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# The pelagic cross-shelf and alongshore boundaries of the North West African upwelling region and their annual variability in terms of zooplankton biomass

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## Abstract

The cross-shelf and alongshore extend of the biological effects of coastal upwelling is estimated on the basis of zooplankton biomass data for the pelagic zone off North West Africa. The definition of a charakteristic biomass for the adjacent pelagic zone of the tropical Central Atlantic is used as an aid. In cross-shelf direction, the "biological" effects of cold water upwelling can be discerned for several hundred kilometres (Tab.2), and off Cap Blanc (20°55´N) it therefore exceeds the range of the "physically" defined upwelling zone by a factor of 2.5 - 3.7 . In alongshore direction the "physical" and "biological" effects are both apparent over a distance exceeding 1000 km. Alongshore seasonal variations are very probably of the same order as the meridional migration of cold water upwelling phenomena (Fig.3). In cross-shelf direction variations off Nouakchott (17°50´N) and Cap Vert (14°45´N) appear to be chiefly seasonal character (Tab.2).

## Introduction

Coastal upwelling in the subtropics and tropics are, compared with surrounding waters, anomalies. This is shown by the field distribution of physical, chemical and biological parameters. Due to the hierarchic nature of the elements of an ecosystem (corresponding to different trophic levels), these differences are not identical in time and / or in space. According to Thiriot (1978), nutrient consumption in a waterbody while it is drifting after upwelling, and after seasonal termination of upwelling action, restores the original state typical for these latitudes.



Boje and Tomczak (1978) showed that it is necessary to know how large such areas are. The following paper tries to delineate the pelagic zones affected by upwelling on the basis of "biological" criteria. This has been done by defining a characteristic zooplankton biomass (ZPB) for the pelagic zone of the tropical Central Atlantic. Measurements taken at different seasons are used to estimate seasonal variations in space.

## Material and methods

The data base consists of ZPB dry weights obtained on board the r/v "A.von Humboldt" from 1970 to 1976 (Tab.1). These formed part of large scale studies performed in the course of a standard station programme off the North West African coast (Fig.1). The mesozooplankton was obtained with a WP-2 net (Tranter, 1968) by vertical hauls from depths down to 200 m. Dry weights were determined at 60° C using the methode of Lovegrove (1966). The 1970 values were obtained by Köhler (1972). Statistical analysis was based on Taubenheim (1969).

## Results and discussion

The mean ZPB in the Central Atlantic at 30° W between 1° N and 15° N over the whole year was less than 10 $mg.m^{-3}$ dry weight (Kaiser and Postel, 1979). In contrast, no such low ZPB which remained constant regardless of season was found in regions where substantial vertical nutrient flux occured, for example on the equator at the same longitude or off Cap Blanc in the North West African upwelling region. A ZPB of 10 $mg.m^{-3}$ was therefore considered the boundary between the pelagic zone "biologically" marked by coastal upwelling and its tropical and subtropical surroundings.

In order to locate this boundary in the cross-shelf direction, the position of the 10 $mg.m^{-3}$ isoline obtained from six large scale studies (Postel, 1979) was plotted in Fig.1. The thick line showes the extreme positions, those farthest off-shore being measured only in the northern part of the area studied. Nevertheless, the 27 times that this isoline was reached in the course of the programme showed that there was some relationship between the distance from the coast and the mean ZPB obtained along the whole oceanographic transect. For a linear correlation (r=0.8981), this dependence is significant at the 99.9 % level. The two parameters were best fitted by a 3rd degree polynomial (Fig.2). This relationship permitted the calculation of the missing values for the maximum extent of the area with exceeding 10 $mg.m^{-3}$. It was also used in case of crossing the oceanographic section more than one time by the chosen isopleth. These points are denoted by "+" in Tab.2. Apart from the extreme values for the different regions, Tab.2 shows the dates on which the measurements were made and, as the differences between extremes, the amplitudes of the cross-shelf variations.

Cushing (1971) found by comparing surface temperature and ZPB that the zone with elevated plankton content extended 2.5 times farther perpendicular to the coast than the upwelling zone defined by physical data. The corresponding factor for the region off Cap Blanc is 2.5 - 3.7 . Here we regard the distance of the shelf edge from the coast (72 km) as the "physical" boundary because according to Costlow and Barber (1980) the coldest water off North West Africa is restricted to this region. The "biological" boundary can be expressed as the mean distance of the 10 $mg.m^{-3}$ isopleth from the coast, i.e. 244 km with a confidence interval of ± 44 km which is significant at the 95 % level.

Delineation of the "biologically" defined upwelling region by means of the alongshore direction than in the cross-shelf direction due to local singularities. In the southern part of the region investigated, off Cap Roxo and Cap Verga (Fig.1), the river input lead also to high plankton standing stocks even when there is no upwelling (Schemainda et al., 1975). Our chosen criterion therefore cannot be used until further north where the 10 $mg.m^{-3}$ isopleth follows more zonal direction (Fig.1) between Cap Roxo and Cap Vert in June (1972) and off Nouakchott in September (1970). The directions and positions of these ZPB isolines coincide with those of the isopleths for physical parameters such as temperature and salinity which are also perpendicular to the coast (Schemainda et al., 1975). The northward migration from June to September suggests some dependence on the seasonal meridional migration of upwelling phenomena (Fig.3). This is shown visually by comparison with Fig.4 where the "annual" variations amounting to the mean ZPB's for the different sea areas are compared with the "annual" mean. The period with above-average ZPB is shown separately in the top part of the figure. This shows, as indicated by physical oceanographic results (Fig.3), that the period lasting almost the whole year can be



observed only in the northern area, including the region off Cap Blanc. The steepest gradient in the duration of above-average ZPB is found between Cap Blanc and Nouakchott. The turning point in the meridional migration of "physically" defined upwellings is also situated in this area (Fig.3). We can therefore assume that the "physical" southern boundary of the upwelling region and its meridional breadth of variation are also "biologically" valid. An analogous correlation may hold for the northern boundary as well. Fig.4 and Tab.2, for example, show that in February (1976) when the northern boundary of the cold water upwelling region reaches its southernmost point (Fig.3), the ZPB off Bahia de Garnet also remains below the 10 $mg.m^{-3}$ level.

The region with elevated zooplankton levels therefore extends more than 1 000 km in the alongshore, and up to several hundred kilometres in the cross-shelf direction. Although the "physical" and "biological" boundaries coincide in space [+] parallel to the coast, perpendicular to it we found the "biological" boundary more than 2 - 3 times farther offshore than the "physical" boundary.

Alongshore variability in the migration of the upwelling region depends on annual variations.

In more southernly sea areas this behavious is modified by local singularities. Upwelling occurs throughout almost the whole year in the northern part of the area. Cross-shelf variability is therefore of a seasonal nature exceeding off Nouakchott and Cap Vert ( in terms of the relationship between ZPB and the extent of the region with above-average plankton levels).

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[+] Along the time scale, the biological reaction time (c.f. Vinogradov et al., 1973) causes a phase lag which must be taken into account.

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## Tables and Figures

Tab.1

| working area | date of investigation | | |
|---|---|---|---|
| Bahia de Garnet (25°N) to | 27. 8. | to | 8. 9.1970 |
| Cap Vert (14°45′N) | 28.10. | to | 8.11.1970 |
| Bahia de Garnet (25°N) to | 20. 6. | to | 8. 7.1972 |
| Cap Verga (10°N) | 24.12.1972 | to | 10. 1.1973 |
| | 23. 2. | to | 14. 3.1973 |
| | 14. 5. | to | 30. 5.1974 |
| Bahia de Garnet (25°N) to | 12. 2. | to | 17. 2.1976 |
| Cap Blanc (20°55′N) | | | |

Tab.2

| working area | maximum | date | minimum | date | max.-min. |
|---|---|---|---|---|---|
| Bahia de Garnet (25°N) | 197+ | 13.-14.3. 1973 | 1 | 12.-13.2. 1976 | 196 |
| Bahia de Gorrei (23°N) | 209+ | 6.11. 1970 | 57 | 22.-24.6. 1972 | 152 |
| Cap Blanc (20°55′N) | 279 | 2.- 4.9. 1970 | 190 | 25.-26.6. 1972 | 89 |
| Nouakchott (17°50′N) | 264+ | 5.- 7.3. 1973 | 29+ | 30.8.-1.9. 1970 | 235 |
| Cap Vert (14°45′N) | 212+ | 2.- 3.3. 1973<br>24.-25.5. 1974 | 1 | 27.8. 1970 | 211 |
| Cap Roxo (12°N) | 296+ | 27.-28.2. 1973 | 129 | 6.7. 1972 | 167 |
| Cap Verga | 435 | 23.-25.2. 1973 | 176 | 7.-8.7. 1972 | 259 |

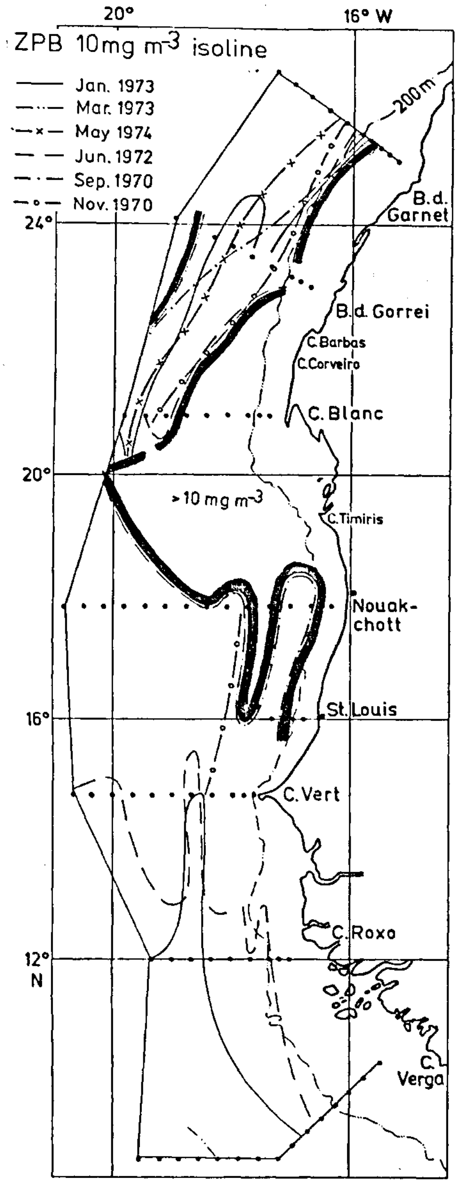


Fig.1

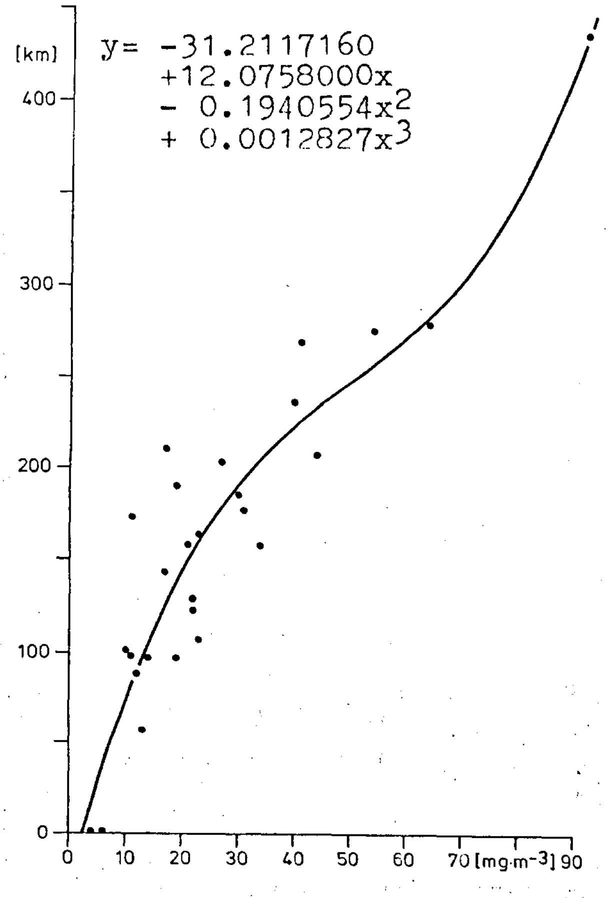


Fig.2

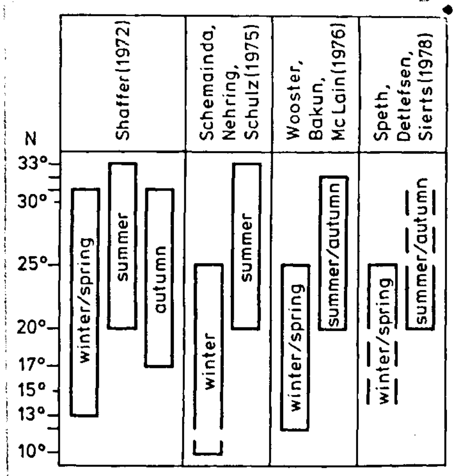


Fig.3

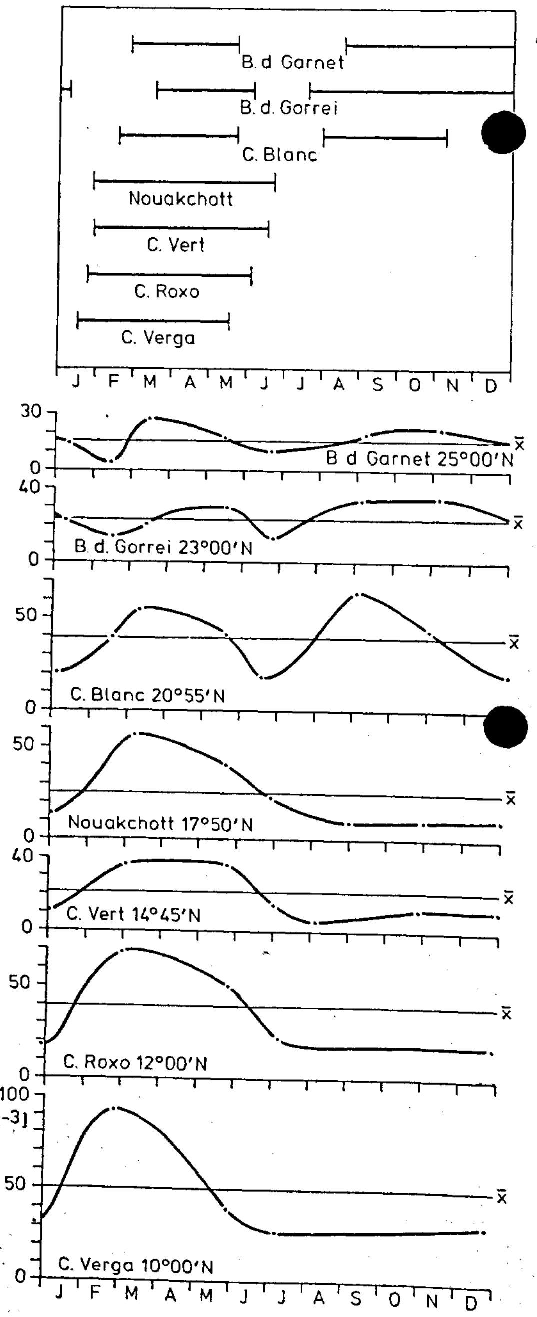


Fig.4