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Linking anchovy and sprat distributions with bio-physical oceanographic features: a Bay of Biscay – North Sea comparison.

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Distribution patterns of small-pelagic fish reveal migration at seasonal and regional scale, with notable differences among species. For each species, different environmental physical and biological factors determine the characteristics of its habitats, and potentially explain its observed migration pattern. In the Bay of Biscay, anchovy gathers in the southern part of the Bay from winter to spring when it spawns, before moving north from summer to fall. In the North Sea, anchovy spends the winter in the north west before moving back to the southern part for the rest of the year. In contrast, sprat is more resident in similar habitats around the year. We use both satellite data (chlorophyll-a data) and physical model outputs (Sea Surface Temperature and salinity, indices of water column stratification and frontal activity) to investigate the link between the observed fish distributions and oceanographic physical and biological features. Fish and environment data were averaged over all available years. General patterns arise, partly explaining seasonal distribution of both species, but calculated correlations between fish abundance and each of the individual environment variable remain poor. Increasing the significance of correlation patterns would require a higher temporal and spatial resolution, as well as using more explicit environment variable of the processes under which fish respond to their environment.

Key words: Fisheries oceanography, fish habitats, anchovy, sprat, Biscay, North Sea

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Introduction

Relationships between anchovy adult distribution and environment parameters have been studied in the Bay of Biscay during spring, the spawning season (Motos et al., 1996), when many scientific surveys have been carried out. Preference for specific hydro-planktonic entities can be deduced from intensive sampling (Petitgas et al., 2007). Modelling spawning habitat is then possible, using field or hydrodynamic simulated data (Planque et al., 2007). But fewer information is available when the temporal scale is added, that is when the spatial distribution of fish is investigated at seasonal scale, taking into account migration patterns. This is the aim of this note.

It compiles results on abundance distribution of anchovy (Engraulis encrasicolus) and sprat (*Sprattus sprattus*) populations in the Bay of Biscay and the North Sea, in relation to physical and biological environment parameters obtained from both remote-sensing data and model outputs, two environmental set of information largely distributed now and providing a complete view of the 3D ecosystem at high frequency. Anchovy and Sprat were chosen as they seem to respond differently to environment parameters, anchovy being in the North Sea at the northern end of its geographic extension, whereas Sprat being approximately at the centre of its extension. The two study areas allow us to verify the coherence of the observed response of fishes to their environment.

Results are displayed as maps of different environmental variables overlaid with fish abundance estimation from field surveys for two different seasons (spring/fall for the Bay of Biscay, and winter/summer for the North-Sea). Maps are climatology mean covering the years when both environment and fish data were available. In comparison with fish distribution at local scale for a given season, here the resolution is somehow eroded in the averaging, but without much consequences on stable features (those potentially responsible for migration) arising at regional/seasonal scale (the Bay or the North Sea) rather than at local/short-time scale. Thus we use this preliminary simple approach of raw averaging to explore some outstanding links between fish distribution and environment information. A later continuation of this work will allow a further investigation of the correlation on a yearly basis, taking into account both fish abundance and environment variability.

Material and Methods

Most of the data used in the two study areas were gathered and processed from different sources, as explained below. Part of it was processed the same way, this is the case for satellite chlorophyll data, and the post-processing for the index of fish abundance was similar.

Bay of Biscay

Abundances of anchovy and sprat were available for the Bay of Biscay area from two different sets of field cruises.

For the spring season, fish abundance is assessed from the French fisheries acoustic surveys (PELGAS surveys, 2000-2007). During the surveys, opportunistic mid-water pelagic trawl hauls are undertaken and are used to derive species-specific abundance estimates from the acoustic signal (echo-traces). The resolution of the distribution was set to $1/5^{th}$ of a degree in longitude, and $1/3^{rd}$ in latitude by averaging raw data.

For the fall season, fish abundance is obtained from the French bottom trawl surveys EVHOE which have been carried out during November-December over the Bay of Biscay and Celtic Sea shelves since 1997. Two modes can be observed in anchovy age-distribution in fall, so only individuals greater than 11 cm were counted, avoiding Age-0 consideration. Only the data from 2000 onwards and over the Bay of Biscay shelf have been retained (for a data coverage similar to PELGAS cruises).

Salinity is extracted from simulations of the hydrodynamic model MARS running over the Bay of Biscay (Lazure and Dumas, 2007). Sea surface temperature (SST) is derived from the NOAA-AVHRR Pathfinder products at 4 Km. Concentration in surface chlorophyll-a is derived from satellite measurements of ocean colour data using SeaWiFS or MODIS sensors (depending on the observation year). Satellite data was processed at Ifremer using an algorithm specially designed for coastal areas (Gohin et al. 2003, 2005).

North Sea

North Sea data from DATRAS (DAtabase for TRAwl Survey data) was used in the first and third quarters of the year (Q1 and Q3). Here again, two modes were apparent in the anchovy age-distribution, and only individuals greater than 11 cm were considered. Survey coverage of the North Sea prior to 1980 was less complete than for the years after. Abundances were averaged by ICES rectangle. The survey scheme being most regular, no spatial weighting was processed (though some surveys had lower spatial coverage than others).

The ECOSMO coupled model (Schrum et al. 2006) can be used to derive a complete set of environmental data, from temperature and salinity to primary and secondary production. In this preliminary work, only physical fields were used. In addition of temperature and salinity, indices of stratification (maximum of the vertical density gradient) and frontal activity (maximum of the horizontal gradient of the density stratification index).

Satellite data for chlorophyll-a was processed the same way as for the Bay of Biscay.

Data processing for fish abundance / environment comparison

Fish abundances values were averaged over areas specific to each survey, as given above. Thus the species abundance index is the data average by cruise-specific area, by year. The data presented in the result section is the abundance indexes averaged across years, and then plotted as circles over the environment maps. The area of the circles is representative of the abundance index over years.

Environment data were average over the time period of the yearly cruises in the case of PELGAS and EVHOE, and then a climatology over the period 2000-2007 was calculated. For the North Sea, environment data were average over quarters of the year, and then a climatology was calculated for the period over which environment data were available, that is 1967-2004 for model outputs, and 2000-2006 for satellite data.

Results

For each of the period, species and area, surface temperature, surface salinity and surface chlorophyll are plotted, over-laid with fish abundances. In the case of summer for the North Sea, we show in addition the indices of density stratification and frontal activity.

<u>Bay of Biscay</u>

+ Anchovy distribution in spring (PELGAS 2000-2006)

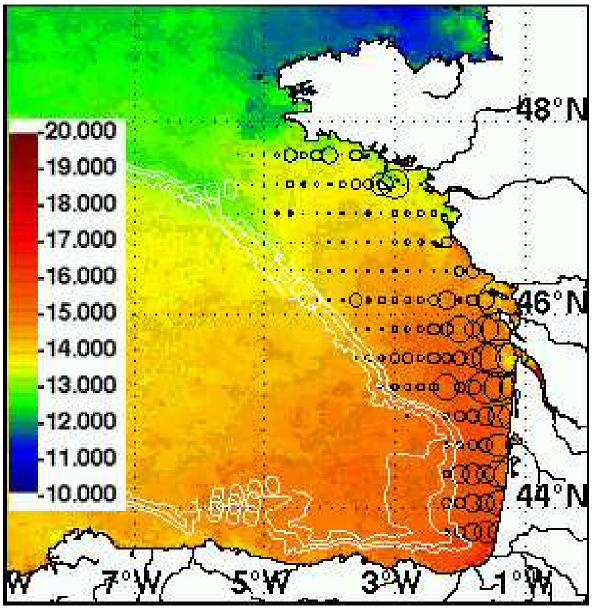

Fig. 1 Sea surface temperature (°C)

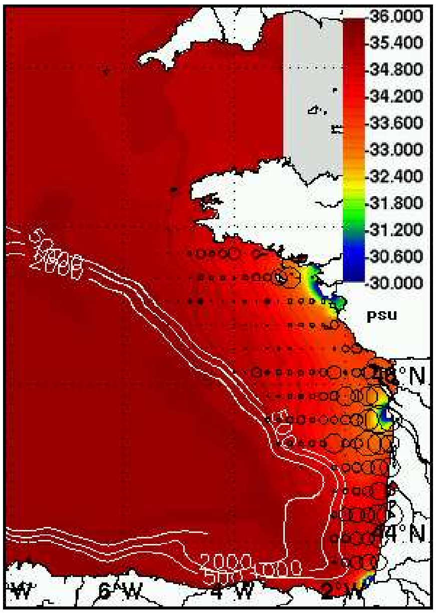

Fig. 2 Sea surface salinity

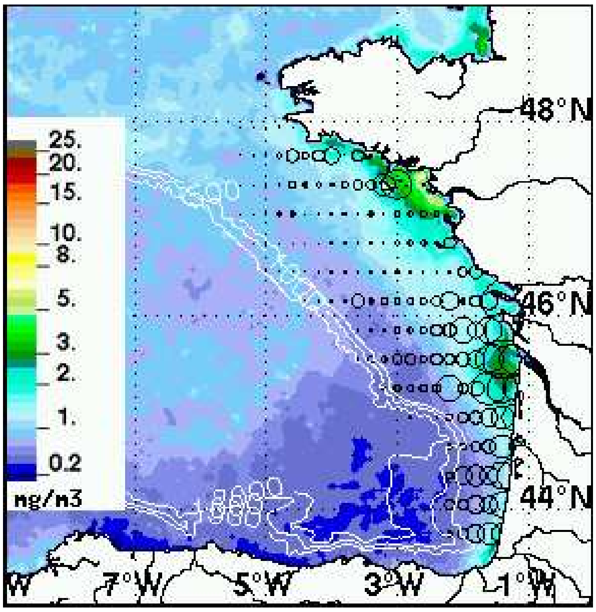

Fig. 3 Sea surface chlorophyll-a concentration

+ Anchovy distribution in Fall (EVHOE 2000-2006)

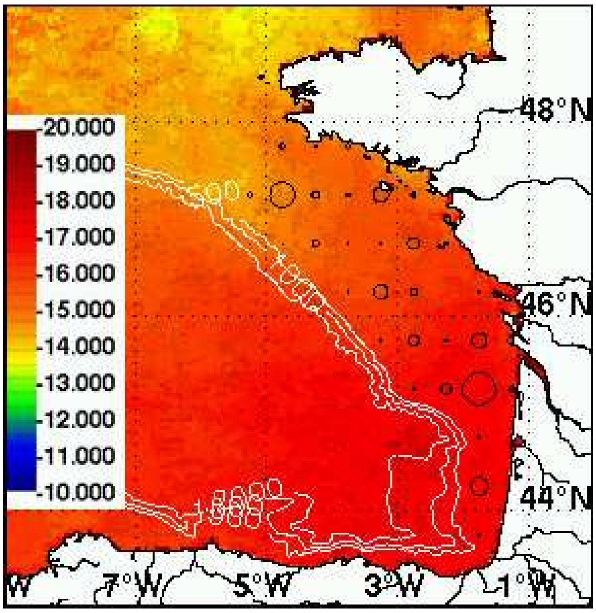

Fig. 4 Sea surface temperature (°C)

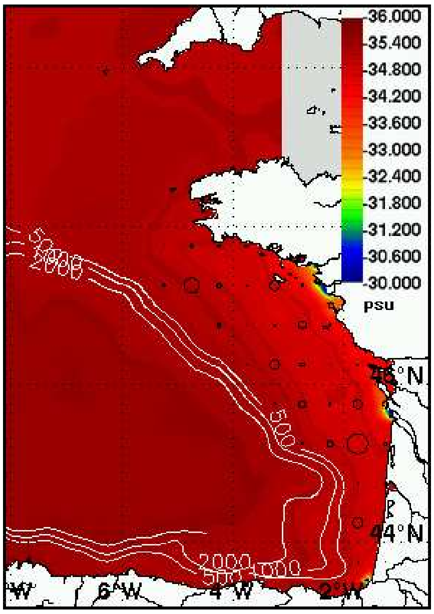

Fig. 5 Sea surface salinity

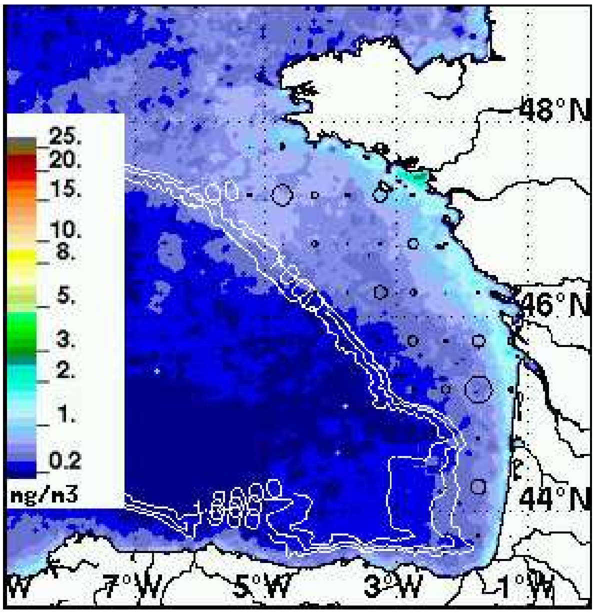

Fig. 6 Sea surface chlorophyll-a concentration

+ Sprat distribution in spring (PELGAS 2000-2006)

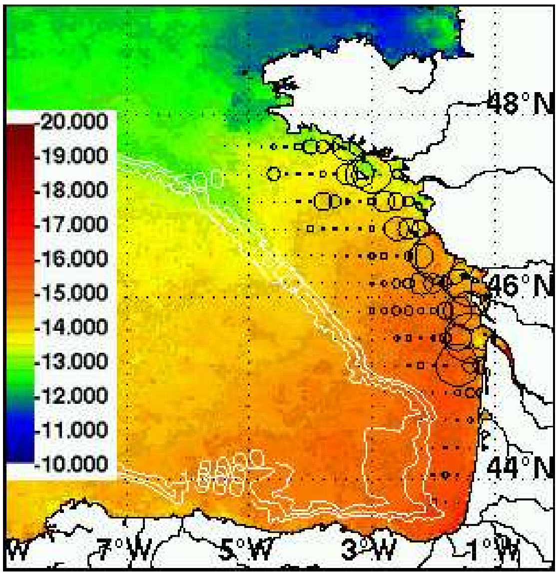

Fig. 7 Sea surface temperature (°C)

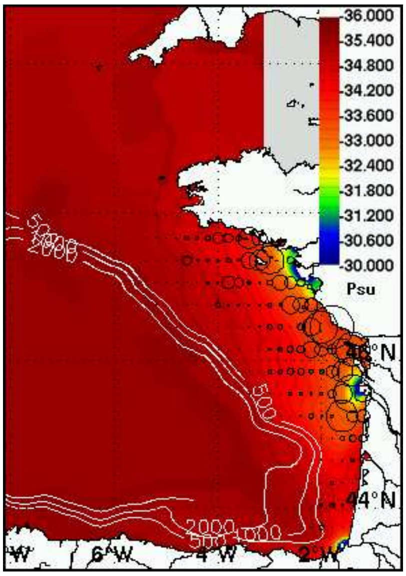

Fig. 8 Sea surface salinity

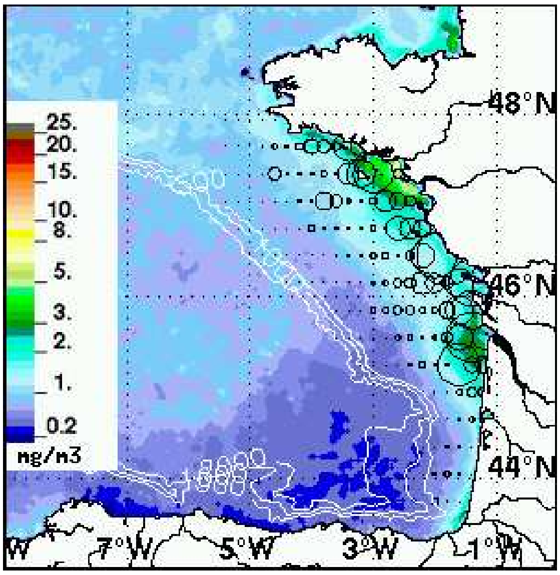

Fig. 9 Sea surface chlorophyll-a concentration

+ Sprat distribution in fall (EVHOE 2000-2006)

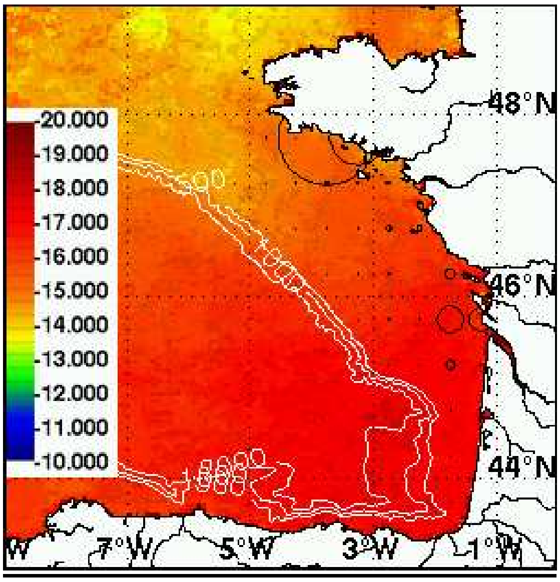

Fig. 10 Sea surface temperature (°C)

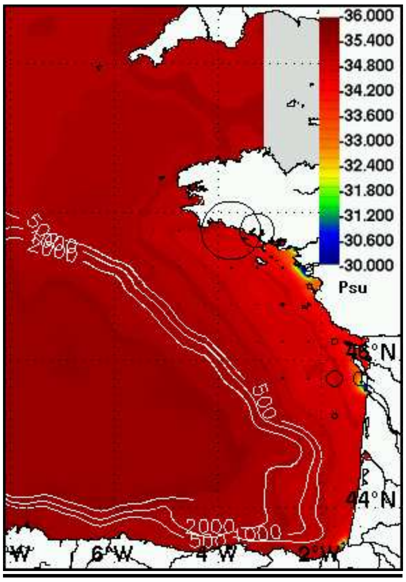

Fig. 11 Sea surface salinity

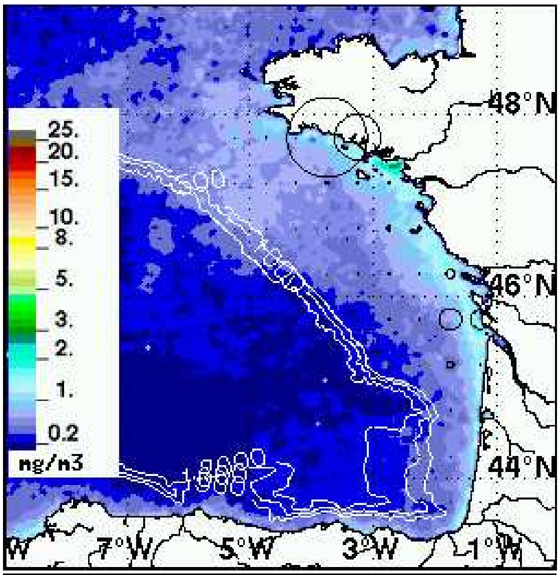

Fig. 12 Sea surface chlorophyll-a

North Sea

+ Anchovy distribution during winter (Q1)

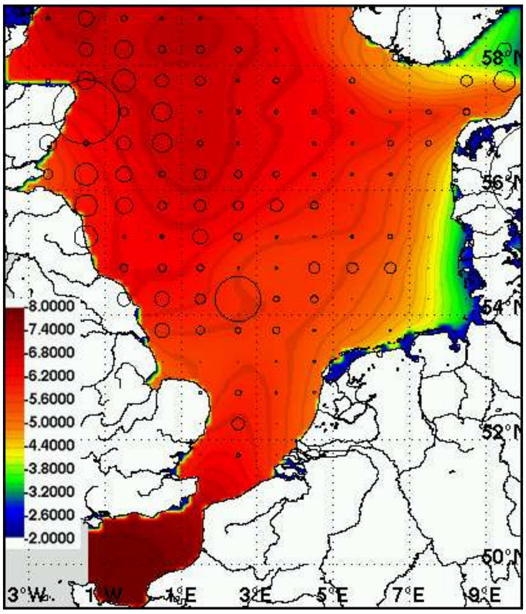

Fig. 13 Sea surface temperature (°C)

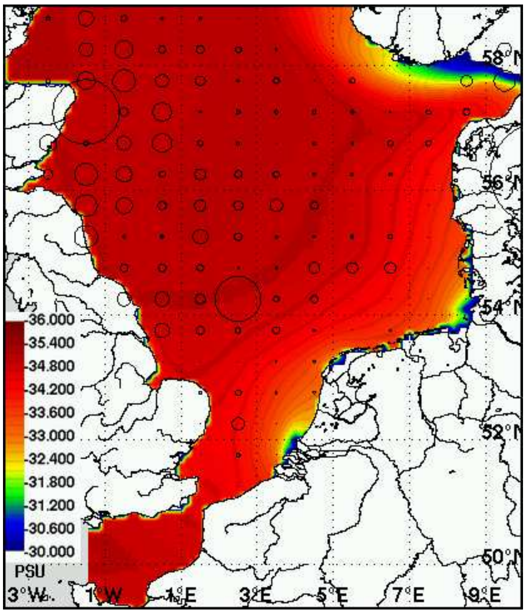

Fig. 14 Sea surface salinity

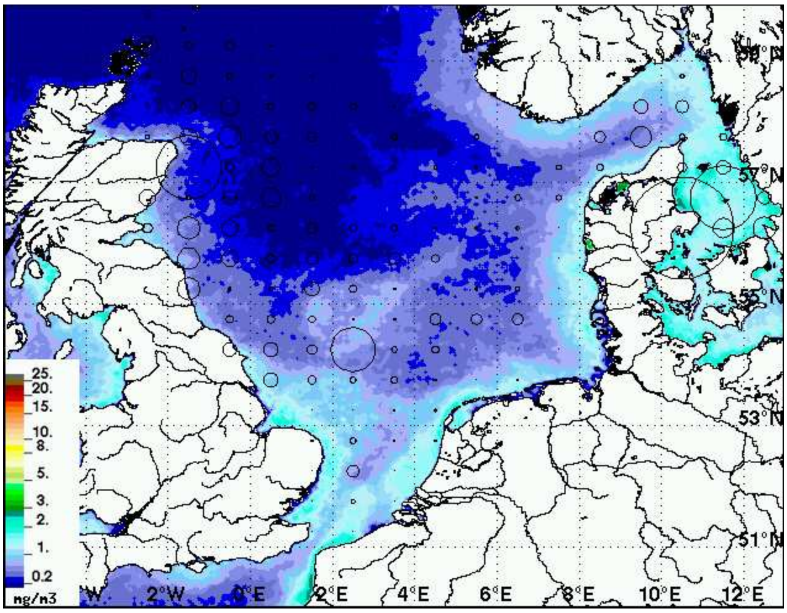

Fig. 15 Sea surface chlorophyll-a concentration

+ Anchovy distribution during summer (Q3)

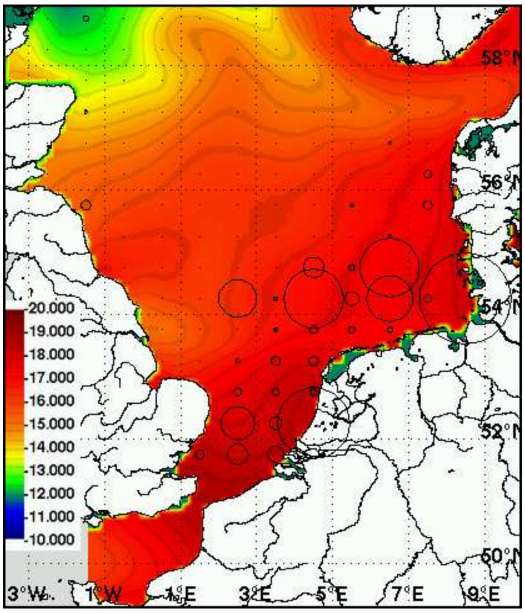

Fig. 16 Sea surface temperature (°C)

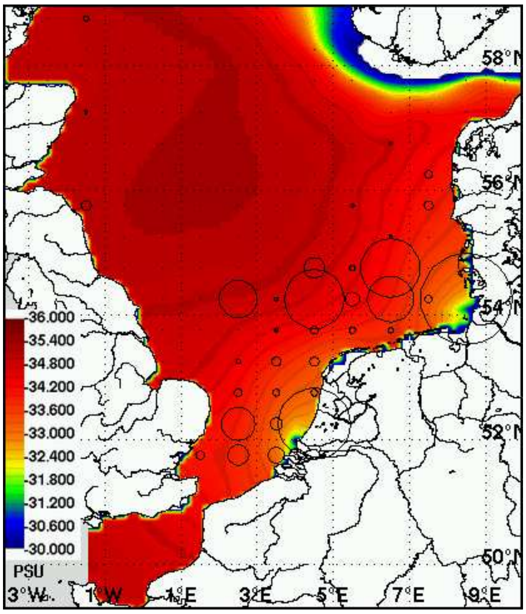

Fig. 17 Sea surface salinity

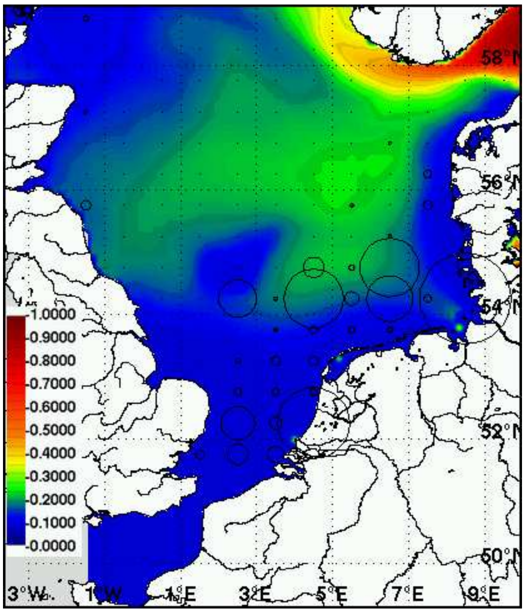

Fig. 18 Stratification index (Kg.m^{-1})

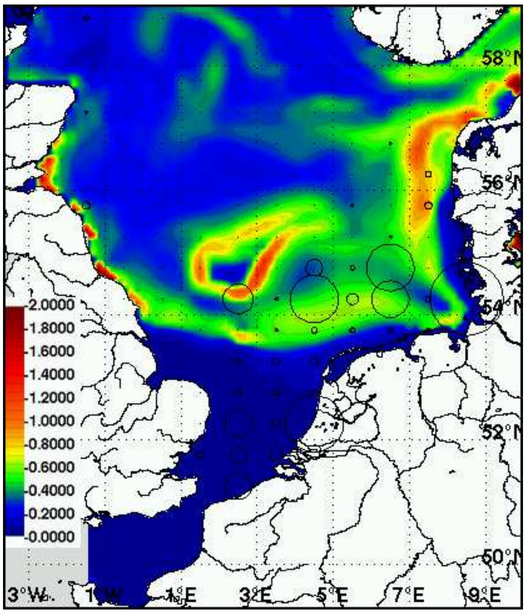

Fig. 19 Frontal index

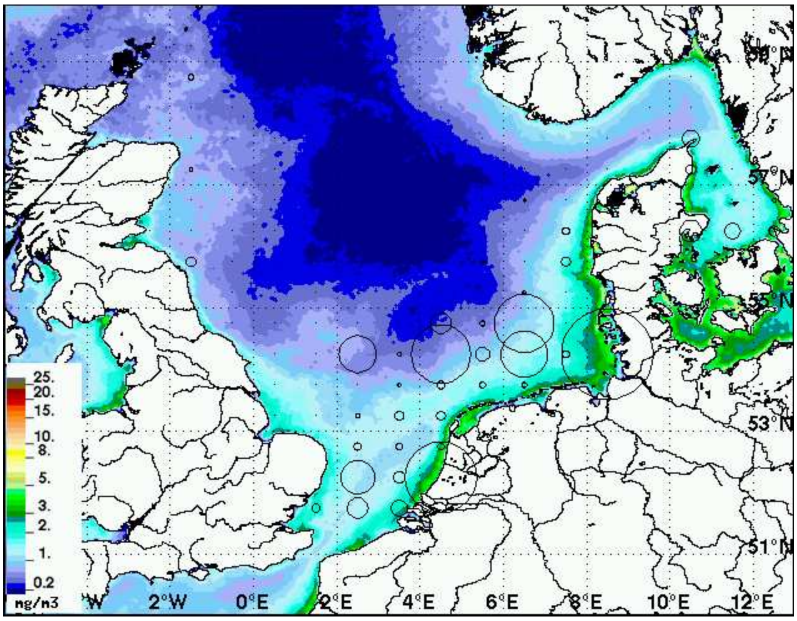

Fig. 20 Sea surface chlorophyll-a concentration

+ **Sprat** distribution during winter (Q1)

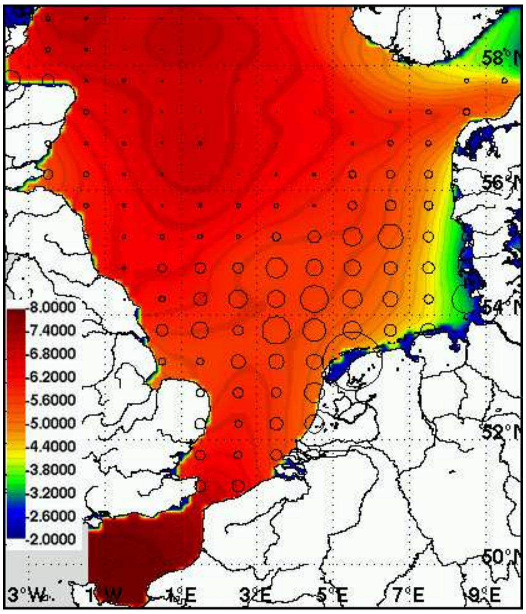

Fig. 21 Sea surface temperature (°C)

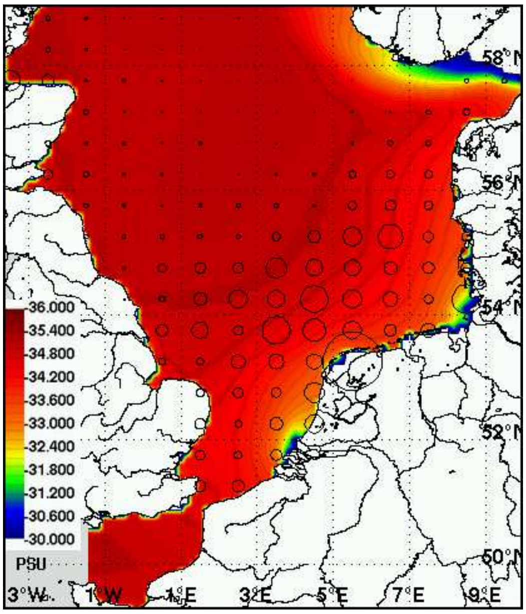

Fig. 22 Sea surface salinity

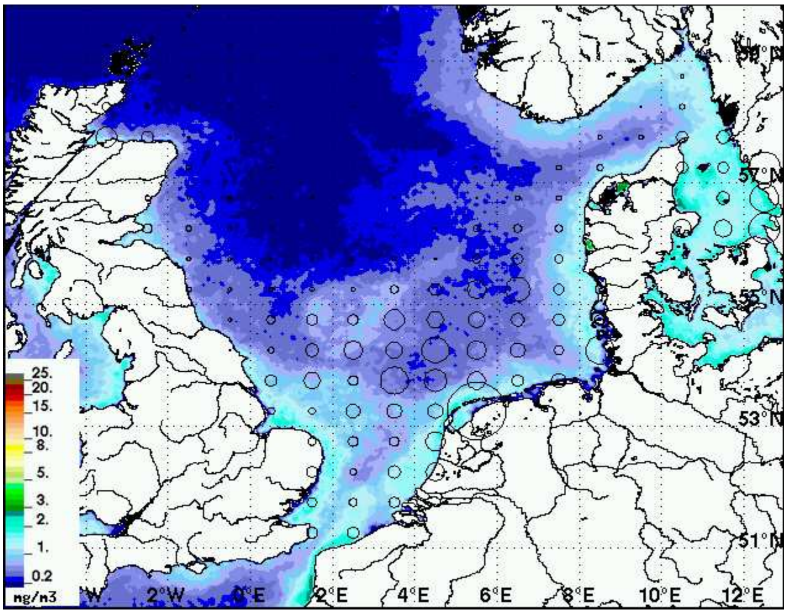

Fig. 23 Sea surface chlorophyll-a concentration

+ Sprat distribution during summer (Q3)

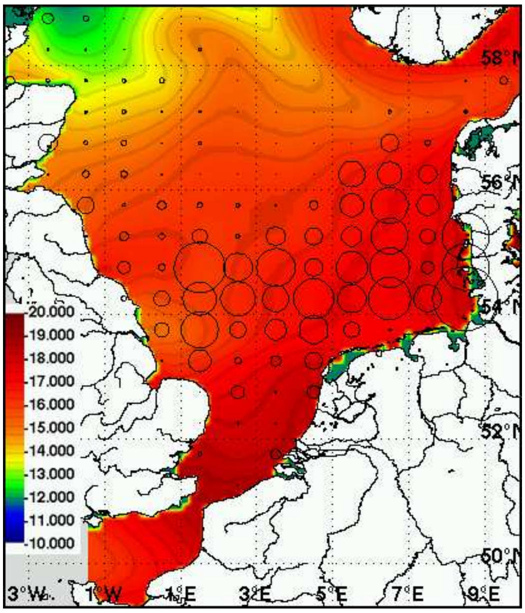

Fig. 24 Sea surface temperature (°C)

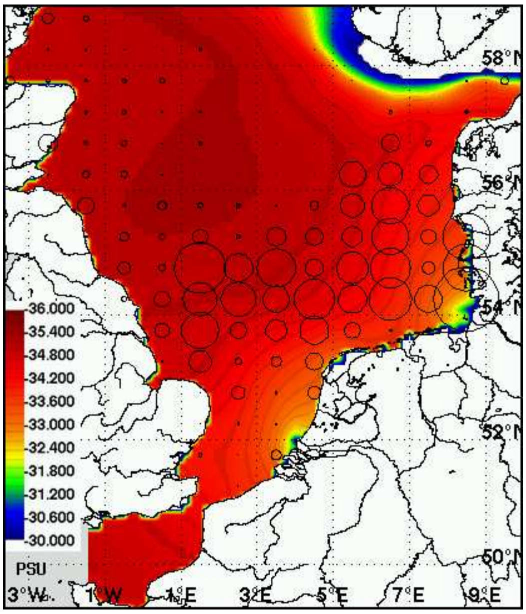

Fig. 25 Sea surface salinity

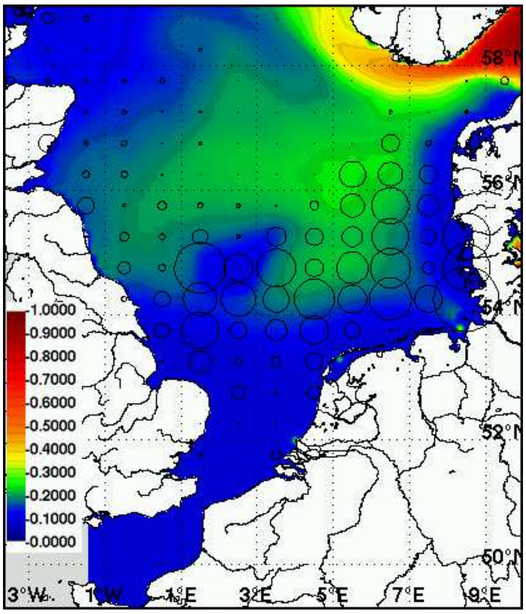

Fig. 26 Stratification index (Kg.m^{-1})

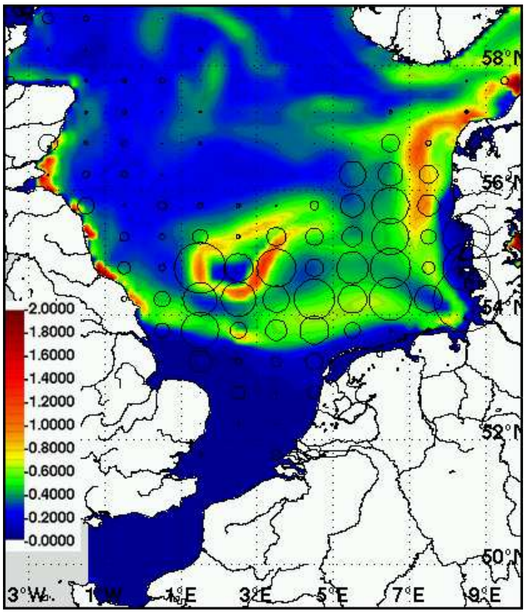

Fig. 27 Frontal index

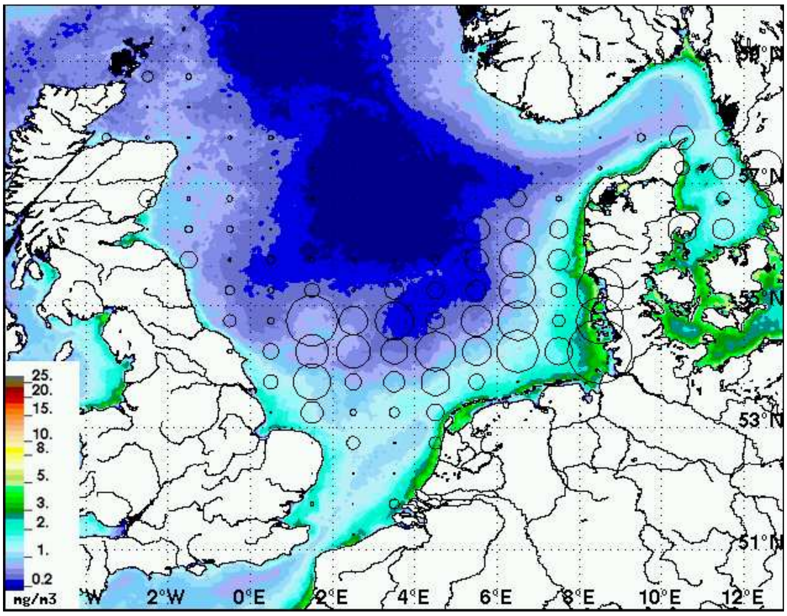

Fig. 28 Sea surface chlorophyll-a concentration

Seasonal migration

Observed spatial distribution for anchovy in the Bay of Biscay from the time-serie 2000-2006 confirms the known migration to the south of the Bay for spawning in spring (Fig. 1-3) (Motos et al., 1996), followed by a northward dispersion in summer. The EVHOE sampling (GOV net) is not designed for pelagic fish, especially over great depth, which probably leads to a limited representation of the distribution in fall. However the known dispersion arises on Fig. 4-6, without any latitudinal patterns but the gravity centre is moved northward when compared to spring.

The same time-serie do not show migration patterns for sprat, that remains along-shore north of 45°N in spring (Fig. 7-9) and fall (Fig. 10-12). Here again data from EVHOE is certainly not appropriate to give a correct view of the distribution in fall, but maximum values are still located just off-shore the Gironde estuary and south of Brittany.

In the North Sea, anchovy distribution shows a strong south-eastward migration from winter to summer. Anchovy is found in the west of the sea in winter, with maximum densities in the northwest (Fig. 13-15). In summer, anchovy is found in the south and southeast of the North Sea (Fig. 16-20).

The migration between both season is relatively low for sprat, it remains in the southern half of the sea, with a preference for its eastern part, with only a slight northward movement between winter and summer. Then very low abundances are found in the south end of the sea in summer (Fig. 24-28) when compared to winter (Fig 21-23), while higher abundances are found in its centre part.

Relationship between fish distribution and environment

Bay of Biscay

The latitudinal gradient in anchovy abundance corresponds well to the surface temperature gradient in spring, and both fish and temperature features disappear in fall. The inshore to offshore decreasing gradient in anchovy abundance in spring may be explained by the influence of surface waters by both the Gironde and Adour rich and low-saline plumes (see Fig. 2-3), and to a lesser extent by the Loire and Vilaine plume that could explain the relative maximum south of Brittany. The lack of any significant environment pattern in fall may then explain the observed dispersion of anchovy.

Sprat distribution seems more related to low-saline and rich waters both in spring and fall than to temperature.

North Sea

As in the Bay of Biscay, temperature (surface as well as bottom, not shown) seems to be the environment variable that best explains maximum abundances of anchovy in the northwest warmest waters, the exception being the local maximum over Dogger Bank. Maximum abundances in fall correspond to the warmest, low saline and rich waters of the south and southeast of the North Sea (Fig. 16,17,20). Stratification and frontal indices (Fig. 18-19) also reveal that the northern limit of anchovy distribution in summer is the tidal front, with high abundances over it. No fish were found in the stratified waters in the north.

For Sprat, temperature is not a limiting factor in defining its habitat in winter, as it remains in the south of the North Sea where highest values of surface chlorophyll-a and low-saline waters are observed. The slight northern shift of the distribution in summer seems to respond to the presence of the front in the centre of the North Sea where highest abundances are found.

Discussion

The data compilation we processed shows some general patterns related to anchovy and sprat seasonal migration in the Bay of Biscay and the North Sea.

First, anchovy shows the strongest movement of both species, which seems to be determined by temperature for the cold season (given by spring distribution in the Bay of Biscay, and by winter in the North Sea), and by food availability for the spawning season (also given by spring distribution in Biscay, and by summer in the North Sea).

Second, Sprat distribution shows only a small migration, remaining in both seasons in coastal or frontal rich waters. This is in coherence with the bio-geographical distribution of both species, leading to a higher sensitivity of anchovy to temperature fluctuation.

Last, fish distribution patterns are more outstanding in the North Sea, in coherence with environment patterns that are stronger too.

When relating fish distribution to the environment characteristics of its habitats, one has to select an appropriate scale depending on what is investigated. We chose in this work a low resolution, both in time and space, averaging fish data over many trawl hauls and over all available years. General patterns arise, but calculated correlations are poor. If the correlation has to be proven significant, then a higher resolution has to be considered, comparing data on a yearly basis, and probably keeping the strict geographical location of both environment and fish data. In one hand this would take into account the whole environment variability to which the fish is sensitive, but on the other hand this would mask the time it needs before responding, which is somehow considered when spatially averaging. A better understanding of relationships between environment and fish distribution require a refinement of biological processes under which fish respond to its environment.

The environment variables we present in this work are correlated, physical variables one to each other through forcing conditions, and biological variables responding to physical forcing. This is the case for phytoplanktonic production intensified through nutrients enrichment from rivers or in frontal zones, this is the case along the tidal front in the North Sea. However it does not appear on the surface chlorophyll-a image of the North Sea in summer. Using the integrated primary production would certainly lead to a better fit between fish maximum abundances and biological production. This example illustrates one limit of our approach, that is mainly considering surface variables. Future work should take advantage of the availability of full set of biological variables from 3D models.

Acknowledgements

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