

STANDARDIZED CATCH RATES IN NUMBER OF FISH BY AGE FOR THE NORTH ATLANTIC SWORDFISH (*XIPHIAS GLADIUS*) INFERRED FROM THE SPANISH LONGLINE FLEET FOR THE PERIOD 1982-2015 AND ENVIRONMENTAL CONSIDERATIONS

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SUMMARY

Standardized catch rates in number of fish for ages 1-5+ during a period of 34-years were updated using log-normal General Linear Modeling (GLM) from trips of the Spanish surface longline targeting swordfish in the North Atlantic stock. The criteria to define areas, periods and models were similar to those used in previous papers. However, the models also take into consideration other factors such as gear-style and the target variable to allow for the two important changes in fishing strategy in recent periods. The base case models explained between 42%- 44% of CPUE variability. The standardized CPUE index for age 1 suggests a very positive phase of recruitments between years 1997-2012 with an overall mean of slightly more than double compared to the period 1982-1996. This positive phase also had positive effects on other ages. The change in the recruitment scenario - and the subsequent demographic change - occurred from the mid-1990s onwards could be the main cause for explaining different availabilities by age, average weights and the overall CPUEs of the different areas-fleets.

RÉSUMÉ

Les taux de capture standardisés en nombre de poissons des âges 1-5+ pendant une période de 34 ans ont été actualisés à l'aide de la modélisation linéaire généralisée log-normale (GLM) à partir des sorties réalisées par la flottille palangrière de surface espagnole ciblant l'espadon dans l'Atlantique Nord. Les critères utilisés pour définir les zones, les périodes et les modèles étaient similaires à ceux utilisés dans des documents antérieurs. Néanmoins, les modèles tiennent également compte d'autres facteurs, tels que le style d'engin et la variable cible pour permettre deux changements importants dans la stratégie de pêche qui se sont récemment produits. Les cas de base des modèles expliquaient entre 42% et 44% de la variabilité de la CPUE. L'indice de CPUE standardisée de l'âge 1 suggère une phase très positive de recrutement entre les années 1997-2012 avec une moyenne globale près de deux fois plus élevée que pendant la période 1982-1996. Cette phase positive a également eu des effets positifs sur d'autres âges. La modification du scénario de recrutement - et les changements démographiques ultérieurs - survenus à partir du milieu des années 90 pourraient être la principale explication des différentes disponibilités par âge, des poids moyens et des CPUE globales des différentes zones-flottilles.

RESUMEN

Se actualizaron para 34 años las tasas de captura normalizadas, en número por edad 1-5+, mediante Modelos Lineales Generalizados (GLM) a partir de mareas de la flota española de palangre de superficie dirigida al pez espada en el stock Atlántico norte. El criterio para definir áreas, periodos y modelos fue similar al usado en anteriores documentos. Sin embargo, los modelos consideraron también los factores estilo de arte y direccionamiento para tener en cuenta importantes sucesos ocurridos en periodos recientes. Los modelos base-case explicaron entre el 42%-44% de la variabilidad de la CPUE. El índice estandarizado de la CPUE edad 1 sugiere una fase muy positiva de reclutamientos entre 1997-2012 con un valor medio global de más del doble del periodo 1982-1996. Esa positiva fase tuvo efectos positivos sobre las otras edades. El cambio en el escenario de reclutamiento -y el cambio demográfico subsiguiente-

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ocurrido a partir de mediados de los noventa, podría ser la principal causa para explicar la distinta disponibilidad por edad, el peso medio y de las CPUE globales en las distintas áreas-flotas.

KEYWORDS

Swordfish, Age specific CPUE, GLM, Longline, AMO, NAO

1. Introduction

The surface longline gear of the Spanish fleet targeting swordfish remained relatively constant over decades of the twentieth century in terms of structure and gear configuration (Rey *et al.* 1988, Hoey *et al.* 1988). The consistency of fishing patterns, fishing areas and gear configurations during those decades facilitated the interpretation or assumption of the catch rates obtained as indices of relative abundance from broad areas of the North Atlantic, taking advantage of the huge geographical expansion of this fleet during the eighties. Some technological improvements in the fishing gear of this fleet were introduced and described during those historical periods in order to make it easier to carry out handling, related to setting out and hauling back the fishing gear. These old improvements generally tended to allow for a greater number of hooks per set which were considered as nominal effort in the respective CPUE calculations.

However, important changes in the fishing strategy and gear “style” of the Spanish fleet have been introduced, recorded and reported since the end of the last century. The monofilament “American style” longline (originally based on the “Florida style longline”) was widely introduced in the Spanish Atlantic fleet at the end of the last century and most vessels have been fishing with this new monofilament style since then (Mejuto and De la Serna 2000, Mejuto *et al.* 2003, García-Cortés *et al.* 2014). On the other hand, the targeting criteria of the Spanish longline fleet fishing on the North Atlantic stock was historically based on targeting swordfish. But this strategy has become progressively more diffuse in recent periods, focusing on a combination of both swordfish and blue shark as the main valuable species, as was also observed and reported for these or other groups of species (e.g. tuna and / vs. swordfish) in the case of other Atlantic surface longline fleets. The “target variable” accounts for trips where tuna and/or sharks were important or predominant in the catch, or potentially also targeted as main species for some fleets. These changes in the fishing strategy of a number of fleets in the North and South Atlantic Ocean have had significant effects on the standardized CPUE for swordfish obtained from each fleet using different and adapted models (e.g. Hazin *et al.* 2010, Mejuto and De la Serna 2000, Ortiz 2010, Ortiz and Scott 2003, Ortiz *et al.* 2010, Paul and Neilson 2010).

The impact of these changes on the nominal and standardized CPUE of the Spanish fleet have been described in literature and compared with results obtained using other approaches (e.g. Anon. 2001^a, Mejuto and De la Serna 1997, 2000; Mejuto *et al.* 1998, 1999, 2001, 2002). Most of these new factors had already been considered in the age-aggregated CPUE standardizations. However, the new events occurring in the most recent periods had not been taken into account in age-specific CPUE analyses of the Spanish longline fleet until the last 2013 assessment (Mejuto *et al.* 2014).

The standardized catch rates of the Atlantic swordfish were obtained in recent decades by means of GLM procedures applied to different commercial fleets, some of which targeted this species while others did not (e.g. Hoey *et al.* 1989, 1993, Anon. 1989, 2010, Nakano 1993, Mejuto 1993, 1994, Scott *et al.* 1993, Mejuto and de la Serna 1995, 2000, Mejuto *et al.* 1999, Ortiz and Scott 2003). Data collected for scientific purposes from the commercial Spanish surface longline fishery targeting swordfish were also used to develop GLM standardized catch per unit effort for the North Atlantic swordfish stock using methods recommended by several authors and the ICCAT working groups (e.g. Anon. 1989, 2001^a, 2010, 2014, Gavaris 1980, Kimura 1981, Robson 1966). These indicators have been used as input parameters for the previous stock assessment of North Atlantic swordfish.

The aim of this document is to update the standardized CPUE series (ages 1 to 5+) previously provided for the North Atlantic swordfish stocks, covering in this case a 34-year period. Additionally, environmental considerations related to recruitment levels and stock trends over time are included and discussed.

2. Material and methods

Trip data used were obtained from landings of the Spanish longline fleet fishing in the North Atlantic swordfish stock over a period of 34 years (1982-2015). Data voluntarily reported was recorded for scientific purposes. The methods and specifications used in this paper aimed to be consistent as far as possible with previous analyses in order to facilitate comparison with earlier results. Two important events which have occurred in recent periods were also taken into consideration in these analyses: (a) The introduction of a new monofilament gear style (American style) and (b) the progressive change of the targeting criteria of this fleet compared with the previous decades reported. The analyses take into consideration the stock structure assumed by ICCAT for Atlantic swordfish (Anon. 2014).

The analysis of CPUE by age (number of fish per thousand hooks) was developed using the methods traditionally applied in the ICCAT swordfish working groups and already reported in previous papers (e.g. Mejuto 1993, 1994, Mejuto and De la Serna 1995, 1997, 2000; Mejuto *et al.* 1998, 1999, 2003, 2014). The sex-combined Gompertz's type equation recommended and assumed by ICCAT (Anon. 1989) was used to obtain number of fish by age (ages 1 to 5+) from catch size data sampled per trip. The conversion from size into age was carried out with software applying the "slicing" technique (Restrepo *pers. comm.*) updated in Visual Basic. Trips with size-sampling coverage below 85% of the total catch in number of fish landed were omitted from the base case analysis, as in previous contributions.

The trip type or fishing strategy for the target species (target variable), the gear style and the bait used were also considered for modelling. The type of trip or "ratio" was defined for each trip as the percentage in weight of swordfish landed in relation to the combined swordfish and blue shark landed. After analyzing the behaviour of this fleet over time and assess the impact of including/excluding this variable into the models it was concluded that this ratio is the best proxy indicator for the skippers targeting criteria belonging to this North Atlantic Spanish fleet over time (Mejuto and De la Serna 2000, Ortiz *et al.* 2010) and performed best of the different proxies simulated (Anon. 2001^a). The "ratio" was broken down into ten categories at 10% intervals for modelling the levels of type of trip. The definition corresponding to "quarters" was as follows: Q1 = January, February, March; Q2 = April, May, June; Q3 = July, August, September; Q4 = October, November and December. Three gear styles were defined: 1 = traditional multifilament mainline, 3 = new monofilament and 9 = unknown. Three bait types were also considered: 1 = mackerel, 6 = squid and 9 = other types or combinations. The hypothetical boundary line between North and South Atlantic stocks was kept at 5°N latitude as assumed by the ICCAT. The spatial definition used for final runs also considered five areas, as in previous analyses by age (Mejuto *et al.* 2014), overall number of fish and biomass (García-Cortés *et al.* 2014, in press).

The base case standardized log-normal CPUE analyses were performed using GLM procedures (*SAS 9.4 ver.*). The models were defined as: $\text{Ln}(\text{CPUE}) = \mu + Y + Q + A + G + B + R + Q \cdot A + e$. Where: μ = overall mean, Y = year effect, Q = time effect (quarters), A = area effect, G = gear style effect, B = bait type, R = "ratio" effect, e = logarithm of the normally distributed error term. More details about the methods can be found in the papers previously cited.

Old trip records from the period 1982-1985 lack some necessary information for this modelling approach, as regards details such as gear style and bait type used, as well as the "ratio" information between the two prevalent species. In such cases, taking into consideration the history of this fishery, available literature and knowledge, the traditional gear style and mackerel as bait were assumed for all trips during that initial period. A ratio equal to the average observed for trips in 1986 was retrospectively applied to all trips in the period 1982-1985. Sensitivity analyses were also performed considering a lower and less demanding size sampling coverage of 50% for the selection of trip records used for the GLM sensitivity run.

3. Results and discussion

3.1. Standardized CPUEs

A total number of 12,624 trips were available from the whole period 1982-2015. However, 10,276 observations fulfilled the demanding size-coverage criteria established for these analyses. **Table 1** is a summary of the ANOVA results for each age-specific analysis. The number of observations used, R-square, mean square error (root) and F-statistics for each age class are provided. The base case model by age explained between 42% and 44% of CPUE variability.

Table 2 shows the estimated parameters obtained from the CPUE analyses in number of fish by age for the base case run. The year, quarter and area are the most important factors for explaining the variability of the age 1 CPUE. The year variable seems to be especially important for age 1 suggesting that inter-annual variability plays a very important role. The ratio and year variables are the most important factors for explaining the variability of the other ages considered. The type III SS suggest a different ranking of the other factors for the different ages, as would be expected in a species segregated by size-age and some of the ages mainly targeted by this fleet with extensive fishing experience. The bait factor regularly explained a minor part of CPUE variability or was not significant for one age.

Figures 1 and 2 represent the normal fit, the frequency distribution of the standardized residuals and the normal probability qq-plot diagnosis of the GLM base case run for standardized CPUE in number of swordfish by age. **Figure 3** presents the variability box-plot of the standardized residuals by year for each age.

Table 3(a-e) provides information on estimated parameters, their standard error, standardized CPUE by age and upper and lower 95% confidence limits obtained for the base case runs. CVs are omitted because they lose meaning when the mean values are close to zero, giving very large CVs that do not necessarily imply scatter of data in those cases. The mean standardized CPUE figures by age and their 95% confidence intervals are plotted (**Figure 4**). The results for age 1 suggest that the mean abundance of this age during the whole period 1997-2012 was around 2.2 times greater than the mean level predicted for the previous period 1982-1996. The results obtained for the whole ages 1-5+ from the size samples are generally very consistent with those obtained in the analysis of CPUE in total number of fish landed per trip ([García-Cortés *et al.*, in press](#)), except for the most recent years in which the number of observations fulfilling the requirements established for the analysis by age has been considerably reduced (**Figure 5**).

The sensitivity analysis including trips with at least a 50% size-sampling coverage of the catch in number did not produce significant effects on most general CPUE trends over time for the whole period analyzed. A minor impact was observed on the absolute values obtained for age 1, probably due to bias on some trips with lower sampling size coverage. But the general trends obtained versus the base case run were very similar, although with a lower fit for all ages. These results suggest that in the case of the size-age specific CPUE analysis the size-sampling criteria and protocols used for each fleet to obtain CAS and create CAA per observation could be an important factor in considering such results as reliable indicators and comparing them with results provided from other fleets. In this sense, no substitution procedure of size information among trips was implemented in these analyses and a very demanding criterion of minimum sampling coverage per trip was selected for the base case runs.

CPUEs by age from several fleets have been routinely provided for most previous North Atlantic swordfish assessments. The use of models structured by age and the informative importance of these indices made it advisable to provide this type of information for several fleets. However, the usefulness of age-standardized CPUE indices has recently been undervalued when used assessment models do not necessarily require this information. The authors -and most previous working groups- always were very aware about the drawbacks of using slicing methods and the growth model selected in previous assessments to convert length into age, when there are no age-length keys available or other better and successful ageing proposals achieved. However, despite the huge difficulty of obtaining highly representative CAS data by trip over several decades and the disadvantage of obtaining the CAA using the sex-combined growth model obtained from tagging-recapture data -as recommended and assumed by ICCAT for North Atlantic swordfish ([Anon. 1989](#))- these indicators by age could also help to better understand stock dynamics and interpret trends observed in the CPUE of each fleet - and between fleets - when standardized catch rates (in terms of number or biomass) are developed for "all" ages-combined. These indices by age are especially useful for the interpretation of the standardized age-combined CPUE in biomass because of the high impact of mean weight of the catch on these combined indices. In the case of age-combined indices and because of the behaviour of the swordfish, it is not easy to discern which fractions of the stock contribute to a greater or lesser extent, in a given year, period or fleet, to that respective age-combined indicator. It is, therefore, difficult to make a simple comparison between fleets of their respective combined CPUE trends without knowing the fractions that contributed over time to the different fleets' annual indices, or the ages omitted in the CPUE calculations in some cases because lack of availability or domestic regulations. In short, this type of "age" analyses, despite its limitations and difficulties, are useful at least as complementary information to be considered, as long as the CAS data are qualitatively adequate and are not affected by substitution among the observations used in the analyses or affected by other bias.

3.2. Environmental considerations

The high recruitment scenario after 1995 -occurring after a prolonged and sustained period of low recruitments- could explain the increase in CPUE and/or the changing trend observed for other ages and could also explain the increased CPUE observed for some other fleets-areas since then. This positive recruitment phase, together with the regulatory measures introduced, has probably contributed to the increase of this stock (Anon. 2014, Neilson *et al.* 2013). Previous studies suggested that, in a sustained scenario of very low recruitments as probably occurred between the mid-1970s and mid-1990s, it would not be feasible to return to the highest biomass levels of the very positive phase of 1970s even if the stock had not been affected at all by fishing (Mejuto 2000, 2007).

The processes governing variability and the different stages of recruitment in fisheries have been studied and discussed by many authors, especially since the beginning of the twentieth century (e.g. Hjort 1914, Cushing 1969). In the case of some fish stocks, this relationship has been identified as the key to interpreting trends and the different periods in the abundance over decades (e.g. Kristiansen *et al.* 2011). However, it has generally been difficult to distinguish between environmental and fishery-related causes to explain variations in recruitment and stock abundance. A weak SSB-R relationship has been verified for many fish stocks probably because of the major importance of the environmental factors (Larrañeta 1996).

The International Council for the Exploration of the Sea (ICES) sought to identify the causes of this abundance variability in some pelagic fish species and initially focused its attention on two *primary mechanisms*: fish migrations and fishing intensity. This Committee pointed out that the observed fluctuations in abundance over time of some studied fish species had been caused not so much by variability in migratory pathways as by variability in reproductive success and recruitment (Houde 2008, Sinclair 1997). Environmental influences such as the advection of eggs and larvae as passive drifters seem to be a very important factor in annual recruitments and stock trends over time (Helbig *et al.* 1992). Similarly, the combination of factors affecting reproduction in areas of higher/lower levels of drift and viability of eggs/larvae from areas described in the Western North Atlantic would support hypotheses such as the “critical periods” and/or “aberrant drift” of eggs and larvae suggested by Dr. Hjort (Houde 2008) to also explain the low/high phases of recruitment of swordfish under respective environmental scenarios, as had been suggested in previous contributions.

Taking into consideration the historic lowest level on record of 5+ ages and spawning biomass of the North Atlantic swordfish observed in the mid-nineties, the high increase in recruitments observed after that period was explained by a plausible change of environmental phase - towards more favourable conditions for swordfish - which had been observed in the North Atlantic after 1995 using different atmospheric and oceanographic indicators (see Mejuto 1999, 2000, 2001, 2002, Neilson *et al.* 2013 for additional information): “*the possible change in the NAO phase that took place as of 1996, along with associated oceanographic effects occurring especially in the NW Atlantic areas, may have led to a new scenario in the recruitment patterns of this stock, which reached maximum levels after 1995*” (Mejuto 2003).

In that sense, several oceanic indices related to the North Atlantic Oscillation (NAO) and sea temperatures had been pointed out. The Gulf Stream NW index (GSNWindex) (Taylor 1995, 1996; Taylor and Stephens 1980, 1998; Taylor *et al.* 1998) is described in literature as a key factor of the ocean temperatures and transports in the North Atlantic related to the NAO index (Hurrell 1995, Hurrell and Dickson 2004). The warm Gulf Stream current plays a key role in the transport and distribution of heat in the northern hemisphere and it is an essential part of the climate system of the North Atlantic. The structure and position of this current, the speed and the amount of water-mass transported as well as the properties of this water, such as size and location of eddies, exhibit geographic and temporal variations of seasonal, interannual or interdecadal nature (Frankignoul *et al.* 2001). Its role is of utmost importance in defining thermal structure and anomalies in the near-surface layers, especially in the western regions of the North Atlantic, affecting the environmental conditions and biological processes of fish species (Beamish 1995, Drinkwater 2000, Stenseth *et al.* 2004), including of course the migration-distribution of swordfish especially in north-western regions (Ward and Elscot 2000). The ocean-atmospheric dynamics in this region affect the location of the swordfish’s preferred habitat, which is mostly based on temperature in the near-surface layers, and provides insight into local abundance of swordfish in those north-western areas where some fleets are regularly fishing as well as the geographical expansion of the different factions of the stock toward other North Atlantic areas.

The warming sea temperatures observed before 1970 (low NAO phase) and cooling thereafter (high NAO phase) were also reflected in subpolar SSTs during the respective periods. These changes were probably the underlying cause of the Cold Ocean part of the “Cold Ocean -Warm Land” (COWL) pattern described in the Atlantic sector during the 25-year period before the mid-1990s (Wallace *et al.* 1995, Broccoli *et al.* 1998). The relationship

between the rising NAO index and the oceanic transport, cooling Labrador Sea and Subpolar SSTs had also been described by other authors (e.g. McCartney and Talley 1984, McCartney 1997). Ocean-climate changes in the subpolar basins and polar seas correlate with variations in the major climate indices such as the NAO and the Atlantic Multidecadal Oscillation (AMO) (Yashayaev *et al.* 2015). In addition, other indices also described the relationship between the NAO phases and the Eastward Baroclinic Transport (Mtons/seg) of the Gulf Stream/North Atlantic Current (EBTGSNAC), as well as the variation in the temperature of the Deeply Convected Water in the Labrador Sea (DCWLS), among other well-known oceanographic processes (McCartney *et al.* 1997). In this sense, positive/negative phases of the NAO were related to greater/smaller phases of the Gulf Stream-North Atlantic Current (EBTGSNAC) as well as to lower/higher values in the temperature of the Deeply Convected Water in the Labrador Sea (DCWLS). The NAO phases have also been related to changes in the basic atmospheric-oceanographic variables such as SSTs, wind stress and westerlies (Visbeck *et al.* 1998, Ottersen *et al.* 2004^b). The Gulf Stream and North Atlantic Current gradually weakened during the low NAO period of the 1960s and then intensified in the subsequent 25 years of a persistently very high NAO phase to a record peak in the 1990s with a very high increase in megatons per second occurring between 1970 and 1995, and latitudinal shifts of the surface westerlies across the North Atlantic during that period (Curry and McCartney 2001). For several decades the annual mean latitude of the Gulf Stream off the coast of the United States has been forecastable from the intensity of the NAO and the predictions account for more than half the variance, but much of the unexplained variance could be accounted for by the Southern Oscillation in the Pacific and the Gulf Stream being displaced northwards following El Niño-Southern Oscillation (ENSO) events (Taylor *et al.* 1998). In other words, the North Atlantic Ocean circulation responds to the NAO and these changes in the circulation affect the decadal evolution of the North Atlantic heat content, SSTs and consequently the phases of the Atlantic Multidecadal Oscillation (AMO) (McCarthy *et al.* 2015).

Based on all of the above, it had been previously suggested that studies on oceanographic variables mostly affecting the NW Atlantic should be given priority. However, the multiple factors make it difficult to establish an unequivocal linkage between changes in the physical environment and the response of fish (Ottersen *et al.* 2014^a). “*Appreciating recruitment variability, explaining its probable causes, considering implications for management, and understanding it in the context of broader variability in marine ecosystems, are all worthy goals*” (Houde 2008).

The sizes-ages of young swordfish tend to be more thermo-dependent than those of pre-adults and adults to be younger swordfish distributed predominantly in tropical and sub-tropical regions and the warmer layers of the epipelagic habitat, whose thermal characteristics vary between different areas of the North Atlantic, even if they lie at the same latitude, especially in certain environmental phases. Accordingly, in line with the current hypothesis for a single North Atlantic stock (Anon. 2014) -assuming that the effects of possible contributions from other stocks are negligible- there is no reason why the positive impact of the high recruitment levels observed since the mid-1990s, and their subsequent year classes, should necessarily exhibit the same pattern and intensity in all areas and fisheries in the North Atlantic, as the forced patterns of sea temperatures, winds, drifts or other factors affecting the whole surface layers and swordfish behaviours are not spatially uniform. It is therefore plausible that the positive impact of the high recruitment described from the mid-1990s on will have been different and probably more intense for small ages in some warm areas-fisheries of the NW Atlantic which are more dependent on the pattern of currents and multidecadal modes affecting the SSTs of these regions (Drinkwater 2000), which are to some extent well represented by the environmental phases of the North Atlantic Oscillation (NAO) (Hurrell 1995), Atlantic Multidecadal Oscillation (AMO) (Schlesinger 1994) and/or other indices described previously. However, subsequent ages caused by the high-recruitment events could be more visible and stronger in temperate North Atlantic areas-fleet, generating distinct CPUE patterns in biomass between areas-fleets. Similarly, the greater/lesser spatial-temporal availability of swordfish in feeding areas of the SE Pacific has been linked to the environmental phases of the ENSO (Espíndola *et al.* 2011).

The change of the phase in the recruitment pattern of the North Atlantic swordfish which has occurred since the mid-1990s has probably led to a progressive demographic change in the population in relation to previous decades, so the different ages are manifested in the respective North Atlantic areas with different prevalence to those occurred during the low recruitment phase before mid-1990s. This new demographic scenario, and the respective selection of preferred hydrographic conditions, could justify the geographical linkage of the different age-combined CPUEs in weight trends to specific fleets-areas of the North Atlantic.

Identifying significant long-term anomalies in the thermal structure of surface layers in different parts of the North Atlantic during the long history of this fishery, whether these are changes of greater or lesser intensity, could *a priori* explain both *direct* and *indirect* responses by stocks (Ottersen *et al.* 2004^b). One of the best known direct responses of swordfish is larger or smaller scale changes in their migratory pathways (horizontal and

vertical migratory patterns) and thus in their spatial-temporal distribution, especially in the case of some stock fractions (size-age-sex) which are more sensitive to temperature changes in more shallow layers. The different stock fractions tend to move towards their respective preferred hydrographic conditions, which can bring about slight changes in their horizontal and vertical migratory patterns, thus affecting in some way the availability and/or catchability of the different fractions. This is one of the principles governing the physiology of this species. It affects its complex behaviour and has influenced the history of these fisheries since ancient times, especially in some relatively coastal-temperate areas affected by seasonal migrations (Goode 1883, Folson *et al.* 1997, Mejuto 2007, Palko *et al.* 1981, Ward and Elscot 2000). This type of spatial readjustment is likely more obvious near the limits of their geographical distribution and its effects on fishing are especially noticeable when this takes place in temperate-feeding areas sensitive to variations in the convergence of warm and cold currents. Consequently, if there has been a small but significantly distinctive, slightly warmer phase affecting all superficial ocean layers since the mid-1990s, it would then be reasonable to expect in some extent a minor horizontal reallocation or adjustments in migratory patterns in relation to the previous period (Schirripa *et al.* 2017), but probably also in vertical patterns and changes in local age-availabilities. However, in this case the change would probably be more noticeable in some stock fractions which are regularly more present in the NW Atlantic or which may reach seasonally higher-eastern latitudes and whose migratory patterns and availability are especially sensitive to the modes and balances of the warm and cold currents characteristic of these areas in the NW Atlantic, where such a system of currents is fundamental to the distribution of this species and its capture by some of the fleets (Palko *et al.* 1981, Neilson *et al.* 2009, 2014; Ward and Elscot 2000). However, we would expect an impact on other central and eastern areas of the North Atlantic to be different with less effect on horizontal migratory patterns, which have been shown to be broader and more diverse (García-Cortés *et al.* 2003, Abascal *et al.* 2015) than those described for NW restricted areas. These differences in availability or local abundance of the different ages should be evident in the combined CPUE in weight of the respective fleets-areas.

However, if we assume a significant long-term anomaly with somewhat warmer temperatures, other *directly* and *indirectly* dependent responses could be also expected, as had been suggested previously. Reproduction is, among other factors, a temperature-dependent *direct* response in this species. Changes would therefore be likely in areas and periods of reproduction and in the effective reproductive biomass (SSBe) due to the expansion/contraction processes of the warm water surface layers which play an important role in explaining the presence/absence of reproductive events in regions adjacent to those regularly most active reproductive regions identified in the north-western Atlantic (Arocha 1997, Mejuto 2000, Mejuto and García-Cortés 2014). But also one would also expect changes in the drift and viability of eggs-larvae, in the availability of food, and in other biotic and abiotic factors that affect the dynamics of this stock, including increased or reduced retention processes and the stabilization of the upper layers (Larrañeta 1996, Ottersen *et al.* 2004^b) which affect the resulting recruitment levels of the swordfish because the more/less intense *aberrant drift* of eggs and larvae and the minor/major success during these *critical periods* (**Figure 6**).

The heterogeneous influence of climate oscillations on the temperature of the sea surface layers can obviously affect the local behaviour of marine pelagic communities. In this sense, natural oscillations influence the abundance of plankton, for instance, and the AMO in particular is described as a driver of plankton abundance. The zooplankton community is found to be primarily influenced by warming trends (Harris *et al.* 2014) and it is one of the key factors for the initial life stages of swordfish. The modes of some important currents in western areas are associated with different phases of the NAO, AMO and/or other indicators, and ecosystems respond both physically and biologically to modal shifts in these currents (e.g. Anon. 2001^b, Greene *et al.* 2003, Greene and Pershing, 2003, Visbeck *et al.* 1998).

The North Atlantic SST exhibits multidecadal time scale fluctuations -a phenomenon known as the Atlantic Multidecadal Oscillation (AMO)-. The revised AMO index in 2006 indicated that after mid-1990s the North Atlantic SSTs had been about 0.3°C warmer than during the previous 1970-1990 period (Anon. 2007). However, the life and behaviour of swordfish is not only conditioned by surface but also by whole surface layers (Abascal *et al.* 2015, Neilson *et al.* 2009). The increases in SSTs are regularly diminished or softened in the context of whole epipelagic layers where swordfish is regularly living.

The multidecadal fluctuations of the winter NAO are to some extent tied to the AMO with an opposite-signed relationship (Eschenbach 2014², D'Aleo and Easterbrook 2011). The ocean circulation responds to the first mode of Atlantic atmospheric forcing (the North Atlantic Oscillation NAO) through circulation changes between the subtropical and subpolar gyres and these circulation changes affect the decadal evolution of North Atlantic heat content and, consequently, the phases of the AMO (McCarthy *et al.* 2015). However, a non-stationary

² <https://wattsupwiththat.com/2014/04/02/amo-nao-and-correlation/>

relationship between the NAO and the AMO was identified. During the negative phase of the AMO, the North Atlantic SST is strongly correlated with the NAO index, but in contrast the NAO index is only weakly correlated with the North Atlantic SST during the AMO positive phase (Anon. 2007), (**Figure 7**).

Previous studies had suggested a possible synchrony between negative/positive phases in the NAOw and positive/negative trends in recruitment over a short period of nearly 30 years. The authors pointed out that generalising that synchrony from such a short time period would be pretentious if we consider the broad time scale of the environmental phases and the non-stationary relationships regularly achieved. However, biomass trend for this stock since the 1960s suggest that periods of greater/lesser abundance could be synchronised in some way with the phases of more/less intense recruitments to be expected according to the positive/negative phases of the environment as represented by the negative/positive phases of the NAOw. A similar synchrony could also be suggested between the positive/negative phases of the AMO and positive/negative periods of recruitment, the recruitment being defined in both cases based on standardised age 1 CPUE (CPUE1) assuming a one-year time lag from the environmental indicator. Average AMO indices (yearly and July-September) have shown both very similar patterns since 1864 (**Figure 8**). But the fact that the best bivariate fit between AMO and CPUE1 is obtained using the average annual AMO index (annual AMO_t vs. $CPUE_{t+1}$) suggests that "responses" other than seasonal migrations, such as reproduction, the drift and viability of eggs and larvae, and/or other biotic or abiotic factors in the environment could have significant impact on the recruitment level for the following year(s) and on stock dynamics in subsequent years (**Figure 9**) with different effects in different areas of the North Atlantic, probably more clearly for some small ages in warm NW Atlantic areas directly linked to the warm Gulf Stream system (**Figure 10**).

Atmospheric indices based on differences in atmospheric pressure at sea level, such as the NAO, are simplifications of complex atmospheric-oceanic processes which do not necessarily bring about an immediate response at a specific point in time with an impact of equal intensity on the biotic and abiotic variables of surface layers in the North Atlantic that affect the dynamics and behaviour of swordfish. Indeed, some of the effects of these indices may be carried over by the populations during a number of years (Ottersen *et al.* 2004^a). Moreover, we should not expect the effects to be the same in all areas and ages. Therefore, as suggested previously, it would be advisable to examine in greater depth the complex phenology influencing this stock and, from this starting point, choose the most satisfactory combination of indicators to explain and model the different multidecadal phases through which the stock passes and which could be seen as related, to a greater or lesser extent, to environmental phases.

Ocean indices such as AMO, or others which represent variables other than only SST, are probably more direct approximations than atmospheric indicators for simplifying the changes in the marine environment: evaluating thermal anomalies in surface and/or near surface layers, the position and strength of currents, the displacement of water masses, and other variables that may influence and help to explain responses in the natural dynamics of this epipelagic stock, including their direct influence on the critical initial stages of life and recruitment. But these oceanic indicators are also simplifications of complex-interacting factors, on which much of the natural dynamics of the stock, its multidecadal periods of abundance and the spatial-temporal availability of the different ages-sexes for fishing fleets depend.

Unfortunately, most of the available fishing data are too short and unsuitable for establishing relationships to environmental variables of the "match-mismatch" type (Curshing 1969) and verifying their consistency over time. Possible linear relationships are in some cases suggested between environmental indicators and fishery data which are usually annual based, assuming an almost immediate response by stocks, or parts of them, to such environmental indicators. This type of relationships are often found to be lacking or minor in significance -or considered spurious in some cases- generating mistrust, criticism and frustration to the authors, as the findings are often not consistent over time. However, to explain the natural dynamics of stocks in relation to the environment we should not be considered only linear relationships between pairs of annual values but the phenology and episodes of synchrony (positive or negative) that may exist between phases. But it is not easy to achieve this objective as smoothed subsets of short fishing data are often used for this purpose, or the results of modelling sets of fishery data which are disparate and of very uneven quality, or affected by lacks, different fishing patterns or model assumptions. Although these outputs may be very useful for providing descriptions and putting forward hypotheses, they are less satisfactory on a statistical level for defining complex multi-factor relationships with the environment. In this sense, we should be cautious and discriminate between generating hypotheses -as an instrument to be able to carry out further research - of what is evidence.

Moreover, if we wish to establish bivariate fits between environmental factors and fishery data and compare these data among fleets, we should not forget the different elements that can influence the latter, including the fleet's target species, the possible effects of current regulations (e.g. quotas, minimum sizes, changes over time in quality of logbooks, changes in hooks, baits and/or branchline types, etc.) (i.e. Cortés in press, Wilson and Diaz 2012) or the missed data or ages omitted on the respective data sets; as well as the methods and procedures used to generate the fleet-specific input data for modelling. Fleets may change or apply different fishing or reporting strategies over time according changes in fleets, domestic regulations, etc., or targeting different species, ages-sizes according to spatial-temporal availability in a particular year or period, which, together with the regulations in force and other qualitative factors mentioned previously, could explain differences in CPUE even between fleets apparently working near each other. Of course, other factors such as different stocks structures and mixing should not be ruled out based on scientific evidence.

3.3. Other considerations

The first ICCAT recommendation on minimum size came into force formally in July 1991 and was fully implemented in 1992. Since then these recommendations (with different updates and formulations such as REC-90-2 or REC 95-10) have been maintained by ICCAT with different effects on the respective fleets depending on the option chosen for each CPC and the respective effects on the scientific data used. So, different impacts on the data by fleet should be expected. In the case of EU fleets, the type of REC-90-02 which allowed tolerance of up to 15% of the catch in number has been implemented. However, this tolerance was temporarily and unilaterally cancelled by the EU at a domestic level between June 2007 and January 2009. The analyses of the Task-II-size data by fleet could in some cases help to interpret the CPUEs of the different fleets.

The current management system implemented at domestic level for swordfish is based on a complex and demanding regulatory network based, *inter alia*, on closed lists of authorized vessels, gear regulations, fishing plans per company-boat, assignment of strict annual quota per vessel, etc. The quota system per boat-year makes vessels extend their fishing activity in an economically sustainable way all-year round, moderating in many cases their levels of swordfish catches per trip. The effect of this self-controlled fishing strategy on the standardized CPUE indicators is not easily modelled, but it is likely to be causing an underestimate in the abundance index in relation to the fishing strategy of other fleets or of previous historical periods in which global annual quotas and different control measures were implemented at domestic level.

The updated figures included in this study could be considered indicators of the abundance of the prevalent ages in this fishery during the period analysed. However, the strict coverage requirements established for the analysis have considerably reduced the number of observations available after 2011 because of changes in landing procedures and other limitations. The authors accordingly place more reliance on indicators of abundance by age prior to 2012.

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Table 1. Summary of ANOVA base case analysis in number of fish by age: Number of trip-observations, R-square, mean square error (root), F-statistics and Pr > F, for each age considered.

Age	# Observa.	R-Square	RMSE	F-Stat	Pr > F
1	9289	0.4157	0.9594	100.94	<0.0001
2	10041	0.4439	0.7170	122.48	<0.0001
3	10037	0.4321	0.6579	166.73	<0.0001
4	9784	0.4187	0.6725	107.70	<0.0001
5+	9624	0.4337	0.7141	112.62	<0.0001

Table 2. Summary of ANOVA by factor for CPUE base case analysis, in number by age in the North Atlantic stock for the 1982-2015 period.

Age	Factor	DF	Type III SS	M-square	F-value	Pr>F
1	Year	33	1144.301089	34.675791	37.68	<.0001
1	Quarter	3	865.009448	288.336483	313.28	<.0001
1	Area	4	506.334903	126.583726	137.53	<.0001
1	Gear	2	105.579681	52.789841	57.36	<.0001
1	Bait	2	16.572357	8.286178	9.00	0.0001
1	Ratio	9	335.801090	37.311232	40.54	<.0001
1	Quarter*Area	12	195.999633	16.333303	17.75	<.0001
2	Year	33	567.556771	17.198690	33.45	<.0001
2	Quarter	3	161.286369	53.762123	104.57	<.0001
2	Area	4	471.913462	117.978365	229.48	<.0001
2	Gear	2	217.045839	108.522919	211.09	<.0001
2	Bait	2	0.956974	0.478487	0.93	0.3943
2	Ratio	9	882.912748	98.101417	190.82	<.0001
2	Quarter*Area	12	148.452659	12.371055	24.06	<.0001
3	Year	33	355.215065	10.764093	24.87	<.0001
3	Quarter	3	12.453318	4.151106	9.59	<.0001
3	Area	4	203.349235	50.837309	117.47	<.0001
3	Gear	2	268.114436	134.057218	309.76	<.0001
3	Bait	2	9.918801	4.959400	11.46	<.0001
3	Ratio	9	1013.600946	112.622327	260.23	<.0001
3	Quarter*Area	12	74.742495	6.228541	14.39	<.0001
4	Year	33	412.647248	12.504462	27.65	<.0001
4	Quarter	3	88.305841	29.43528	65.09	<.0001
4	Area	4	75.518165	18.879541	41.75	<.0001
4	Gear	2	256.098733	128.049367	283.14	<.0001
4	Bait	2	23.668264	11.834132	26.17	<.0001
4	Ratio	9	1075.829971	119.536663	264.32	<.0001
4	Quarter*Area	12	29.670513	2.472543	5.47	<.0001
5+	Year	33	542.368459	16.435408	32.23	<.0001
5+	Quarter	3	258.634026	86.211342	169.05	<.0001
5+	Area	4	264.476240	66.119060	129.65	<.0001
5+	Gear	2	161.044706	80.522353	157.89	<.0001
5+	Bait	2	29.448572	14.724286	28.87	<.0001
5+	Ratio	9	893.682503	99.298056	194.71	<.0001
5+	Quarter*Area	12	85.288193	7.107349	13.94	<.0001

Table 3(a). Estimated parameters (Lsmean), standard error (Stderr), standardized CPUE in number by **age 1** (Cpu1) and upper and lower 95% confidence limits (Ucpu1, Lcpu1) for the case base analysis of the North Atlantic for the years 1982-2015.

YR	LSMEAN	STDERR	Ucpu1	Cpu1	Lcpu1
1982	-1.5346	0.3202	0.425	0.227	0.121
1983	-1.1805	0.2483	0.515	0.317	0.195
1984	-1.1856	0.2480	0.512	0.315	0.194
1985	-1.2057	0.2418	0.495	0.308	0.192
1986	-0.8341	0.2349	0.707	0.446	0.282
1987	-0.3931	0.2400	1.112	0.695	0.434
1988	-0.1898	0.2327	1.341	0.850	0.539
1989	-0.3370	0.2334	1.159	0.734	0.464
1990	-0.9593	0.2336	0.622	0.394	0.249
1991	-1.0380	0.2329	0.574	0.364	0.231
1992	-0.9492	0.2322	0.627	0.398	0.252
1993	-0.7480	0.2323	0.767	0.486	0.308
1994	-0.7553	0.2316	0.760	0.483	0.307
1995	-0.6915	0.2304	0.808	0.514	0.327
1996	-0.6966	0.2304	0.804	0.512	0.326
1997	0.0456	0.2315	1.692	1.075	0.683
1998	-0.1008	0.2315	1.462	0.929	0.590
1999	0.0790	0.2336	1.758	1.112	0.704
2000	0.0833	0.2351	1.771	1.117	0.705
2001	0.1227	0.2341	1.839	1.162	0.734
2002	-0.1966	0.2337	1.335	0.844	0.534
2003	-0.2129	0.2360	1.320	0.831	0.523
2004	-0.0989	0.2401	1.492	0.932	0.582
2005	-0.0635	0.2454	1.565	0.967	0.598
2006	0.2027	0.2509	2.067	1.264	0.773
2007	0.4302	0.2663	2.685	1.593	0.945
2008	0.2702	0.2621	2.267	1.356	0.811
2009	-0.4723	0.2625	1.080	0.645	0.386
2010	-0.4924	0.2519	1.034	0.631	0.385
2011	-0.0584	0.2589	1.620	0.975	0.587
2012	-0.2084	0.2777	1.454	0.844	0.490
2013	-1.0162	0.2866	0.661	0.377	0.215
2014	-0.5898	0.3154	1.081	0.583	0.314
2015	-0.4766	0.2772	1.111	0.645	0.375

Table 3(b). Estimated parameters (Lsmean), standard error (Stderr), standardized CPUE in number by **age 2** (Cpu2) and upper and lower 95% confidence limits (Ucpu2, Lcpu2) for the case base analysis of the North Atlantic for the years 1982-2015.

YR	LSMEAN	STDERR	Ucpu2	Cpu2	Lcpu2
1982	-0.1506	0.2312	1.3899	0.8835	0.5616
1983	-0.2753	0.1825	1.1041	0.7721	0.5400
1984	-0.4748	0.1812	0.9019	0.6323	0.4434
1985	-0.1314	0.1786	1.2644	0.8910	0.6279
1986	0.0713	0.1746	1.5355	1.0905	0.7744
1987	0.4864	0.1788	2.3461	1.6527	1.1642
1988	0.3078	0.1737	1.9412	1.3811	0.9826
1989	0.4809	0.1740	2.3098	1.6423	1.1676
1990	0.5655	0.1740	2.5135	1.7872	1.2707
1991	0.2900	0.1736	1.9067	1.3567	0.9654
1992	0.2591	0.1732	1.8470	1.3154	0.9367
1993	0.2453	0.1732	1.8218	1.2973	0.9238
1994	0.3306	0.1728	1.9821	1.4127	1.0069
1995	0.5743	0.1718	2.5239	1.8023	1.2869
1996	0.1337	0.1719	1.6248	1.1601	0.8282
1997	0.2930	0.1727	1.9088	1.3606	0.9698
1998	0.6309	0.1727	2.6758	1.9075	1.3598
1999	0.7914	0.1742	3.1516	2.2403	1.5924
2000	0.9504	0.1748	3.6993	2.6265	1.8647
2001	0.8929	0.1745	3.4905	2.4796	1.7615
2002	0.6368	0.1742	2.7003	1.9193	1.3642
2003	0.7037	0.1761	2.8991	2.0528	1.4536
2004	0.4192	0.1781	2.1907	1.5451	1.0897
2005	0.7364	0.1816	3.0308	2.1231	1.4872
2006	0.6465	0.1869	2.8021	1.9426	1.3467
2007	0.8865	0.1983	3.6499	2.4747	1.6779
2008	1.1950	0.1936	4.9188	3.3660	2.3034
2009	0.9267	0.1941	3.7662	2.5743	1.7596
2010	0.8160	0.1864	3.3159	2.3011	1.5969
2011	0.4425	0.1900	2.2997	1.5849	1.0922
2012	0.5910	0.2014	2.7347	1.8428	1.2418
2013	0.1831	0.2095	1.8508	1.2275	0.8141
2014	0.5608	0.2210	2.7684	1.7953	1.1643
2015	1.0023	0.2033	4.1427	2.7815	1.8675

Table 3(c). Estimated parameters (Lsmean), standard error (Stderr), standardized CPUE in number by **age 3** (Cpu3) and upper and lower 95% confidence limits (Ucpu3, Lcpu3) for the case base analysis of the North Atlantic for the years 1982-2015.

YR	LSMEAN	STDERR	Ucpu3	Cpu3	Lcpu3
1982	-0.2873	0.2101	1.1578	0.7670	0.5081
1983	-0.1345	0.1671	1.2300	0.8865	0.6389
1984	-0.1549	0.1656	1.2013	0.8684	0.6277
1985	-0.0676	0.1635	1.3051	0.9472	0.6875
1986	-0.0040	0.1602	1.3809	1.0089	0.7371
1987	0.2506	0.1640	1.7960	1.3022	0.9443
1988	0.0815	0.1593	1.5016	1.0988	0.8041
1989	0.0030	0.1597	1.3892	1.0159	0.7429
1990	0.2711	0.1596	1.8161	1.3282	0.9713
1991	0.3473	0.1592	1.9584	1.4333	1.0491
1992	0.2444	0.1589	1.7656	1.2931	0.9470
1993	0.0886	0.1590	1.5111	1.1066	0.8103
1994	-0.0680	0.1585	1.2908	0.9461	0.6935
1995	0.2423	0.1577	1.7572	1.2901	0.9472
1996	-0.0521	0.1577	1.3093	0.9611	0.7056
1997	-0.2593	0.1585	1.0661	0.7813	0.5726
1998	-0.2134	0.1585	1.1161	0.8180	0.5996
1999	0.1525	0.1598	1.6136	1.1797	0.8625
2000	0.3918	0.1603	2.0522	1.4988	1.0946
2001	0.3078	0.1601	1.8859	1.3780	1.0069
2002	0.1819	0.1598	1.6618	1.2149	0.8882
2003	0.2881	0.1616	1.8550	1.3515	0.9846
2004	-0.0739	0.1635	1.2969	0.9413	0.6832
2005	0.0338	0.1666	1.4539	1.0489	0.7567
2006	-0.1280	0.1717	1.2500	0.8929	0.6378
2007	0.0301	0.1819	1.4965	1.0477	0.7335
2008	0.2117	0.1779	1.7794	1.2555	0.8859
2009	0.3730	0.1785	2.0932	1.4754	1.0400
2010	0.1060	0.1712	1.5779	1.1282	0.8067
2011	-0.0990	0.1747	1.2952	0.9197	0.6530
2012	-0.0060	0.1873	1.4603	1.0116	0.7009
2013	-0.5004	0.1940	0.9037	0.6178	0.4224
2014	0.1840	0.2000	1.8149	1.2263	0.8286
2015	0.4951	0.1871	2.4095	1.6697	1.1570

Table 3(d). Estimated parameters (Lsmean), standard error (Stderr), standardized CPUE in number by **age 4** (Cpu4) and upper and lower 95% confidence limits (Ucpu4, Lcpu4) for the case base analysis of the North Atlantic for the years 1982-2015.

YR	LSMEAN	STDERR	Ucpu4	Cpu4	Lcpu4
1982	0.1936	0.2148	1.8923	1.2420	0.8152
1983	0.0325	0.1709	1.4654	1.0483	0.7499
1984	0.0469	0.1692	1.4813	1.0631	0.7630
1985	0.0709	0.1672	1.5105	1.0886	0.7845
1986	-0.0268	0.1637	1.3601	0.9867	0.7159
1987	0.1054	0.1677	1.5654	1.1269	0.8113
1988	-0.0870	0.1630	1.2786	0.9290	0.6750
1989	-0.1364	0.1633	1.2178	0.8842	0.6420
1990	-0.1192	0.1633	1.2388	0.8996	0.6532
1991	0.0616	0.1629	1.4829	1.0777	0.7832
1992	0.0868	0.1625	1.5197	1.1052	0.8038
1993	-0.1367	0.1626	1.2156	0.8839	0.6427
1994	-0.3026	0.1621	1.0287	0.7487	0.5449
1995	-0.1663	0.1612	1.1766	0.8578	0.6254
1996	-0.3729	0.1614	0.9573	0.6978	0.5086
1997	-0.5417	0.1623	0.8102	0.5895	0.4289
1998	-0.6296	0.1623	0.7420	0.5399	0.3928
1999	-0.4844	0.1636	0.8604	0.6244	0.4531
2000	-0.1327	0.1640	1.2241	0.8876	0.6436
2001	-0.3568	0.1639	0.9782	0.7094	0.5144
2002	-0.3473	0.1636	0.9869	0.7161	0.5197
2003	-0.1727	0.1653	1.1793	0.8529	0.6169
2004	-0.4209	0.1673	0.9241	0.6657	0.4796
2005	-0.6079	0.1708	0.7722	0.5525	0.3954
2006	-0.6804	0.1758	0.7259	0.5143	0.3644
2007	-0.7142	0.1860	0.7173	0.4982	0.3460
2008	-0.5847	0.1833	0.8117	0.5667	0.3957
2009	-0.3136	0.1828	1.0634	0.7432	0.5194
2010	-0.7357	0.1753	0.6861	0.4866	0.3451
2011	-0.5041	0.1789	0.8717	0.6138	0.4322
2012	-0.3893	0.1930	1.0076	0.6903	0.4729
2013	-0.9507	0.1994	0.5827	0.3942	0.2667
2014	0.1079	0.2074	1.7092	1.1382	0.7580
2015	0.0821	0.1914	1.6087	1.1056	0.7598

Table 3(e). Estimated parameters (Lsmean), standard error (Stderr), standardized CPUE in number by **age 5+** (Cpu5+) and upper and lower 95% confidence limits (Ucpu5+, Lcpu5+) for the case base analysis of the North Atlantic for the years 1982-2015.

YR	LSMEAN	STDERR	Ucpu5+	Cpu5+	Lcpu5+
1982	0.4245	0.2281	2.4534	1.5690	1.0035
1983	0.1824	0.1814	1.7409	1.2200	0.8550
1984	0.2474	0.1797	1.8510	1.3016	0.9152
1985	0.1704	0.1775	1.7058	1.2046	0.8506
1986	0.0314	0.1738	1.4729	1.0476	0.7451
1987	0.0764	0.1781	1.5546	1.0966	0.7735
1988	-0.0991	0.1731	1.2906	0.9194	0.6549
1989	-0.1527	0.1734	1.2242	0.8714	0.6203
1990	-0.2065	0.1734	1.1600	0.8257	0.5878
1991	-0.0758	0.1729	1.3206	0.9410	0.6705
1992	0.0469	0.1726	1.4918	1.0637	0.7585
1993	-0.1198	0.1727	1.2630	0.9004	0.6419
1994	-0.3076	0.1721	1.0456	0.7462	0.5325
1995	-0.2608	0.1713	1.0937	0.7818	0.5589
1996	-0.4705	0.1715	0.8871	0.6339	0.4530
1997	-0.6660	0.1724	0.7312	0.5215	0.3719
1998	-0.6568	0.1725	0.7381	0.5263	0.3753
1999	-0.8365	0.1740	0.6186	0.4398	0.3128
2000	-0.2853	0.1743	1.0740	0.7633	0.5424
2001	-0.5473	0.1742	0.8264	0.5873	0.4175
2002	-0.4670	0.1740	0.8951	0.6364	0.4525
2003	-0.3375	0.1758	1.0229	0.7247	0.5134
2004	-0.5451	0.1778	0.8346	0.5890	0.4157
2005	-0.5781	0.1813	0.8136	0.5703	0.3997
2006	-0.6184	0.1871	0.7913	0.5483	0.3800
2007	-0.2390	0.1991	1.1866	0.8032	0.5437
2008	-0.3309	0.1940	1.0705	0.7319	0.5004
2009	-0.2521	0.1946	1.1598	0.7920	0.5409
2010	-0.6636	0.1869	0.7558	0.5240	0.3633
2011	-0.3800	0.1901	1.0107	0.6963	0.4797
2012	-0.0908	0.2050	1.3937	0.9326	0.6240
2013	-0.6182	0.2129	0.8367	0.5513	0.3632
2014	0.2197	0.2204	1.9657	1.2763	0.8287
2015	0.2656	0.2033	1.9831	1.3314	0.8939

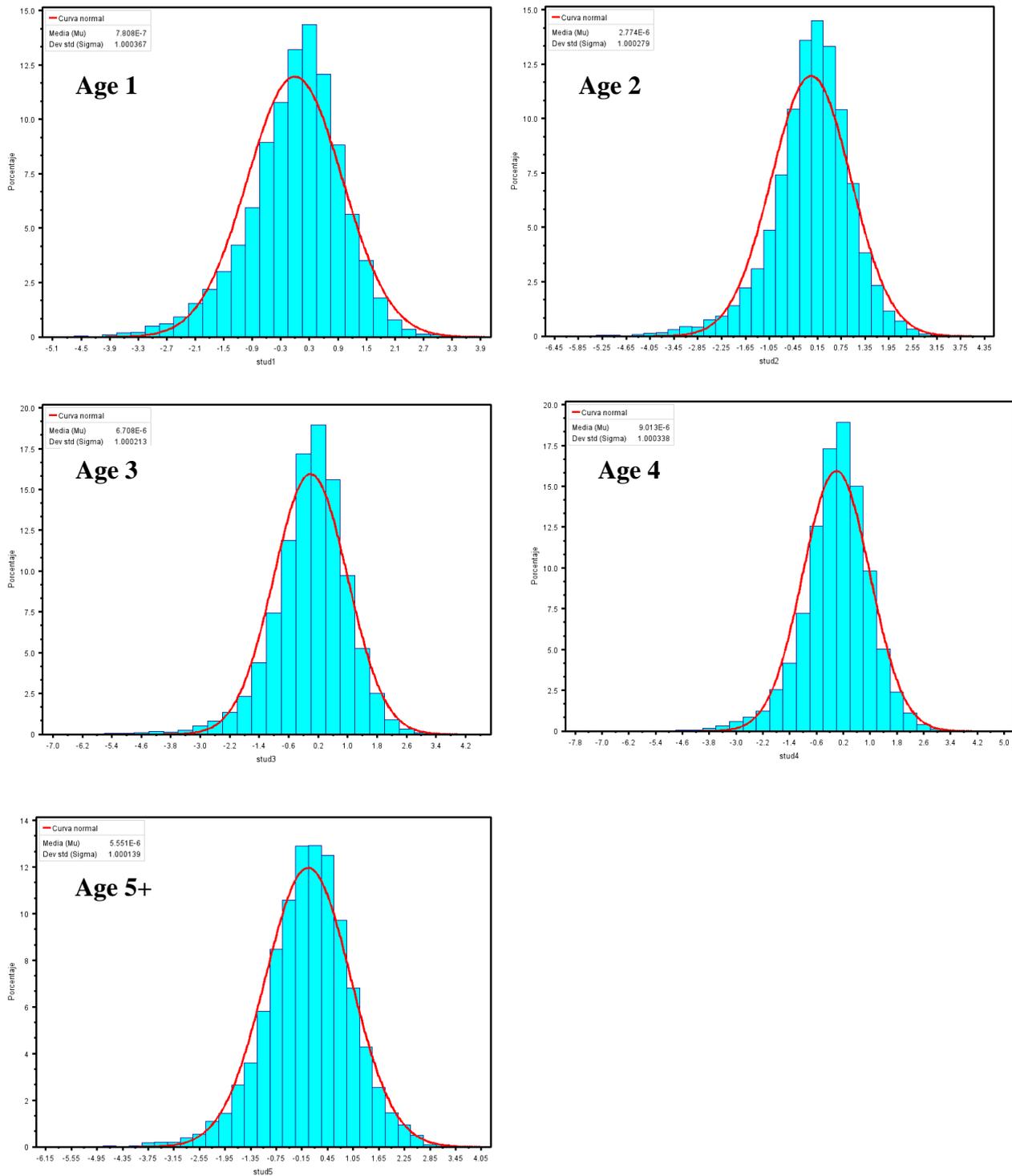


Figure 1. Normal fit and frequency distribution of the standardized residuals by age, years combined, obtained as diagnosis of the standardized CPUE in number of swordfish from the base case analyses of the North Atlantic stock for the period 1982-2015.

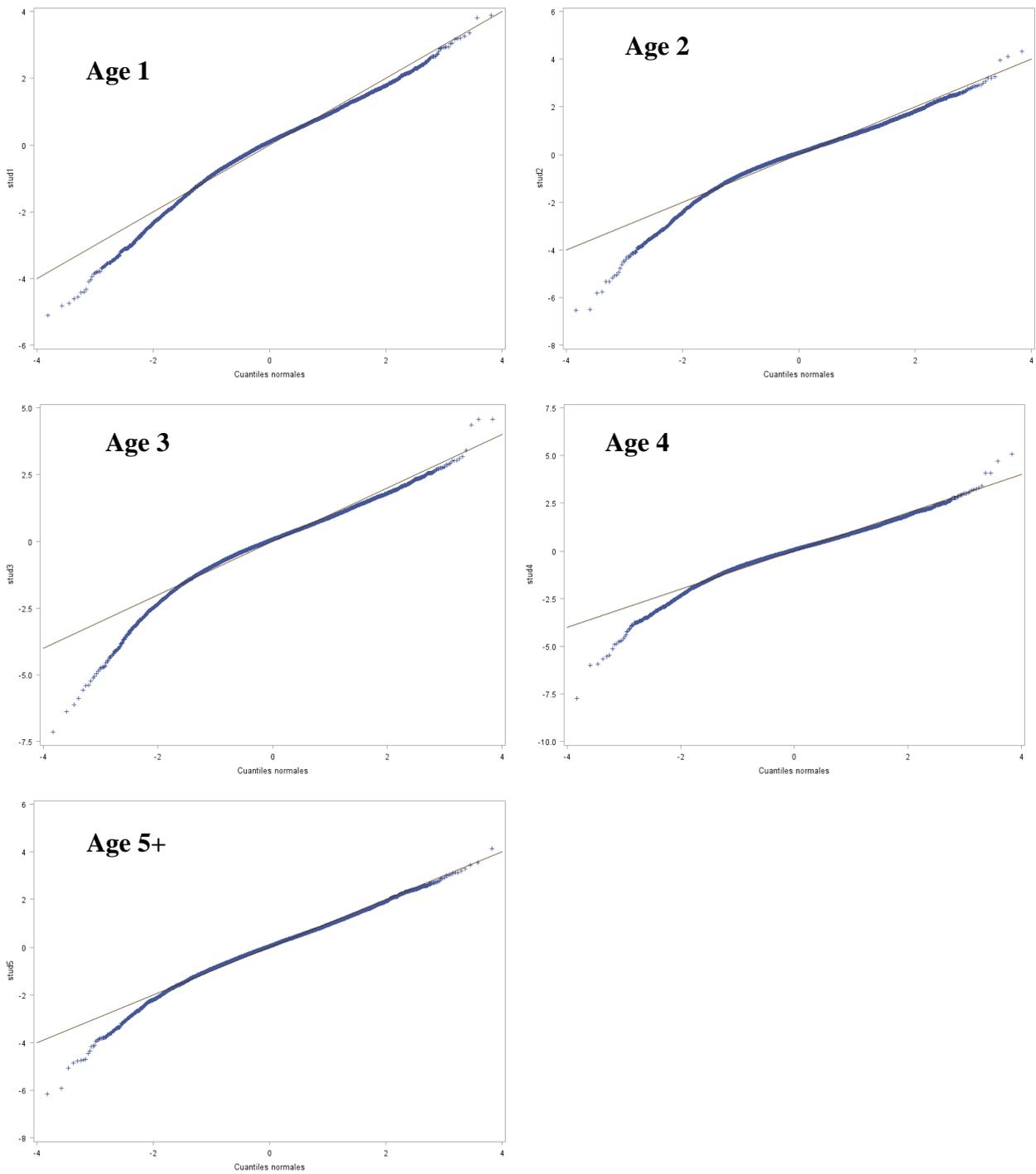


Figure 2. Normal probability qq-plot obtained for the GLM base case analyses for standardized CPUE in number of swordfish by age in the North Atlantic stock for the period 1982-2015.

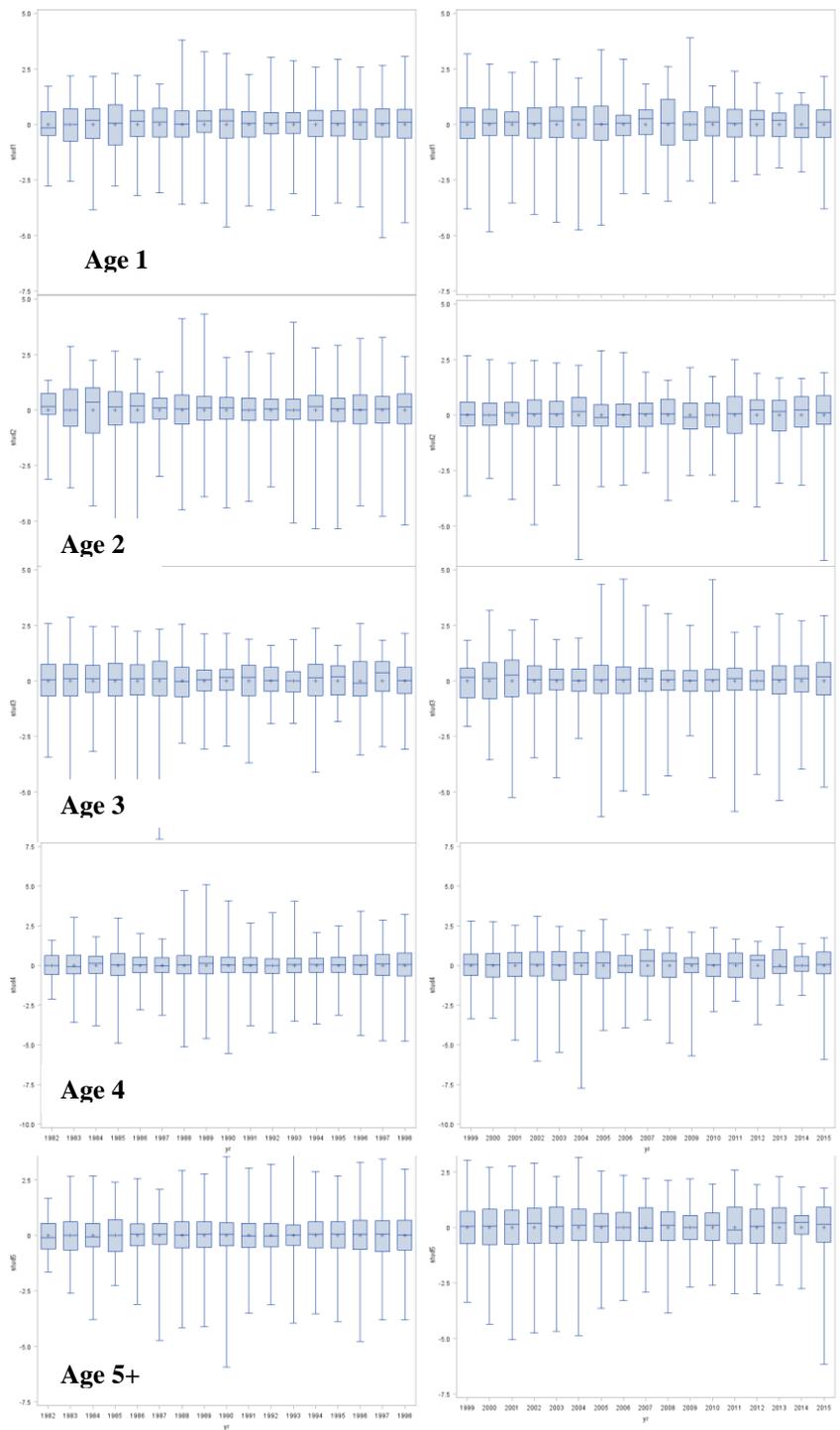


Figure 3. Variability box-plot of the standardized residuals by year obtained from GLM base case analyses of the standardized CPUE in number of swordfish by age for the North Atlantic stock during the period 1982-2015.

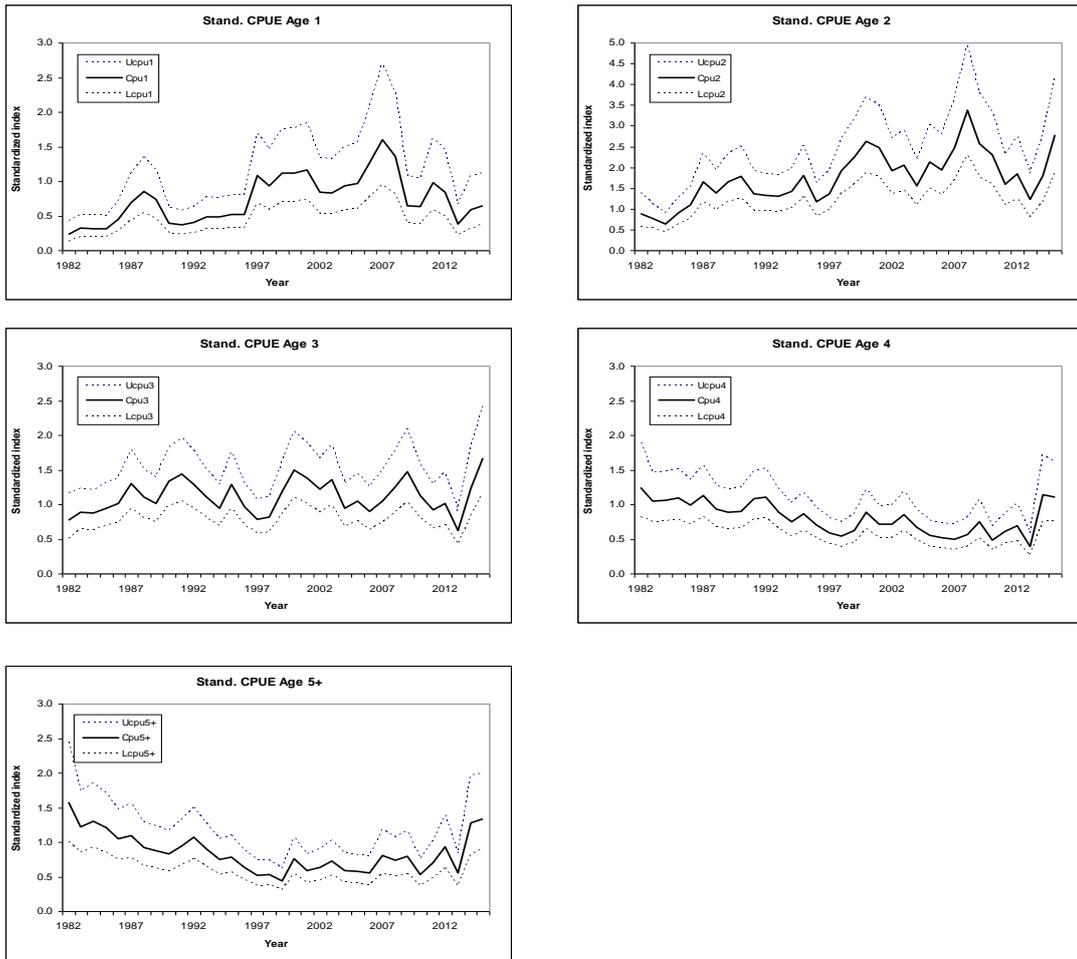


Figure 4. Annual change of the standardized catch rates in number of fish per thousand hooks for ages (1-5+) and 95% confidence intervals obtained in the North Atlantic, for the period 1982-2015.

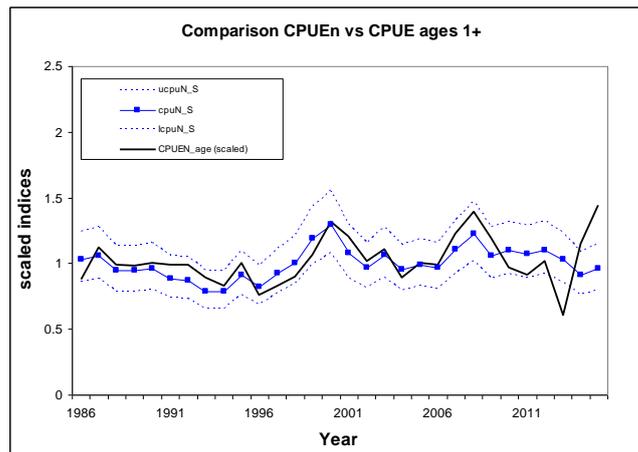


Figure 5. Comparison between the scaled mean values and 95% confidence intervals of the standardized CPUE in number of fish aggregated (see García-Cortés *et al.* in press SCRS/2017/105) and the scaled base case standardized CPUE in number of fish by age (additive ages) obtained in the present study.

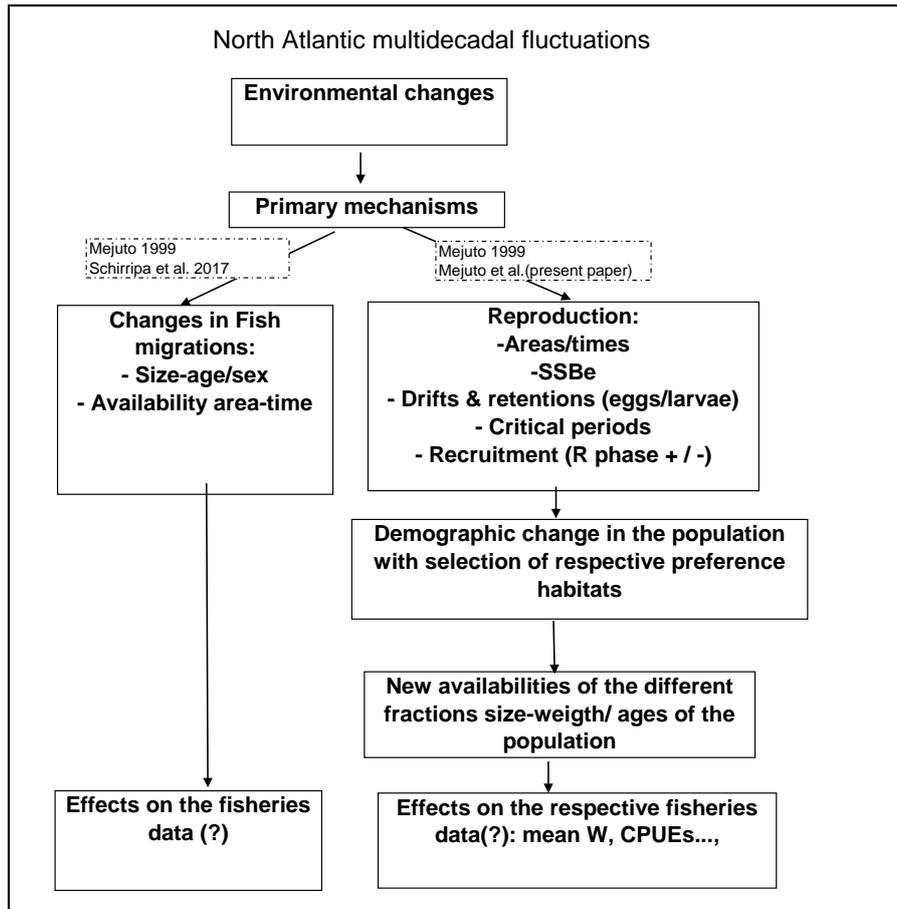


Figure 6. Some of the most important direct responses expected in the swordfish population as a consequence of multidecadal environmental fluctuations in the North Atlantic.

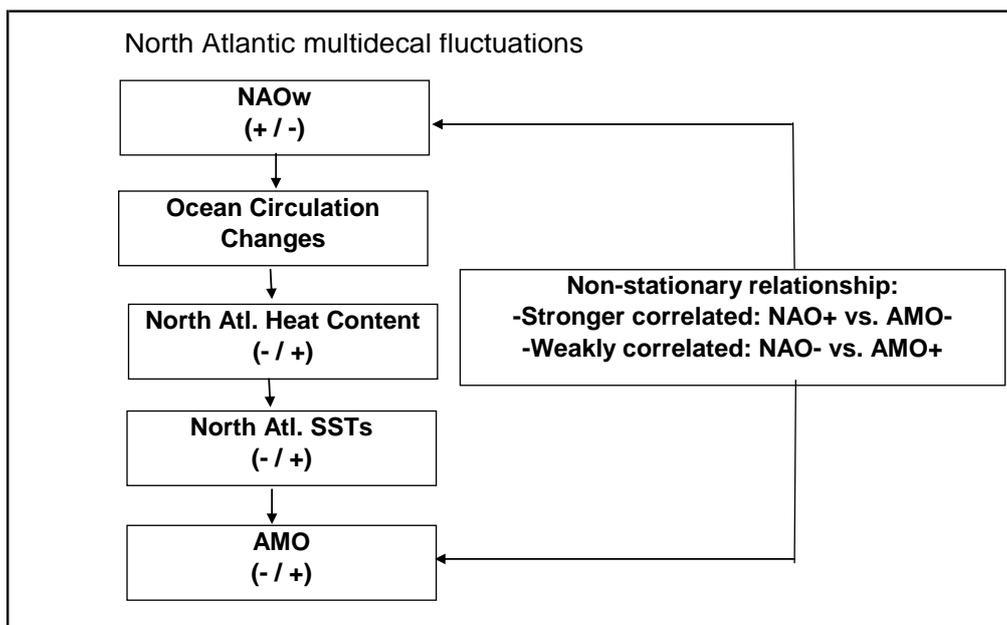


Figure 7. Simplification of the most important environmental responses expected in the North Atlantic ocean circulation, heat content, SSTs and the Atlantic Multidecadal Oscillation (AMO) phases as a consequence of the North Atlantic Oscillation (winter NAO) phase.

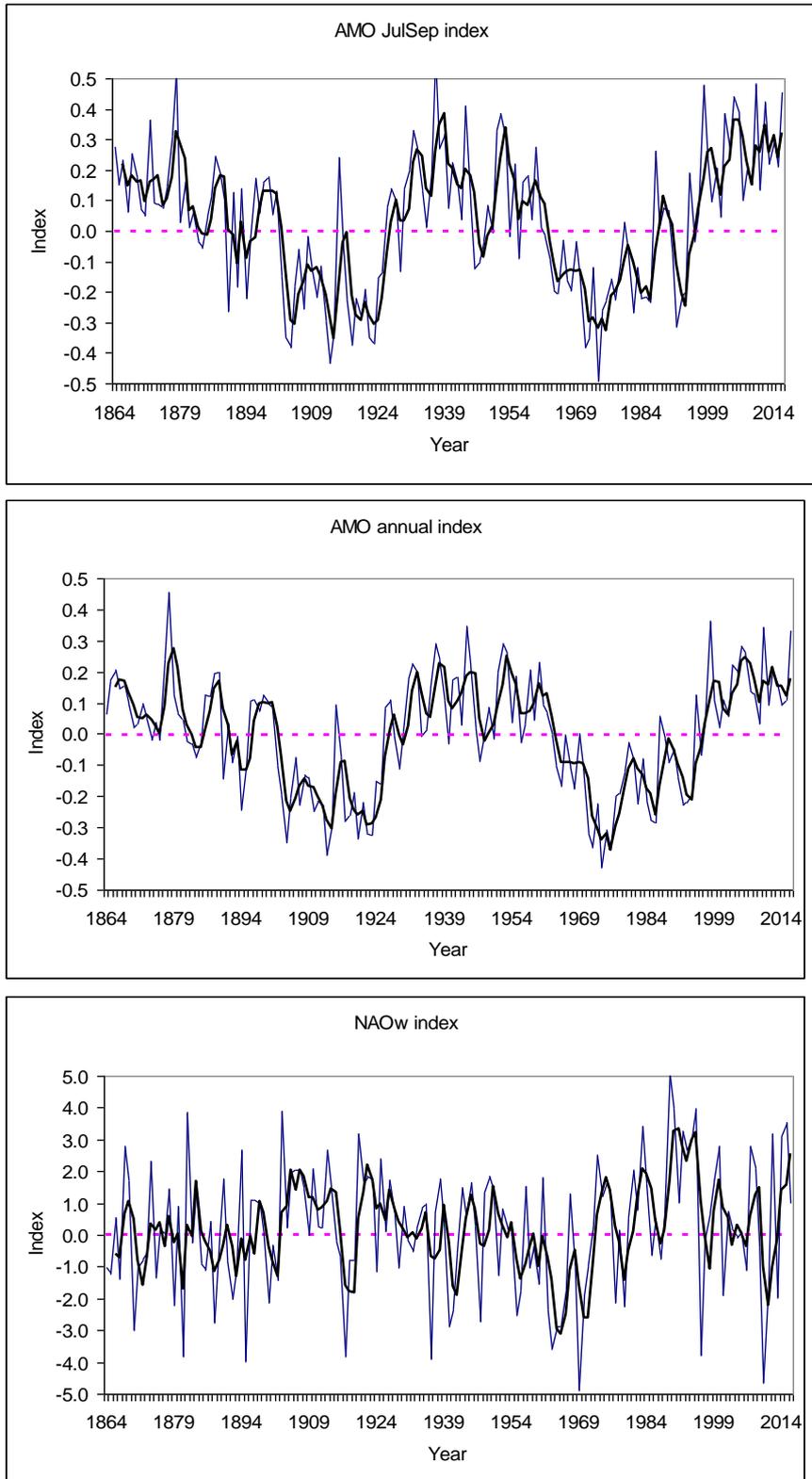


Figure 8. Atlantic Multidecadal Oscillation (AMO) and North Atlantic Oscillation (NAO) during the 1864-2016 period. Mean July-September AMO index (upper panel) and mean annual AMO index (medium panel). Winter NAO index (lower panel).

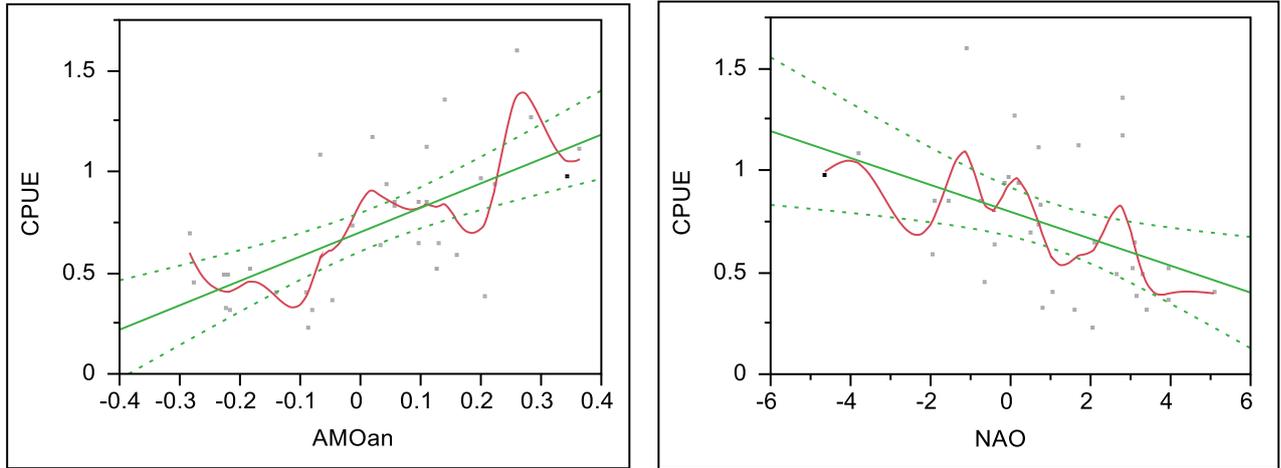


Figure 9. Bivariate fit of standardized CPUE age 1 (year= t+1) vs. annual AMO and winter NAO indices (year= t). Left panel: Smoothing spline fit ($\lambda=8.73E^{-06}$, R-Square= 0.6475) (red line) and linear fit and 95% confidence intervals (R-Square= 0.403617, Prob>F=<0.001*) (green lines). Right panel: Smoothing spline fit ($\lambda= 5.1E^{-02}$, R-Square= 0.4692) (red line) and linear fit and 95% confidence intervals (R-Square= 0.187, Prob>F=0.1007*) (green lines).

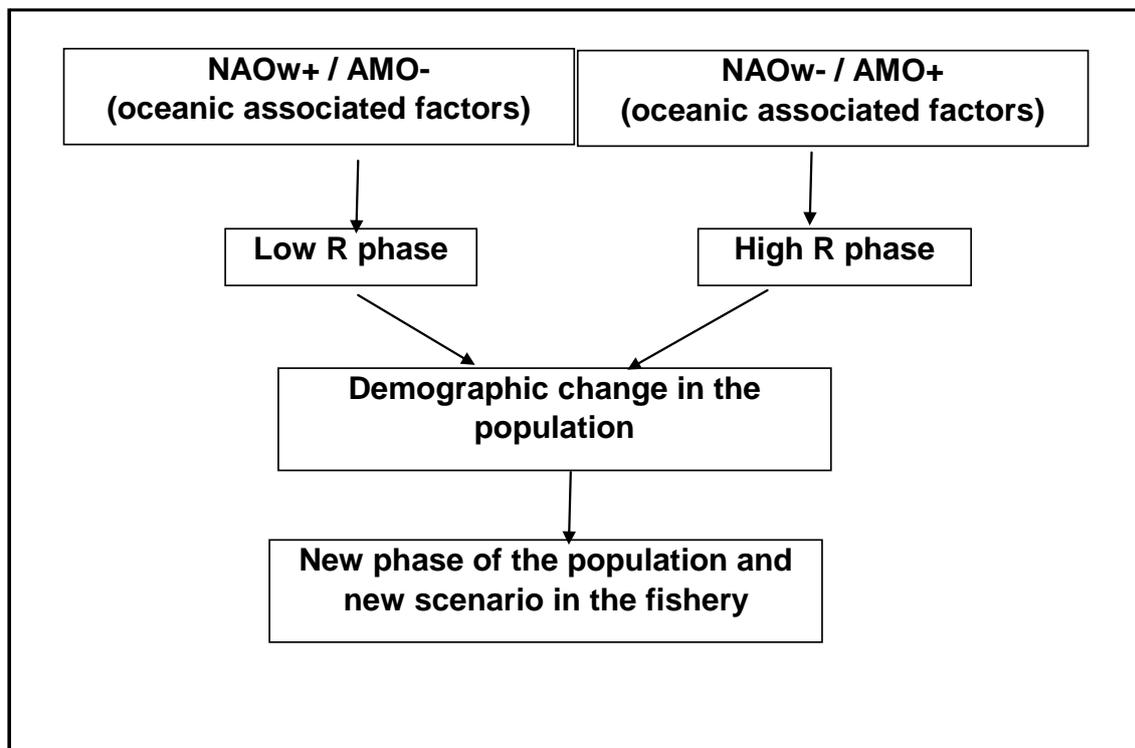


Figure 10. Multidecadal phases of the winter NAO and AMO, expected effects on the phases-levels of the recruitment and demographic changes in the population, during the respective phases-scenarios in the North Atlantic swordfish fisheries.