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Does the timing of the spawning migration change for the southern component of the Northeast Atlantic Mackerel (*Scomber scombrus*, L. 1758)? An approximation using fishery analyses

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ABSTRACT

Part of the Northeast Atlantic mackerel population migrates towards the southern spawning area (Cantábrian Sea) at the end of winter. In this seasonal handline fishery targeting mackerel, the most important in the study area that targets this species, the timing of the peak of catches has shifted forward (later) in recent years. This paper presents results pointing to the likelihood that this shift is due to a change in the timing of the spawning migration to the southern area of the Northeast Atlantic mackerel population. Three types of fleet have been identified within this fishery, and in all of them there is a forward shift in time in effort exerted. Moreover, a new model has been defined for the standardization of catch per unit effort (CPUE). The fishing season appears to have shifted forward by 29 days between 2000 and 2006. Nevertheless, changes have been detected neither in the exploitation pattern nor in the duration of the fishing season during the period studied. A shift on this scale has important consequences for the management of the resource, the fleets that exploit it and the resource assessment survey designs that will have to be adapted to this new scenario.

1. Introduction

The Northeast Atlantic mackerel (*Scomber scombrus*, L. 1758) spawns over the edge of the continental shelf from the south of the Iberian Peninsula up to Scotland. The main spawning areas are to the west and southwest of Ireland, the Celtic Sea slope and the Cantabrian Sea (Reid et al., 1997). Since 1995, for the purposes of assessment and management, ICES (1996) has considered the Northeast Atlantic mackerel to be a single stock with three spawning components (ICES, 2000): the western component, the members of which spawn in western European waters (respectively, ICES areas VI, VII and VIIIabde); the southern component, the members of which spawn in southern European waters (VIIIc and IXa) and the North Sea component, that spawns in the North Sea and the Skagerrak (IIIa and IV).

The mackerel is a migratory species whose routes of migration in the Northeast Atlantic are well known (Uriarte and Lucio, 2001; Uriarte et al., 2001). Once adult mackerel of the Southern and Western components have spawned (post-spawning migration), they make a northward trophic migration at the end of spring or the beginning of summer up the western side of the British Isles. Between June and August, they reach the Norwegian Sea and the North Sea where they mix with local spawners.

The mackerel migrate to the spawning ground of the Southern component in the first half of the year. At this season, the greatest mackerel concentrations are found in the Cantábrian Sea, and this is the main spawning ground of the Southern area (ICES, 2005). The annual start of the Spanish mackerel fishery in the Cantábrian Sea and northwest is determined by this migration (Punzón et al., 2004; Villamor, 2007). The resource is exploited by a large number of fisheries, but the handline fishery is the most important, and makes over 50% of landings (Punzón, et al., 2004). In the first half of the year, the main catches are made in the Cantabrian Sea using handlines. In the second half of the year the main catches are made up principally of juveniles, and are taken mainly to the southwest of Galicia using purse seine gear (Villamor et al., 1997; Punzón et al., 2004; Villamor, 2007).

Historically, mackerel have reached these areas at the end of February or March, and fishing then began. This pattern remained constant year after year and peak catches appeared in April until 1997. From that year on a change has been seen in the development of the fishery, and the largest landings are now made in March (Fig. 1). This forward shift in the timing of the best yields has three possible causes:

- Punzón et al. (2004) identified three vessel types depending on length, and the largest vessels taking part in the fishery

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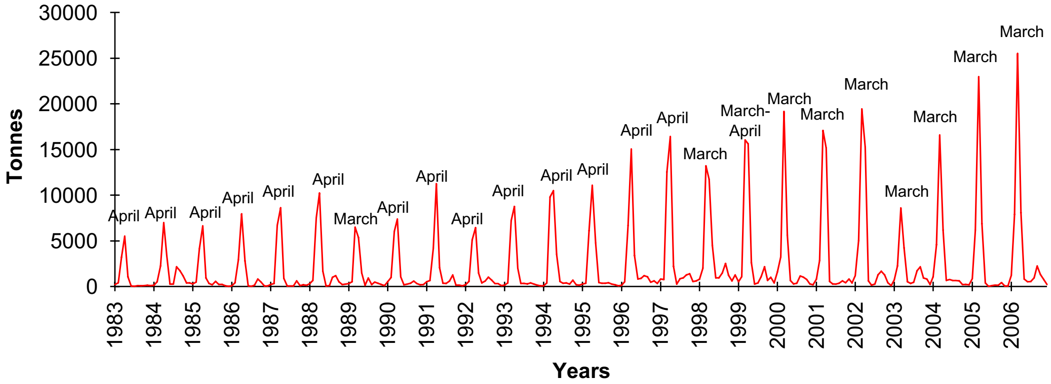

Fig. 1. Monthly mackerel total landings (tonnes) of the Spanish fishery in the North and Northwest of the Iberian Paninsula (VIIIc and IXa North ICES Divisions) in the period 1983–2006.

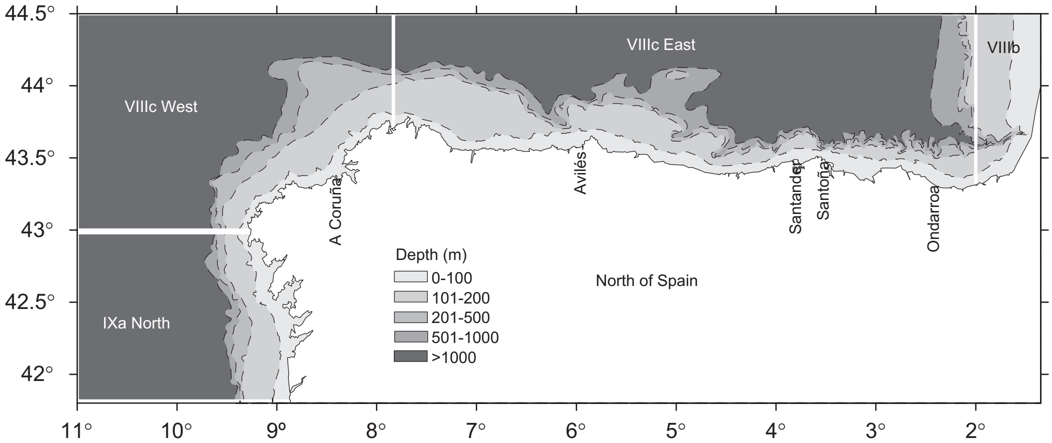

Fig. 2. Fishing area of the handline fishery targeting mackerel (VIIIc and VIIIb ICES Divisions).

obtained the best yields. On the other hand, the timing of the the fishing activity by each of the vessel types may be different. The forward shift in the peak of catches may be because the largest vessels, therefore those with the best yields, join the fishery earlier.

- Recruitment to the mackerel stock has become more variable (ICES, 2007, 2008) and this may have led to changes in the distribution of the stock. Northeast Atlantic mackerel year classes did not vary greatly until 2000, when the year class was the smallest in the historical series, 1972–2007. On contrast, the year classes of 2001 and 2002 were very strong, that of 2002 being the largest of the historical series.
- Walsh et al. (1995) and Reid et al. (2003) suggest that the timing and place of fishing is a good indicator of the timing of migration and they point to changes in the timing of mackerel migration by over 2 months in Scottish waters. Therefore, a change in the timing of mackerel migration may be the reason behind the forward shift.

Changes in these characteristics may have consequences for correct assessment and management of the resource, and may further point to changes in the environment. The aim of this study is to identify the possible existence of changes in the mackerel migratory pattern.

1.1. *Material and methods*

The study area is ICES Subdivision VIIIc East, where the handline fleet targeting mackerel operates (Fig. 2). This study analyzes the historical series (1995–2006) of catches by fishing trip for the handline fleet landing at the port of Santoña. This port is one of the most representative of the Cantábrian Sea coast, where the handline fleet targeting mackerel works, and information from the port is supplied annually to ICES assessment groups (Punzón et al., 2004; ICES, 2005). The data used to obtain the catch by fishing trip matrices were those reported on the sales sheets supplied by the Fishermen's association of the port of Santoña.

Following the methodology and classification described in Punzón et al. (2004), the fleet taking part in the fishery was classified into three groups using the non-hierarchical classification technique of partition around medoids. The fleet matrix is made up of 435 vessels. The technical characteristics of the fleet were obtained from the census of vessels of the Secretaría General de Pesca Marítima. The variables used for the classification of the fleet were length, gross tonnage (GT) and horse-power (HP). In addition, information was collected on the year the vessel was built for use in the standardization of catches by fishing trip as an indicator of the age of the vessel at the time the catch was made. Using the fleet classification, the number of fishing days (number of fishing trips) was obtained by fortnight and by year with the aim of analyzing the temporal behaviour by fleet type.

To eliminate all variability unrelated to species abundance, the catch by fishing trip was standardized for the period between 1995 and 2006 using generalized linear models (GLM) (O'brien and Kell, 1997; Maunder and Punt, 2004). To determine which variables to include in the final model the significance level was checked for each variable liable to be used in the model and those best in terms of the proportion of explained variability were selected (stepwise procedure) (Chambers and Hastie, 1993). To obtain the significance, the *p*-values of the *F* statistics were calculated, and those variables with a significance level of $>5\%$ (i.e. a *p*-value greater than 0.05), were rejected. The proportion of explained variability by the final model was obtained using the quotient of variation in the prediction as a proportion of the total variation.

Of the original matrix 3% of the cases were omitted, those for which no characteristics of the fleet were available or which contained atypical landings. The final matrix had 24065 cases. To detect atypical elements in addition to the classical exploratory analyses (boxplots, etc.), once the model had been applied, the Cook distance (D_i) was used, which is a measurement of the distance between the coefficient of regression and the particular observation *i* absent or present (Fox, 2002)

$$D_i = \frac{e_i^2}{s^2(k+1)} \times \frac{h_i}{1-h_i}$$

where ${e_i}^2$ is the square of the residual for observation *i*, s^2 is the variance of the residuals, and h_i the hat value of observation *i*.

To assess the forward shift in the fishing season with the catch standardized by fishing trip, the day of the year on which 50% of the total catch of the entire fishing season had been reached (T_50%) was calculated. Similarly, to observe the evolution of the fishing season, the time points at which 20% (T_20%) and 80% (T_80%) of the total catch had been reached were calculated, and these time points were considered to be the start and the end of the fishing season.

Lastly, the age structure of the catches of the Santoña handline fleet between 1995 and 2006 was determined, half-year length-age keys were applied to the length distributions of catches by month to reveal the monthly exploitation pattern by this fleet and to analyze any possible changes in the behaviour of the fleet.

Age was determined by counting otolith (sagittae) growth rings. For preparation and analysis of the otoliths, the procedures and criteria described in ICES (1995) were followed. Otoliths were obtained by sampling mackerel specimens obtained from commercial catches taken during the first half of the year and from the annual acoustic surveys made in the study area in March–April. In this way, a full representation of the entire length range was obtained. The monthly length distributions were obtained by sampling lengths from catches of the Santoña handline fleet at monthly intervals throughout the first half of the year, when the fishery takes place.

2. Results

2.1. Effort

The technical characteristics of the three types of fleet identified are as follows: cluster 1 one is made up of 196 vessels with the lowest technical characteristics, averaging 10 m in vessel length, 85 hp and 10 GRT; the second cluster, with 146 vessels, has mean characteristics of 15 m vessel length, 185 hp and 36 GRT; Lastly, the third cluster is composed of 94 vessels, and these have the greatest technical characteristics (means of 21 m in vessel length, 362 hp and 98 GRT). The differences in all characteristics among the three vessel types are significant.

If we analyze the yields obtained by each of the vessel types, important differences are observed (Fig. 3). There is an increase in catch rates as vessel size increases except in 1995, 1999 and 2003, when the catch rates of the largest vessels, i.e. those belonging to cluster 3, were lower than those of medium size (cluster 2). For the three vessel types the maximum yields are found in the last two years. Thus, the catch per unit effort (CPUE) of the smallest vessels varied between 1.1 t by fishing trip in 1996 and 3.4 t by fishing trip in 2006; for medium-sized vessels between 1.5 (2003) and 6 (2006); and the largest vessels had yields of between 1.2 (2003) and 6.4 (2005).

When we simultaneously take into account the annual and seasonal evolution of effort (Fig. 4), a forward shift is seen in the start and the end of fishing activity for all three vessel types. In the series, we find two atypical years that affected the three types of fleet equally. In 2000, there was a sharp fall in effort from the seventh fortnight, whereas in the previous and following years this fall is observed from the eighth fortnight. In the case of 2003, there was an absence of effort at the start of the fishing season in all three series.

Regarding participation, the fleets of small and medium-sized vessels show their highest values of effort (number of fishing days) between 1997 and 1999 between the sixth and the ninth fortnights (end of March and throughout April). In the case of the

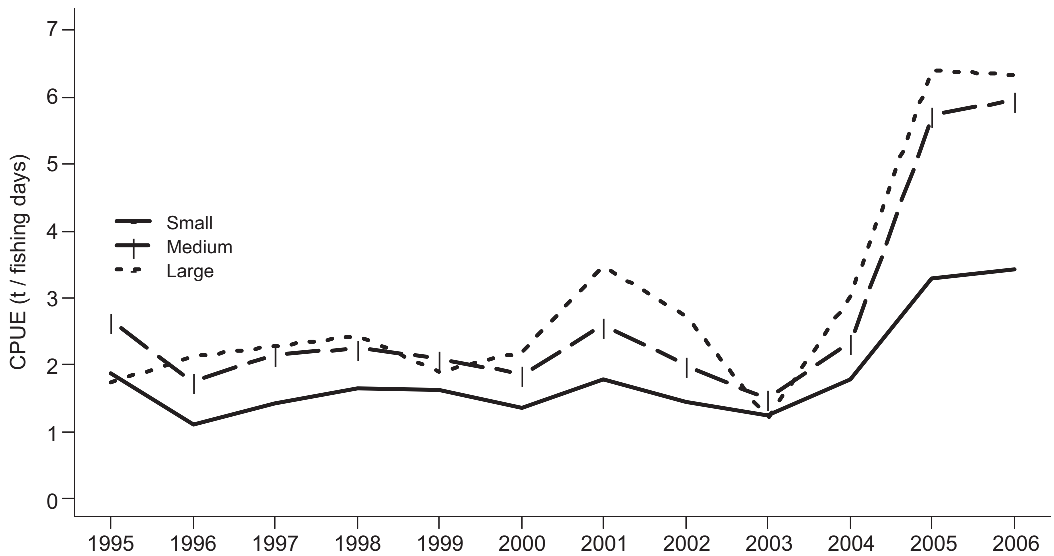

Fig. 3. Evolution of the catch per unit effort (CPUE, tonnes by trip) by vessel type in the period 1995–2006.

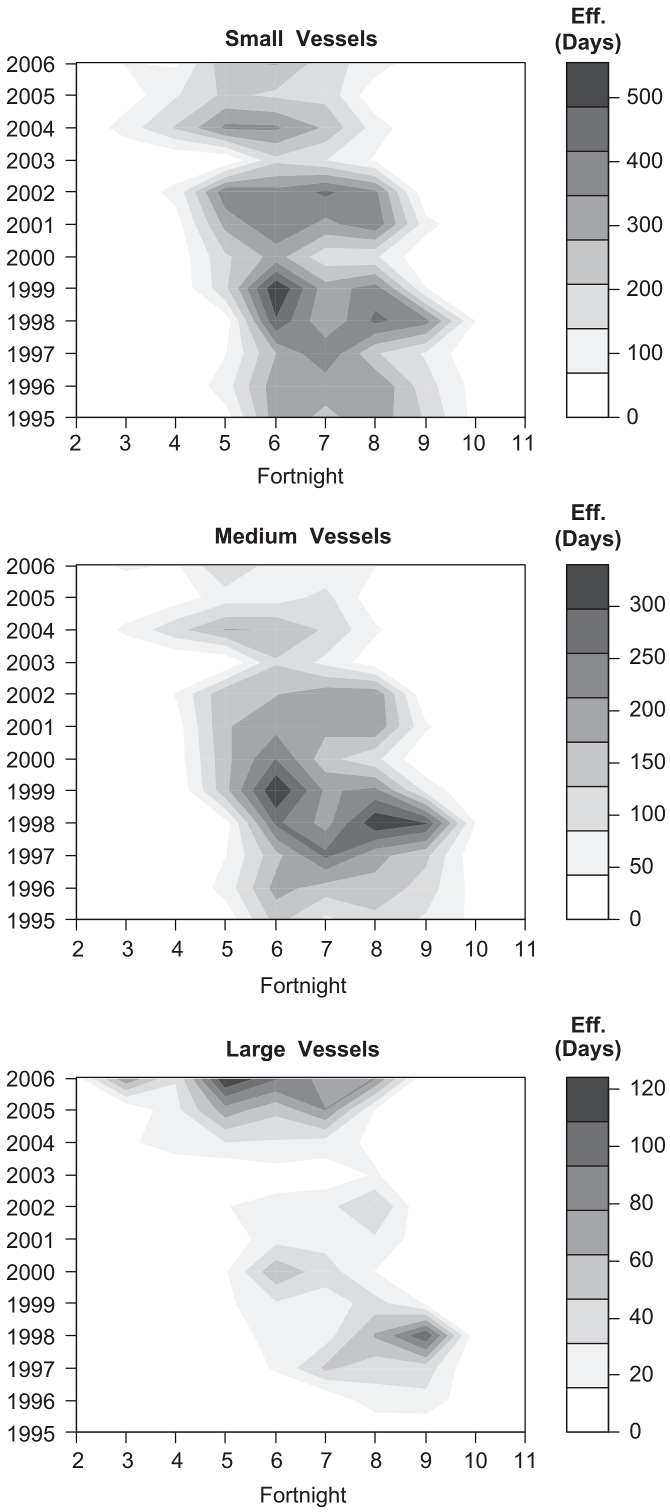

Fig. 4. Evolution of the effort (fishing days) by fortnight and year for each vessel type in the period 1995–2006.

fleet with the largest vessels the maxima were reached in 2005 and 2006 between the fifth and eighth fortnights.

For small vessels in 1995, the fishery took place from the fifth or sixth fortnight (March) to the ninth or tenth fortnight (end of April and beginning of May), at the end of the time series the activity began in the third fortnight (beginning of February) and finished between fortnights 8 and 9 (April). The development of the fishing activity of medium-sized vessels was very similar to that of the fisheries. In the case of this fleet in 2005, a delay in the start of activity is seen with respect to the previous and following years (the start coming between the fourth and fifth fortnights).

In the case of the largest vessels, on one hand an increase is observed in the duration of participation in the fishery from 2004, and on the other, as with the other two fleets, there is a forward shift in the timing of the activity. Between 1995 and 1997, the fishery began between the sixth and eighth fortnights and ended between fortnights 9 and 10 (May). From 2004 this fleet began to work between the second and third fortnights (February) and broke off its activity in fortnights 8 and 9.

2.2. Standardization of landings by trip

Different probability distributions for catch by fishing trip (CPUE) were tested, among them the normal distribution, using the different transformations (logarithmic, box cox, etc.). In all cases, the differences between the distribution of values observed (transformed or not) and the theoretical distribution were significant. For this reason, we decided to assume a gamma distribution of CPUEs as it was visibly the closest to the distribution of untransformed observations (Marchal et al., 2006).

The variables used for the initial model were: year, fortnight, vessel type and vessel age. For this latter variable 5-year ranges were made, leaving the fleet of vessels older than 40 years in the last category.

Fig. 5 shows the median values of CPUE for the levels of each of the factors we considered: year, fortnight, vessel type and vessel age at the time the catch was made. Year and fortnight are the two factors that present the highest variability. In the case of year, this is fundamentally due to the high yields obtained in the last two years of the series. In the case of fortnight, the best yields were obtained in the central part of the fishing season (fortnights 4–8) and the lowest came at the end of the series, as might be expected. The yields by fleet type also follow the above pattern. In the case of vessel age, although variability is very low, a fall is seen in the yields of vessels belonging to categories 7, 8 and 9, i.e. the fleet aged over 30 years.

The different combinations of variables were tested to observe the combined effect on the response variable. Noteworthy differences are only seen when considering the combined effect of year and fortnight on CPUE (Fig. 6), between fortnights 3 and 6 (February–March). Yields improve as we approach the end of the series. In fortnight 7 (first half of April) yields are constant throughout the whole series. Lastly, between fortnights 8 and 10 (second half of April and May) yields worsen as we advance through the time series. The final picture is that there is a forward shift in yields (without standardize) as we progress through the time series.

Although the length of the vessel that made the catch is involved in the vessel type variable, it was itself also tested in the final model, with the aim of selecting which variable, vessel length or vessel type, would best explain the variation in the catch by fishing trip. Given the distribution of the response variable the model proposed was a glm model with a gamma distribution. For this distribution of CPUE, the most suitable link function is the "log" (McCullagh and Nelder, 1989). The final formula of the model was

$$\begin{aligned} &\mathrm{CPUE} \sim \mathrm{Year} + \mathrm{Fortnight} + \mathrm{Length} + \mathrm{Age(Vessel)} \\ &+ \mathrm{Year} : \mathrm{Fortnight}, \mathrm{family} = \mathrm{Gamma(link} = \text{``log''}) \end{aligned}$$

As we see in the final model, vessel length (continuous variable) was incorporated instead of vessel type, since it was better at explaining the distribution of residuals and it also simplified the model. The remaining variables were incorporated as factors.

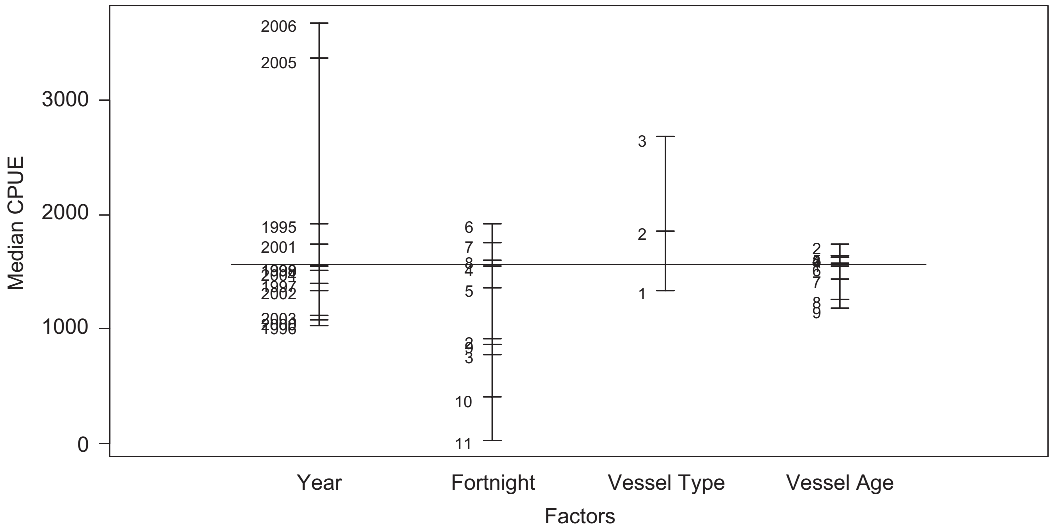

Fig. 5. Median CPUE (kg by fishing trip) for the different levels of each factor (variables) considered in the initial model (year, fortnight, vessel type and vessel age). The horizontal line is the median overall of CPUE.

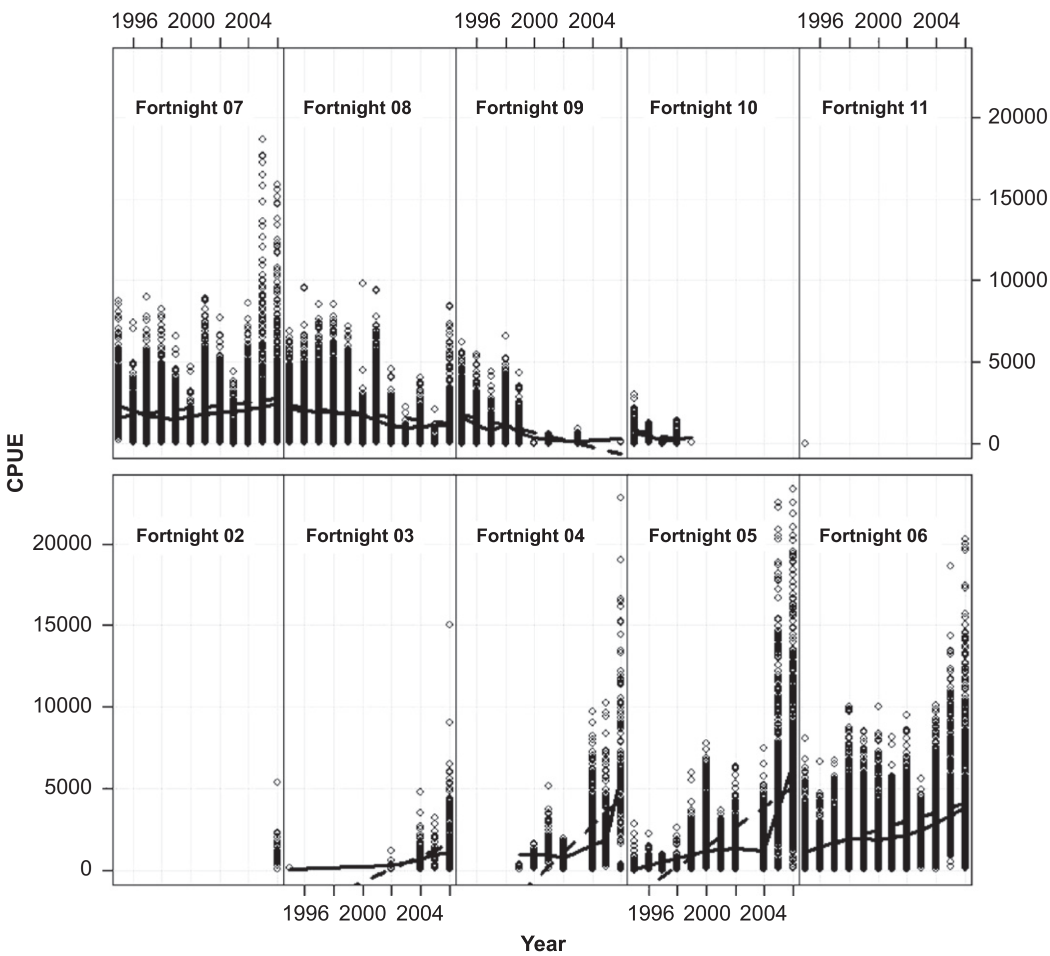

Fig. 6. Effect on CPUE (kg by fishing trip) of the interaction between year and fortnight (from left to right and from bottom to top, from fortnight 2–11 of the year (from second fortnight of January to first fortnight of June)).

Table 1 shows the analysis of the variance for the final model. All the factors selected were significant. The final model explains 48% of the total variation.

Fig. 7 shows that the variance remains more or less constant with the mean. In the case of the Pearson residuals, they fit the normal probability line, although the ends are slightly separated

Table 1
ANOVA for the glm model with gamma distribution.

	Df	Deviance	Residual Df	Residual deviance	*F*	Pr(>*F*)	Significance
NULL			24062	23771.46			
Year	11	3312.26	24051	20459.21	619.18	0	***
Fortnight	9	1310.06	24042	19149.14	299.32	0	***
Length	1	1228.73	24041	17920.41	2526.64	0	***
Age (vessel)	8	53.93	24033	17866.48	13.86	2.79E-20	***
Year:fortnight	54	3902.09	23979	13964.39	148.59	0	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

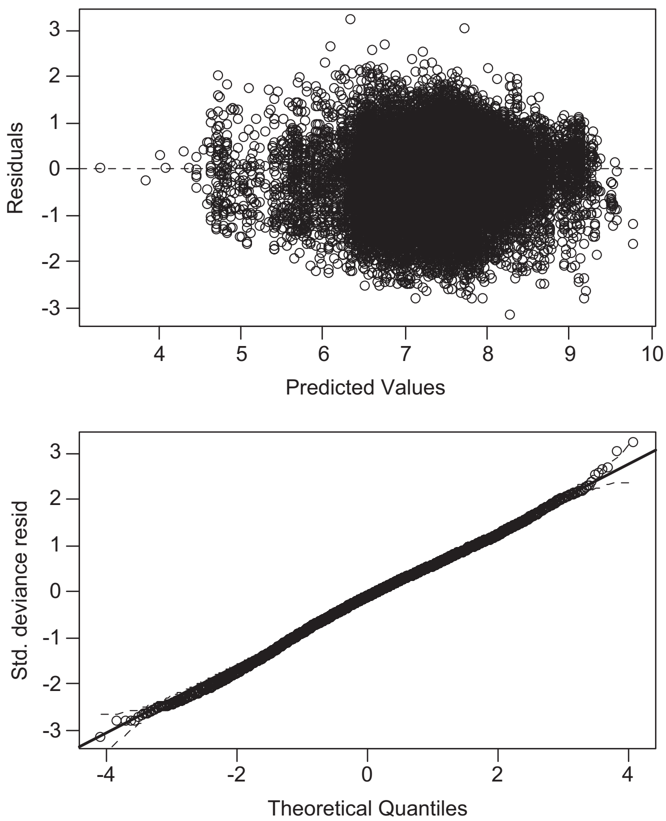

Fig. 7. Residual deviance against fitted values (top) and normal probability of Pearson residuals (bottom) of the final GLM model.

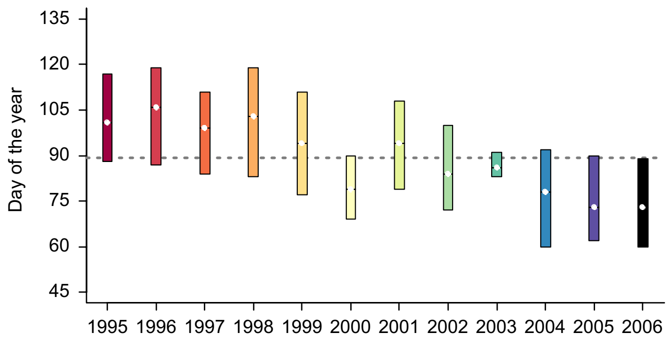

Fig. 8. Evolution of the day of the year on which 20%, 50% (white point) and 80% of the total catch of mackerel was reached (the line indicates the mean day of all the years on which 50% of the total catch was reached) in the period 1995–2006.

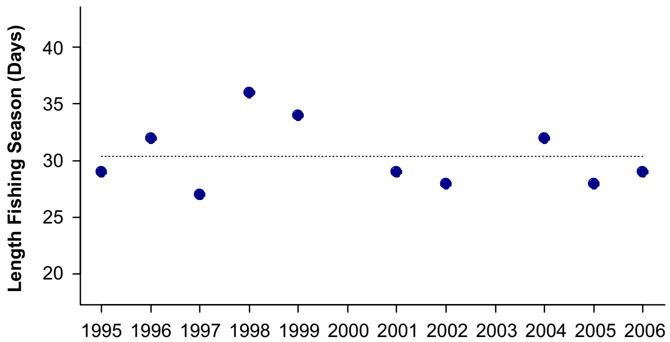

Fig. 9. Duration of the fishing season (days) by year with respect to the mean duration (horizontal line) of the time series 1995–2006 (the years 2000 and 2003 have been omitted).

from the line, which indicates that the tails of the residuals are thicker than the theoretical distribution.

2.3. Behaviour of yields

The mean day on which 50% of the total catch (accumulated catch by standardized fishing trip) was reached was day 90, i.e. the first week of April (Fig. 8). Prior to 1999 (T_50% day 94), the mean day on which T_50% was reached was day 102, 1996 being the year in which this percentage of the catch was reached the latest (day 106). After 1999 (except 2001), 50% of the landed weight was reached before day 92 (day 84 in 2002 and day 73 in 2005 and 2006), which represents a forward shift of 29 days in reaching 50% of the total catch in 2006 with respect to the period 1995–1998.

Regarding the development of the fishery (Fig. 8), a very similar pattern is observed in all the years with the exception of 2000 and 2003. In 2000 the beginning of fishing activity was absolutely normal, but ended much earlier than the previous or the following years, and at the same point as in the last years of the series, on day 90. In 2003 the start was abnormal, day 83 marking the start of the fishery and day 86 being the point at which 50% of the standardized accumulated total catch was reached.

If we do not take the years 2000 and 2003 into account, in the first four years the fishery appears to develop quite similarly, beginning between days 83 (1998) and 88 (1996) and ending between days 111 (1997) and 119 (1996 and 1998). From 1999 inclusive, there is a forward shift both in the start and the end of the fishing season, the start coming between days 60 (2004 and 2006) and 79 (2001) and the end between days 89 (2006) and 111 (1999).

Regarding the duration of the mackerel fishing season (T80%–T20%) in Santoña (Fig. 9), without considering the atypical years (2000 and 2003), there is no detectable trend in the series.

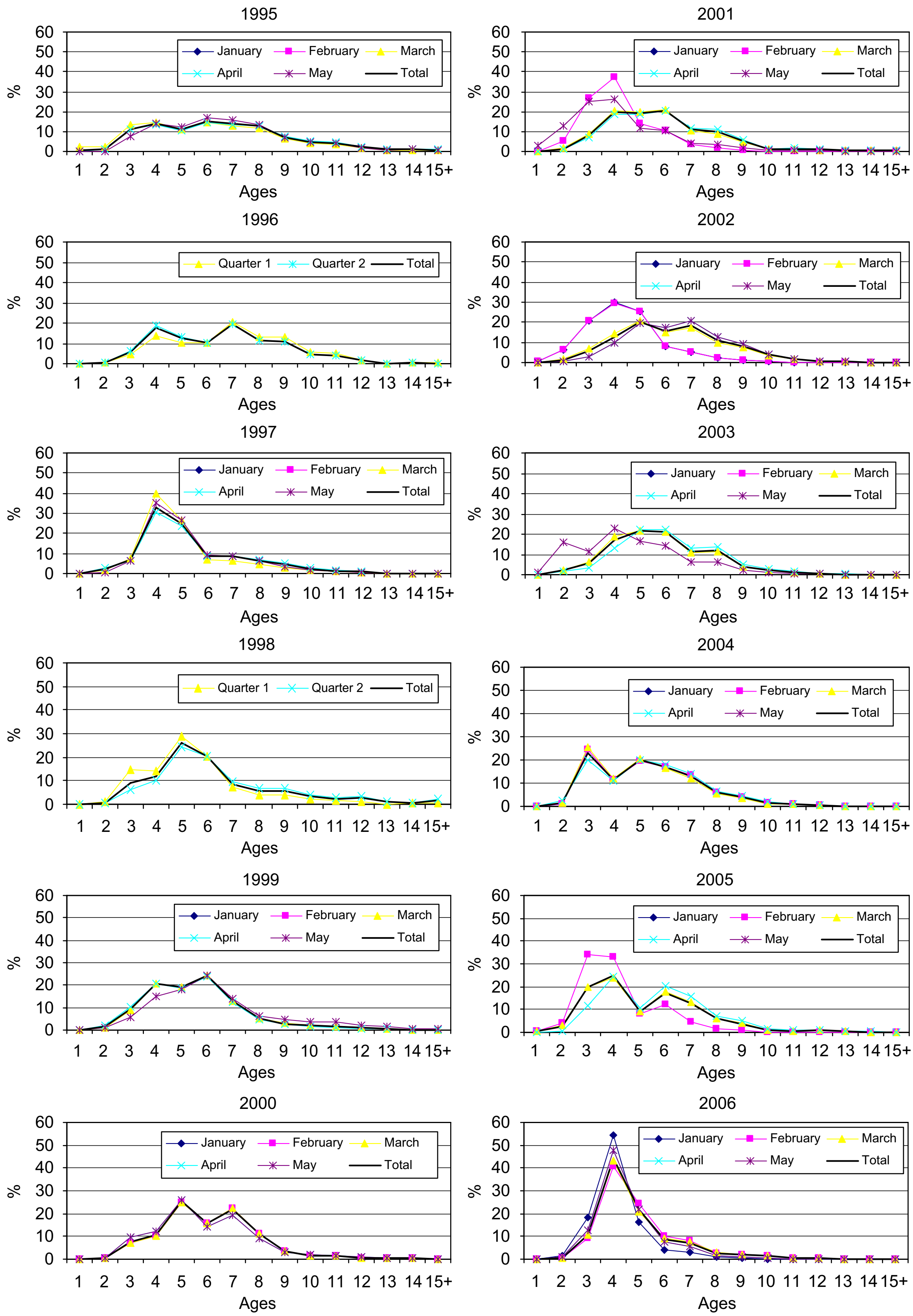

Fig. 10. Catch at age composition (percentage) of mackerel of the Santoña handline fishery by year, month and total in the period 1995–2006.

Leaving aside 2000, when the fishing season lasted 22 days, and 2003, when it lasted just 8 days, the mean duration was 31 days, 1998 being the year in which the fishing season was the longest (36 days) and 2002 the shortest (26 days).

2.4. Landings by age

The mackerel age structure (Fig. 10) of the Santoña handline fleet in the period studied, 1995–2006, is mainly composed of adult fishes (over 2 years), with a similar age range in all years. Ages between 3 and 7 years dominate the catch of this fishery. The catch of age 1 mackerels is null throughout the period. The exploitation pattern did not vary for the overall catch of the study period, and the strong (born in 2001 and 2002) and weak (born in 2000) *year classes* were well identified. If we analyze by month, an exploitatiuon pattern similar to the overall pattern in all months is also seen, except in 2001, 2002, 2003 and 2005. In 2001, 2002 and 2005 the percentage of the catch of the youngest mackerels caught by this fishery (ages 3 and 4 years) was greatest in the first months of the year (January and February). In 2001 and 2003, a higher percentage of mackerels aged between 2 and 4 years is observed in May.

3. Discussion

The yields obtained by each of the three fleet types followed the pattern described in Punzón et al. (2004). They increase as a function of vessel size. To the exceptions indicated in this study must be added those of 2003, in which the yields of the largest fleet are lower than those of the medium-sized vessels. In that case, as in the previous cases (1995 and 1999) Punzón et al. (2004), it is due to the smaller participation of this fleet in the fishery because the fishing activity was subject to important closures as a result of the *Prestige* oil spill. Moreover, these closures mainly affected the first part of the fishing season.

Temporal distribution of fishing activity was similar for the three types of fleet is similiar. A forward shift in the timing of the activity is seen from the beginning of the series. This is more evident in the largest vessels (those belonging to cluster 3), since their participation at the beginning of the series was the least. The forward shift observed in the timing of the peak of catches (Fig. 1) is not, therefore, due to a change in the behaviour of the largest fleet, since in the three types the pattern was very similar.

To obtain standardized catch by fishing trip, and thus eliminate as much variability as possible unrelated to the abundance of the species, a glm model was defined. Unlike the model defined by Punzón et al. (2004), here we have assumed a gamma distribution. Regarding the variables used in the final model, we used vessel length instead of vessel type as the results obtained were more significant. The effort exerted by each vessel was strongly related to vessel length, since the number of handlines depends on vessel size (Punzón et al., 2004). Moreover, vessel age was incorporated in the final model. This variable is associated in many cases with efficiency and vessels' equipment. In this case, the differences in yields may be due to the fact that the most modern vessels, unlike the older ones, are equipped with a hydraulic reel and so the number of times that each line can be raised and lowered is greater, and fishing operations can be performed in a more constant way throughout the day.

As stated earlier, the start of the fishery is marked by the spawning migration that mackerel make to these areas, and as described by Punzón et al. (2004) for the study period (1995–2000), the fishery develops stably mainly between the second fortnight in March and the end of April. In our case, which considers a longer time series (1995–2006), a forward time-shift of the whole fishery is seen (both in effort and in yields) for both the start of the fishery and for the end. If we take into account the point at which 50% of the total catch has been taken, the forward shift of 2006 with respect to 1998 is of almost a month, 29 days. Regarding the duration of the fishing season no trend is observed.

In the current decade, there have been considerable changes in effort and in the development of the fishery. In the case of the year 2000 there was a fall in effort. In April, when the fishing season was greatly shortened to 22 days, almost 20% shorter than any other year in the series. The timing of the start of the fishery was completely normal, but it finished early. This may have been due more to the adverse meteorological conditions of that year in the fishing season (Lavín and González-Pola, 2002) than any fall in the abundance of the resource or legal limitation to accessing the resource or fishing ground. In the case of the year 2003, the reason was the Prestige oil spill and the spatial and temporal closures imposed on pelagic fisheries in the area in which the handline fishery targeting mackerel operates (Punzón et al., 2005). In this case the start of the fishery was abnormal, the point at which the activity was deemed to have begun (T20%) and the point at which 50% of the standardized accumulated catch was reached were almost simultaneous.

The exploitation pattern of this fleet remained constant throughout the period studied, the catch of age 1 mackerels was null and that of age 2 very small. The increase in yields, therefore, and the forward shift in the timing of the fishery from 1999 were not due to an increase in catches of juveniles (ages 1 and 2), as the strong year classes of 2001 and 2002 might suggest (ICES, 2007), and that mackerel juveniles remain in the southern area until they reach maturity, as the tagging surveys carried out in the area suggest (Uriarte et al., 2001; Villamor, 2007). At the same time, the strong year classes of 2001 and 2002 were detected in these catches when they had reached 3 years of age and over and had already joined the adult migration, which means that they were mackerels that came to the area following the mackerel spawning migration pattern. Nevertheless, the greatest fluctuations are observed in the monthly age composition from 2001, possibly more related to the increase in the variability in stock recruitment in recent years (ICES, 2007) rather than any change in the exploitation pattern of the fleet.

Therefore, there are no differences in behaviour between fleet types, and catches according to age seem to follow a stable pattern. No direct evidence is available of mackerel migration at the time of exploitation. Given that the evolution of catches by statistical rectangle reflects mackerel movement in its migration (Villamor et al., 1997; Villamor, 2007); however, and the example of the Scottish fisheries in which the time and place of fishing is a good indicator of the timing of migration (Walsh et al., 1995; Reid et al., 2003), the forward shift that we have detected from 1999 to 2000 in the activity of the fleet and in the timing of the best yields of the fishing season may be manifesting a change in mackerel migration. Moreover, this idea is supported by the fact that in acoustic surveys for the purposes of the evaluation of pelagic resources carried out in the study area, a fall in the biomass in April has been recorded (ICES, 2007). This fall may be due more to a change in mackerel migration than a fall in the resource itself.

It is well known that mackerel distribution and migration may be affected by environmental variables or by movements in water masses such as the slope current (D'Amours and Castonguay, 1992; Studholme et al., 1999; Reid et al., 1997, 2001; Walsh and Martin, 1986; Walsh et al., 1995). In the seventies, the return migration (spawning) to the spawning areas came in autumn (Walsh and Martin, 1986). Nevertheless, in the eighties and nineties mackerel spent the winter more extensively in the Norwegian Sea and North Sea (Iversen and Skagen, 1989; Holst and Iversen, 1992; Belikov et al., 1998), above all over the Viking and Tamp banks (Reid, 2001) where they remained for longer before returning to spawning areas between December and February. More recently, there have been indications that the spawning migration is taking place, once more, at an earlier date (Reid et al., 2003).

There are diverse hypotheses to explain this modification in the migration pattern, all related to environmental conditions: Walsh and Martin (1986) attribute it to unusual hydrographic conditions; Walsh et al. (1995), associate temperate high salinity waters with favourable, or at least minimal conditions for this species, and point to the possibility that the start of migration is triggered by the appearance of cold waters or falls in salinity below the preference threshold; Reid et al. (1997) similarly point to the importance of a drop in temperature as a trigger factor for migration, and that the appearance of warmer waters slows down the migration of shoals or causes them to remain static.

Recently, Reid et al. (2003) detected a sudden change in the migratory pattern of the same kind which was almost simultaneous (from the spawning migration of 1999) with that occurring in the Cantábrian Sea. Since 1999, the timing of mackerel migration in ICES Division VIa (waters of Scotland) has shifted forward with respect to the pattern of the preceding years. Unlike what happened in the delayed migration, this change could not be correlated with any environmental variable. In our case, we have been unable to establish direct relationships between the change in the timing of the fishing season and environmental variables. But recently, an increase has been detected in the temperature and salinity of Northeast Atlantic waters (Hátún et al., 2007) which, according to ICES (2008), may have triggered a forward shift in the start of the mackerel spawning migration. Moreover, this forward shift has led to a forward shift in the spring bloom, and therefore the availability of prey to mackerel, which has led, in turn to a forward shift in the trophic migration from the southern spawning areas towards the north. Also in the Cantabran Sea, changes similar to those described by Hátún et al. (2007) have been detected, with global warming affecting the Cantabrian Sea, as described by García-Soto et al. (2002); González-Pola et al. (2005) and Llope et al. (2006).

Given that a change of a similar nature has taken place in both areas almost simultaneously, and moreover involving the same population, the reason behind this change and the conditions governing mackerel migration should be investigated further. If this change occurs as we have described, it might also be expected that in the past we could find a similar delay to that described by Walsh and Martin (1986), Walsh et al. (1995) and Reid et al. (1997) in our fisheries. At the same time hydrographic anomalies should be identified, such as those that occurred along the transect off Santander in the winters of 2005 and 2006 (Lavín et al., 2005, 2006, 2007), and their effects on migration studied. Indeed, these are the 2 years that provided the best yields of the entire series analyzed.

4. Conclusions

We can conclude that a forward shift has occurred in the timing of the migration of mackerel to the spawning area located in the Cantabrian Sea. Fishing activity, as described by Walsh et al. (1995) and Reid et al. (2003), has adapted to this change in the migratory pattern by bringing its activity forward in time. Given that this forward shift occurs almost simultaneously with changes detected in the northern area of distribution of this species, other techniques (changes in spawning peaks, estimation of abundance indices by direct methods, analysis of environmental conditions at the time of the catch, etc.) should be used to evaluate the trend and intensity of these changes in the migratory pattern in both areas.

The detection of changes in the patterns of migration is of fundamental importance. In addition to being an indicator of global change affecting oceanographic conditions in the area, they have clear effects on the management of resources, such as the implantation of possible spatial-temporal closures or the concession of annual quotas (Reid et al., 2003). Also, in the study area oceanographic acoustic surveys are conducted, whose aims include the assessment of mackerel biomass. This survey has been conducted between March and April, although in recent years it has carried out slightly later, practically all of it in April. A forward shift in the timing of mackerel migration would mean that changes in the estimated abundance of this species would not be due to changes in its biomass, but rather to changes in its migratory behaviour. This factor must be taken into account in future survey designs, in the use of indices deriving from them in the assessment, and in the assessment itself.

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