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Conseil International pour l'Exploration de la Mer
H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Climate variability and recruitment success of European hake (*Merluccius merluccius* L.) in NW Africa

César Meiners, Lourdes Fernández, Pedro Torres and Ana Ramos

Instituto Español de Oceanografía. Centro Oceanográfico de Malaga, Puerto pesquero s/n, 29640 Fuengirola (Málaga), Spain. cesar.meiners@ma.ieo.es

ABSTRACT

Recently it was stated a strong dependence of European hake abundance with climate variability in NW Africa. This relationship was explained by the North Atlantic Oscillation (NAO) driving the upwelling temporality and its geographic coverage, which could be responsible of changes in survival rate during early life stages of this species. Following this hypothesis, this work focuses on the relative importance of climate variability on recruitment dynamics of European hake. Interannual variability of recruitment success were analyzed through two types of time series: (i) from monthly and annual length distribution fishery data (1982-1999) of Spanish trawling fleet that worked under Spanish or European-Moroccan fishery agreements and (ii) recruits annual abundance from scientific Moroccan surveys (1982-2004). The time series were compared with the annual smoothed NAO index to evaluate the type of relationship, persistence and their relative contribution as a variation source of recruitment success. The recruitment to the fishery took place during all year with peaks in spring and summer, but the seasonal component was weak. The time series were in synchrony with NAO index of the previous year and showed strong positive correlation. The variation of recruitment success explained by NAO was 25 to 82 % depending on time series size. The main NAO effect in recruitment dynamics was the widening-contraction of Recruitment Window. During NAO+ phase several success cohorts were recruited by year, while in NAO- the success cohorts were scarce and weak. The climate signal in recruitment dynamics of European hake was robust, recurrent and persistent independently of fishing effort.

Keywords: recruitment, European hake, NAO, NW Africa.

Introduction

In recent times several authors had been focused in the probable relationship between climate variability and ecological changes of marine populations at different time scales. However the climate impacts over ecological processes such as recruitment, distribution, inter- and intra-specific relationships, etc. are difficult to elucidate because climate do not affect through a single factor, whether a set of several factors of local conditions (Stenseth *et al.*, 2003).

Recruitment is a complex and noisy biophysical process determined by the interaction of biological and environmental factors influencing reproductive output and survival of eggs, larvae and juveniles (Cushing, 1996; Bailey *et al.,* 2003). The recruitment variability is the principal cause of abundance fluctuations in fish stocks and, hence, catches (Cushing, 1996). However the sources of recruitment variability and the relative importance of involved factors remains uncertain (Wooster and Bailey, 1989: Myers *et al.*, 1997).

In general terms, the fishery production is linked to underlying stock-recruitment relationship, but survival processes during recruitment are highly influenced by physical and biological environment experienced during the early life stages (Bakun, 1996; Cushing, 1996). Thus the strength of recruitment could depend on oceanographic conditions that are in turn governed by climate (Brunel & Boucher submitted) and consequently the relationship between the abundance of the spawning stock and subsequent annual recruitment weaken.

As they give a simplified approach view, reducing temporal and spatial variability of local environmental factors that influence population dynamics, large-scale climatic indices, such as NAO index, often predict ecological processes better than local environmental variables (Hallett *et al*., 2004).

The North Atlantic Oscillation (NAO) describes the atmospheric mass oscillation between the pressure centers of Iceland (low) and the Azores (high) (Walker & Bliss, 1932), and is the most robust pattern of recurrent atmospheric behavior in the North Atlantic region (Barnston & Livezey 1987). NAO fluctuations occur throughout the year; however, they are widest during the colder months (November-April) when the atmosphere is most dynamically active (Barnston & Livezey, 1987; Rogers, 1990; Hurrell *et al*., 2003; Stenseth *et al*., 2003).

The NAO index quantifies the amplitude of this oscillation. The positive NAO phase (NAO+) corresponds to enhanced sea level pressure (SLP) differences between the pressure centers which produce intensification of the westerlies at mid-latitudes and the easterly trade winds over the subtropical North Atlantic. During the negative NAO phase (NAO-), both the Icelandic low- and Azores high-pressure centers are weaker than normal, which produces weakening of the mid-latitude westerlies and subtropical trade winds (Hurrell, 1995; Hurrell & Dickson, 2003; Stenseth *et al*., 2003).

The Northwest African coast is located in the NAO's influence area, is one of the world's four largest productive marine regions by wind induced upwelling (Freudenthal *et al*., 2002; Kearns & Carr, 2003; Carr & Kearns, 2003) and it supports a multinational fishery in which

Merluccius merluccius is a highly valuable target species. However, our knowledge about the effects of NAO-induced climate variability over *M. merluccius* recruitment dynamics in the area is scarce.

In a previous works it was established that in Cantabric Sea, the upwelling processes are responsible of small-scale recruitment dynamics variability of *M. merluccius.* But in longer periods, the recruitment is in phase with a decadal component of climatic system (Sánchez *et al.,* 2002), foreseeable by NAO index (Lavín *et al.,* 2000).

In the case of NW African coast, it was stated a high positive correlation between NAO index and European hake abundance lagged by size class, suggesting a close dependence of recruitment process with the upwelling variability induced by large-scale NAO (Meiners *et al.*, submitted). These authors hypothesized that enhance of fishery recruitment success at year (t) is produced by high productivity conditions during NAO+ during previous year (t-1) which increase the survival rate of young hakes. This means that several cohorts are incorporated to the fishery because the widening of Recruitment Window (RW)

The aim of this study was test this hypothesis and determine the relative importance of climate variability on recruitment dynamics using the NAO index as a main proxy and at the same time verify the persistence of climate signal after abrupt change in fishing effort due to the ceased of European-Moroccan fishing agreements.

Methods

Data source

Because the scarcity of historical records about recruitment of *M. merluccius* in NW Africa, the recruitment time series were calculated from two main sources. (1) Catch data records obtained in landing harbours by the Information and Sampling Net (RIM in Spanish) of "Instituto Español de Oceanografía" (IEO). (2) Juveniles abundance estimated in scientific surveys conducted by the "Institute Nationnal de Recherche Halieutique" of Morocco (INRH). All these data are available in CECAF working group's reports for hakes evaluation (FAO, 1997; in press).

The RIM series consists in landings, length distributions and fishing efforts (fishing days) of *M. merluccius* caugths by Spanish trawling fleet (40-50 mm mesh size). The fishery was conducted under fishery agreements between Spain (later UE) and Morocco (1982 – 1999) in Moroccan and Saharan waters (36ºN to 28ºN). The Spanish trawling fleet fished over the younger component of the hake stock (juveniles and preadults).

Two types of time series were derived from Spanish data. The first one was a detailed monthly time series of length frequency distributions of total landings recorded from January 1991 to November 1999 in the port of Malaga, which was one of the main base ports of the fleet during the fishery agreements. The second one consisted of annual length frequency distributions between 1982 and 1999 that was estimated for the total catch of Spanish trawling fleet (ports of Algeciras, Huelva, Malaga and Puerto Santa Maria). Both time series are expressed in number of hakes per total length (TL) class.

The Moroccan time series of juvenile abundance (kg/h) came from 32 scientific surveys carried out in different months between 1982 and 2004 (see Table I) from 36ºN to 30ºN at depths from 50 to 200 m.

The Moroccan time series was utilized with two main goals. In first term, to verify the persistence of climatic signal (until 2004) despite of strong decreasing of fishing effort as consequence of the giving up of Moroccan fishing grounds by European fleets after ceasing the fishery agreements in 1999. In the other hand, to use data independent of the fishing fleet dynamics as a measurement comparable with time series from commercial fleet.

Recruitment indices
The length distributions (monthly and annual) were corrected by fishing gear selectivity based on selection vectors reported in Fiorentino *et al*. (1998) to emphasize small sizes sub represented as a consequence of commercial trawling net mesh size: 40 mm (1982-1984) and 50 mm (1985-1999). Once corrected, it was defined the length interval that we consider that *M. merluccius* recruits to the fishery (the first length mode) and was utilized as an indicator of biological recruitment success.

The monthly time series (January 1996 to November 1999) was used to analyze the seasonal and interannual changes of recruitment and to determine a proper index to amplify the analysis to annual time series (1982 – 1999).

The monthly recruitment index between 1991 and 1999 was defined as recruits caught per fishing day (R_i). To determine the seasonality and trend of recruitment, R_i was standardized (mean = 0 and SD = 1) to obtain R'_i as follows:

$$R'_i = \frac{R_i - \overline{R}}{SD_R}$$

Where R_i is the recruitment index at month i, R and SD_R are the mean and standard deviation of monthly recruitment time series from 1991 to 1999.

The annual recruitment index (R_t) (1982 – 1999) was calculated in the same way that monthly one (recruits per fishing day). But it was corrected to minimize the effect of strong decreasing of hake individuals every year t, it was made through removing trend of total annual individuals (I_t) respect to the total individuals caught in the entire series.

NAO Index
The annual winter NAO index was taken from the webpage of the Climate and Global Dynamics Division of the National Center for Atmospheric Research (NCAR) (http://www.cdg.ucar.edu/cas/climind/nao/).The index is based on the SLP difference between Lisbon (Portugal) and Stykkisholmur/Reykjavik (Iceland) (Hurrell, 1995). These NAO data were smoothed by running average of 3 years to reduce time series noise.

Analysis
In order to describe the temporal characteristics of recruitment monthly time series, it was calculated the trend and seasonal component by running of X-12-ARIMA routine (autoregressive-integrated-moving-averages) through DEMETRA 2.0 Software (Eurostats, 2002).

To test the hypothesis about widening-contraction of RW, the number of new cohorts into the fishery based on monthly length distributions between 1991 and 1999 was determined. If RW is wide we will expect several new cohorts recruited to the fishery along the year. In the opposite situation, a contracted RW would result in less new cohorts into the fishery along the year.

Correlation techniques were used to analyze and to quantify the relationships between climate variability (NAO index), the annual recruitment time series and the widening-contraction of RW and, of course, to verify the synchrony and persistence between climate signal and abundance of *M. merluccius* juveniles recorded during Moroccan scientific surveys until 2004.

Results

The selectivity correction curves applied to length distributions increased at least at 50% the number of hakes minot than 13 and 18 cm TL caught with 40 and 50 mm mesh size, respectively (Fig. 1). The corrected length distributions remark the first length mode and made it proportionally more important respect to the total distribution (Fig. 2).

The length interval covered from 10 to 50 cm LT. The first length mode was 14 -18 cm LT. According to the monthly detailed length distributions, the upper limit of recruits size was fixed in 20 cm, independently of number of length modes found in every year (Fig. 3). In the same way the Moroccan scientific surveys supports this consideration because the first mode of length distributions grouped by season ranged between 14 and 18 cm and the upper limit was 20 – 22 cm (Fig. 4).

There were found recruits of *M. merluccius* all-year, but the highest abundant peaks took place during spring-summer time (Fig. 5a). However the recruitment seasonal component was weak (less than 100 % of R'_i annual mean). The trend of recruitment time series showed a clear decrease since the middle of 1996 (Fig. 5b).

The monthly recruitment index (R_i) grouped by year showed the same decreasing after 1996 and the number of new length modes (cohorts . $year^{-1}$) followed the same way (Fig. 6a).

Both of them were in synchrony with NAO index from previous year (t-1) and showed high positive correlation ($r = 0.91$; $p = 0.0005$ and $r = 0.87$; $p = 0.0045$ respectively) (Fig. 6b). The recruitment variability between 1991 and 1999 was explained in 82% by NAO index of previous year. In the case of cohorts number by year the explained variation was 75%.

Because the proportional behavior and synchrony with NAO index of R_i grouped by year and the number of cohorts . year^{-1}, we consider adequate amplify the analysis to whole annual time series (R_t) (1982 – 1999) as general approximation of recruitment success to test the relationship previously found.

In the Figure 7a is showed the original R_t and the trend of I_t which was removed from R_t to obtain R_t detrended. This criteria was adopted to reduce the associated error to abrupt decreasing of the annual number of hakes from the fishery.

Such as it happened with monthly recruitment time series and cohorts . year^{-1}, R_t detrended showed interannual variations in phase with NAO(t-1) (Fig. 7b) with a positive correlation of their regression residuals ($r = 0.59$; $p = 0.0095$), which means that NAO(t-1) explained 35 % of recruitment variability between 1982 and 1999 (Fig 8).

Finally, the abundance of European hake juveniles recorded in Moroccan Scientific surveys varied in phase with NAO (t-1) (Fig. 9) still after 1999 (ceased fishery agreements). However the magnitude of correspondence between NAO variations and hake abundance (log transform) varied depends the long of the time series. It was weaker for the whole time series (1982 – 2004: $r = 0.49$; $p = 0.0153$) than the last part of time series (1992 to 2004: $r = 0.63$; $p = 0.0116$), explaining the 24 and 40 % of recruitment variability by NAO(t-1).

Discussion

The considering and use of climate hypothesis as main source of variation in fish stocks is the simplest one and at the same time the most attractive. Simple, because it is assumed that marine population respond to environmental changes, especially during their early life stages (i.e. recruitment) and that this response it is proportional to these environmental changes. Attractive, because it could be tested with historical data and it supplies methodological tools to understand the low-frequency stock variations after quantifying the relationships with environment.

This is the case of interannual variability of European hake recruitment success in NW Africa. Two relevant and complementary results that support the climatic hypothesis are presented here. In one hand, the recruitment time series derived from fishery data were in synchrony and positively correlated with NAO(t-1). In the other hand, the synchrony and correlation were determined also with juvenile abundance estimated from non-dependent fishing fleet dynamics and the climate signal was traced until 2004.

Beyond the differences of NAO explained variability, the convergence of both results suggest that climate signal into recruitment success of European hake is robust, recurrent and more over is persistent, even in spite of that large changes in fishing effort occurs.

The correlation differences into the same recruitment time series it has been reported in other demersal species (*Gadus morhua* and *Melanogrammus aeglefinus*: Solow, 2002; *Limanda ferruginea*: Sullivan *et al.*, 2005) and they can be the result of interactions that were not taken into account. In our case, part of the difference could be relates with the origin, precision and temporal cover of data, as well as numeric procedures utilized to isolate the climatic signal.

The weak recruitment seasonality of *M. merluccius*, reported also for Western Mediterranean Sea (Loret & Lleonart, 2002), could be a plasticity feature and an adaptation capacity that could allow to *M. merluccius* to take advantage of any widening of RW. This offers more possibilities to survival enhancement during early life stages, which means the increasing of annual recruitment signal by the incorporation of several cohorts at the same year. During NAO+(t-1) phase (1991-1995) at least 18 cohorts (~4.5 cohorts by year) were detected and during marked NAO-(t-1) (1997-1998) only just 4 cohorts (2 cohorts by year).

The key processes that links the climate variability induced by NAO with their relative contributions and their effects in *M. merluccius* recruitment are different depending the geographic region. In Western Mediterranean the recruitment variability is associated with changes in flux of Ebro and Rhone rivers (Loret *et al.,* 2001), inversely related with NAO. In Cantabric Sea, the recruitment dynamics of *M. merluccius* is controlled by the upwelling variability and oceanographic mesoscale structures and at the same time by long time climatic decadal component (Sánchez & Gil, 2000; Sánchez *et al.,* 2002).

However, whether in Western Mediterranean, the Cantabric Sea or NW African coast, these processes are local and regional mechanisms that control the marine productivity scenarios. This supports the idea that *M. merluccius* could broaden its RW through the survival maximizing during favourable production conditions.

In NW African coast, the wind induced upwellings are the main oceanographic and persistent feature (Schemainda *et al.,* 1975; Wooster *et al.,* 1976; Speth *et al.,* 1978; Belvèze, 1983; van Camp *et al.,* 1991). They are responsible of marine productivity and system carrying capacity (Davenpport *et al.,* 1999; Basterretxea & Arístegui, 2000; Fung *et al.,* 2000; Freudenthal *et al.,* 2001; Nave *et al.,* 2001; Neuer *et al.,* 2002; Abrantes *et al.,* 2002) and their intensity and temporality are affected by wind condition changes induced by NAO (Arístegui *et al.,* 2001; Meiners *et al.,* submitted)

Hence, in NW African coast the widening of RW of European hake is positively and proportionally related with NAO amplitude through the modifying of upwelling temporality induced by the wind.

These results emphasize the importance of NAO index as an indicator and prediction tool spatial and temporal simplified, not only about the climate, but the sense and magnitude of ecological impact in European hake stock through recruitment.

The NAO property as simplified proxy is very important in ecological terms, because in absence of information about distribution and abundance of eggs and larvae of *M. merluccius* in NW Africa (Ramos & Fernández, 1995), through the NAO index it is possible to approach the sum of processes, do not evaluated till now, from the spawning time to the recruitment to the fishery an year after.

The recruits abundance at certain year (t), will be strongly determined by the NAO of previous year (t-1) but after recruited the hakes will be under influence of actual NAO (t), that could affect the growth dynamics and the factor condition, that eventually determines the quality and quantity of future spawners during the next years (t+n).

That's why it is important to emphasize in other possible effects and interactions of population dynamics with NAO, to build an integrated and adequate numeric prediction tool in terms of fishery management.

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Table I. Juvenile yields of *M. merluccius* (kg . h^{-1}) from Moroccan scientific surveys carried out between 1982 and 2004 (FAO, 2004)

Year	**Spring**	**Summer**	**Autumn**	**Winter**
1982	14.58			
1983	13.91	13.77		16.86
1984	25.73			10.58
1985	19.56			
1986	15.80		20.40	
1987			12.29	
1988	15.40			
1989		17.16		
1990				
1991				
1992		12.81		
1993	11.89			
1994		17.37	11.50	
1995	11.42	13.34		12.15
1996	8.69			
1997		6.64		6.53
1998		1.82		5.04
1999	9.00		9.21	
2000			18.57	
2001	15.68		15.53	
2002	13.99			
2003		14.89		
2004		10.93		

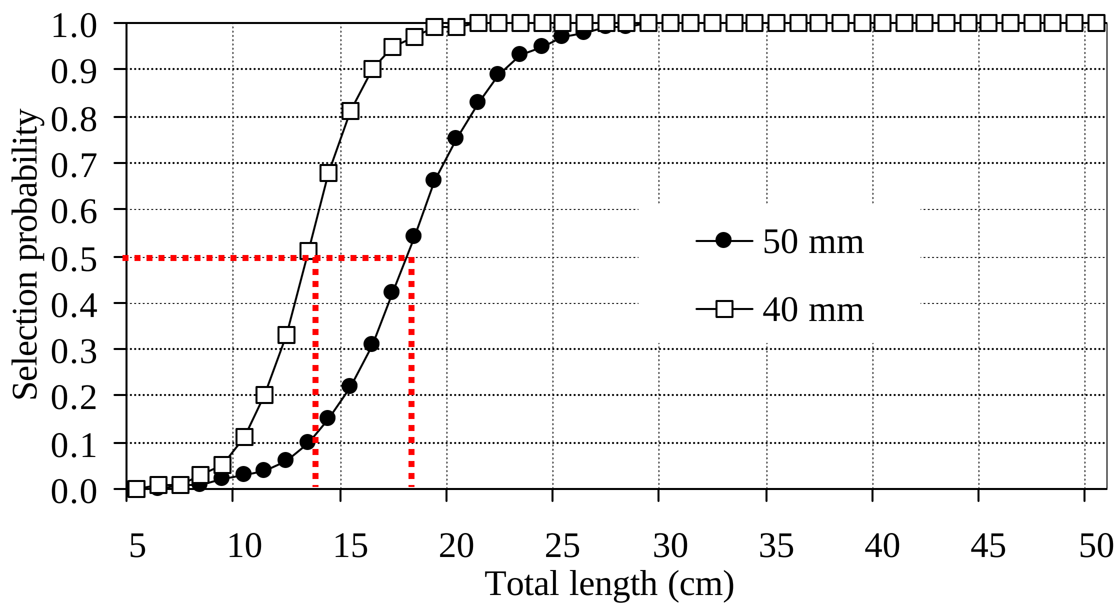


Figure 1. Selectivity curves for 40 and 50 mm mesh size trawling net applied to correct the length distributions of European hake (Fiorentino *et al.*, 1998).

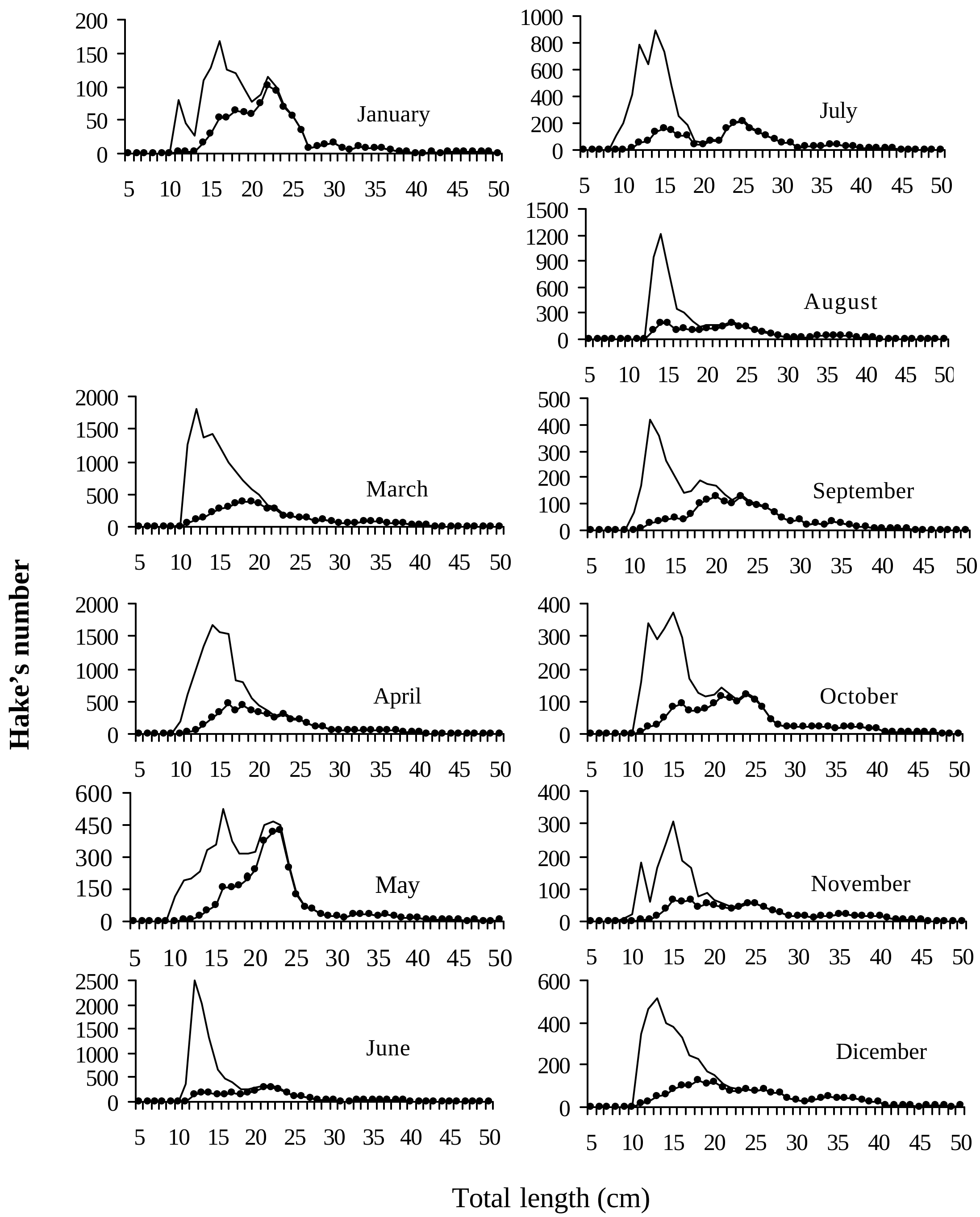


Figure 2. Monthly landings (solid line) and corrected length distributions by gear selectivity (thin line) of total *M. merluccius* catch from the Port of Malaga (1991 to 1999).

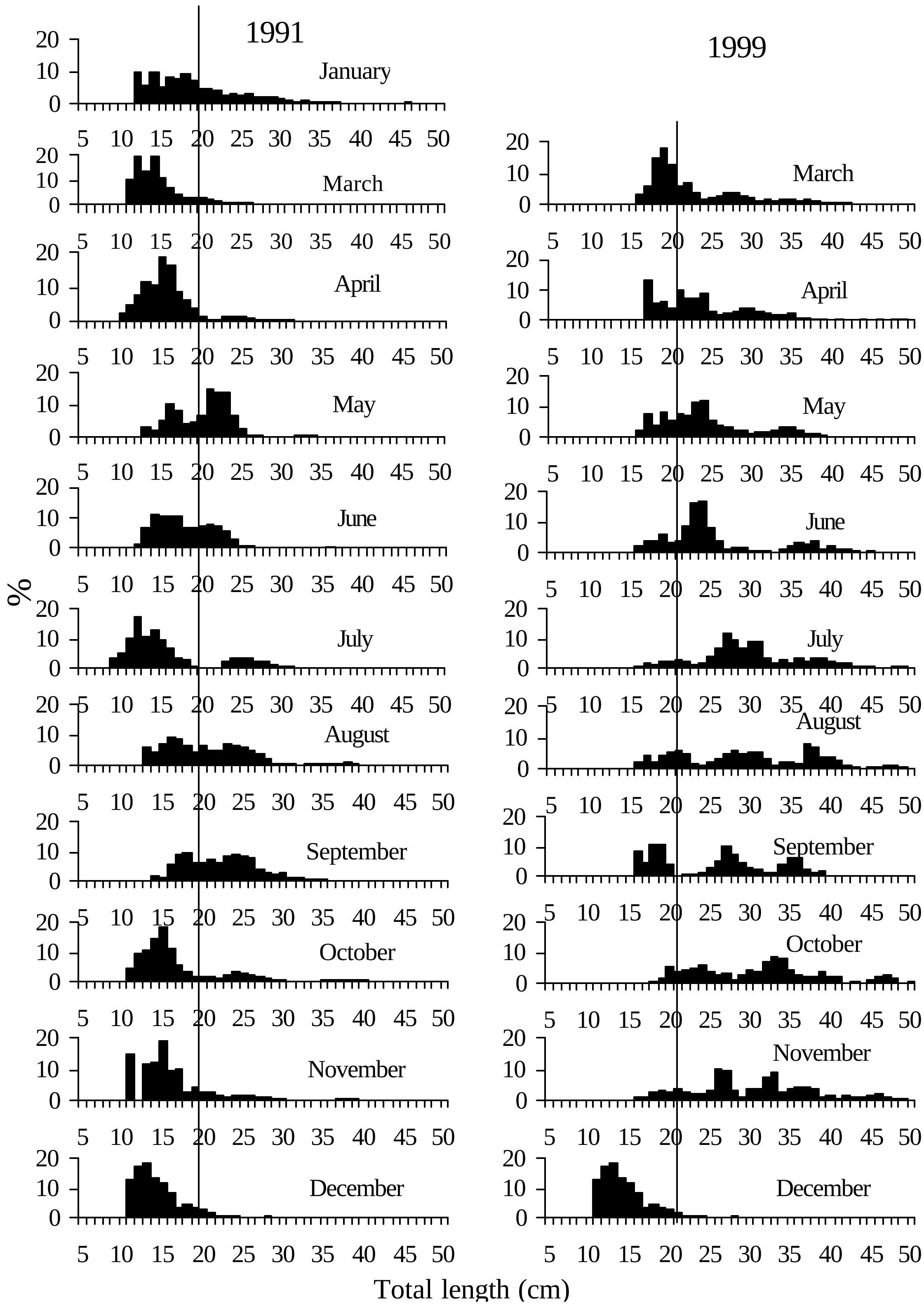


Figure 3. Corrected length distribution (%) of 1991 (left side) and 1997 (right side) as examples of how it was established the cut length to consider recruits (<20 cm LT) and identified de number of new length modes (cohorts) incorporated to the fishery.

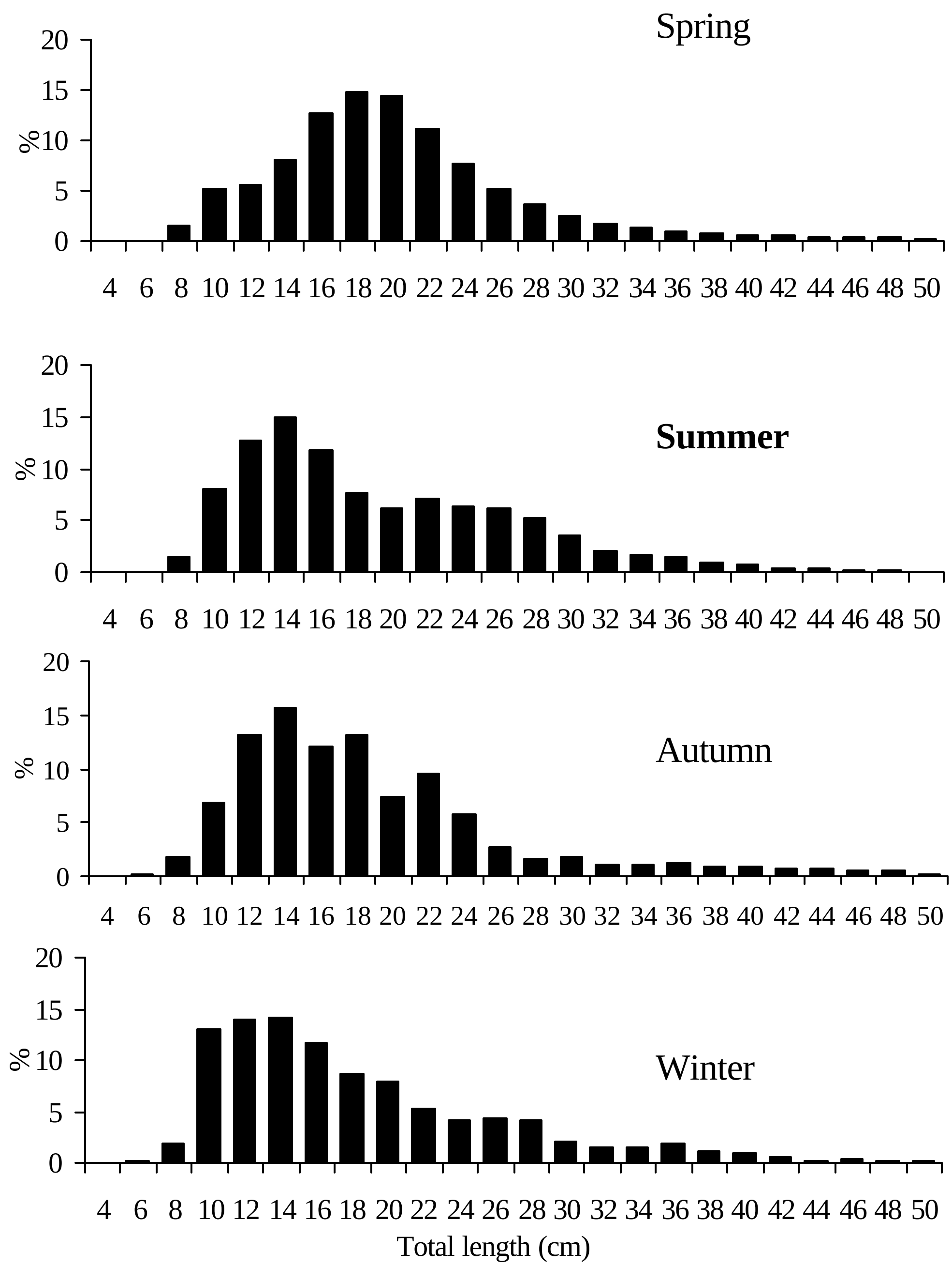
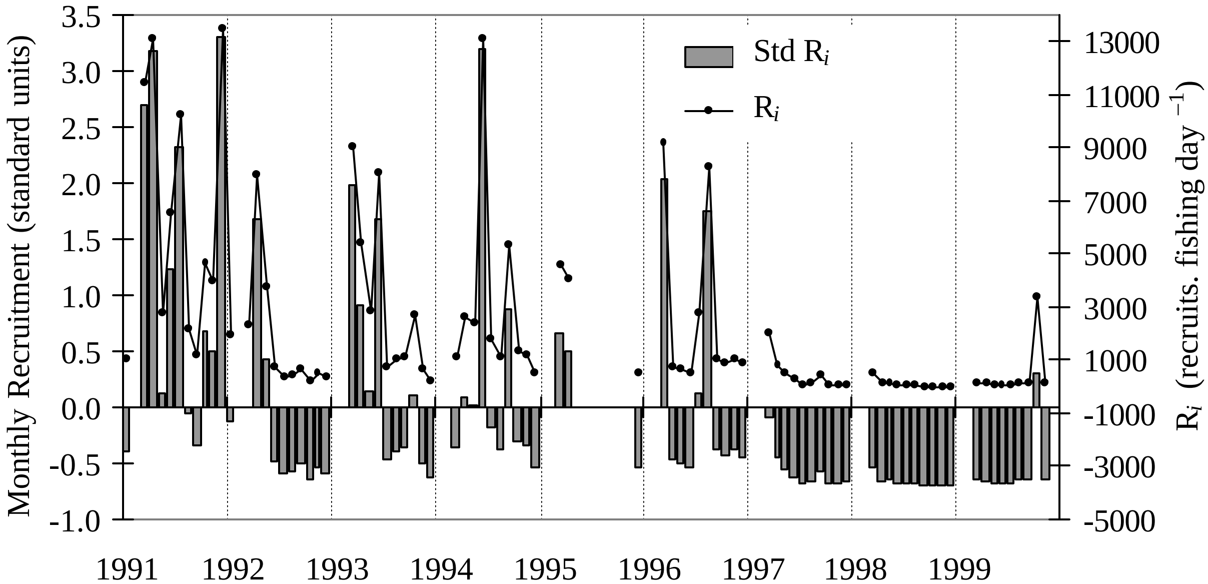


Figure 4. Length distributions (%) grouped by season of European hake recorded during scientific surveys carried out by INRH – Morocco along the continental shelf of between 36ºN and 30ºN.

(a)



(b)

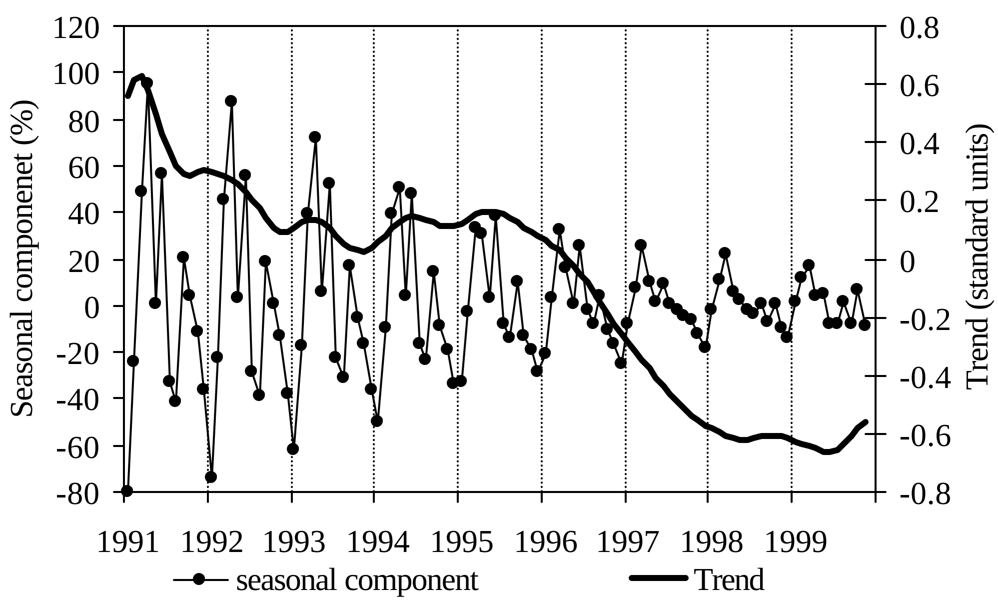
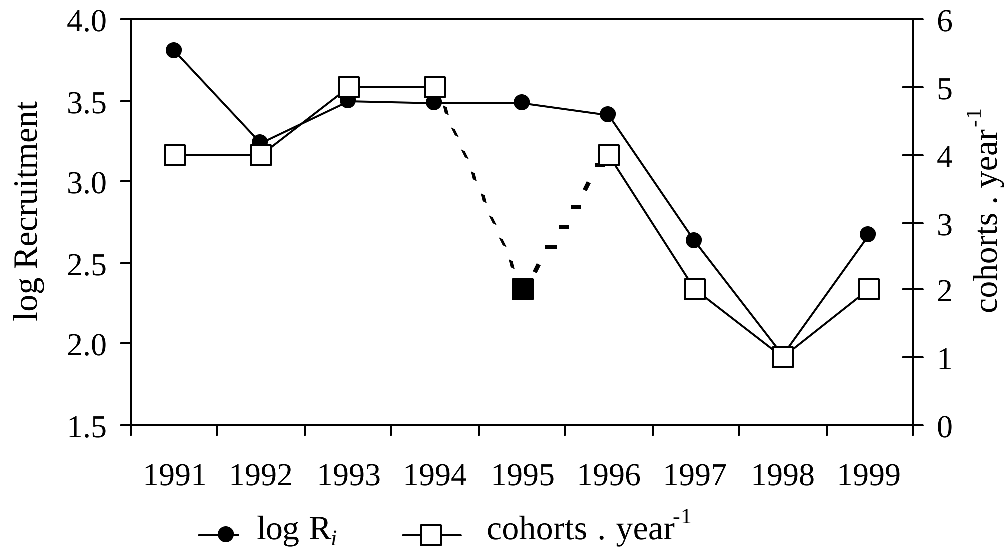


Figure 5. (a) Monthly recruitment index (recruits . fishing day^{-1}: line) and standardized index (mean = 0; SD = 1: bars) of *M. memrluccius* derived from total landings of Port of Málaga between January 1991 and November 1999. (b) Seasonality (% above or below of annual mean) and trend of standardized monthly recruitment index (R_i).

(a)



(b)

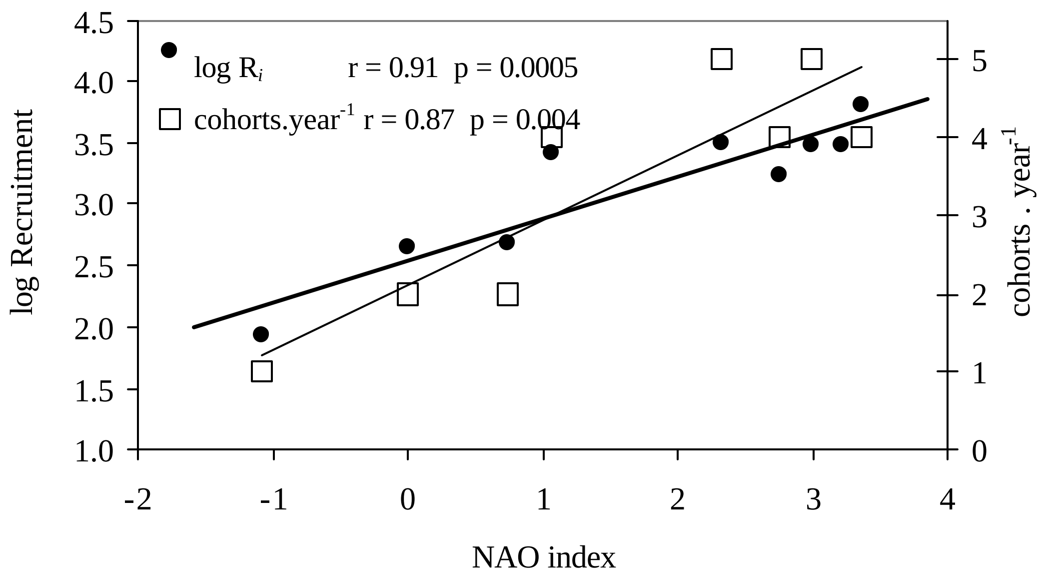
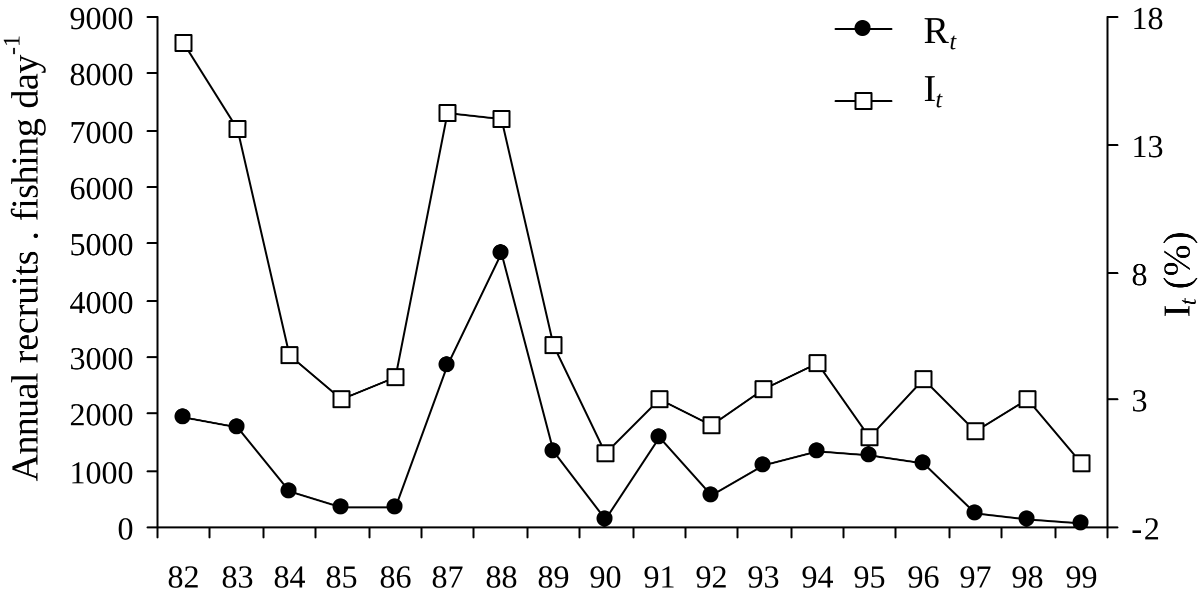


Figure 6. (a) Annual recruitment index (log transform) from 1991 to 1999 grouped from monthly recruitment (R_i) and number of cohorts . year^{-1} incorporated to the fishery. The case of 1995 is marked (filled in black) because during that year there were only three months of fishing due to problems with fishing agreement. (b) Scatter plot and adjust between NAO(t-1) and log R_i and cohorts . year^{-1} (1995 was excepted for adjust).

(a)



(b)

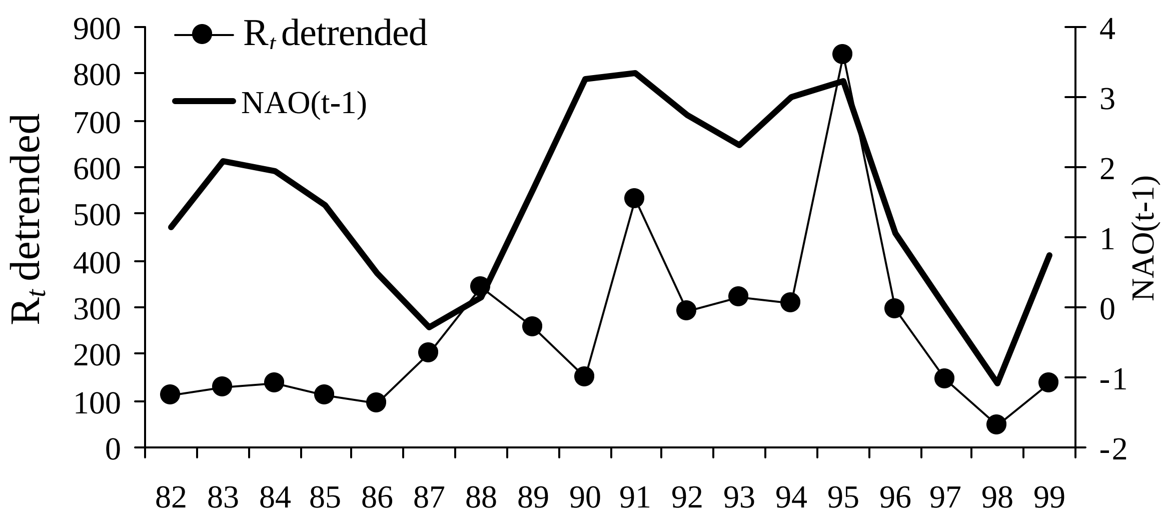


Figure 7. (a) Annual recruitment time series (R_t: line with circle) for whole Spanish trawling and the trend of annual percentage of hakes (I_t: line with square) caught respect to the grate total between 1982 and 1999. (b) Detrended annual recruitment time series (R_t detrended) through removing I_t time series.

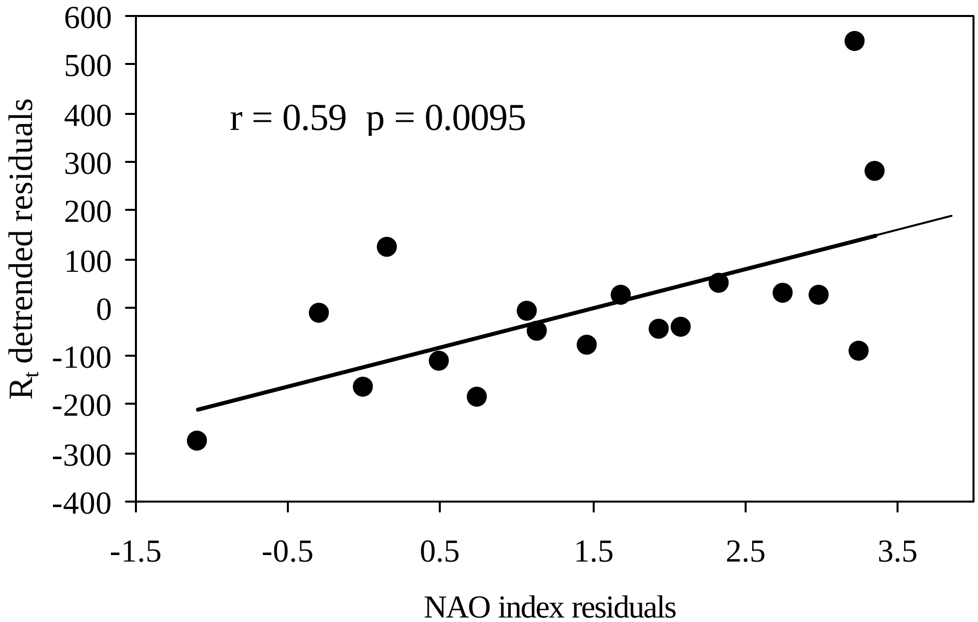


Figure 8. Scatter plot and lineal adjust between regression residuals of annual recruitment (R_t) time series and NAO(t-1)

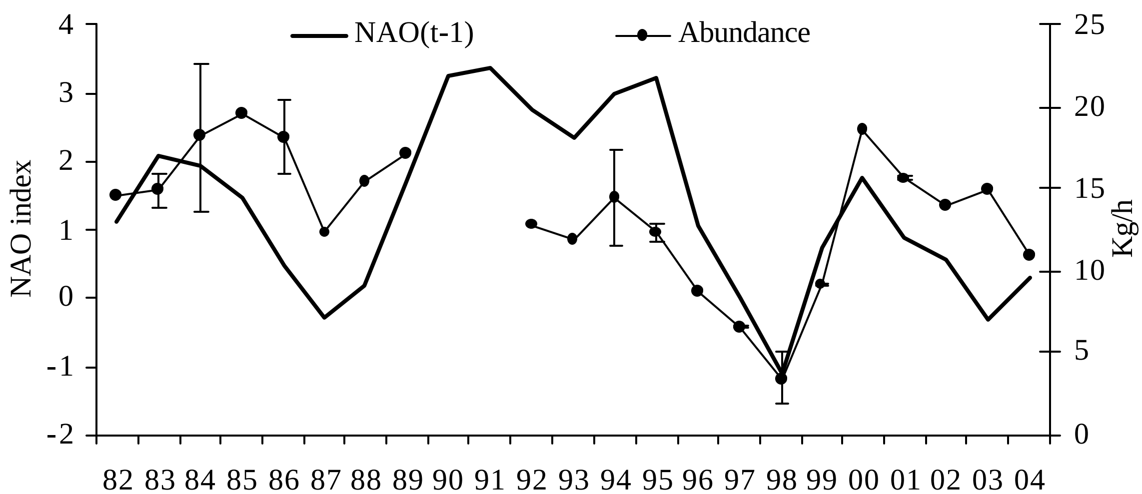


Figure 9. Coincidence between juvenile mean abundance (kg . h^{-1} ± SD) of *M. merluccius* and NAO(t-1). Abundance data were obtained from Moroccan scientific surveys between 1982 and 2004. There were no surveys in 1990 and 1991).