A YEAR-CLASS CURVE ANALYSIS TO ESTIMATE MORTALITY OF ATLANTIC BLUEFIN TUNA CAUGHT BY THE NORWEGIAN FISHERY FROM 1956 TO 1979

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SUMMARY

At the ICCAT symposium on bluefin tuna that held in Santander in April 2008, Tangen et al.(2009) presented a first quantification of the fishing effort deployed by the Norwegian fishery targeting bluefin tuna in the North Sea and Norwegian Sea. Using a year-class curve analysis on the Norwegian CPUE, this document presents the first estimates of mortality rates of Atlantic bluefin tuna that migrated north from the mid-1950s to the late 1970s. The results indicate that bluefin tuna would have experienced a total mortality rate (Z) of 0.2 to 0.4 yr^{-1} (i.e. F at around 0.3 yr^{-1}) during the late 1950s, 0.2 yr^{-1} during the 1960s and 0.1 yr^{-1} afterwards (assuming M=0.1 yr^{-1}). These results appear to be rather robust and consistent with the VPA estimates from the 1970s and early 1980s, albeit slightly higher. The fishing mortality rates experienced by bluefin tuna in the North Sea and Norwegian Sea during the period 1956-1979 were thus significant (so that local overfishing may have occurred, especially during the 1950s), but lower than F estimated by year-class curve analysis in recent years (i.e. 1992-2004). This comparison between two distant periods of time during which BFT was significantly (highly) exploited tend to confirm, with new pieces of information, the pessimistic conclusions of the 2006 stock assessment.

RÉSUMÉ

Lors du symposium ICCAT sur le thon rouge qui s'est tenu à Santander en avril 2008, Tangen et al. (2009) a présenté une première quantification de l'effort de pêche déployé par la flottille norvégienne ciblant le thon rouge dans la Mer du Nord et la Mer de Norvège. En utilisant l'analyse des courbes de captures sur cohortes sur les données de PUE norvégiennes, ce document présente les premières estimations de taux de mortalité du thon rouge migrant au Nord entre le milieu des années 1950 et la fin des années 1970. Les résultats indiquent que le thon rouge aurait subi des taux de mortalité totale (Z) de 0,2 à 0,4 yr^{-1}, i.e. F autour de 0,3 yr^{-1} durant la fin des années 1950, 0,2 yr^{-1} durant les années 1960 et 0,1 yr^{-1} au delà (en considérant M=0,1 yr^{-1}). Ces estimations apparaissent assez robustes et cohérentes avec les sorties de VPA pour les années 1970-1980, quoique légèrement supérieures. Les taux de mortalité par pêche supportés par le thon rouge en Mer du Nord et Mer de Norvège durant la période 1956-1979 ont donc été significatifs (rendant possible une surpêche locale, notamment durant les années 1950), mais plus bas que les Fs estimées par la même méthode lors des années récentes (i.e. 1992-2004). Cette comparaison entre deux périodes de temps éloignées durant lesquelles le thon rouge a été significativement exploité tend à confirmer, avec de nouvelles sources d'informations, les conclusions pessimistes de l'évaluation de 2006.

RESUMEN

Con ocasión del Simposio sobre atún rojo, que se celebró en Santander en abril de 2008, Tangen et al. (2009) presentó una primera cuantificación del esfuerzo pesquero desplegado por la pesquería noruega dirigida al atún rojo en el mar del Norte y en el mar de Noruega. Utilizando un análisis de la curva de la clase anual en la CPUE noruega, este documento presenta las primeras estimaciones de tasas de mortalidad para el atún rojo del Atlántico que migraba hacia el Norte desde mediados de los cincuenta hasta finales de los setenta. Los resultados indicaban que el atún rojo habría experimentado una tasa de mortalidad total (Z) de 0,2 a 0,4 yr-1 (es decir F en aproximadamente 0,3 yr-1) durante finales de los cincuenta, 0,2

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yr-1 durante los sesenta y 0,1 yr-1 posteriormente (asumiendo que M=0,1 yr-1). Estos resultados parecen bastante robustos y coherentes con las estimaciones de VPA para los años setenta y ochenta, aunque ligeramente superiores. Las tasas de mortalidad por pesca experimentadas por el atún rojo en el mar del Norte y el mar de Noruega durante el periodo 1956-1979 fueron por tanto importantes (por lo que podría haberse producido sobrepesca local, especialmente durante los cincuenta). Sin embargo, estas estimaciones son menores que la F estimada mediante el análisis de la curva de la clase anual en años más recientes (es decir, 1992-2004). Esta comparación entre dos periodos de tiempo alejados durante los cuales el atún rojo fue objeto de una importante explotación tiende a confirmar, con nuevas fuentes de información, las conclusiones pesimistas de la evaluación de stock de 2006.

1. Introduction

At the ICCAT Symposium for the Study into the Stock Fluctuations of Northern Bluefin Tuna that was held in Santander in April 2008 (Anon. 2009), M. Tangen *et al.* (2009) presented a first quantification of the fishing effort deployed by the Norwegian fishery targeting bluefin tuna in the North Sea and Norwegian Sea during the second half of the 20th Century (Tangen *et al.* 2009). This estimate, which is in number of boats, is highly valuable as the total catch and catch-at-age data of this fishery are well documented and reported in various ICES reports (see data section, below). Using the above information, this document presents the first estimates of total mortality of Atlantic bluefin tuna from the mid-1950s to the late 1970s, using the year-class curve analysis. The final aim of this work is to compare mortality estimates from past fisheries with those from current fisheries, using the same approach.

2. Methods

The year-class curve analysis has been fully described in a recent SCRS document (Fromentin *et al.* 2007) and is therefore more briefly depicted. Assuming an age range from 0 to *a*, the number of fish that survived at age *a* may be written as:

$$N_a = R.e^{-Z.a} \tag{1}$$

where Z is the total mortality from age *a-1* to age *a* and R the recruitment (or the abundance of the first age-class). Equation (2) may be linearized by taking the log of the two terms:

$$Log(N_a) = Log(R) - Z.a \tag{2}$$

Assuming that catch is proportional to abundance (number, the equation (2) becomes:

$$Log(C_a) = Log(Rv) - Z.a \tag{3}$$

where *v* is the vulnerability to the fishing gear (i.e. $N=C.v$). At the difference of the catch curve analysis (e.g. Restrepo et al. 2007), which assumes constant recruitment from year-to-year, the year-class curve analysis is calculated over cohorts. Therefore, the assumption of constant recruitment may be relaxed and equation (5) be rewritten as:

$$Log(C_{a,c}) = Log(R_c v) - Z.a \tag{4}$$

where, $C_{a,c}$ is the catch at age *a* of cohort *c*, R_c is the initial recruitment of that cohort.

To take into account for changes in effort, $CPUE_{a,c}$ must be used instead of $C_{a,c}$ (unless effort has remained constant over time, such as for trap fisheries) and Z can be simply estimated by solving equation (5) through the linear model framework:

$$Log(CPUE_{a,c}) = Log(R_c v) - Z.a + \varepsilon_{a,c} \qquad (5)$$

where Z is thus the slope and $_{a,c}$ represents the random term that is generally assumed to be normally distributed.

Similar to catch-at-age analysis, such as VPA, year-class curve analysis cannot split Z into M and F components, unless M is known or assumed (Cotter *et al.* 2004). The main difference with VPA is that year-class curve analysis cannot provide stock size estimates (i.e. $N_{a,t}$), as v is unknown. However, it is applied here as the year-class curve is relatively straightforward and rather robust and could be more effective than sophisticated age-structured model, such as VPA (Cotter *et al.* 2004). More importantly, VPA must be applied at the scale of the stock. So in the present case, we should include BFT catch from other important fisheries from the 1950s and 1960s, such as the Spanish and Italian traps, the French and Spanish baitboat, the Danish and German fisheries as well as the Japanese long-line fisheries for which catch-at-age and/or CPUE time series remain incomplete over this historical period.

Year-class curve analysis was therefore chosen, but this method implies two strong assumptions that should be kept in mind when interpreting results:

- Z the total mortality is assumed to be constant over the age range of a given cohort (but not between cohorts).

- The vulnerability to the fishing gear, v, remains constant over an age range (as for the catch curve analysis). Such assumptions may be partially circumvented if the analysis is computed over an age range, which is known (believed) to display similar natural mortality and vulnerability to the fishing gear.

Any significant variation in age-specific selectivity of the fishery or in Z over a given cohort may significantly affect the slope of the regression (see e.g. Butterworth & Punt, 1990).

3. **Data**

Year-class curve analysis was applied on the catch-at-age (raised from size samples and total catch) of the Norwegian purse seine fishery operating in the Norwegian Sea (offshore the Nordland and Troms provinces) and the North Sea from the 1920s until the mid 1980s (for more details on this fishery, see Tiews 1978, Mather *et al.* 1995, Pusineri *et al.* 2002, Cort and Nøttestad 2007).

A continuous time series of annual yields (in tonnes, **Figure 1a**) from both areas has been built up from 1927 to 2000 from the archives of the Institute of Marine Research in Bergen (Norway), the official Norwegian catch statistics and the seven ICES reports of the bluefin tuna working group being published between 1964 and 1980 (Hamre and Tiews 1964, Hamre *et al.* 1966, 1968, Hamre *et al.* 1971, Aloncle *et al.* 1974, 1977, Aloncle *et al.* 1981). A time series of catch-at-size (CAS) from 1956 to 1979 and 1956 to 1969 (with a missing period from 1963 to 1966 due to the fishery collapse) have been collected from the ICES reports solely for the North Sea and the Norwegian Sea areas, respectively.

As previously mentioned, fishing effort of the Norwegian fishery was firstly presented during the Santander Symposium (Tangen, 2009). Effort is the number of boats (small purse seiners) targeting bluefin tuna in the Norwegian Sea and the North Sea from 1945 during summer and early fall (**Figure 1b**). Note that these boats targeted other fish species (such as herring) outside of the BFT season. This time series has been compiled by M. Tangen from official Norwegian fisheries statistics and a nominal CPUE time series has been calculated from 1945 to 1986 by simply divided total catch by total effort (**Figure 1c**). The CPUE time series is normally distributed over the 1950-1986 (**Figure 1d**, i.e. when the years 1945-1949 are removed).

4. Results

As indicated by **Figure 2a**, bluefin tuna is, in average (over 1956-1979), not fully recruited by the Norwegian fishery before age 11. From age 11 to age 19, the decrease in the log(catch) decreases linearly, as expected from the theory (age 20 being a plus-group is not considered).

However, this fishery was characterized by an increase in the mean size of the catch since the late 1950s, especially after the collapse of this fishery that happened in 1963 (see **Figure 2b** and for more details Fromentin and Powers 2005). Consequently, bluefin tuna was only fully recruited at age 14 or 15 in the 1970s. To take such pattern into account, the year-class curve analyses have been computed over the following age ranges: 11-19, 12-19 and 13-19.

When considering full recruitment at age 11, the goodness of fit of the linear regressions was, as expected from above, good for the first cohorts (i.e. 1945 to 1954, except 1952), but bad the last ones (1955 to 1960, see **Figure 3**). However, the goodness of fit of the regressions becomes better for the last cohorts when considering a later age at full recruitment (**Figures 4** and **5**). We, however, did not consider later age at full recruitment because the number of points on which the regressions are fitted would have become too small (which would have affected the robustness of the analyses).

In most of the cases, the goodness of fit is satisfactory (r^2 is rarely < 0.5 and the residuals did not show any special pattern except for the last cohorts when considering age 11 at full recruitment).

Interestingly, the slopes, i.e. Z, for a given cohort are similar among the different treatments (i.e. the different age ranges, **Table 1**). This indicates that the results are rather robust (in other words that the goodness of fit of the regressions was not dependent on the number of points on which the linear regression was fitted). For the first cohort being common to 3 age ranges (i.e. the 1945 cohort), which corresponded to the fishing years going from 1956, 1957 or 1958 to 1964 (depending on the age ranges), Z varied little and was at around 0.38. In general, for the 1945 to 1951 cohorts (i.e. fishing years going from 1956 to 1970), Z were rather homogeneous and varied between 0.26 yr^{-1} and 0.39 yr^{-1} (average at 0.31). Z were significantly higher for the first two cohorts (1943 and 1944), but these estimates must be interpreted with caution because of the lack of data for older ages (see Figure 4 and 5).

After 1970, Z were significantly lower, between 0.12 yr^{-1} and 0.25 yr^{-1} (average at 0.19 yr^{-1}, **Figure 6**) when considering the age-range 13-19 (which is the most reliable for these cohorts, see above). The catches were low during that period while the total CPUE remained at the same level until 1977 and then declined to a lower level (**Figure 1**).

Assuming M=0.1 yr^{-1} for ages 10 + (as in the last stock assessments), F would have been at around 0.3 yr^{-1} for the 1956-1964 period, at 0.2 yr^{-1} for the 1960-1970 and slightly below 0.1 yr^{-1} during the 1970s and 1980s. F estimates from VPA-ADAPT (Anon. 2007) , as everybody knows, have to be interpreted with the greatest care. However, it is of interest to compare the outputs as the VPA did not take into consideration the CPUE from the Norwegian fishery. F for age 8+ were at around 0.05 from 1970 to the mid-1980s, at around 0.1 yr^{-1} from the mid-1980s to the early 1990s and reached or exceeded 0.2 yr^{-1} after the mid-1990s. The year-class curves estimates from the common period (i.e. 1970-1986) were thus in rather good agreement with VPA outputs, albeit slightly higher (0.09 yr^{-1} against 0.05 yr^{-1}).

4. Discussion and conclusion

The results of the year-class curves analysis indicated that bluefin tuna caught by the Norwegian fishery would have experienced a total mortality rate (Z) of 0.2 to 0.4 yr^{-1}, i.e. F at around 0.3 yr^{-1} during the late 1950s, 0.2 yr^{-1} during the 1960s and 0.1 yr^{-1} afterward (assuming M=0.1 yr^{-1}). These results appear to be rather robust (i.e. Zs for a given cohort are similar among the different age ranges) and rather consistent with the VPA estimates from the 1970s and early 1980s, albeit slightly higher. Although strong uncertainties in catch-at-age have been documented for the East Atlantic and Mediterranean bluefin tuna stock (Anon. 2005), we may postulate that VPA estimates from between 1970s to the early 1990s are more trustworthy because of a higher quality of the catch data and because of the convergence property of the VPA. Furthermore, this comparison is of special interest, as the Norwegian fishery CPUE time series was not used to tune the VPA.

The nominal CPUE fluctuated around 30 fish/boat between 1950 and 1977 and then declined to about 12 fish/boat afterward. The mean of the nominal CPUE has thus remained constant over the 1956-1977 year while estimated Z steadily decreased from 0.3 yr^{-1} to 0.1 yr^{-1}. There was thus no apparent link between nominal CPUE and Z, so that the decline in the catch-rates from 1978 to 1986 may be primarily interpreted as a decreasing catchability and/or availability of the fish. It is worth noting that catch and effort were very low during this period (about 100 tonnes and 10 boats in average, respectively).

It thus seems that the fishing mortality rates experienced by bluefin tuna in the North Sea and Norwegian Sea during the 1956-1979 years were significant (F=0.1 yr^{-1} to 0.3 yr^{-1}, i.e. about one to three times the magnitude of natural mortality). So, if we consider that overfishing can be approximated when $F \gg M$ and if we assume that $M = 0.1$ yr^{-1} is a reasonable value for the ages 10+, local overfishing may have occurred in the North Sea and Norwegian Sea, especially during the 1950s. In a peripheral area, such the North Sea, such values of F may be even more severe if the proportion of BFT migrating in the North Sea and Norwegian decreases because of external effects, such as adverse environmental conditions, decline in foraging preys, increasing exploitation along the migration route (Fromentin 2009; Nøttestad *et al.* 2008). However, the stability of the Norwegian CPUE time series did not indicate any changes in catch rates before 1978, so 15 years after the collapse of the German and Danish fisheries and the severe decline of Norwegian one. Additionally, the CPUE has remained stable when Fs have steadily declined, so that it is rather unlikely that the collapse of the Nordic fisheries was due to the eradication of a BFT sub-population, but more likely to a change in BFT availability (that could result from various processes, among which changes in migratory pattern, see Tiews 1978, Pusineri *et al.* 2002, Fromentin 2009).

The estimates of Z and F from the year-class curve analysis of the Norwegian fishery were, however, quite lower than Z and F estimated by year-class curve analysis in recent years, (Fromentin *et al.* 2007). In this latter study, Z calculated on the trap catch over the same age-range (i.e. ages 11-19) varied between 0.32 yr^{-1} and 0.69 yr^{-1} during 1992-2004, so about 2 to 3 times more than Z calculated on the Norwegian CPUE during 1956-1979 (note that the Z calculated on the Japanese longline CPUE during the 1992-2004 years on younger fish also led to higher mortality rates, ranging between 0.3 yr-1 and 0.5 yr-1, see Fromentin *et al.* 2007). This comparison between two distant periods of time during which BFT was significantly (highly) exploited tend to confirm, with new pieces of information, the pessimistic conclusions of the 2006 stock assessment (Anon. 2007).

Acknowledgments

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Table 1. Annual *Z* estimates from year-class curve analyses (i.e. slope of the above regressions) computed on various age ranges for the Norwegian $CPUE_{a,c}$ from 1956 to 1979.

|	Norway Z13-19	Norway Z12-19	Norway Z11-19
1943 Cohort	-0.498	-	-
1944 Cohort	-0.586	-0.534	-
1945 Cohort	-0.392	-0.379	-0.380
1946 Cohort	-0.347	-0.304	-0.306
1947 Cohort	-0.305	-0.302	-0.264
1948 Cohort	-0.278	-0.276	-0.267
1949 Cohort	-0.264	-0.267	-0.257
1950 Cohort	-0.262	-0.296	-0.291
1951 Cohort	-0.443	-0.269	-0.281
1952 Cohort	-0.324	-0.280	-0.126
1953 Cohort	-0.203	-0.215	-0.139
1954 Cohort	-0.250	-0.211	-0.180
1955 Cohort	-0.153	-0.149	-0.091
1956 Cohort	-0.121	-0.064	-0.036
1957 Cohort	-0.188	-0.134	-0.052
1958 Cohort	-0.157	-0.097	-0.022
1959 Cohort	-0.223	-0.140	-0.033
1960 Cohort	-0.200	-0.132	-0.039
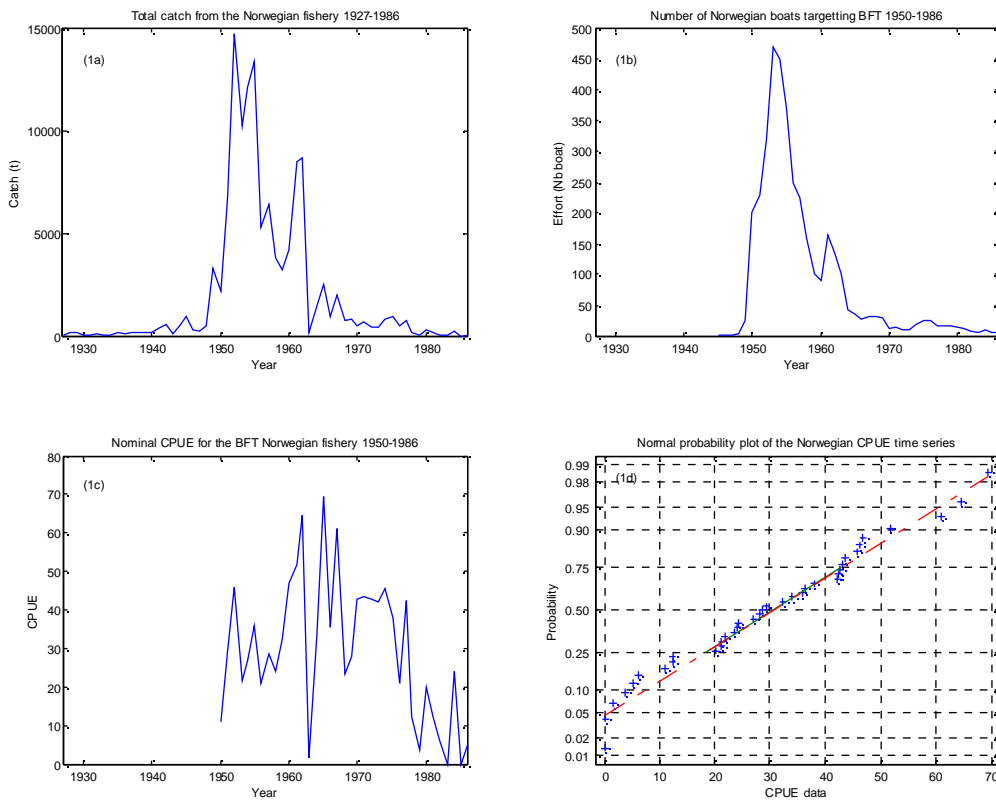
Figure 1. Data from the Norwegian BFT fishery operating in the Norwegian Sea and North Sea during the 20th century. (1a): Plot of the total catch in tons; (1b): Plot of the number of fishing boats, (1c): Plot of the nominal CPUE and (1d): normal probability plot of the nominal CPUE.
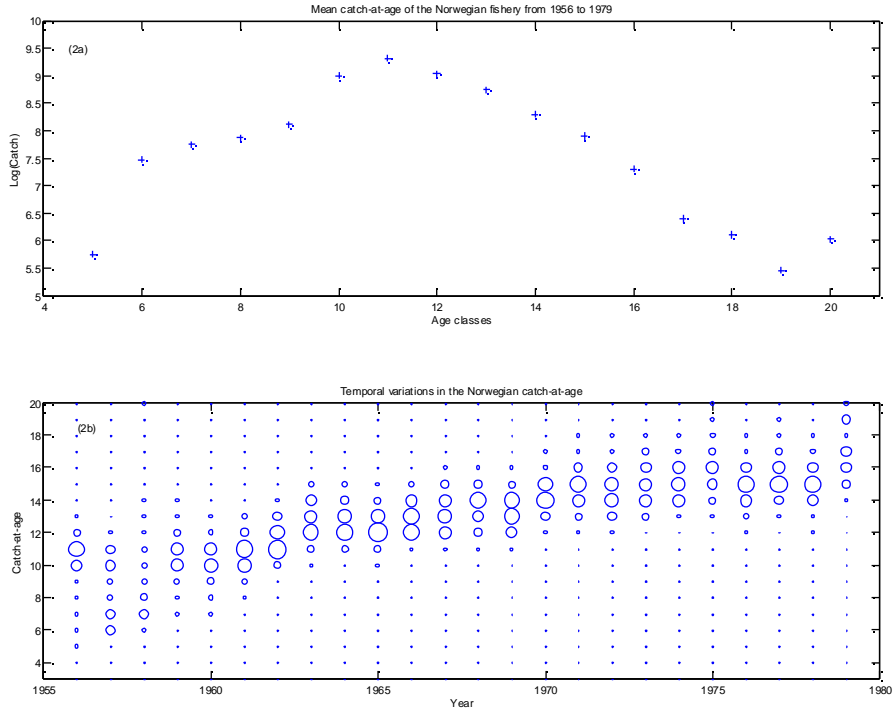
Figure 2. (2a): Mean catch-at-age of the Norwegian fishery from 1956 to 1979; (2b): year-to-year of the same catch-at-age dataset (data are in frequency and the size of the bubble is proportional to the value of the catch).
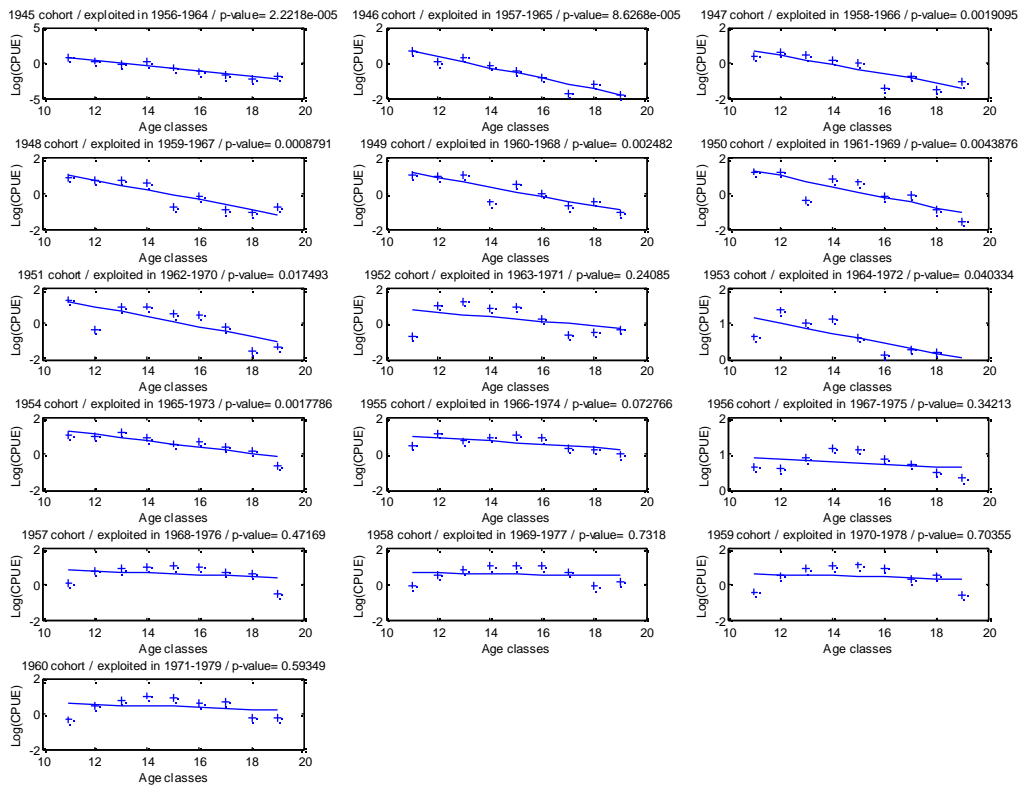
Figure 3. Year-class curves computed on ages 11-19 of Norwegian $CPUE_{a,c}$ from 1956 to 1979. Corresponding cohort, fishing years and p-value of the regression are given in the title of each plot.
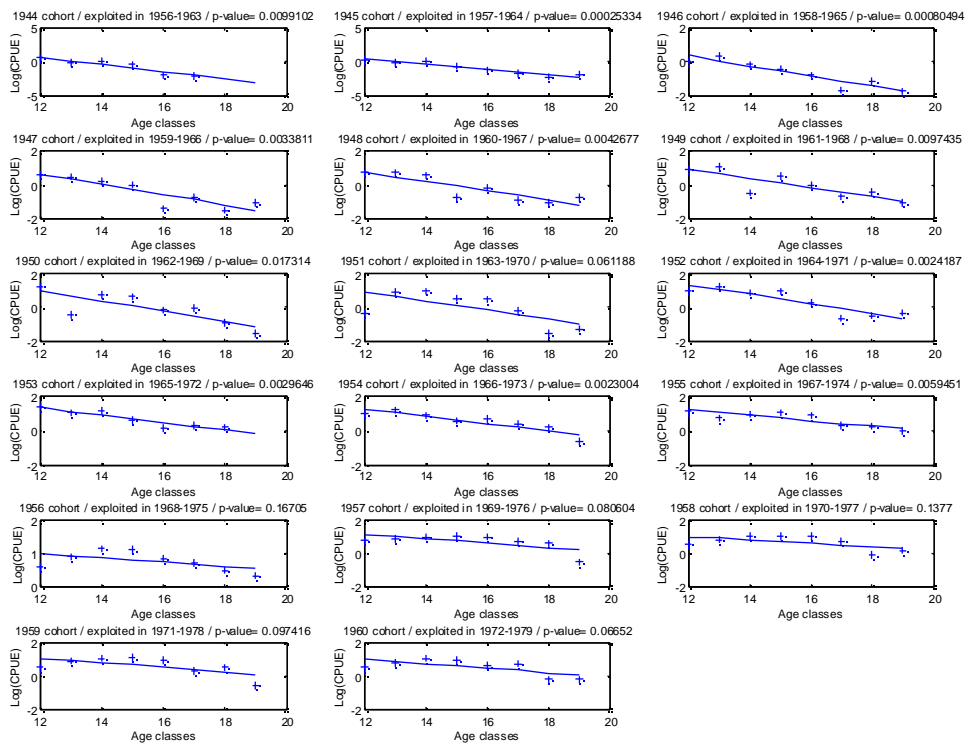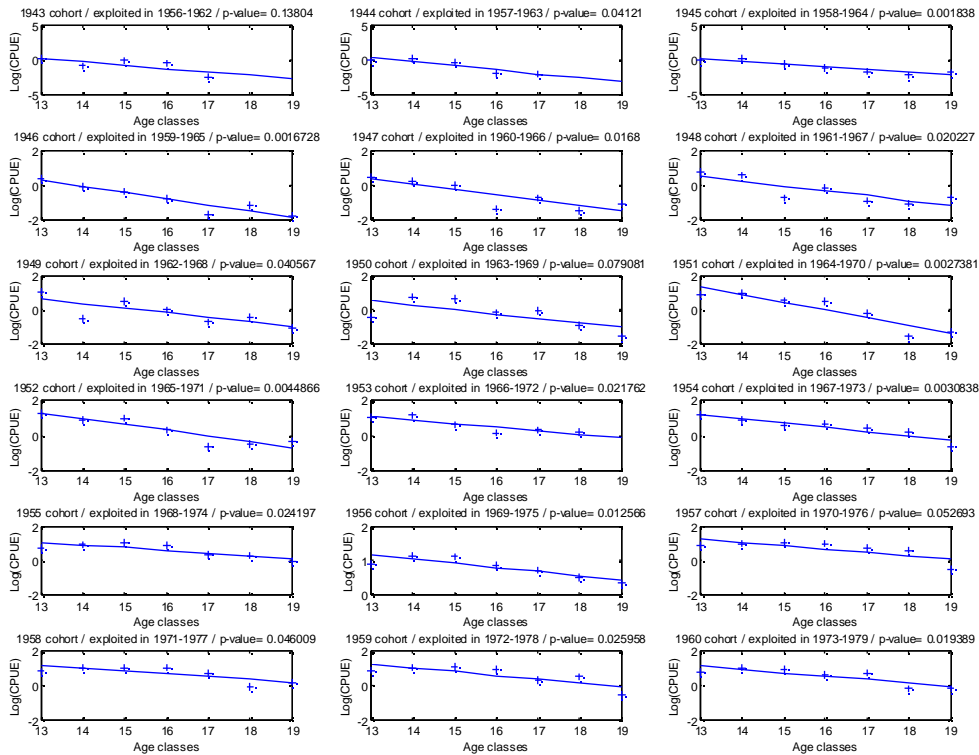
Figure 4. Year-class curves computed on ages 12-19 of Norwegian $CPUE_{a,c}$ from 1956 to 1979. Corresponding cohort, fishing years and p-value of the regression are given in the title of each plot.

Figure 5. Year-class curves computed on ages 13-19 of Norwegian $CPUE_{a,c}$ from 1956 to 1979. Corresponding cohort, fishing years and p-value of the regression are given in the title of each plot.
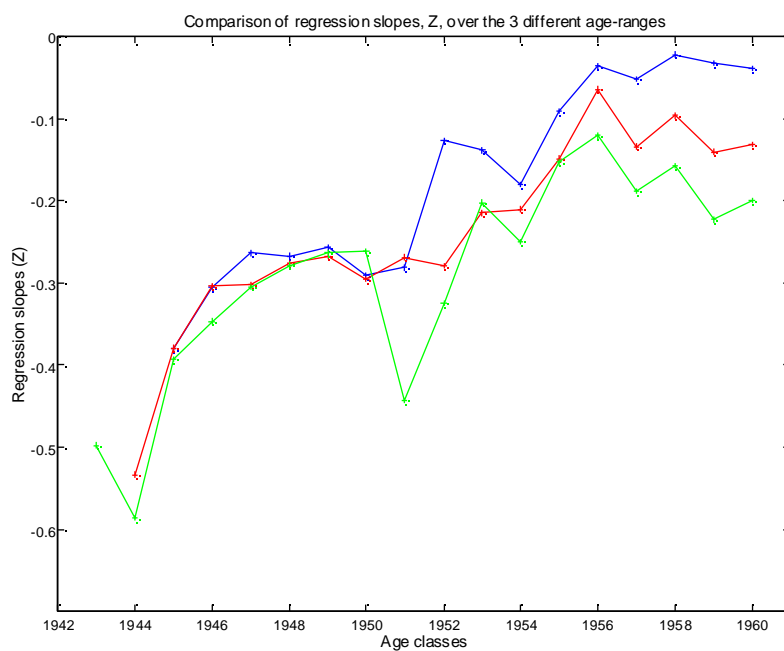
Figure 6. Plot of the annual *Z* estimates from year-class curve analyses (i.e. slope of the above regressions) computed on various age ranges for the Norwegian *CPUE$_{a,c}$* from 1956 to 1979.