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Variability of physical factors relevant to fisheries production in the Mediterranean Sea, North Sea and Baltic Sea

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ABSTRACT

Recent publications have shown that river runoff and wind mixing are two major environmental factors affecting productivity of fish populations in subtropical and tropical areas, as opposed to water temperature in colder waters. In the present paper, we compare the variability of seawater temperature, river runoff and wind mixing in three different seas: a subtropical sea (the Mediterranean) and two cold seas (the North Sea and the Baltic). Temperature variability decreased from colder to warmer areas. The highest temporal variability in the river runoff corresponded to rivers flowing into the Mediterranean, and the lowest corresponded to rivers flowing into the North Sea and the Baltic Sea. The variability in the wind mixing index (cube of the wind speed) depended on the area under consideration, and attained maximum values in the Cap Béar station (northwestern Mediterranean). The effect of these regional variability differences in environmental factors on fisheries production is briefly discussed.

Keywords: Environmental variability, fisheries production, river runoff, wind mixing, water temperature.

RESUMEN

Variabilidad de factores físicos importantes para la producción pesquera en el mar Mediterráneo, Mar del Norte y el mar Báltico

Investigaciones recientes demuestran que las descargas fluviales y los vientos son factores ambientales clave para la productividad de las poblaciones explotadas en zonas subtropicales y tropicales, mientras que en mares fríos la temperatura del agua constituye el factor ambiental más importante para la productividad pesquera. Este estudio compara las diferencias geográficas en la variabilidad temporal de tres factores físicos (temperatura del agua, aportes fluviales y velocidad del viento) en un mar subtropical (Mediterráneo) y dos mares fríos (Mar del Norte y Báltico). La variabilidad temporal de la temperatura del agua es mayor en los dos mares fríos que en el subtropical. Así mismo, los ríos que desembocan en el Mediterráneo presentan mayor va-

riabilidad temporal en cuanto a los aportes fluviales que los ríos que desembocan en el Mar del Norte y el mar Báltico. La variabilidad temporal en el índice de mezcla del viento (velocidad del viento al cubo) es distinta según la zona que se considere, y es máxima en la estación de Cap Béar (Mediterráneo noroccidental). Finalmente, se discuten los efectos de esta variabilidad ambiental geográfica sobre las poblaciones explotadas.

Palabras clave: *Variabilidad ambiental, productividad pesquera, descargas fluviales, vientos, temperatura del mar.*

INTRODUCTION

Whereas in relatively cold areas, such as the Baltic and North Seas, water temperature has been widely reported to impact fishery productivity (see e.g., Brander, 1995; Hare and Francis, 1995; Sundby, 1998; Rätz, Stein and Lloret, 1999; Hollowed, Hare and Wooster, 2001; Rätz and Lloret, 2005), in relatively warm and oligotrophic seas, such as the Mediterranean, and tropical areas, such as the Gulf of Mexico, fisheries production has been commonly related to physical factors enhancing fertilisation, such as river runoff and wind mixing (Dickson and Brander, 1993; Conway, Coombs and Smith, 1998; Stergiou, Christou and Petrakis, 1997; CAST, 1999; Grimes, 2001; Lloret *et al.*, 2001; Lloret *et al.*, 2004). All of these physical parameters vary widely, and are important features of the oceanographic and meteorological conditions in the study areas (Probst, 1989; Astraldi and Gasparini, 1992; Heburn, 1994; Fromentin and Ibanez, 1994; Stein, 1994; Poulos, Drakopoulos and Collins, 1997; Castellari, Pinardi and Leaman, 1998; CAST, 1999). However, there is little information about how the differences in variability of these physical factors between cold and warm seas may affect fish production.

The present study aims to compare temporal variability in three physical factors in three different seas: the Mediterranean Sea, the North Sea, and the Baltic Sea. The paper focuses on three physical factors –water temperature, river flow, and wind– which have been demonstrated to impact productivity (growth, recruitment or condition) of commercial fish species inhabiting these areas. This study does not aim to analyse the influence of physical factors on fisheries production; instead, it intends to find any evidence that the impact of a given physical variable on fish production is more probable in one area or location compared with another one, simply because there are differences in environmental variability among these areas or locations. The effects of environmental conditions on fish recruitment should be more detectable in areas of high variability.

MATERIALS AND METHODS

Oceanographic and meteorological data were obtained from different sites and sources, and in different years (table I, figure 1). Data included temperature, runoff and wind data from different oceanographic stations, areas and rivers. Temperature data were the monthly and annual mean sea surface temperature (0-5 m depth) recorded at Estartit oceanographic coastal station (Mediterranean) and Helgoland oceanographic island station (North Sea), and the monthly and annual mean SST (0-2 m depth) of the averages of the North Sea, the Bornholm Basin (Baltic Sea), and the Aegean Sea (Mediterranean), based on weekly observations (from research and commercial vessels). Runoff data from different rivers recorded downstream, near the mouth, included: the Rhône, the Ebro, the Muga, the Acheloos, the Nestos and the Aliakmon, flowing into the Mediterranean; and the Rhine, the Elbe, the Weser, the Thames and the Nene, flowing into the North Sea. Daily wind speed and direction were recorded at sea level in different areas: Helgoland meteorological island station (North Sea), Cap Béar meteorological coastal station (Mediterranean), and the average for the Aegean Sea (information based on vessel observations). We estimated a wind mixing index, which is the rate at which wind imparts mechanical energy from the ocean to produce turbulent mixing of the upper water column, and it is roughly proportional to the third power, or cube, of wind speed (Bakun and Parrish, 1991). Monthly and annual mean wind cubic speeds were derived after transformation of daily raw data into U and V components. Positive U values indicate wind blowing east to west, and V values indicate north to south. From the wind components, we calculated the mean monthly and mean annual scalar wind, which is the square root of $U^2 + V^2$. We used scalar wind as an indicator of the intensity of input of mechanical energy by the wind, which induces the turbulent mixing of the upper ocean. The present study focuses on wind mixing

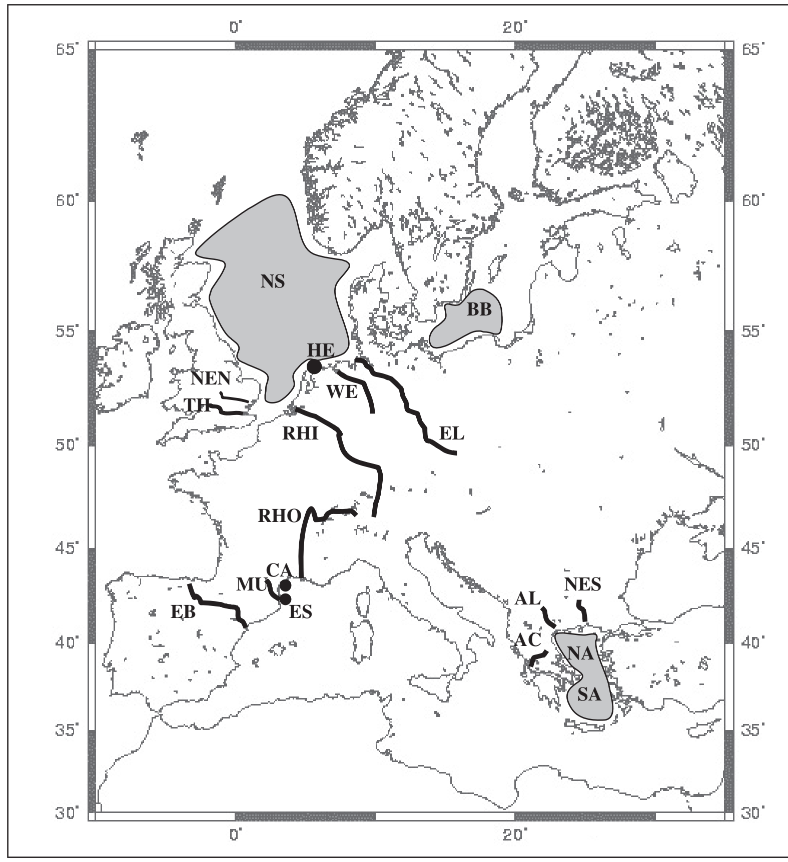

Figure 1. Map of areas –North Sea (NS), Bornholm Basin/Baltic (BB), Northern Aegean (NA), Southern Aegean (SA)–, rivers –Thames (TH), Nene (NEN), Elbe (EL), Weser (WE), Rhine (RHI), Rhône (RHO), Muga (MU), Ebro (EB), Nestos (NES), Aliakmon (AL), Acheloos (AC)– and oceanographic and meteorological stations –Helgoland (HE), Estartit (ES), Cap Béar (CA)– considered in this study

instead of wind-induced upwelling; this is because winds promoting upwelling are different from area to area, and in some areas, such as the northwestern Mediterranean, nutrient enrichment is mainly through wind mixing rather than upwelling.

Time series of environmental variables were described by calculating the seasonal component and the trend by means of multiple moving averages, using the time series statistical package Tess (Prat, Catot and Sole, 2001). This software is based on arima (autoregressive integrated moving average) models (Box and Jenkins, 1976). Whereas the seasonal component (i.e. seasonal variability) shows spectral peaks at seasonal frequencies (the seasonal value for a given month is the percentage above/below the annual mean), the trend represents the smoothed evolution of the series. Tess software fits the best trend for each time series using the optimum filter in each case after considering the length of the time series, the seasonal pattern, and the magnitude of interannual fluctuations. For each time series, the monthly mean seasonal values were computed using all available data, as shown in table I.

Furthermore, we analysed the coefficient of variation (CV) for annual mean river runoffs and scalar wind, while we computed the SD for the annual mean water temperatures because CV is calculated only for ratio scale data, whereas it is not valid for temperature data measured on the Celsius or Fahrenheit scales (Sokal and Rohlf, 1981).

Because area averages are less variable than data registered at single locations (stations), we compared variability in temperature and wind speeds between stations (i.e. Cape Béar versus Helgoland) and between areas (i.e. Northern Aegean versus Southern Aegean).

RESULTS

Water temperature

There were marked seasonal fluctuations of water temperature, as well as geographic differences in variability between areas (figure 2). At the Estartit coastal station (northwestern Mediterranean), interannual fluctuations were nearly absent, and only a constant warming trend was observed (figure 2). Maximum water temperatures occurred from June through October in all areas (figure 3A,B). Water

Table I. Data on the physical factors studied at the different areas, together with the sources and the S.D. and C.V. values of annual means

Variable	Area/station/River	Area	Time series	Source	S.D.	C.V. (%)
Water temperature (0-5m depth)	Estartit station	Northwestern Mediterranean	1974-1997	Mr Josep Pascual (Spain); Estartit oceanographic station	0.44	
	Helgoland station	Southern North Sea	1960-1995	Biologische Anstalt Helgoland (Germany); island station	0.64	
SST	Northern Aegean Sea	Eastern Mediterranean	1960-1997	COADS data base; vessel trips	0.39	
	Southern Aegean Sea	Eastern Mediterranean	1960-1997	COADS data base; vessel trips	0.27	
	North Sea	North Sea	1971-1998	Bund. für Seesch. und Hydrogr. (Germany); vessel trips	0.49	
	Bornholm Basin	Baltic Sea	1960-1997	ICES (Denmark); research cruises	0.91	
River flow	Rhône	Northwestern Mediterranean	1955-1999	Compagnie National du Rhône (France)		19
	Muga	Northwestern Mediterranean	1973-1998	Servei d'Hidrologia de Catalunya (Spain)		83
	Ebro	Western Mediterranean	1955-1999	Confederación Hidrográfica del Ebro (Spain)		40
	Acheloos	Eastern Mediterranean	1965-1988	Institute of Marine Biology of Crete (Greece)		19
	Aliakmon	Eastern Mediterranean	1962-1981	Institute of Marine Biology of Crete (Greece)		38
	Nestos	Eastern Mediterranean	1965-1989	Institute of Marine Biology of Crete (Greece)		29
	Rhine	North Sea	1956-1998	Deutsches Ozeanogr. Datenzentrum (Germany)		21
	Weser	North Sea	1956-1998	Deutsches Ozeanogr. Datenzentrum (Germany)		31
	Elbe	North Sea	1956-1998	Deutsches Ozeanogr. Datenzentrum (Germany)		28
	Thames	North Sea	1955-1999	National Water Archive, Centre for Ecol. & Hydr. (UK)		31
	Nene	North Sea	1955-1987	National Water Archive, Centre for Ecol. & Hydr. (UK)		33
Wind mixing index (W^3)	Cape Béar	Northwestern Mediterranean	1968-1998	Météo France (France); meteorological station		36
	Northern Aegean Sea	Eastern Mediterranean	1960-1997	COADS data base; vessel trips		22
	Southern Aegean Sea	Eastern Mediterranean	1960-1997	COADS data base; vessel trips		14
	Helgoland	Southern North Sea	1956-1997	Deutscher Wetterdienst (Germany); meteorological station		20

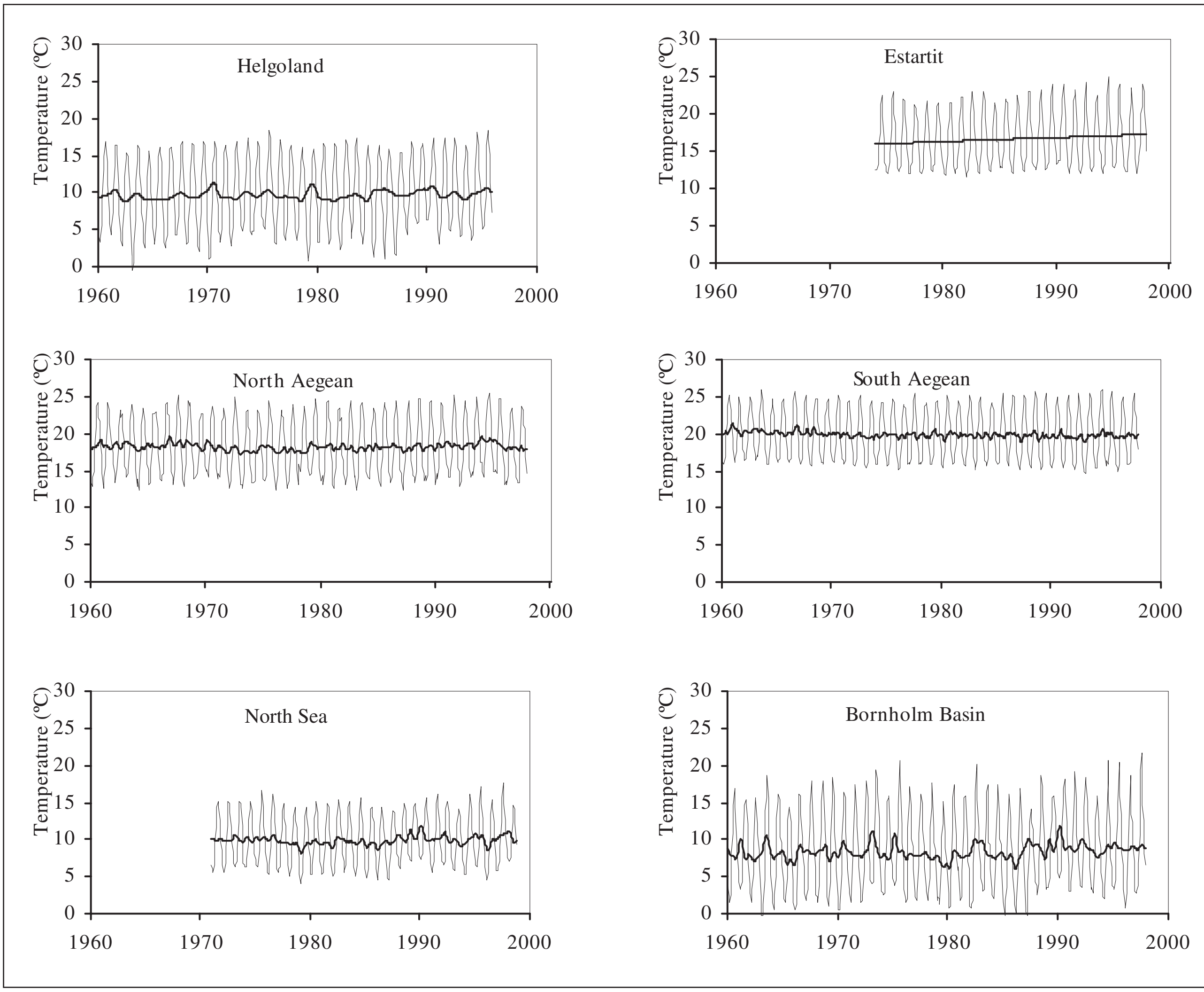

Figure 2. Time series of monthly means (thin line) and trend (thick line) of surface water temperature (0-5 m depth) at two oceanographic coastal stations (Helgoland, North Sea and Estartit, northwestern Mediterranean); and monthly means of sea surface temperature (SST) obtained from vessel trips covering different areas: Northern Aegean, Southern Aegean, North Sea and Bornholm Basin (Baltic Sea)

temperatures at the Helgoland island station (North Sea) were more variable than at the Estartit coastal station (western Mediterranean) as shown by the seasonal values (figure 3A) and the SD of annual values (table I). In addition to this, the largest fluctuations of SST (highest seasonal and SD values) occurred in the Bornholm Basin (Baltic), followed in order of magnitude by the North Sea, the Northern Aegean (Mediterranean) and the Southern Aegean (Mediterranean; figure 3B and table I).

River flow

Mean monthly river flows varied widely (figure 4). Minimum river flows occurred during the warmer months (i.e. from June through October; figure 3C,D). With the exception of the Rhône River, the monthly runoffs of the rivers flowing into the Mediterranean (Ebro, Muga, Acheloos, Aliakmon and Nestos) showed a negative long-term trend (figure 4). This is in contrast to rivers flowing into the North Sea, which did not show any long-term trend (figure 4). Again, with the exception of the Rhône, those rivers flowing into the Mediterranean had higher seasonal values (figure 3C) than those flowing into the North Sea (figure 3D). In addition to this, three rivers flowing into the Mediterranean (Ebro, Aliakmon and Muga) displayed the highest interannual variability (highest CV values; table I).

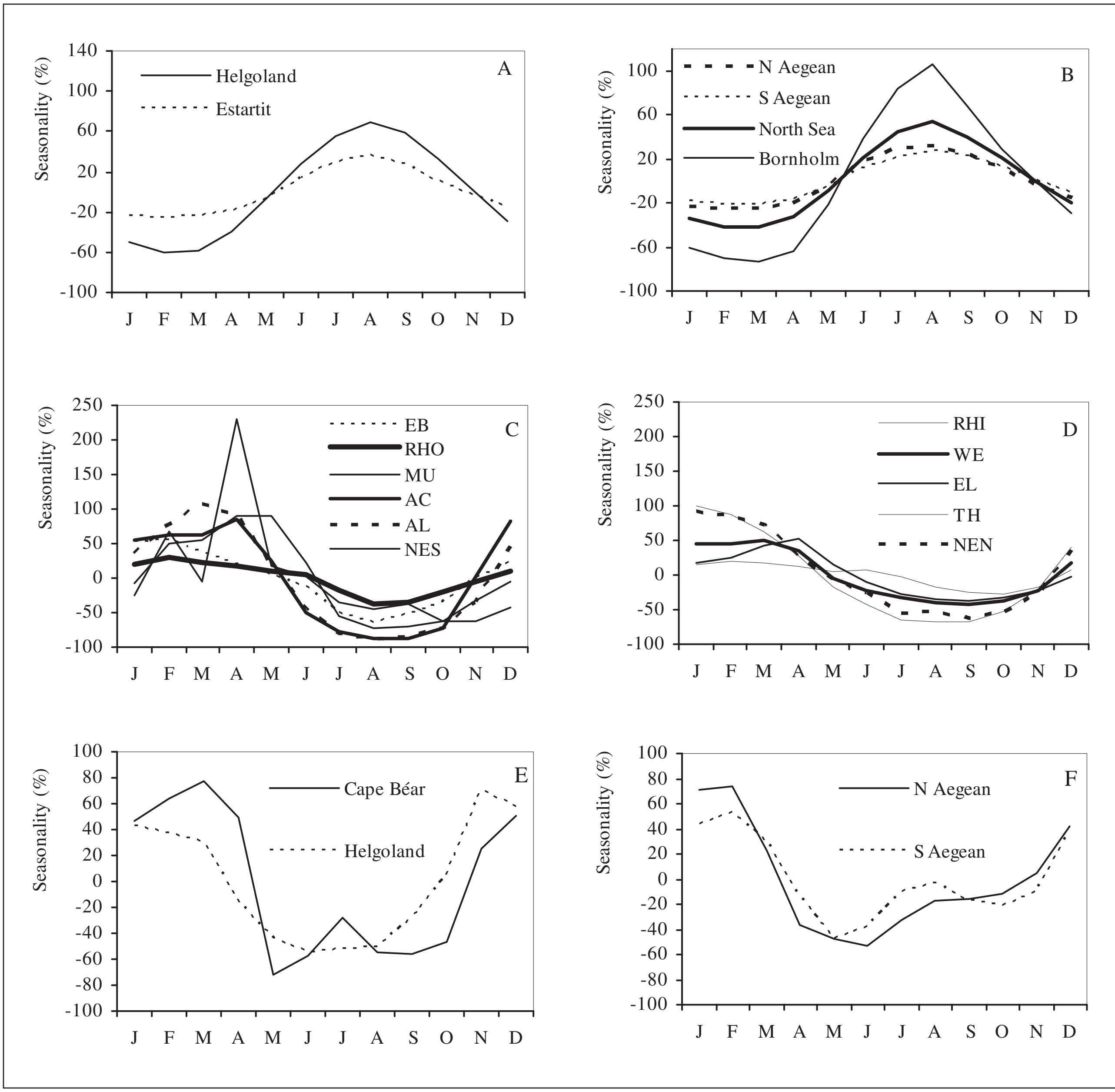

Figure 3. Mean seasonal patterns (in % above/below the annual mean) of (A): surface water temperature (0-5 m depth) at Helgoland and Estartit oceanographic stations; (B): sea surface temperature (SST) obtained from vessel trips covering different areas (Northern Aegean, Southern Aegean, North Sea and Bornholm Basin); (C): runoffs of rivers flowing into the Mediterranean; (D): runoffs of rivers flowing into the North Sea; (E): wind mixing index (cube of the wind speed) in Cape Béar and Helgoland meteorological stations; and (F): wind mixing index (cube of the wind speed) in the Northern and Southern Aegean. River codes are: (EB): Ebro; (RHO): Rhône; (MU): Muga; (AC): Acheloos; (AL): Aliakmon; (NES): Nestos; (EL): Elbe; (WE): Weser; (RHI): Rhine; (TH): Thames; (NEN): Nene

Wind mixing index

Mean monthly values of the wind mixing index showed strong fluctuations (figure 5). Seasonally, maximum values at all sites occurred from October through March (figure 3E,F), although strong wind mixing also occurred during summer (July-August) in the Aegean Sea. CV annual values of the wind mixing index were similar at all stations and areas. The Southern Aegean presented a lower interannual variability (lower CV) in the wind mixing index than the Northern Aegean (figure 5, table I), whilst this index shows greater interannual fluctuations in Cap Béar station (northwestern Mediterranean) than in Helgoland station in the North Sea (figure 5, table I).

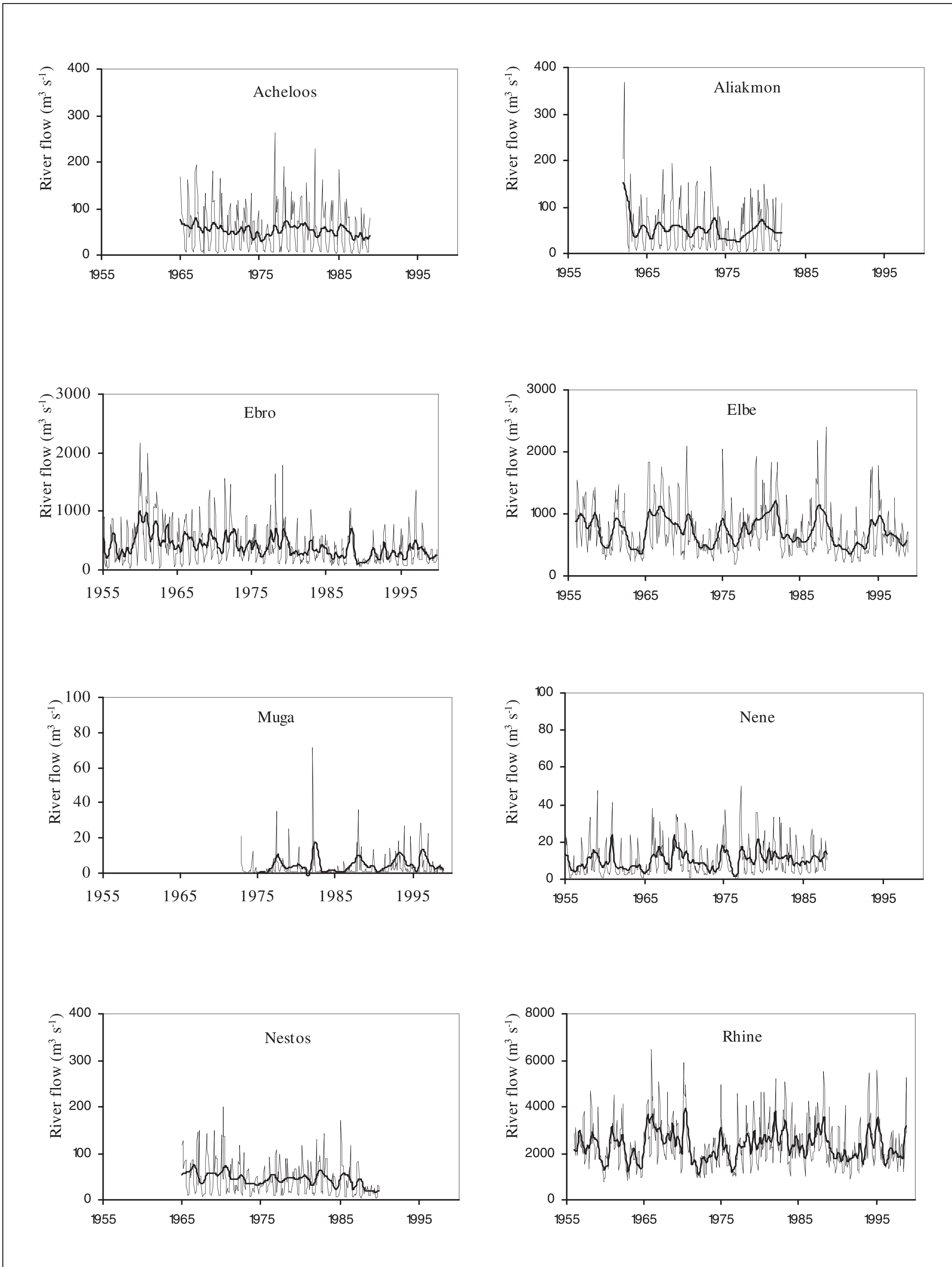

Figure 4. Time series of monthly means (thin line) and trend (thick line) of river runoffs

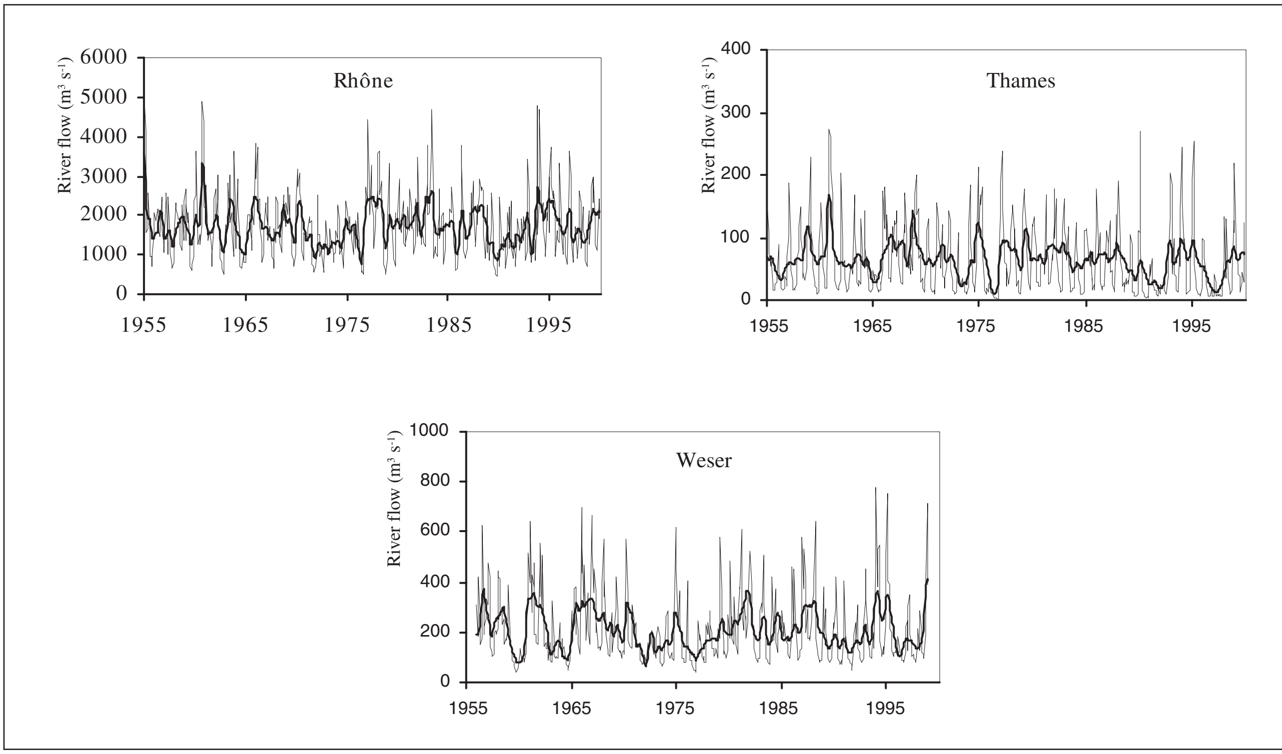

Figure 4 (continued)

DISCUSSION

The physical parameters studied showed spatial differences in temporal variability. There was a decrease in variability of water temperature from colder to warmer areas, i.e. from the Baltic to the North Sea, from the North Sea to the Mediterranean, and from the Northern to the Southern Aegean Sea. Amongst all rivers considered, the highest variability in runoff corresponded to rivers flowing into the Mediterranean. The variability in the wind mixing index (cube of the wind speed) depended on the area considered, and attaining maximum values at the Cap Béar station (northwestern Mediterranean).

We may assume that under conditions of strong environmental variability, environmental impact on fish biology is more likely, easier to detect statistically. In fact, most of the significant correlations between fish production and physical variables have been observed in highly variable environments, such as upwelling systems and the subarctic areas, and at the limits of the species' geographical ranges (Laevastu and Favorite, 1988; Myers, 1998; Planque and Frédou, 1999). In this context, our results suggest that: 1) evidence of an impact of water temperature on fish production could be detected more easily in the Baltic and the North Seas than in the Mediterranean, because of the higher temperature variability in the former areas; 2) relationships between local fish production and river discharges are also more likely to be detected in areas where river runoff displays strong fluctuations, such as some flowing into the Mediterranean; and 3) the effect of wind mixing on fishery productivity may depend on the specific area (not sea) under study.

Apart from environmental variability, other factors are also important for fish production, e.g. overexploitation (Laevastu and Favorite, 1988, degradation of fish habitats (Benaka, 1999) and pollution (CAST, 1999). The biological characteristics of a given species or population (e.g. growth, maturity, fecundity and behaviour) are adaptations to the ecosystem in which they are embedded (Love, 1974; Shulman and Love, 1999). Differences among rivers in the amount of runoff also imply differences in size of the sea area influenced by their river plumes. For example, water runoff of the Rhône is about three to four times that of the Ebro River, which implies that discharges of the former have a much broader area of influence once at sea than the discharge of the latter. Moreover, some areas have prevailing wind systems

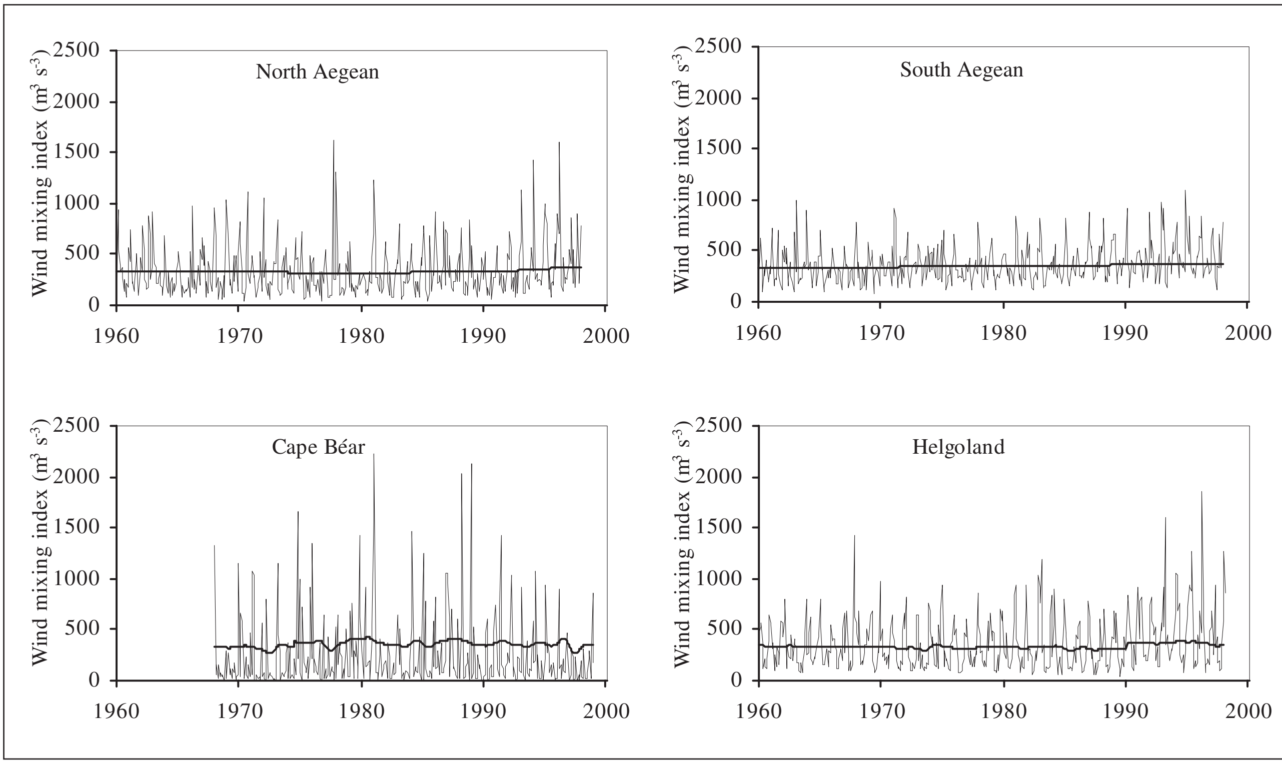

Figure 5. Time series of monthly means (thin line) and trend (thick line) of the wind mixing index (cube of the wind speeds) at different areas: North and Southern Aegean, Cape Béar (northwestern Mediterranean) and Helgoland (North Sea)

(e.g. northwestern Mediterranean), and thus are more sensitive to local wind anomalies than areas where wind direction is more variable (e.g. North Sea). It is known that near-coast upwelling, which is created by prevailing wind systems, is very sensitive to local wind anomalies (Laevastu, 1993). Finally, small changes in a physical factor may be more crucial for the productivity of a species than large changes in another factor, even if the former is less variable.

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