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THE DISTRIBUTION OF ABUNDANCE, SPECIES DIVERSITY, AND PHYTOHYDROGRAPHIC REGIONS IN WEST INDIAN OCEAN PHYTOPLANKTON*

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ABSTRACT

Phytoplankton bottle samples collected in 1964 by R. R. S. *DISCOVERY* during the International Indian Ocean Expedition in the West Indian Ocean were studied, Samples were concentrated on millipore filters. All species were identified as far as possible and counted. 237 species were identified from the 59 samples.

The samples were taken from 6 different water masses : Tropical surface water; the South Equatorial current; South Equatorial subsurface water; mixed water from the equatorial undercurrent; North Equatorial subsurface water and Arabian Sea water. Each has characteristic temperature/salinity/nutrient ranges.

The millipore filter samples provided quantitative phytoplankton data from which different population parameters were estimated. Phytoplankton abundance was found to be largely dependent on nutrient level. Regions of high abundance were associated with environmental instability in the upwelling region off the Arabian coast; in the shear zone region at 10°S and at the boundary of the equatorial undercurrent. The overall abundance was low. Species diversity estimates were made. Species diversity was found to increase with nutrient level, largely due to an increase in the species component of diversity; and decrease in regions of fluctuating conditions caused mainly by a decrease in the equitability component. Phytohydrographic regions were delimited using an adaptation of numerical taxonomic methods to classify the phytoplankton samples into groups on a basis of their phytoplankton content. These groups were found to the related to the water masses and ocean currents. Floral elements of associated species with similar distributions were derived, also using numerical taxonomic techniques. Co-ordinating these results it was possible to divide the sampling area into phytohydrographic regions with characteristic species abundance, diversity and floral elements. These different regions tended to be bounded by areas of increased phytoplankton abundance and decreased species diversity due to environmental instability in the boundary zone.

THE phytoplankton for this study was collected from the West Indian Ocean by R. R. S. *DISCOVERY* during the International Indian Ocean Expedition in 1964. Bottle samples of phytoplankton were taken in conjunction with hydrological data (Royal Society, 1965) and chlorophyll analyses were made. The phytoplankton from a known volume of bottle sample water was concentrated on a millipore filter, which was subsequently cleared for microscopic examination using the method of Holmes (1962). These millipore filter discs provided both qualitative and quantitative data on the phytoplankton and a total of 237 different species were identified (Thorrington-Smith 1970 a, b, c). In addition, the quantitative data were used to derive different population parameters of : overall abundance (Thorrington-Smith 1970a), species diversity (Thorrington-Smith, in press), and species associations (Thorrington-Smith, 1970d).

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The object here is to correlate briefly the regional distribution of these different aspects of the phytoplankton populations and to see how these related to the different water masses in the area as described by Ivanenkov and Gubin (1960) and Rochford (1966), and as deduced from the hydrological data of the cruise (Thorrington-Smith 1970a). No detailed treatment of the numerical methods used on the phytoplankton data has been attempted here as this is discussed in some detail in the above relevant papers. For the same reason no detailed reference to the data is given. The full phytoplankton sampling programme from which this discussion derives extended from April to July inclusive and covered the onset of the South West Monsoon. Seasonal factors were found to affect the phytoplankton in various ways (Thorrington-Smith, 1970a). In order to avoid the complicating influence of seasonal factors as far as possible, the samples discussed here were all taken from a transect on 67°E between 17°N and 3°N during the months of April and May. Reference is made here to these 19 stations. Although these are only a proportion of the total phytoplankton coverage; they are a representative sample and general conclusions reached also apply to the other samples, with seasonal modifications.

Samples were taken from 5 different water masses (Fig. 1). The two ocean currents traversing the area were the westward flowing surface South Equatorial Current between 7°S and 18°S and the Equatorial Undercurrent at the Equator. The

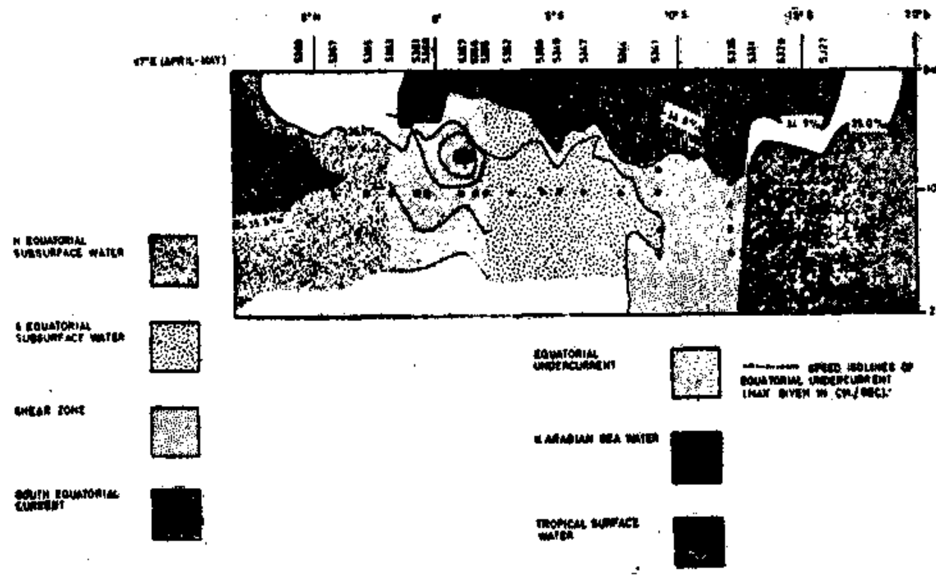

Fig. 1. A depth profile to show the different water masses. The different water masses were isolated according to their temperature/salinity/nutrient relations, and the different water masses are shown by different tone shades.

South Equatorial current is characterised by a low nutrient content (PO_4 concentration is less than 0.60 μg at / Litre). The Equatorial Undercurrent derives largely from surface Arabian Sea water and also has a low PO_4 content, particularly at its core.

To the south and beneath the South Equatorial Current at the surface is the Tropical surface water also characterised by low nutrient (PO_4 concentration is less than 0.60 μg at / litre). There was only one station in this water mass in April. The South Equatorial Subsurface water beneath the South Equatorial Current is relatively nutrient rich (the PO_4 concentration being greater than 1.00 μg at / litre). There is a shear zone between this water mass and the Tropical Surface water and it is postulated that the South Equatorial Subsurface water has its origin from deeper water here (Ivanenkov and Gubin, 1960), this accounting for its relative nutrient richness. To the north the South Equatorial Subsurface water extends to the Equator and part is drawn into and is incorporated in the Equatorial Undercurrent. North of the Equator is the North Equatorial Current with similar nutrient properties to the South Equatorial Subsurface water.

The phytoplankton on the filter discs was identified and counted. The counts provided a measure of abundance. Chlorophyll concentrations were also made. The former were expressed in cells/litre, and the latter in mg/litre. These values when plotted against each other increase together with a high degree of scatter (Fig. 2),

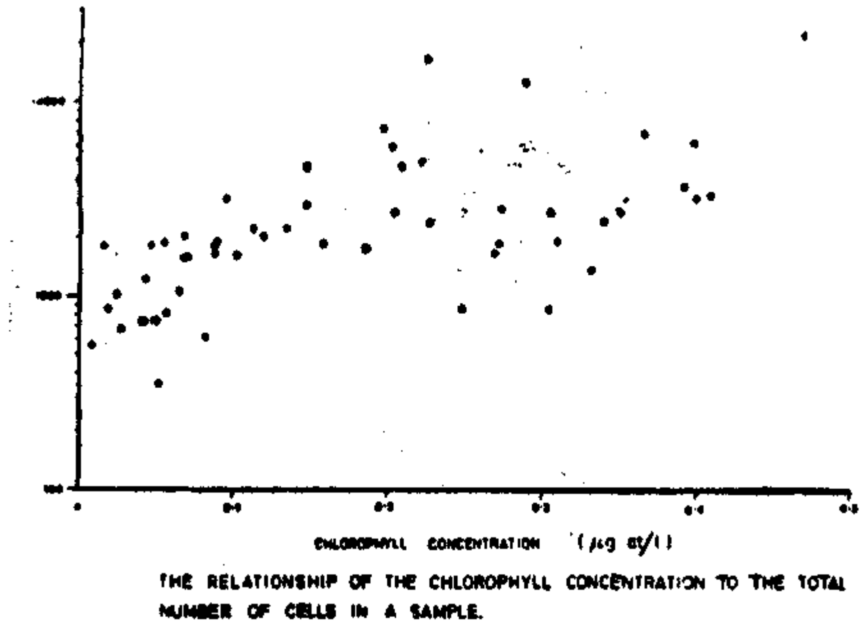

Fig. 2. A plot of chlorophyll concentrations against the numbers of cells/litre in the samples studied. This shows that they do increase together with a high degree of scatter.

showing them to be comparable. Considering the chlorophyll concentrations, which are plotted in a depth profile in Fig 3 ; it is seen that the highest chlorophyll concentrations are in the North and South Equatorial Subsurface waters. These are the waters where the nutrient concentrations are highest (see above). The traversing currents and Tropical surface water have lower chlorophyll concentrations related to the lower nutrient content.

Using the data of numbers of species and the number of different cells in each sample, species diversity indices were calculated, using the Shannon and Weaver

(1963) index. The values ranged from 2.23 to 3.54. In general species diversity increased with nutrient level and decreased with environmental instability (Thorring-

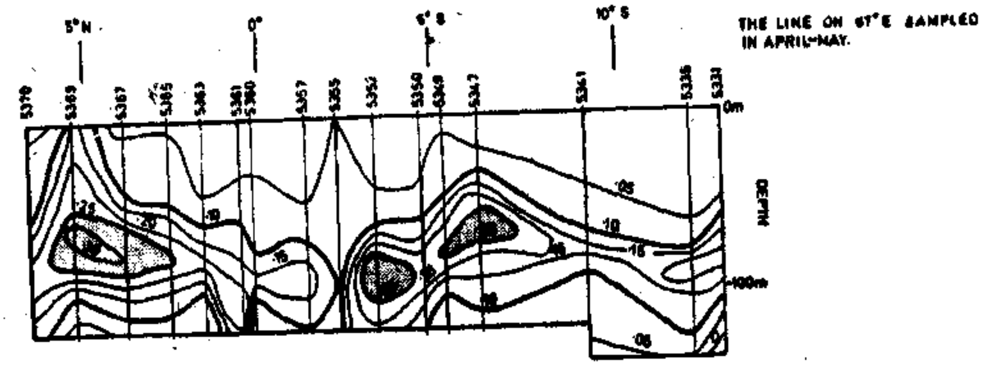

Fig. 3. A depth profile to show the distribution of chlorophyll concentrations (mg / litre) with depth. The shaded area represents chlorophyll concentrations greater than 0.25 mg / litre.

ton-Smith in press). As is indicated in Fig. 4, the boundaries of water masses and currents are demarcated by a relatively low species diversity. In these regions of relative instability where there is contact and stress between water masses and consequent disruption of microhabitats, more sensitive species do not flourish and only adaptable and ' opportunist ' species are able to capitalise on the situation. This

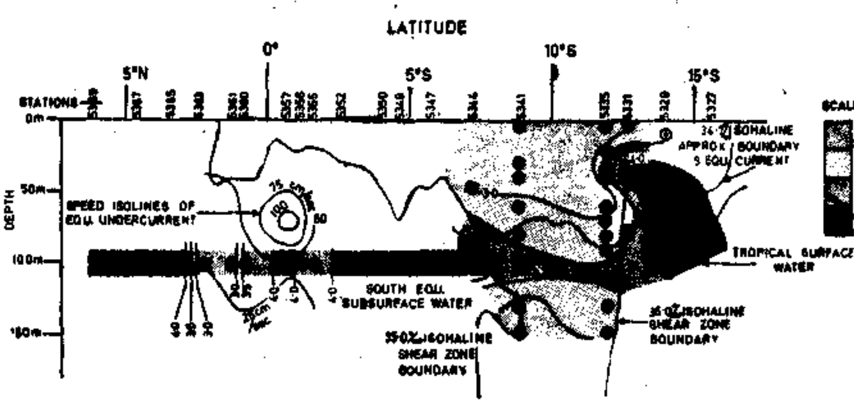

Fig. 4. Depth profile to show the distribution of species diversity with depth, calculated from samples of phytoplankton taken during April and May on 67°E.

results in inequitable distribution of species, which may result in domination by one or a few species which accounts for the low diversity. The South Equatorial Current and Equatorial Undercurrent are both bounded by low species diversity (Fig. 4), and there is relatively low diversity in the shear zone between the Tropical Surface Water and Equatorial Subsurface Water.

The different water masses are characterised by different ranges of diversity, with highest diversity (4.00 to 4.50) in Equatorial Subsurface water. This water had the highest nutrient concentration (greater than 1.0 μg at / litre). The low nutrient South Equatorial current had diversity values between 2.50 and 3.00. Equatorial Undercurrent had a wide range of diversity values from the lowest, 2.23 on the northern unstable boundary, to the highest value of 4.47 at its core. The latter high value represents Equatorial Subsurface water entrained into the current, and aside from this value they are all lower than 3.55 which relates to both the instability and relative lack of nutrient. It is postulated (Thorrington-Smith, in press) that diversity increases with nutrient concentration, as an increase in nutrient will enable the environment to support a larger population with a greater number of species. However, this is only true under stable conditions where it is possible for a complicated system of microhabitats and nutrient recycling to develop. Where there is a high nutrient under unstable conditions, as in the Arabian Coast upwelling region, there will be low diversity in spite of the high nutrient. The overriding factor then is the environmental stability.

In general, then, a water mass will develop its typical phytoplankton flora, whose abundance (in the Tropics) is largely dependent on nutrient level, and with a typical species diversity range limited by two opposing factors—increasing nutrient favouring a high diversity and environmental instability favouring a low diversity. Species diversity is a dynamic function and will vary as does the environment. However, as there is generally an increase in environmental instability at water mass and current boundaries, there will be a tendency for them to be bounded by regions of low diversity. This is useful as an initial pointer to the boundaries of phytohydrographic regions.

The next thing was to investigate the species distributions in relation to the above regionation. The samples were grouped according to similarity of phytoplankton species. The method used here was similar to that used largely in Numerical Taxonomy. Initially each possible pair of *samples* was compared on grounds of its phytoplankton composition using a dissimilarity index. The Preston (1962) resemblance equation was found to be most suitable. The derived matrix of dissimilarity indices were subjected to a cluster analysis (Thorrington-Smith, 1970d). The single linkage method was used to derive a dendrogram, which grouped the samples into 3 main phytohydrographic regions. In addition the *species* were grouped using the same technique, except that the Holloway and Jardine (1968) dissimilarity index was used. The clusters in the dendrogram were then recognised as the floral elements, each element being composed of different species with similar distribution patterns. These floral elements were then related to the phytohydrographic regions of which they were typical.

The dendrogram which illustrates the phytohydrographic regions is shown in Fig. 5, and the attached chart shows the hydrographic distribution. Different symbols and tones have been used to make it easier to see the distribution of the clusters on the chart. The largest region corresponded with samples from the Equatorial Subsurface water, and divided into three subgroups: Equatorial Subsurface water north of the Equator, Equatorial Subsurface water in the Southern Shear Zone, and Equatorial Subsurface water South of the Equator with distribution centred on 5°S. The second main group consisted of samples from the Equatorial Undercurrent. One subgroup contained samples from the boundaries, and the other was a subgroup which showed Equatorial Undercurrent affinities with the South Equatorial Subsurface water, indicating inclusion of this water in the Undercurrent. There was also one sample which showed affinity with the South Equatorial Current. The third main Phytohydrographic region was centred in this water—the surface South Equatorial Current.

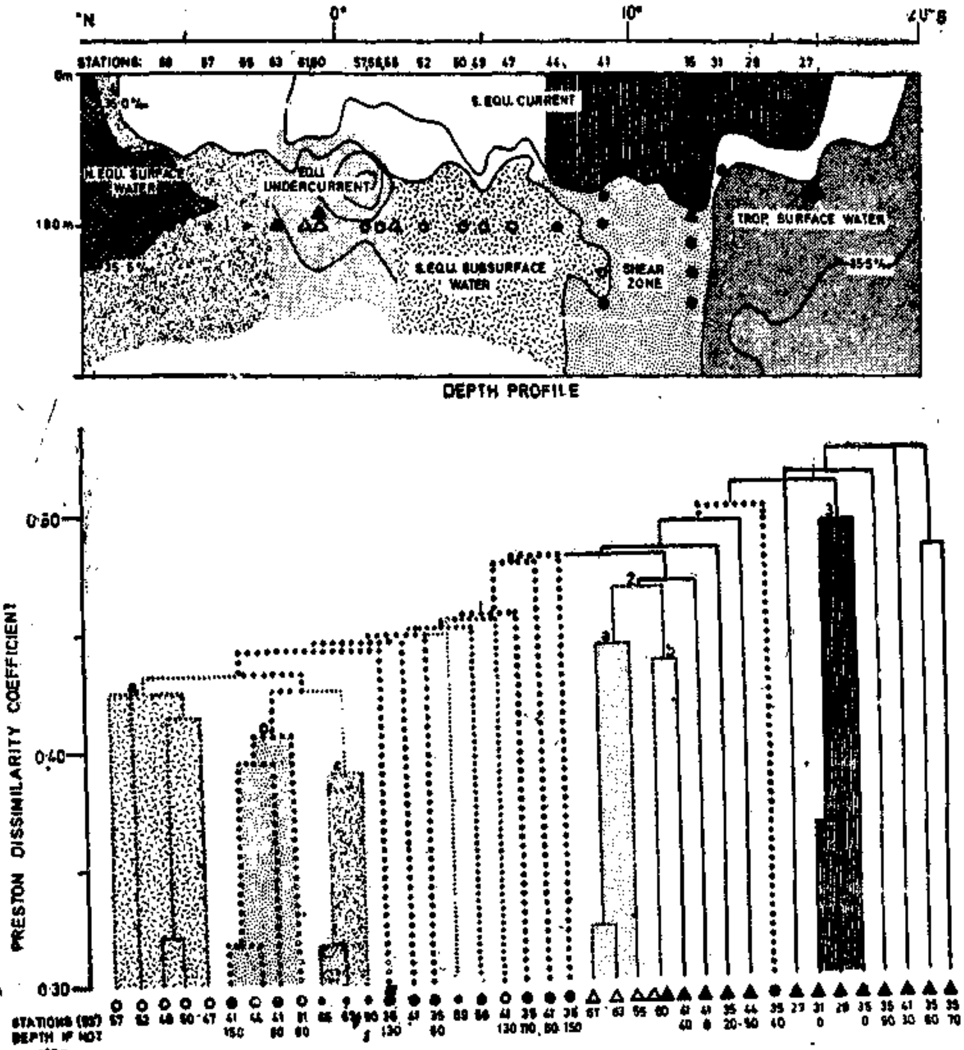

Fig. 5. Dendrogram to illustrate the clusters of stations which group to form the phytohydrographic regions. The group nuclei are shown by differential shading and different symbols indicate the affinities of the different stations. The attached chart shows their hydrographic distribution.

Using similar techniques the species were grouped into the Floral elements which typified the different regions. Altogether, in the samples from both before and after the South-west Monsoon, 11 different Floral elements were isolated but only those relevant to the samples from April and May will be discussed here. By far the dominant Floral element isolated was Floral Element 2 with distribution centred in the Equatorial Subsurface water. This group contained a total of 50 different species. The main close clustering species which form the core of this Floral Element are found in more than 40 of the 59 samples studied in the entire sampling programme. These are: *Coscinodiscus lineatus, Chaetoceros atlanticum, Chaetoceros*

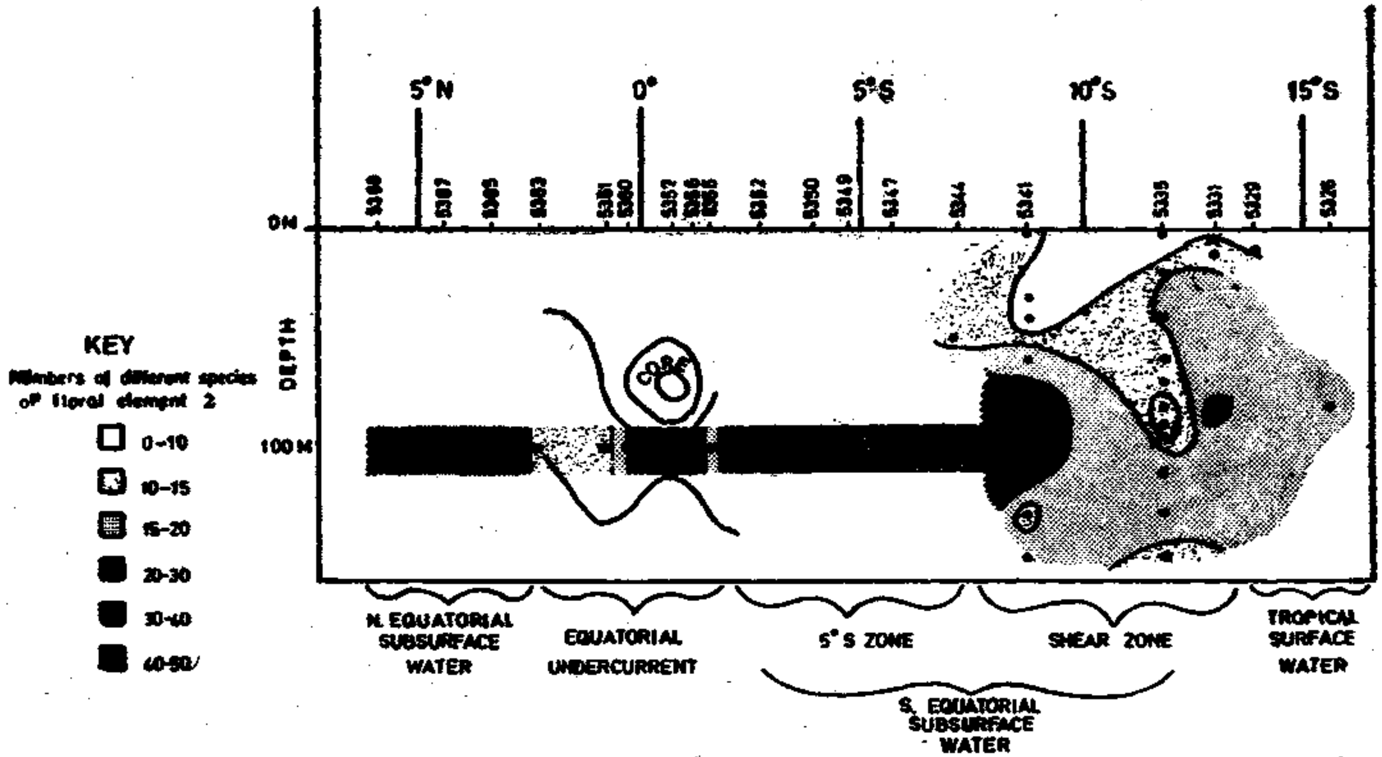

Fig. 6. Depth profile to show the distribution of the Equatorial Subsurface-based Floral Element 2 in the transect on 67° E. The number of species of this element present is represented by differential shading.

TABLE 1. A summary of the phytohydrographic properties of the water masses studied, to show the extent to which the zonation of different properties is similar.

Water Mass	Phytohydrographic Region	Estimate of Phytoplankton standing Crop	Species Diversity (D) (See Figs. 20)	Salinity Range (‰)	Nutrient Range (ug at/l PO_4	Position (Latit. Range)	Depth Range (m)	Species of Floral Element 2	Other Minor Floral Elements
Surface S. Equatorial Current	3: S. Equatorial Current	Low	3.0-3.5	34.2-35.0	0.20-0.40	±5°S-±20°S	0-±100	Few	11
Tropical Surface Water	Tropical Surface Water	Low	3.7-4.0	35.0-35.7	0.20-0.40	±12°S-20+°S	±50-500+	Few	
N. Equatorial Water	1: Equatorial Subsurface Group (c) N. Equat. Subsurface Group	High	4.0-4.5	35.2-35.5	1.0-1.5	3°S-5°N	±0-500+	Abundant	
S. Equatorial Subsurface Water	1: Equatorial Subsurface Group (b) Shear Zone Group	Very High in Parts	3.5-4.0	34.8-35.0	1.0-1.3	±9°S-±12°S	±90-500+	Less Abundant	4, 10
	1: Equatorial Subsurface Group (a) 5°S Centred Group	High	4.0-4.5	35.0-35.2	1.0-1.4	±3°S-±9°S	±0-500+	Abundant	6
Equatorial Under Current Mixed Water	1: Equatorial Subsurface Group (c) Undercurrent Core	Low	3.5-4.0	35.0-35.3	0.2-1.0	±2°N-±2°S	±20-±100	Abundant	5
	2: Undercurrent Boundary	High	3.0-3.5					Few	4, 5, 9.

danicum, *Dactyliosolen mediterraneus*, *Thalassionema nitzscoides*, *Nitzschia bicapitata*, members of the *Nitzschia seriata* group, a species of *Navicula* (all of these are diatoms); a species of *Coccolithus* (Coccolithophore); *Dictyocha fibula*, *Mesocena polymorpha* (Silicoflagellates) and *Meringosphaera mediterranea* (Xanthophyceae). Most of these species have world-wide distributions and are therefore tolerant of a variety of conditions. In combination here, they are typical of the endemic West Indian Ocean phytohydrographic region. The distribution of this element is plotted in Fig. 6 where it is seen that its distribution is centred in the Equatorial Subsurface water where the greatest concentrations of these species are found. The two traversing currents by comparison are distinguished by a low concentration of species or this element. The presence of the other Floral elements is of minor importance. Floral element 6 is also found in Equatorial Subsurface water, but its distribution is limited to the 5°S, South Equatorial phytohydrographic region. It has 13 typical species.

There are two Floral elements with distribution centred on the Equatorial Undercurrent. Element 5 consists of 5 species, all of which are dinoflagellates. Element 9 consists of 6 species and has a very particular distribution in the two samples on the southern boundary of the Undercurrent. The South Equatorial Current is the centre of distribution of Floral element 11 which contains 9 species.

In the light of this study, this area of the West Indian Ocean divides phytohydrographically into 4 main regions : (1) Equatorial Subsurface Water, (2) the Equatorial Undercurrent, (3) the South Equatorial Current and (4) the Tropical Surface Water, (the latter water was represented by only one sample in April and May samples). The characteristics of the Sub-divisions are summarised in Table 1. Each region was characterised hydrographically by salinity/temperature/nutrient relations, and particular hydrodynamics. Consequently the water environment will support a phytoplankton population of particular abundance and species diversity. According to the water origin and hydrological conditions it will be colonised by particular species associations, thought of in terms of Floral Elements which divide the area phytohydrographically.

It should be emphasised that this dissertation is a summary of work done on phytohydrographic regions in the West Indian Ocean and that the published data and details are referred to in the text. This study can only attempt to be an initial study in a previously neglected area and it is to be hoped that further work will be done to clarify and substantiate the conclusions reached.

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