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ESTIMATES OF TOTAL MORTALITY OF EASTERN ATLANTIC BLUEFIN TUNA BASED ON YEAR-CLASS CURVES*

J.-M. Fromentin[1], H. Arrizabalaga[2], V.R. Restrepo[3] and J. Ortiz de Urbina[4],

SUMMARY

The 2004 data exploratory meeting concluded that it was no longer defensible to assess the East Atlantic and Mediterranean population using methods that assume that the catch-at-size/age is known exactly, until extensive improvements in fisheries statistics are made. For these reasons, we here investigated the potential benefits of the year-class curve analysis. The robustness and consistency of our results tend to advocate that this method is, in the present situation, a good alternative to ADAPT (among others). As a whole, the estimates of Z from the year-class curve analyses applied on the Spanish trap and Japanese long line fishery data appear indeed to be in good or excellent agreement with ADAPT outputs for the same period and same age-classes. This would indicate that Z of ages 10+ obtained on trap and long line fisheries are fairly representative of Z of ages 10+ for the whole stock. Furthermore, results obtained on these 2 independent data sets are also in good agreement with each other, both in absolute values and in relative trends. The most striking result remains the steep increase in Z over time calculated from the trap fishery data (secondarily from the long line data). If the catch rates of these fisheries were indeed representative of the abundance of these age-classes (10+), this would indicate that the total mortality of most spawners of the East Atlantic and Mediterranean bluefin tuna was more than two times higher during the 1996-2004 years than it was during the 1992-2000 years.

RESUME

Le groupe de travail sur les données de 2004 a conclu qu'il n'était plus acceptable d'évaluer le stock de thon rouge de Méditerranée et d'Atlantique Est par le biais de méthodes qui assument que la matrice des captures par taille/âge est exacte, avant que cette base de données soit améliorée de manière substantielle. Pour ces raisons, nous explorons ici le bénéfice potentiel de l'analyse des courbes de captures sur cohortes. La robustesse et la cohérence de nos résultats laissent à penser que cette méthode est une bonne alternative (avec d'autres méthodes) à ADAPT dans la situation présente. En général, les estimations de Z de l'analyse des courbes de captures sur cohortes appliquée sur les captures de madragues espagnoles et de palangre japonaise apparaissent en effet en bonne ou excellente adéquation avec les estimations d'ADAPT sur la même période et les mêmes âges. Ceci indiquerait que les Z obtenus à partir de ces pêcheries seraient représentatifs des Z des âges 10+ de l'ensemble du stock. De plus, les résultats obtenus sur ces 2 pêcheries totalement indépendantes sont également cohérents entre eux, que ce soit sur les valeurs absolues ou les tendances. Le résultat le plus marquant reste celui de la forte hausse des Z obtenus à partir des pêcheries de madrague (secondairement des palangres). Si ces pêcheries sont effectivement bien représentatives de l'abondance des ces classes d'âge, ceci indiquerait que la mortalité totale des principaux reproducteurs du thon rouge de l'Atlantique Est et de la Méditerranée aurait plus que doublé entre les années 1992-2000 et 1996-2004.

* Following the initial submission of this document, the 2006 Bluefin Tuna Species Group carried out computations based on the approach presented here, but using improved datasets. Thus, the conclusions derived from the assessment may differ somewhat from those presented here. Nevertheless, the authors decided to publish this paper in order to make a detailed description of the method used permanently available.

[1] IFREMER, Centre de Recherche Halieutique Méditerranéen et Tropical, avenue Jean Monnet, BP 171, 34203 Sète cedex, France. E-Mail: jean.marc.fromentin@ifremer.fr
[2] AZTI, Herrera Kaia Portualdea z/g, 20110 Pasaia, Spain. E-mail: harri@pas.azti.es
[3] ICCAT Secretariat, Corazon de Maria 8, 28002 Madrid, Spain. E-mail: victor.restrepo@iccat.int
[4] IEO, Fuengirola, Spain. E-mail: urbina@ma.ieo.es

RESUMEN

El Grupo de trabajo sobre datos de 2004 concluyó que ya no era aceptable evaluar la población de atún rojo del Atlántico Este y Mediterráneo utilizando métodos que asumen que la captura por tallas/edad es exacta, antes de hacer ampliar mejoras en las estadísticas de pesca. Por estas razones, hemos investigado los posibles beneficios del análisis de las curvas de la clase anual. La robustez y coherencia de nuestros resultados nos hacen pensar que este método, en la actual situación, una buena alternativa (entre otras) a ADAPT. En conjunto, las estimaciones de Z a partir de los análisis de la curva de la clase anual aplicados a los datos de las almadrabas españolas y de la pesquería de palangre japonés parecen estar en buena o excelente correspondencia con los resultados de ADAPT para el mismo periodo y las mismas clases de edad. Esto indicaría que la Z de las edades 10+ obtenida en las pesquerías de almadrabas y palangre es bastante representativa de la Z de las edades 10+ para todo el stock. Además los resultados obtenidos a partir de estos dos conjuntos de datos independientes son coherentes entre sí, tanto en los valores absolutos como en las tendencias relativas. El resultado más notable sigue siendo el agudo incremento en la Z en el tiempo calculada a partir de los datos de la pesquería de almadrabas (también en menor medida de los datos de palangre). Si las tasas de captura de estas pesquerías son efectivamente representativas de la abundancia de estas clases de edad (10+), esto indicaría que la mortalidad total de la mayoría de los reproductores de atún rojo del Atlántico este y el Mediterráneo era más del doble durante los años 1996-2004 que durante los años 1992-2000.

KEYWORDS

Fishing and natural mortalities, year-class curves, stock assessment

1. Introduction

During the 1998 and 2002 stock assessment sessions and the 2004 data exploratory meeting, ICCAT scientists identified several key problems regarding the quality of the catch and effort databases of the East Atlantic and Mediterranean bluefin tuna, among which: (i) the great uncertainties about the total catches and size composition of many fisheries and (ii) the presence of many data sets which are unclassified as to gear or are aggregated over gears, areas and seasons (ICCAT 1999, ICCAT 2003, ICCAT 2005). This together with the unknown adequacy of available CPUE indices as measures of overall stock abundance, make it difficult to interpret trends in SSB and recruits estimated from the VPA (Fromentin and Powers, 2005).

Furthermore, the recent development of caging and farming operations, where fish are held in cages and fed and are not immediately landed, has generated a lack of size composition of the catches of several major purse seine fleets, that represent more than 50% of the total Mediterranean yields (Di Natale, *et al.* 2003; Fromentin, 2003). The proportion of the catches, which have been sampled for sizes and reported to ICCAT always fluctuated, but it dropped below 5% in the Mediterranean Sea since 1998 (ICCAT 2005). Consequently, many substitutions (data pooling strategies) have to be used to construct the final catch-at-size and catch-at-age matrices. The SCRS (ICCAT, 2005), thus, concluded that it was no longer defensible to assess the east Atlantic and Mediterranean population using methods that assume that the catch-at-size (age) is known exactly, until extensive improvements in fisheries statistics are made. In the interim the efficacy of ‘more robust’ methods involving simple management procedures should be explored.

For these reasons, a set of several documents aims to explore the benefits of various approaches being more robust to data uncertainties, such as the Yield-per-recruit (Restrepo, *et al.* 2006; Arrizabalaga, *et al.* 2007), the catch curves (Restrepo, *et al.* 2007), whereas we here investigated the potential benefits of the year-class curves.

2. Methods and data

As the catch curve analysis, the year-class curve analysis is based on the same basic equation (Hilborn and Walters, 1992):

$$N_a = N_{a-1} . e^{-Z} \qquad (1)$$

where N_a is the number of fish at age a and z is the total mortality from age $a-1$ to age a. Assuming an age range from 0 to a, equation (1) may be written as:

$$N_a = R.e^{-Z.a} \quad (2)$$

where R is the recruitment or the abundance of the first age-class. Equation (2) may be linearized by taking the log of the two terms:

$$Log(N_a) = Log(R) - Z.a \quad (3)$$

Assuming that catch is proportional to abundance (number) through:

$$N = C.v \quad (4)$$

where v is the vulnerability to the fishing gear, equation (3) may be rewritten as:

$$Log(C_a) = Log(Rv) - Z.a \quad (5)$$

At the difference of the catch curve analysis (Restrepo, *et al.* 2007), which assumes constant recruitment from year-to-year, year-class curve analysis is calculated over cohorts. Therefore, the assumption of constant recruitment may be relaxed and equation (5) be rewritten as:

$$Log(C_{a,c}) = Log(R_c v) - Z.a \quad (6)$$

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

Note that Z the total mortality is assumed to be constant over the age range of a given cohort, but not between cohorts. Another assumption, that is common to catch curve and year-class curve analyses, is that the vulnerability to the fishing gear, v, remains constant over an age range. 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.

If year-class curve analysis is, thus, more powerful than the catch curve analysis in the sense that it makes fewer assumptions, it cannot provide stock size estimates (i.e. $N_{a,t}$), as v is unknown and cannot be estimated. In the same way as traditional 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).

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 (7) through the linear model framework:

$$Log(CPUE_{a,c}) = Log(R_c v) - Z.a + \varepsilon_{a,c} \quad (7)$$

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

Here we applied year-class curve analysis to two sets of data:

- The catch-at-age (raised from size samples and total catch) of the Spanish trap fisheries (including Tarifa, Barbate, Conil and Zahara de los Atunes traps) from 1992 to 2004. Effort is indeed believed to have stayed constant over the whole period (and since decades), because trap is a passive gear that did not support technological/size modifications and which has been set at the same locations over the whole period (Ortiz de Urbina, *et al.* 2007).

- CPUE-at-age of the Japanese long line fishery between 1975 and 2000, using CPUE, partial catch and total catch being published in the 2002 detailed report of the bluefin stock assessment (ICCAT, 2003).

3. Results

3.1 Year-class curves on Spanish trap fisheries

As indicated by **Figure 1** and selectivity patterns calculated from catch curve analysis (Restrepo, *et al.* 2007), bluefin tuna is not fully recruited by trap before ages 10 or 11. Therefore, the year-class curve analyses have been computed over the following age ranges: 10-16, 10-17; 10-18 and 10-19 as well as 11-17; 11-18 and 11-19 (we did not consider the age 20 which is a plus-group).

The goodness of fit of the linear regressions were better when starting at age 11 than at age 10, because age 10 was, in some cohorts, not fully recruited. However, the general patterns of *Z* estimates were similar and we, therefore, only present results from age ranges starting at age 11.

In all cases, the goodness of fit is satisfactory (r^2 is rarely < 0.5 and the residuals did not show any special pattern), but becomes better as the number of points per regression increases. The main output is that the slopes, *Z*, are not similar between cohorts, but increase quite a lot from the earlier cohorts (i.e. 1981 and 1982) until the last (1984 to 1987, **Figures 2, 3, 4** and **Table 1**).

For the first cohort being common to 3 age ranges (i.e. the 1981 cohort), which corresponds to the fishing years going from 1992 to 1998 or 1999 or 2000 (depending on the age ranges), *Z* vary between 0.2 and 0.32. *F* estimates of VPA-ADAPT for age 10+ ranged from 0.11 to 0.24 between 1992 and 2000 (ICCAT, 2003). Assuming *M*=0.1 for these ages (as in the last stock assessments), *Z* would have varied between 0.21 and 0.34. So, *Z* estimated by ADAPT and year-class are highly similar.

For the last cohort being common to 3 age ranges (i.e. the 1985 cohort), which corresponds to fishing years going from 1996 to 2002 or 2003 or 2004, *Z* vary between 0.54 and 0.69. In comparison to the first cohort (i.e. 1981), there is, thus, a ~2.5 fold increase in *Z* between the 1992-2000 years and the 1996-2004 years.

3.2 Year-class curves on Japanese long line fisheries

From 1975 to 1985, the cohorts do not always display a negative exponential pattern across the fully recruited ages (i.e. 8+), as it should be **(Figure 5)**. Therefore, we restricted our analysis on the 1986-2000 period which displays better patterns and which is also the more interesting for comparison with the trap fisheries. As age 15 is a plus group **(Figure 6)**, age 14 was the last age considered in the following analyses.

Year-class curves were also calculated on age ranges 8-14 **(Table 1)**, but goodness of fit was in general lower because age 8 is also not always fully recruited. However, the general pattern remains similar (see **Table 1**). Roughly, variations in estimated slopes between cohorts appear less pronounced than for the traps. Estimates of *Z* appear to be rather stable, at around 0.3 $year^{-1}$, for the 1977 to 1982 cohorts, so for fishing periods ranging from 1986 to 1995 or 1996 (depending on the age range). Recognizing that *Z* estimated through ADAPT ranged between 0.19 and 0.39 $year^{-1}$ over the same period (1986-1996), *Z* estimated by ADAPT and year-class curve appear again to be in good agreement. For the 1983 to 1986 cohorts (i.e. fishing periods spreading from 1992 to 2000), the year-class curves display higher *Z*, ranging from 0.29 to 0.55 $year^{-1}$. These values are slightly higher than ADAPT ones, which ranged from 0.21 to 0.44 $year^{-1}$, for the same period. This difference is, however, likely to be due to the shrinkage used in the last stock assessment and which is known to considerably reduce the absolute values of the terminal *Fs*.

4. Discussion and conclusion

Year-class curve analysis is rarely applied, mostly because catch-at-age analysis, such as VPA, are believed to be much more powerful since they do not make equilibrium assumptions (Hilborn and Walters, 1992). However, all VPA models (being statistical, such as ADAPT, or mostly arithmetical, such as XSA) are also limited by strong assumptions, especially the facts that: (i) the total catches and the catch-at-age matrix are supposed to be exact, i.e. with no (or little) observation errors in landings and ageing and that (ii) M is known with confidence. These two assumptions are clearly violated in the case of the east Atlantic and Mediterranean bluefin tuna (ICCAT 2005).

For the above and other reasons, Cotter *et al.* (2004) concluded, in a recent review paper contrasting different stock assessment models (VPAs, year-class curve, state-space models and Bayesian approaches), that *"the year-*

class-curve was the favoured method, because of their applicability to data sets separately, their visual appeal, simple statistical basis, minimal assumptions, the availability of confidence limits and the ease with which estimates can be combined from different data sets after separate analyses".

The robustness and consistency of our results tend also to advocate that the year-class curve analysis is a good alternative (among others) to VPA in the case of east Atlantic and Mediterranean bluefin tuna. As a whole, the estimates of Z from the year-class curve analyses applied on the Spanish trap and Japanese long line datasets appear indeed to be in good or excellent agreement with ADAPT outputs for the same period and same age-classes. Although uncertainties in catch-at-age are not new (and thus possibly biased past VPA estimates), we can postulate that past F estimates of ADAPT are, however, more trustworthy, because of the convergence property of the VPA. Keeping that in mind, the similarity between year-class curves and ADAPT outputs could further indicate that Z estimates obtained on trap and long line fisheries are fairly representative of the whole stock for these age classes (i.e. 10+).

Furthermore, results obtained on these two independent data sets are also in good agreement with each other, both when considering absolute values and relative trends **(Table 1)**. The most striking result remains the steep increase in Z over cohorts (and time) calculated from the trap fishery data (secondarily from the long line data). If these fisheries were indeed representative of the abundance of these age-classes (i.e. age 10+), this would indicate that the total mortality of most spawners of the east Atlantic and Mediterranean bluefin tuna is more than two times higher during the 1996-2004 years than it was during the 1992-2000 years.

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Table 1. Annual Z estimates from year-class curve analyses computed on various age ranges of the Spanish trap and Japanese longline fisheries datasets.

Cohorts	*Trap* Z_{11-17}	*Trap* Z_{11-18}	*Trap* Z_{11-19}	*LL* Z_{8-14}	*LL* Z_{9-14}
1977	-	-	-	-	0.35
1978	-	-	-	0.18	0.35
1979	-	-	-	0.31	0.31
1980	-	-	-	0.28	0.29
1981	0.22	0.20	0.32	0.22	0.30
1982	0.16	0.30	0.42	0.29	0.33
1983	0.23	0.41	0.40	0.31	0.38
1984	0.41	0.44	0.50	0.22	0.29
1985	0.54	0.63	0.69	0.36	0.55
1986	0.76	0.73	-	0.42	0.50
1987	0.69	-	-	-	-

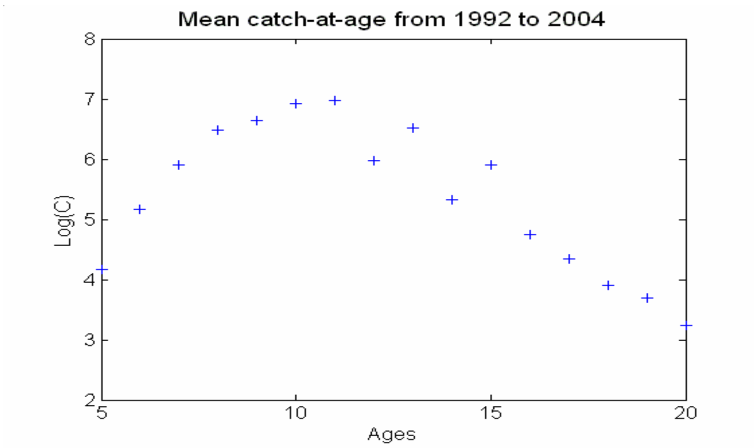

Figure 1. Mean catch-at-age from the Spanish traps between 1992 and 2004.

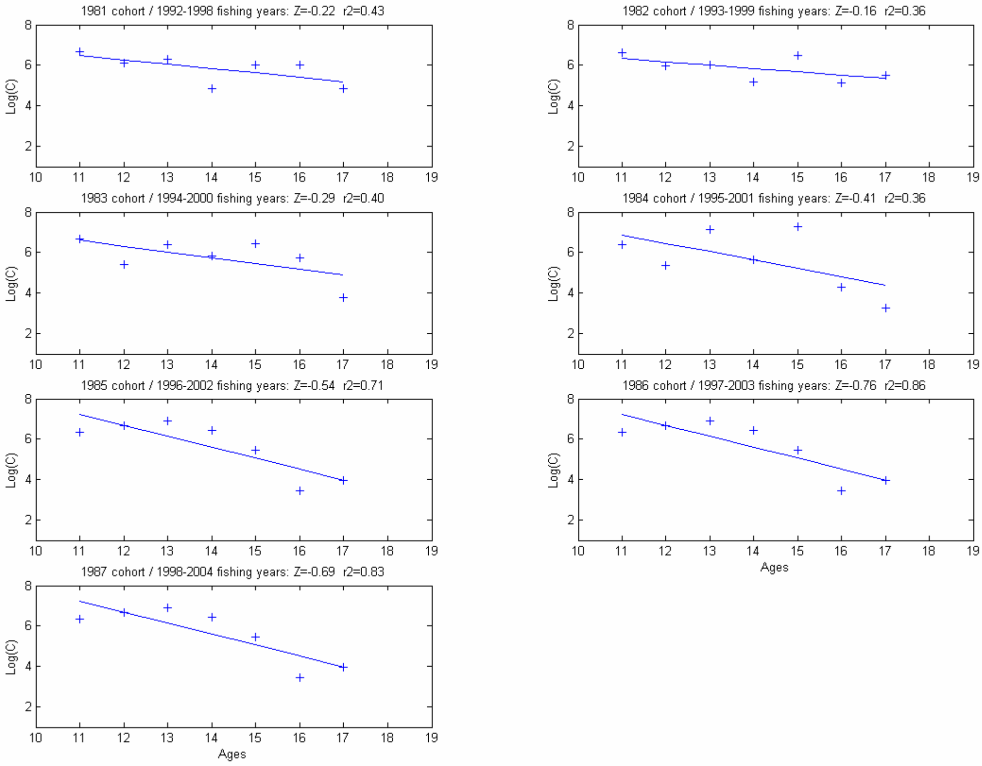

Figure 2. Year-class curves computed on ages 11-17 of Spanish trap $C_{a,c}$ from 1992 to 2000. Corresponding cohort, fishing years, total mortality (*Z*) and r^2 are given in the title of each plot.

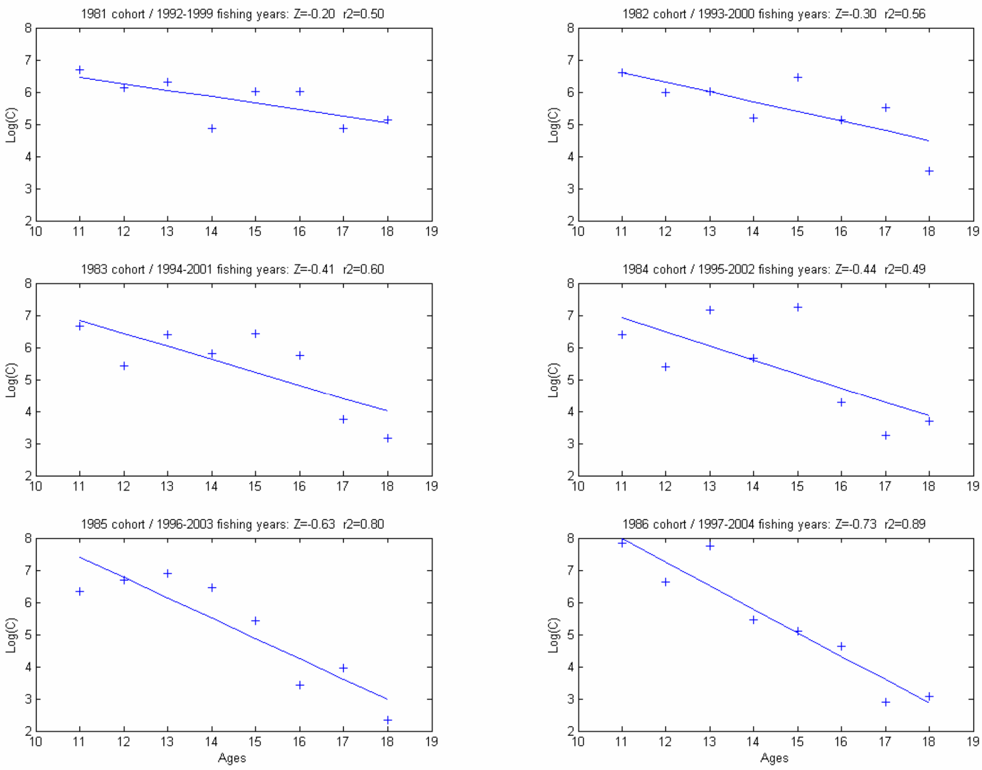

Figure 3. Year-class curves computed on ages 11-18 of Spanish trap $C_{a,c}$ from 1992 to 2000. Corresponding cohort, fishing years, total mortality (*Z*) and r^2 are given in the title of each plot.

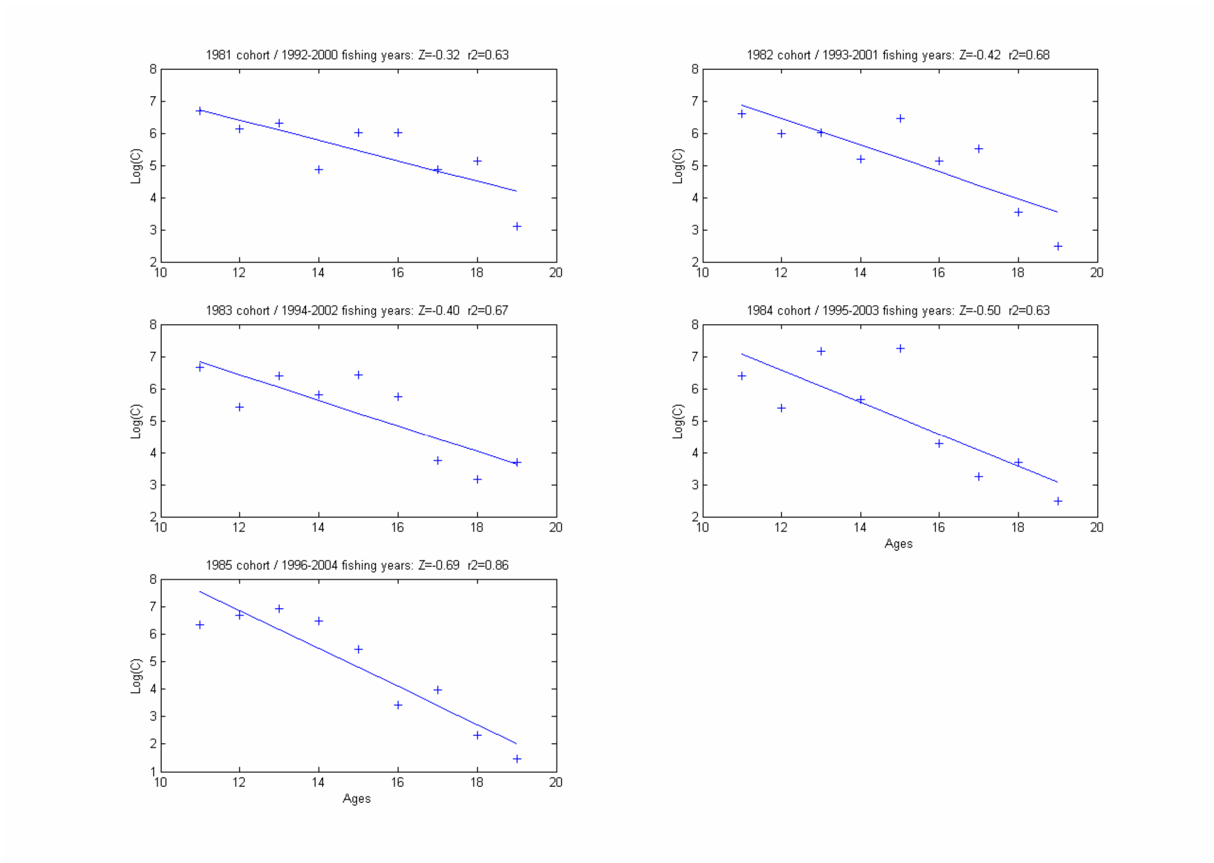

Figure 4. Year-class curves computed on ages 11-19 of Spanish trap $C_{a,c}$ from 1992 to 2000. Corresponding cohort, fishing years, total mortality (Z) and r^2 are given in the title of each plot.

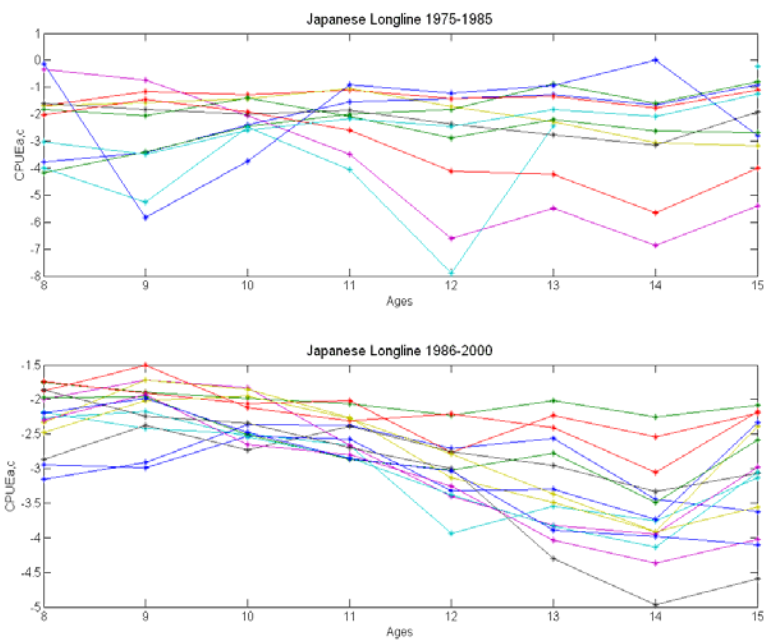

Figure 5. Patterns of the $CPUE_{a,c}$ from Japanese longline fisheries in the east Atlantic and Mediterranean.

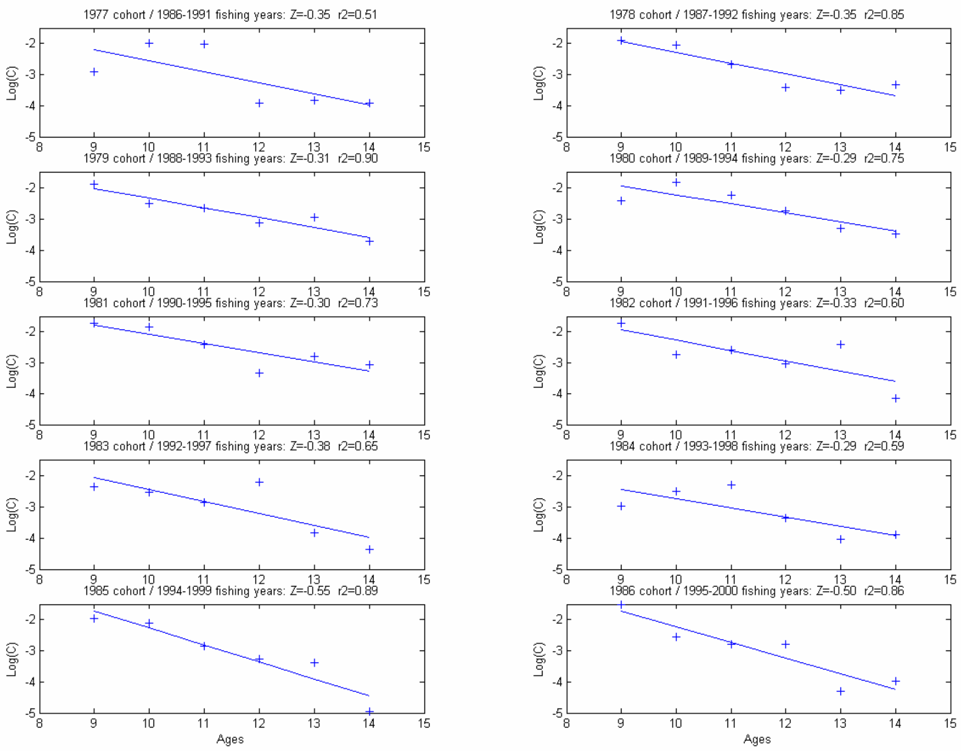

Figure 6. Year-class curves computed on ages 9-14 of Japanese longline $CPUE_{a,c}$ from 1986 to 2000. Corresponding cohort, fishing years, total mortality (Z) and r^2 are given in the title of each plot.