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The hydrography and the distribution of chaetognaths over the continental shelf off North Carolina

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Summary—Temperature, salinity and quantitative plankton data have been obtained from the continental shelf area and Florida Current off North Carolina in May and June 1953 and January 1954.

Two water types, Virginian Coastal water and Carolinian Coastal water, and one water mass, Florida Current water, are identified.

A breaching of the barrier at Hatteras between the two coastal water types was witnessed, and Virginian Coastal water was driven south-westerly across Diamond Shoals into Raleigh Bay by a north-east storm. The import of such an hydrographic event on the distribution of plankton is discussed.

The distribution of the chaetognaths in the area was investigated and their association with the water type and water mass tabulated. Twelve species representing three genera were collected. All of these are found in tropical and sub-tropical waters. Chaetognaths fail as satisfactory indicators of the Virginian Coastal water intrusion into Raleigh Bay because of the absence, in our collection, of characteristically Virginian types in the southern limits of that faunal subprovince.

INTRODUCTION

PRIOR TO the efforts of PIERCE (1953), who described the distribution of the chaetognaths over the continental shelf off North Carolina in relation to the hydrography of the area, and BUMPUS (1955), who considered the circulation of these waters, little was known about the effect of the circulation system on the distribution of planktonic elements of the flora and fauna in the Hatteras area. PARR (1933) noted in winter a temperature barrier at Cape Hatteras corroborated by BIGELOW (1933) and a fairly large cold-water temperature zone southwest of Cape Hatteras. This temperature barrier is well illustrated in the surface temperature charts of FUGLISTER (1947). BIGELOW and SEARS (1935) pointed out the abrupt transition in salinity which occurs at Cape Hatteras, occasioned by the wedge of pure oceanic water ($>35{\cdot}5^{\circ}/_{\circ\circ}$) which presses in close across the shelf in Raleigh Bay and entirely separates the shelf and slope water bands to the north from the low coastal salinities farther south. The data available at that time suggested that the situation exists throughout the year.

The existence of a barrier at Cape Hatteras has been postulated in defining the Carolinian and Virginian faunal subprovinces (JOHNSON, 1934). Many other zoologists have separated the cold-water and warm-water fauna on the continental shelf at this cape. WILLIAMS (1948, 1949), SUTCLIFFE (1950) and PEARSE and WILLIAMS (1951)

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found bottom living fauna, algae and plankton in Onslow Bay having in general tropical affinities. However, they noted in their winter and spring collections, in addition to the usual populations, a few individuals from a small number of species with northern affinities.

Our recent collections provide material for a better understanding of the hydrographic influence on the distribution of the chaetognaths in the area than has been available heretofore and indicate how the hydrographic barrier at Cape Hatteras is occasionally breached, thus permitting the temporary establishment of the anomalous communities noted by WILLIAMS, PEARSE and SUTCLIFFE.

ACKNOWLEDGEMENT

While the many outstanding investigations of HENRY B. BIGELOW do not strictly pertain to the area under discussion, the authors are especially grateful for his studies of the waters of the Gulf of Maine and the continental shelf from Cape Cod to Chesapeake Bay. His efforts have been a constant influence as we have attempted to extend the knowledge of shelf waters slightly beyond the area he so carefully and completely considered.

THE DATA

The data comprise a series of hydrographic sections together with plankton collections made in May and June 1953 (*Caryn* Cruise 64) and January 1954 (*Atlantis* Cruise 196) (Fig. 1).

At each station serial temperature–salinity depth determinations were made to the bottom or to nearly 500 metres, whichever was less. At most stations quantitative oblique plankton tows, using Plankton Samplers (CLARKE and BUMPUS, 1950) fitted with #2 silk nets, were made from near the bottom or 100 metres. When feasible two Plankton Sampler tows were made dividing the water column in two. The chaetognaths were picked out of the plankton samples and identified (Tables I and II, Fig. 12). These plankton data are more nearly quantitative and extend closer to the shore than those of PIERCE (1953).

HYDROGRAPHY

BUMPUS (1955) has shown that, south of Cape Hatteras, a southerly flowing coastal current, such as is common north of Cape Hatteras, is a transient affair. Such a current, when present, is restricted to a very narrow portion of the continental shelf. The dynamic pressure gradient resulting from the combined effect of the runoff and the cross-shelf thermal gradient together with the prevailing wind and the frictional drag of the Florida Current provide for a northeasterly drift over a broad part of the Carolina continental shelf.

In addition to the water of the Florida Current there are two types of water in this region which we have named Virginian Coastal water and Carolinian Coastal water.* There are also mixtures of each of these with the Florida Current water. Virginian refers to the shelf water from Cape Cod to Cape Hatteras. Carolinian refers to the

* We have used here two names apparently new to oceanography inasmuch as we have been unable to find names concisely describing the separate continental shelf regions north and south of Cape Hatteras. Because the terms Virginian and Carolinian are used to describe the faunal subprovinces of the continental shelf, we shall introduce these terms to identify the water types on the shelf.

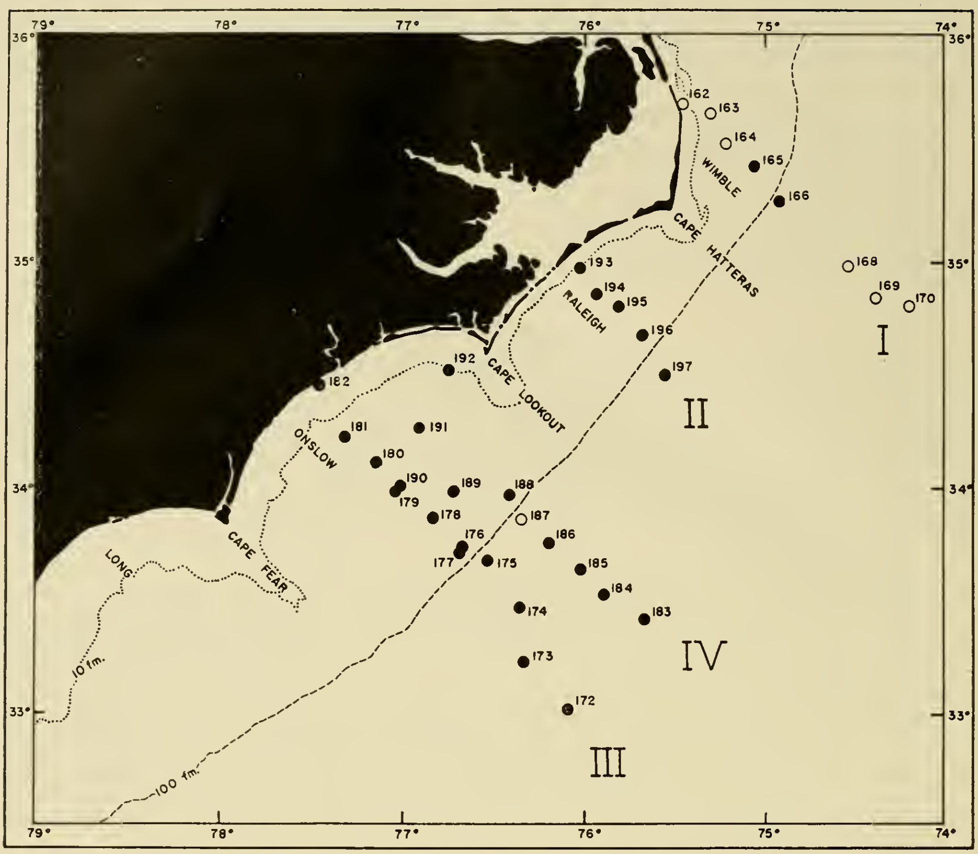

Fig. 1 (A). Location of stations, on *Caryn* Cruise 64, May and June 1953. Open circles indicate no plankton tows were made.

shelf water from Cape Hatteras southwards. Unpublished data indicate that Carolinian Coastal water, as described below, extends to the offing of Daytona Beach and possibly at certain times to the offing of Cape Canaveral.

The Virginian Coastal water is freshened by river water entering close to the surface inshore and salted by indrafts of slope water over the bottom from offshore (BIGELOW and SEARS, 1935). There is no widespread contribution to this coastal water from the south, nor flooding of the surface water with pure oceanic water of high temperature, nor upwelling onto the shelf of cold abyssal water (BIGELOW, 1933).

The Carolinian Coastal water is composed of Florida Current water and river effluent. This mixture is in general more saline than most coastal waters because the river runoff is less than for other sections of the coast; the effluent from the sounds is more saline than from river mouths; and the highly saline Florida Current frequently makes broad invasions over the continental shelf.

There is no regular communication between the Virginian and Carolinian Coastal waters, although the frequent northeast storms from November to May (MILLER,

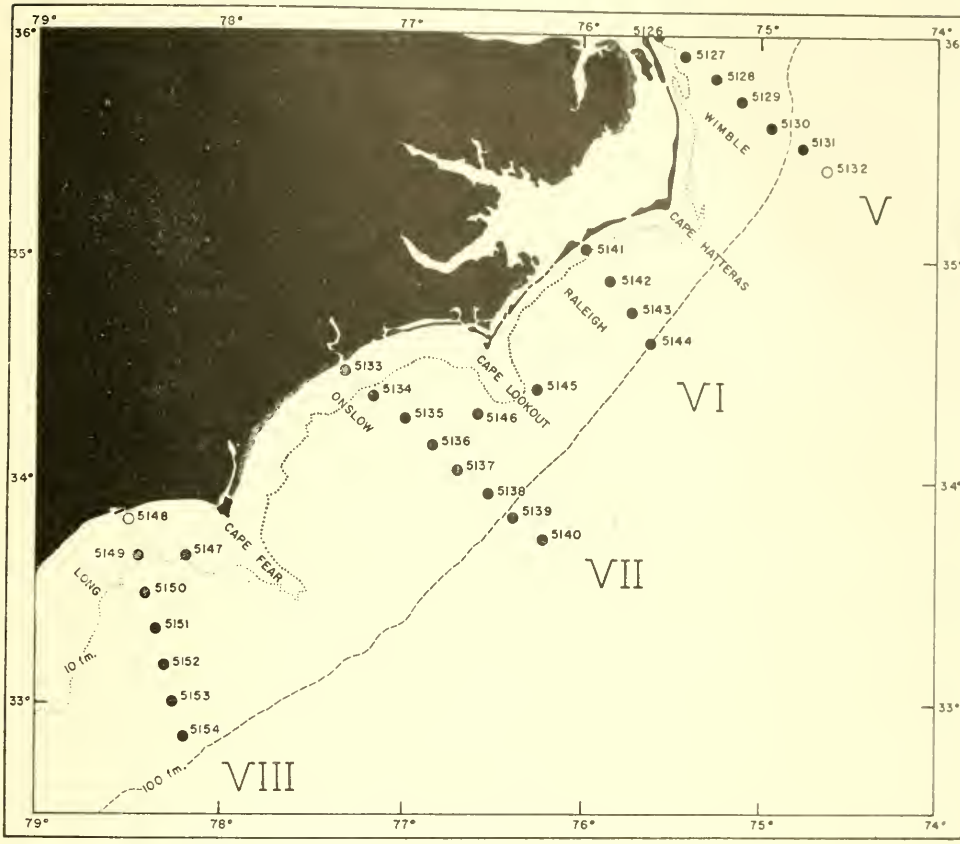

Fig. 1 (B). Locations of stations on *Atlantis* Cruise 196, January 1954. Open circles indicate no plankton tows were made.

1946; New York University, 1954) provide the energy for transient indrafts of Virginian Coastal water into Raleigh Bay. Three events may take place following such an indraft:

A. If the storm lasts for only a short period, one or two days, this water will eventually become absorbed within the Carolinian Coastal water, modifying it in proportion to the mixture.

B. A violent meander of the Florida Current may completely sweep the indrafted Virginian Coastal water out of Raleigh Bay toward the northeast. Such an event would be aided by a southeast storm.

C. If the northeast storm lasts for a period longer than two days or if another northeast storm follows within a few days, the indrafted water may eventually be driven around Cape Lookout into Onslow Bay. Such an occurrence could account for the presence there of the winter–spring species with northern affinities described by Williams (1948, 1949), Sutcliffe (1950), and Pearse and Williams (1951). Should this occur at a time of substantial runoff when a southerly flowing coastal current is being maintained in Onslow Bay and southward, such water movements may distribute planktonic elements of Virginian fauna for some distance along the coast.

We have postulated here a sporadic occurrence which may contribute appreciably to the finding of anomalous species in the inshore waters of the northern part of the Carolinian subprovince. These species will find themselves in waters compatible to their existence until vernal warming traps them. Vernal warming or reduction in runoff with a consequent increase in salinity will kill those species least resistant to higher temperatures and salinities.

THE DISTRIBUTION OF TEMPERATURE, SALINITY AND DENSITY IN MAY AND JUNE, 1953, AND JANUARY, 1954

Typical spring conditions were encountered on the May and June cruises (Figs. 1, 2, 3, 4 and 5). These are the weak cross-shelf temperature gradient, moderate vertical temperature gradient, and the penetration across the shelf of highly saline Florida Current water along the bottom into Raleigh and Onslow Bays. In contrast the temperature and salinity in the Wimble Section are lower with weaker vertical temperature gradients and stronger salinity gradients.

Typical winter conditions for the Wimble, Onslow and Long Bay sections were observed in January 1954 (Figs. 1, 6 to 10). Note the cold coastal water in the Wimble section and the nearly as cold, highly saline water in Onslow Bay and Long Bay. But Raleigh Bay was filled in its inner part with coastal water from north of Cape Hatteras, in contrast to the typical winter conditions of January and February 1950 (BUMPUS, 1955) and February 1931 (BIGELOW and SEARS, 1935), when the 36‰ isohaline (Florida Current water) was pressed well in across the continental shelf. This anomalous condition was due to a north-east storm several days earlier.

This intrusion of Virginian Coastal water into Raleigh Bay is further discerned in the temperature–salinity relation (Fig. 11). The water at Stations 5141, 5142 and 5143 is clearly Virginian Coastal water.

The temperature–salinity relations also provide a clue to the sources in the Florida Current contributing to the composition of Carolinian Coastal water. The water over the inner middle part of Long Bay (Stations 5149, 5150, 5151), Onslow Bay (Stations 5134, 5135, 5136, 5146) and the southern part of Raleigh Bay (Station 5145) in January appears to be from depths in the Florida Current, i.e. from depths perhaps as great as 150 metres. This water has been forced up onto the shelf in the course of current meanders and chilled by the colder air temperatures encountered there. Stations 5133 in Onslow Bay and 5147 and 5148 in Long Bay, the closest inshore stations, indicate appreciable dilution of this Florida Current water with river effluent and greater chilling as a result of the colder air temperatures near the coast. In contrast, the water over the outer parts of the shelf (Stations 5144 in Raleigh Bay, 5137, 5138 and 5139 in Onslow Bay and 5152, 5153, 5154 in Long Bay) is Florida Current water which has moved in over the shelf with no change in depth and has mixed only slightly with the water inshore of it.

The intrusion of Florida Current water along the bottom in Onslow and Raleigh Bays in May and June (Figs. 3, 4, 5 and 11) was probably along surfaces of equal density. It has been forced onto the shelf by the meanders of the current as it passes

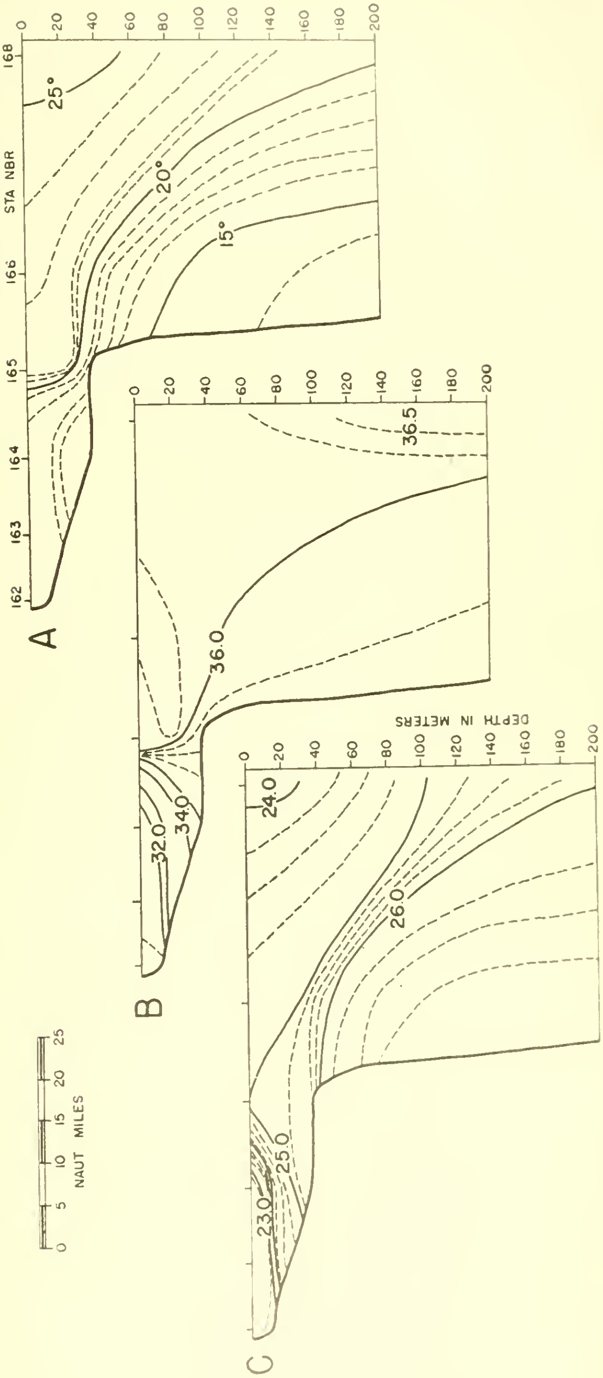

Fig. 2. (A) Distribution of temperature in °C, (B) salinity in ‰ and (C) density (σt), in Section I, Wimble Shoals, May 1953.

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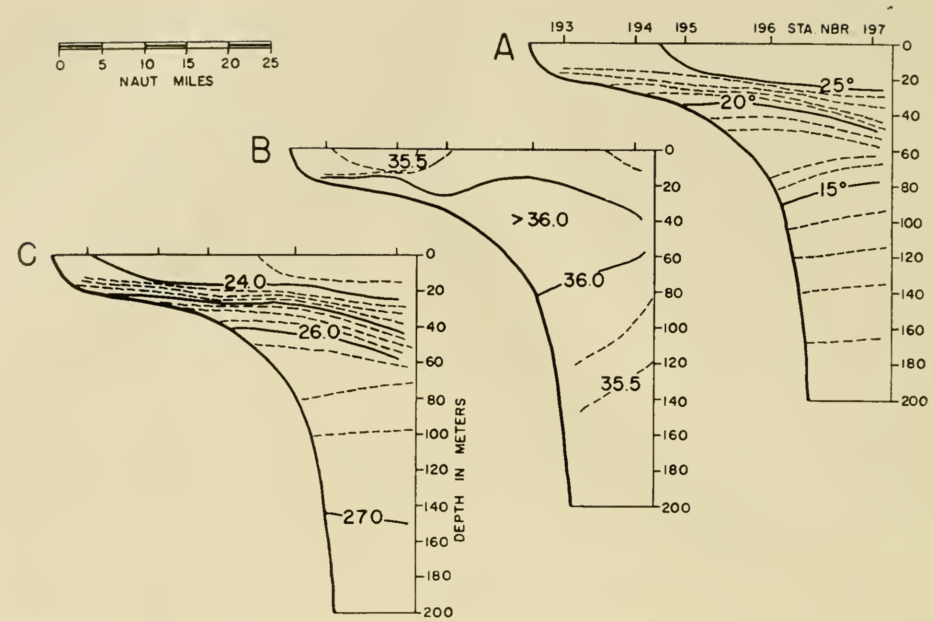

Fig. 3. (A) Distribution of temperature in ° C, (B) salinity in °/₀₀ and (C) density (σ_t), in Section II, Raleigh Bay, June 1953.

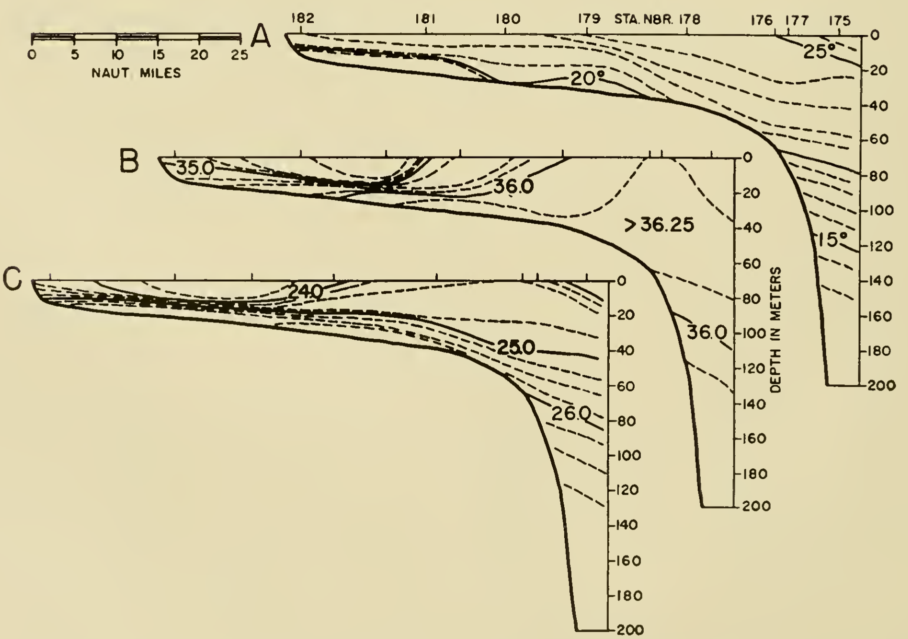

Fig. 4. (A) Distribution of temperature in ° C, (B) salinity in °/₀₀ and (C) density (σ_t), in Section III, Onslow Bay, May 1953.

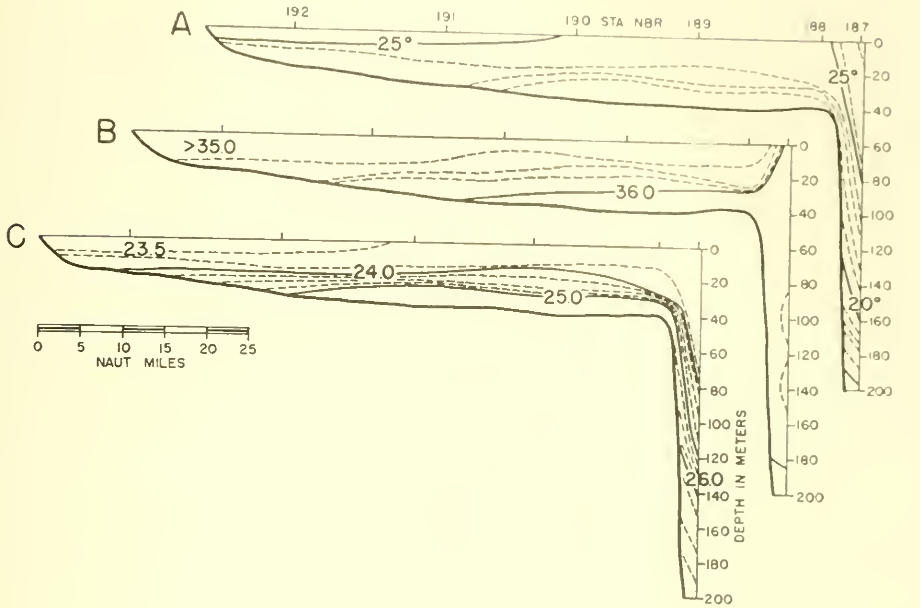

Fig. 5. (A) Distribution of temperature in C, (B) salinity in ‰, and (C) density (σ_t), in Section IV, Onslow Bay, June 1953.

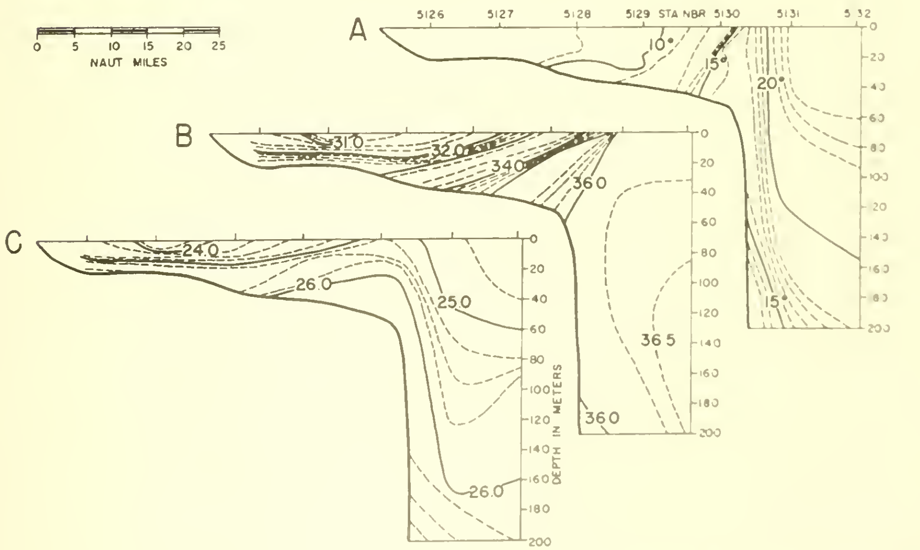

Fig. 6. (A) Distribution of temperature in C, (B) salinity in and (C) density (σ_t), in Section V, Wimble Shoals, January 1954

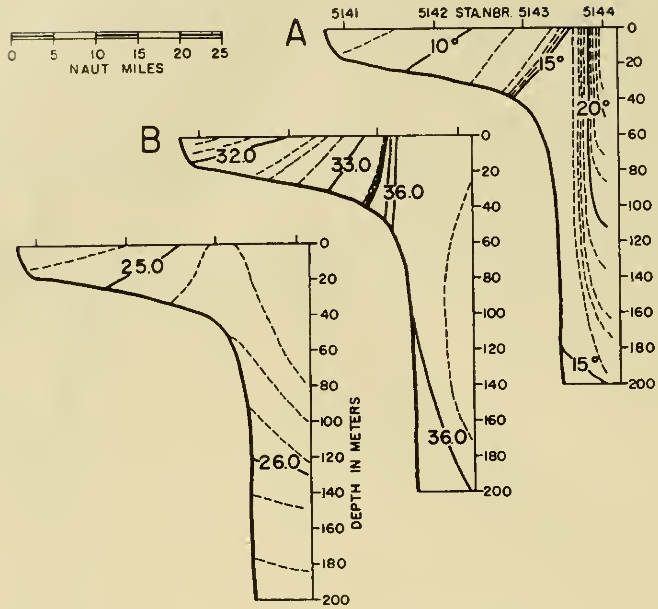

Fig. 7. (A) Distribution of temperature in ° C, (B) salinity in °/$_{oo}$ and (C) density (σ_t), in Section VI, Raleigh Bay, January 1954.

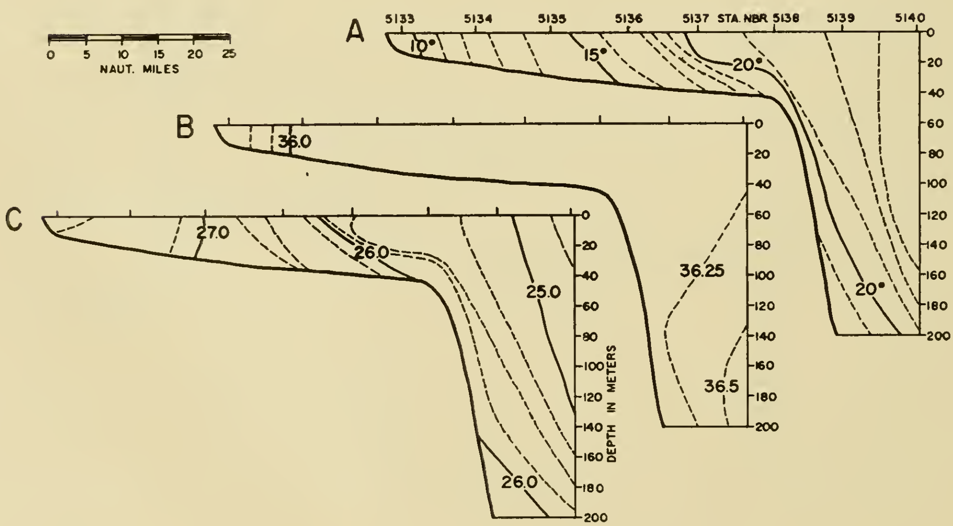

Fig. 8. (A) Distribution of temperature in ° C, (B) salinity in °/$_{oo}$ and (C) density (σ_t) in Section VII, Onslow Bay, January 1954.

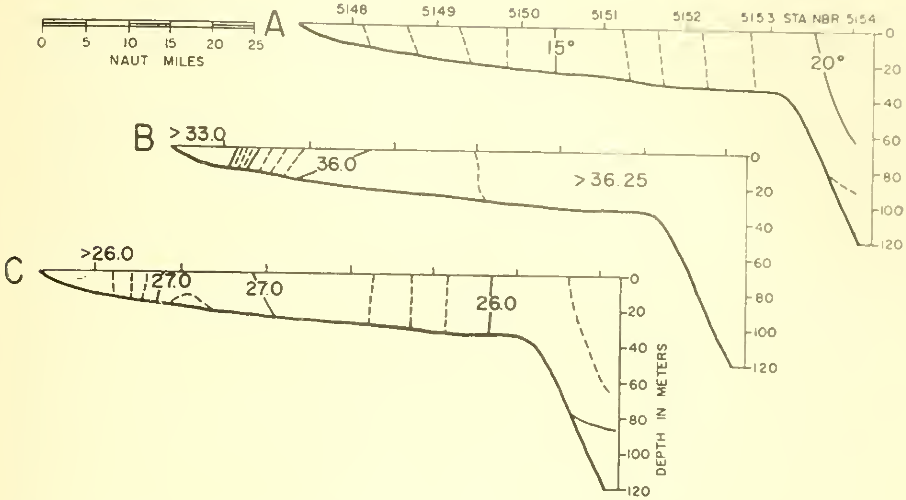

Fig. 9. (A) Distribution of temperature in ° C, (B) salinity in ‰ and (C) density (σ_t), in Section VIII, Long Bay, January 1954.

along the continental slope. During other parts of *Caryn* Cruise 64, the position of maximum current was observed to shift as much as 14 miles either side of the mean axis of flow (which off Onslow Bay normally lies about 18 miles south-east of the 100 fathom line. Associated with these shifts of position were onshore and offshore deflections in the direction of the current (von Arx, Bumpus and Richardson, 1955). This provides the energy to push water up the slope across the shelf. It also appears from salinity measurements that as the meanders move offshore they draw low salinity water (from the surface over the shelf) into the current.

The proximity of the Florida Current to the continental shelf precludes the occurrence (between the Current and the Carolinian coastal water) of slope water such as is found north-east of Cape Hatteras between the continental shelf and the Gulf Stream.

DISTRIBUTION OF THE CHAETOGNATHS

The chaetognaths collected in this area include 12 species representing three genera: *Sagitta bipunctata*, *S. enflata*, *S. helenae*, *S. hexaptera*, *S. hispida*, *S. lyra*, *S. minima*, *S. serratodentata*, *S. tenuis*, *Krohnitta pacifica*, *K. subtilis*, and *Pterosagitta draco*.

The quantitative composition of the plankton tows is recorded (Tables I and II). The species are listed in the order of their association with water of low or high salinity from left to right. The stations are arranged in the order of distance from the coast. The ranges of individual species overlap others considerably and in many cases completely. Nevertheless the tables show that there is a general correlation between salinity tolerance and the distance from the coast at which various species were found.

The most euryhaline–eurythermal species was *S. enflata* (Pierce, 1953), although it is doubtful if it can tolerate for long periods salinities as low as those in which *S. hispida* are usually found. *S. hispida*, *S. helenae*, and *S. tenuis* are species which are largely restricted to water of the continental shelf below Hatteras. The remainder of

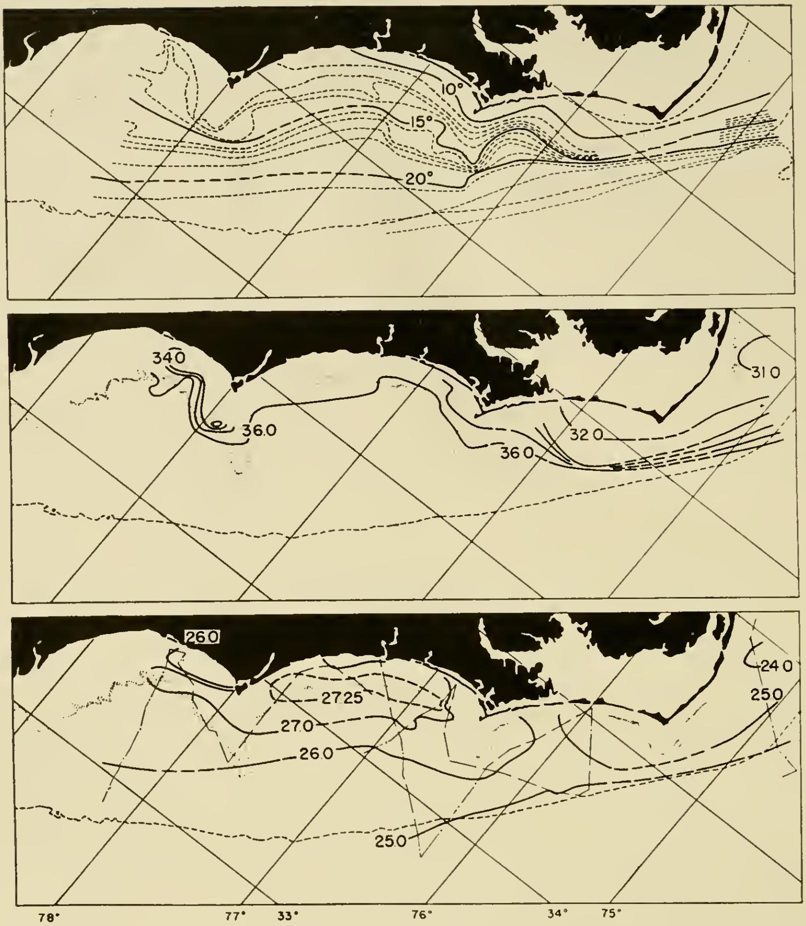

Fig. 10. Distribution of surface temperature in ° C (upper), salinity in $^{\circ}/_{\circ\circ}$ (middle) and density (σ_t) (lower) on North Carolina Shelf, January 1954. Dash-dot line indicates track of ship.

the species were found principally in the Florida Current. The increase in number of species is evident as one proceeds offshore over the shelf into Florida Current water.

Sagitta bipunctata. The distribution and abundance of this species was similar in the area covered by spring (*Caryn* 64) and winter (*Atlantis* 196) cruises. *S. bipunctata* was collected in small numbers at several of the stations beyond the continental shelf and in a few instances they ranged shoreward about midway over the shelf (Tables I and II). With one exception (Station 5143) it was taken only in water where salinity was greater than $35{\cdot}5^{\circ}/_{\circ\circ}$. It therefore appears to be restricted in this region to Florida Current water or water recently mixed with such water. BIGELOW and SEARS (1939) did not find this species between Cape Cod and Chesapeake Bay.

Sagitta enflata was taken in almost every plankton sample on both cruises (Fig. 12). It was the most abundant chaetognath as well as the most widely distributed. The greatest concentrations were found near the edge of the shelf where as many as 160 per ten cubic metres were recorded. That they are sensitive to extreme conditions which are occasionally encountered in this area is borne out by their absence in the winter cruise from the three inshore stations north of Cape Hatteras. Here in water of less than 10° C and $32^{\circ}/_{\circ\circ}$ not a specimen was found. Moreover only one specimen was present at the two inshore stations south of Hatteras, where the water had been derived from Virginian Coastal water driven around the cape.

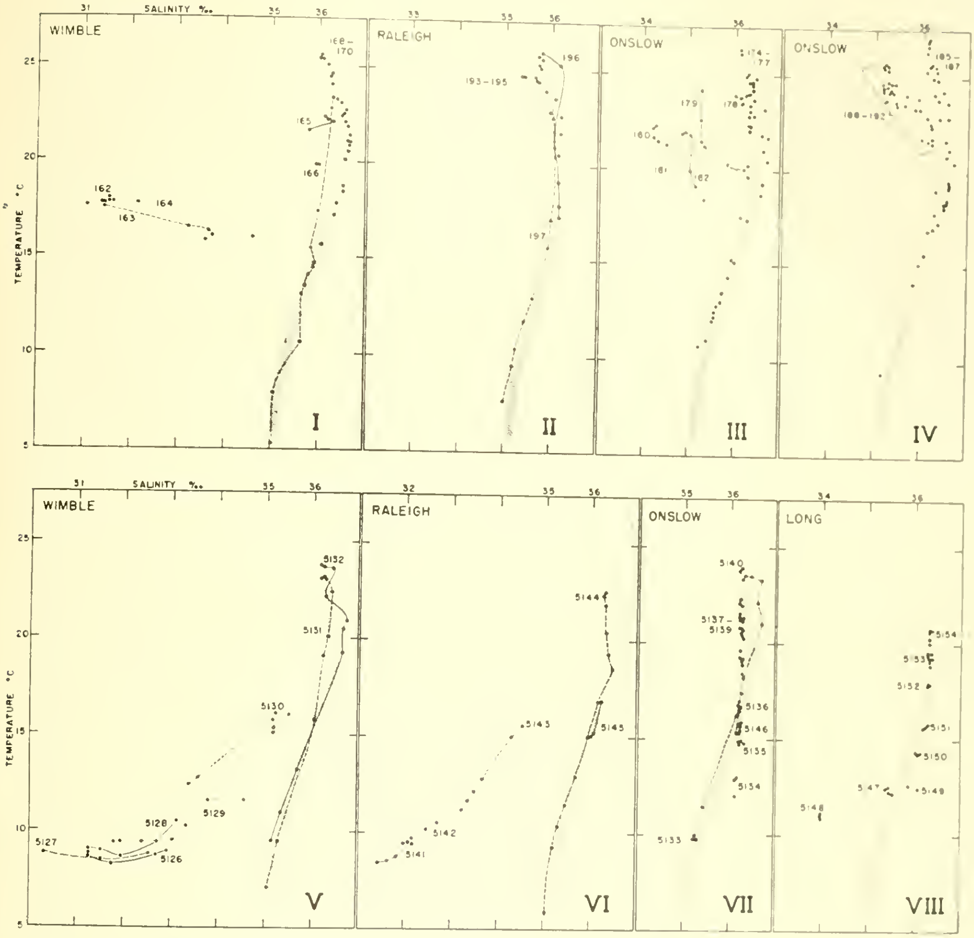

Fig. 11. Temperature–salinity diagrams, upper for *Caryn* Cruise 64, May and June 1953; lower for *Atlantis* Cruise 196, January 1954. The stippled line in the diagrams is the left side of an envelope describing the T–S characteristics of the Florida Current, PARR's (1937) stations in the Straits of Florida.

Sagitta helenae was found all over the continental shelf south of Cape Hatteras but it disappeared at the stations beyond the edge (Fig. 12). The greatest concentrations were found in the middle of the shelf where as many as 94 specimens per ten cubic metres were collected. This species is able to tolerate a rather wide range of salinity, varying from approximately 32 to 36‰. Although present in the edge of the Florida Current at times, it was never found far inside the current proper, and it does not appear from these data that it is a true inhabitant of such water.

This species has been closely associated with continental shelf water from the Gulf of Mexico (RITTER-ZAHONY, 1910; PIERCE, 1951, 1953) to Cape Hatteras. Apparently it disappears just north of the cape where the colder, less saline water is encountered over the shelf. Only a few specimens were taken near the edge of the shelf above Hatteras in the spring and winter cruises. BIGELOW and SEARS (1939) do not record this species in their plankton studies from Chesapeake Bay to Cape Cod. Because of its close relation to continental shelf waters from North Carolina southward, this species appears to be of special interest in its relation to the hydrography of this area. The movement of Virginian Coastal water around Hatteras in January displaced this species from the inshore stations in Raleigh Bay where it usually occurs (Fig. 12).

Table I

The distribution of chaetognaths by station during Caryn *Cruise* 64. *Species arranged in approximate series with respect to salinity, those which normally occur in coastal water on the left. Figures indicate number per* 10 *cubic metres of water strained*

Station No.	*Depth of Sample (metres)*	*S. enflata*	*S. hispida*	*S. tenuis*	*S. helenae*	*S. minima*	*S. serrato-dentata*	*S. bipunctata*	*S. hexaptera*	*S. lyra*	*K. pacifica*	*K. subtilis*	*P. draco*	*Total No. in sample*	*Volume strained (m^3)*
						SECTION I—WIMBLE SHOALS									
165*	0·14	82				48	51						8	134	71
166	0·19	23				14	19	3	1	1				60	98
	0·40	111				6	44	3					3	120	72
						SECTION II—RALEIGH BAY									
193	0·20	18		47	56									140	113
194	0·10	72		2	16									98	111
195	0·15	7		2	8		8	6			3		1	39	114
	15·30	83		3	79	11	5	1			1		1	163	89
196*	0·30	10						1			1			11	90
	30·60	38			4	35	4	1	1			3	1	244	270
197	0·80	46			2	8	18						3	100	131
	80·160					11	6			1		1		30	158
						SECTION III—ONSLOW BAY									
182	0·12		9	1										7	73
181	0·20	4		5	27									84	152
180	0·15	35		1	10									65	141
	15·30	40		1	46									140	161
179	0·31	94		4	52	23								314	180
178	0·15	52		1	13		41				3			172	158
	15·30	54		2	32	10								164	168
177*	0·50	67			1	6	62				1	1	11	208	138
	50·100	29			1	29	5			1			2	184	287
176	0·30	4			2		54	2			2	2		110	163
	30·62	43			15	8	41						5	138	122
175	0·90	137			3	12	121	3			16			150	51
	90·180	11				3	7				2		1	31	122
174	0·80	30					39	4	2		3		18	198	206
	80·160	3				2	5	1	1			2	7	44	278
173	0·80	21				1	25		1			1	7	136	244
	80·160	1				1	4		1				1	17	300
172	0·75	3				1	5		4	1		1	1	24	207
	75·150	3				3	6		1			2	3	59	318
						SECTION IV—ONSLOW BAY									
192	0·10													0	130
	10·20	2			5									11	140
191	0·13	54		1	25									65	81
	13·26	29		2	38	1								93	135
190	0·16	23			30		3							39	70
	16·37	23		41	70	20								98	98
189	0·20	102		6	10	16	2							114	84
	20·40	48		8	94	7								194	124
188*	0·20	35			4	1							2	35	83
	20·40	25			18	3	3						4	53	98
186	0·50	9					19						4	106	337
	50·100	1				1	1		2			1	1	23	385
185	0·65	30					24		2		2		3	184	297
	65·130					5	10		8			1	5	111	332
184	0·70	10					16		1		3		8	90	235
	80·140					5	6	1	1	1	1	1	2	60	297
183	0·80	9					19		2		1		7	89	231
	80·100	1			·	2	3		1	1	3	1		26	297

* One hundred fathom contour lies between this station and the next.

Table II

The distribution of chaetognaths by station during Atlantis *Cruise* 196. *Species arranged in approximate series with respect to salinity, those which normally occur in coastal water on the left. Figures indicate number per* 10 *cubic metres of water strained*

Station No.	*Depth of sample (metres)*	*S. euflata*	*S. hispida*	*S. tenuis*	*S. helenae*	*S. minima*	*S. serrato-dentata*	*S. bipunctata*	*S. hexaptera*	*K. pacifica*	*K. subtilis*	*P. draco*	*Total No. in sample*	*Volume strained (m³)*
				SECTION V—WIMBLE SHOALS										
5126	0·30			47									72	154
5127	0·20			21		2	1						34	141
5128	0·28			1		1							3	159
5129	0·45	1		7		1	19						47	167
5130*	0·25	34		5	2		45					2	145	165
5131	0·100	7											3	43
				SECTION VI—RALEIGH BAY										
5141	0·15		1	98									113	115
5142	0·16			13		1	4						19	108
	12·24	1		8		1	8						29	169
5143	0·20	78		16	14	2	30			6		3	241	161
	20·40	49		15	4	2	10	1	2	1		2	152	178
5144	0·50	9		3	1	1	17	1	1			2	64	193
	50·100	8		3		1	21	1		1		4	79	208
5145	0·15	33		1	11	4	13	5		3		3	95	142
	15·30	2		1		1							5	120
5146	0·15	16		1	4	1	8			4		1	40	111
	15·30	11		3	7	1	4						26	97
				SECTION VII—ONSLOW BAY										
5133	0·13	21	14	183	8								267	118
5134	0·19	59		30	66	7	2						401	185
5135	0·25	56		2	5	11	6			1		1	124	152
5136	0·28	3		2	2	2	2			1			14	120
5137	0·39	27		5	12	6	21			1		4	156	204
5138*	0·20	50		5	38		13			2		3	145	132
	20·40	9				1	3					1	22	147
5139	0·50	166		3	6	2	31	1		3		6	174	156
	50·100	25				6	23			3		3	78	129
5140	0·50	9					12	1	2		1	3	50	181
	50·100	6				4	6				1	5	40	192
				SECTION VIII—LONG BAY										
5147	0·15	5 minute unidentified chaetognaths in sample											5	167
5149	0·15	83		10	68	3							97	59
5150	0·20	17		4	20	1							48	113
5151	0·24	13		3	50	2							89	133
5152	0·30	122		13	44	1	9			1		1	265	137
5153	5·30	89		1	22	1	5						198	168
5154	0·50	39			2	1	13			1		3	69	155
	50·100	29			1	1	5			1		1	84	226

* One hundred fathom contour lies between this station and the next.

Sagitta hispida is an inshore species which was taken at Stations 182, 5133, 5141 in water with a salinity of 31 to 35‰. No specimens were collected as far offshore as the ten-fathom line. Other records (Pierce, 1951) indicate that this species is present in bays and at points close to shore south of Cape Hatteras.

Sagitta minima was taken many miles on either side of the continental slope (Fig. 12). It was not taken at the stations within the ten-fathom curve or at the stations farthest in the Florida Current.

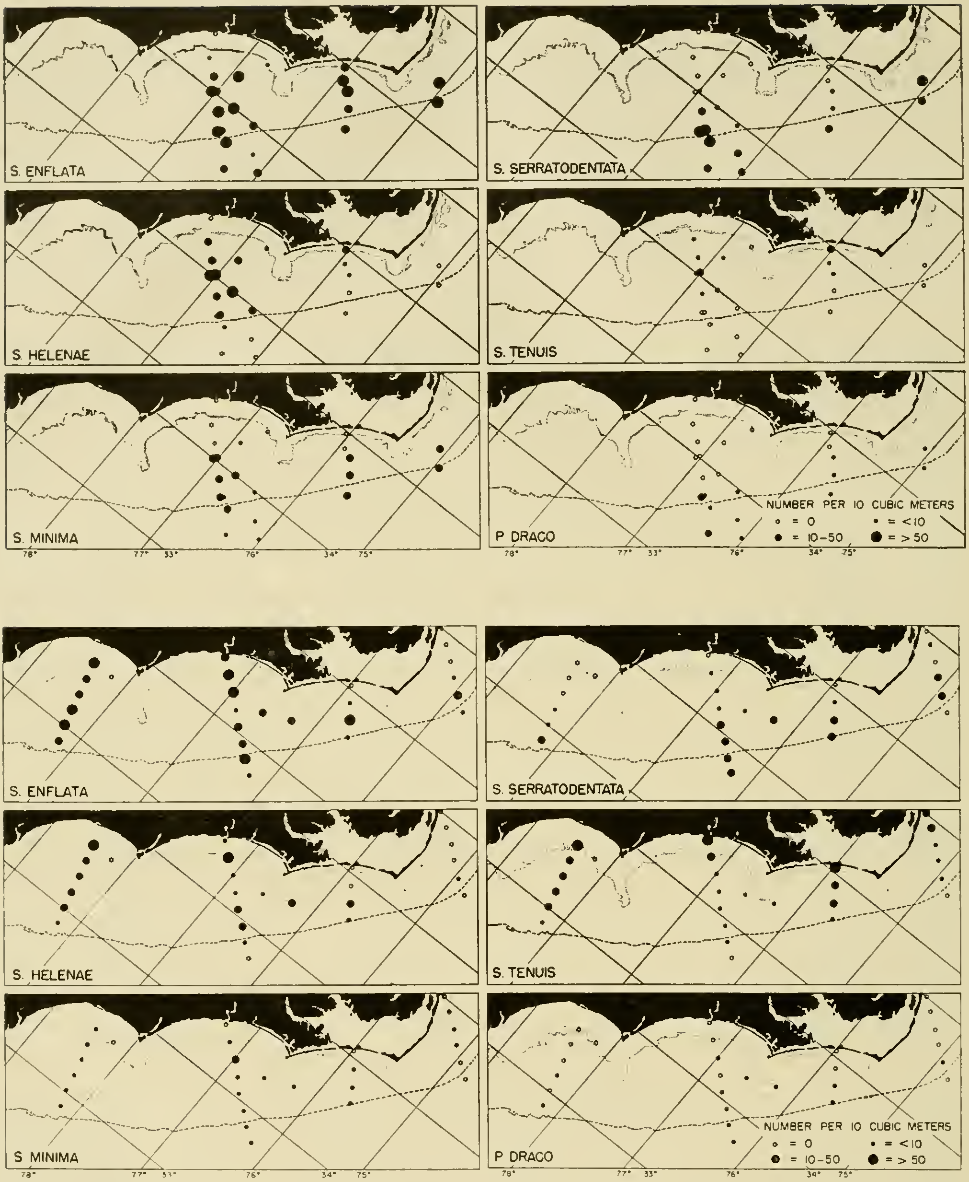

Fig. 12. Distribution of *S. enflata*, *S. helenae*, *S. minima*, *S. serratodentata*, *S. tenuis* and *P. draco*, upper in May and June 1953, *Caryn* Cruise 64, lower in January 1954, *Atlantis* Cruise 196.

It was a common chaetognath over the shelf but seldom appeared in numbers as large as *S. enflata*, *S. helenae*, or *S. serratodentata*. It was somewhat more abundant in the spring than in the winter and was usually associated with water close to 36°/₀₀ in salinity.

Sagitta serratodentata was one of the most abundant and widely distributed species found in these collections (Fig. 12). It covered the continental shelf in Carolinian and Virginian Coastal water from the ten-fathom line into the Florida Current as far as the stations extended. This species occurred commonly in numbers of 10 to 40 per ten cubic metres in both spring and winter and was noticeably more abundant near the edge of the continental shelf. Its distribution was similar to that of *S. minima* except that it was almost invariably more numerous in samples taken near the surface than in the deeper samples at any given station. This was true for samples taken during the day as well as at night.

Sagitta tenuis was restricted to the continental shelf waters both north and south of Cape Hatteras (Fig. 12). It extended from within a few miles of shore to the edge of the shelf. Many more specimens were caught and their range from shore was greater in the winter than in the spring. This species is one of the more euryhaline forms in this area, having been found in water ranging from less than 31 to 36·6‰. It does not appear beyond the shelf where the Florida Current proper is encountered. Specimens were commonly found in greatest abundance at the less inshore stations. Like many other species in this area it was collected in water ranging in temperature from 9° to 25° C and little can be said about its optimum temperature.

Krohnitta pacifica and *K. subtilis* were never very abundant in any of the tows. They ranged from midway over the shelf outward as far as the stations extended. *K. subtilis* was noticeably rarer than *K. pacifica*. No significant difference could be seen between shallow and deep hauls in terms of either species or abundance. These species were almost always found in water whose salinity was 36‰ or above. They were therefore directly associated with the Florida Current water. In the winter when a large incursion of Florida Current water moved into Onslow Bay a number of specimens of *K. pacifica* were taken in this water about as far inshore as it extended.

Pterosagitta draco was always identified in these catches with the warm saline water of the Florida Current (Fig. 12). Although one of the less abundant species it was widely distributed and found at almost all stations from midway over the shelf seaward. This species was closely associated with *K. pacifica* in these samples.

Sagitta hexaptera and *S. lyra* were also represented in some of the samples taken well inside the Florida Current. They were markedly more abundant in the spring than in the winter. Only a few *hexaptera* were found in the winter cruise and no *lyra*. Because they were present in small numbers their affinities are not obvious.

DISCUSSION

Chaetognaths were common and important members of the plankton community in all parts of the area studied. As a general rule those stations closest inshore and farthest offshore had fewer species than those near the edge of the shelf. The increase in number of species is the result of some of the typically shelf forms such as *S. tenuis* and *S. helenae* being present with species normally found in the Florida Current proper. This probably is the result of mixing which augments the total number of species in this area.

A comparison of the total number of chaetognaths collected at each station together with the abundance of each species shows surprisingly little difference between the spring and winter collections. The more abundant species such as *S. enflata* and *S. serratodentata* were abundant in spring as well as winter. *S. tenuis* was more abundant and widespread during the winter than in the spring. *S. hexaptera* was less numerous in winter, and *S. lyra*, an uncommon form in these collections was not found at all during the winter cruise.

Certain species of chaetognaths have been observed to exhibit diurnal vertical migration (MICHAEL, 1911; RUSSELL, 1933). In these cruises samples were taken at all hours. Position of the ship dictated when a sample would be taken rather than hour of the day or night. An inspection of these samples shows no consistent evidence for vertical migration or pronounced abundance of individuals in the shallow samples as compared with the deeper samples (Tables I and II). *S. minima* in the spring samples is an exception and does appear to be significantly more abundant in the deeper samples.

All species of chaetognaths collected in the area surveyed are known to occur in tropical and subtropical waters. None were typically Virginian (Table III). Published records do not show that *S. helenae*, *S. hispida* and *S. tenuis* are found over the continental shelf much farther north than Cape Hatteras. *S. minima* was found in the slope water over Block Canyon off Long Island in October 1952.* *S. serratodentata* in addition to being found in Florida Current, Carolinian and Virginian Coastal water, is found in Virginian and Boreal Slope waters (BIGELOW and SEARS, 1939; CLARKE, PIERCE and BUMPUS, 1943; REDFIELD and BEALE, 1940; HUNTSMAN, 1919).

Table III

*Distribution of chaetognaths with respect to water types**

Florida Current	*Carolinian*	*Virginian*
S. bipunctata		
S. enflata	S. enflata	
	S. helenae	
	S. hispida	
S. minima	S. minima	S. minima
S. serratodentata	S. serratodentata	S. serratodentata
	S. tenuis	S. tenuis
K. pacifica		
K. subtilis		
P. draco		
S. hexaptera		
S. lyra		

* No inference is made that these chaetognaths are indicators of the above water types, see text.

The Virginian Coastal water in the area just north of Cape Hatteras had relatively few chaetognaths present and none which could be selected as indicators of that water type. *S. elegans*, which occurs in abundance farther north in coastal water was observed by BIGELOW and SEARS (1939) to diminish in numbers in the offing of Chesapeake Bay. None were found in either of the Wimble Shoal sections in the present study. The higher temperature found in the southern portion of its range may be a limiting factor. COWLES (1930) reports it in Chesapeake Bay in salinities as low as 13°/₀₀.

The presence of a barrier to the southward movement of plankton in the Hatteras area is not as clearly demonstrated by the chaetognath distribution as one would expect in comparison with the hydrographic evidence. This is due to the lack of Virginian indicator species.† Evidence of the breaching of the barrier as far as Raleigh Bay in January 1954 is provided by the absence of the truly Carolinian species of chaetognaths, *Sagitta enflata* and *S. helenae*, at the inshore stations. Their distribution is compatible with the hydrographic evidence.

The occurrence and distribution of chaetognaths described in this study is in substantial agreement with the earlier investigation (PIERCE, 1953). PIERCE's Zones I and II have been labelled Carolinian Coastal water. The difference between Zones I and II is a matter of dilution with river effluent. Zone III remains as unmodified Florida Current water. As was found to be the case in the earlier collections, the largest number of species was taken near the outer part of the continental shelf.

* Personal communication from Dr. RICHARD BACKUS.

† The distribution of other elements of the plankton communities sampled in these collections is being examined by Philip St. John, a student at Harvard College.

The sources of Carolinian Coastal water are now better understood than heretofore. Mixing of Florida Current water with Carolinian Coastal water may be confined to the outer shelf zone or may occur over broad parts of the shelf. This is occasioned by the intrusion of the Florida Current up the slope along the bottom and across the shelf, penetrating more deeply into one bay than another. Occasional winter storm-driven indrafts of Virginian Coastal water may temporarily convert the inner part of Raleigh Bay from a warm, highly saline environment, to a cold, less saline one.

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