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SEASONAL CHANGES IN THE SURFACE WATER MASSES AND IN THEIR PLANKTON IN THE BERMUDA AREA

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ABSTRACT

Bermuda plankton studies showed seasonal differences in the fauna which suggested different origins of the water in summer and winter. Studies of the geographical distribution of typical summer and winter species confirmed this, showing widely different centers of distribution for the two seasonal groups. Previous studies of currents and of the distributions of temperature and transparency suggested an eddy of the Gulf Stream, reaching Bermuda from the east or southeast. The present current studies confirm the indications of the plankton distribution in showing that Bermuda summer water comes from the North Equatorial Current, while the winter water comes from an eddy of the Gulf Stream approximately along the 30° parallel.

In an earlier study of the zooplankton of the Bermuda area (Moore, 1949), it was shown that the plankton was distinctly different in summer and winter. There was a sharp transition in October, and a second, less well defined, in late winter or spring. The change was apparent in the species comprising the zooplankton, in the number of species present, and in the total volume of plankton per standard haul at a single station. These changes are shown in Figure 1. The volume changes at a single station were shown to be due to a shift in the position of a plankton-rich area which lay to the east of the islands in summer and to the west in winter. This shift strongly suggested a change in the circulation system around the island, which was borne out by the nature of the summer and winter faunas.

[1]Contribution No. 677 from the Woods Hole Oceanographic Institution.
Contribution No. 206 from the Bermuda Biological Station.
Contribution No. 113 from the Marine Laboratory, University of Miami.

It was hoped that some of the typically summer and winter zooplankton species might be used as indicators of the origin of their respective water masses, and with this in view, a study of the Atlantic

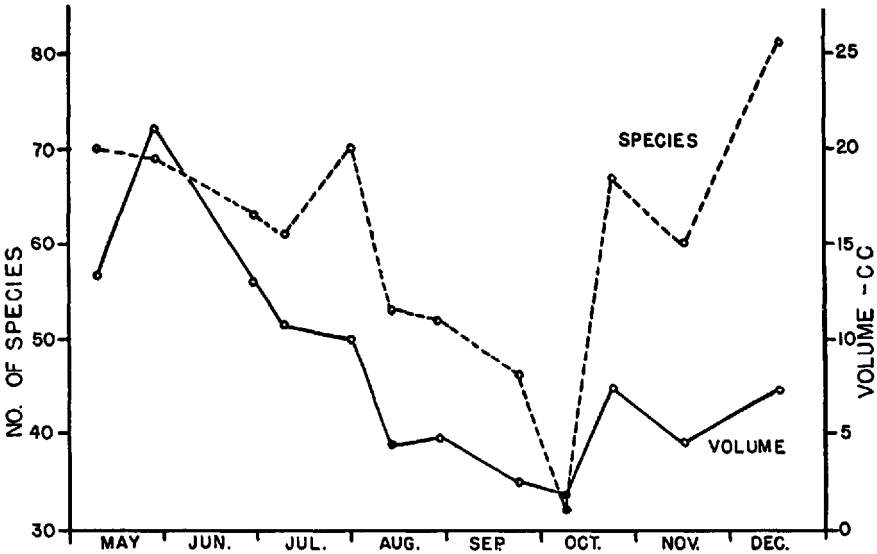

FIGURE 1. Seasonal variation in number of species present and in size of catch at a standard station off Bermuda.

distribution of a series of selected forms was commenced in 1947. The study was begun at the Woods Hole Oceanographic Institution and later continued at the Marine Laboratory of the University of Miami. At the latter, Hela undertook a study of the seasonal surface drift of the Bermuda area, which was part of a more general survey of the North Atlantic (Hela, 1954).

ZOOPLANKTON STUDIES

The following species, all of which showed marked seasonal fluctuation in numbers at Bermuda, were selected as possible indicator forms:

SUMMER SPECIES	WINTER SPECIES
SIPHONOPHORA	
Diphyes dispar Chamisso & Eysenhardt	*Diphyes bojani* (Eschscholtz)
	Eudoxoides spiralis (Bigelow)
	Abylopsis eschscholtzii Huxley
	A. tetragona Otto
	Bassia bassensis (Quoy & Gaimard)

CHAETOGNATHA

Sagitta bipunctata Quoy & Gaimard
S. hexaptera D'Orbigny
S. lyra Krohn
Sagitta planktonis Steinhaus
Pterosagitta draco (Krohn)
Krohnitta subtilis (Grassi)

The groups chosen were limited to those with widespread records from the North Atlantic. Unfortunately these did not include the Pteropoda, which otherwise would have been ideal. Also a considerable series of hauls, referred to below and examined by us, had not been properly preserved. Their examination was delayed by World

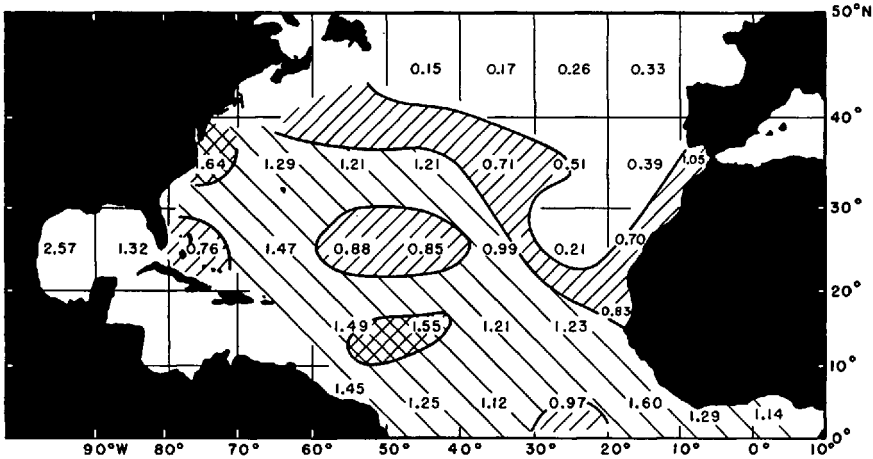

FIGURE 2. Distribution of species typical of Bermuda waters in winter.

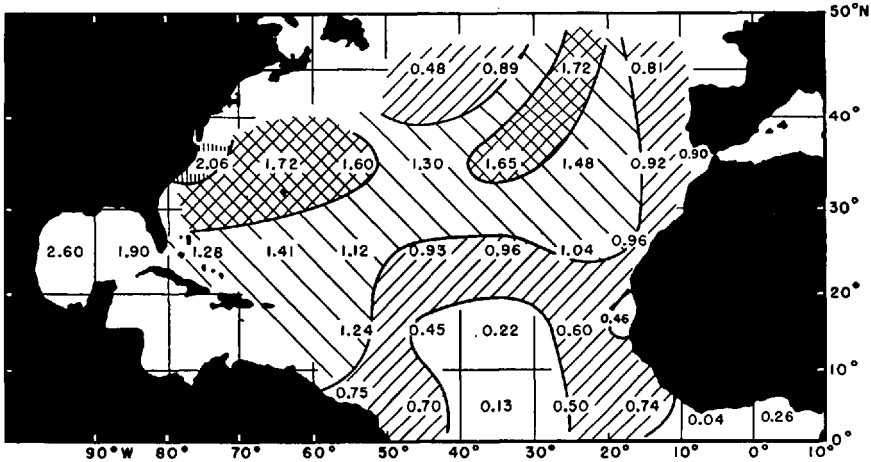

FIGURE 3. Distribution of species typical of Bermuda waters in summer.

War II, and after a lapse of several years they had become decalcified and many of the pteropods were no longer identifiable. However, the larger pteropods did provide verification for the belief that the seasonal changes mentioned above recurred in successive years. In material collected by Dr. M. V. Lebour in the summer of 1947, they were very scarce, as they had been in the summers previously studied. These appear to be typically winter forms in Bermuda.

Abstracts were made from the published records of all expeditions which have worked in the North Atlantic[2]. They were grouped by 10° squares, and presence or absence of each of the selected species was noted. The percentage occurrence of each species was then calculated for each square. Allowance was made for the varying relative total abundance of the different species by weighing each value in proportion to the total number of records of the species for the whole area. Finally, for each 10° square, a mean value was obtained for the combined winter forms, and for the combined summer forms. Figures 2 and 3 show these values, expressed in arbitrary units, and it is clear that those species which are common in Bermuda waters in winter have characteristically different distributions from those common in summer.

These two charts indicate the centers of abundance of the Bermuda summer and winter forms. However, at these centers, the species in question may occur more abundantly than they do in the Bermuda area at the appropriate season. An attempt was therefore made to locate the areas where the frequency of occurrence most closely approximated that found around Bermuda. It would have been desirable to separate the published data into two groups according to whether the hauls were made in summer or winter, omitting those made in the transition periods, but this would have reduced the available data unduly. The best that could be done was to determine those areas in which mean annual conditions most closely approximated those found in the Bermuda area in summer and winter respectively. For the Bermuda area, sufficient seasonal data were already available. The results (Figure 4) show that Bermuda winter conditions are most closely matched by a band of water lying well to the south of the islands, and extending from the West Indies across to the African coast at approximately 20° north latitude. Summer conditions are most closely matched by a band of water lying roughly along the course of

[2]Bedot, 1904; Bigelow, 1918; Burfield, 1930; Chun, 1897; Fowler, 1906; Germain and Joubin, 1916; Haeckel, 1888; Leloup, 1933; Leloup and Hentschel, 1935; Moser, 1925; Ritter-Zahony, 1911, 1911a; Thiel, 1938; Totton, 1936.

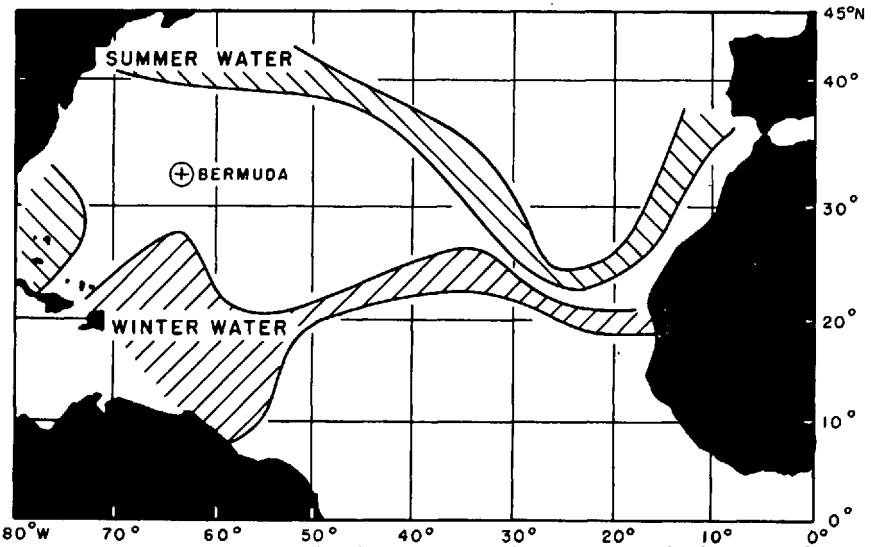

FIGURE 4. Centers of distribution of Bermuda summer and winter species.

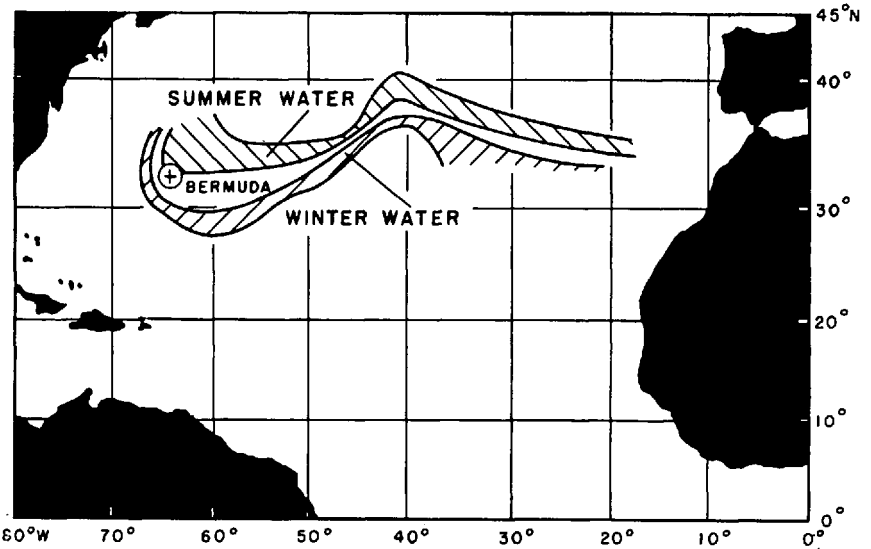

FIGURE 5. Areas most closely approximating Bermuda summer and winter conditions.

the Gulf Stream from Florida to the northeast of Bermuda, and swinging southward to the east.

Most of the expedition reports give records of presence or absence,

but do not include counts of the relative abundance of the different species. The latter give a far more reliable picture of distribution, but are available for only a limited series of stations. In order to extend these data, the *Atlantis* has collected plankton samples, usually night surface hauls, on a number of cruises extending widely over the North Atlantic. The siphonophores and chaetognaths have been counted in all of these hauls. For each selected siphonophore species, a value was calculated expressing its numerical abundance as a percentage of the total summer siphonophore population in the Bermuda area. A winter value was obtained in the same way. Similarly, the chaetognaths were expressed as percentages of the total chaetognath population. Finally, weighted values which expressed the typical ratio of total summer to total winter forms in the area in each season were obtained. The ratio of Bermuda summer species to winter species was calculated in the same way for those parts of the North Atlantic where these species occurred and a chart of the distribution of this ratio was prepared. From this, the areas in which the annual mean values most closely approximate Bermuda summer and winter conditions, respectively, were determined and are shown in Figure 5. There is some resemblance between these and the areas indicated from other data in Figure 4, but in this case the two areas lie considerably closer together.

Both methods indicated that the water masses whose plankton most closely corresponded with Bermuda summer and winter conditions lie respectively further north and further south. The fact that mean annual plankton, rather than appropriate seasonal plankton, was compared, has masked any possible seasonal change within these areas, but their separation is still marked. However, both areas extend for a considerable distance, more or less along the line of flow of the Gulf Stream. It has not, therefore, been possible to associate any very circumscribed area with the Bermuda plankton. Such information must be sought in a study of the current system.

Current Systems

Bermuda lies well to the east of the Gulf Stream system and within the Sargasso Sea, but there are some indications that it may, at least on occasions, be influenced by an eddy of the main stream. Iselin (1936) has indicated the existence of such an eddy in a generalized way (Figure 6). Fuglister (personal communication) has prepared charts showing the distribution of temperature (Figure 7) and salinity

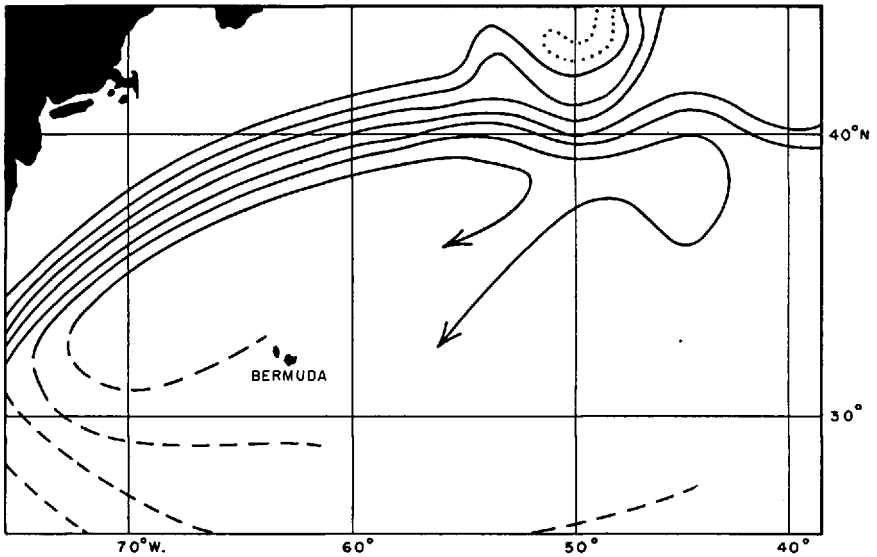

FIGURE 6. Portion of the Gulf Stream System, according to Iselin (1936).

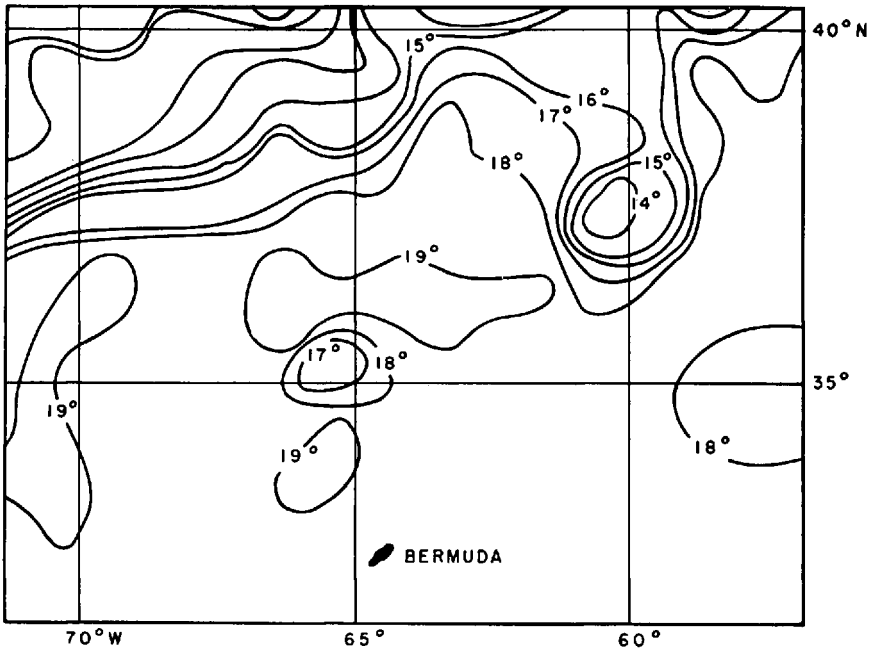

FIGURE 7. Temperature (°C.) at 200 meters, after Fuglister.

at a depth of 200 meters in the North Atlantic, and finally Moore (1952) has published a chart of water transparency in the area (Figure 8). Both of these suggest the presence of such an eddy in the

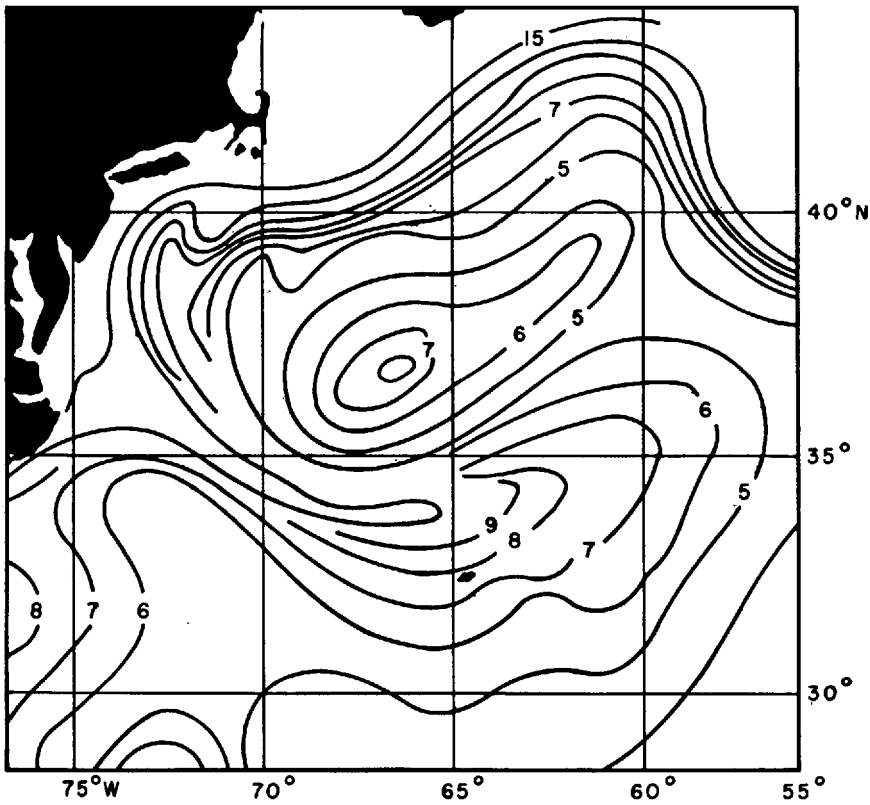

FIGURE 8. Extinction coefficients (× 100), according to Moore (1952).

neighborhood of Bermuda. One may assume that a comparatively slight seasonal shift might well bring summer and winter plankton populations from widely separated areas into the vicinity of Bermuda.

Hela (1954) has computed the resulting surface currents of every degree square and for the different seasons separately by means of the monthly current charts published by the U. S. Navy Hydrographic Office (H. O. Publ. 571, sheets 1 through 12). The winter and summer current conditions are given schematically in Figures 9 and 10. In the winter chart (Figure 9), the eddy pointed out by Iselin (Figure 6) can be seen distinctly. The shaded area has been copied from

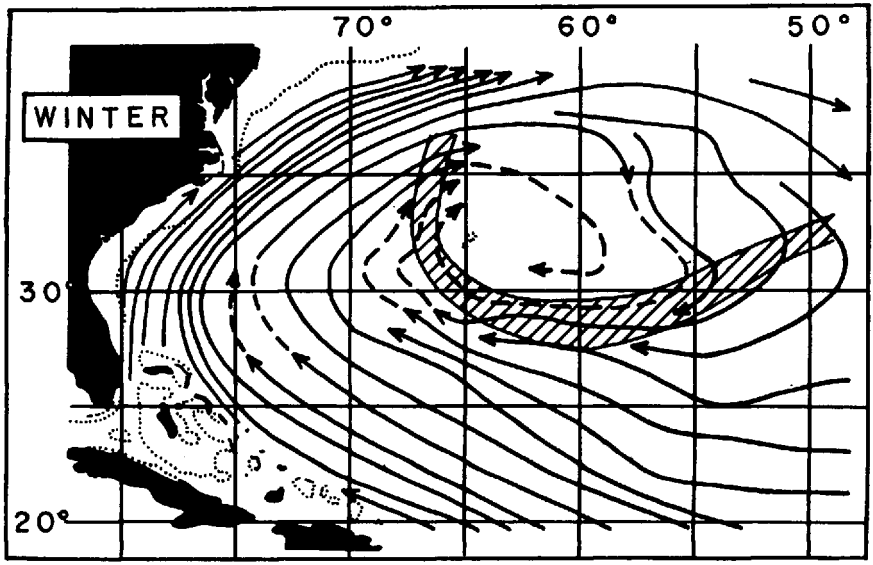

FIGURE 9. Winter current conditions with the "winter water" area (shaded) from Figure 5 included.

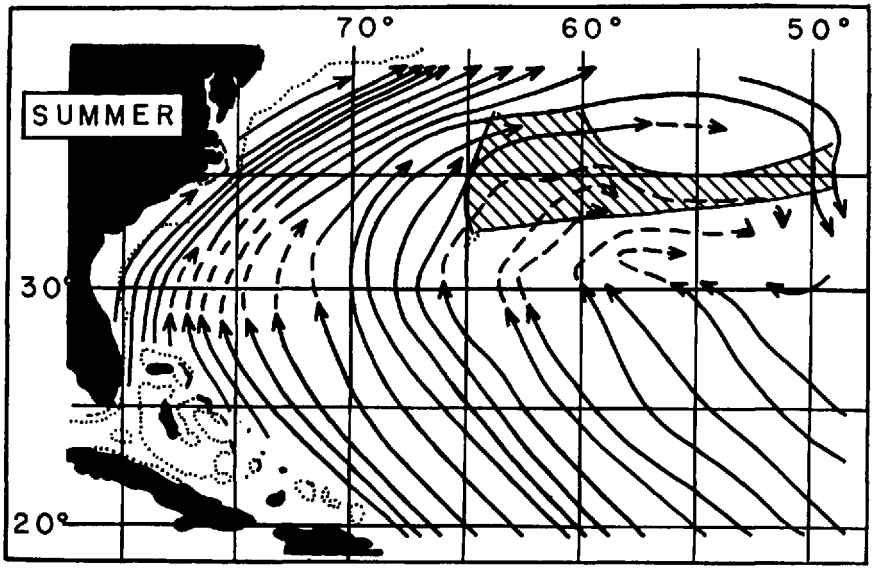

FIGURE 10. Summer current conditions with the "summer water" area (shaded) from Figure 5 included.

Figure 5 and corresponds to the "winter water" area south and west of Bermuda. In the summer chart (Figure 10), no indication whatsoever can be seen of the above eddy. In this case the shaded area has similarly been copied from Figure 5 and corresponds to the "summer water" area north and northeast of Bermuda.

The difference in the current system between winter and summer can be simply interpreted as follows. In winter the waters reaching Bermuda seem to come from the southeast and east roughly along the 30° north latitude parallel. These waters build the eastern and southern sections of an eddy of the Gulf Stream south of it, as indicated in Figure 9. Thus the "winter water" which is to be found south and southeast of Bermuda during the winter is nothing else but the south and westbound eddy of the Gulf Stream.

In summer the waters reaching Bermuda seem to come, directly from the south and southeast, from the North Equatorial Current. The mean direction of the surface currents (usually called Antilles Current) in the area seems to be roughly 300° in winter and 330° in summer. There are some indications, too, that in summer, in addition to the regular Antilles Current, another current branch exists with an approximate path from 20°N. and 60°W. to 30°N. and 67°W. Thus the "summer water" which is to be found west and southwest of Bermuda during the summer is just water coming directly from the North Equatorial Current.

The evidence from the geographical distribution of the plankton indicates the passage of waters of different origins around Bermuda in winter and summer. The above interpretation of the surface current systems is consistent with the indications from the plankton. The water, and its fauna, which passes Bermuda in winter has a more southerly origin than that which passes there in summer.

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