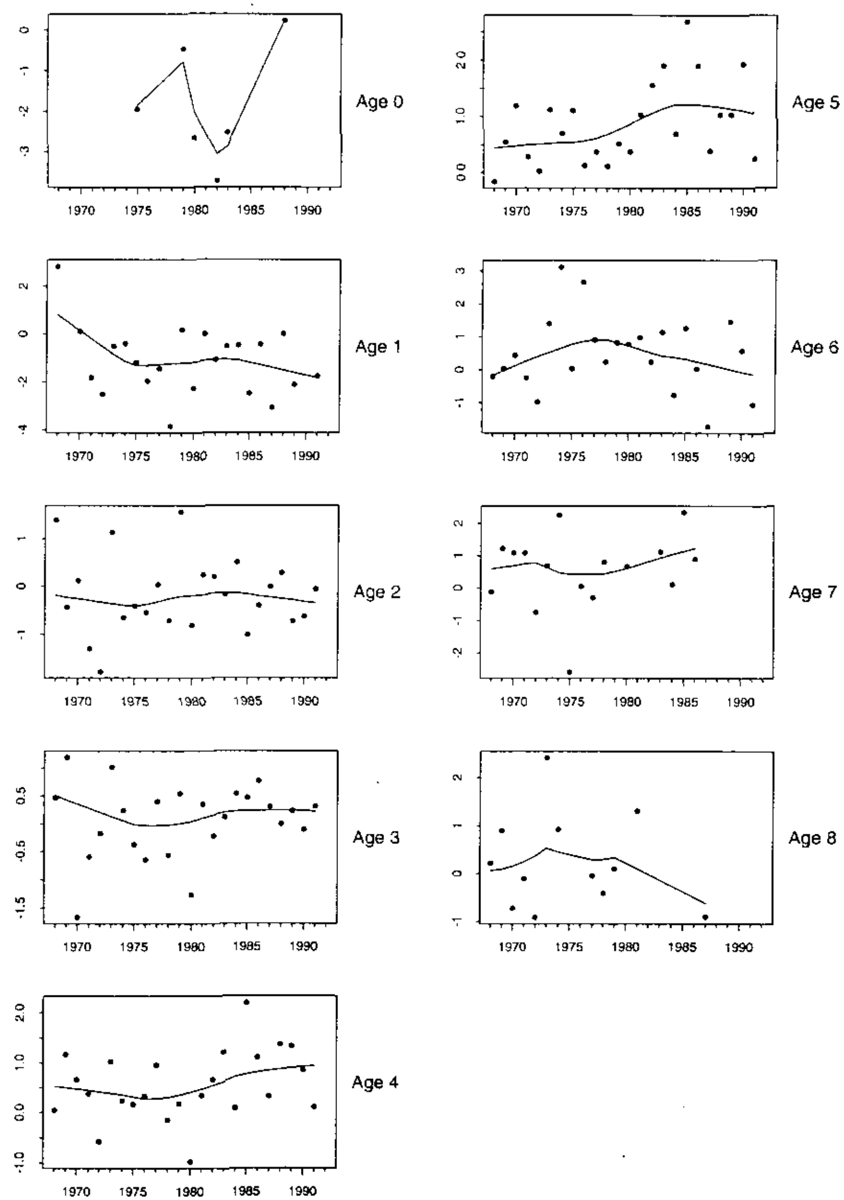

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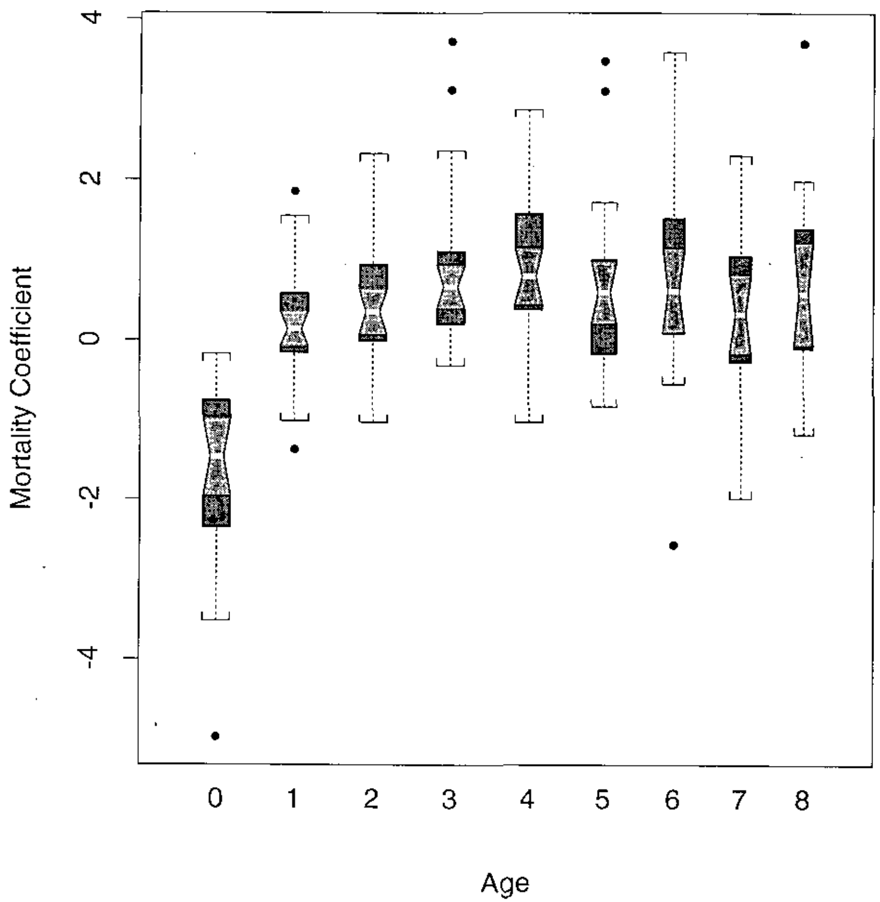

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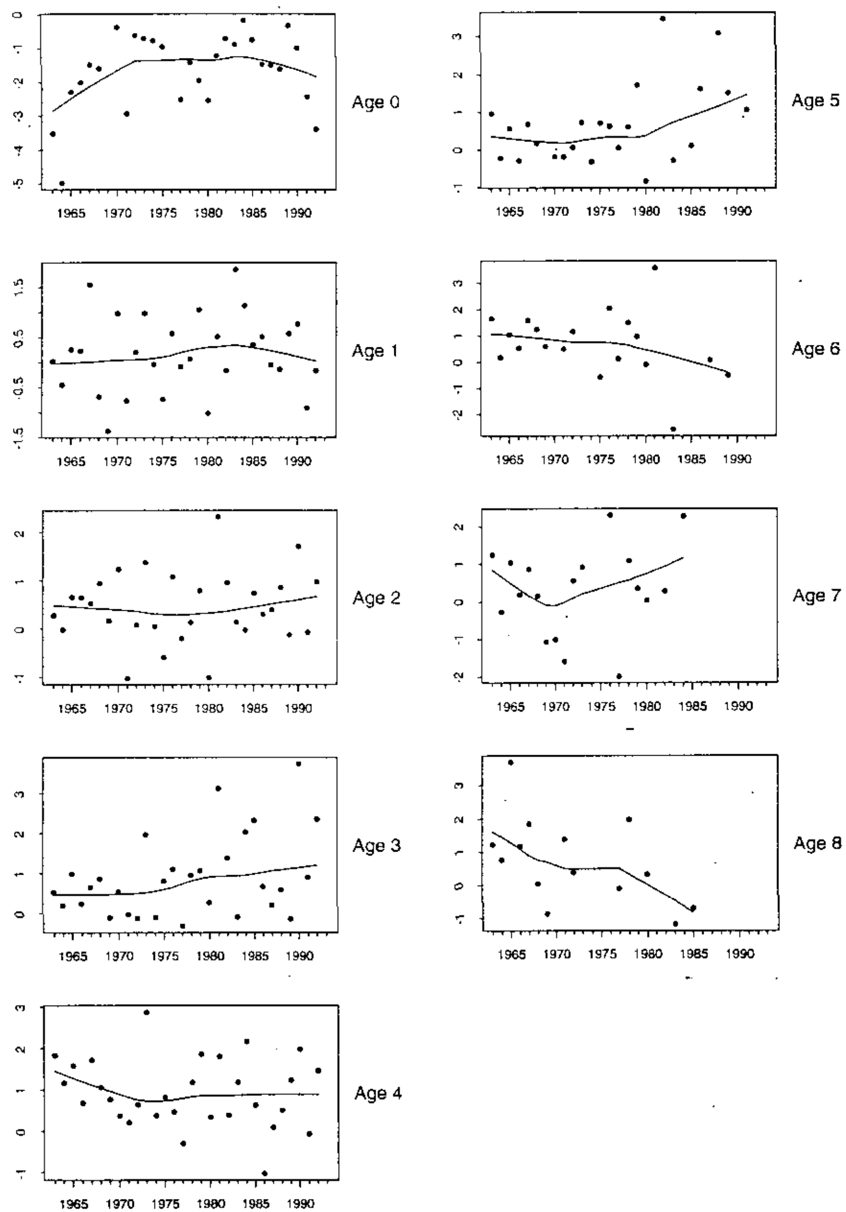

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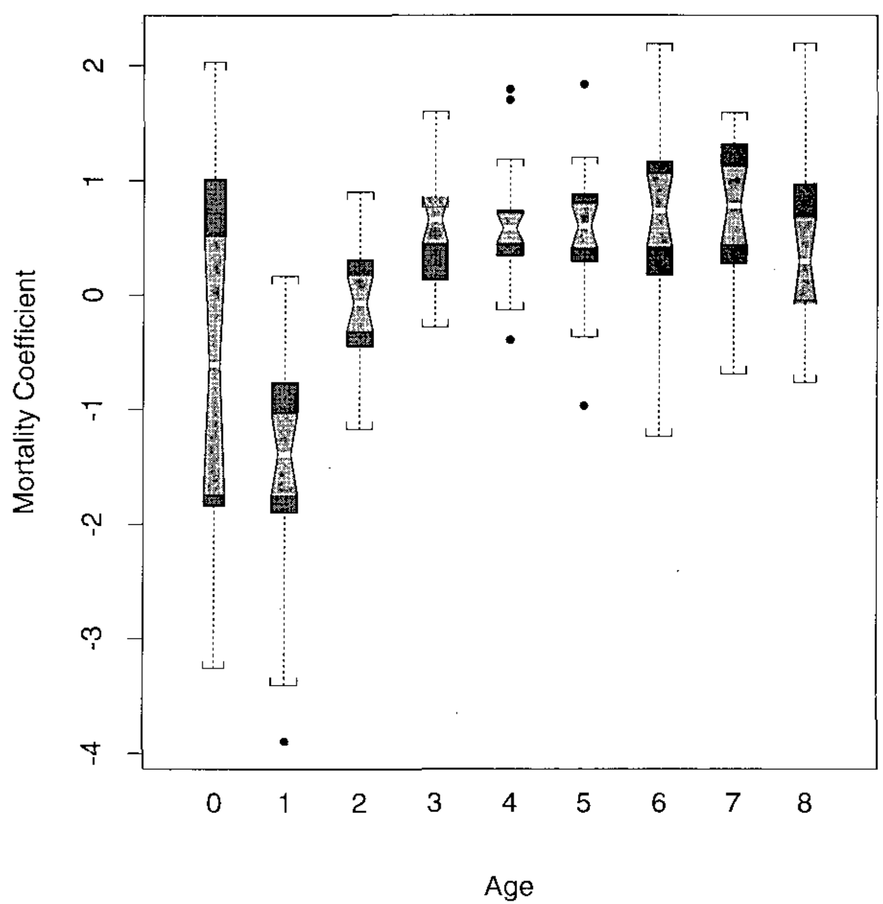

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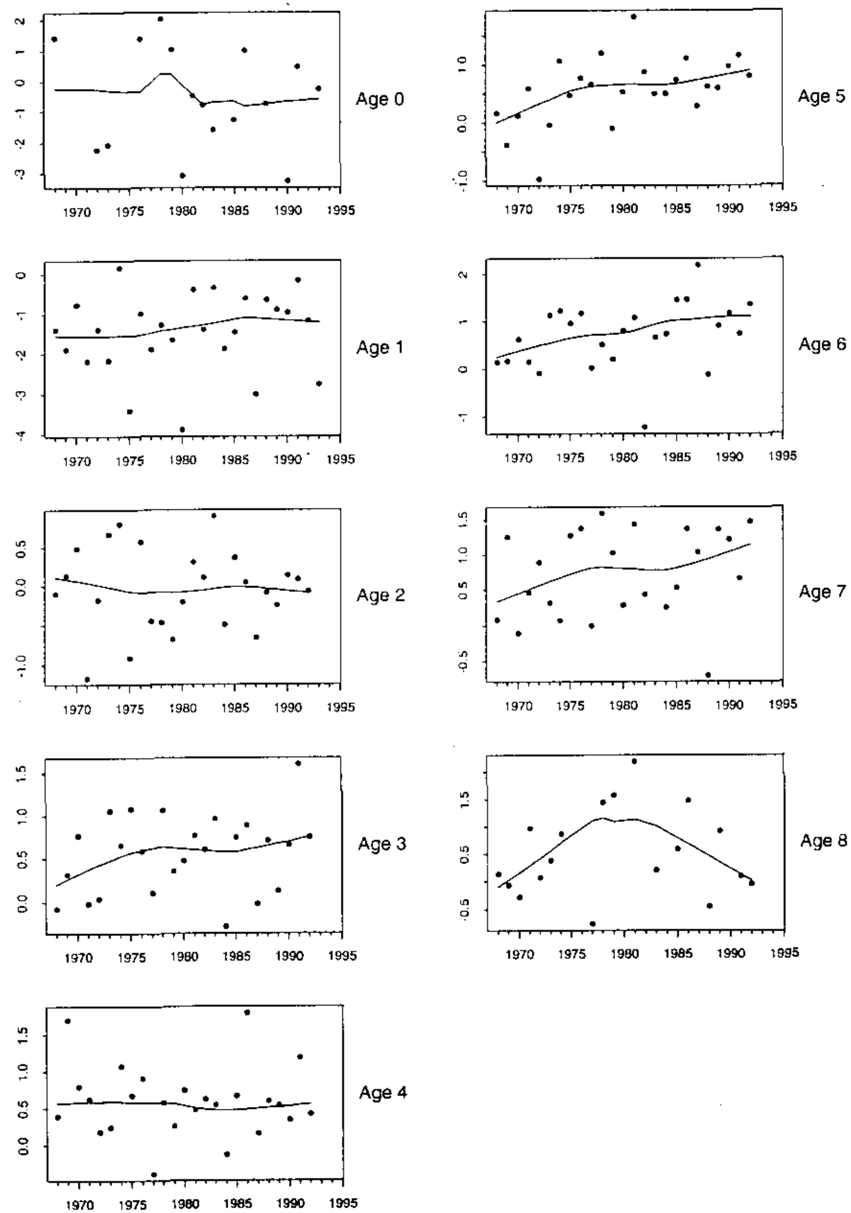
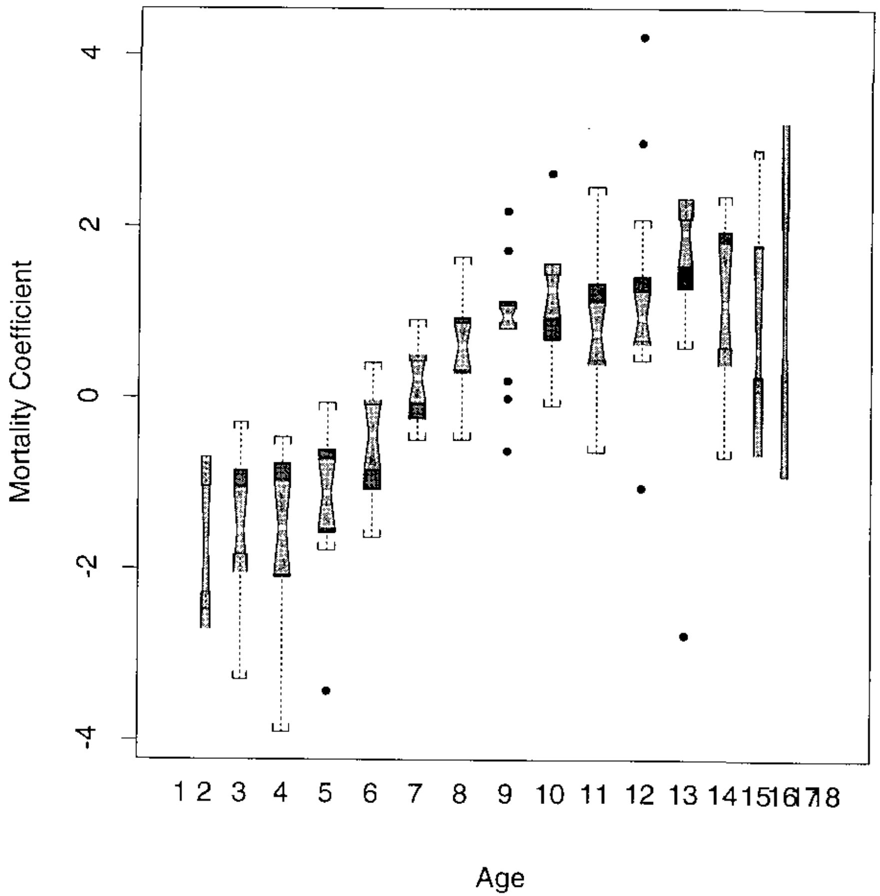


American plaice 2J Canada .



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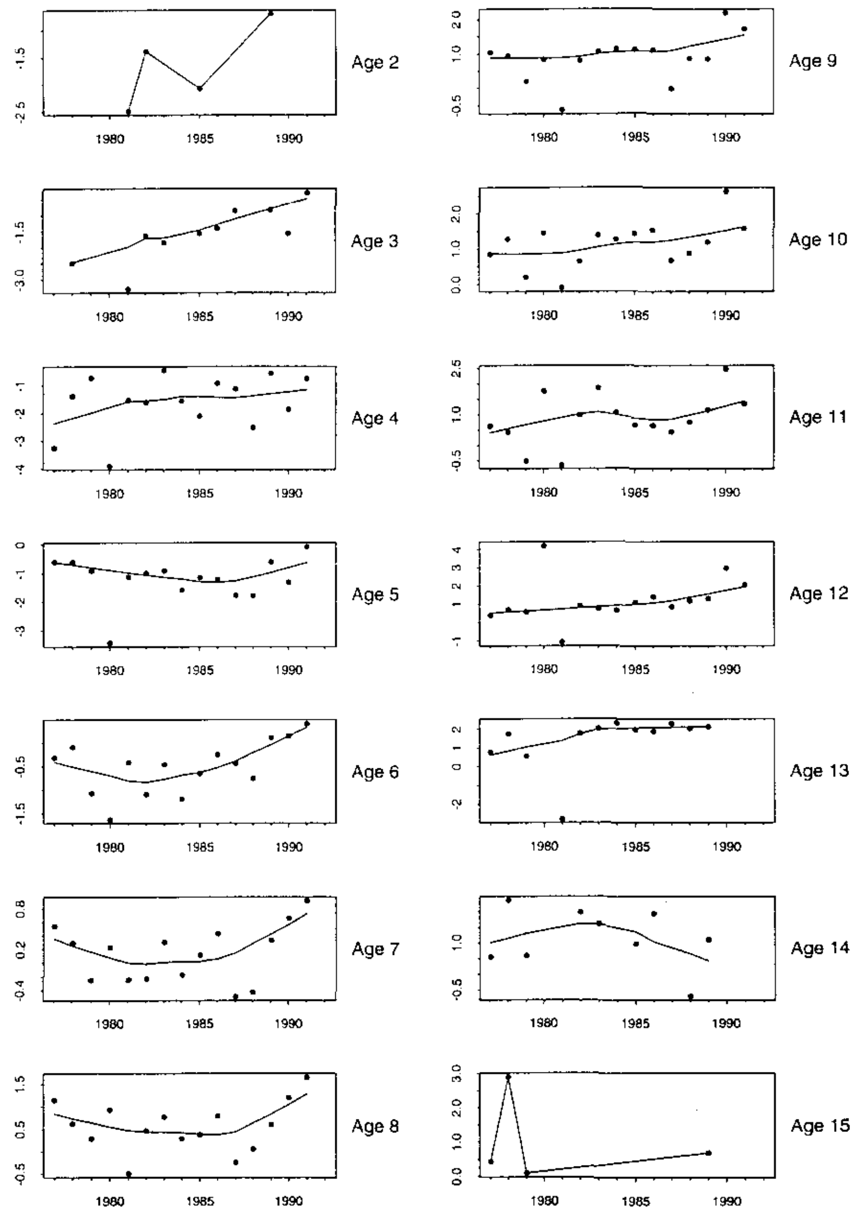
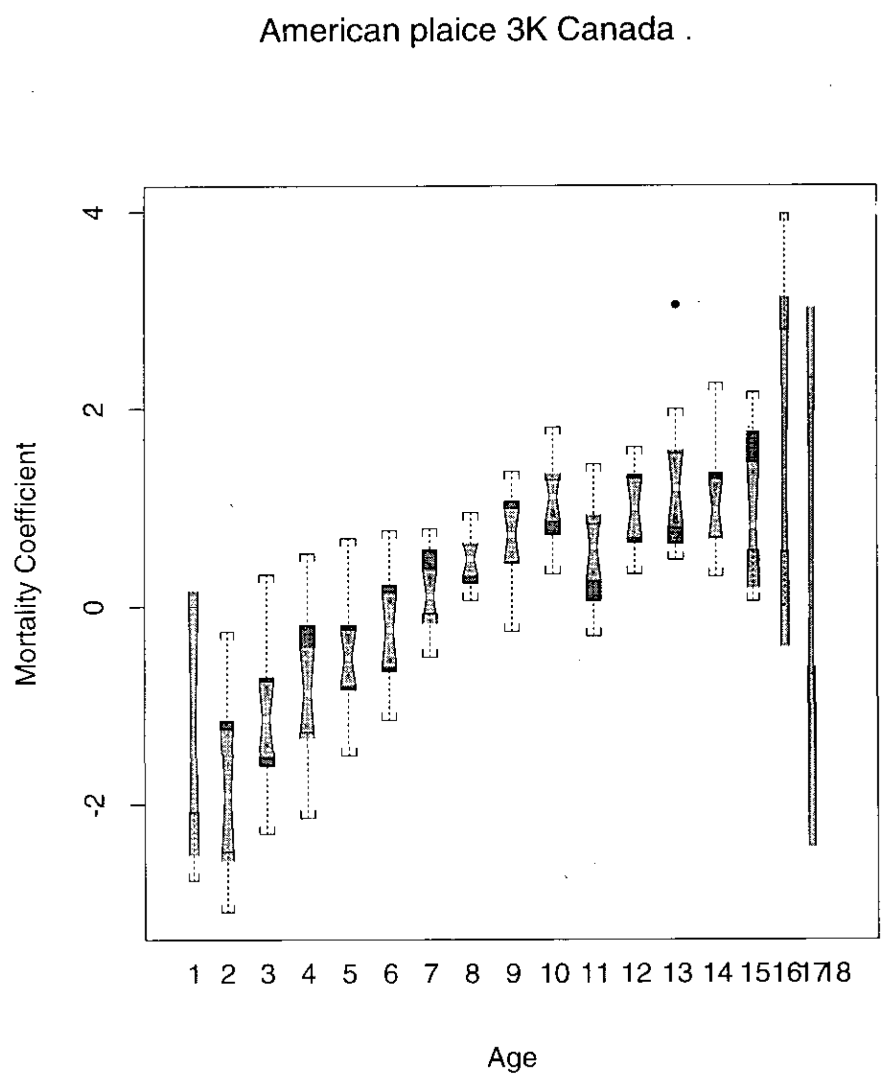
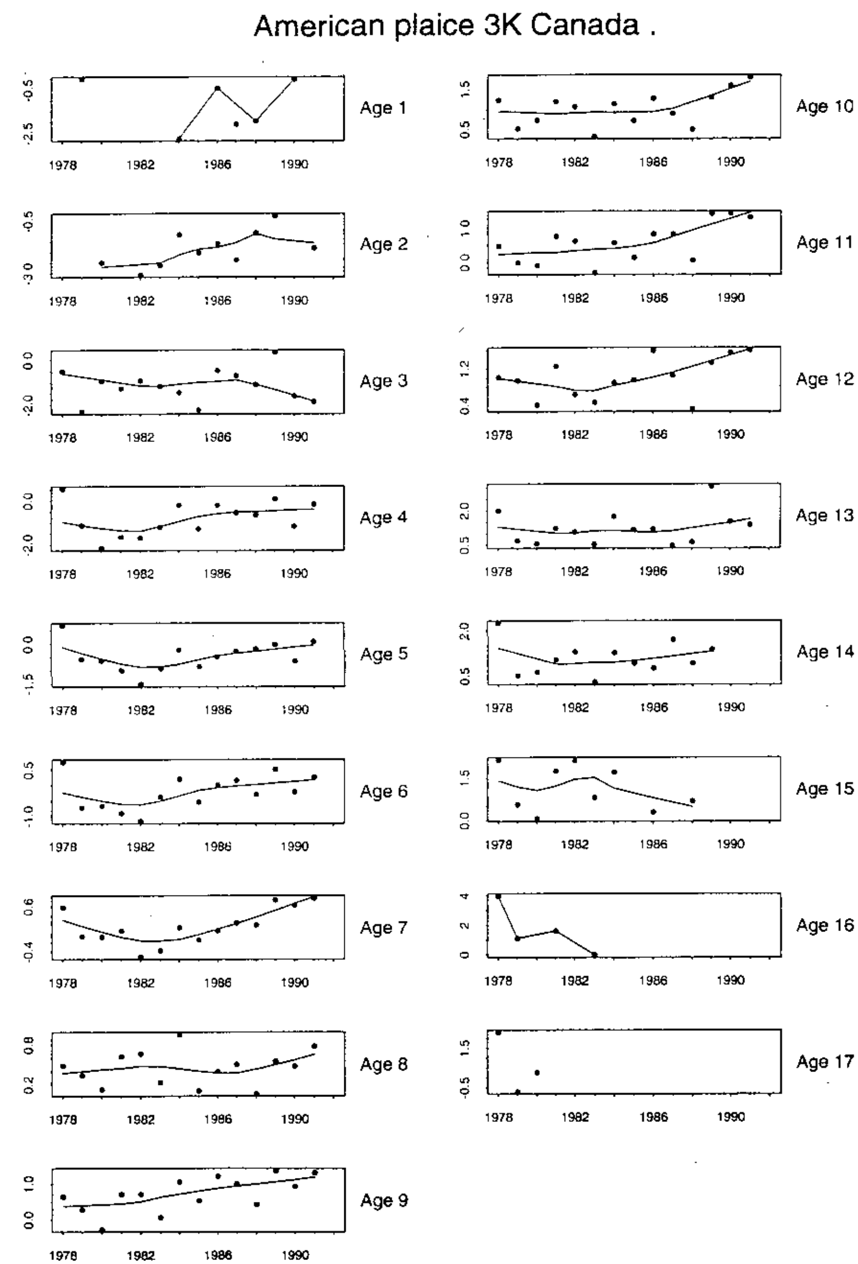



American plaice 3K Canada .
Mortality Coefficient
4
2
0
-2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Age


American plaice 3K Canada .
Age 1
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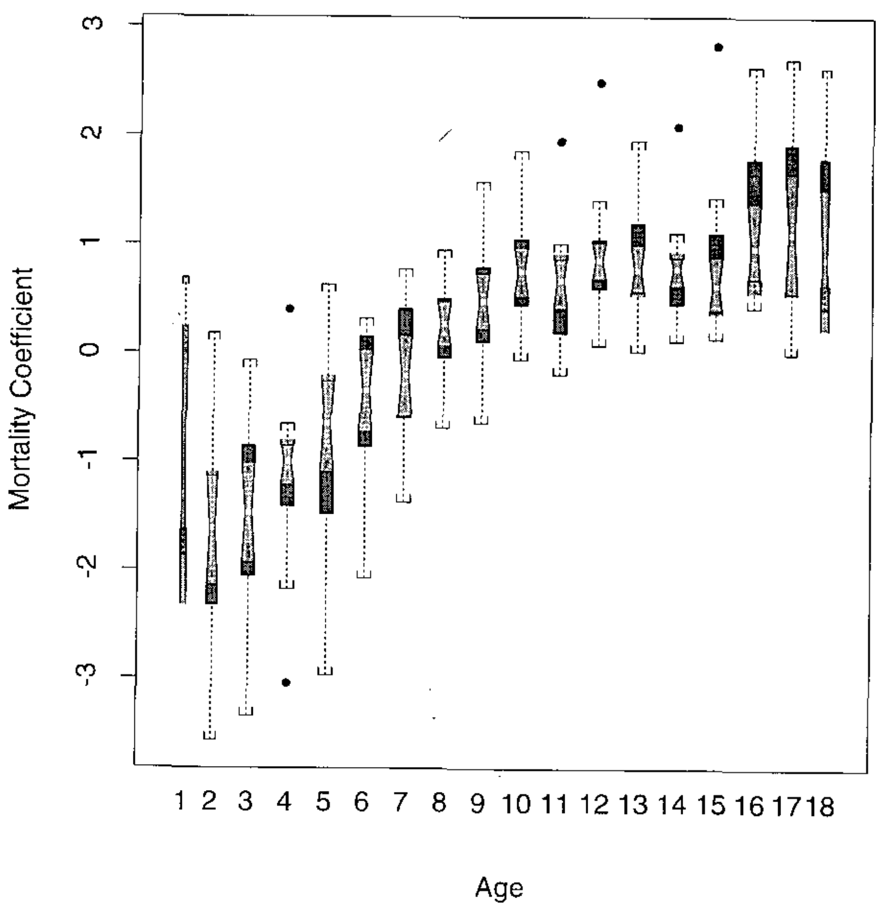
Age 14
Age 15
Age 16
Age 17
1978
1982
1986
1990

American plaice 3L Canada .



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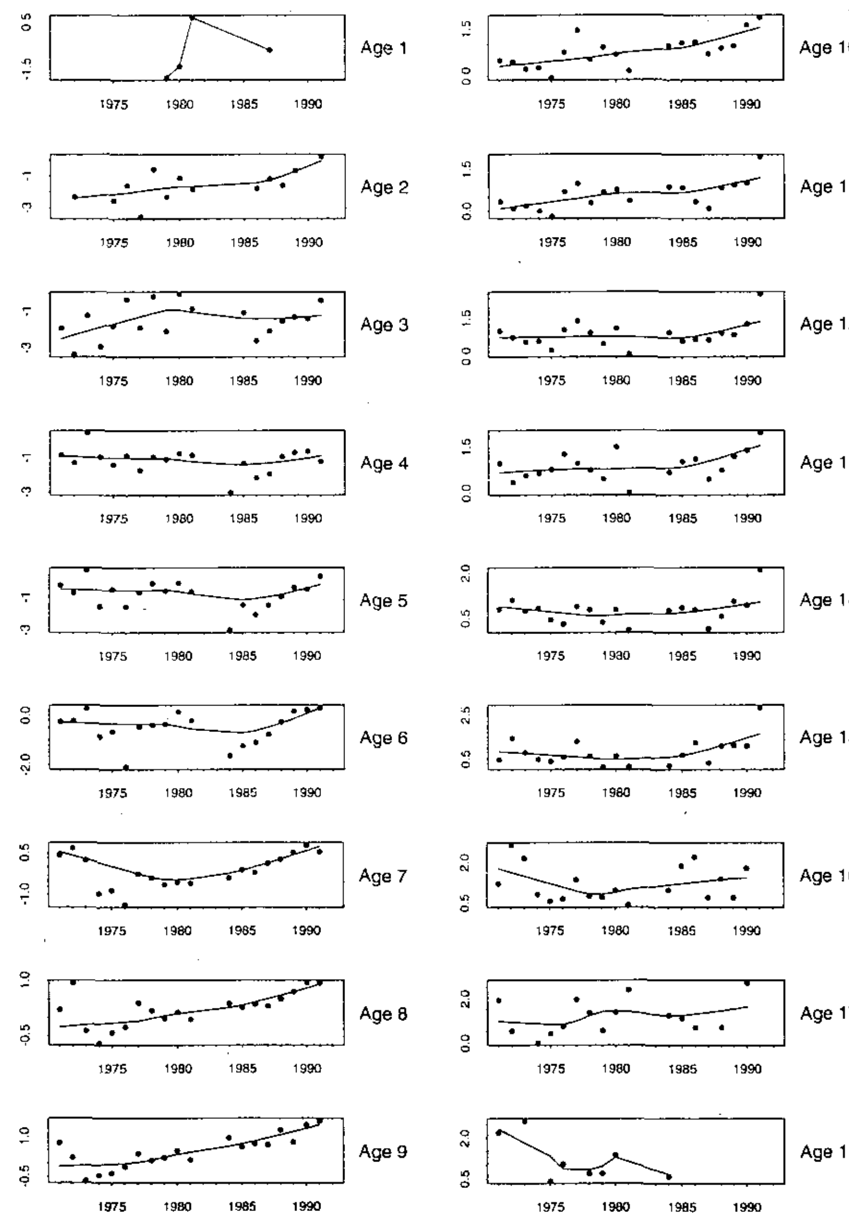
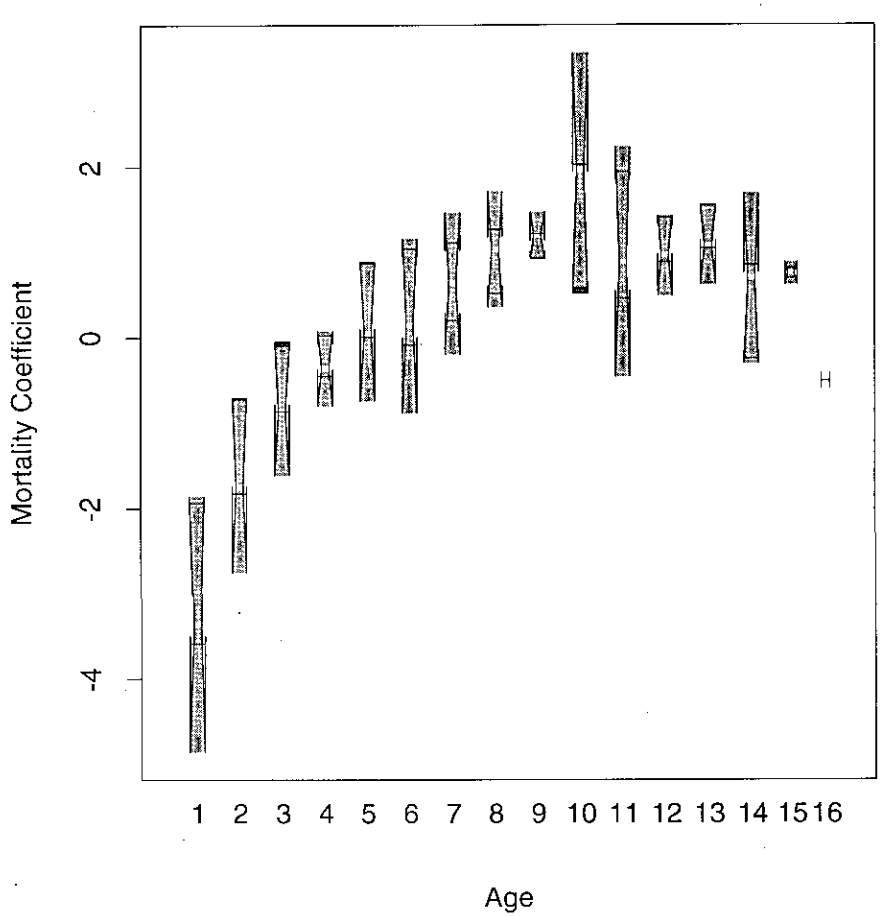


American plaice 3L Canada Juvenile



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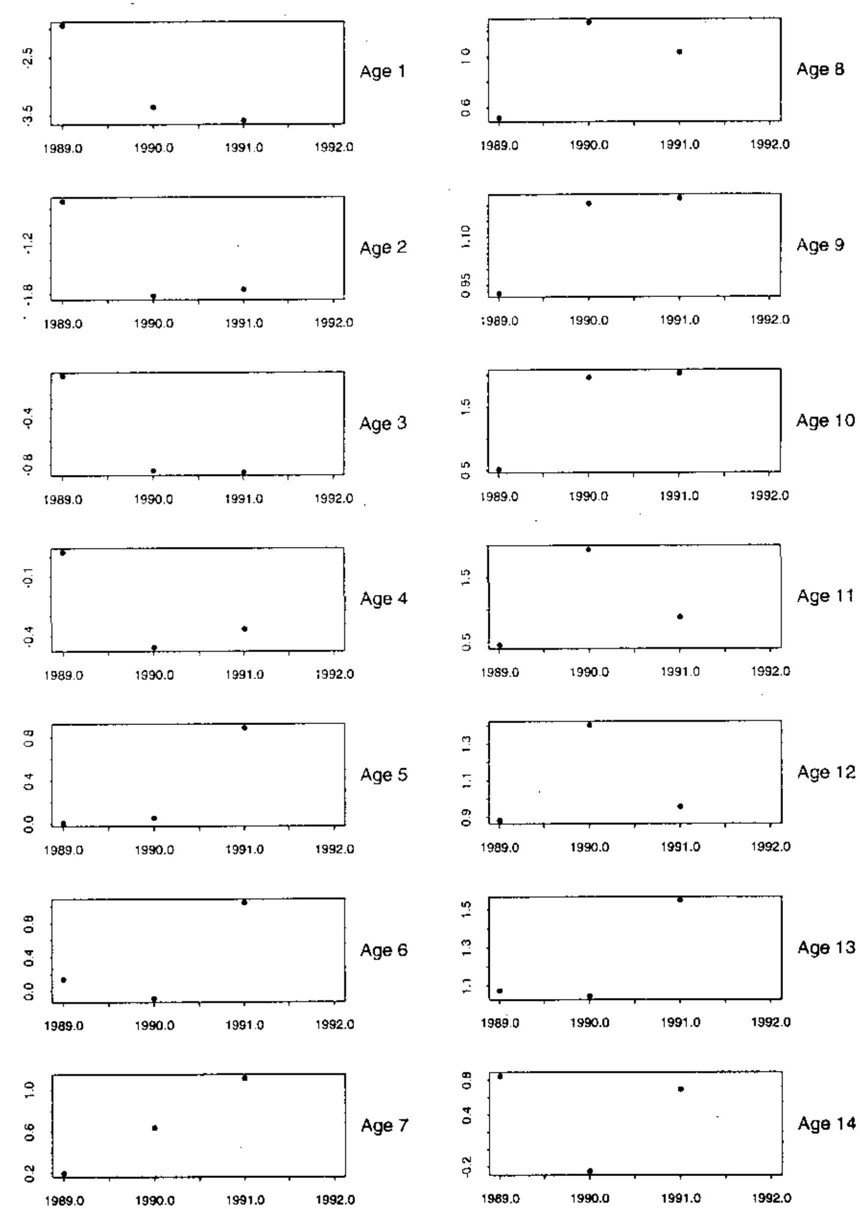
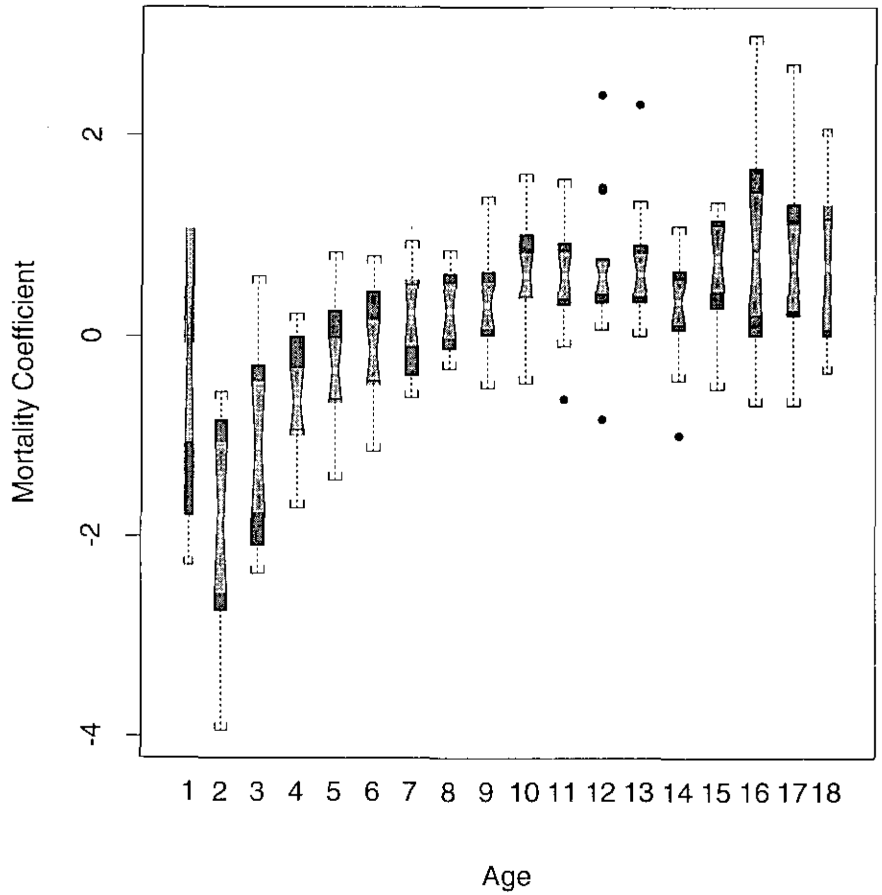


American plaice 3N Canada .



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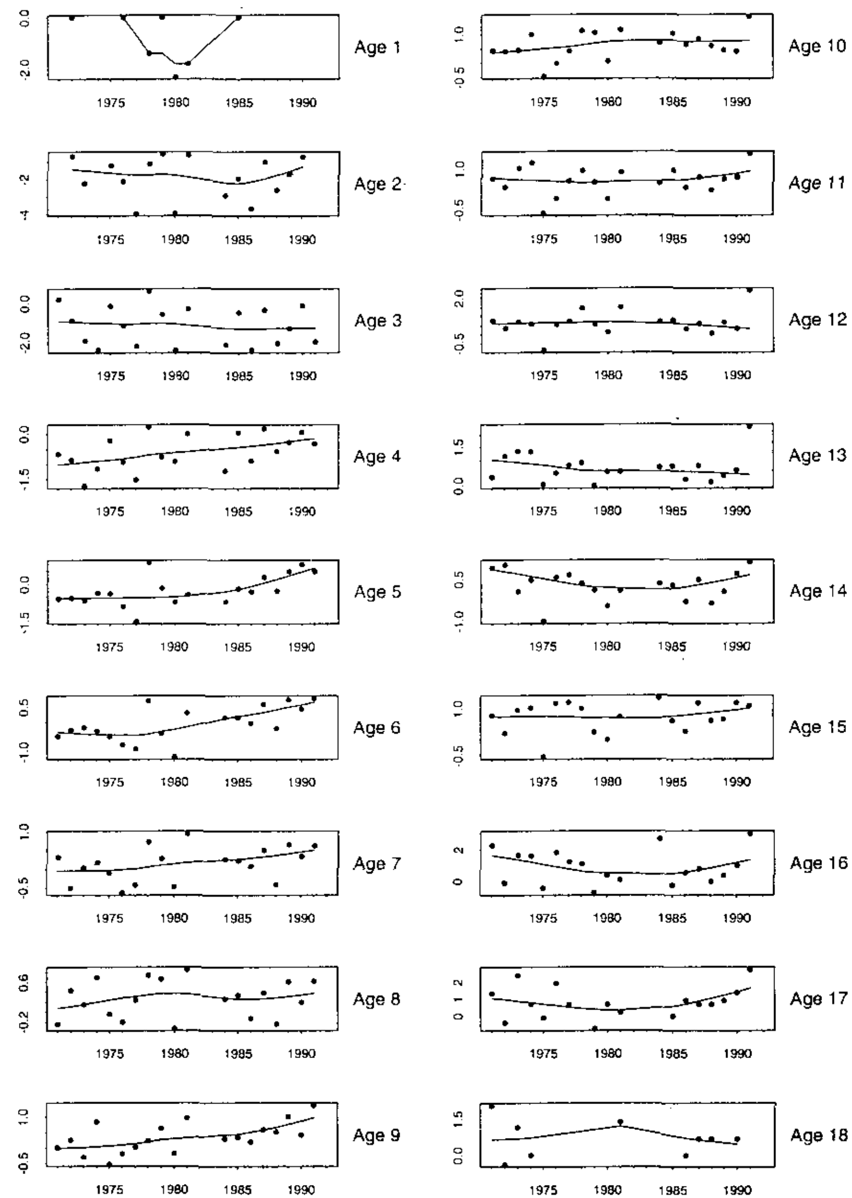

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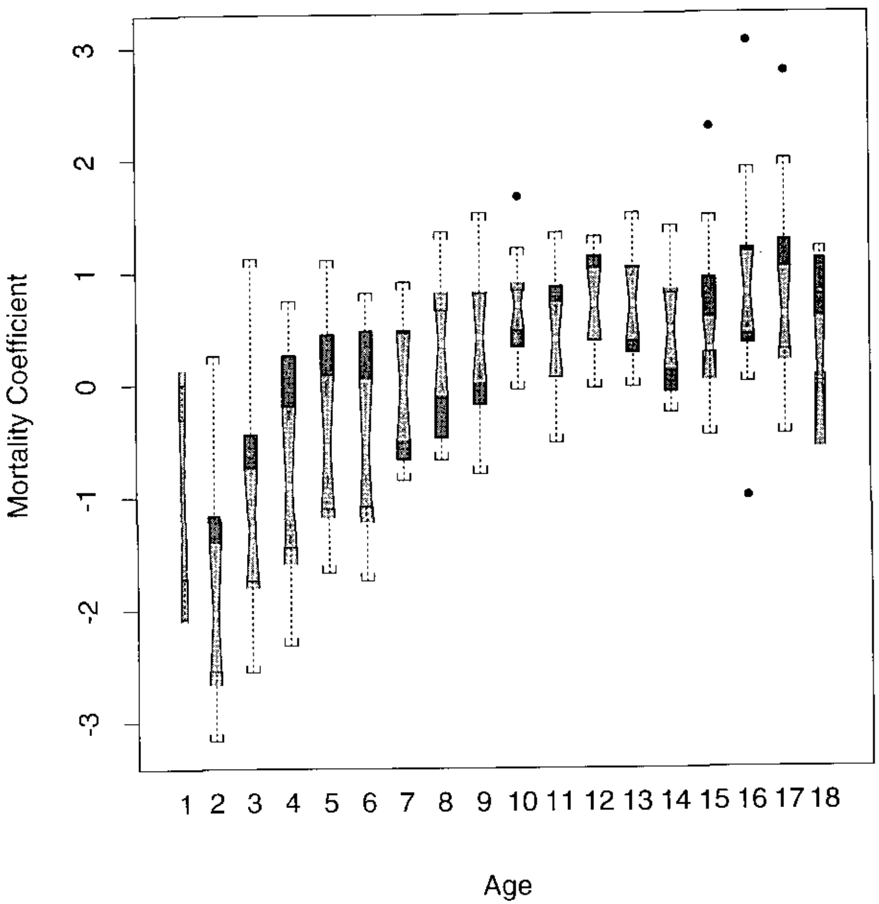

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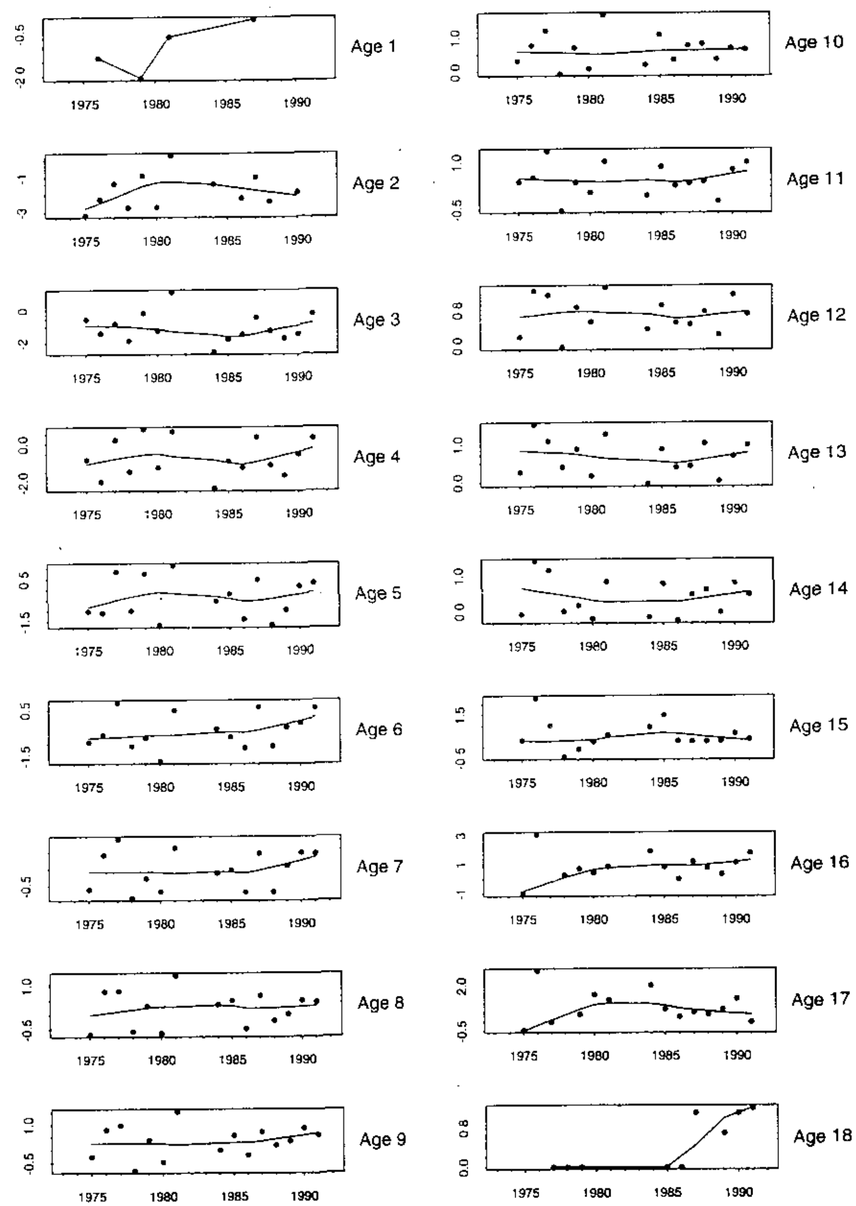
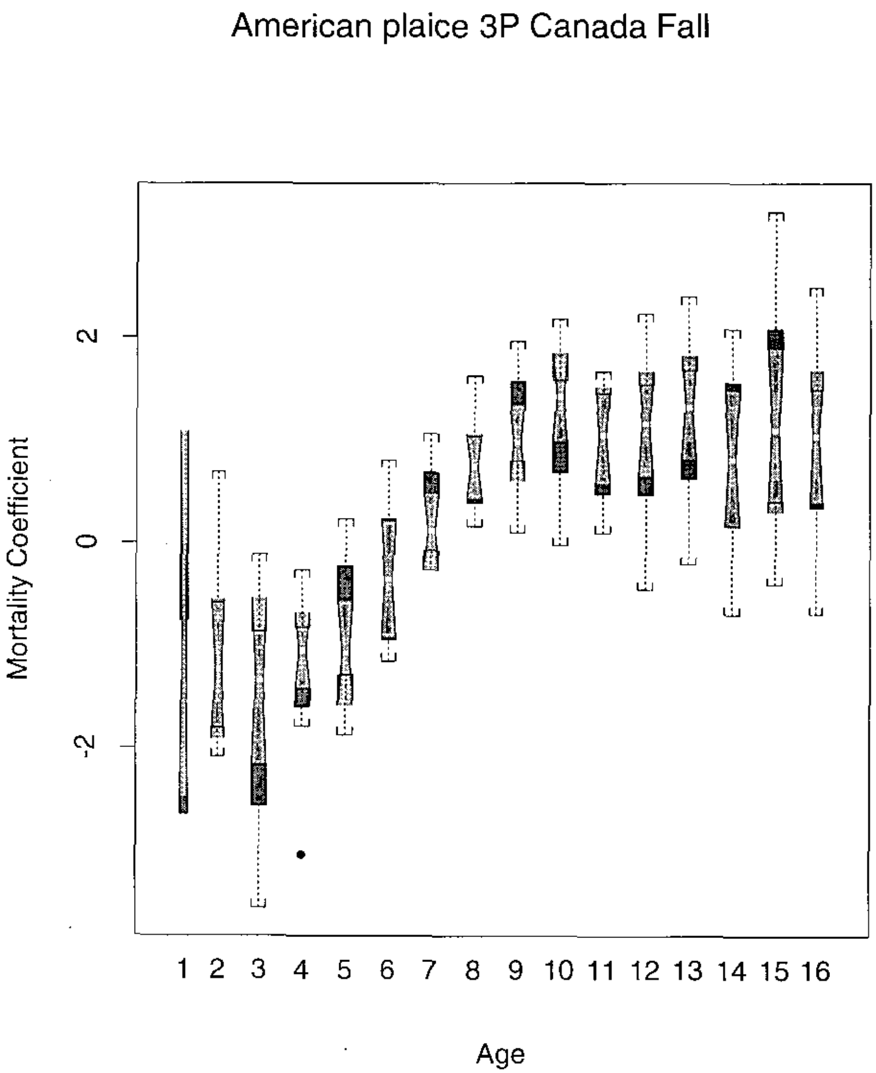
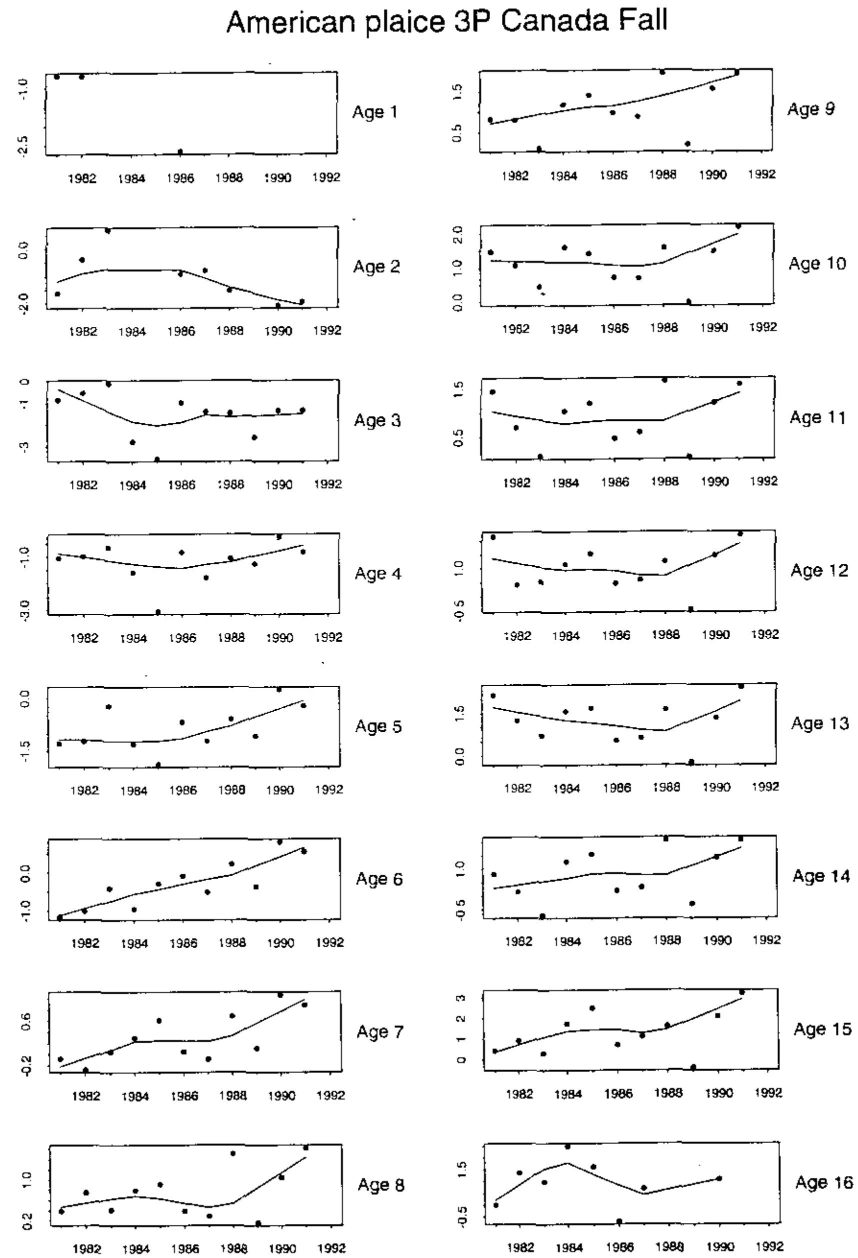



American plaice 3P Canada Fall
Mortality Coefficient
2
0
-2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age


American plaice 3P Canada Fall
Age 1
Age 2
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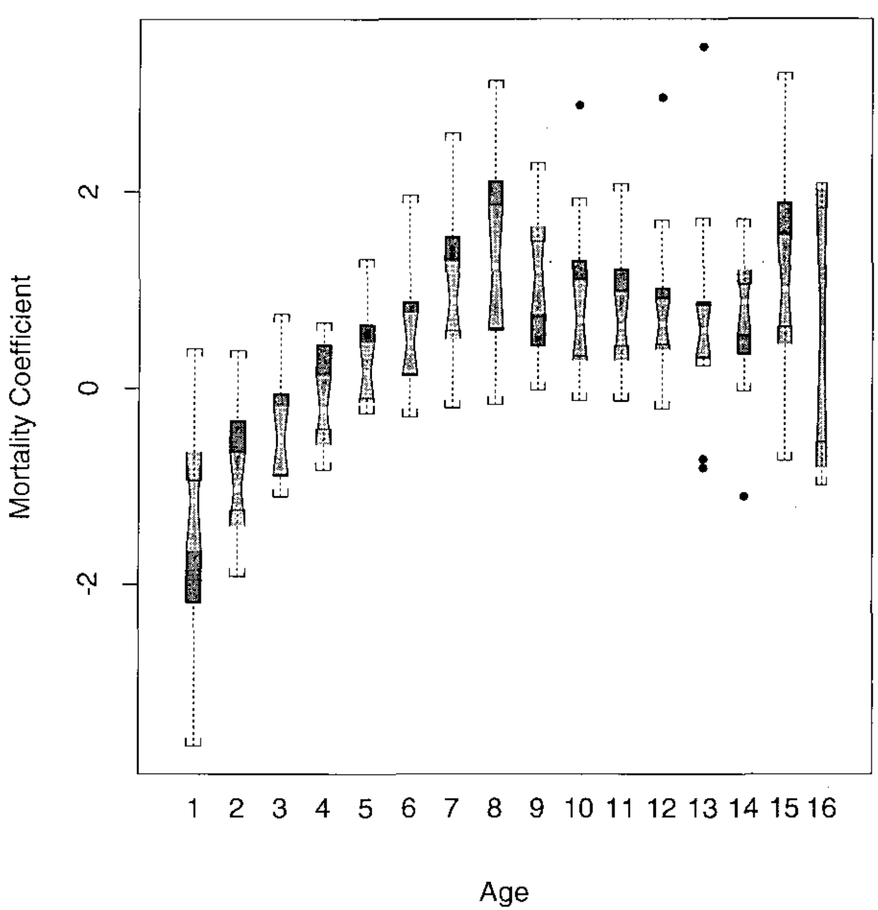
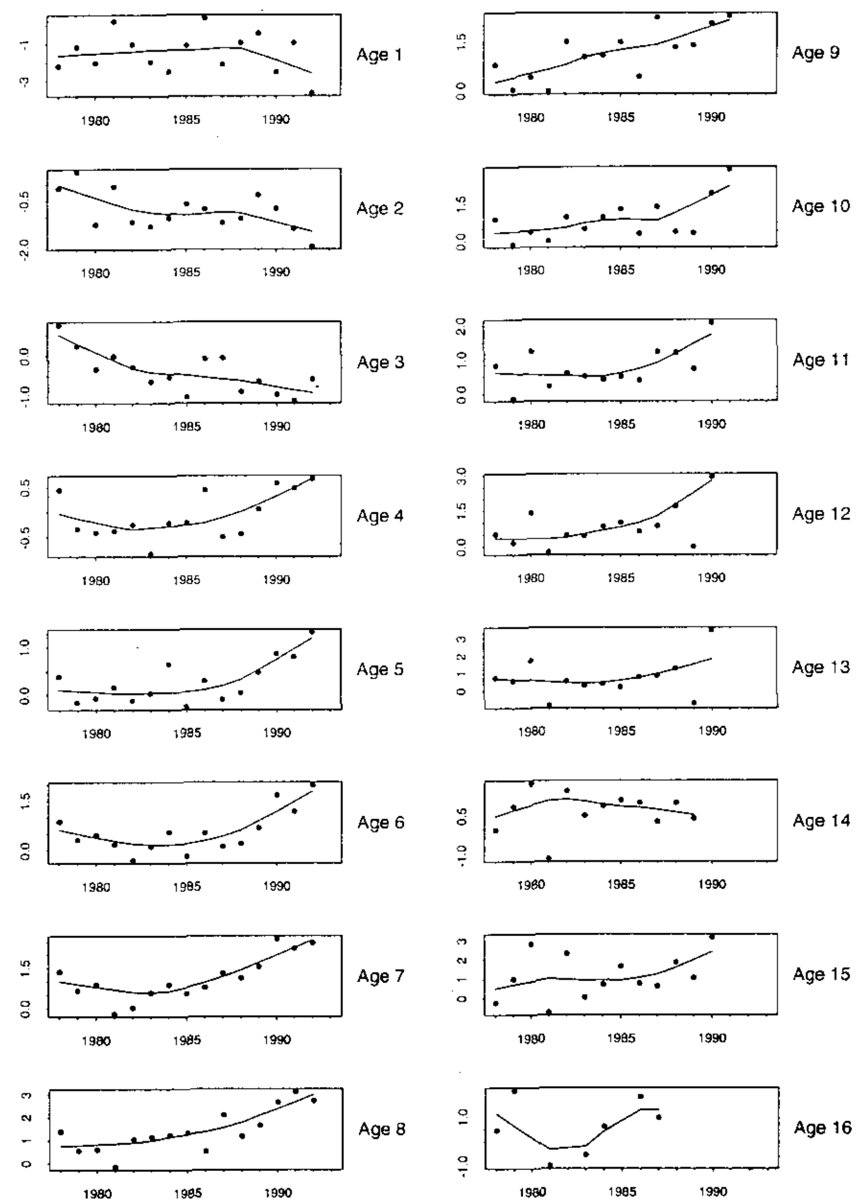
Age 14
Age 15
Age 16
1982 1984 1986 1988 1990 1992

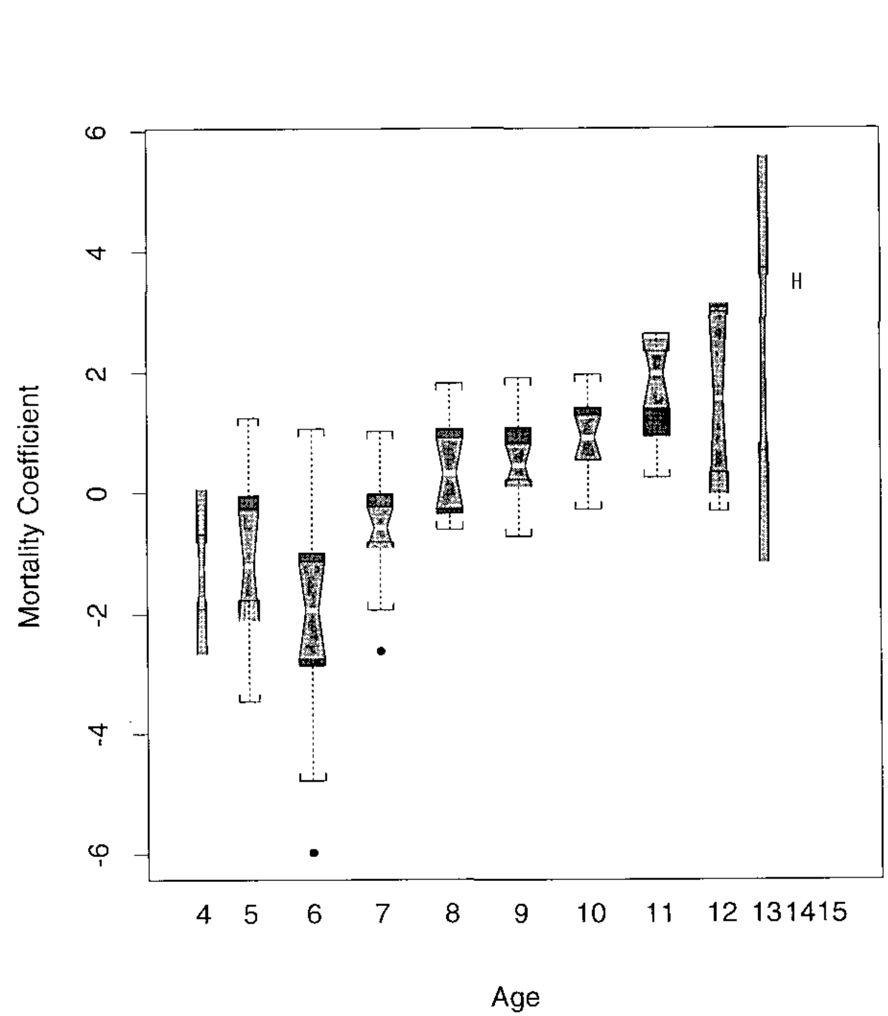
Greenland halibut 2J3KL Canada .



Greenland halibut 2J3KL Canada .



Witch flounder 2J Canada .



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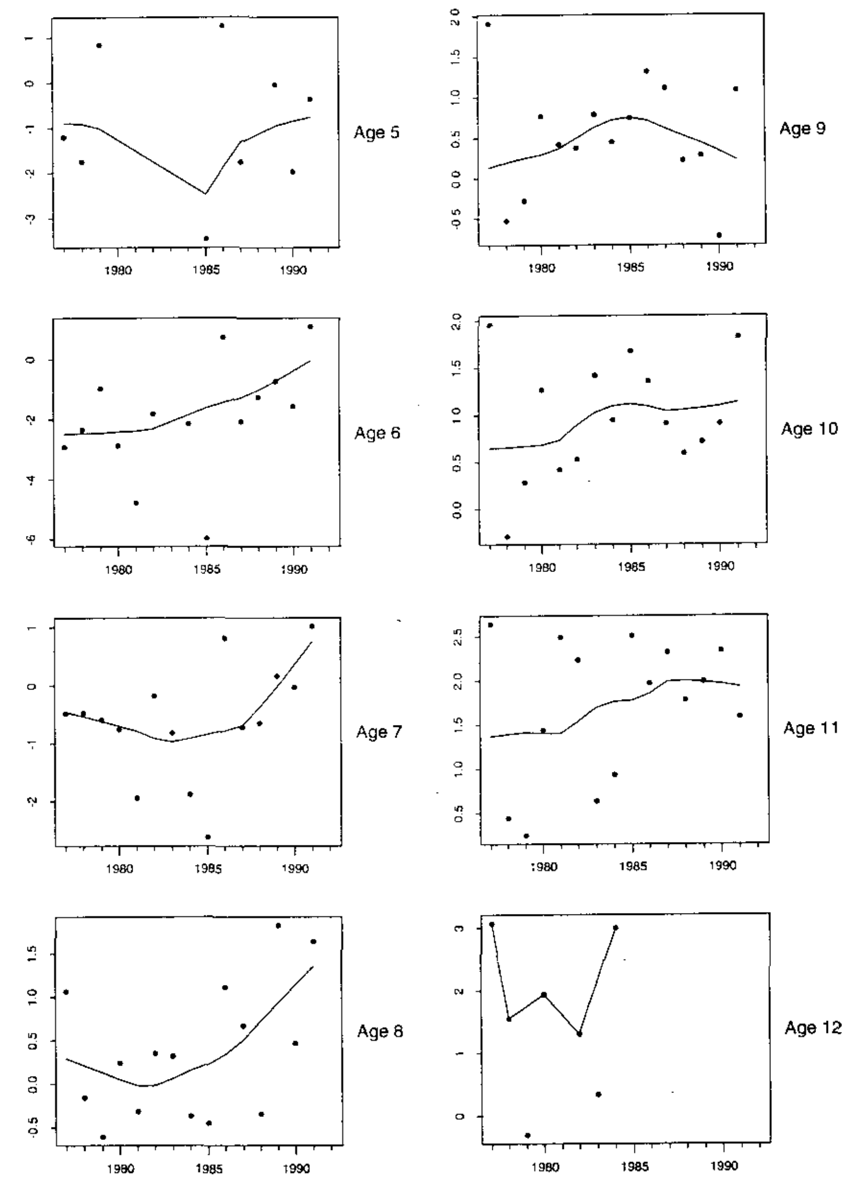

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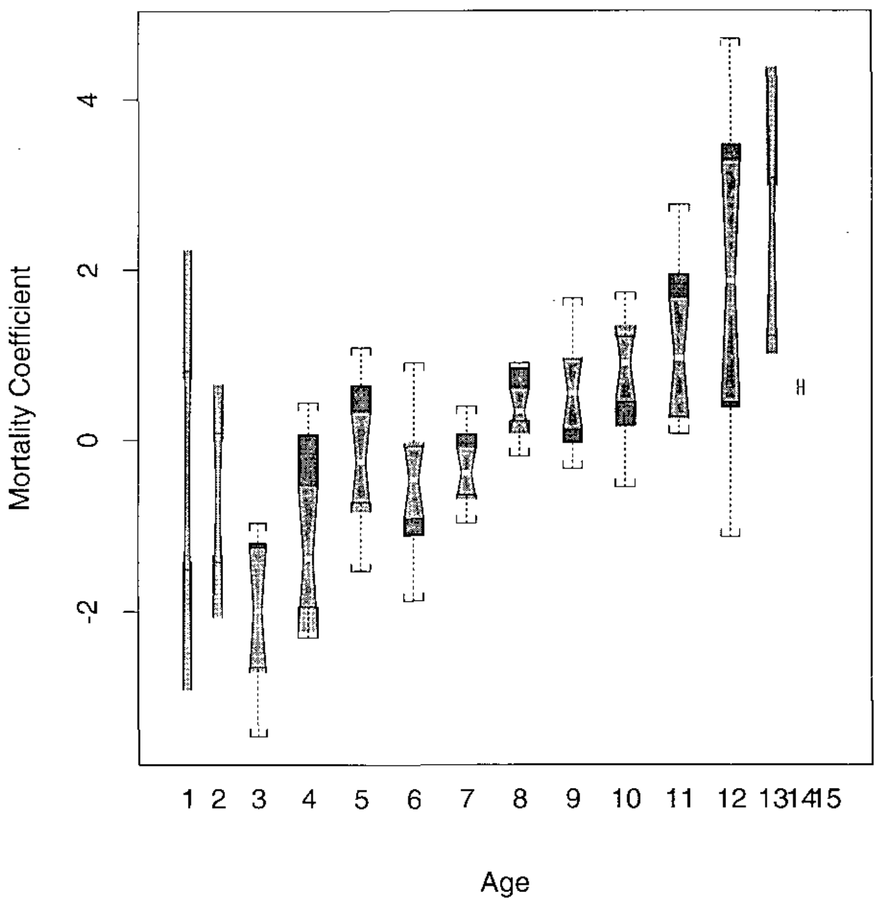
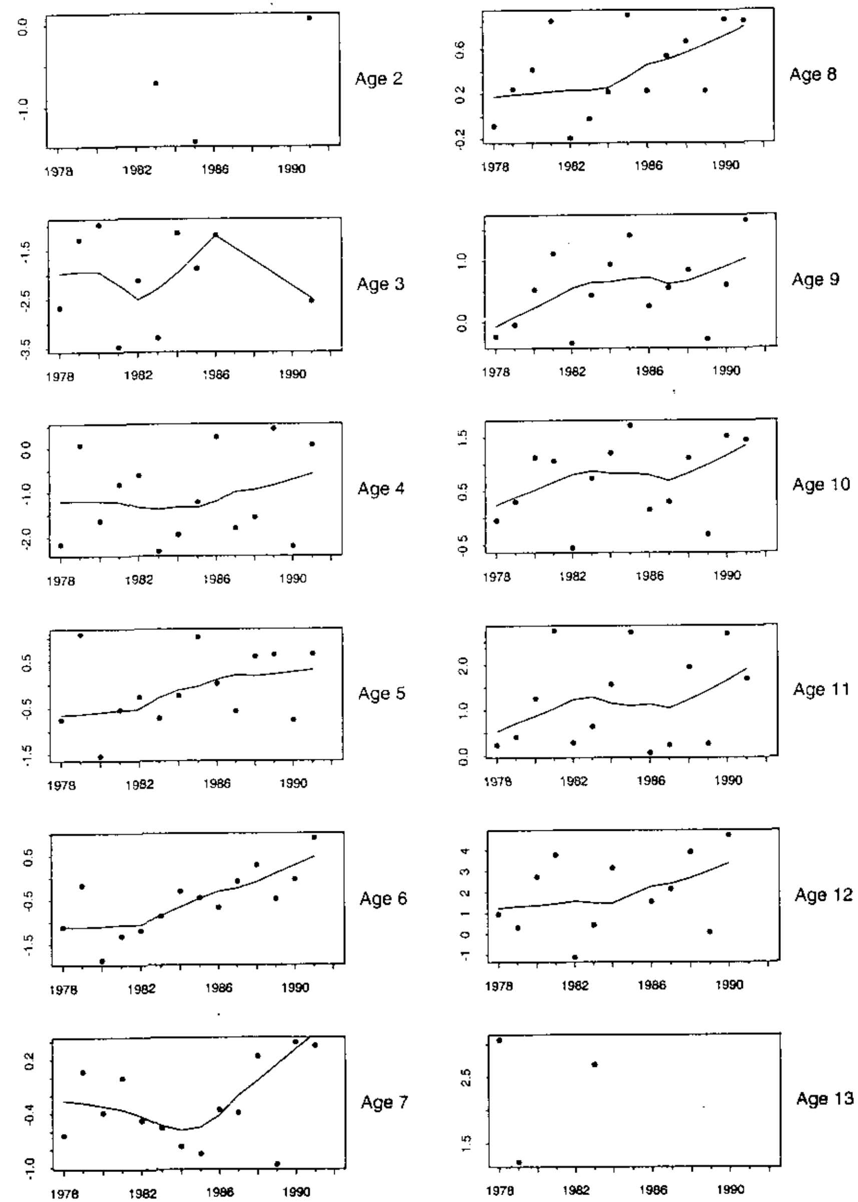


Witch flounder 3K Canada .



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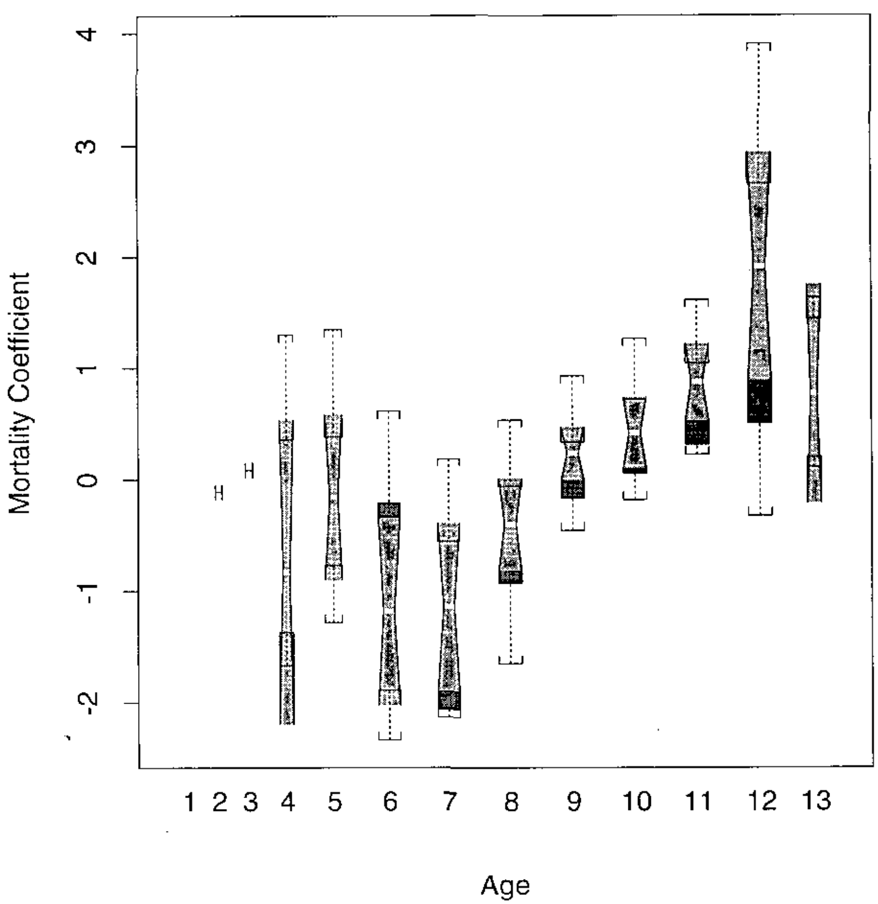

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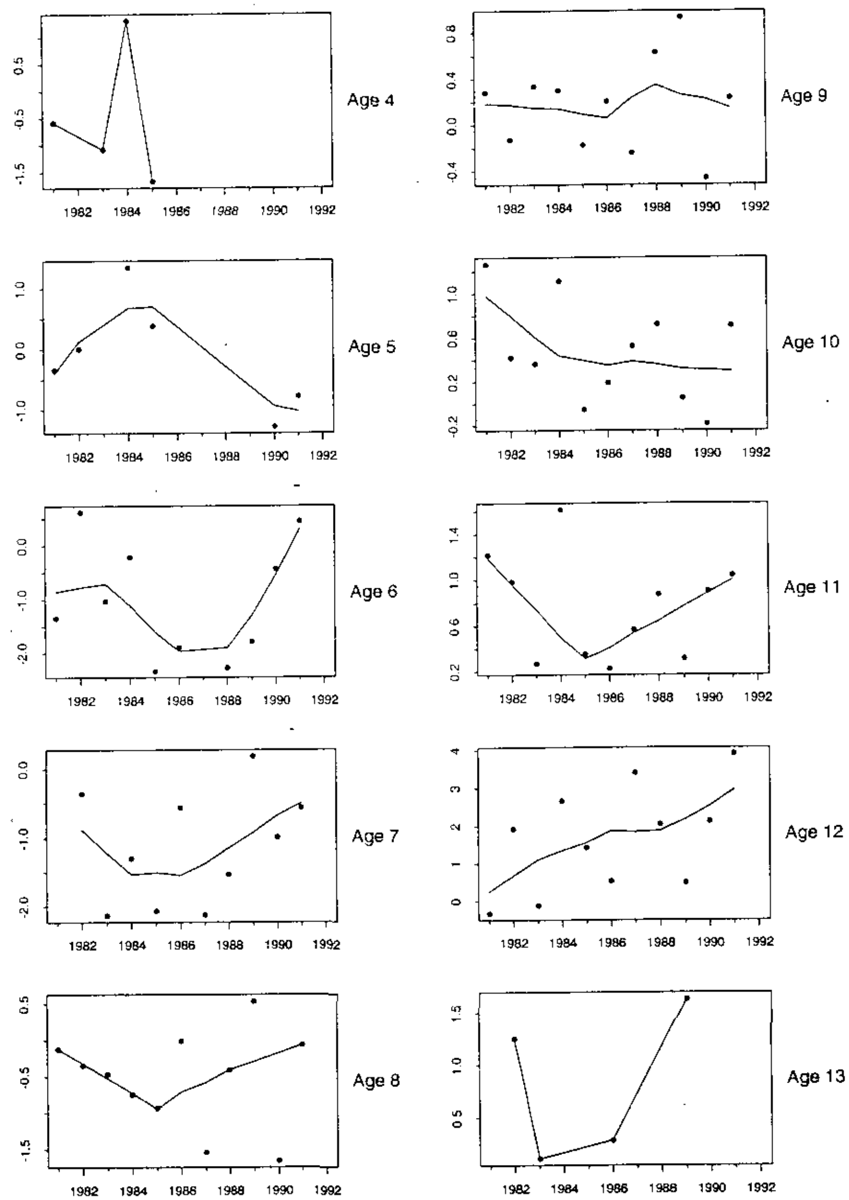

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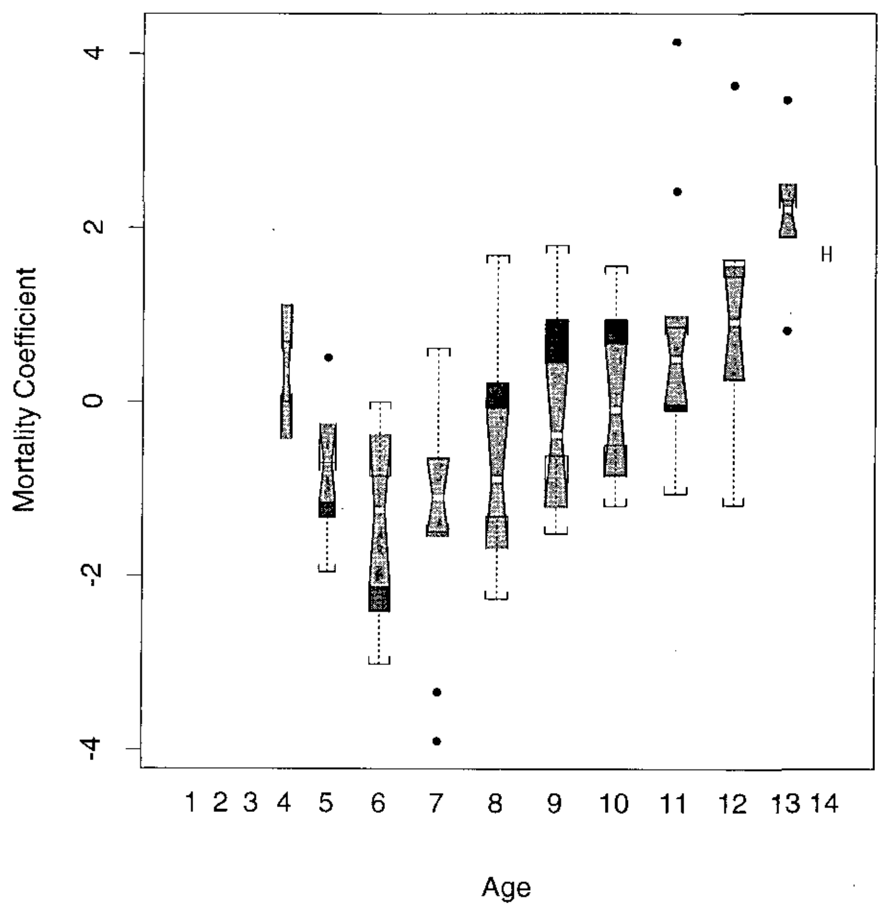

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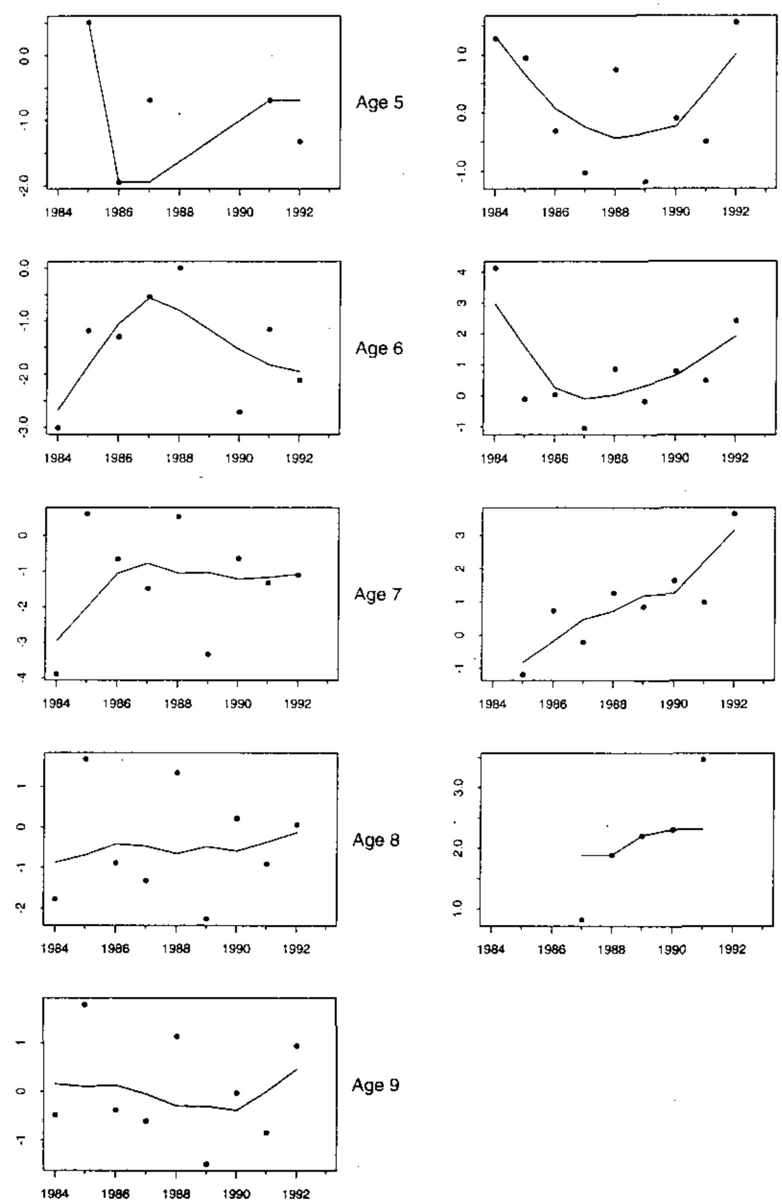
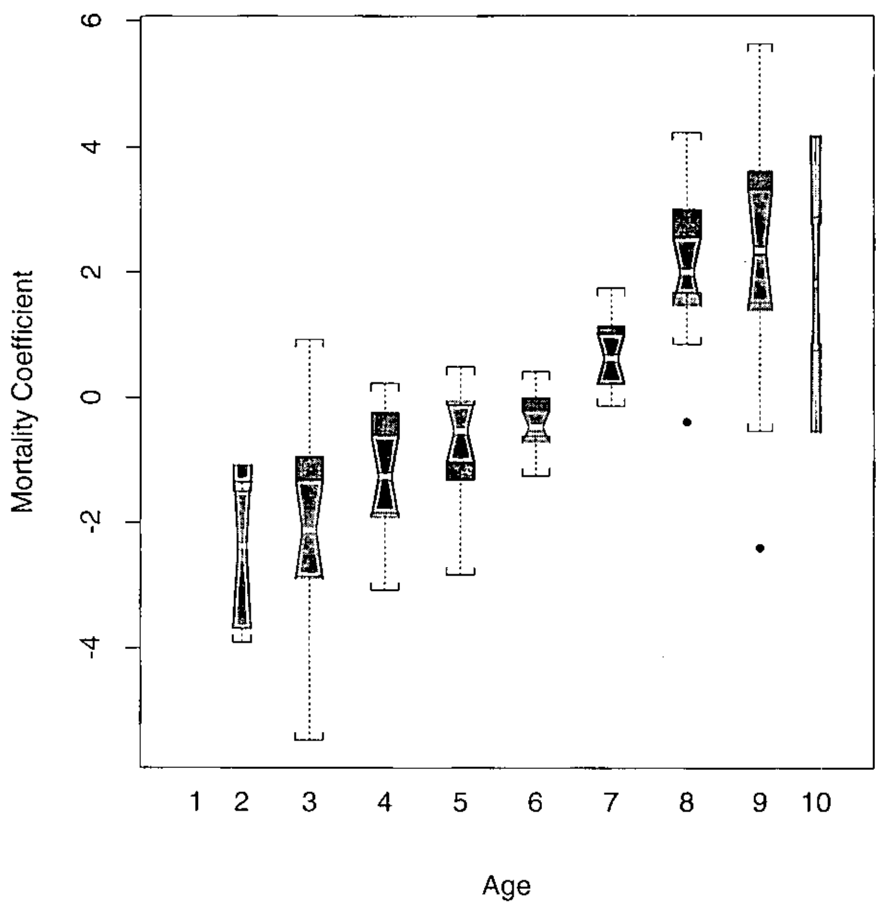


Yellowtail flounder 3LNO Canada .



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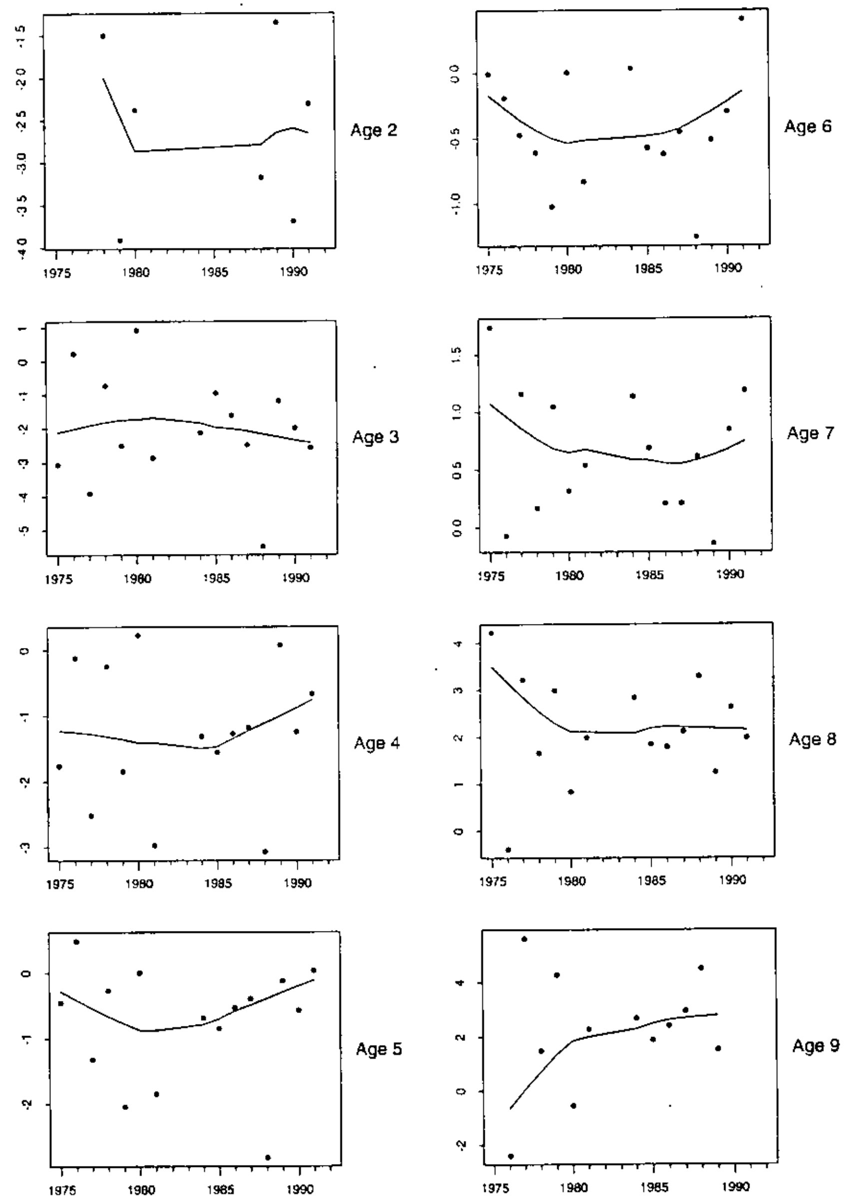

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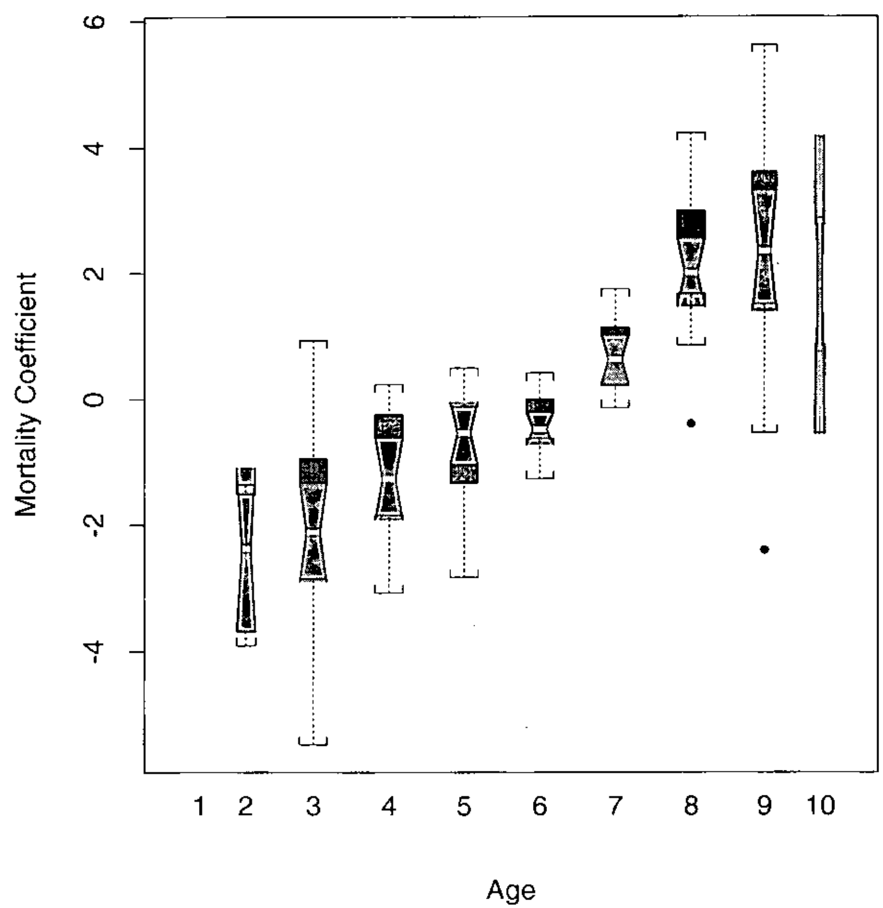
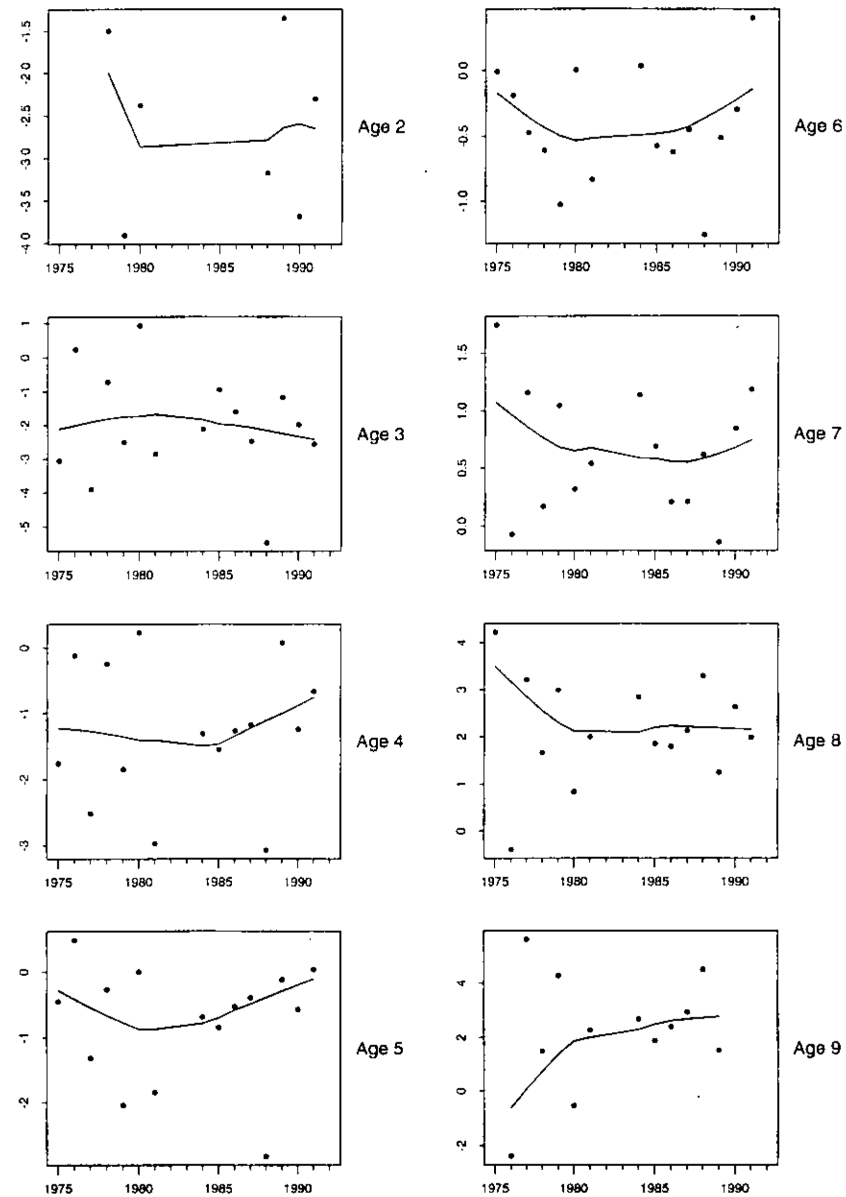
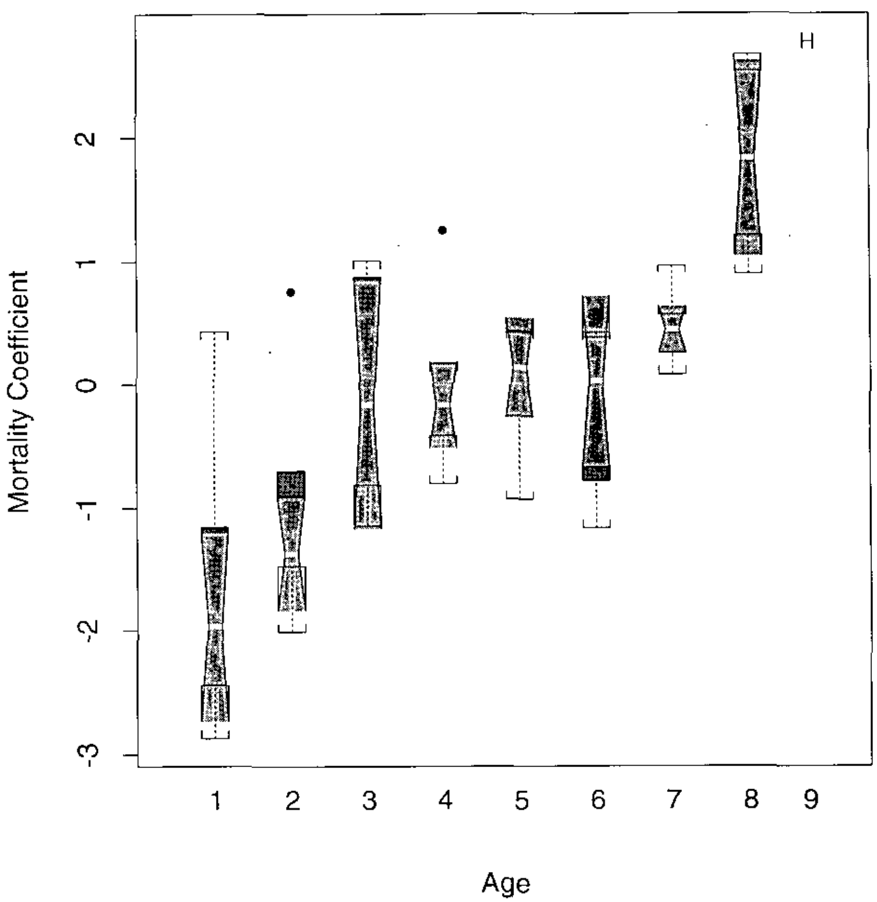


Yellowtail flounder 3LNO . .



Yellowtail flounder 3NO . Juvenile



Yellowtail flounder 3NO . Juvenile