

# Fluctuations of landings and environmental conditions in Northwest Mediterranean Sea

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## Abstract

Most of the monthly catches and CPUE of 13 studied commercial species in the coastal waters off north-western Mediterranean were significantly positively correlated with runoff of local rivers (Rhône and Muga) and the wind mixing index during the spawning season, with time lags of less than 18 months (transfer function analyses). Rhône and Ebre runoffs displayed synchronous interannual fluctuations and were further related to the North Atlantic Oscillation (NAO), river runoffs being negatively correlated to high NAO episodes. The fluctuations of river discharges and the wind mixing index were cyclic but not related. The results showed that enhanced hydroclimatic conditions in the NW Mediterranean were favourable for the productivity of the fish and invertebrate stocks, and suggest the presence of linkage between recruitment of Mediterranean species and local (river discharges, wind conditions) and global (NAO) environmental conditions.

Key words: Mediterranean fisheries, Rhône River, Muga River, Ebre river, wind, Gulf of Lions, Gulf of Roses - Cape Creus, NAO index, Box-Jenkins models.

## Introduction

Production of harvested fish and invertebrate populations of the Northwestern Mediterranean has fluctuated cyclically during the last decades and these fluctuations do not seem to be totally dependent on fishing activities (Demestre *et al.*, 1987; Oliver, 1993; Farrugio and Marin, 1999; Lloret *et al.*, 1999). Regardless of a long tradition in fisheries investigations in the Mediterranean Sea (e.g. Farrugio *et al.*, 1993), environment-fish population relationships have been sporadically studied (e.g. Bas and Calderon, 1989). Recently published papers (Palomera, 1992; Caddy *et al.*, 1995; Sabatés, 1996; Regner, 1996; Coombs *et al.*, 1997; Conway *et al.*, 1998; Daskalov, 1999; Levi *et al.*, 1999; Sabatés *et al.*, 1999) allow us to reconsider the problem of the environmental control on the fish production.

The Gulf of Lions (Fig.1) is one of the most productive zones of the Mediterranean Sea due to a number of hydrographic features which includes: a wide shelf, river runoff, strong vertical mixing in winter and occasional coastal upwelling. The large fresh water input in the area comes mainly from the Rhône River, whose catch basin is about 98000 km<sup>2</sup>. This river flows through areas where agriculture and farming are important, so that phosphorus and nitrogen discharges are important (Estrada, 1996). Intense water mixing is induced by the predominant, strong, dry and cold northwesterly winds blowing at the Gulf of Lions (the so called Tramuntana and Mistral). The Gulf of Lions supports fisheries that include bottom and pelagic trawls, purse seines, gill nets and long-lines, and is furthermore an important spawning area for many pelagic and demersal species (Lleonart, 1990; Farrugio and Marin, 1999).

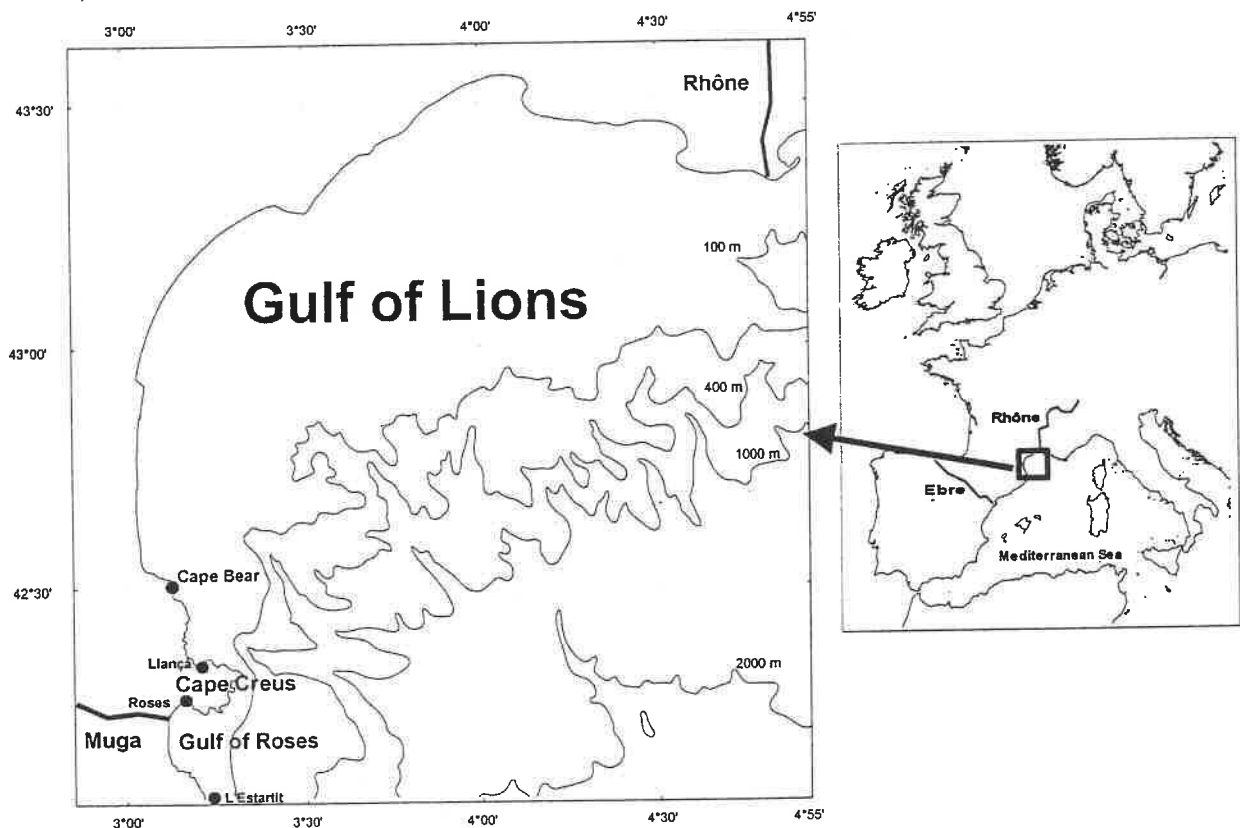


Figure 1. Location of the study area (marked with a square): the Gulf of Lions and the Gulf of Roses-Cape Creus (NW Mediterranean). Selected ports (Roses and Llançà), river basins (Rhône, Ebre and Muga), oceanographic (L'Estartit) and meteorological stations (Cape Bear and Roses) are also shown.

The Gulf of Roses is at the southern part of the Gulf of Lions, from which is separated by the Natural Park of Cape Creus (Fig. 1). This gulf receives fresh water input from the river Muga, whose catch basin is about 15 000 km<sup>2</sup> and supports a multispecific fishery carried out by bottom trawlers, purse seiners and by a small-scale fleet using long lines, gill nets and shellfish dredges. Some species have their habitat or spawning area in the Gulf of Roses and are therefore locally fished, e.g. *Donax trunculus* and *Penaeus kerathurus*. An artisanal gillnet fishery occurs around the Natural Park of Cape Creus too.

Our purpose is here to model the relationships between river runoffs and wind conditions with fishery resources of the Gulf of Lions and the Gulf of Roses-Cape Creus, using transfer function models (Box and Jenkins, 1976). Transfer function models are a subclass of the Box-Jenkins ARIMA (autoregressive-integrated-moving-average) models, a group of linear, stochastic-dynamic models that can describe fairly complex behaviour. Both local environmental variables –river flows and wind conditions- have been selected because they are known to play an important role in the planktonic production and fish larval retention in the area (Estrada *et al.*, 1985; Palomera, 1992; Estrada, 1996; Sabatés, 1996; Olivar *et al.*, 1998; Sabatés *et al.*, 1999). The basic working hypothesis behind this study is that recruitment of many species of the Northwestern Mediterranean is influenced by the amount of water discharged from the local rivers and by local wind conditions during the reproduction season, through enhanced fertilization and/or larval retention. Local environmental conditions in the Gulf of Lions and Gulf of Roses-Cape Creus may ultimately be linked to global environmental conditions. Thus, this study also intends to characterize the temporal fluctuations of the local environmental conditions and their associated global environmental conditions in the coastal waters off the NW Mediterranean.

## Materials and Methods

### Data sources

A series of monthly total catch records was available for 53 species or group of species (henceforth called species) landed in Roses harbour for different periods of time, 1972-98. In most cases, catch data were available from 1990. Our time series span more than 50 months, which is adequate for a proper time-series analysis (Pankratz, 1991). Catch was recorded in kg and for some species it was available by two commercial size-classes, big and small. We selected for the analyses the catch figures of those target species and commercial size classes that, according to a sampling program carried out during year 1999 at the Roses Fishmarket (not yet published), are mainly composed by individuals in the first and/or second year of life (Table 1). Landings were –depending on the species- from trawlers, seiners, dredgers and gill-neters. Fishing effort (number of boats and daily time at sea) for all gears remained nearly stable during the study period (Confraria de Pescadors de Roses, 1998). A series of daily catch records was also available for 32 species landed by a single target trawler of the neighbouring port of Llançà (Fig. 1), for the period January 1986 - September 1994. We selected for the analyses those target species that were also considered in Roses harbour. Monthly catches per

unit of fishing effort (CPUE, kg trip-month<sup>-1</sup>) were calculated from the daily information. As the fishing grounds for both ports are located in their vicinity, trawlers, dredgers and gill-neters fish in daytime and land their catches in the late afternoon at the harbour fish market while seiners fish in night-time and land their catches in the early morning. Fishermen associations' auction catches in each of the ports.

Monthly mean sea temperatures (°C) were obtained from the oceanographic station of l'Estartit (1974-97) operated by Mr. Josep Pascual (Fig. 1). Meteorological data including monthly total precipitation in mm (1956-98) and daily wind data (speed and direction, 1968-98) were obtained from the meteorological stations of Roses (Catalan Meteorological Office) and Cape Bear (Météo-France), respectively (Fig. 1). Due to its position, Cape Bear Station has long been recognized as a suitable observational point for the wind blowing in the western Mediterranean basin (Ascensio *et al.*, 1977). We estimated the intensity of input of mechanical energy by the wind, which would then become available for turbulent mixing of the upper ocean, by means of a "wind mixing index". This index is the monthly mean value of the third power (cube) of the wind speed (Bakun and Parrish, 1991; see Appendix 1). Monthly mean flow data (m<sup>3</sup>/s) of the Rhône River (1920-98), Muga River (1973-98) and Ebre River (1914-34 and 1952-96) recorded downstream near to their mouth (gauging stations of Beaucaire, Castelló d'Empúries and Tortosa, respectively) were obtained from the National Company of the Rhône, the Catalan Hydrological Service and the Ebre's Hydrological Confederation, respectively (Fig. 1). The North Atlantic Oscillation (NAO) winter index was obtained from the web site: "[http://www.cgd.ucar.edu:80/cas/climind/nao\\_winter.html](http://www.cgd.ucar.edu:80/cas/climind/nao_winter.html)", and is computed as the difference in normalized sea level pressures between Lisbon (Portugal) and Reykjavik (Iceland, see Hurrell 1995). Ebre runoff and NAO index are only considered in this study to seek for possible relationships between local and global (large-scale) environmental conditions.

#### Analysis of environmental variables

Two analyses were performed. First, we described the environmental time series in terms of two basic classes of components: trend and seasonality. Decomposition of time series provides additional information on their structure and dynamics (Chatfield, 1984; Pankratz, 1991). We used the decomposition method "tramo-seats" (Gómez and Maravall, 1997), which is included in the software package Force 4/R Research System and that is an extension of the so-called X-11 decomposition method (Makridakis *et al.*, 1983; Makridakis and Wheelwright, 1989). Second, the linear relationship was analyzed between the different environmental variables, including the North Atlantic Oscillation (NAO) Index, which is an important feature of the atmospheric circulation in the North Atlantic and Mediterranean (Visbeck *et al.*, 1998). We used here annual data (annual averages for the wind mixing index, the river runoffs and temperature; annual total for the rainfall and winter NAO index). Annual data are the most appropriate for determining the long-term hydroclimatic relations and in order to eliminate seasonal variation (Probst, 1989).



Table 1.Cont.

Scientific name	Harbour	N	Reproduction season	RSEU (kg)	River	River runoff			Wind mixing index						
						R <sup>2</sup>	RSE (kg)	Coefficients (kg)	Time lag (months)	t	r <sup>2</sup>	RSE (kg)	Coefficients (kg)	Time lag (months)	t
<i>Loligo vulgaris</i>	Llançà	105	March-July	3.37	Rh	0.64	2.82	0.00162	4	4.2	0.49	3.36	4.15	5	4.09
<i>Merluccius merluccius</i> (Small)	Roses	108	September-January	8928	Rh	*	*	*	*	*	0.56	7522	18.0	9	3.76
<i>Merluccius merluccius</i> (Big)	Roses	108	September-January	3690	Rh	*	*	*	*	*	0.52	3671	6.90	12	3.21
<i>Merluccius merluccius</i>	Llançà	105	September-January	7.85	Rh	*	*	*	*	*	0.57	7.79	9.40	11	3.55
<i>Micromesistius poutassou</i> (Small)	Roses	117	February-June	21005	Rh	0.63	16050	7.49	5	3.73	0.39	20684	26.0	5	3.43
<i>Micromesistius poutassou</i> (Big)	Roses	117	February-June	10181	Rh	0.76	9536	4.19	12	3.34	0.74	10044	19.0	12	5.07
<i>Micromesistius poutassou</i> (Big + Small)	Roses	324	February-June	22010	Rh	0.38	21700	6.41	5	4.29	0.38	21688	13.0	13	3.00
<i>Mullus barbatus</i> + <i>M. surmuletus</i>	Roses	90	May-July	1718	Rh	0.44	1490	1.83	5	6.92	0.28	1694	8.00	3	3.04
<i>Mullus barbatus</i> + <i>M. surmuletus</i>	Llançà	105	May-July	8.50	Rh	0.14	7.53	0.00461	4	4.12	*	*	*	*	*
<i>Pagellus acarne</i> + <i>P. bogaraveo</i>	Roses	105	July-October	1331	Rh	0.27	1317	0.92	12	5.35	0.34	1252	7.90	12	5.15
													6.60	14	4.26

Table 1.Cont.

Scientific name	Harbour	N	Reproduction season	RSEU (kg)	River	r <sup>2</sup>	River runoff		Time lag (months)	t	r <sup>2</sup>	RSE (kg)	Wind mixing index		t
							RSE (kg)	Coefficients (kg)					Coefficients (kg)	Time lag (months)	
<i>Pagellus acarne</i> + <i>P. bogaraveo</i>	Llança	105	July-October	8.88	Rh	0.48	7.96	0.00738	11	6.04	0.38	8.67	43.0	14	3.99
<i>Penaeus kerathurus</i>	Roses	105	June-August	35	Mu	0.67	29	0.00521	12	3.81	0.67	28	0.14	11	3.22
								8.34	11	3.26				0.23	12
<i>Sardina pilchardus</i>	Roses	115	November-March	90204	Rh	0.26	84427	12.46	12	4.79	0.35	78832	115.0	13	3.12
								49.39	17	5.9				160.0	17
<i>Sepia officinalis</i>	Roses	216	March-August	1351	Rh	0.23	1268	0.62	7	6.07	0.20	1296	166.0	18	4.72
								0.62	10	3.85				1.40	9
<i>Sepia officinalis</i>	Llança	105	March-August	1.48	Rh	*	*	*	*	*	*	*	*	*	*
								0.87	8	4.44				0.53	1578
<i>Trisopterus minutus capelanus</i>	Roses	90	January-May	1589	Rh	0.61	1481	0.63	10	3.20	0.53	1578	2.40	8	3.42
<i>Trisopterus minutus capelanus</i>	Llança	105	January-May	6.62	Rh	0.37	6.51	0.00344	4	4.37				*	*
								0.00316	8	4.34	*	*			
								0.00300	10	3.61					*

### Transfer function analyses between catch and CPUE

We analysed the relationship between the monthly total catch in Roses harbour and the monthly CPUE in Llançà harbour using transfer function models (Box and Jenkins, 1976) to see whether they follow or not the same patterns. These models describe the time-lagged relationship between dependent and independent variables while taking into account the autocorrelation of the disturbance. Data were not seasonally adjusted because seasonal adjustment can obscure the underlying time structures of the individual series as well as the relationships between variables (Neftçi, 1979). To build transfer function models, we followed the Box and Jenkins' modelling strategy (Box and Jenkins, 1976; Appendix 2) and used the software package Force 4/R Research System developed by the Polytechnical University of Catalonia (Prat *et al.*, 1998).

### Transfer function analyses between yield and environmental variables

To determine the possible relationships between time series of yield (catch and CPUE) and the selected environmental variables (river flows and wind mixing index) during the reproduction season (see table 1), we constructed for each species bivariate transfer function models (Box and Jenkins, 1976) using the monthly data. It must be noticed that time series of the inputs (river flows and wind mixing index) had not any seasonal component as we used here only the values for those months when the species in question was reproducing, i.e. the time period when eggs and larvae are in the water column and that is a key determinant of interannual survival variability (Houde, 1987; Cushing, 1982). The physical values for the rest of the months were replaced for "zeros" that meant "no influence on catches" in our models. The greatest portion of catches for nearly all species considered is composed by individuals in the first year of life, so those catches can be considered as a proxy of the recruitment. Thus, we compared the environmental conditions only during the spawning seasons with the resulting recruitment (reflected on landings and CPUE). Rhône river runoff was compared with catch and CPUE of those species whose reproductive and fishery areas are placed at the Gulf of Lions (e.g. *Eledone cirrhosa*; Sánchez and Martín, 1993), whereas those in the Gulf of Roses (e.g. *Donax trunculus*; Ramon, 1993) were compared to Muga river runoff. The reproduction season for each species was based on information provided elsewhere (Naef, 1923; FAO, 1973; Whitehead *et al.*, 1973; Armengol, 1986; Demestre, 1986; Sostoa, 1990; Lleonart, 1990; Cristian, 1991). Before fitting transfer function models, univariate ARIMA models (Box and Jenkins, 1976) were built for the local environmental factors and catch and CPUE using the monthly data. To build univariate ARIMA and transfer function models, we followed the same methodology as described at the paragraph before (see also Appendix 2).



## Results

### Description and relationships between environmental variables

During the sampling period, the river discharges and the wind mixing index displayed important seasonal and interannual fluctuations. The monthly average Rhône runoff varied from 420 to 5077 m<sup>3</sup>/s, and prolonged low discharges were successively recorded during years 1920-21, 1942-44, 1971-73, 1989-91 and 1997-98 (Fig. 2). The monthly average Ebre runoff, that showed a progressive decline from 1914 to the present, varied from 19 to 2471 m<sup>3</sup>/s, and showed the lowest values during years 1989 and 1990 (Fig. 2). The successive floods in 1977, 1982 and 1988 and a dry period in mid 80's mainly described the monthly average Muga runoff, which varied from 0 to 72 m<sup>3</sup>/s (Fig. 2). Minimum river flows occurred from July through October (Fig. 3). The wind mixing index varied from 0 to 2200 m<sup>3</sup>/s<sup>3</sup>, (which correspond to speeds of 0 and 13 m/s), and showed cyclic fluctuations at a periodicity of about 5 to 8 years (Fig. 2). From 1968 onwards, the wind mixing index dropped successively in years 1972, 1977, 1982-83, 1989 and 1997. Prevailing monthly average wind directions were north and west (indicated by predominant positive V and negative U wind components, respectively; Fig. 2), although intensity of northwesterly winds diminished during spring, summer and fall (Fig 3). Rainfall and the NAO index showed important interannual fluctuations too (Fig. 2). Total annual rainfall varied from 178 to 1132 mm, while the winter NAO index varied from -4.89 to 5.08 and displayed very high positive values in years 1973, 1981-83 and 1989-95. In contrast, water temperature did not show important interannual fluctuations but a continuous warming trend from the beginning of the time series (an increase of about 2 °C, Fig. 2) and a clear seasonal pattern (Fig. 3). Warmer than the annual average temperatures at a depth of 20 m occurred from June through October.

There were significant ( $p < 0.05$ ) positive correlations between the flows of the Rhône and the Ebre rivers, between the flows of the Rhône and the Muga rivers and between the flow of the Muga River and rainfall in Roses (Fig 4). In contrast, there were significant ( $p < 0.05$ ) negative correlations between the NAO index and runoff of the major rivers studied (Rhône and Ebre, Fig. 4). Thus, Rhône and Ebre river discharges were lower during high NAO winters. The rest of the environmental variables were not correlated among them at the 5% threshold.

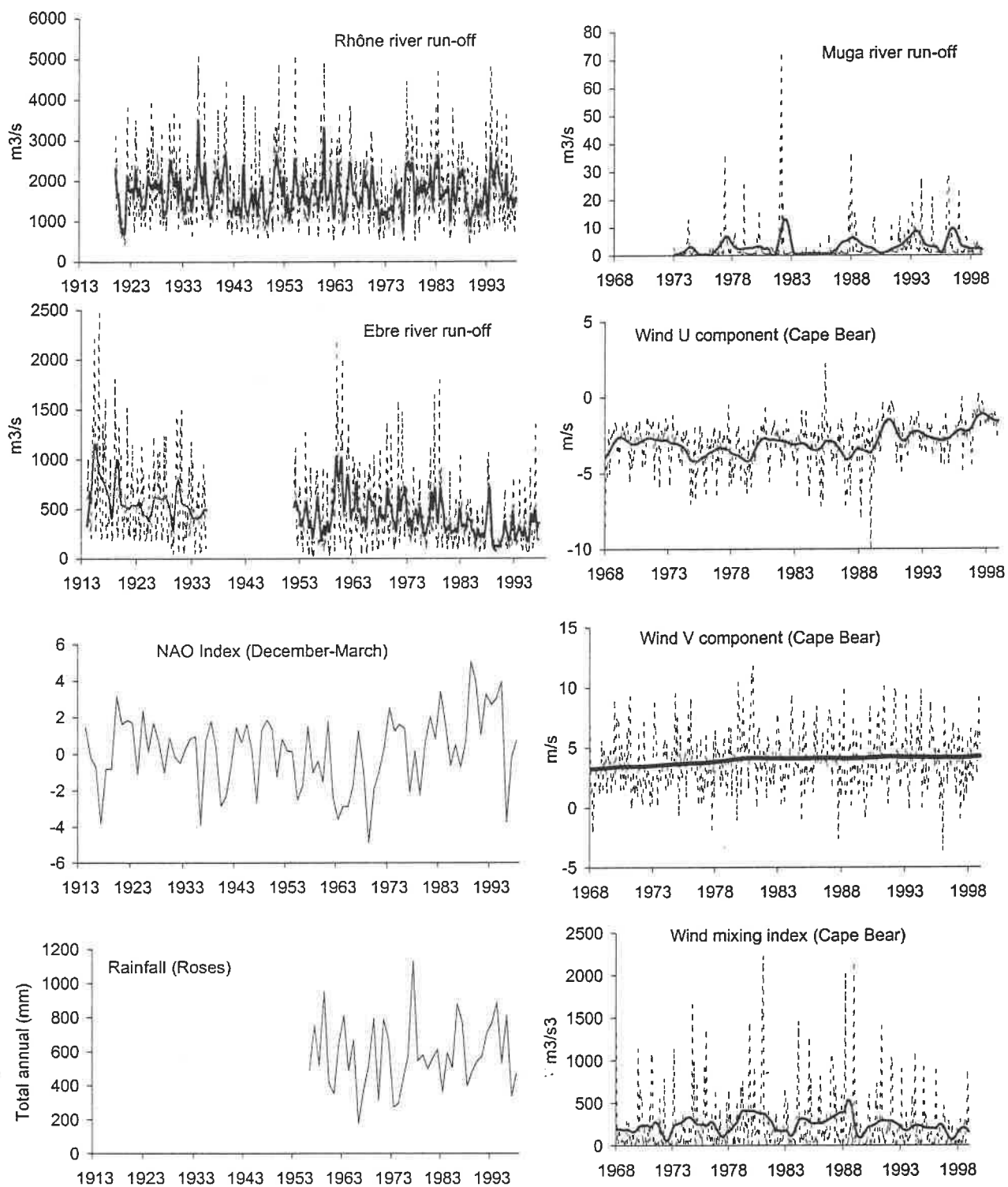


Figure 2. Monthly time series (dotted line) and trend (solid line) of the Rhône, Ebre and Muga rivers runoff, wind U and V components and wind mixing index, together with the total annual rainfall and the annual (mean over December through March) time series of the NAO index.

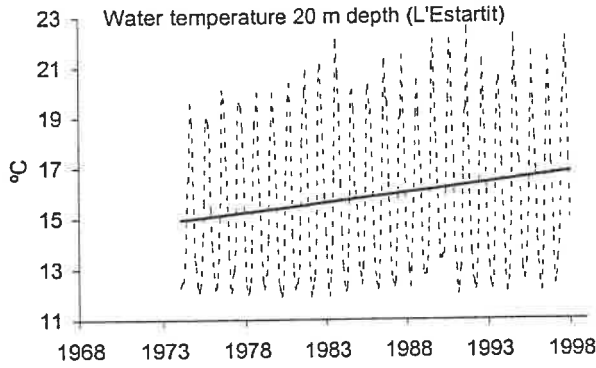


Fig. 2 Cont. Monthly time series (dotted line) and trend (solid line) of water temperature.

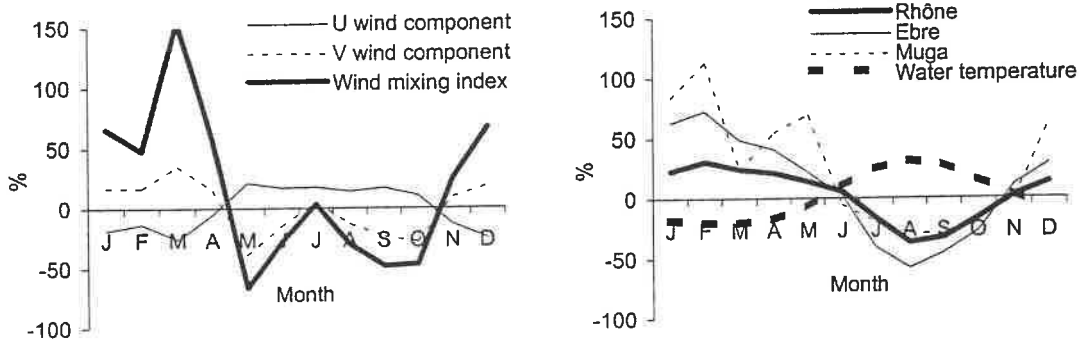


Figure 3. Mean seasonal patterns (% over/below the annual mean) of the full time series of U and V wind components and wind mixing index (left graph) and river runoffs and water temperature (right graph).

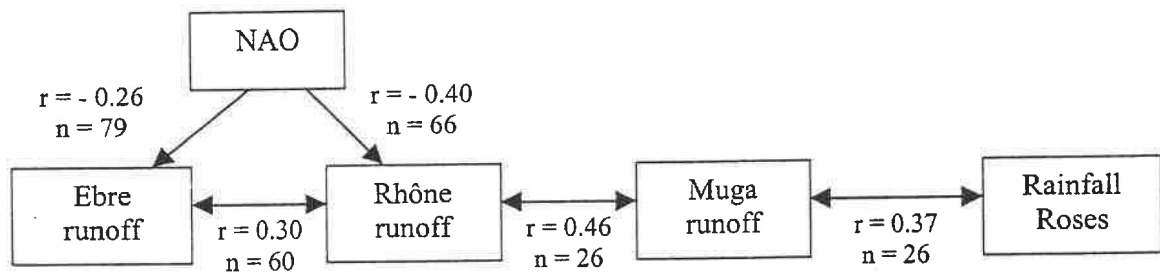


Figure 4. Significant synchronous correlations ( $p < 0.05$ ) of the annual time series among environmental variables. R-values and number of years (n) of the linear regressions are shown on arrows.

### Relationships between total catch and CPUE

The transfer function models between catch and CPUE showed that, for most of the species studied, monthly total landings in Roses harbour were significantly positively and nearly synchronously correlated with monthly CPUE in Llançà harbour (Table 2). Figure 5 displays some examples.

Table 2. Results of the transfer function models between catch (Roses harbour) and CPUE (Llançà harbour). N is the number of data points (months) fitted; RSE is the residual standard error of each of the transfer function models;  $r^2$  is the explained variance. Significant coefficients at a t value  $> |3|$  ( $p < 0.05$ ) together with time lags are shown (the symbol “\*” denotes that there was not any significant relationship).

Scientific name	N	$r^2$	RSE (kg)	Coefficients (kg)	Time lag (months)	t
<i>Pagellus acarne</i> + <i>P. bogaraveo</i>	54	0.27	1030	86	1	5.03
				71	2	3.64
<i>Eledone cirrhosa</i> (Small)	67	0.61	2302	368	1	3.26
<i>Eledone cirrhosa</i> (Big)	67	0.42	5328	184	1	5.79
<i>Merluccius merluccius</i> (Small)	57	0.65	12307	857	0	4.22
				624	1	3.20
<i>Trisopterus minutus capelanus</i>	39	0.54	1665	199	0	4.62
<i>Mullus barbatus</i> + <i>M. surmuletus</i>	39	0.53	1029	332	0	15.1
<i>Sepia officinalis</i>	117	*	*	*	*	*
<i>Loligo vulgaris</i>	117	0.65	1582	275	0	6.20
<i>Liocarcinus depurator</i>	54	0.42	900	212	0	4.07

### Relationships between yield (catch and CPUE) and environmental variables

The transfer function models between yield (dependent) and environmental variables (independent) showed that, for most of the species studied, catch and CPUE were significantly positively correlated at different time lags with river flows and the wind mixing index during the reproduction seasons (Table 1). Figures 6 and 7 display some examples of the models constructed using river flows and wind mixing index, respectively. Significant time lags ranged from about 2 to 6 months for small *Eledone cirrhosa*, *Loligo vulgaris* and *Mullus barbatus* + *M. surmuletus*; from about 6 to 10 months for big *Eledone cirrhosa*, *Liocarcinus depurator*, small *Merluccius merluccius*, small *Micromesistius poutassou*, *Sepia officinalis* and *Trisopterus minutus capelanus*; from about 10 to 16 months for *Engraulis encrasicolus*, big *Merluccius merluccius*, big *Micromesistius poutassou*, *Pagellus acarne* + *P. bogaraveo* and *Penaeus kerathurus*; from about 16 to 18 months for *Sardina pilchardus*; and from about 18 to 26 months *Donax trunculus*. Thus, for example, the bivariate transfer function model fitted to small *Eledone cirrhosa* landed in Roses harbour ( $Y_t$ ; output) and Rhône runoff ( $X_t$ ; input) is represented by the following equation (Table 1, Fig. 6C):

$$Y_t = f(X_t) = 1.23X_{t-2} + 1.26X_{t-3} + 1.54X_{t-4} + 1.14X_{t-6} + a_t$$

Thus, an additional 1 m<sup>3</sup>/s Rhône runoff during the reproduction time of *Eledone cirrhosa* (i.e. March through July) leads to a 1.23 kg added catch of small *Eledone cirrhosa* during the second following

month, 1.26 kg added catch during the third following month, 1.54 kg added catch during the fourth following month and 1.14kg added catch during the sixth following month, with a total gain of 5.17 kg for all these months. The  $r^2$ -value of this equation was 0.78. This indicated that 78% of the variance of the  $Y_t$  time series of catch was explainable by the variance of the Rhône flow at a lag of 2, 3, 4 and 6 months.

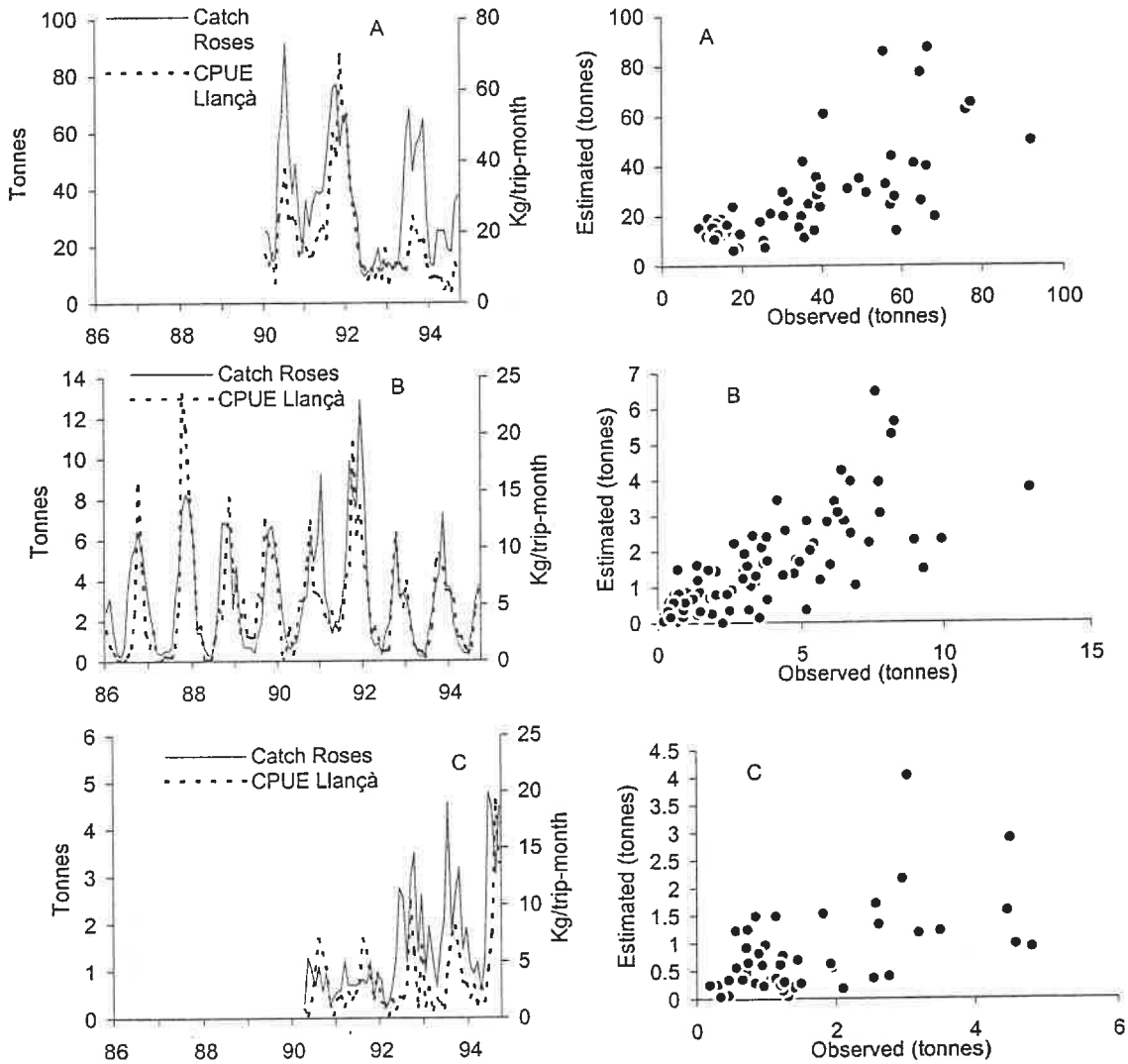


Figure 5. The time series of catch in Roses harbour and CPUE in Llança harbour (left column) and the observed against the estimated catches in Roses from the transfer function models (right column). A: *Merluccius merluccius* (Small), B: *Loligo vulgaris*, C: *Liocarcinus depurator*

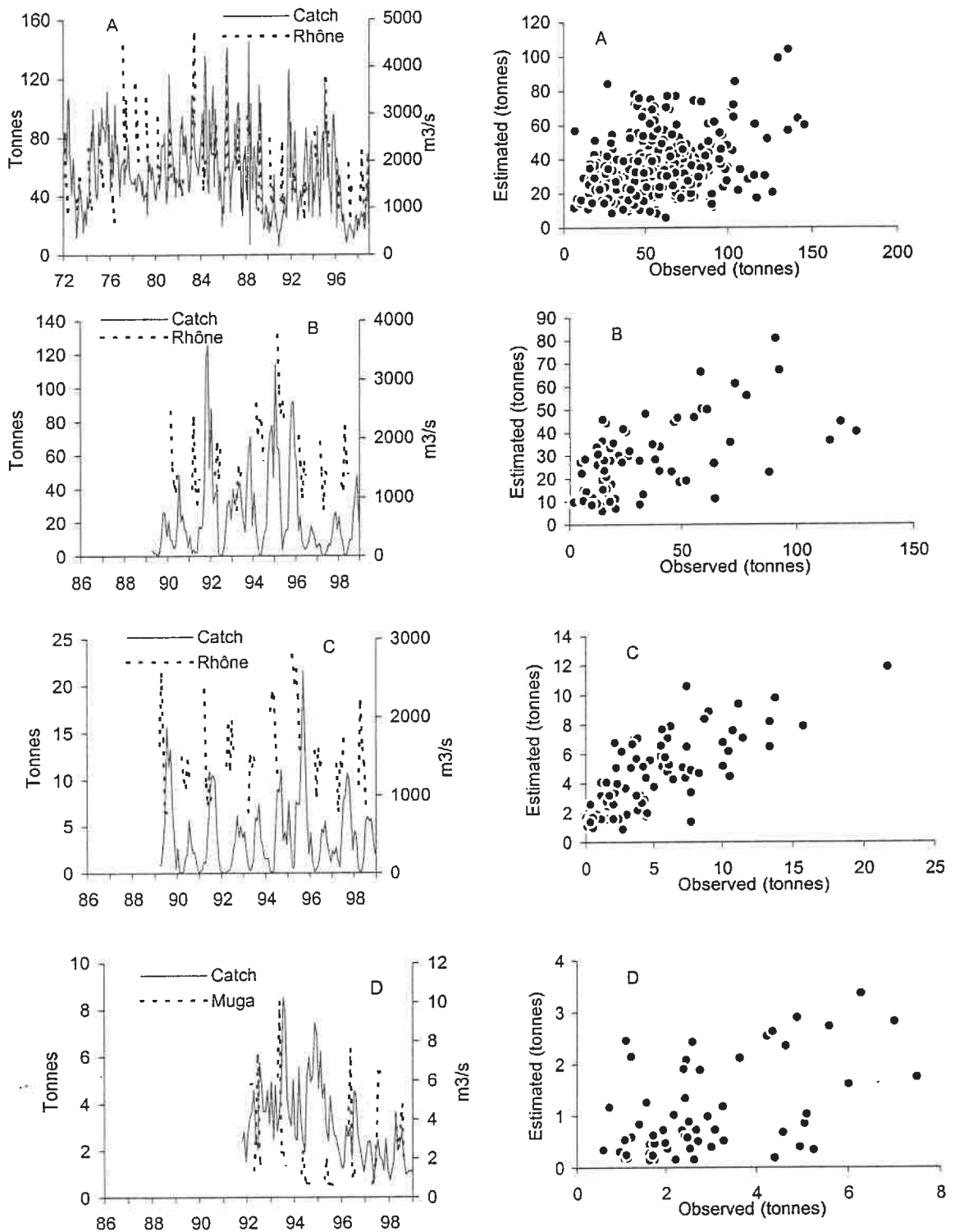


Figure 6. The time series of yield (catch and CPUE) and of river runoffs (Rhône and Muga) during the spawning season of each species (graphs on the left), and the observed against the estimated yield from the transfer function models (graphs on the right). A: *Micromesistius poutassou* (Big + Small), B: *M. poutassou* (Small), C: *Eledone cirrhosa* (Small); D: *Donax trunculus*

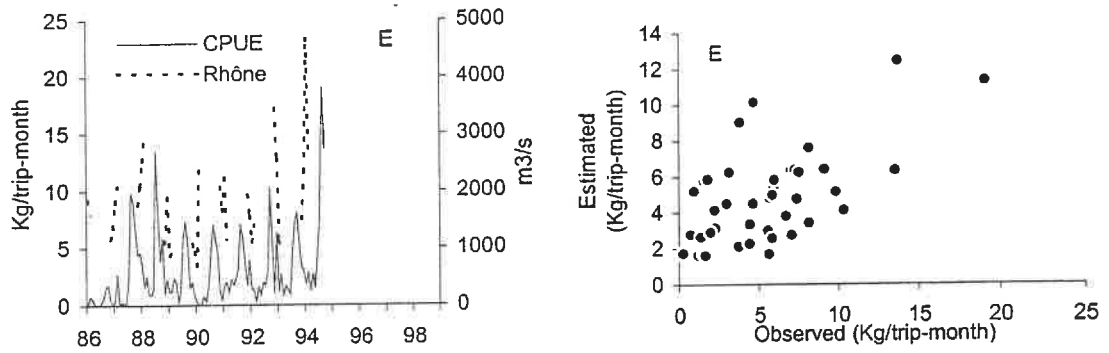


Fig. 6. Cont. E: *Liocarcinus depurator*

## Discussion

The transfer function models between yield and environmental variables during the spawning seasons of the species studied showed that, for most of the species, catch and CPUE were significantly positively correlated with river flows and the wind mixing index. The comparative examinations of all cases studied revealed important similarities in the responses of recruitment size to considered variables. The biggest portion of catches for nearly all species considered is composed by individuals in the first year of life (according to a sampling program carried out during year 1999 at the Roses Fishmarket, which is not yet published), and can be therefore considered as a proxy of the recruitment. This explains why we found lags of about one year and less in nearly all species. These lags might indicate the time required for incorporation of nutrients into the food chain and for growth of the larvae to recruitment (into the fishery) sizes. Thus, for example, small *Eledone cirrhosa* presents a short time lag at around 2-6 months with Rhône runoff during its spawning season (March-July). Recruitment of small *Eledone cirrhosa* into the fishery in our area of study occurs from 2 to 6 months after spawning (Sánchez and Martín, 1993). Small *Merluccius merluccius* had a significant time lag at 9 months with the wind mixing index. *Merluccius merluccius* mainly spawns from September to January in the Northwestern Mediterranean, while offspring mainly recruit into the fishing grounds after 8-10 months (i.e. spring- autumn; Recasens *et al.*, 1998). *Engraulis encrasicolus* had a significant time lag at 13 months with the Rhône runoff. This species spawns and is mainly caught during summer when most of the individuals are one year old (Palomera, 1992; Perterra and Leonart, 1996). Although significant positive correlations of fish and invertebrate recruitment to river runoff and wind mixing index were established for nearly all species studied, none of the models was very good. This indicates that other variables, such as the parental stock biomass and density dependence processes (e.g. Myers and Cadigan 1993, Fromentin *et al.* 1997, Bjørnstad *et al.* 1999) also influence the year class strength. Our results show that enhanced hydroclimatic activity (i.e. enhanced river flow and wind activity) in the NW Mediterranean has a positive but not dominant influence on production of fish and invertebrate stocks.

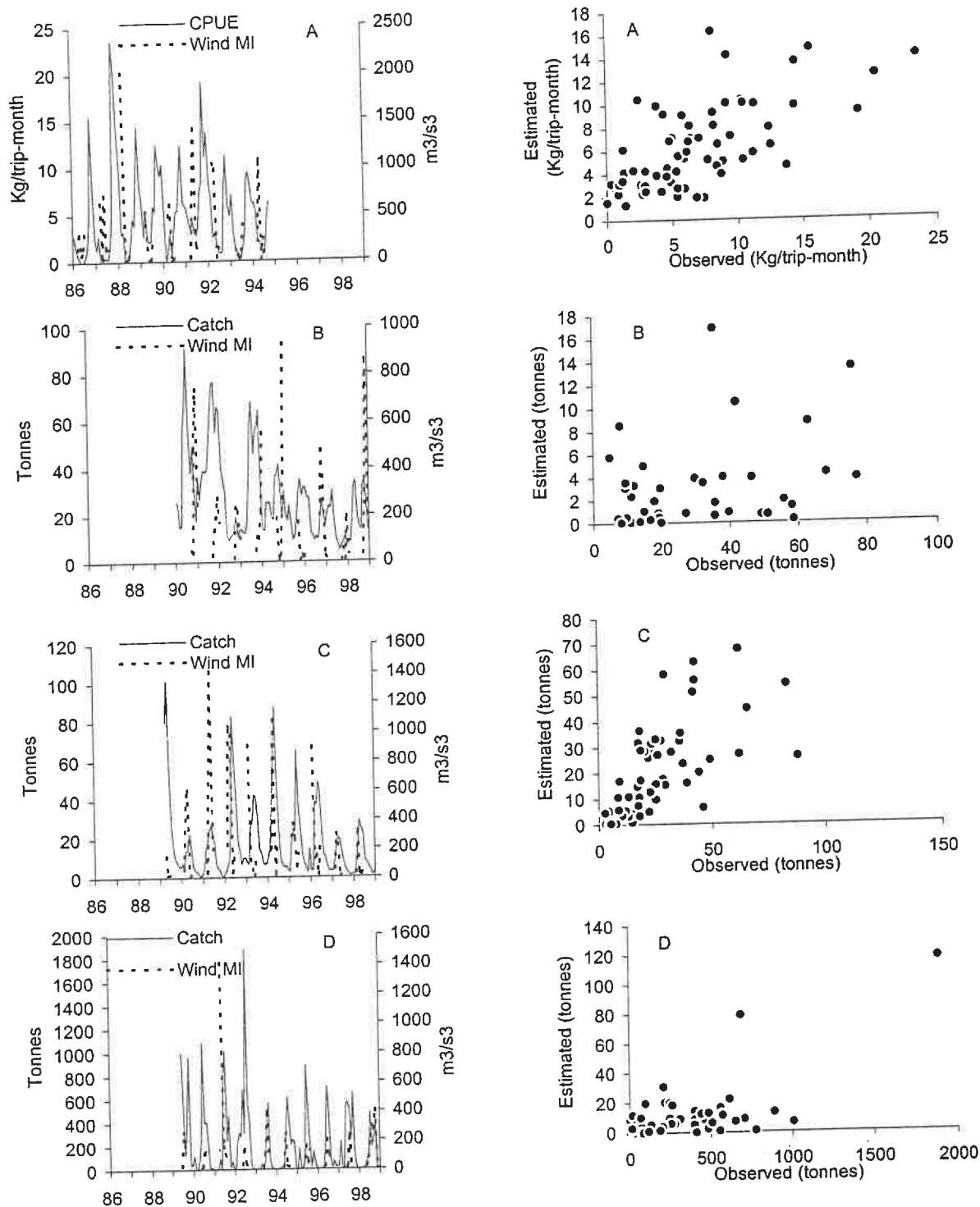


Fig. 7. The time series of yield (catch and CPUE) and of wind mixing index (Wind MI) during the spawning season of each species (graphs on the left) and the observed against the estimated yield from the transfer function models (graphs on the right). A: *Loligo vulgaris*, B: *Merluccius merluccius* (Small), C: *Micromesistius poutassou* (Big), D: *Engraulis encrasicolus*



The fluctuations of river discharges and the wind mixing index are cyclic but independent between them. Nevertheless, periods of low discharges and low wind mixing index can coincide (e.g. 1972, 1989 and 1997). This combination is especially unfavourable for the reproduction of many NW Mediterranean species. During these drier and calmer than normal periods, lower than normal catches were recorded for many species, and a great number of outliers (shifts) were observed in the catch figures of many of them (Lloret *et al.*, 1999). Landings in Roses harbour have been also observed to follow a quite cyclic behaviour (Lloret *et al.*, 1999). Water temperature at 20 m depth showed a progressive warming trend but did not follow important interannual fluctuations. Increasing water temperature in the western Mediterranean has been reported for other oceanographic stations too (Francour *et al.*, 1994). We did not relate water temperature with fishery yield mainly because of the weak interannual water temperature variability, but also because water temperature has probably an indirect relationship with primary productivity in the area (e.g. warmer temperatures might reduce wind-induced mixing through enhanced stratification; Salat, pers. com.). The influence of temperature on Mediterranean fishes remains however unclear for the moment. Daskalov (1999) found insignificant effects of temperature on recruitment of whiting and anchovy in the Black Sea, and negative effects on sprat and horse mackerel, while Regner (1996) found a positive influence of temperature on survival of egg and postlarvae of anchovy in the Adriatic. In addition to this, ring formation in otoliths of some Mediterranean fishes (e.g. hake) seems not to be related to water temperature (Morales-Nin *et al.*, 1998). Other environmental variables like salinity, atmospheric pressure, oxygen and light conditions have been not considered in this study because they might have a possible indirect and less clear relationship with productivity of fish stocks. For the same reasons, NAO Index has been not compared with fishery yield (it is a large-scale factor which is related to local environmental conditions like temperature, precipitation, storms and atmospheric pressure; Visbeck *et al.*, 1998).

Transfer function models usually did not outperform the ARIMA univariate models for the output variables, as the residual standard errors (RSE) of transfer function models were only slightly lower than those of the ARIMA models for catch and CPUE. Thus, transfer function models are explanatory and have no more predicting power than the univariate models. Transfer function models give inconsistent estimates of the coefficients when there is feedback from the output to the inputs, a problem that arises when there is an influence of the output on the inputs or when data are temporal averages (Pankratz, 1991). In the present case it is not reasonable to think that changes in catch or CPUE will lead to later changes in river runoffs or wind conditions. In addition to this, environmental data and CPUE are monthly averages, and only catch data are temporal aggregates. Therefore, statistical feedback problems cannot arise here. The Box-Jenkins methodology has been also used to model dynamics of marine species in other areas in relation to climate variability (e.g. Keller, 1987; Fogarty, 1988; Hare and Francis, 1995; Tsai *et al.*, 1997; Stergiou *et al.*, 1997; Downton and Miller, 1998).

Because of the oligotrophic character of the Mediterranean (Margalef, 1985), local events like wind-driven mixing and river discharge can have an important role on the local fertilization (Estrada *et al.* 1985; Estrada, 1996). Rhône river runoff is responsible for an abundant nutrient input in the Gulf of

Lions (Estrada *et al.*, 1985; Pont, 1997) as well as for increasing stratification and enhancing the thermohaline shelf-slope front which occurs in the area (Salat and Font, 1987; Masó and Tintoré, 1991). The geographical position and strength of this front limits the offshore dispersal of larvae of coastal and shelf species in the area (Sabatés, 1996; Olivar *et al.*, 1998) and is a main spawning area for anchovy (Palomera, 1992). Anchovy larvae are associated with the presence of surface less saline water of continental influence (Palomera, 1992; Sabatés *et al.*, 1999). Freshwater discharges have been demonstrated to enhance recruitment of marine species in other areas of the world, e.g. cod off north coast of Norway (Skreslet, 1976); cod in the Gulf of St Lawrence (Bugden *et al.* 1982; Chouinard and Fréchet, 1994); American lobster and Atlantic halibut in the Gulf of St Lawrence (Sutcliffe, 1973); sprat, whiting, anchovy and horse mackerel in the Black Sea (Daskalov, 1999) and anchovy in coastal waters off south-western Taiwan (Tsai *et al.*, 1997) and in the northern Adriatic (Levi *et al.*, 1999). Caddy *et al.* (1995) also suggested that large inputs of nutrients from river flows could have contributed to the continuous rise of the overall Mediterranean landings in the 1970s and 1980s despite the high exploitation rates. Water mixing induced by the predominant strong, cold and dry northwesterly winds blowing at the NW Mediterranean leads to upwelling of nutrients and a subsequent increase in planktonic production (Millot 1979, Pinazo *et al.* 1996, Estrada 1996). This air mass determines in part the horizontal general circulation in the region as enhances thermohaline fronts (Salat and Font, 1987; Astraldi and Gasparini, 1992; Castellari *et al.*, 1998), and intervenes in the deep water formation during winter (Salat and Font, 1987). Positive relationships between wind activity and recruitment of marine species have been also found in other seas, e.g. anchovy of the southwestern Atlantic (Bakun and Parrish, 1991) and sprat, anchovy and horse mackerel in the Black Sea (Daskalov, 1999).

Hydrological variables studied themselves interact with one another at different spatial scales, showing synchronous interannual fluctuations (e.g. Rhône and Ebre runoffs). Global hydroclimatic fluctuations in Europe are well-described (Maheras, 1988; Probst, 1989; Vivian, 1989, Martín-Vide, 1994). Although the Rhône and Ebre runoffs were significantly correlated with NAO, the Muga runoff and rainfall in Roses were not, probably because of their local structure. We have shown that runoffs of the Rhône and Ebre rivers are reduced during high NAO index winters. Drier (reduced precipitation) and warmer than normal conditions occur during high NAO index winters over much of central and southern Europe (the northern Mediterranean) and west North Africa (Hurrell, 1995; Visbeck *et al.*, 1998; Martín-Vide *et al.*, 1999). At the same time, wetter than normal conditions occur from Iceland through Scandinavia. According to this, not only local fishery resources of the NW Mediterranean should be negatively influenced by drier conditions during high NAO index but also the fishery resources of other areas of the Mediterranean (as much as the NAO is known to influence zooplanktonic production, see Fromentin and Planque 1996).

In summary, it can be concluded that: (i) Increased river flow and wind mixing index are favourable conditions for the productivity of the NW Mediterranean fish and invertebrate stocks; (ii) The fluctuations of river discharges and the wind mixing index are cyclic but independent between them; (iii) Despite the interactions between hydrological variables studied, runoffs of the two main rivers of the NW Mediterranean (Rhône and Ebre) are negatively affected by high winter NAO episodes.

## Appendix 1: Wind mixing index

The wind mixing index is the rate at which wind imparts mechanical energy of the ocean to produce turbulent mixing of the upper water column, and it is roughly proportional to the third power, or cube, of the wind speed (Bakun and Parrish, 1991). Here the cube of the mean monthly wind speed has been calculated using data on wind speed and direction recorded every three hours in a daily basis. Monthly mean speeds were derived after transformation of daily raw data into U (along-shore) and V (cross-shore) wind components, and so the wind speed value was not incorporated directly but after vector analyses. Positive U and V values indicate wind blowing from the east toward the west and from the north toward the south, respectively.

## Appendix 2: Box-Jenkins modelling strategy

The Box and Jenkins modelling strategy considers three steps: identify the model, estimate the coefficients and verify the model. These procedures apply to stationary series (time series with no systematic change in mean and variance) whose data are normally distributed. First- or second-order differencing (non-seasonal and/or seasonal) remedies non-stationary mean and logarithmic transformation remedies non-stationary variance and also non-normal distributions of original data. In the same way that autocorrelation function was used to identify univariate ARIMA models, the data analysis tool employed for the identification of transfer function models is the cross correlation function between the input and output. Estimation of the coefficients of the model was done by means of the maximum likelihood method. Verification of the model was done through diagnostic checks of residuals. For the univariate-ARIMA models, the histogram and normal probability plots of residuals and the standardized residuals (which are found by dividing each residual by the residual standard deviation) were examined. For the transfer function models, the autocorrelation and the partial autocorrelation functions of the residuals (noise or disturbance) and the cross correlation functions involving input and residuals were examined. In case of evidence of transfer model inadequacy from the behaviour of individual autocorrelations, autoregressive and/or moving average parameters were fitted to noise and the iterative cycle of identification, estimation and diagnostic checking was repeated until a suitable model was found. The residual standard error was used to compare the accuracy between the univariate-ARIMA and the transfer models obtained. It is important to notice that we were not interested here in forecasting catch and CPUE using environmental variables but only in assessing the role of the input variables (river runoffs and wind conditions) in explaining the behaviour of the output variable (catch and CPUE). This is because the forecasting accuracy of transfer function models of catch or CPUE depends on the accuracy of the forecasts for the environmental variables, and predicting environmental variables (predicting climate) is at a rather early stage (Latif, 1999). Therefore, we simplified the transfer function models as much as we could, without differencing neither transforming logarithmically the raw data and allowing the random appearance of some outliers in the residuals of the models (diagnostic checking of residuals did not indicate any inadequacy; disturbance series were stationary and did not show any structure).

The bivariate transfer function models are expressed by the following general equation (Pankratz, 1991):  $Y_t = f(X_t) = v_0 X_t + v_1 X_{t-1} + v_2 X_{t-2} + \dots + a_t$ . Coefficient  $v_0$  is a weight that states how  $Y_t$  responds to a change in  $X_t$  (current month change in  $X_t$ ); coefficient  $v_1$  states how  $Y_t$  responds to a change in  $X_{t-1}$  (one month earlier change in  $X_t$ ); coefficient  $v_2$  states how  $Y_t$  responds to a change in  $X_{t-2}$  (two months earlier change in  $X_t$ ), and so forth. The  $v$  weights can be positive or negative. Of course, the larger the absolute value of any weight  $v_k$ , the larger the response of  $Y_t$  to a change in  $X_{t-k}$ . The sum of these weights gives the total gain. Only significant coefficients at a  $t$  value  $> |3|$  ( $p < 0.05$ ) were considered.  $a_t$  are random shocks. Before fitting transfer function models, univariate ARIMA models (Box and Jenkins, 1976) were built for the local environmental factors and catch and CPUE using the monthly data. There are several advantages to performing these preliminary analyses. First, univariate time series models give a baseline model for the output series of the transfer function models. In particular, we can consider the transfer function residual standard errors and compare them with the residual standard errors of the ARIMA models for the output variables. Second, in the transfer function model testing stage, residuals from ARIMA models for the input series are needed at the checking stage of transfer function models.

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