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Chaetognatha from the Florida Current and Coastal Water of the Southeastern Atlantic States

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CHAETOGNATHA FROM THE FLORIDA CURRENT AND COASTAL WATER OF THE SOUTHEASTERN ATLANTIC STATES[1]

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ABSTRACT

This paper reports the Chaetognatha in plankton samples collected in the waters off the coast of the southeastern Atlantic States during nine cruises of the U. S. Fish and Wildlife Service's M/V THEODORE N. GILL. From a total of 590 samples examined 12 species representing 3 genera are identified. The results show the distribution of chaetognaths to be very uniform paralleling the coast in a north-south direction. There are no apparent seasonal changes in the distribution of the species. Across the continental shelf and Florida Current they decreased noticeably in abundance. The inshore stations usually have two to five times as many individuals per cubic meter as do the stations in the Florida Current.

Three kinds of water are identifiable in the area, Carolinian Coastal, Florida Current and Sargasso Sea water. *Sagitta hispida* has its highest percentage of incidence in Carolinian Coastal water. *S. hexaptera, S. lyra,* and *Krohnitta subtilis* occur in more than 90 per cent of the samples from the Florida Current; their presence in Coastal water probably indicates recent incursions of Florida Current water. Of the remaining eight species *S. helenae* and *S. tenuis* are characteristically coastal forms that appear frequently in the edge of the Florida Current. The other six species live principally in the Florida Current in this area but often appear in Coastal water. Over a long period of time development of tolerance to varied conditions probably explains the lack of sharply defined distributional limits of most species in the area.

INTRODUCTION

The Chaetognatha constitute an important fraction of the marine plankton and they are predators on smaller zooplankton. Areas in the western North Atlantic covered by published reports on Chaetognatha include: the west coast of Greenland (Kramp, 1917), eastern Canada (Huntsman, 1919), Gulf of Maine (Redfield and Beale, 1940), Georges Bank (Clarke, Pierce, and Bumpus, 1943), middle Atlantic coast (Bigelow and Sears, 1939), Delaware Bay region (Deevey, 1960), continental shelf of North Carolina (Pierce, 1953, Bumpus and Pierce, 1955), Florida Current off Miami Beach (Owre, 1960), coast of Cuba (Suarez Caabro, 1955), and waters around Trinidad (Vannucci and Hosoe, 1952).

[1]These studies were aided by a contract (NR 104-343) between the Office of Naval Research, Department of the Navy, and the University of Florida.

There are no publications on this group between North Carolina and Florida. It was therefore with considerable interest that we took advantage of the opportunity to examine the chaetognaths collected over a large area off the southeastern Atlantic States by the U.S. Fish and Wildlife Service's M/V THEODORE N. GILL.

ACKNOWLEDGMENTS

We are especially indebted to William W. Anderson, Laboratory Director, Bureau of Commercial Fisheries, Biological Laboratory, Fish and Wildlife Service, Brunswick, Georgia, for making available the plankton samples and the physical and chemical data collected on the nine cruises of the GILL. Jack W. Gehringer and Frederick H. Berry, Fishery Research Biologists, and other personnel at the above laboratory have been most cooperative in providing us with supplementary information concerning the cruises. Dean F. Bumpus of the Woods Hole Oceanographic Institution kindly provided drawings of the distribution of surface salinities and temperatures obtained from those cruises. The Graduate School and the Department of Biology of the University of Florida provided research facilities and stenographic aid.

SOURCE OF THE DATA

During the period between 10 February 1953 and 12 December 1954, the U.S. Fish and Wildlife Service undertook a biological, chemical, and physical oceanographic survey of the waters along the south Atlantic coast of the United States. Nine cruises were made in the two-year period of the field work with the GILL. The dates for the beginning and termination of the cruises follow. Each cruise started and ended at Brunswick, Georgia.

Cruise 1: 10 February - 10 March 1953
Cruise 2: 16 April - 15 May 1953
Cruise 3: 15 July - 16 August 1953
Cruise 4: 1 October - 14 November 1953
Cruise 5: 20 January - 25 February 1954
Cruise 6: 14 April - 29 April 1954
Cruise 7: 9 June - 13 July 1954
Cruise 8: 27 August - 1 October 1954
Cruise 9: 3 November - 12 December 1954

The area covered by this investigation extended from Cape Hatteras to the Florida Straits and from the coast across the continental shelf

and Florida Current. Eighty regular stations, 9 special stations and 1 standard station were established. These stations were in lines extending seaward from the shore. The regular stations were 20 miles apart and the lines of stations about 40 miles apart. The special stations were located about 200 miles offshore. Samples were not available from the standard station near Elbow Cay in the Bahamas. The basic station plan is shown in Fig. 1.[2]

The biological, physical, and chemical data collected have been published in nine Special Scientific Reports—Fisheries. Each report covers the results of one cruise (Anderson, Gehringer, and Cohen, 1956a, 1956b, Anderson and Gehringer, 1957a, 1957b, 1958a, 1958b, and 1959a, 1959b, 1959c).

Because of bad weather or mechanical failure of equipment, all stations were not visited on each cruise. From the nine cruises, 590 plankton samples were collected which were examined in this study.

These samples were collected on Cruises 1 and 2 with a standard half-meter No. 1 silk net. Beginning with Cruise 3, plankton tows on station were usually taken with an all metal half-meter sampler, designated Gulf III (Gehringer, 1952). The filtering mesh of the sampler consisted of monel wire cloth approximately equal to No. 1 silk net in mesh size. A calibrated flow meter in the nets was used to determine the volume of water filtered. The volume filtered varied considerably but was usually between 100 to 200 cubic meters. In deep water, the nets were towed obliquely to depths of 80 meters or less. In shallow water, the nets were kept a safe distance above the bottom.

One-tenth of each plankton sample collected with the half-meter nets was made available for this investigation. The chaetognaths were sorted, identified, and counted in this fraction. As a rule, there were between 100 and 200 specimens in this fraction of the sample. Counts and specific identifications were not made on specimens less than four millimeters in length because they lacked recognizable features. Total counts made at the Brunswick Laboratory were usually higher than our counts of the same sample. This was the result of the inclusion of smaller specimens in the Brunswick Laboratory counts which were not identified to species.

Temperature and Salinity

Temperatures were taken with reversing thermometers attached to Nansen bottles. Casts were made at each station at standardized

[2]This is a copy of the basic station plan supplied me by William W. Anderson.

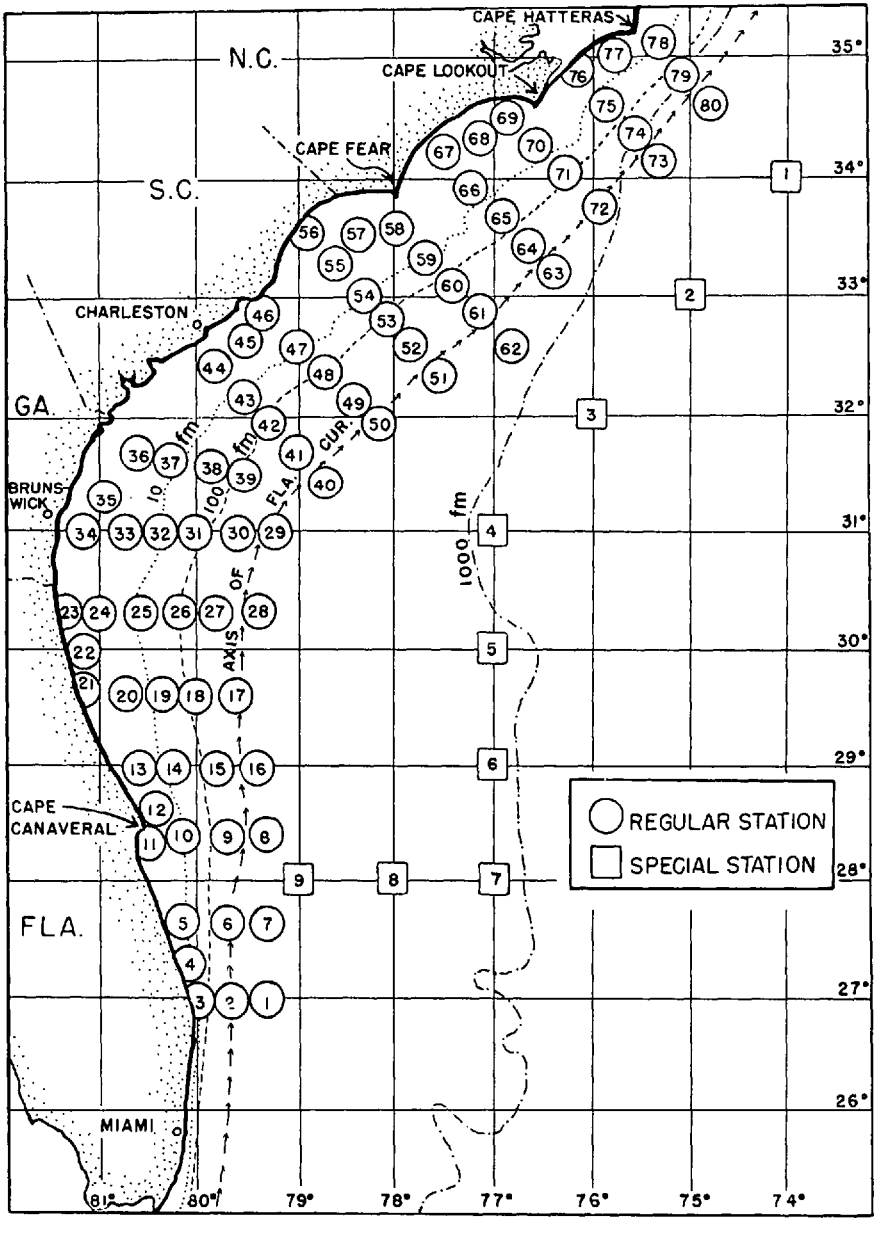

FIGURE 1. The basic station plan for the nine cruises of the GILL made during the period February 1953 to December 1954.

depths using 12 or fewer bottles per cast. Salinities were collected and determinations were made by titration in the Brunswick Laboratory. The detailed data, together with temperature, salinity, and density sections, are included in the published reports of the nine cruises of the GILL.

THE CHAETOGNATHA

Twelve species of chaetognaths representing three genera, *Sagitta, Krohnitta,* and *Pterosagitta,* were identified from the plankton samples. They are listed under each genus in order of abundance (Table 1). A total of 89,784 specimens was counted from 590 samples collected in nine cruises. The actual count multiplied by ten (1/10 of each sample examined) results in an estimated 897,840 specimens in the entire 590 samples. This resulted in an average number of 8.7 specimens per cubic meter of water filtered. *Sagitta enflata, S. tenuis, S. helenae,* and *S. serratodentata* averaged one or more per cubic meter; the remaining species were less abundant. *S. enflata* accounted for 36.1 per cent of all chaetognaths collected and this species was present in 88.5 per cent of all samples. At the other extreme *S. lyra* totaled only 0.03 per cent and was found in 0.8 per cent of the samples.

TABLE 1
THE CHAETOGNATHA COLLECTED IN THE NINE CRUISES OF THE *Gill*

Species	Number Collected	Average No./M3	Per Cent of Total	Per Cent of Samples
1. *S. enflata*	323,730	3.1	36.1	88.5
2. *S. tenuis*	172,090	1.7	19.2	36.9
3. *S. helenae*	138,520	1.4	15.4	50.5
4. *S. serratodentata*	105,480	1.0	11.7	65.2
5. *S. hispida*	53,200	0.5	5.9	14.4
6. *S. minima*	19,820	0.2	2.2	31.7
7. *S. bipunctata*	15,220	0.2	1.7	49.1
8. *S. hexaptera*	5,720	0.1	0.6	27.6
9. *S. lyra*	250	Tr	0.03	0.8
10. *K. pacifica*	23,120	0.2	2.6	60.2
11. *K. subtilis*	1,510	Tr	0.2	10.2
12. *P. draco*	39,180	0.3	4.4	54.4
Total	897,840	8.7	100.03	

There was a noticeable difference in the numbers of chaetognaths across the continental shelf and into the Florida Current. These animals were much more abundant at the inshore stations and generally decreased progressively farther offshore. To illustrate this difference, the chaetognaths from three widely spaced lines of stations

across the shelf have been tabulated in Table 2. The most noticeable decrease occurred near the edge of the shelf where Florida Current water was encountered. In general, it appears that the number of inshore chaetognaths is from two to five times as great as the number offshore.

Attempts to relate this decrease in abundance in the offshore stations with measurements of total phosphorus, nitrate, nitrogen, and arabinose (GILL cruise reports) showed no positive correlation. These substances did not appear to show any consistent change in concentration from inshore to offshore stations.

Chaetognaths Collected above Cape Hatteras and from the Miami Area Compared to the Results of this Study.—Bigelow and Sears (1939), reporting on plankton samples taken over the continental shelf from Cape Cod to Chesapeake Bay, listed the following chaetognaths: *S. elegans, S. enflata, S. serratodentata, S. hexaptera, S. maxima, Eukrohnia hamata, Krohnitta subtilis,* and *Pterosagitta draco.* The first three listed were the more abundant species. *S. elegans* was taken in large numbers over the shelf. This species extends northward to the arctic in coastal waters and southward almost to Cape Hatteras over the continental shelf. *S. enflata* was recognized as a warm water species which invaded the shelf for 30 miles. It was less common in winter. *S. serratodentata* was common over most of the shelf between Cape Cod and Chesapeake Bay but more abundant over the outer half. There is evidence that it is endemic and breeds in this area. The remaining five species were much less abundant and were taken near the edge of the shelf. *S. elegans, S. maxima,* and *E. hamata* were not collected in this present study. They are characteristically colder or deeper water species and are not apt to be encountered in the warm upper layer of the Florida Current.

TABLE 2

DECREASING NUMBERS OF CHAETOGNATHS FROM INSHORE TO OFFSHORE SHOWN IN THREE LINES OF STATIONS. STATION NEAREST SHORE LISTED AT THE TOP OF EACH COLUMN. THE NUMBERS ARE AVERAGES FOR ALL NINE CRUISES.

Station	No./M³	Station	No./M³	Station	No./M³
13 regular	16.8	23 regular	4.4	69 regular	10.7
14 "	6.8	24 "	7.4	70 "	13.7
15 "	2.2	25 "	13.4	71 "	10.7
16 "	2.6	26 "	7.7	72 "	6.8
6 special	2.8	27 "	2.8	2 special	2.8
		28 "	2.8		
		5 special	2.7		

Owre (1960), in a study of the Chaetognatha in the Florida Current, made a series of plankton tows 10 miles east of the Miami Beach Seabuoy. These tows reached a depth of 350 meters and were made twice a month, when possible, over a period of a year. These collections included all the species found in the GILL samples, except *S. tenuis,* and in addition *S. decipiens, S. planctonis, S. macrocephala,* and *E. hamata.* A series of samples taken on the east side of the Florida Current near Bimini produced one specimen of *E. fowleri. S. tenuis, S. helenae,* and *E. hamata* were not collected there.

S. decipiens was abundant in Owre's (1960) tows and it no doubt occurs in the Florida Current in the area covered by this investigation; however, it is characteristically found deeper than 80 meters, the limit of regular tows made by the GILL. In the Florida Current near Miami only single specimens of *S. planctonis, S. macrocephala,* and *E. hamata* were collected. These three are deep water species, as reported by Ritter-Záhony (1911) and other investigators.

Distribution and Abundance by Species.—The species of chaetognaths will be discussed in order of their abundance within each genus (Table 1). The distribution and abundance of each species are shown in Figs. 2 to 4.

S. enflata was the most abundant and widely distributed chaetognath in the area covered by this investigation (Fig. 2); 323,730 specimens were collected. This species was found at least once from every regular and every special station and was present in 88.5 per cent of the samples. At some of the inshore stations it was collected in fewer than half the samples. Farther offshore it was found in almost every tow. Thus it ranges from close inshore across the shelf and Florida Current. Optimum conditions appeared to be close to the 20-fathom curve, where numbers of three or more per cubic meter were common. Nearer the coast and farther offshore the numbers diminished.

S. enflata is an epiplanktonic warm water species found in the Atlantic, Indian, and Pacific Oceans. Ritter-Záhony (1911) indicates that its general range lies between 40°N and 40°S latitude. Actually, northern records in the Gulf Stream exceed these limits in some instances. Huntsman (1919) found it as far north as 43°, where its presence indicated an invasion of Gulf Stream water near Nova Scotia. Along the Atlantic coast it has been reported by Bigelow and Sears (1939), Deevey (1960), Pierce (1953), Owre (1960), and from

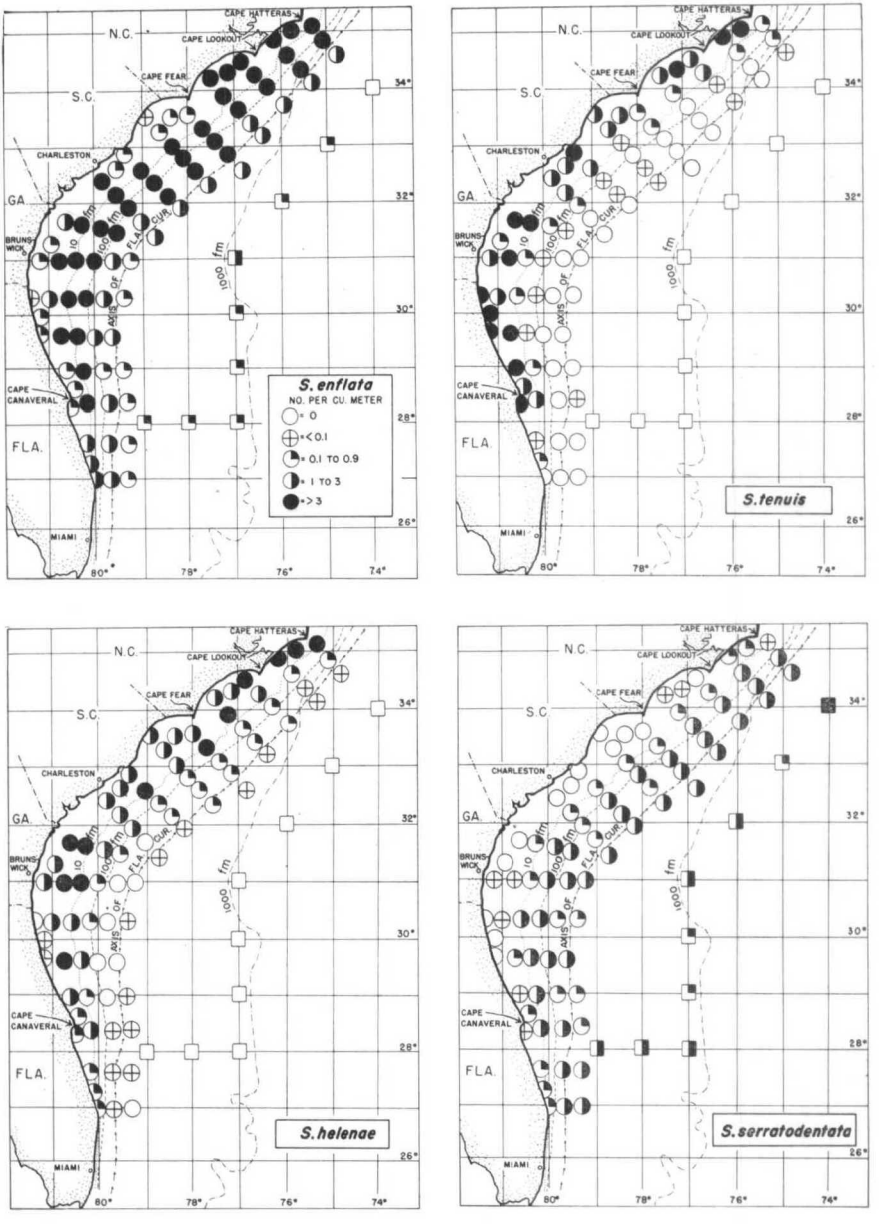

FIGURE 2. The distribution and abundance of *S. enflata*, *S. tenuis*, *S. helenae*, and *S. serratodentata*. The data have been averaged by station for the nine cruises.

the coastal waters of Cuba by Suarez Caabro (1955).

S. tenuis was the second most numerous species in the samples. A total of 172,090 specimens was collected in 36.9 per cent of the samples. Fig. 2 shows that it was most abundant close inshore and decreased with distance from the coast. Beyond the 10-fathom line *S. tenuis* diminished rapidly and almost disappeared in the Florida Current. It was not found at any of the special stations. Owre (1960) did not take it in repeated samplings 10 miles east of the Miami Beach seabuoy in the Florida Current.

This species has been collected immediately north of Cape Hatteras in Virginian-type water (Bumpus and Pierce, 1955), along the North Carolina coast (Pierce, 1953, 1958), in Florida waters (Pierce, 1951), and along the coast of Cuba (Suarez Caabro, 1955). It appears to be a coastal species which at times is carried into the Florida Current. There is a dearth of records of this species from the inshore waters off Cape Cod and farther north.

S. helenae was the third most abundant species in the collections and was represented by 138,520 specimens from 50.5 per cent of the samples (Fig. 2). It is a typically continental shelf species, which in this area occupies a niche similar to that of *S. tenuis*. It ranged from the inshore stations into most of the stations in the Current. Its peak of abundance was clearly inside the 10-fathom line. Catches of from two to four specimens per cubic meter were common in this shallow water. In the Florida Current, average catches of 0.3 or fewer individuals per cubic meter were the rule. None was taken at any of the special stations.

This species appears to tolerate Florida Current water, but the reduced numbers near the axis and complete absence on the eastern side of the current indicate that it probably is drawn in from the shelf and is not living under favorable circumstances in the Florida Current proper.

Along the Atlantic coast, *S. helenae* has been reported as a temporary inhabitant outside Delaware Bay (Deevey, 1960). It has been collected in numbers off the coast of North Carolina (Pierce, 1953). Ritter-Záhony (1910) described it originally from specimens collected near the Dry Tortugas. Owre (1960) took it off Miami and Suarez Caabro (1955) from Cuba. There are no records from the Eastern Atlantic, Pacific, or Indian Oceans. Its range appears to be limited to the tropics and subtropics of the western Atlantic.

S. serratodentata was represented by 105,480 specimens from

65.2 per cent of the samples (Fig. 2). This open-ocean species is also widely distributed over the continental shelf and across the Florida Current. Its average abundance was never high, seldom exceeding two individuals per cubic meter. It was noticeably absent from most of the stations bordering the coast. This cosmopolitan species has been reported (Ritter-Záhony, 1911) from all oceans between 50°N and 50°S latitude. It has been recorded along the Atlantic coast of the United States (Redfield and Beale, 1940; Bigelow and Sears, 1939; Deevey, 1960; Pierce, 1953; Owre, 1960; Suarez Caabro, 1955; Vannucci and Hosoe, 1952, and others).

S. hispida was usually an abundant species where it occurred (Fig. 3). A total of 52,320 specimens was taken, but from only 14.4 per cent of the samples. With minor exceptions, its range was limited to the stations nearest the shore. Previous studies (Pierce, 1958) have shown that this species was abundant in the bays and sounds and in the water immediately adjacent to the coast of North Carolina. There is little doubt that it is a stray in the Florida Current and does not exist for long periods in that environment.

S. hispida is common from Cape Hatteras southward to Florida (Pierce, 1953, 1958) and along the west coast of Florida (Pierce, 1951). Deevey (1960) found that it appeared briefly outside Delaware Bay. Suarez Caabro (1955) reports this species from Cuban coastal waters. Owre (1960) found it in the Florida Current off Miami Beach, but attributes its presence there to coastal water transported from the west coast of Florida. *S. hispida* has also been reported from the west coast of Africa (Scaccini and Ghirardelli, 1941).

S. minima was moderately abundant (19,820 specimens collected) over the portion of the shelf outside ten fathoms, and across the Florida Current (Fig. 3). It was present in 31.7 per cent of the samples. Its region of maximum abundance was along the edge of the continental shelf. It was occasionally found at the inshore stations.

This is a cosmopolitan species which Ritter-Záhony (1911) indicates as occurring in the Atlantic, Pacific, and Indian Oceans between 40°N and 40°S latitude. Along the Atlantic coast it has been reported off Long Island (Bumpus and Pierce, 1955) and in many samples south of Cape Hatteras (Pierce, 1953). Owre (1960) also found it abundant along the western edge of the Florida Current off Miami.

S. bipunctata was widely distributed over the outer portion of the shelf and across the Florida Current (Fig. 3). A total of 15,220 specimens was counted from 49.1 per cent of the samples. This species

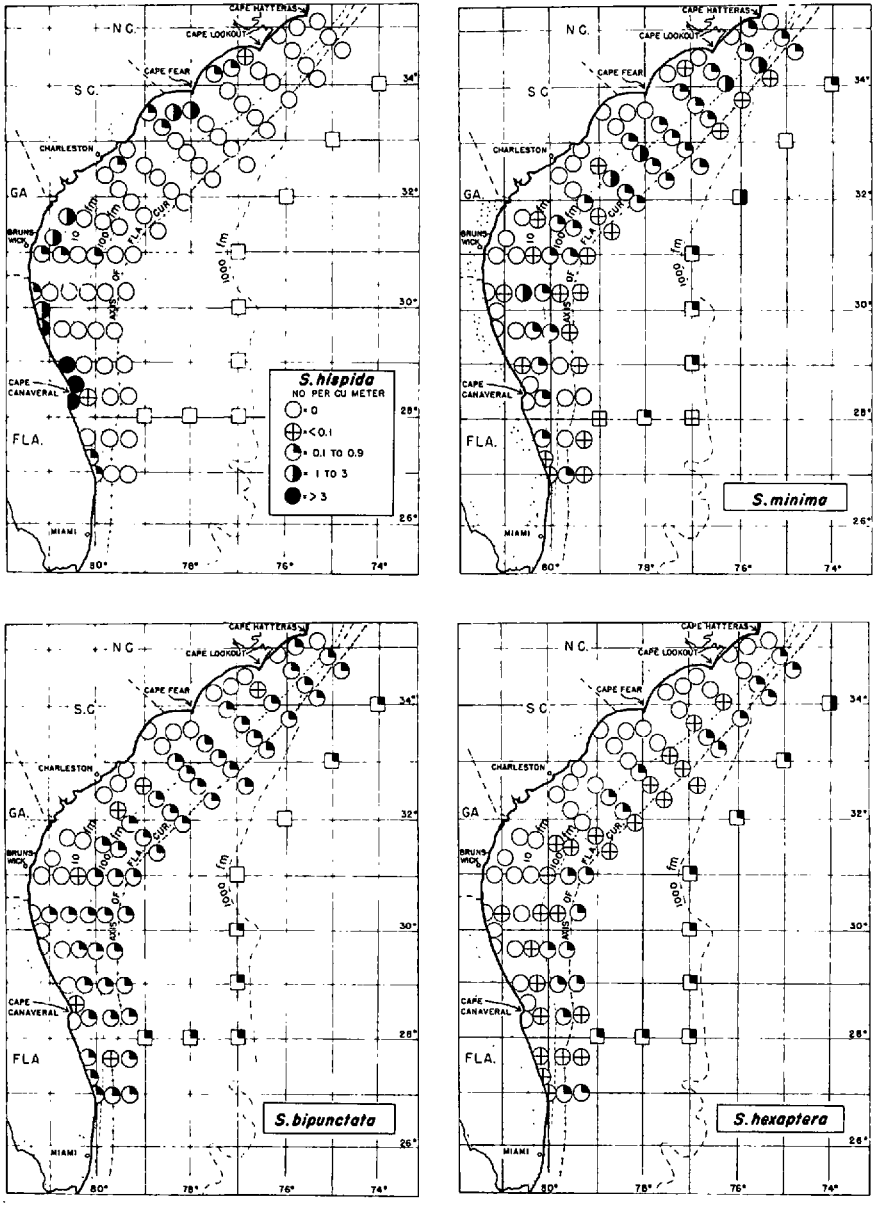

FIGURE 3. The distribution and abundance of *S. hispida, S. minima, S. bipunctata,* and *S. hexaptera.* The data have been averaged by station for the nine cruises.

was seldom very abundant but was taken consistently in the offshore water. Its distribution along the Atlantic coast is similar to that of *S. minima.*

This species is cosmopolitan in all oceans between 40°N and 40°S latitude (Ritter-Záhony, 1911). It may occasionally be taken in more northern localities in the Atlantic. Hunstman (1919) caught seven specimens in the edge of the Gulf Stream southeast of Nova Scotia. Fraser (1949) records a few specimens from as far north as 58°50'N, 6°26'W. It has been reported from Cuba by Suarez Caabro (1955). Numerous authors record it from the Pacific and Indian Oceans.

S. hexaptera was collected (5,720 specimens) from only 27.6 per cent of the samples (Fig. 3). It was taken occasionally over the outer edge of the shelf but principally in the Florida Current. It was present at least once at every station beyond the shelf. The numbers taken at these stations would undoubtedly be higher if the tows had been deeper than 80 meters.

This species has been reported from all oceans. Its confusion with *S. maxima* and *S. lyra* in some earlier papers poses a question concerning certain details of its distribution. Along the western Atlantic it appears to be absent from Greenland waters (Kramp, 1917). Huntsman (1919) reported it in Gulf Stream waters off Nova Scotia but not in the cold Labrador Current water. He found that it was characteristic of intermediate depths from 100 to 200 meters. Redfield and Beale (1940) did not report it in their study of the Chaetognatha of the Gulf of Maine. Bigelow and Sears (1939) collected some specimens at the edge of the shelf off Long Island. Pierce (1953), Bumpus and Pierce (1955), Owre (1960), and Suarez Caabro (1955) have collected this species along the Atlantic Coast south to Cuba. Fraser (1949) records this species as a stray collected occassionally in the Faroe-Shetland Channel off Scotland.

S. lyra was the least abundant of all Chaetognatha collected in this study (Fig. 4). Only 250 specimens were counted from 0.8 per cent of the stations sampled. It was rarely found over the shelf in these samples. It occurred typically in the Florida Current. The figures concerning its abundance are misleading, because it normally occurs below 80 meters, the depth limit for these plankton hauls.

This species is reported by Ritter-Záhony (1911) to be cosmopolitan in all oceans from 100-200 meters downward. Huntsman (1919) found it in association with *S. hexaptera* in the Gulf Stream off Nova Scotia. Fraser (1949) has collected it in deep water off Scotland.

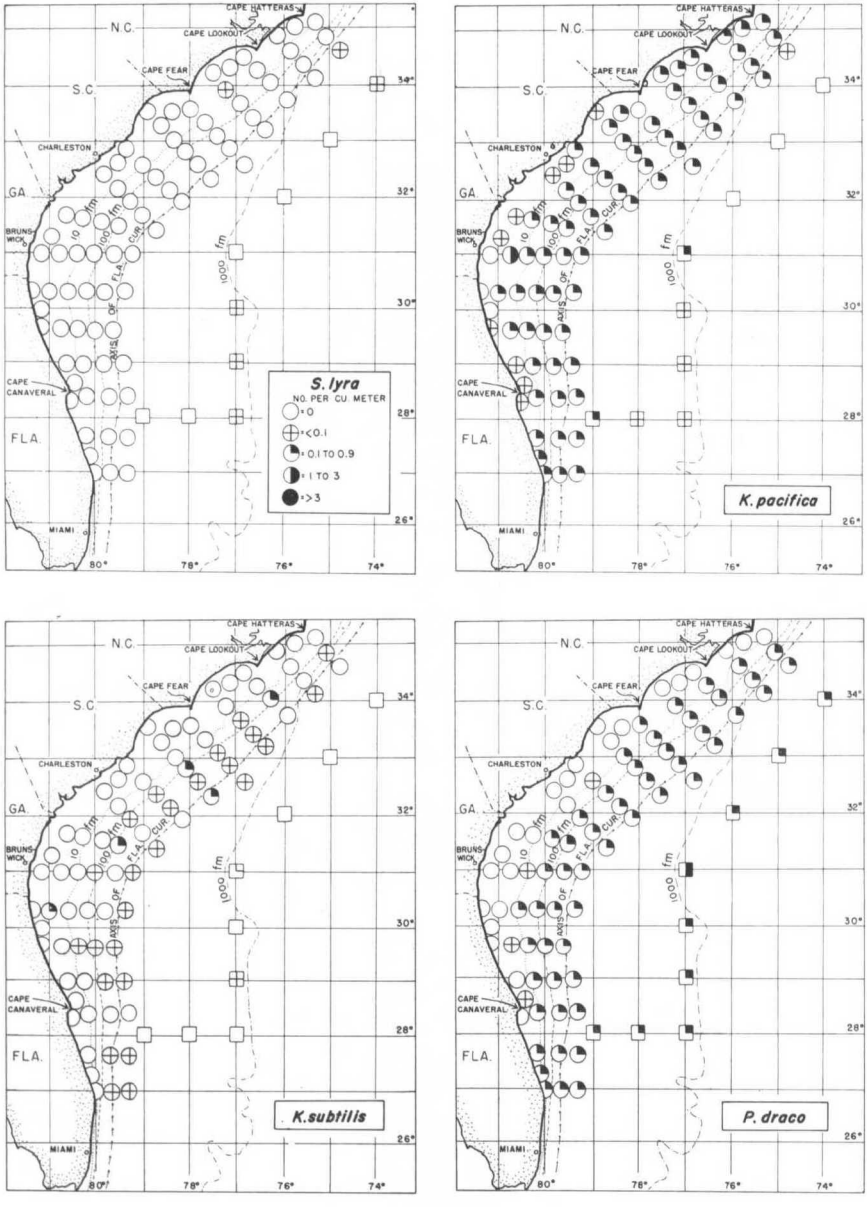

FIGURE 4. The distribution and abundance of *S. lyra, K. pacifica, K. subtilis,* and P. draco. The data have been averaged by station for the nine cruises.

Along the Atlantic coast it has been reported by the same authors cited under the name of *S. hexaptera,* with the exception of Suarez Caabro, who did not collect it off Cuba.

Krohnitta pacifica occurred in 60.2 per cent of the samples (23,120 collected)and was very widespread from the coast to several of the special stations on the eastern side of the current (Fig. 4). Despite its wide range in the area covered by this investigation, it was never abundant. At no station did it average more than one per cubic meter for the nine cruises.

This species has been reported by Tokioka (1940), Thomson (1947), and others from the tropical and subtropical Pacific. Pierce (1953, 1958), Bumpus and Pierce (1955), Owre (1960), Suarez Caabro (1955), and Vannucci and Hosoe (1952) have recorded it from Cape Hatteras to Cuba and Trinidad. *K. pacifica* has often been placed in the synonymy of the allied species *K. subtilis,* which has confused many earlier records.

K. subtilis was much less abundant than *K. pacifica.* Only 151 specimens were collected from 10.2 per cent of the samples (Fig. 4). It was taken in most cases from the Florida Current—in rare instances over the shelf.

It has been reported by the same authors as referred to under *K. pacifica.* In addition Fraser (1952) and Furnestine (1952) have collected it from the Atlantic and Mediterranean, respectively. Furnestine suggests that it is principally a mesoplanktonic species in the Mediterranean. This may account for its scarcity in these samples.

Pterosagitta draco was a widely distributed species found over the outer continental shelf and across the Florida Current (Fig. 4). A total of 39,180 specimens was counted from 54.4 per cent of the samples. It was taken from every station beyond the 10-fathom curve but at only a few stations inside this depth.

Its distribution is world wide in tropical and subtropical waters between 40°N and 40°S latitude (Ritter-Záhony, 1911). In the western Atlantic a few specimens were reported by Huntsman (1919) off the southeastern edge of Nova Scotia in Gulf Stream waters. Bigelow and Sears (1939) collected it south of Cape Cod from the outer portion of the shelf. Owre (1960) found it in abundance in the Florida Current off Miami, and Suarez Caabro (1955) has reported it from Cuban waters.

Chaetognaths and Hydrography

In this investigation along the Southeastern Atlantic States, one water type and two water masses were encountered. The water type is the water over the continental shelf, which has been designated Carolinian Coastal water (Bumpus and Pierce, 1955). The predominant water mass is the Florida Current. The other water mass is Central Atlantic or Sargasso Sea water (Iselin, 1936).

The Carolinian Coastal water extends from Cape Hatteras south to Daytona Beach and possibly farther down the coast. The seaward range covers most of the shelf; however, this is subject to considerable variation depending in part on the position of the Florida Current.

Carolinian Coastal water is formed of the runoff from the land mixed with Florida Current water which has moved or been blown over the shelf. It does not receive any regular supply of water from the colder Virginian Coastal water north of Cape Hatteras. The Cape acts as a barrier to the north-south movement of coastal water. The salinity of this water is less than 36‰, and little thermal stratification is evident from the surface to the bottom.

The Florida Current is characterized by salinities of almost 36‰ to about 36.5‰ near the surface; also by velocities of 10 centimeters per second or greater (Iselin, 1936). Stommel (1958) defines the limits of the Florida Current as that point on either side of the Current where the horizontal pressure gradient becomes zero. Neither measurements of velocity nor the determination of the horizontal pressure gradient are easily made. For our purposes, temperature-salinity curves based on data from the Florida Straits (Wennekens, 1959) where used to determine whether or not a plankton sample was taken in the Florida Current. The T-S envelope (Figs. 6, 7, and 8) constructed from Wennekens' data compares closely with earlier T-S curves for the Florida Current published by Iselin (1936) and Parr (1937). Because all plankton tows were made in depths of less than 100 meters, it is the surface or shallow water features of the Florida Current which are of primary interest in this study. Because both temperature and, to a lesser extent, salinity are subject to seasonal variation in the upper layers, precise identification of the water from which the samples were obtained is not always possible. This is especially true at the edges of the Current.

The western border of the Florida Current runs close to or over the edge of the continental shelf. This edge is more sharply defined and can usually be identified by salinities as low as 36.0‰ at or near

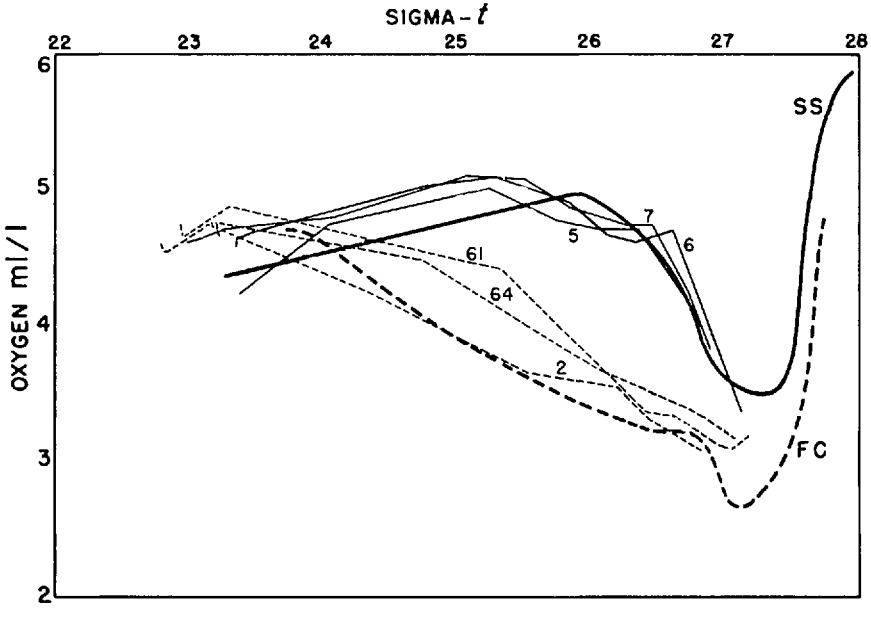

FIGURE 5. The quantity of dissolved oxygen found at special stations (solid lines) and regular stations (dashed lines) for Cruise 3. Heavy solid line (SS) represents oxygen concentration for Sargasso Sea (Richards and Redfield 1955); heavy dashed line (FC) indicates oxygen in the Florida Current (averaged after Wennekens 1959). The solid lines approximate the curve for Sargasso Sea water indicating its presence at the special stations. The regular stations show more influence from the Florida Current.

the surface. Below this salinity, Carolinian-type water is encountered.

The eastern border of the Florida Current merges with the Sargasso Sea. There is no sharp boundary between these two water masses. The apparent entrainment of water from the Sargasso Sea into the Florida Current (Iselin, 1936) further complicates the problem of separation. Plots of T-S curves do not show enough distinctive features to be of value in separating the two water masses in this border zone. Wennekens (1959), referring to an earlier work by Richards and Redfield (1955), has utilized the amount of dissolved oxygen at various sigma-t surfaces to distinguish between Florida Current[3] and Sargasso Sea water. In the latter water the oxygen values are higher with increasing sigma-t values than they are in the Florida Current (Fig. 5). At sigma-t = 26.0 the oxygen in Sar-

[3]Wennekens (1959) refers specificially to Yucatan water in the Florida Straits. For the purpose of detecting the presence of Sargasso Sea water, the oxygen values of Yucatan and Florida Current water are assumed to be the same.

gasso Sea water is near its first peak of 5 milliliters per liter. In contrast, in the Florida Current at this density the oxygen is between 3 and 4 milliliters per liter. A sigma-t of 26.0 is found in these waters near a depth of 200 meters. Nearer the surface the amount of oxygen converges for both water masses to 4 or 5 milliliters per liter. In the upper 100 meters it is difficult to distinguish these water masses on any basis. It appears logical to assume that in the areas studied, if mixing is evident from several hundred meters deep to within 100 meters of the surface, the surface water is also a mixture of Florida Current and Sargasso Sea water. This assumption is of some importance because the plankton samples came from the upper 100 meters of water.

In Fig. 5 the oxygen, sigma-t values are plotted for some of the easternmost stations (Cruise 3, special station 5, 6, and 7) and are compared with those values at stations near the axis of the Florida Current (Cruise 3, regular stations 2, 61, and 64). A difference in oxygen between sigma-t values of 25 and 27 is evident. This may be interpreted as the intrusion of Sargasso Sea water at the special stations and as little noticeable intrusion at regular stations 2, 61, and 64 near the axis of the Current. This mixing is evident principally between 100 and 400 meters. Near the surface the amount of oxygen approaches 4.5 to 5 milliliters per liter for both water masses. An additional comparison was made between regular stations 2, 61, and 74 and special stations 1, 3, 5, and 7 for Cruise 2 with similar results. High oxygen values were found in water at 100 to 400 meters at the special stations and lower values at the regular stations.

These data support the theory that Sargasso Sea water is added to the Florida Current and is noticed principally at the special stations. There is also evidence for Sargasso Sea water at some of the easternmost of the regular stations.

Because of the similarity of species in the upper layers of the Florida Current and in the western edge of the Sargasso Sea, and because of the practical difficulties in distinguishing these water masses at the depths sampled, only Carolinian Coastal water and Florida Current water will be distinguished. Sargasso Sea water mixed with the Florida Current will be included under Florida Current water as far as the association of chaetognaths with hydrography is concerned.

The frequency of occurrence of the chaetognaths in each kind of water is shown statistically in Table 3. It is obvious from this table

TABLE 3

CHAETOGNATHA IN CAROLINIAN AND FLORIDA CURRENT WATER COUNTS MADE FROM ALL SAMPLES TAKEN DURING THE FIRST FOUR CRUISES OF THE *GILL*

Species	Carolinian Coastal Salinity <36.0‰		Florida Current Salinity >36.0‰		Species* Predominant in	
	Times Present	Per Cent	Times Present	Per Cent	Carolinian Water	Florida Current
S. bipunctata	9	11	76	89		x
S. enflata	61	34	118	66	x	x
S. helenae	55	49	57	51	x	x
S. hexaptera	3	6	48	94		xx
S. hispida	18	72	7	28	xx	
S. lyra	0	0	5	100		xx
S. minima	6	10	55	90		x
S. serratodentata	13	12	98	88		x
S. tenuis	65	70	28	30	x	
K. pacifica	24	24	75	76	x	x
K. subtilis	1	8	11	92		xx
P. draco	6	6	90	94		xx

*The double crosses indicate the species which appear to be most restricted to the indicated water.

that all species except *S. lyra* are found at least occasionally in both environments.

In Figs. 7 and 8 are plotted the extreme ranges of temperature and salinity encountered by each of the 12 species of chaetognaths at all stations. Because plankton samples were not taken below 100 meters, temperature and salinity below this depth were not included in these graphs. Also in an attempt to discover the optimum conditions for each species, the T-S curves for that station where each species occurred in greatest number for each cruise (Table 4) have been plotted within the rectangle of temperature and salinity extremes. Moreover, in each of these graphs the T-S envelope characterizing the Florida Current water (Wennekens, 1959) has been included (Figs. 7 and 8). An examination of each of the 12 graphs will show the extremes of temperature and salinity which each species has encountered; the T-S curves of the water at the stations (nine) where that species was most abundant; and, by proximity to the Florida Current envelope, the kind of water in which each species is found in maximum abundance.

Of the 12 species taken, *S. enflata* occurs so commonly in Carolinian Coastal and Florida Current water that it has little value as

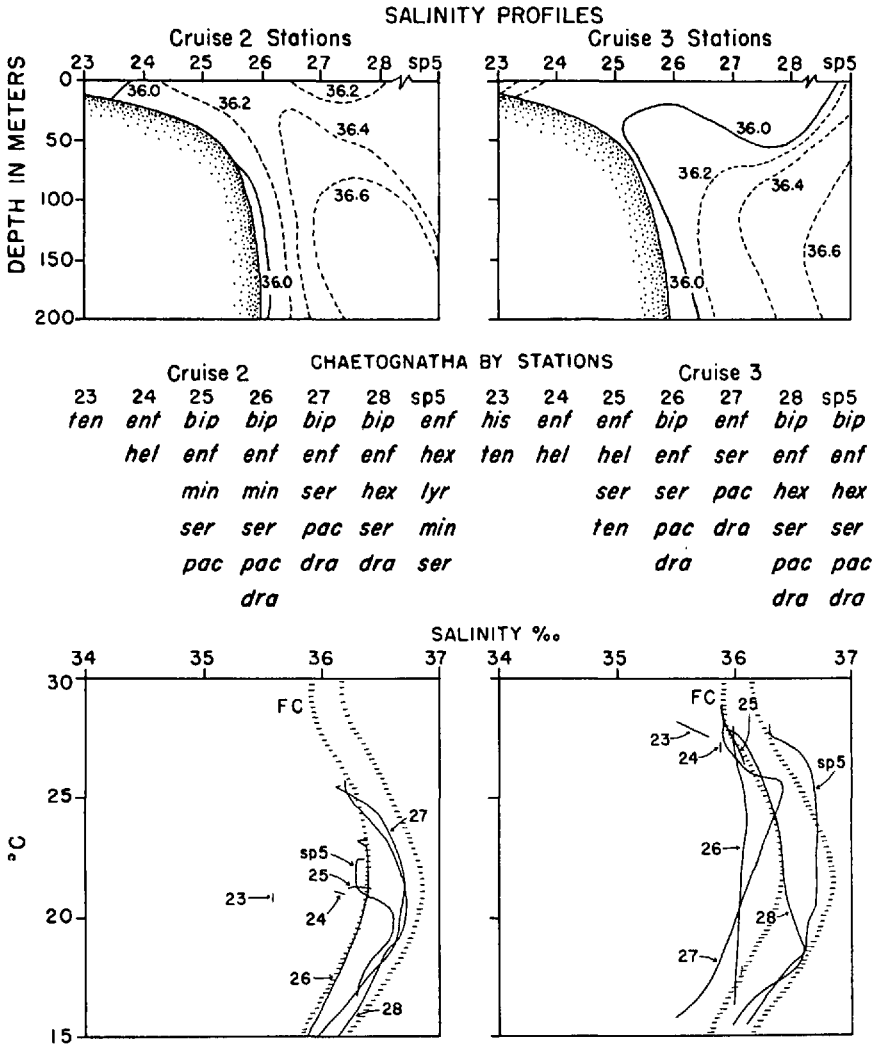

FIGURE 6. The distribution of species across the continental shelf and Florida Current for the same line of stations in Cruises 2 and 3. The upper graphs represent salinity profiles, below are shown the species collected at each station. The bottom graphs illustrate the T-S curves for each station. The hatched lines represent the envelope of Florida Current water. Station 23 is clearly in Coastal water; stations 24, 25, and 26 are marginal; the remainder are in the Florida Current. Special station 5, Cruise 3, probably shows influence of Sargasso Sea water. Note the characteristic increase in species as Florida Current water is approached.

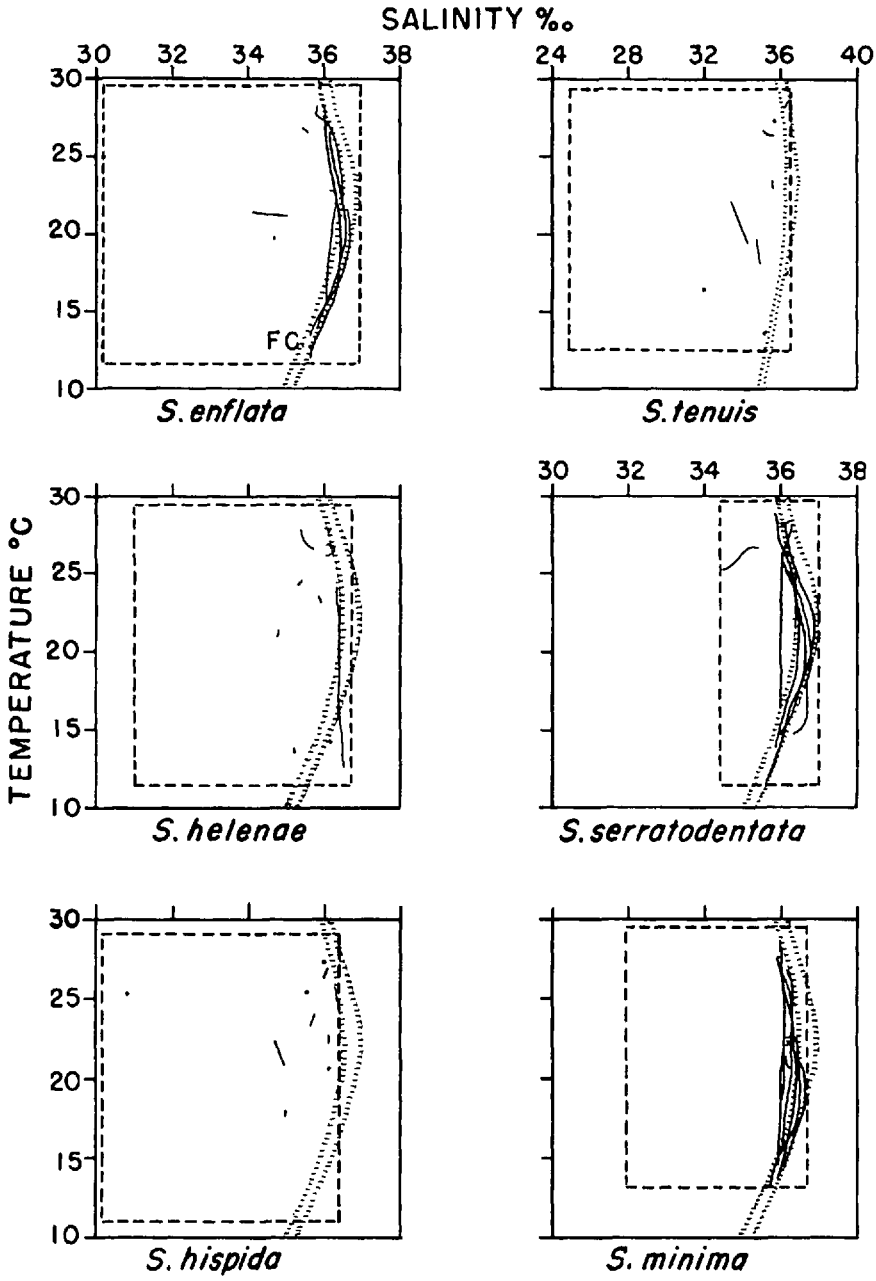

FIGURE 7. The extreme ranges of temperature and salinity (dashed rectangle) encountered by the listed species for all cruises. T-S curves are plotted for the one station in each cruise where the largest number of individuals of that species was taken. The T-S envelope of the Florida Current is indicated by hatched lines.

an indicator organism in this area. The over-all distribution of this species is shown in Fig. 2. Its occurrence in a profile across the shelf and Current (Fig. 6) and its relation to temperature and salinity is shown in Figs. 7 & 8. These latter figures indicate a salinity tolerance from just above 30‰ to 36.5‰ and a temperature tolerance of 12°C to 29°C. These were the limits encountered on these cruises. Doubtless, this species is able to withstand even wider extremes of temperature and salinity. The T-S curves from stations where this

TABLE 4
MAXIMUM ABUNDANCE OF THE SEVERAL SPECIES OF CHAETOGNATHA*

S. enflata			*S. tenuis*			*S. helenae*			*S. serratodentata*		
No.	Sta.	Cr.	No.	Sta.	Cr.	No.	Sta.	Cr.	No.	Sta.	Cr.
208	32	1	162	24	1	625	36	1	59	1	1
344	59	2	92	43	2	289	59	2	123	71	2
508	32	3	116	76	3	480	69	3	146	sp9	3
584	70	4	3572	77	4	308	33	4	54	14	4
340	38	5	846	36	5	531	58	5	186	40	5
74	9	6	102	13	6	92	13	6	41	1	6
299	7	7	188	37	7	138	37	7	110	72	7
384	79	8	66	13	8	424	47	8	68	49	8
257	53	9	515	21	9	64	57	9	81	26	9
S. hispida			*S. minima*			*S. bipunctata*			*S. hexaptera*		
No.	Sta.	Cr.	No.	Sta.	Cr.	No.	Sta.	Cr.	No.	Sta.	Cr.
8	3	1	57	49	1	12	4	1	4	73	1
129	35	2	56	25	2	15	26	2	17	sp1	2
292	13	3	94	48	3	46	75	3	21	1	3
208	11	4	13	2	4	16	5	4	4	64	4
104	12	5	42	9	5	19	26	5	2	16	5
959	13	6	3	sp5	6	3	sp6	6	10	sp9	6
48	11	7	46	73	7	25	31	7	3	sp5	7
20	56	8	87	71	8	17	17	8	13	17	8
1308	11	9	72	71	9	19	sp6	9	12	sp6	9
S. lyra			*K. pacifica*			*K. subtilis*			*P. draco*		
No.	Sta.	Cr.	No.	Sta.	Cr.	No.	Sta.	Cr.	No.	Sta.	Cr.
		1	14	26	1	2	71	1	34	39	1
9	sp5	2	15	26	2	3	6	2	34	80	2
		3	55	47	3	16	18	3	42	41	3
		4	64	33	4			4	34	50	4
1	66	5	18	3	5	6	26	5	42	18	5
		6	3	1	6			6	26	sp7	6
		7	24	31	7	6	17	7	37	64	7
		8	28	70	8	9	53	8	66	17	8
		9	34	37	9	4	71	9	54	26	9

*One station per cruise has been selected where each species was collected in greatest numbers. T-S curves for these stations are plotted in Figs. 7 and 8.

species was found in maximum abundance (Fig. 7) also indicate a preference for water close to or inside the Florida Current. This supports the general picture of distribution in Fig. 2.

S. tenuis and *S. helenae* are characteristically Coastal water species but often occur in the edge of the Florida Current. Their general distribution is shown in Fig. 2. In both instances they appear in reduced numbers toward the axis of the Current and are entirely absent in the special stations. Fig. 6 shows in specific sections how they are distributed across the shelf in Cruises 2 and 3. Fig. 7 illustrates wide temperature and salinity tolerances for each species. In both species the T-S curves of water at stations of maximum abundance occur close to but usually outside of the envelope of Florida Current water. Although these species appear to be characteristically shelf forms, their tolerance for Florida Current water is such that they do not appear to be precise indicators of recent movements of Coastal water into the Florida Current.

Four species, *S. bipunctata, S. minima, S. serratodentata,* and *K. pacifica*, occur widely over the shelf (Figs. 2, 3, and 4) and are common in salinities less than 36.0‰. Despite the rather wide range of salinities (Figs. 7 and 8) in which they are found, they occur most often and are most abundant in the Florida Current (Table 4). The evidence suggests that their principal recruitment is from the Florida Current. Whether successful reproduction takes place in Carolinian Coastal water is not known. From their prevalence in the Coastal water, it appears that they can tolerate conditions in the outer shelf for long periods, and they do not appear, therefore, to be very useful as indicators of recently introduced Florida Current water.

The species most restricted to inshore Coastal water is *S. hispida.* With few exceptions, this species occurs near shore and is not normally found over the outer shelf or in Florida Current water (Figs. 3 and 7). That it can tolerate salinities up to 36.0‰ was shown by Pierce (1958) in collections made along the North Carolina coast. In this study, two of the most abundant catches were made in Florida Current water, but these were at Station 11 where the shelf is very narrow and the Current flows near the shore. Owre (1960) also found *S. hispida* under similar circumstances off Miami Beach. She attributes their presence to shelf water brought around from the west coast of Florida in the Florida Current. Off the coast of Georgia and the Carolinas this species was seldom found in Florida

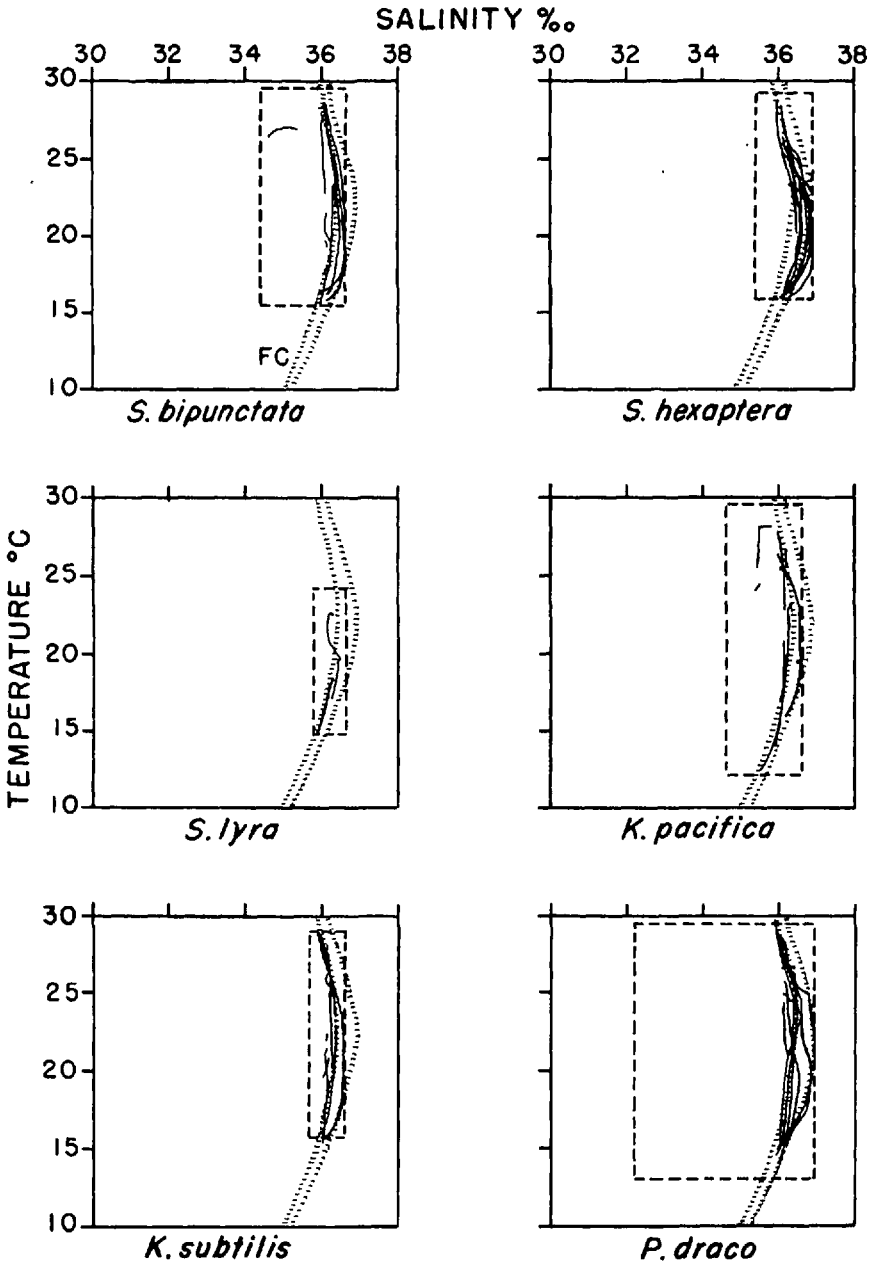

FIGURE 8. The extreme ranges of temperature and salinity (dashed rectangle) encountered by the listed species for all cruises. T-S curves are plotted for the one station in each cruise where the largest number of individuals of that species was taken. The T-S envelope of the Florida Current is indicated by hatched lines.

Current water. These observations suggest that offshore movements of inshore water must be very limited or slow where the shelf is wide. In the Miami-Canaveral region, inshore water may have a better opportunity for direct mixing with the Florida Current and it is probably for this reason that *S. hispida* is found more frequently in the Florida Current between these points.

The species which are most restricted to the Florida Current are *S. hexaptera, S. lyra, K. subtilis,* and *P. draco* (Table 3 and Fig. 8). Where the shelf is wide, these species are rarely found inside the 10-fathom line and only *K. pacifica* was found adjacent to the coast. They were restricted to the Florida Current water more than 90 per cent of the time. A typical example of the offshore nature of their distribution is shown in Fig. 6. The range of salinity (Fig. 8) where *S. hexaptera, S. lyra,* and *K. subtilis* were found was relatively narrow (35.5 to 36.5‰) compared to the other species. Their optimum occurence (Fig. 8) was regularly in Florida Current water. *P. draco* had the widest range over the shelf of any of these four species (Fig. 6) and was encountered occasionally in water of reduced salinity, but it was found in water above 36.0‰ in 94 per cent of the times it was taken (Table 3). The fact that *P. draco* can tolerate Carolinian Coastal water and as a result ranges widely over the shelf suggests that its importance as an indicator species deserves careful attention.

Discussions and Conclusions

The aquatic environment sampled by the nine cruises of the GILL is divisible into Carolinian Coastal, Florida Current, and to a limited extent Sargasso Sea water. In each of these regions the chaetognaths showed a very uniform north-south distribution. The same species were taken under similar hydrographic conditions off the Florida coast and off the coast of North Carolina. There was no significant change in the chaetognath fauna of the Florida coast as compared to the coast of North Carolina and, as could be expected, there was no change in the chaetognath fauna of the Florida Current in this distance. No distinction could be made between the fauna of the Florida Current and of the Sargasso Sea at the depths sampled.

In terms of the abundance of the coastal water species, there is a slight tendency for increased numbers of several species to occur around Cape Canaveral and again off the coast of North Carolina; but this trend is not positive enough to warrant much emphasis.

The variation in species composition and abundance across the

continental shelf and into the Florida Current was pronounced. *S. hispida, S. helenae,* and *S. tenuis* were observed in progressively reduced numbers as stations further from shore were sampled. The largest number of species was characteristically collected near the edge of the shelf where coastal and Florida Current water were encountered. The above species almost disappeared in the Florida Current where *S. bipunctata, S. hexaptera, S. minima, K. subtilis, P. draco,* and others predominated.

There is very little noticeable overall seasonal change in species distribution. In winter and summer the same species appear in the same environment. At any one station the species present are very consistent in all cruises. There is often a several-fold change in abundance but this is erratic and does not conform to any readily apparent pattern.

The true value of any chaetognath as an indicator species is a challenging problem. From the evidence gathered in this study, only suggestions can be made concerning the importance of any of the species as indicators of particular kinds of water. A fundamental question concerning the length of time each species will last in different kinds of water must be answered. Also, if a species is not able to tolerate a different water mass it would be enlightening to know if salinity, temperature, food, or some other factor was limiting.

These questions are theoretically susceptible of experimental testing but, to date, practical problems of keeping arrowworms alive in the laboratory have not been solved for many species, although some progress has been made. With more attention directed towards the study of their ecology under controlled conditions much could be learned. The following discussion, then, of the several species as indicators refers to general or relative usefulness rather than any specific origin or period of residence of the species in an alien water mass.

S. hispida is the best indicator for inshore water. *S. tenuis* and to a lesser extent *S. helenae* are more widespread over the shelf. *S. tenuis* occurred in Coastal water in 70 per cent of the samples (Table 3), and in the Florida Current 30 per cent of the tows. Neither species invaded the center or eastern side of the Current in quantity. Their presence in the Current suggests some movements of Coastal water into the Florida Current.

The species most restricted to the Florida Current are *S. hexaptera, S. lyra, K. subtilis,* and *P. draco.* The first three were rather un-

common, but *P. draco* is very widespread in the Current. Any of these species in Coastal water would indicate the presence of Florida Current water. *S. bipunctata, S. serratodentata,* and *K. pacifica* are also found more commonly in the Current, but their apparent tolerance for Coastal water raises a question concerning their values as indicators of recent mixing of the two kinds of water.

In recent years no results have been published of an examination of the Chaetognatha from Gulf Stream water off New England or Nova Scotia. It would be of value to determine how long some of these species persist in Gulf Stream water after it passes Cape Hatteras. Older records are not always reliable because *S. tenuis* and *S. helenae* may have been confused with *S. bipunctata* or *S. serratodentata.* Fraser, (1949) has recorded *S. serratodentata, S. lyra,* and *S. bipunctata* as warm water indicators off the Scottish coast, but he has not mentioned *S. tenuis, S. helenae,* or *S. enflata* as appearing in those waters. More precise information on the fate of these and other plankton animals found in the warm saline waters of the Gulf Stream is needed. What fraction dies as it encounters the cold waters of the North Atlantic? And what fraction is shunted east and south and kept alive in the warm water of this system to produce another generation? These are questions on which we can only speculate, but a great mass of organisms is involved.

The lack of a sharp line separating the distribution of the species of Chaetognatha along the southeastern Atlantic coast, despite the presence of two distinct kinds of water, is noteworthy. It appears logical to assume that over long periods of time a considerable amount of selection may have taken place in this particular group of species to develop tolerance to both Coastal and Florida Current waters. Because both kinds of water are continually undergoing some mixing, and with storms this may be considerable over the shelf, those species with little salinity or temperature tolerance would be selected against in favor of those which were more eurythermal and euryhaline. On these grounds, the general gradation in distribution of these species may in part be explained.

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