# PTEROPODS IN THE GULF OF ST. LAWRENCE MAY TO NOVEMBER, 1969

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DISTRIBUTION AND ABUNDANCE OF PTEROPODS IN THE GULF OF ST. LAWRENCE FROM MAY TO NOVEMBER, 1969

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SOHEIR M. EL-NAHAS, B.Sc. (Alexandria) Dipl. of Oceanog. (Alexandria) DISTRIBUTION AND ABUNDANCE OF PTEROPODS IN THE GULF OF ST. LAWRENCE FROM MAY TO NOVEMBER, 1969

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by

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# ABSTRACT

A study is made of the distribution patterns and population densities of Spiratella helicina, Spiratella retroversa and Clione limacina in the Gulf of St. Law-Samples collected from 24 International Biolorence. gical Programme (I.B.P.) stations are analyzed statistically and the frequency distributions of the three species at individual stations are grouped to form four regional samples. The variations in size associated with the distribution patterns of Spiratella are comdescriptive statistics with particuputed using lar attention given to stochastic shape factors and the corresponding cumulative frequency distributions. The variations in size together with the distribution patterns of pteropods are related to the water circulation in the Gulf to interpret breeding aspects. Co-occurrence of the predator, Clione, and its prey, Spiratella, is The developmental stages of Clione and their studied. distribution features in the Gulf of St. Lawrence are investigated.

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### CHAPTER I

### INTRODUCTION

The cosomes and gymnosomes, commonly known as pteropods, form two distinct orders of holoplanktonic opisthobranch molluscs. Pteropods found in the Gulf of St. Lawrence include two genera, <u>Spiratella</u> (<u>Limacina</u>) and <u>Clione</u>, which belong to the orders The cosomata and Gymnosomata, respectively. Although these are important members of the marine holoplankton, very little work has been done on their general biology. A selected review of the distribution patterns and life cycles of <u>Spiratella helicina</u> (Phipps), <u>Spiratella retroversa</u> (Fleming) and <u>Clione limacina</u> (Phipps) is presented in the following introductory sections.

## Distribution of Pteropods in the Atlantic Ocean

Distributional studies of pteropods in the Atlantic Ocean are of special relevance to the present study as the Gulf of St. Lawrence represents a marginal sea of the north Atlantic, with considerable water exchange between these two bodies of water.

<u>S. helicina</u> has been described as an arctic or arcticboreal species. Odhner (1907), Jespersen (1927), Kerswill (1940), Dunbar (1942) and Kramp (1961) all reported that <u>S. helicina</u> commonly occurs in west Greenland waters. It is common also in Baffin Bay and is particularly abundant in the cold waters of Jones Sound and off Lancaster Sound (Kramp, 1961). This species is variable in abundance in southern Greenland waters (Kramp, 1961) and was observed during the summers of 1939 and 1940 along the eastern Canadian coast between Hebron in Labrador and Clyde River in the northern part of Baffin Island (Dunbar, 1942). It was recorded also in the Labrador Sea (Kielhorn, 1952). Kerswill (1940) noted remarkably large numbers of <u>S. helicina</u> in Hudson Bay and Strait, and smaller populations southerly towards Cape Sable.

S. retroversa was classified by Vane (1961), Bary (1963) and Chen and Bé (1964) as a boreal-Atlantic, oceanic species. Chen and Bé, however, considered S. retroversa a sub-arctic species, while Bary included it in his warm-transitionalneritic zooplankton group. S. retroversa has been recorded along the Canadian Atlantic coast from the Strait of Belle Isle to Cape Sable. Large populations of S. retroversa have been recorded in the Gulf of St. Lawrence especially in the summer (Kerswill, 1940). It was observed also in the Gulf of Maine by Bigelow (1926), Redfield (1939) and Hsiao (1939, a & b). S. retroversa was reported also in the North Sea by Glover and Robinson (1966). Despite the fact that S. retroversa is not usually found at high latitudes, it occasionally was recorded west of Greenland at 64° N and penetrating up to 70° % in the North Sea (Kramp, 1961). It has been reported as far south as the Sargasso Sea (Kramp, 1961).

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<u>S. helicina</u> characteristically inhabits environments different from those inhabited by <u>S. retroversa</u>. <u>S. helicina</u> normally inhabits water of  $-0.4^{\circ}$  C to  $+4.0^{\circ}$  C, infrequently up to  $7.0^{\circ}$  C, and salinities mostly lower than 34.0% (Van der Spoel, 1967). <u>S. retroversa</u> is found in water having a temperature range of  $2.0^{\circ}$  C to  $16.0^{\circ}$  C in the Gulf of Maine (Bigelow, 1926). It has been reported from water of  $0.9^{\circ}$  C and  $6.0^{\circ}$  C, but is most abundant at temperatures above  $3.0^{\circ}$  C (Kramp, 1961). <u>S. retroversa</u>, being a euryhaline species, inhabits water salinities of 31.06% to 36.0% (Bigelow, 1926) and this agrees rather well with the lowest limit of 30.0% to 31.0% found by Paulsen (1909) (Cited by Van der Spoel, 1967). Bary (1963) noted that <u>S. retroversa</u>, infrequently, was found below salinities of 34.9%.

Because of these distinct environmental tolerances, <u>S. helicina</u> and <u>S. retroversa</u> have been used as indicators of certain water masses. <u>S. helicina</u>, on one hand, is characteristic of Arctic water. It indicates Arctic water entering the northern North Sea (Russel, 1939) and the Gulf of Maine (Bigelow, 1926). <u>S. retroversa</u>, on the other hand, has been considered as an indicator of both Atlantic (Tesch, 1946) and the northern North Sea waters (Russel, 1939 and Praser, 1965). Its existence in the southern North Sea (Russel, 1939) and in the western Baltic (Fraser, 1965) indicates an inflow from the northern North Sea to these regions. Bigelow (1926) described <u>S. retroversa</u>, in the Gulf of Maine, as a permanent pelagic inhabitant whose numbers depended on local reproduction and not on immigration from elsewhere. However, Redfield (1939) noted that <u>S. retroversa</u> existed, in the Gulf of Maine, for more than 9 months, but that it failed to maintain a permanent population, in any locality, because of its dependence upon the current system of the region.

From the foregoing, it is presumed that the two <u>Spiratella</u> species may not be found simultaneously in equally large numbers. For example, if <u>S. retroversa</u> is abundant in a particular area, the chances are that <u>S. helicina</u> will be rare or absent. This fact is borne out by previous literature reports. Kerswill (1940) noted remarkably large numbers of <u>S. retroversa</u> during the summer at stations south of Miquelon and in the southern part of the Gulf of St. Lawrence; at the same time, <u>S. helicina</u> was absent in those regions. Further confirmation is obtained from a table given by Kramp (1961) in which great differences between the simultaneous abundance of <u>S. helicina</u> and <u>S. retroversa</u> were obvious at various latitudes west of Greenland.

<u>Clione limacina</u> is an arctic-boreal species, widely distributed in all the seas around the North Pole (Pelseneer 1007 and Mileikovsky, 1970) and is especially well known in the North Atlantic (Van der Spoel, 1964, and others). It extends along the Atlantic coast of North America in the

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waters of the cold Labrador Current. It was recorded by Dunbar (1942) at several localities between Hebron in Labrador and the Clyde River in the northern part of Baffin Island. Kerswill (1940) noted that <u>C</u>. <u>limacina</u> was more abundant in the Arctic, Hudson Bay and Hudson Strait than at Cape Sable and in the Gulf of St. Lawrence. Lalli (personal communication) reported <u>C</u>. <u>limacina</u> in spring and early summer east of Newfoundland. Odhner (1907) and Kramp (1961) reported <u>C</u>. <u>limacina</u> in west Greenland waters. The range of this species extends southerly along the Atlantic coast of North America to Cape Hatteras (35° N) (Kramp, 1961 and Mileikovsky, 1970).

<u>C. limacina</u> usually co-occurs with either <u>S. helicina</u> or <u>S. retroversa</u>, or both. This may be explained by the fact that <u>Spiratella</u> represents the exclusive prey of adult <u>Clione</u> (Ussing, 1938; Lalli, 1967 and 1970; Mileikovsky, 1970).

# Reproduction and Life Cycles of Pteropods

The reproductive tract morphology, breeding seasons, egg masses and larval stages of pteropods, known to be hermaphroditic, have been investigated by a number of workers. Nost pteropods, including the species examined in the present study, have been found to lay fertilized eggs in thin, transparent, gelatinous ribbons. Hatching takes place two or three days later.

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Little information has been published on the breeding seasons of Spiratella helicina. However, Paranjape (1968) reported that spawning of S. helicina in Saanich Inlet, British Columbia, occurred in the summer. Further support for summer breeding was given by Massy (1920) who found that spawning of S. helicina in the Antarctic Ocean occurred in December through February, which is the summer period in this area. The newly hatched larvae of S. helicina described by Paranjape (1968) had symmetrical shells. The anterior body region of S. helicina veligers is surrounded by a velum. As the shell increases in diameter, two lappets develop from the sides of the foot forming the wings; these grow relatively quickly while the velum dwindles. In larger and older individuals. the velum disappears entirely and the wings become larger.

Lebour (1932), Hsiao (1939, a & b), Morton (1954), Chen and Bé (1964) and others contributed to the description of the reproductive system, spawning and life cycle of <u>Spiratella</u> <u>retroversa</u>. At Plymouth, egg-bearing <u>S</u>. <u>retroversa</u> have been observed during most of the year (Lebour, 1932). Hsiao (1939, a & b) discovered that spawning in the Gulf of Maine began in April and May and continued until the fall, with May being the most important breeding period. In the North Atlantic  $(52^{\circ}45^{\circ}N, 35^{\circ}30^{\circ}W)$ , Chen and Bé (1964) found that juvenile <u>S</u>. <u>retroversa</u> first appeared in March and April and reached maximum concentrations between Kay and September. The Developmental stages of <u>S</u>. <u>retroversa</u> are generally similar to those of <u>S</u>. <u>helicina</u>. However, the Cap-like spinistrall shell of <u>S</u>. <u>retroversa</u> apparently develops after hatching instead of before (Lebour, 1932). Moreover, the stage at which the two wing lappets develop from the sides of the foot takes place in <u>S</u>. <u>retroversa</u> at 0.32 mm. shell diameter (Lebour, 1932).

Mileikovsky (1970) recently summarized the available data on the breeding of <u>Clione limacina</u> in the Atlantic and Pacific Oceans. He stated that the breeding season of  $\underline{C}$ . limacina differed from one region to another. However, the most intensive spawning is said to be correlated with the spring/summer period of annual heating of the local waters, and that the highest larval abundance parallelled maximum growth of phytoplankton which served as food for veligers. Newly hatched C. limacing were described by Lebour (1931); they also have a symmetrical shell and a well developed, The Clione veliger casts off the shell when bilobed velum. it is about 0.28 mm. long and becomes a polytrochous larva with three ciliary rings. The polytrochous larva has an anterior ciliary ring around the head, a posterior ring at the hind end and a third ring near the centre of the body; the digestive gland occupies much of the body As the larva increases in size, the wings develop and the ciliated rings begin to disappear starting with the anterior ring, then the median ring, and finally the posterior ring. As the size increases further, a gradual shift in the digestive gland occurs until it occupies only the middle : part of the body.

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## General Description of the Gulf of St. Lawrence

A brief physical and geographical description of the Gulf of St. Lawrence (Fig. 1) is included here because of its relevance to the present research. A more complete review of the past research on the water circulation in the Gulf of St. Lawrence, has been presented by El-Sabh, Forrester and Johannessen (1969); most of the following literature has been abstracted from this reference.

The Gulf of St. Lawrence is  $214 \times 10^3 \text{ Km}^2$  in area (Forrester and Vandall, 1968). It is connected with the Atlantic Ocean to the southeast by Cabot Strait and to the northeast by the Strait of Belle Isle. The Laurentian Channel extends from the continental shelf south of Newfoundland into the Gulf at Cabot Strait, and varies in depth from 600 to 400 m. The Esquiman Channel branches off the Laurentian Channel and extends from the centre of the Gulf northerly towards the Strait of Belle Isle; its depth varies generally between 150 and 250 m. except in shallower areas closer to the Strait. The Nagdalen Shallows are located to the south of the Laurentian Channel in the southwestern part of the Gulf.

Dawson (1913) and Sandstrom (1919) made the earliest studies of circulation in Cabot Strait. More recently, McGregor (1956) showed that water circulation in Cabot Strait is characterized mainly by an outflowing current along the Cape Breton side and an inflowing current along the Newfoundland

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Fig. 1. The Gulf of St. Lawrence

side. The strongest outflowing and inflowing currents occur in August, while the weakest ones occur in April and May.

Water from the southern portion of the Magdalen Shallows has been found to contribute to the drift observed along the Cape Breton side of Cabot Strait. This drift consequently contributes to the southwesterly drift along the outer coast of Nova Scotia. This latter drift develops maximally during the spring, breaks down during the summer and forms again to a lesser extent in the fall (Bumpus and Lauzier, 1965).

Although the present study is concerned with the water circulation in all parts of the Esquiman Channel, information will be cited only from the Strait of Belle Isle which has been best studied. This information also allows a better interpretation of the water circulation in the Esquiman Channel as a whole. The water circulation in the Strait of Belle Isle has been investigated by Dawson (1907), Huntsman, Bailey and Hachey (1954), Bailey (1958), and Farquharson and Bailey (1966). They reported an inward movement of Labrador coastal water on the Labrador side, and an outflow of Gulf water on the Newfoundland side. On some occasions a strong outflow through the Strait was observed to last for several days, or even weeks, while at other times a strong inflow dominated for an equal period of time.

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The water circulation southeast of Anticosti Island is characterized by a large, permanent, anticlockwise gyre. During the summer, Blackford (1965, 1967) distinguished between clockwise and anticlockwise gyres, 20-30 Km. in diameter, in the layer above the thermocline in the southern Gulf. These small gyres were observed to move with the southeasterly flow along the north shore of Prince Edward Island. This southeasterly flow contributes, as was previously mentioned, to the drift observed along the Cape Breton side of Cabot Strait.

# Purpose of the Present Study

Although there are extensive distribution records of <u>Spiratella</u> and <u>Clione</u> from other areas, no previous study has concentrated on the distribution and population changes of these pteropods in the Gulf of St. Lawrence. The present study has considered the following areas of interest:

- Geographic distribution patterns of <u>Spiratella helicina</u>, <u>Spiratella retroversa</u> and <u>Clione limacina</u> within the Gulf of St. Lawrence.
- Regions and degrees of co-occurrence of <u>S</u>. <u>helicina</u> and
  <u>S. retroversa</u> on a seasonal basis.
- Seasonal changes in the sizes of both <u>S. helicina</u> and <u>S. retroversa</u>.

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- 4. Relationships of <u>Spiratella</u> and <u>Clione</u> distributions and abundances.
- An analysis of the various developmental stages of
  <u>C. limacina</u>.

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#### CHAPTER II

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#### MATERIALS AND METHODS

# Collection of Samples

As a part of the International Biological Programme (I.B.P.), thirty-one stations were assigned in the Gulf of St. Lawrence. These stations were located throughout the Gulf at the localities shown in Fig. 1.

Seven oceanographic cruises were made from May to September 1969, in the Gulf of St. Lawrence. Most of the stations were scanned continuously by the cruises, while those stations located in the central Gulf and in the Magdalen Shallows were sampled only intermittently. Samples analysed during the course of the present investigation did not include those collected from stations 13 through 19. Preliminary analysis of samples collected from these stations showed that pteropods were rare, or absent, in these localities.

A supplementary cruise, referred to throughout the text as "cruise J", was made in November 1969, and collected samples from localities other than the I.B.P. stations. Stations located within the study area, and from which samples were collected during cruise J, are shown in Fig. 1. The present study deals with samples taken from oblique plankton tows made during the various cruises. All the oblique tows were taken from bottom to surface, and their operations lasted from 5 to 25 minutes. Although individual oblique tows usually do not yield enough information about the discrete depth distribution of organisms, the data have been sufficient to provide information on the general distributions of the various pteropod species.

Two standard plankton nets, of number "O" and number "6" mesh, were used at each station. Both nets had mouth diameters of 0.5 m. The volume of filtered water was computed for every tow, making it possible to determine the number of pteropods per unit volume of water.

The number "6" net, of the smaller mesh size, did not collect specimens of <u>Spiratella</u> smaller than 0.20 mm. shell diameter or of <u>Clione</u> smaller than 0.44 mm. in length. A smaller mesh size, therefore, should have been used. Pteropods collected by the number "0" net were generally larger.

Samples collected by both nets were combined, in the present study, to give a unified result for each station.

# Sorting, Counting and Measuring

After collection, all plankton samples immediately were preserved in formalin buffered with calcium carbonate.

In the laboratory, the three pteropod species were sorted and preserved separately. <u>Spiratella helicina</u> and <u>Spiratella retroversa</u> were preserved in 70% ethyl alcohol to prevent dissolution of the shells, while <u>Clione limacina</u> was preserved in 10% formalin.

Subsampling was necessary when pteropods were relatively abundant in a sample. Subsamples were taken from thoroughly mixed samples, and the volumes were measured in graduated cylinders. The size of the subsample depended upon total pteropod abundance, but was usually more than 10% of the total sample for sorting and counting procedures. Because of the limited number of specimens of <u>C. limacina</u>, no subsampling was needed.

A minimum of 100 individuals of each species was selected randomly from each subsample and measured. A dissecting microscope with a calibrated ocular micrometer was used to measure <u>Spiratella</u>. Individuals of <u>S. retroversa</u> were measured with the shell apertures facing the observer while those of <u>S. helicina</u> were measured with the umbilicus facing upward. The diameter of the largest whorl of the shell was used to designate size, as illustrated in Fig. 2. Conover and Lalli (personal communication) have found that this dimension most accurately indicates the weight, and presumably age, of <u>Spiratella</u>.



The total length of <u>C</u>. <u>limacina</u> was measured using either an ocular micrometer or a millimeter ruler, depending on the size of the specimen. It is worth mentioning that, unlike <u>Spiratella</u> which has a fixed shell diameter, <u>Clione</u> tends to contract upon rapid fixation. Bent <u>Clione</u> specimens were measured after straightening them.

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#### CHAPTER III

#### ANALYSIS OF DATA

#### Regional Division of the Study Area

The analysis of data on the basis of individual stations proved to be rather tedious and a broader outlook was attempted. This necessitated grouping stations into geographical regions.

The number of stations examined in the present work totalled twenty-four, sixteen of which were chosen to form four regions of four stations each. The remaining eight stations were treated individually in the analysis. The basis on which regions were selected was purely geographical. The selected regions were given the letters A, B, C and D, and their corresponding station numbers are as follows (Fig. 1):

Region	A	encompasses	stations	1,	2,	3	and	14	
Region	B	•		5,	6,	7	and	18	
Region	C	•	*	21	, 23	2,	23	and	24
Region	D	•	•	25	, 20	5,	27	and	28

More credence may be granted to this regional division if we regard the fact that the various cruises followed, in collecting the samples, the same sequential pattern given by this division. In other words, stations belonging to any one region were visited sequentially and at approximately the same time. Stations belonging to a particular region were subject, of course, to individual features. Differences among the various stations of one region were confined mainly to the water depth and to the corresponding water currents. Having discussed water currents in the Gulf in CHAPTER I, only variations in water depth at different localities will be commented on here.

In region A, stations 2, 3 and 4 were located in the Laurentian Channel with an average water depth of 480 m. Station 1 was at a shallower locality, with a depth of 150 m.

In region B, stations 6 and 7 were located in the Esquiman Channel and had an average water depth of 150 and 250 m. respectively. The water depth in the locality of stations 5 and 8 was between 75 and 100 m.

In region C, located in the Magdalen Shallows, a depth of about 50 m. prevailed at all stations.

In region D, stations 25 and 27 on the extension of the Laurentian Channel had water depths of 350 m. - 400 m., while stations 26 and 28 were located in a shallower area of 75 m. depth.

### Statistical Treatment of Data

Statistical analysis of the data was made with the aid of McGill University's digital computer, model IBM 360/75. The programs were written in FORTRAN IV which was thought to be most suitable for the type of computational operations used in the analysis.

#### Grouping of Data

Data on <u>Spiratella</u> sizes were grouped, as this leads to a more cohesive and smooth-looking distribution. The selected class interval, and hence the number of classes, influences the precision of determining the statistical parameters. The larger the class interval, i.e., fewer number of intervals, the less accurate will be the numerical results.

Because of the large number of observations, it was necessary to set up the data in a frequency distribution before carrying out the statistical computations. Since the digital computer was available, relatively small class intervals (0.05 mm.) were chosen for the shell diameters of <u>Spiratella</u>. This caused the number of classes, for a part'cular sample, to be very large. Numbers of classes as large as 75 were attained.

# Combination of Samples

Two types of sample combinations were dealt with in the statistical analysis. Firstly, the samples collected using nets of two different mesh sizes had to be combined to yield a resultant value describing <u>Spiratella</u> at each particular station. Secondly, it was necessary to sum the data from various stations in order to form a unified regional sample representation of <u>Spiratella</u>. Both sample combination processes were achieved adequately by means of the digital computer. Subroutine WEZZAH (APPENDIX II), was written to combine data from the two differently collected samples into one quantity. Each of the two given samples was expressed as a numerical array representing the size frequency distribution of <u>Spiratella</u>. The first and second entries of the frequency distribution array were chosen to represent the lower and upper limits of the distribution, respectively. In other words, the first entry was the lower limit of the first class interval; the second entry was the upper limit of the last class interval in the given data.

The two values,  $Z_1$  and  $Z_2$  of the subroutine, represented the total number of <u>Spiratella</u> in 100 m<sup>3</sup> of water collected by the number "0" and number "6" nets, respectively. These values were calculated by simply referring the number of specimens found in a known volume of filtered water to a volume of 100 m<sup>3</sup>. It also should be noted that, in general, the frequency distribution given to the program represented a known fraction of the collected sample. The first step in the statistical process was, therefore, to normalize the two given frequency distributions,  $F_1$  and  $F_2$ , to a water volume of 100 m<sup>3</sup>. This was achieved by multiplying the individual entries of  $F_1$  and  $F_2$  by the ratio of  $Z_1$  and  $Z_2$  to the actual number of specimens in the given samples.

Thereafter, subroutine WEZZAH performed a selection technique in which it compared the corresponding entries of the corrected  $P_1$  and  $P_2$  (now called X<sub>1</sub> and X<sub>2</sub>). The larger

of the two entries was selected to become an entry of the resultant frequency distribution F. Figure 3 demonstrates a typical selection process in which the envelope of the two size distributions of <u>Spiratella</u> from number "0" and number "6" nets accurately represented a combined frequency distribution.

Completion of subroutine WEZZAH resulted in the samples from each station being represented by a frequency distribution in which the <u>Spiratella</u> shell diameter was the statistical variate. The second step was to sum the samples from stations of a selected region, forming one regional frequency distribution. Subroutine SOHEIR (APPENDIX II) was developed to add the frequency distributions of two stations at a time. The input frequency distributions already were normalized to a unit volume of water of 100 m<sup>3</sup>.

Subroutine SOHEIR initially compared the two first entries of the two distributions  $F_1$  and  $F_2$ . The smaller of the two entries was assigned to represent the lower limit of the resultant array. The larger of the two second entries represented the upper limit of the resultant distribution. The program, thereafter, proceeded with a simple addition of the corresponding entries of the two input arrays  $F_1$  and  $F_2$ .

#### Determination of Statistical Parameters

The tabulation of the new data and pictorial representation in terms of a histogram, as in Fig. 3, provides a great deal of information. Many times, however, this is inadequate



and the frequency distribution of shell diameters can be better characterized by certain numerical measures. It was hoped that such characteristics as central measures and deviations from symmetry would yield a further quantitative grasp of the empirical data, and that this would aid in comparison of sets of data from various stations and regions.

For this purpose, APPENDIX I provides the basis of this characterization. The statistical measures, elaborated on in APPENDIX I and dealt with later, comprise mean, mode, standard deviation and shape factors. The latter represent adequate measures for the deviation from normal in the distribution of shell diameters.

### Sources of Error

Having now described the various techniques used in this study, an assessment of these methods seems necessary. An objective criticism of the technical and statistical processes will be presented in this section.

As was previously mentioned, some stations were not covered continuously by the assigned cruises. This slightly biased the seasonal results at certain localities.

One-quarter (sometimes one-half) of each plankton sample was taken for biomass analysis before the collection

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was received and consequently before the pteropod sorting had been done. Thus, the samples used in the present work were subject to a certain degree of inaccuracy. This is mainly because the heavy shells of <u>Spiratella</u> are known to settle quickly, thus influencing the homogeneity of the initial subsample.

The fact that cruise J did not cover exactly the I.B.P. stations, forced a few approximations in tabulating the data. It should be noted that, for this cruise, attention was given only to samples collected from localities within, or close to, the specified I.B.P. regions.

<u>Spiratella</u> of shell diameters less than 0.2 mm. and <u>Clione</u> larvae less than 0.44 mm. in length were not collected. This was a direct result of the large mesh size used. Furthermore, the technique used to compare samples from nets of two different mesh sizes, although it proved adequate, sometimes may produce results of limited precision. This could be the case if the samples collected by the two nets were remarkably scattered.

The physical differences between individual stations, chosen to constitute a certain region, presented a further slight inadequacy. These differences have been discussed in earlier sections of this text. Other sources of errors in the present work are those which arose in the computing processes and which are known as "round-off errors". This type of error has been avoided by using large enough printing FORMAT. Further, no correction for "stochastic bias" was made in the process of determining standard deviations and the shape factors  $G_1$  and  $G_2$ . However, this is justified by the relatively large amount of data.
### CHAPTER IV

### RESULTS

### Spiratella in the Gulf of St. Lawrence

### Population Density Distribution

Results obtained by means of the techniques of CHAPTERS II and III are presented in Tables 1 and 2. The two tables show the total numbers of the two <u>Spiratella</u> species in 100 m<sup>3</sup> of water and the corresponding mean shell diameters for various cruises and at different localities. Conclusions can be drawn from Tables 1 and 2 in an attempt to summarize the general features of the distribution of <u>Spiratella</u> in the Gulf.

In May, 1969, (Cruise I), <u>S. helicina</u> was very abundant (281 per 100 m<sup>3</sup>) whereas <u>S. retroversa</u> was less so at station 6 in the Esquiman Channel. The northerly located station 9 showed, however, equally large populations of the two species. In the Magdalen Shallows, station 22 showed a relatively high abundance of <u>S. helicina</u>. The two species were rare at other stations.

In early June, 1969, (Cruise II), <u>S</u>. <u>retroversa</u> was rare except at station 5 in the Esquiman Channel. At the same time, <u>S</u>. <u>helicina</u> was present in very high numbers at station 1 in Cabot Strait, stations 5, 6 and 8 in the Esquiman

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Cruise	]		I	I	II	I	]	[ <b>V</b>	1	<b>I</b>	V	/I	V I	[]	J	۴ (
Date	7/5 -	21/5	31/5	- 14/6	21/6	- 4/7	15/7	- 25/7	30/7	- 12/8	18/8	- 30/8	9/9 -	- 26/9	14/11	23/11
Station	T	M	T	M	T	M	Т	M	Т	M	T	М	Т	М	T	M
12 34 56 78 90 11 12 01 22 34 56 78 90 11 12 02 12 23 24 56 78 90 31	$3.0 \\ 10.0 \\ 15.0 \\ - \\ 281.0 \\ - \\ 333.4 \\ 22.6 \\ - \\ 69.9 \\ 2.6 \\ 136.7 \\ 0.0 \\ - \\ - \\ - \\ - \\ - \\ - \\ - \\ - \\ - \\ $	0.640 0.864 0.883 - 0.543 0.459 0.361 0.431 0.000 0.487 0.904 0.904 0.000 - - - - - -	245.0 222.0 53.0 311.0 398.0 398.0 398.0 263.0 428.7 348.8 10.5 1.0 - - - - - - - - - - - - - - - - - - -	1.294 0.987 1.201 0.988 0.786 0.858 1.126 0.764 0.881 0.764 0.881 0.778 0.606 1.700 - - - 1.340 0.800 1.019 1.253 -	5.0 $1.0$ $14.0$ $88.0$ $157.0$ $175.0$ $148.0$ $51.9$ $34.2$ $2.0$ $0.0$ $-$ $17.0$ $7.0$ $17.5$ $-$ $7.0$ $1.5$	1.558 0.600 0.776 0.000 0.978 0.723 0.809 0.683 1.316 0.774 1.059 0.950 0.950 0.950 0.950 0.950 0.950 0.9794 1.175 0.619 1.050	0.0 27.0 15.0 0.0 14.0 15.6 20.0 14.0 15.6 20.0 0.0 0 15.6 20.0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.000 1.437 0.919 0.600 0.751 0.000 0.846 0.837 0.000 0.844 0.667 0.000 0	0.0 1.0 1.0 1.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 1.0 0.0 0	$\begin{array}{c} 0.000\\ 1.225\\ 0.431\\ 1.150\\ 0.000\\ 0.814\\ 0.590\\ 0.901\\ 0.833\\ 0.000\\ 0.901\\ 0.833\\ 0.000\\ 0.901\\ -\\ -\\ -\\ 0.000\\ 0.934\\ 0.934\\ 0.471\\ -\\ -\\ -\\ -\\ -\\ -\\ -\\ -\\ -\\ -\\ -\\ -\\ -\\$	6.00100000190000 6.00490458860000 1.000040	$\begin{array}{c} 0.412\\ 0.675\\ 0.800\\ 0.650\\ 0.733\\ 0.000\\ 0.683\\ 0.342\\ 0.800\\ 0.812\\ 0.000\\ 0.000\\ -\\ -\\ -\\ 0.550\\ 0.000\\ -\\ -\\ 0.000\\$	$\begin{array}{c} 0.0\\ 1.0\\ 2.0\\ 0.0\\ 0.0\\ 0.0\\ 0.0\\ 366.6\\ 0.0\\ 0.0\\ 0.0\\ 0.0\\ 0.0\\ 0.0\\ 0.0\\$	$\begin{array}{c} 0.000\\ 0.750\\ 1.300\\ 0.000\\ 0.000\\ 0.000\\ 0.000\\ 0.000\\ 0.000\\ 0.000\\ 0.000\\ 0.000\\ 0.000\\ 1.050\\ 0.000\\ 0.000\\ 1.050\\ 0.000\\ 0.$	$\begin{array}{c} 0.0 \\ - \\ 2.3 \\ 0.0 \\ - \\ 24.6 \\ - \\ - \\ - \\ 5.6 \\ 0.0 \\ 0.0 \\ 5.7 \\ 0.0 \\ - \\ 1.6 \end{array}$	0.000 - 0.500 0.000 - 0.486 - - - 0.300 0.000 0.000 0.000 0.000 0.000 0.000 0.430 0.000 - 0.430 0.000 - 0.430 0.000 - 0.430 0.000 - 0.430 0.000 - 0.430 0.000 - 0.000 - - - - - - - - - - - - -

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TABLE I DISTRIBUTION PATTERN AND SIZE OF SPIRATELLA HELICINA IN THE GULF OF ST. LAWRENCE

(MAY-NOVEMBER, 1969)

T = Total number of <u>S</u>. <u>helicina</u>/100 m<sup>3</sup>.

M = Mean shell diameter in mm.

- \* Supplementary cruise, stations approximated to nearest I.B.P. stations.
- no collection was taken.

### TABLE 2

# DISTRIBUTION PATTERN AND SIZE OF SPIRATELLA RETROVERSA IN THE GULF OF ST. LAWRENCE

(May-NOVEMBER, 1969)

Date $7/5 - 21/5$ $31/5 - 14/6$ $21/6 - 4/7$ $15/7 - 25/7$ $30/7 - 12/8$ $18/8 - 30/8$ $9/9 - 26/9$ $14/8$ StationTMTMTMTMTMTMTM15.1 $0.743$ $0.0$ $0.000$ $1.6$ $1.050$ $17.0$ $0.559$ $7.1$ $0.726$ $239.9$ $0.623$ $30101.6$ $0.429$ $4/2$ 2 $5.7$ $0.823$ $12.2$ $0.974$ $5.0$ $0.925$ $546.4$ $0.395$ $12.4$ $0.473$ $120.3$ $0.443$ $96.6$ $0.526$ 3 $19.6$ $1.131$ $34.3$ $0.910$ $3.5$ $0.775$ $13.1$ $0.607$ $36.0$ $0.438$ $75.0$ $0.552$ $268.0$ $0.595$ 4 $4.7$ $1.737$ $0.0$ $0.000$ $385.2$ $0.395$ $77.8$ $0.620$ $15.8$ $0.652$ $401.3$ $0.462$ $1$ 5 $112.7$ $0.594$ $0.0$ $0.000$ $0.8$ $0.250$ $0.0$ $0.000$ $47.6$ $0.442$ $0.0$ $0.000$ 6 $77.0$ $0.539$ $19.3$ $1.089$ $0.6$ $0.550$ $0.0$ $0.000$ $47.6$ $0.442$ $0.0$ $0.000$ 7 $12.7$ $0.750$ $1.0$ $0.550$ $0.0$ $0.000$ $0.000$ $47.6$ $0.442$ $0.0$ $0.000$ 7 $10.7$ $0.788$ $0.0000$	Cruise	J *
Station         T         Ni         T         Ni         T         M         T	Date	14/11 - 23/11
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Station	<u>т</u> М
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	1 2 3 4 5 6 7 8 9 10 11 12 20 21 22 23 24 25 26 27 28 29 30 31	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$

- T = Total number of <u>S</u>. <u>retroversa</u>/100 m<sup>3</sup>.
- M = Mean shell diameter in mm.
- \* Supplementary cruise, stations approximated to nearest I.B.P. stations.
- no collection was taken.

Channel, and stations 9 and 10 northeast of Anticosti Island.

In late June and early July, 1969, (Cruise III), populations of <u>S</u>. <u>helicina</u> were very dense in the Esquiman Channel and decreased in density towards the north of Anticosti Island. At the same time, <u>S</u>. <u>retroversa</u> was rare throughout the Gulf.

Late in July, 1969, (Cruise IV), <u>S. helicina</u> was moderately abundant in the Gulf, while <u>S. retroversa</u> population densities were high in both Cabot Strait and the Magdalen Shallows waters.

In early August, 1969, (Cruise V), small numbers of <u>S. retroversa</u> were present in Cabot Strait. The largest populations were in the central area of the Gulf (stations 27 and 28). Numbers of <u>S. helicina</u>, meanwhile, were low in the whole Gulf.

Late in August, 1969, (Cruise VI), <u>S. retroversa</u> was still relatively abundant especially in Cabot Strait, while S. helicina remained scarce at all localities.

S. retroversa was maximally abundant in late September, 1969, (Cruise VII). Populations as high as 30101 individuals per 100 m<sup>3</sup> of water were recorded in Cabot Strait and as high as 12678 per 100 m<sup>3</sup> in the Magdalen Shallows. Meanwhile, S. helicina was rare throughout the Gulf except at station 8

in the Esquiman Channel, an area in the direct path of the Labrador coastal water. The size of the population there was 366 specimens per 100 m<sup>3</sup> of water.

In November, 1969, (Cruise J), while <u>S</u>. <u>helicina</u> was rare in the Gulf area, very large numbers of <u>S</u>. <u>retroversa</u> were found mainly in Cabot Strait and the Magdalen Shallows.

### Regional and Seasonal Population Distribution

The seasonal population distributions of <u>Spiratella</u> in the four assigned regions were established from the data and are presented in Table 3.

In Cabot Strait, region A, <u>S</u>. <u>helicina</u> was always rare except in early June when a density of 91 specimens per 100 m<sup>3</sup> was recorded. <u>S</u>. <u>retroversa</u>, on the other hand, appeared in small numbers during May and June. However, in July through November, with the exception of early August, <u>S</u>. <u>retroversa</u> became abundant and attained peak numbers in September.

In the Esquiman Channel, represented by region B, S. <u>helicina</u> exhibited population densities as high as 280 per 100 m<sup>3</sup> in Kay and June. Smaller populations (less than 100 per 100 m<sup>3</sup>), however, were recorded until November with a crest of 91.7 per 100 m<sup>3</sup> in September. S. <u>retroversa</u>, meanwhile, appeared in Kay with a population density of 46.4 per 100 m<sup>3</sup>. A noticeable decrease in the population density was

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TABLE 3

POPULATION DISTRIBUTION OF <u>SPIRATELLA HELICINA</u> AND <u>SPIRATELLA RETROVERSA</u> REGIONS A, B, C, AND D, (MAY-NOVEMBER, 1969)

		Total Number /100 m <sup>3</sup>							
		ŀ	l .	]	3	(		D	
Date	Cruise	S. helicina	<u>S.</u> retroversa	<u>S.</u> helicina	<u>S.</u> retroversa	<u>S.</u> helicina	<u>S.</u> retroversa	<u>S.</u> helicina	<u>S.</u> retroversa
7/5-21/5	I	9.7	10.1	281.0	77.0	46.4	6.5		
31/5-14/6	II	91.5	12.8	251.5	36.3			22.5	9.9
21/6-4/7	III	5.0	2.6	142.0	0.4			11.4	2.3
15/7-25/7	IV	12.5	240.5	28.2	0.3	0.0	336.7		
30/7-12/8	v	5.0	33.3	7.7	0.0			4.2	53.0
18/8-30/8	VI	3.3	112.8	24.5	19.5			1.4	0.0
9/9-26/9	VII	0.5	7716.9	91.7	9.7	0.5	5588.5	1.0	3.2
14/11-23/1:	J	0.0	457.2	24.6	152.4	1.9	9368.1	1.9	67.0

-- no collection was taken

noticed thereafter. This was followed by an increase which finally reached a value of 152.4 specimens per  $100 \text{ m}^3$  by November.

In the Magdalen Shallows, region C, a steep and rather steady increase in the population of <u>S</u>. <u>retroversa</u> resulted in a very high density (9368.1 per 100 m<sup>3</sup>) in November<sup>(1)</sup>. <u>S</u>. <u>helicina</u>, in the mean time, was very rare except in May when a population density of 46.4 per 100 m<sup>3</sup> was calculated.

In the Central Gulf, region D, <u>S. helicina</u> attained a maximum population of 22.45 per 100 m<sup>3</sup> in June and declined thereafter. <u>S. retroversa</u> also had relatively small populations with two peaks of 53.0 per 100 m<sup>3</sup> in late July and 67.0 per 100 m<sup>3</sup> in November.

Figure 4 gives a general view of the population densities distribution of <u>Spiratella</u> species in the Gulf. Figures 5, 6, 7 and 8 show this distribution for regions A, B, C, and D, respectively. Pteropod species are known to be epipelagic. Mad vertical hauls been counted , the numbers of pteropods under a square meter of water surface may have been calculated, rather than per cubic meter, and thus the population density comparisons from stations or regions of different depths may not have been statistically different.

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<sup>(1)</sup> No collection was taken in region C for Cruises II, III, V and VI.



Fig. 4. Population densities distribution of <u>S. helicina</u> and <u>S. retroversa</u> in the Gulf of St. Lawrence (Kay-November, 1969

 $\mathbf{C}^{\mathbf{b}}$ 

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Fig. 5. Population densities distribution of <u>S. helicina</u> and <u>S. retroversa</u>, region A (May-November, 1969).

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Fig. 6. Population densities distribution of <u>S. helicina</u> and <u>S. retroversa</u>, region B (May-November, 1969).

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Fig. 7. Population densities distribution of <u>S. helicina</u> and <u>S. retroversa</u>, region C (Kay-November, 1969).



Fig. 8. Population densities distribution of <u>S. helicina</u> and <u>S. retroversa</u>, region D (May-November, 1969).

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#### Regional Variations in Size

The shell diameter of <u>Spiratella</u>, defined in CHAPTER II, is positively correlated with body weight and is indicative of the age of the individual (Lalli, personal communication). The data compiled in the present study was analyzed in an attempt to relate changes in shell sizes of the two species to season and locality. Tables 4 and 5 resulting from the statistical analysis allow the following descriptive remarks to be established.

In Cabot Strait, region A, the size of <u>S</u>. <u>helicina</u> ranged, throughout the study period, between 0.60 mm. and 1.68 mm. with a 1.22 mm. average for the highest population concentration of early June. <u>S</u>. <u>retroversa</u> attained relatively large average shell diameters of 0.89 to 1.01 mm. which prevailed between May and July. These sizes were followed by smaller diameters (0.40 - 0.57 mm.) until November. The very large concentrations recorded in September had a mean shell diameter of 0.43 mm.

In the Esquiman Channel, region B, diameters for <u>S</u>. <u>helicina</u> of 0.40 - 0.82 mm. were observed, i.e., relatively smaller than those of the Cabot Strait area. The shell diameter reached an almost constant peak value, between June and mid-August, of about 0.80 mm. Much smaller sizes (0.40 - 0.49 mm.) were recorded thereafter until the end of the collection period. <u>S. retroversa</u>, on the other hand,

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### TABLE 4

STATISTICAL	PARAMETERS	CALCULATED	FROM	SPIRATELLA	HELICINA

### DATA (MAY - NOVEMBER, 1969)

REGION A

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Cruise	e I	II	III	IV	V	VI	VII	J
DATE	7/5 to 21/5	31/5 to 14/6	21/6 to 4/7	15/7 to 25/7	30/7 to 12/8	18/8 to 30/8	9/9 to 26/9	4/11 to 23/11
Para- meters								
T N G G MD	9.70 0.85 0.23 0.06 -0.90 0.90	91.50 1.22 0.37 0.50 1.40 1.40	5.00 1.00 0.62 1.70 2.30 0.60	12.50 1.12 0.70 0.80 -0.07 2.60	5.00 0.71 0.47 0.86 -0.43 1.60	3.30 0.60 0.22 -0.40 -1.40 0.30	1.50 11.68 0.92 -1.04 -1.86 1.70	0.0 - - - -
REGION	B							
Para- meters								
T M S G 1 G 2 MD	281.00 0.54 0.16 2.50 7.37 0.45	251.00 0.82 0.25 2.80 16.30 0.65	142.00 0.78 0.35 1.90 4.80 0.60	28.20 0.80 0.48 4.00 18.30 0.65	7.70 0.78 0.16 -1.50 1.92 0.80	24.50 0.40 0.15 1.50 1.20 0.30	91.60 0.41 0.07 3.40 21.30 0.40	24.60 0.49 0.16 -0.30 -1.50 0.55

- T = Total number of <u>S</u>. <u>helicina</u>  $/100 \text{ m}^3$ .
- M = Mean shell diameter in mm.
- S = Standard deviation in mm.
- $G_1$  and  $G_2$  = Shape factors.
- MD = Mode in mm.

### STATISTICAL PARAMETERS CALCULATED FROM <u>SPIRATELLA</u> <u>RETROVERSA</u> DATA (MAY-NOVEMBER, 1969)

### REGION A

Cruise	I	II	III	IV	v	VI	VII	J
Date	7/5 to 21/5	31/5 to 14/6	21/6 to 4/7	15/7 to 25/7	30/7 to 12/8	18/8 to 30/8	9/9 to 26/9	14/11 to 23/11
Para- meter								
T M S G 1 G 2 MD	10.10 1.01 0.42 -0.12 -1.20 0.45	12.80 0.97 0.44 0.94 -0.44 0.65	2.60 0.89 0.37 0.37 -0.81 0.35	240.50 0.40 0.30 7.30 16.80 0.30	33.30 0.56 0.21 0.83 0.00 0.40	112.80 0.56 0.24 0.56 -0.74 0.30	7716.90 0.43 0.19 1.50 2.40 0.40	457.20 0.57 0.23 0.37 -0.83 0.30
REGION B								
T M S G 1 G 2 MD	70.70 0.54 0.24 3.80 17.90 0.40	36.30 0.70 0.35 1.90 3.50 0.50	0.40 0.55 0.00 1.00 -2.00 0.45	0.30 0.66 0.46 0.47 -1.80 1.10	0.30 0.75 0.00 0.00 0.00 0.75	19.50 0.48 0.20 1.98 3.80 0.40	9.70 0.44 0.17 1.10 -0.46 0.30	152.40 0.90 0.36 0.00 -0.95 1.15
REGION C								
T M S G 1 G 2 MD	6.50 0.52 0.05 -0.02 -1.17 0.45			336.70 0.74 0.21 0.31 0.06 0.70			5588.00 0.36 0.13 2.78 8.39 0.30	9368.00 0.84 0.30 -0.20 -0.51 0.90
REGION D								
T K S G 1 G 2 MD	- - - - -	9.90 0.61 0.46 2.55 5.78 0.40	2.30 0.87 0.80 0.71 -1.50 1.90		53.00 0.88 0.31 -0.10 -1.04 1.15	- - - - -	3.20 0.80 0.10 -0.07 -1.24 0.80	66.90 0.79 0.26 0.33 -0.56 0.65

- no collection was taken.

For symbol abbreviations, see Table 4.

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fluctuated in size between 0.44 and 0.75 mm., except in November where large concentrations of 0.90 mm. mean shell diamter were recorded.

In the Magdalen Shallows, region C <sup>(1)</sup>, the only pronounced population of <u>S. helicina</u>, found at station 22 in May, had a mean shell diameter of 0.90 mm. In May, the small concentration of <u>S. retroversa</u> had a 0.52 mm. diameter. In July, however, larger sizes (0.74 mm.) appeared, while in September large concentrations of small sizes were reported (0.36 mm.) followed by very large concentrations of relatively large individuals (0.84 mm.) in November.

In the Central Gulf, Region  $D^{(2)}$ , the few <u>S</u>. <u>helicina</u> observed in June and July had comparatively large shell diameters (0.80 - 1.30 mm.). <u>S</u>. <u>retroversa</u>, meanwhile, displayed slightly fluctuating sizes between 0.61 and 0.88 mm. The relatively high concentrations of early August and November had mean shell diameters of 0.88 mm. and 0.79 mm., respectively.

Figures 9 and 10 show the variations in the mean shell diameters of <u>S</u>. <u>helicina</u> and <u>S</u>. <u>retroversa</u> throughout the study period. The limits of dispersion, expressed by the corresponding standard deviation are also shown for each mean value.

<sup>(1)</sup> No collection was taken in the Magdalen Shallows area for Cruises II, III, V and VI.

<sup>(2)</sup> No collection was taken in region D for Cruises I, IV and VI.



Fig. 9. Seasonal size variation of <u>S. helicina</u> and <u>S. retroversa</u>, region A (May-November, 1969).

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Seasonal size variation of S. helicina and S. retroversa. Pig. 10. region B (May-November, 1969).

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### Application of the Statistical Parameters

The foregoing description of the observed changes in the size of <u>Spiratella</u> was based on the mean values of the successive frequency distributions. In general, it is not proper to rely on the mean value alone to describe a particular observation, and other measuring parameters should be used. A more comprehensive description of distributions was achieved by determining the standard deviation "S" and shape factors  $G_1$  and  $G_2$ , described in CHAPTER III and APPENDIX I.

For the sake of illustration, the seasonal changes of <u>S. retroversa</u> sizes in region C (Table 5) were chosen for this purpose. In the first cruise where the mean shell diameter was 0.52 mm., the standard deviation S was 0.05. This small value indicates remarkably little dispersion of shell diameters about the mean. The considerably small magnitude of  $G_1$  (0.02) denotes an almost perfect symmetry about the 0.52 mm. mean diameter. Furthermore, the negative value of  $G_2$  (-1.17) although not appreciably large, emphasizes the concentration of shell diameters about the mean.

In the fourth cruise  $\binom{1}{}$ , the shell mean diameter was 0.74 mm. The moderate value of S (0.21), indicates a

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<sup>(1)</sup> No samples were collected from cruises II, III, V, VI, from Region C.

noticeable dispersion of results about the mean. The low value of  $G_1(0.31)$ , shows symmetry of distribution. The extremely small value of  $G_2$ , together with  $G_1$ , implies the normality of the observation.

In the seventh cruise<sup>(1)</sup>, the mean shell diameter was 0.36 mm. The large positive value of  $G_2$  indicates a quasiuniform distribution, yet confined to diameters closer in value to the mean as indicated by the relatively small standard deviation (0.13).  $G_1$ , being -2.78, denotes more concentration of frequencies for diameters smaller than 0.36 mm.

In cruise J, the mean diameter was 0.84 mm. with more deviation than exhibited previously (S=0.30). Both  $G_1$  and  $G_2$  have small magnitudes indicating that the distribution is quasi-normal.

The above discussion may be applied to the rest of the results of Tables 4 and 5.

The particular importance of the cumulative distribution plot is illustrated in APPENDIX I. Figure 11 demonstrates the applicability of this plot to the data of Table 5. It was possible from the cumulative distributions, printed results of which are shown in APPENDIX II, to derive information about the concentration of specimen numbers in the various size groups.

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<sup>(1)</sup> No samples were collected from cruises II, III, V, VI from Region C.



Fig. 11. Cumulative distribution of shell diameter of <u>S</u>. <u>retroversa</u>, region C, (May-November, 1969).

<u>S. retroversa</u>, the more common the cosome in the Gulf of St. Lawrence, was classified into size groups. These size groups were assigned in accordance with the findings of Lebour (1932) who noted that <u>S. retroversa</u> larva, with the two wings lappets developing from the sides of the foot, measured 0.32 mm. shell diameter, and Hsiao (1939 b) who related <u>S. retroversa</u> size to stages of sexual development as follows:

Group 1: Specimens less than 0.60 mm. shell diameter; the gonad is sexually undifferentiated.

- Group 2: Specimens of shell diameter between 0.60 and 0.85 mm.; the male reproductive cells are developing.
- Group 3: Pure male gonad; sizes range from 0.85 to 1.1 mm. shell diameter.
- Group 4: Shell diameters of 1.2 to 1.8 mm.; a high proportion of these specimens are functioning males. Among larger animals, the functional hermaphroditic and functional female phases replace the male phase.
- Group 5: Specimens more than 1.5 mm. in shell diameter; proportion of female reproductive cells in the ovotestis is greater than male cells.

Using the cumulative frequency distributions, percentage concentrations of the above size groups are shown in Table 6 TABLE 6

### SIZE GROUPING OF THE POPULATION OF S. RETROVERSA, REGIONS A AND C

CABOT STRAIT (REGION A)

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		Total	Percentage Concentrations								
Date	Cruise	/100 3	<b>&lt;</b> •3 mm	.36 mm	.685 mm	.85-1.1 mm	1.2-1.8 mm	>1.5 mm			
7/5-21/5 31/5-14/6 21/6-4/7 15/7-25/7 30/7-12/8 18/8-30/8 9/9-26/9 14/11-23/11	I II IV V VI VII J	10.1 12.8 2.6 240.5 36.3 112.8 7716.9 457.2	3.40.00.049.011.023.030.021.0	23.6 20.0 30.0 45.0 52.0 36.0 57.0 37.0	16.0 48.0 21.0 5.0 28.0 29.0 8.0 31.0	14.0 10.0 28.0 1.0 9.0 12.0 5.0 11.0	43.0 22.0 21.0 0.0 0.0 0.0 0.0 0.0	7.0 18.0 6.0 0.0 0.0 0.0 0.0 0.0			

MAGDALEN SHALLOWS (REGION C)

7/5-21/5	I	6.5	2.0	98.0	0.0	0.0	0.0	0.0
15/7-25/7	IV	336.7	1.9	25.4	50.0	21.0	2.3	0.0
9/9-26/9	VII	5558.0	66.8	26.7	4.0	1.9	0.1	0.0
14/11-23/11	J	9368.0	7.0	14.8	33.0	35.3	10.4	1.1

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for Cabot Strait and the Magdalen Shallows where <u>S</u>. retroversa was found to be most abundant.

Hsiao (1939 b) measured the diameter of the largest whorl of the shell excluding the protruding margin of the shell opening. Therefore, <u>S. retroversa</u> shell measurements given in the present study are approximately 15% larger, because I measured the entire shell aperture. The conversion was not calculated as the size classification is somewhat arbitrary and the size differs slightly. Table 6 gives a general idea of the relation between the percentage concentration of <u>S. retroversa</u> and the corresponding stage of sexual maturing in the Gulf of St. Lawrence.

### Clione limacina in the Gulf of St. Lawrence

#### Population Density Distribution

Although relatively few specimens of <u>Clione limacina</u> were collected in the present study, general remarks can still be made about its ecology in the Gulf of St. Lawrence. Table 7 shows the total numbers of <u>Clione</u> collected during the study period.

Throughout the eight cruises, the largest populations of <u>C</u>. <u>limacina</u> were found within the Esquiman Channel and in Cabot Strait. Stations 7 and 8 (Fig. 1) on the west side of the Esquiman Channel, yielded, on the average, more than 30,3 TABLE 7

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	1	·	Numb	ers per	100 m <sup>3</sup>		S <u>piratella</u>
Cruise	Stn.	Date	<u>C.lim-</u> acina	<u>S.hel-</u> icina	<u>S.ret-</u> roversa	<u>Spira-</u> tella	<u>Clione</u>
II	34 57 89 12	June 1 June 2 June 4 June 5 June 6 June 7 June 8	0.91 1.27 2.02 0.67 2.69 5.82 0.51	53.0 44.0 311.0 33.0 263.0 428.7 10.5	34.34.7112.710.42.764.41.1	87.3 88.7 423.7 43.4 265.7 493.1 11.6	96.46 69.84 209.75 64.78 98.40 84.73 22.75
III	7 8	June 24 June 25	1.26 1.47	175.0 148.0	0.6 1.0	175.6 149.0	139.37 101.36
IV	4 8 22	July 16 July 19 July 25	3.64 2.51 1.60	15.0 37.0 0.0	385.7 0.0 73.8	400.7 37.0 73.8	110.08 14.74 46.13
v	4	July 31	1.81	5.0	77.8	82.8	45.75
VI	1 3	Aug. 17 Aug. 19	1.56 2.36	6.0 0.0	239.9 75.0	245.9 75.0	157.63 31.78
VII	1 4	Sep. 23 Sep. 24	95.24 3.70	0.0	30101.6 401.3	30101.6 401.3	316.06 108.46
J	*	Nov. 18	4.10	24.6	152.4	177.0	43.17

COMPARATIVE ABUNDANCE OF <u>CLIONE LIMACINA</u>, <u>SPIRATELLA HELICINA</u> AND <u>S. RETROVERSA</u> (GULF OF ST. LAWRENCE, MAY - NOVEMBER, 1969)

\* Station located in the Esquiman Channel close to Station 8.

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of the total population of <u>C</u>. <u>limacina</u> in the Channel. This agrees with the findings of Kerswill (1940). <u>C</u>. <u>lima-</u> <u>cina</u> was especially abundant in the Esquiman Channel during June and July. It was rare in August and September, but increased in numbers by November, particularly along the western coast of the Channel.

In Cabot Strait, the <u>C</u>. <u>limacina</u> population density reached its peak between June and August at localities closer to the Newfoundland coast, namely stations 3 and 4. <u>C</u>. <u>lima-</u> <u>cina</u> was remarkably abundant late in September at station 1 on the west side of Cabot Strait.

#### Relation Between <u>Clione</u> and <u>Spiratella</u>

Comparative information about the populations of <u>Clione</u> and <u>Spiratella</u> in the Gulf of St. Lawrence can be given. Ratios of the population densities of <u>Clione</u> and <u>Spiratella</u> at different localities of the Gulf have been computed. Table 7 shows the comparative abundances of <u>C. limacina, S.</u> <u>helicina</u> and <u>S. retroversa</u> at various stations and for successive cruises. The ratio between the <u>Spiratella</u> population combined <u>S. helicina</u> and <u>S. retroversa</u> numbers and that of Clione ranged between 14.7 and 316 with an average value of 98.

Two typical cases were chosen to illustrate pictorially the comparative seasonal variations in the populations of  $\underline{C}$ . limacina, S. <u>helicina</u> and S. <u>retroversa</u>. Figures 12 and 13





Pig. 13. Population densities of <u>C</u>. <u>limacina</u>, <u>S</u>. <u>helicina</u> and <u>S</u>. <u>retroversa</u>, station 8 of the Esquiman Channel (May-November, 1969).

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demonstrate the results obtained for station 4 of Cabot Strait and station 8 of the Esquiman Channel, respectively.

### Developmental stages of Clione

An anatomical study was carried out in an attempt to describe the various developmental stages of <u>Clione limacina</u>. Since the nets used in collecting **samples** were not small enough to collect shelled <u>Clione</u> veligers, they were not included in this study.

<u>C. limacina</u> collected was classified into seven stages. These classifications were established in accordance with the presence or absence of ciliary rings, the relative development of the wings, and the relative physical extent of the digestive gland which is known to be influenced by feeding as well as by the total growth. Significant features of each of the seven stages are presented below and are shown in Fig. 14; recorded lengths of each stage are given in Table 8.

Stage 1: The larva has three ciliary rings encircling the head, the mid-body and the posterior end. The digestive gland occupies the entire posterior; the wings are short and little developed. This stage averaged 0.58 mm. in length.

Stage 2: The larva has essentially the same features as stage 1, but the wings are slightly more developed and the body size is larger, average length being 1.06 mm.

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Fig. 14 Developmental stages of <u>Clione limacina</u> in the Gulf of St. Lawrence.

ACR, anterior ciliary ring; MCR, mid-ciliary ring; PCR, posterior ciliary ring; FL, foot lobe; DG, digestive gland; W, wing; P,penis.

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### TABLE 8

## DEVELOPMENTAL STAGES OF <u>CLIONE</u> <u>LIMACINA</u> IN THE GULF OF ST. LAWRENCE

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Stages	Average Length in mm.	Minimum Length in mm.	Maximum Length in mm.
1	0.58	0.44	0.88
2	1.06	0.69	2.25
3	2.21	1.44	3.13
4	2.80	2.19	4.06
5 *	4.80	3.13	6.19
6	2.84	2.44	3.38
7	16.67	7.00	28.00

\* All specimens were collected on 18 November from the most western station 8 of the Esquiman Channel.

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Stage 3: The wings are well developed. The anterior ciliary ring is rudimentary or has completely disappeared, while the mid and posterior ciliary rings are still present. The digestive gland may still occupy most of the body or is slightly retracted as the body increases in length. The average length of this stage is 2.21 mm.

Stage 4: The posterior ciliary ring is still retained while the mid-ciliary ring is rudimentary or absent. The anterior ring is completely absent. The posterior part of the body clearly extends beyond the digestive gland. In this stage the average length was 2.80 mm.

Stage 5: The posterior ciliary ring is still present, but the gut lies entirely in the anterior half of the body. An average length of 4.8 mm. was recorded for this stage. It is worth mentioning that specimens of this stage were collected from a single tow at station 8 of the Esquiman Channel on November 18th.

Stage 6: All three ciliary rings are now entirely absent, the wings are well developed and the penis was everted at the right side in some specimens. An average length of 2.84 mm. was recorded for this stage.

Stage 7: This stage is represented by the adult. A typical adult <u>Clione</u> has no ciliary rings, its wings are well developed and the digestive gland occupies only the

most anterior part of the body. The average length of adults was 16.67 mm. All collected specimens of stage 7 were found to be mature males.

Since <u>C</u>. <u>limacina</u> is a protandric hermaphrodite, a fully mature specimen, in which the female accessory glands are well developed, should be classified in a later stage than number 7. However, no fully mature specimens were obtained in the Gulf during this study.

### Distribution Patterns of Clione Stages

The Esquiman Channel and Cabot Strait are the two main areas where <u>Clione limacina</u> was recorded. In the Esquiman Channel, <u>C. limacina</u> of stages 1, 2 and 3 appeared in June accompanied by stage 7 individuals. Stage 7 became more abundant in July. <u>C. limacina</u> of stages 1, 2 and 3 reappeared in low abundance in November together with those of stage 5.

In Cabot Strait, larvae belonging to stages 1 and 2 were recorded between June and September. <u>C. limacina</u> of stage 3, accompanied by those of stage 6, appeared in September with the latter being less abundant.

More complete information can be drawn from Table 9 in which the numbers and distribution of various stages are given for different seasons.

### TABLE 9

POPULATION DISTRIBUTION, BY STAGES, OF <u>CLIONE</u> <u>LIMACINA</u> IN THE GULF OF ST. LAWRENCE

			1	Number	of Cli	lone /	100 m-	3	
Cruise	Stn.	Date	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
I		May	0.00	0.00	0.00	0.00	0.00	0.00	0.00
II	34 57 8 912	June 1 June 2 June 4 June 5 June 6 June 7 June 8	0.00 0.00 1.01 0.00 1.35 5.82 0.00	0.33 1.03 0.00 0.00 1.35 0.00 0.00	0.58 0.00 1.01 0.00 0.00 0.00 0.00	0.00 0.24 0.00 0.00 0.00 0.00 0.00	0.00 0.00 0.00 0.00 0.00 0.00	0.00 0.00 0.00 0.00 0.00 0.00 0.00	0.00 0.00 0.67 0.00 0.00 0.51
III	7 8	Jun 24 Jun 25	0.00 1.47	1.26 0.00	0.00	0.00	0.00 0.00	0.00	0.00 0.00
IV	4 8 22	Jul 16 Jul 19 Jul 25	1.21 0.00 0.00	2.43 0.00 0.00	0.00 0.00 0.00	0.00 0.00 1.6	0.00 0.00 0.00	0.00 0.00 0.00	0.00 2.51 0.00
v	4	Jul 31	0.90	0.90	0.00	0.00	0.00	0.00	0,00
VI	1 3	Aug 17 Aug 19	0.00	1.56 2.36	0.00	0.00	0.00	0.00 0.00	0.00 0.00
VII	1 4	Sep 23 Sep 24	46.68 3.70	29.98 0.00	14.18 0.00	0.00	0.00	4.39 0.00	0.00 0.00
J	*	Nov 18	0.46	0.69	0.23	0.00	2.76	0.00	0.00

\* Station located in the Esquiman Channel close to Station

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#### CHAPTER V

#### DISCUSSION AND CONCLUSIONS

The present study deals only with oblique tows taken from the bottom to the surface of the waters under investigations. It was not possible, therefore, to derive information on the depths at which the three pteropod species may have existed. However, it is known from the literature that the most prolific depth zone of <u>Spiratella</u> ranges from 20 m. to about 80 m. in the Gulf of Maine (Bigelow, 1926) and to about 50 m. depth in northern European water (Paulsen, 1910). Data on temperature and salinity variations for the 20-80 m. depth zone in the Gulf of St. Lawrence were obtained for the purpose of the following discussion.

### Abundance of Spiratella Related to Environmental Factors

The results have shown a very high abundance of <u>Spira-tella helicina</u> in the Esquiman Channel during May and June. In May the temperature was found to vary along the water column from -0.89 to  $2.20^{\circ}$  C, while in June it ranged between -0.89 and  $6.60^{\circ}$  C. The corresponding water salinity was reported between 30.45 and 32.40%. At Station 8 in the Esquiman Channel, large concentrations of <u>S</u>. <u>helicina</u> were reported in September. The temperature and salinity ranged correspondingly from 0.12 to 5.60° C and from 30.55 to 32.48%, respectively.

Temperature and salinity of the Magdalen Shallows water during September, when <u>Spiratella retroversa</u> was observed in large populations, ranged from 0.34 to 14.59° C and from 28.16 to 32.78%, respectively. The corresponding values at Cabot Strait, where <u>S. retroversa</u> was again found in comparatively large numbers, were from 1.2 to 13.97° C and from 29.27 to 32.78%, respectively.

In conclusion, S. helicina in the Gulf of St. Lawrence is found to inhabit waters of temperatures equal to, or close to, those reported by Kramp (1961). The existence of S. helicina in the relatively low salinity Gulf water, is in accordance with the finding that it also inhabits the estuary water of Hudson Bay (Kerswill, 1940). The temperature range inhabited by S. retroversa in this study, is consistent with that quoted in the literature. However, with regard to water salinity, there is a contradiction between the published values and those observed in the present study. Bary (1963) stated that high S. retroversa populations usually were found at salinities above 34.90%. Chen and Bé (1964) indicated that S. retroversa existed in abundance in water salinities of 34.75 - 35.00%. Bigelow (1926) found this euryhaline species to live in water of salinities ranging from 31.06 to 36.00%. However, S. retroversa populations as high as

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#### Cooccurrence of Spiratella helicina and Spiratella retroversa

Previous work has indicated that <u>Spiratella helicina</u> and <u>Spiratella retroversa</u> inhabit different, discrete, water masses. Since both species were present in the Gulf of St. Lawrence, the data were analyzed for joint occurrences of the two species.

Table 3 shows the average seasonal populations of the two species in the four main regions A, B, C, and D. Although joint occurrences were frequent, the populations of the two species were for the most part discrete except for populations of comparatively low densities (less than 25 specimens per  $100 \text{ m}^3$  of water.)

It is worth mentioning that populations of <u>S</u>. <u>retroversa</u> everywhere in the Gulf area were less dense than those of <u>S</u>. <u>helicina</u> during May and June. However, between July and November <u>S</u>. <u>retroversa</u> displayed larger populations mainly in the waters of the Magdalen Shallows<sup>(1)</sup> and Cabot Strait, with particularly high concentrations during September and November. This agrees with the findings of Kerswill (1940)

<sup>(1)</sup> No samples were collected from the Magdalen Shallows for cruises II, III, V and VI.

who reported considerable abundance for <u>S</u>. <u>retroversa</u> in the southern Gulf during the summer, while <u>S</u>. <u>helicina</u>, at that time, was not present.

#### Breeding of Sniratella in the Gulf

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The distribution of the larval stages of <u>Spiratella</u> indicated by shells of less than 0.3 mm. in diameter, was examined. Larvae of <u>S</u>. <u>retroversa</u> were found abundantly in both the Magdalen Shallows and Cabot Strait between July and November with specially high concentrations in September.

Based on the results presented in Tables 5 and 6, more adequate conclusions concerning breeding of <u>S</u>. <u>retroversa</u> in the Gulf can be drawn. The very high population densities of <u>S</u>. <u>retroversa</u> in the Magdalen Shallows and Cabot Strait can be attributed to one of two factors, perhaps to a combination of both. First, it may be rightly postulated that <u>S</u>. <u>retroversa</u> had invaded the Gulf via its inlet at Cabot Strait where the water flows parallel to the coast of Newfoundland. The anticlockwise movement of water within the Gulf then could have carried <u>S</u>. <u>retroversa</u> to the Central Gulf. The presence of the species in large numbers at station 4, amid the inflow to the Gulf, can be taken as adequate evidence of the above hypothesis, previously presented by Kerswill (1940). The second explanation, believed to be more feasible, is prompted by the very high densities of <u>S</u>. retroversa larvae in the Magdalen Shallows, accompanied by specimens of larger sizes (1.2 - 1.8 mm.) which are known to be sexually mature animals (Table 6). It is possible that breeding of S. retroversa took place in these areas late in the summer. The drift observed along Cape Breton might account for the presence of the large numbers of <u>S</u>. retroversa larvae at Cabot Strait where they could have been conveyed from the Magdalen Shallows.

<u>S. helicina</u> was recorded mainly in the Esquiman Channel, in areas north of Anticosti, and in Cabot Strait, with the larger population densities observed in the former region. Small sizes of <u>S. helicina</u> (less than 0.45 mm. in diameter) were found mainly in May at the northerly located station 9 and during May, June and September at the western stations of the Esquiman Channel. It is probable, therefore, that these small individuals could have entered the Gulf through the Strait of Belle Isle, being conveyed by the cold Labrador coastal water. The fact that the inflow water from Belle Isle Strait continues westerly along the coast of Quebec may explain the existence of <u>S. helicina</u> north of Anticosti Island. <u>S. helicina</u> recorded in Cabot Strait, meanwhile, may have entered with the water inflow.

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#### Distribution Features of <u>Clione</u>

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<u>Clione limacina</u> was found mainly in the Esquiman Channel, north of Anticosti Island, and in Cabot Strait. More than 80% of <u>Clione</u> collected from the Esquiman Channel were found in the locality of stations 7 and 8 on the western side of the Channel. This may be a direct result of the inflow of the Labrador coastal water along the western side of the Channel, while its continuation along the south shore of Quebec may account for the specimens collected from stations 9 and 12 north of Anticosti Island.

Specimens of <u>C</u>. <u>limacina</u> collected from the Gulf comprised polytrochus larvae and juveniles in addition to small numbers of mature males. No fully mature <u>Clione</u>, having the female accessory glands, were recorded in the Gulf. This pelphomenon, together with the distribution pattern, suggests that <u>C</u>. <u>limacina</u> could have been conveyed into the Gulf by the inflowing currents through the Strait of Belle Isle and Cabot Strait. It may also be concluded that no spawning takes place in the Gulf waters, unless at a different time of year.

#### Relation between Clione and Spiratella

The frequent cooccurrence of <u>Clione limacina</u> and <u>Spiratella</u> is related to the fact that <u>Spiratella</u> represents the exclusive prey of <u>Clione</u> (Ussing, 1938; Lalli, 1967 and 1970; Mileikovsky, 1970). Distribution patterns of <u>Clione</u> and <u>Spiratella</u> have been provided by the studies of Kerswill (1940), Dunbar (1942), Kielhorn (1952), Kramp (1961), Vane and Colebrook (1962), Chen and Bé (1964) and Glover and Robinson (1966). The latter gave special attention to the joint occurrence of <u>Clione</u> and <u>S. retroversa</u> in the North Sea, reporting similarities in the periods of maximum and minimum population size of the two species. They found that both species were rare in the period from 1953 through 1966, but that both species reappeared in relatively high numbers at the end of this period.

<u>Spiratella</u> often has been reported to be more abundant than <u>Clione</u>, a phenomenon which again may be explained by the fact that <u>Spiratella</u> is the prey of <u>Clione</u>. Williamson (1961) studied the populations of both <u>Spiratella</u> and <u>Clione</u> in the north-western North Sea between 1949 and 1959. The ratio between the population densities of the two species varied from 51.9 to 12,200 <u>Spiratella</u> to <u>Clione</u> with an average of 1,560. This ratio has been studied in the Gulf of St. Lawrence and was found to range between 14.7 to 316.0 with an average of 98.0.

#### Comparative Study of <u>Clione</u> Stages

<u>Clione</u> collected from the Gulf of St. Lawrence comprised larvae, juveniles, and mature males. No fully mature specimens were collected nor shelled veligars. <u>Clione</u> veligers, if present, were not collected because of the net mesh size.

<u>C. limacina</u> in the Gulf of St. Lawrence were classified into seven stages with regard to the chronological disappearance of the ciliary rings, the development of wings and the site occupied by the digestive gland. The following comparisons were made between the results obtained in this study and the findings of Lebour (1931), who studied the developmental stages of the southern variety of <u>C. limacina</u> at Plymouth(England).

1. In the Gulf of St. Lawrence, the early larvae (stage 1) had an average length of 0.58 mm., while the morphologically similar larvae of Plymouth waters had a 0.48 mm. average length.

2. In Plymouth, the <u>Clione</u> which were 0.9 mm. to 2.0 mm. in length, had wings still developing and the anterior ciliary ring had become gradually irregular. The wings projected well beyond the sides of the body at a total length of 2.0 mm., while the digestive gland lay at the level of the mid-ciliary ring. <u>C. limacina</u>, stage 2 and 3, from the Gulf of St. Lawrence showed a distinct resemblance to those from Plymouth, with the exception that the digestive gland occupied most of the body, and the length was between 1.06 and 2.21 mm.

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3. In the late stage 6, in which all the ciliary rings had disappeared, the wings were well developed and the penis was present, <u>Clione</u> in the Gulf had an average length of 2.84 mm. The corresponding stage at Plymouth attained a 2.8 mm. average length. <u>C. limacina</u> of the Gulf had the digestive gland only slightly retracted toward the anterior part of the body.

4. The largest specimen of <u>Clione</u> recorded in the Gulf was 28 mm. long and was not fully mature, while those at Plymouth had a length of 12 mm. and were fully mature. It is not known, however, if Lebour made her measurements on preserved or live specimens. More credence could be given to the above discussion had this information been available, since <u>Clione</u> is known to contract upon rapid fixation.

Two factors are known to influence the size of the digestive gland, namely the process of feeding and the growth rate of specimens. This fact may account for the differences in size of the digestive gland between the <u>Clione</u> of Plymouth and those of the Gulf.

The growth rate of <u>Clione</u>, as well as its level of sexual maturity, is affected by the temperature regime. This was made evident by Pelseneer (1887) who mentioned that the arctic form of <u>C</u>. <u>limacina</u> lost the anterior ciliary ring at a length of 2 - 3 mm., while the mid-ciliary ring disappeared at a size of 5.6 mm. Corresponding sizes of <u>Clione</u> in the Gulf of St. Lawrence were 2.25 and 3.12 mm., respectively. Arctic specimens of 15 mm. long, found by Pelseneer, retained their posterior ciliary ring, while the largest similar specimen recorded in the Gulf was 6.19 mm. long.

#### Suggestions for Future Work

Areas of study relating to the present work and requiring further investigation include:

1. Extensive plankton sampling in the Magdalen Shallows and the Central Gulf on a seasonal basis. These areas have not been regularly sampled in the present work.

2. The examination of plankton samples collected by means of horizontal tows, in an attempt to correlate the distribution of pteropod species in respect to depth and water masses.

3. The use of plankton nets with smaller mesh sizes to collect the egg masses and early larval stages of pteropods. This should yield more accurate information about breeding of the three pteropod species in the Gulf of St. Lawrence.

#### SUMMARY

- The distributions and relative abundances of three pteropod species, <u>Spiratella helicina</u>, <u>Spiratella</u> <u>retroversa</u> and <u>Clione limacina</u>, were studied in the Gulf of St. Lawrence.
- 2. Plankton samples were collected from 24 I.B.P. stations located throughout the Gulf. The area was divided into four geographical regions to generalize the conclusions of the study.
- 3. Because the quantity of data obtained in the course of this study was unusually large, an accurate statistical analysis was developed using the digital computer.
- 4. The areas within the Gulf where <u>S</u>. <u>retroversa</u> was particularly abundant were Cabot Strait, Kagdalen Shallows and the central Gulf. <u>S</u>. <u>retroversa</u> was relatively rare during May and June and more abundant in July and August. It acquired its maximum population density in September and November.
- 5. The Esquiman Channel and the area north of Anticosti Island were the regions of maximum concentration of <u>S. helicina</u>. The population of <u>S. helicina</u> was especially dense in June and May.
- <u>S. helicina</u>, less than 0.5 mm. shell diameter, were found in the Esquiman Channel and north of Anticosti Island during Kay and September.

- 7. Very high population densities of <u>S. retroversa</u> larvae, accompanied by adults, were recorded in the Magdalen Shallows and Cabot Strait waters from July to November with a peak of abundance in September and November.
- 8. Specimens of <u>C</u>. <u>limacina</u> were classified morphologically into seven developmental stages and the seasonal distribution of these stages was studied.
- 9. <u>C. limacina</u> was mainly recorded in waters of the Esquiman Channel and in Cabot Strait. The early stages were abundant in June and the last days of September, while the larger stages were found in June, late in September and in November.
- 10. The ranges of temperature and salinity, where <u>S</u>. <u>helicina</u> was abundant, were from -0.89 to 6.60° C and from 30.45 to 32.40%, respectively. Corresponding values for <u>S</u>. <u>retroversa</u> were 0.34 to 14.59° C and 28.16 to 32.78%. These figures were compared with those quoted in the literature.
- 11. There was no evidence that <u>S</u>. <u>helicina</u> and <u>S</u>. <u>retroversa</u> concurrently acquired large and comparatively equal abundances in this study. This phenomenon was compared with published reports.
- 12. Cooccurrence of <u>Clione</u> and <u>Spiratella</u> was investigated and compared with previous findings.
- Sizes and general morphology of the different developmental stages of <u>C</u>. <u>limacina</u> in the Gulf were compared with those collected from Plymouth waters.

14. Distribution patterns of the larvae of both <u>Clione</u> and <u>Spiratella</u>, together with the available water circulation data, were used to interpret seasonal breeding within the Gulf. It is suggested that <u>S. retroversa</u> spawns within the Gulf, but that <u>S. helicina</u> and <u>C. limacina</u> populations are maintained by recruitment from the inflow of Labrador coastal water.

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#### APPENDIX I

#### DETERMINATION OF STATISTICAL PARAMETERS

For a set of empirical data  $m_i$  (i=1,2,...k), the following parameters were established to attempt a more adequate description of the data.

#### Mean and Mode

The Mean "M" and Mode "MD" are among the most common measures of location of a set of observed data

$$M = \frac{1}{T} \sum_{i=1}^{k} f_{i} m_{i}$$
(1)

where  $m_i = mid$  value of the ith interval in mm.

$$f_{i} = \text{frequency of the ith interval}$$

$$T = \sum_{i=1}^{k} f_{i} = \text{total population}$$

$$MD = \max(f_{i}) \qquad (2)$$

#### Standard Deviation

The standard deviation is the most common measure of dispersion and is given by

$$S = \left( \sum_{i=1}^{k} f_{i} (m_{i} - M_{i})^{2} / \sum_{i=1}^{k} f_{i} \right)^{\frac{1}{2}}$$
(3)

The larger the value S, the more dispersed are the shell diameters.

### $G_1$ and $G_2$

The parameters  $G_1$  and  $G_2$  were recommended to measure the skewness and kurtosis of a distribution, respectively.

$$G_{1} = \left(\sum_{i=1}^{k} f_{i} (m_{i} - M)^{3} / \sum_{i=1}^{k} f_{i}\right) \div s^{3} \qquad (4)$$

and

$$G_{2} = \left[ \sum_{i=1}^{k} f_{i} (m_{i} - M)^{4} / \sum_{i=1}^{k} f_{i} \right] \div S^{4} - 3 \quad (5)$$

A positive value of  $G_1$  indicates a skewed distribution to the left, while a negative  $G_1$  indicates skewness to the right. A  $G_1$  value of zero denotes symmetry.

A positive  $G_2$  value indicates that the distribution is of the platykurtic type, while a negative  $G_2$  indicates that it is of the leptokuric type. A normal distribution would yield a zero value for  $G_2$ .

The above parameters were used to describe more precisely the variations of the <u>Spiratella</u> shell diameters for various localities and seasons.

### Cumulative Distributions

The probability that the variable  $m_i$  is less than or equal to a certain value m is referred to as the cumulative probability with a variate m. This means of representing a frequency distribution yields the normalization of the ordinates (frequencies) of the data. That is to say, frequencies are plotted as percentages of the total number (T). The cumulative distribution usually is plotted on a special graph paper (normal graph paper), as in Fig. 11. The plot will be linear if the distribution is exactly normal.

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### APPENDIX II

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### COMPUTER PROGRAMS

The three computer subroutines used for data analysis (CHAPTER III) are presented in this appendix. The programs are in FORTRAN IV language, G level, suitable for use on IBM 360 series computers.

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SUBROUTINE WEZZAH (F1,F2,Z1,Z2,F) С C THE SUBROUTINE FORMS ONE (NORMALIZED) DISTRIBUTION FROM THE Ç DISTRIBUTIONS OF TWO INDEPENDENT SAMPLES С С С THE FIRST TWO ENTERIES OF THE VECTORS F1, F2, AND F ARE THEIR LOWER AND UPPER BOUNDERIES RESPECTIVELY C NOTE: F1 AND F2 SHOULD HAVE ONE TO ONE CORRESPONDENCE С DIMENSION F1(1), F2(1), F(80) DIMENSION X1(80), X2(80) DD 2 I = 1,802 F(I) = 0.0CALCULATE THE NO OF INTERVALS С N=((F1(2)-F1(1))/0.05)+0.2С COMPUTE THE TOTALS T1 = 0.0T2=0.0 00 1 L=1,N I=L+2 T1 = T1 + F1(1)T2=T2+F2(I). 1 CONTINUE WRITE (6,20) T1,T2 FORMAT (' T',2F10.3) 20 DO 6 L=1,N I=L+2 X1(I) = F1(I) + Z1/T1X2(I) = F2(I) + Z2/T2IF (X1(I) .GE. X2(I)) F(I) = X1(I)IF (X1(I) .LE. X2(I)) F(I)=X2(I) 6 F(1) = F1(1)F(2) = F1(2)N=N+2WRITE (6,10) (F(I), I=1,N) 10 FORMAT (' F',6F9.3) CALL D(F) RETURN END

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SUBROUTINE SOHEIR (F1,F2,F)
      THE SURROUTINE SUMS UP TWO INDEPENDENT DISTRIBUTIONS F1 AND F2
С
      TO FORM A UNIQUE DISTRBUTION F
С
С
      THE FIRST TWO ENTERIES OF THE VECTORS F1,F2 OR F ARE THEIR LOWER
C
      AND UPPER BOUNDERIES RESPECTIVELY
С
С
      DIMENSION F1(1), F2(1), F(1), X(80), Y(80)
      DD 4 I=1,80
      F(I)=0.0
  4
      A1 = F1(1)
      Δ=Δ1
      \Delta 2 = F2(1)
      B1=F1(2)
      B=B1
      B2=F2(2)
      N1=((F1(2)-F1(1))/.05)+0.2
      N2=((F2(2)-F2(1))/.05)+0.2
      IF (A2 .LT. A1) A=A2
      IF (B2 .GT. B1) B=B2
      N = ((B - A) / .05) + .2
      KA=ABS(( A1-A2)/.05)+.2
      KB = \Delta BS((B1 - B2)/.05) + .2
      DD 1 J=1
      IF (A1 .LE. A2) GO TO 2
      IF (J .LE. KA) GD TO 5
      X(J) = F1(2+J-KA)
      Y(J) = F2(2+J)
      IF (J .GT. N2) Y(J)=0.0
      IF (J .GT. (N1+KA)) X(J)=0.0
      GO TO 3
      X(J)=0.
  5
      Y(J) = F_2(2+J)
      GO TO 3
      IF (J .LE. KA) GD TO 6
  2
      Y(J) = F2(2+J-KA)
      X(J) = F1(J+2)
      IF(J.GT. N1) X(J)=0.0
      IF (J .GT. (N2+KA)) Y(J)=0.0
      GO TO 3
      Y(J) = 0.0
  6
      X(J) = F1(2+J)
      F(2+J)=X(J)+Y(J)
  3
      CONTINUE
 1
      F(1) = \Delta
      F(2)=E
      N=N+2
      WRITE (6,10) (F(I), I=1,N)
   10 FORMAT (' F ',6F 9.3)
      RETURN
      END
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Fig. 16. Subroutine (SOHEIR)

SUBROUTINE ANIS(F) Ç C THIS SUBROUTINE COMPUTES , FOR A GIVEN DISTRIBUTION, THE FOLLOWING: Ċ T=TOTAL POPULATION > A=THE MEAN > S=THE STANDARD DEVIATION > C G1=MEASURE OF SKEWNESS , G2=MEASURE OF KURTOSIS , AMODE=MODE C CF=GENERATED CUMULATIVE DISTRIBUTION C C \*\*\*\*\*\* \* \* C \* ANALYSIS PREPARED BY \* C \* SOHEIR EL-NAHAS \* C \* Ċ \*\*\*\*\*\* C DIMENSION F(1), CF(80) C COMPUTE THE NUMBER OF INTERVALS N=((F(2)-F(1))/.05)+0.2C CALCULATE THE TOTAL T=0.0 00 7 I=1,N 7 T=T+F(I+2)С С FIRST MOMENT С M=N+2 A=0.0 00 2 I=1,N FI=IL=I+2 2 A=A+F(L)\*(F(1)+(FI-0.5)\*0.05)A = A / TC C C SECOND MOMENT V=0.0 DO 3 1=1,11 FI=IL = I + 23 V=V+F(L)\*((F(1)+(FI-0.5)\*0.05-A))\*\*2 S=SORT(V/T) С С G1 FROM THE THIRD MOMENT C AM3=0.0 DO 4 I = 1 > NFI = IL = I + 2AM3=AM3+F(L)\*(F(1)+(FI-0.5)\*0.05-A)\*\*3 4  $G1 = (\Delta M3 / T) / (S \neq \neq 3)$ С Ĉ G2 FROM THE FOURTH MOMENT С AM4=0.0 DO 5 I=1,N F1=1

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L=I+2
   5
       AM4=AM4+F(L)*(F(1)+(FI-0.5)*0.05-A)**4
       G2 = ((\Delta M4/T)/(S**4)) - 3.0
C
С
       GENERATE THE CUMULATIVE DISTRIBUTION
       Y=0.0
       DO 8 I=1,N
       Y = Y + F(I + 2)
  8
       CF(I) = (Y/T) * 100.
C
Ċ
       DETERMINE THE MODE
       BIG =0.0
       DO 9 I=1,N
       L=I+2
       IF (F(L) .GE. BIG) GD TD 11
       GO TO 9
  11
       BIG = F(I)
       I I = I
  9
       CONTINUE
       L=II-2
       FF=L
       AMODE = F(1) + (FF - 0.5) * 0.05
       NT=T
С
Ċ
      PRINT RESULTS
      WRITE (6,10) NT, A, S, G1, G2, AMODE
     FORMAT (' ') TOTAL=') I6, ' ) MEAN=')F7.3, ' ) STANDARD DEVIATION=')
  10
     (/F7.3/ G1=+>F8.4 ارا G2=+>F8.4 ارا MDDE=+>F7.3/
C
С
      WRITE (6,20) (CF(I), I=1,N)
  20
      FORMAT (' CUMULATIVE FREQUENCY ',6F8.3)
      SS = F(1) + 0.025
C
      WRITE (6,30) SS
      FORMAT (' START AT THE VALUE ', F7.3)
  30
      RETURN
      END
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### EXCERPTS OF COMPUTER RESULTS

In the following pages, selected results, printed by digital computer, are shown. The results comprise the cumulative frequency distributions of <u>S</u>. <u>helicina</u> and <u>S</u>. <u>retroversa</u> within various regions and during different cruises. All class intervals are 0.05 mm. with the first frequency value corresponding to a shell diameter indicated by the signal "START AT THE VALUE" in mm.

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# ECXERPTS OF COMPUTER RESULTS

# <u>Spiratella</u> <u>helicina</u>

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# Region A

# cruise |

CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY START AT THE VALUE	6,436 43,974 84,566	12.209 49.746 84.566	14.153 49.746 90.338	14,153 61,353 92,283	25.174 71.046 100.000	35,531 74,935
	01420					

# cruise II

CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY	0,135 8,459 .44.082 50,362 94,625 96,952 98,615 99,470 99,865 99,865	0.673 12.814 45.626 50.362 94.824 97.627 98.615 99.605 99.865 100.000	1 • 481 15 • 436 45 • 626 67 • 842 95 • 809 97 • 988 98 • 835 99 • 605 99 • 865	3.743 15.436 46.501 69.097 96.111 98.263 98.835 99.605 99.865	3.743 17.035 46.715 77.918 96.557 98.263 99.153 99.605 99.865	6.151 26.747 49.242 94.625 96.557 98.355 99.336 99.605 99.865
START AT THE VALUE	99,865 0,400	100.000				

#### cruise III

CUMULATIVE FREQUENCY	4.283	36.779	45.346	66.762	74.529	74.529	
CUMULATIVE FREQUENCY	79.383	79.383	79.383	79.383	79.383	79.383	
CUMULATIVE FREQUENCY	79.383	79.383	79.383	83.667	87.950	87.950	
CUMULATIVE FREQUENCY	87.950	87.950	87.950	92.233	97.087	97.087	
CUMULATIVE FREQUENCY	97.087	97.087	97.087	97.087	97.087	97.087	
CHINE AT IVE FREELIENCY-		-97-087		-97-087-	-97-087-	-97-087-	
			,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,				
CWELLATIVE FREQUENCY	97.087	97.087	97.087	97.087	97.087	97.087	
CUMULATIVE FREQUENCY	97.087	97.087	104.854				
START AT THE VALUE							

### cruise IV

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START AT THE VALUE	0.250					
CUMULATIVE FREQUENCY	101.371	101.371	101.371	101.991		
CUMULATIVE FREQUENCY	101.371	101.371	101.371	101.371	101.371	101.371
CUMULATIVE FREQUENCY	99.510	100.130	100.130	100.130	100.130	101.371
CUMULATIVE FREQUENCY	77.544	78.784	78.784	98.890	98.890.	98.890
CUMULATIVE FREQUENCY	76.923	76.923	76.923	77.544	77.544	77.544
CUMULATIVE FREQUENCY	76.303	76.923	76.923	76.923	76.923	76.923
CUMULATIVE FREQUENCY	75.063	75.683	75.683	76.303	76.303	76.303
CUMULATIVE FREQUENCY	51.684	66.315	66.315	67.390	70.916	72.157
CUMULATIVE FREQUENCY	11.559	12.800	43.390	44.630	45.251	51.063
CUMULATIVE FREQUENCY	10.484	10.484	10.484	10.484	10.484	10.484

### cruise V

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CUMULATIVE	FREQUENCY	7.701	34.654	46.205	46.205	50.055	50.055
CUMULATIVE	FREQUENCY	54.511	54.511	58.361	65.058	78.452	82.302
CUMULATIVE	FREQUENCY	. 82.302	82.302	85.520	85.520	85.520	85.520
CUMULATIVE	FREQUENCY	88.366	88.366	88.366	88.366	88.366	88.366
CUMULATIVE	FREQUENCY	92.822	96.040	96.040	96.040	96.040	104.950
START AT TH	E VALUE	0.250					

# cruise VI

CUMULATIVE FREQUENCY	23.485	23.485	35.227	46.970	46.970	62.121
CUMULATIVE FREQJENCY	62.121	73.864	73.864	89.015	95.833	95.833
CUMULATIVE FREQUENCY	107.576					•
START AT THE VALUE	0.300					

# cruise VII

CUMULATIVE	FREQUENCY	25.000	25.000	25.000	25.000	25.000	25.000
CUMULATIVE	FREGUENCY	75.000	75.000	75.000	75.000	.100.000	100.000
CUMULATIVE	FRECUENCY	100.000	100.000	100.000	100.000	100.000	100.000
CUMULATIVE	FREQUENCY	100.000	100.000	100.000	100.000	100.000	100.000
CUMULATIVE	FRECUENCY	100.000	100.000	150.000			
START AT TH	IE VALUE	0.500					

# Region B

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### cruise 1

		•	01001				
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	CUMULATIVE FREQUENCY	57,647	61.961	77.647	77.647	84,706	89.020
	CUMULATIVE FREQUENCY	91.373	94,902	94,902	95.687	97,255	97.647
	CUMULATIVE FREQUENCY	98,432	.98,432	99.216	99.216	99.216	99.608
	CUMULATIVE FREQUENCY	99,608	99,608	100,000			•
	START AT THE VALUE	0:450					

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### cruise ||

CUMULATIVE EREQUENCY	0.0	0.0	0.0	0.252	1.492	10.507
CUMULATIVE FREQUENCY	10.507	24.640	41.653	57.880	67.460	67.460
CUMULATIVE FREQUENCY	75.511	81.184	84 898	88.610	90.068	92.564
CUMULATIVE FREQUENCY	94,906	95 696	97.032	97.032	97.666	97,994
CUMULATIVE FREQUENCY	98.208	98,272	98.272	98,747	99.016	99.048
CUMULATIVE FREQUENCY	99,499	99.499	99.599	99,686	99.718	99.718
CUMULATIVE FREQUENCY	99,718	99.718	99,718	99.718	99,786	99.786
FUMPLATIVE FREQUENCY	99,786	99,786	99,786	99.786	99.786	99,785
<b>华</b> 创得LATIVE FREQUENCY	99,786	99,818	99.818	99,818	99,813	99,818
CUMULATIVE FREQUENCY	99,818	99.818	100.000	· · · ·		
START AT THE VALUE	0.300					

# cruise III

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CUMULATIVE FREQUENCY	0.319	0.319	1.011	2.713	4.521	11.257
CUMULATIVE FREDJENCY	18.769	27.735	38.740	47.517	57.776	63.629
CUMULATIVE FREQUENCY	70.093	7 <b>5.</b> 097	78.536	80.823	83.674	85.192
CUMULATIVE FREQUENCY	87.593	88.410	89.815	91.253	92.410	92.918
CUMULATIVE FREQUENCY	94.662	94.941	95.592	96•545	97.144	97.430
CUMULATIVE FREQUENCY	97.430	97.743	97.923	98.070	98.383	98.530
CUMULATIVE FREQUENCY	98.859	99.032	99.364	99.697	99.697	99.697
CUMULATIVE FREQUENCY	99.697	99.697	99.844	99.844	99.844	99.844
CUMULATIVE FREQUENCY	100.176					
START AT THE VALUE	0.200					

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### cruise IV

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CUMULATIVE FREQUENCY	2.744	2.744	2.744	6.110	9.518	16.485
CUMULATIVE FREQUENCY	25.135	25.135	36.533	55.884	67.647	78.411
CUMULATIVE FREQUENCY	78.411	83.496	92.031	93.121	95.039	95.039
CUMULATIVE FREQUENCY	95.584	95.584	95.584	96.129	96.129	96.129
CUMULATIVE FREQUENCY	96.129	96.129	97.854	97.854	97.854	97.854
CUMULATIVE FREQUENCY	97.854	97.854	97.854	97.854	97.854	97.854
CUMULATIVE FREQUENCY	97.854	97.854	97.854	97.854	97.854	97.854
CUMULATIVE FREQUENCY	97.854	97.854	97.854	97.854	97.854	97.854
CUMULATIVE FREQUENCY	97.854	97.854	97.854	97.854	97.854	97.854
CUMULATIVE FREQUENCY	98.524	98.524	99.195	99.195	99.195	99.195
CUMULATIVE FREQUENCY	99.195	99.195	99.195	99.195	100.878	
START AT THE VALUE	0.250					

### cruise V

CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY START AT THE VALUE	4.701 14.103 95.726	4.701 25.214 100.000	4.701 39.744 104.273	4.701 52.564	4.701 78.632	14.103 78.632
START AT THE VALUE	0.300					

### cruise VII

CUMULATIVE FREQUENCY	8.889	8.889	77.778	88.889	95.556	98.889
CUMULATIVE FREQUENCY	98.889	98.889	98.889	98.889	98.889	98.889
CUMULATIVE FREQUENCY	100.000					
START AT THE VALUE	0.300					

### cruise J

 CUMULATIVE FREQUENCY
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Region A

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# cruise l

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CUMULATIVE FREQUENCY	3.409	3.409	5.806	17.555	21.656	27.182
CUMULATIVE FREQUENCY	27.182	32.709	32.709	34.413	36.118	36.118
CUMULATIVE FREQUENCY	42.198	42.198	45.883	49.567	49.567	55.093
CUMULATIVE FREQUENCY	57.490	66.700	74.623	74.623	83.834	91.202
CUMULATIVE FREQUENCY	92.907	94.749	94.749	96.453	98.295	98.295
CUMULATIVE FREQUENCY	98.295	98.295	100.000			
START AT THE VALUE	0.300					

# cruise IV

CUMULATIVE FREQUENCY	1.066	16.688	48.801	50.933	74.357	87.171
CUMULATIVE FREQUENCY	92.701	93.984	94.018	95.501	95.936	97.198
CUMULATIVE FREQUENCY	98.371	98.405	98.458	98.686	98.719	98.719
CUMULATIVE FREQUENCY	98.75 <b>3</b>	98.860	98.860	98.934	98.934	98.934
CUMULATIVE FREQUENCY	98.934	98.934	98.934	98.934	98.934	98.934
CUMULATIVE FREQUENCY	98.934	98.934	98.934	98.934	98.934	98.934
CUMULATIVE FREQUENCY	98.934	98.934	98.934	98.934	98.934	98.934
CUMULATIVE FREQUENCY	98.934	98.934	98.934	98.934	98.934	98.934
CUMULATIVE FREQUENCY	98.934	98.934	98.934	98.934	98.934	98.934
CUMULATIVE FREQUENCY	98.934	98.934	100.000			
START AT THE VALUE	0.200					

# cruise V

CUMULATIVE FREQUENCY	0.679	11.356	11.356	32.622	47.019	54.288
CUMULATIVE FREQUENCY	63.470	63.470	69.827	76396	83.659	89.758
CUMULATIVE FREQUENCY	89.768	91.384	94.778	97.285	99.321	99.321
CUMULATIVE FREQUENCY	99.321	99.321	100.000			
START AT THE VALUE	0.250					

# cruise VI

CUMULATIVE FREQUENC CUMULATIVE FREQUENC CUMULATIVE FREQUENC	Y 1.732 Y 59.133 Y 86.433	22.621 59.133 92.901	29.551 65.092 95.661	39.546 71.022 96.605	46.478 77.555 98.174	51.854 86.433 98.174
CUMULATIVE FREQUENC	Y 99.307	100.000				
START AT THE VALUE	0.250					

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# cruise VII

CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY CUMULATIVE FREQUENCY	1.191 78.813 91.005	3.574 84.908 94.691	28.653 86.170 94.691	29.617 86.953 95.973 99.980	29.617 88.350 96.070 99.994	60.801 89.701 97.320 99.996
CUMULATIVE FREQUENCY START AT THE VALUE	99.750 99.996 0.150	100.000		///////////////////////////////////////	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	

# cruise J

CUMULATIVE FREQUENCY	0.952	6.667	20.952	20.952	31.429	41.90
CUMULATIVE FREQUENCY	48.572	58.095	58.095	63.810	67.619	76.19
CUMULATIVE FREQUENCY	88.571	88.571	92.381	95.238	96.190	99.04
CUMULATIVE FREQUENCY	99.048	100.000				
START AT THE VALUE	0.200					

# Region B

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### cruise 1

CUMULATIVE FREQUENCY	34.286	51.429	71.429	81.429	81.429	85.714
CUMULATIVE FREQUENCY	90.000	91.429	91.429	91.429	94.286	95.714
CUMULATIVE FREQUENCY	95.714	97.143	97.143	97.143	97.143	98.571
CUMULATIVE FREQUENCY	98.571	98.571	98.571	98.571	98.571	98.571
CUMULATIVE FREQUENCY	98.571	98.571	98.571	98.571	98.571	98.571
CUMULATIVE FREQUENCY	98.571	98.571	100.000			
START AT THE VALUE	0•400					
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# cruise ||

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CUMULATIVE F	KEQUENCY	5.223	5.223	9.402	19.848	35.134	41.340
¢ψi444ATIVE F	REQUENCY	52.831	63.668	69.511	77.868	80.799	80.799
CUMULATIVE F	REQUENCY	86.145	89.699	89.699	89.699	89.699	90.581
CUMULATIVE F	REQUENCY	90.581	91.059	91.535	91.535	93.537	93.537
CUMULATIVE F	REQUENCY	93.537	94.015	94.015	94.419	97.858	98.336
CUMULATIVE F	REQUENCY	98.336	98.336	98.740	100.000		
START AT THE	VALUE	0.300					

# cruise III

CUMULATIVE FREQUENCY 100.000 START AT THE VALUE 0.550

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# cruise IV

CUMULATIVE FREQUENCY	61.538	61.538	61.538	61.538	61.538	61.538
CUMULATIVE FREQUENCY	61.538	61.538	61.538	61.538	61.538	61.538
CUMULATIVE FREQUENCY	61.538	61.538	61.538	61.538	61.538	61.538
CUMULATIVE FREQUENCY	61.538	100.000				
START AT THE VALUE	0.250					

### cruise VI

CUMULATIVE FREQUENCY	3.934	25.527	25.527	43.173	66.527	74.396
CUMULATIVE FREQUENCY	90.132	90.132	91.643	91.643	91.643	91.643
CUMULATIVE FREQUENCY	91.643	91.643	91.643	94.600	97.300	97.300
CUMULATIVE FREQUENCY	100.000		-			
START AT THE VALUE	0.250					

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### cruise VII

CUMULATIVE FREQUENCY 42.228 42.228 73.899 73.899 73.899 78.692 CUMULATIVE FREQUENCY 78.692 78.692 84.650 95.207 100.000 START AT THE VALUE 0.300

# cruise J

CUMULATIVE	FREQUENCY	1.099	5.495	5.495	10.989	15.385	20.879
CUMULATIVE	FREQUENCY	26.374	26.374	31.868	38.462	40.659	45.055
CUMULATIVE	FREQUENCY	45.055	45.055	52.747	56.044	61.538	61.538
CUMULATIVE	FREQUENCY	69.231	78.022	89.011	90.110	90.110	96.703
CUMULATIVE	FREQUENCY	97.802	97.802	98.901	98.901	98.901	98.901
CUMULATIVE	FREQUENCY	98.901	98.901	100.000			
START AT TH	IE VALUE	0.250				·	

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# Region C

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### cruise |

CUMULATIVE FREQUENCY 27.404 50.437 88.483 100.000 START AT THE VALUE 0.450

# cruise IV

CUMULATIVE	FREQUENCY	0.693	1.505	1.985	1.985	3.407	4.927
CUMULATIVE	FREQUENCY	20.727	27.095	27.296	34.863	45.203	60.149
CUMULATIVE	FREQUENCY	74.215	74.215	78.345	84.712	90.542	93.657
CUMULATIVE	FREQUENCY	95.336	96.139	97.684	99.242	99.735	99.735
CUMULATIVE	FREQUENCY	99.735	100.000			• .	
START AT TH	HE VALUE	0.200					

### cruise VII

CUMULATIVE FREQUENCY	4.844	66.813	66.813	86.317	89.992	93.230
CUMULATIVE FREQUENCY	93.558 98.010	99.276	94•110 99•609	99.798	99.909	99.909
CUMULATIVE FREQUENCY	100.000	100.000	100.000			
START AT THE VALUE	0.250			•		

### cruise J

CUMULATIVE I	REQUENCY	2.307	7.151	7.151	14.186	18.799	21.292
CUMULATIVE N	REQUENCY	21.870	21.870	23.987	31.862	37.394	45.281
CUMULATIVE N	REQUENCY	45.281	54.906	63.179	72.413	80.552	80.552
CUMULATIVE N	REQUENCY	86.287	89.644	94.310	98.692	98.692	98.763
CUMULATIVE P	REQUENCY	98.834	98.904	98.904	98.904	100.000	•
START AT THE	E VALUE	0.250					
# Region D

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### cruise II

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CUMULATIVE	FREQUENCY	7.127	14.254	14.254	46.437	60.690	67.817
CUMULATIVE	FREQUENCY	67.817	67.817	67.817	85.746	85.746	85.746
CUMULATIVE	FREQUENCY	85.746	85.746	92.873	92.873	92.873	92.873
CUMULATIVE	FREQUENCY	92.873	92.873	92.873	92.873	92.873	92.873
CUMULATIVE	FREQUENCY	92.873	92.873	92.873	92.873	92.873	92.873
CUMULATIVE	FREQUENCY	92.873	92.873	92.873	92.873	92.873	92.873
CUMULATIVE	FREQUENCY	92.873	92.873	100.000			
START AT TH	IF VALUE	0.250	_				•

### cruise III

CUMULATIVE	FREQUENCY	66.667	66.667	66.667	66.667	66.667	66.667
CUMULATIVE	FREQUENCY	66.667	66.667	66.667	66.667	66.667	66.667
CUMULATIVE	FREQUENCY	66.667	66.667	66.667	66.667	66.667	66.667
CUMULATIVE	FREQUENCY	66.667	66.667	66.667	66.667	66.667	66.667
CUMULATIVE	FREQUENCY	66.667	66.667	66.667	66.667	66.667	66.667
CUMULATIVE	FREQUENCY	66.667	66.667	66.667	66.667	100.000	
START AT TH	IE VALUE	0.300					

## cruise V.

CUMULATIVE FREQUENCY	3.537	3.537	11.142	14.889 43.058	18.209	21.643
CUMULATIVE FREQUENCY	52.003	55.627	61.874	71.010	71.010	77.585
START AT THE VALUE	0.300	72.070	73•134	73.134	90.00/	100.000

### cruise VII

CUMULATIVE FREQUENCY	21.094	21.094	42.188	63.281	63.281	84.375
CUMULATIVE FREQUENCY	100.000					
START AT THE VALUE	0.650	•				

#### cruise J

CUMULATIVE FREQUENCY	0.572	3.816	3.816	3.816	7.646	14.329
CUMULATIVE FREQUENCY	25.422	25.422	35.669	47.067	56.613	65.499
CUMULATIVE FREQUENCY	65.499	67.582	73.428	77.190	85.579	85.579
CUMULATIVE FREQUENCY	91.394	94.031	97.563	98.688	98.688	99.260
CUMULATIVE FREQUENCY	100.000				•	
START AT THE VALUE	0.250					