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*The Life Cycle of Sagitta elegans
in Arctic and Subarctic Seas, and
the Modifying Effects of Hydrographic
Differences in the Environment*¹

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ABSTRACT

Sagitta elegans arctica of the Canadian eastern Arctic waters has a life span of two years. Its breeding cycle is two-phase, or alternating, and the population consists of two distinct groups breeding in different years. The spawning period is long, extending from July into the winter, probably up to February. Winter spawning is taken to imply that the breeding behaviour is not timed to coincide with the maximum abundance of food, but that the cycle is determined by the growth limitations imposed by the low temperature.

Hydrographic differences between Hudson Bay, Foxe Channel, Ungava Bay and Frobisher Bay, though not great, are reflected in the biology of *Sagitta*. Strong tidal turbulence in Ungava Bay and Frobisher Bay appears to remove the young-of-the-year from these two areas quickly, or to cause such vertical mixing that they are not properly sampled. The very special conditions in Lake Ogac produce rapid growth, small size and a single-phase or nonalternating breeding cycle.

Introduction. Much effort is currently going into the study of primary production in the sea, the rate at which living stuff is produced by plant plankton, as a measure of the relative productivity of different marine regions. This primary production, however, gives a real measure of usable resources only so far as the phytoplankton is used by the zooplankton, which in turn has to be converted to fish and mammal before the seas can be harvested, at least until the direct use of plankton becomes economically feasible on a large scale. The rate at which the zooplankton populations grow, and their abundance, depend on many factors besides the phytoplankton production, and hence a complete understanding of marine productivity demands the study of the zooplankton populations themselves: their growth, metabolism, reproduction, distribution.

¹ *Calanus* Series No. 24.

The chaetognaths of subarctic and arctic waters are represented almost exclusively by one form, the highly successful and abundant *Sagitta elegans arctica* Aurivillius, a cold-water variant of *Sagitta elegans* Verrill. In an earlier publication (Dunbar, 1941), *Sagitta* material from the eastern and southern coasts of Baffin Island, and from Hebron in northern Labrador, was analyzed in terms of size-frequency and breeding cycles, with the conclusion that there was a spawning period in spring and summer, probably extending from June to October, and that the individual *Sagitta* took two years to reach maturity. Populations from the Disko Bay area in western Greenland have been treated in the same way (Dunbar, 1940). The present account is much more extensive, covering material collected in 1947 at Ungava Bay, in 1951 at Ungava Bay and Frobisher Bay, in 1953 at Hudson Bay, and in 1955-56 during an overwintering expedition in Foxe Basin. Certain material from 1948, 1949, 1950 and 1951, from Ungava Bay, has also been used to corroborate the 1947 results, as mentioned in the text. Only those plankton hauls in which *Sagitta* was found appear in the tables; the full field data may be obtained in manuscript from the Arctic Unit, Fisheries Research Board of Canada. All of the collection comes from CALANUS Expeditions. The Frobisher Bay collection includes samples from Lake Ogac, a meromictic lake on the southwestern shore of the Bay, which offers special environmental conditions and specialized planktonic cycles. For the winter specimens from Foxe Basin the author is indebted to Dr. E. H. Grainger, Arctic Unit, Fisheries Research Board of Canada.

Methods. The chaetognath populations were sampled with open stramin nets and open silk and nylon nets which were hauled horizontally and vertically; during the 1955-56 winter the sampling was done twice or three times per month by hauling half-metre nets vertically through the ice. Collection data are given in Table I; the station lists have already been published (Dunbar and Grainger, 1952; Grainger, 1954; Grainger and Dunbar, 1956). The Foxe Basin collections were made near Igloolik (Grainger, 1959) in water of 50 m depth. The map (Fig. 1) shows the areas covered.

The specimens, preserved in 5% formalin in sea water, were measured in the laboratory under a low power microscope and analyzed for maturity stages. Subsamples were randomly taken from the larger catches; the smaller catches were examined completely. Measurements were made to the nearest quarter-millimetre and referred to integer millimetre pivotal lengths for presentation in the size-distribution histograms.

The Environment. The physical oceanographic results of the CALANUS Expeditions of 1949-55 have been published (Dunbar, 1958), as have those of the 1947 season in Ungava Bay (Dunbar, 1951) and the Foxe Basin wintering expedition (Grainger, 1959). The whole region is dominated by arctic

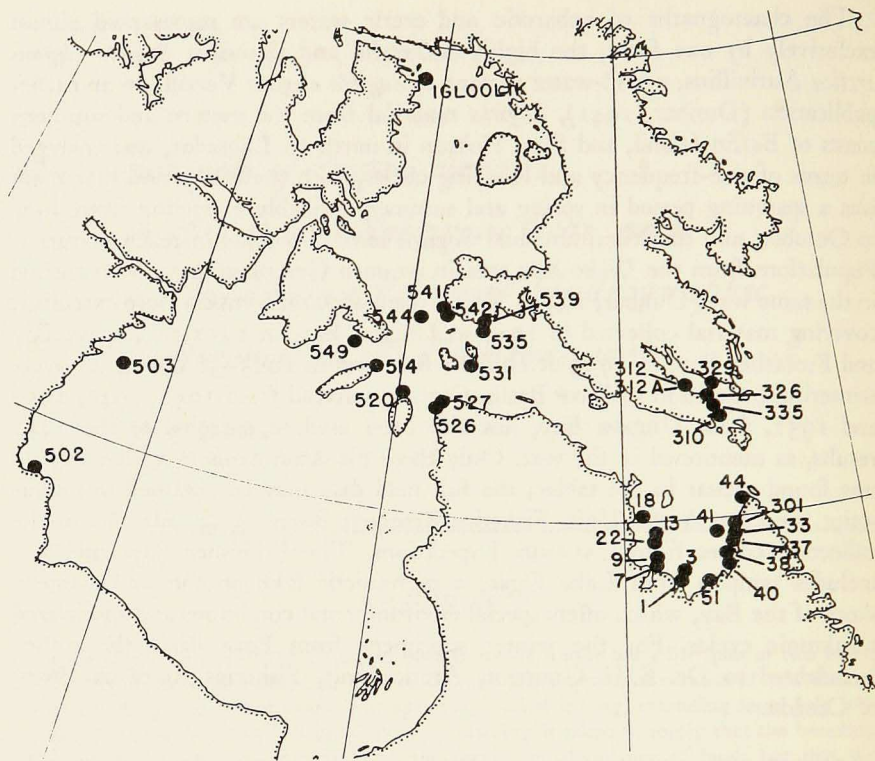


Figure 1. Stations at which *Sagitta* material was taken. For station lists, see Grainger (1952, 1954), Grainger and Dunbar (1956).

water, originating in the Arctic Sea, modified by coastal and other influences. The extent of intrusion of Atlantic water appears to be significant in the biology of *Sagitta*, as will appear below. There is evidence of intrusion of Atlantic water, usually below 100 m, in Frobisher Bay and Ungava Bay, and recent biological evidence, from the distribution of *Calanus finmarchicus* and *C. glacialis* in the eastern Arctic, suggests that Atlantic water also penetrates into Foxe Basin to some extent (Grainger, in press), which may also be reflected in the *Sagitta* behaviour. Evidence of penetration into Hudson Bay is not convincing.

In some parts of the area the tidal ranges are extremely high, resulting in strong currents and turbulence which are clearly very important environmental factors. The maximum ranges involved (at springs) are as follows: head of Frobisher Bay (Frobisher's Farthest), 38 feet; Port Burwell, at the northern tip of the Labrador, 22.5 feet; Koksoak River entrance at the head of Ungava Bay, 45 feet; Leaf Basin (Ungava Bay), 54.5 feet; Lake Harbour (southern Baffin Island), 35 feet; Wakeham Bay, 30 feet; Nottingham Island, 15.75 feet. Tides in Hudson Bay and Foxe Basin are less.

TABLE 1. COLLECTION DATA FOR THE *Sagitta elegans* MATERIAL. ALL HAULS ARE HORIZONTAL UNLESS OTHERWISE STATED. DEPTHS OF HAULING ACCURATE TO CA. $\pm 10\%$.

| Date | Haul No. | St. No. | Depth (m) | | | Time EST | Duration (min.) |
|------|----------|---------|-----------|-------|-------|----------|-----------------|
| | | | St. | Haul | Net* | | |
| 1947 | | | | | | | |
| June | 29..... | P-6 | 3 | 28 | 1.5 | Str. 1 | 1200 30 |
| | 29..... | P-8 | 3 | 28 | 6 | 0 | 1204 25 |
| July | 3..... | P-11 | 7 | 10 | 5 | 0 | 1000 30 |
| | 3..... | P-12 | 7 | 10 | 9 | Str. 1 | 1000 30 |
| | 3..... | P-13 | 7 | 10 | 6 | 6 | 1004 25 |
| | 11..... | P-14 | 9 | 24 | 15-17 | 0 | 1320 30 |
| | 11..... | P-15 | 9 | 24 | 13 | Str. 1 | 1320 30 |
| | 11..... | P-17 | 9 | 24 | 7.5 | 6 | 1323 25 |
| | 13..... | P-18 | 13 | 46-55 | 31-50 | 0 | 0936 30 |
| | 13..... | P-19 | 13 | 46-55 | 39 | Str. 1 | 0936 30 |
| | 13..... | P-21 | 13 | 46-55 | 17 | 6 | 0938 25 |
| | 13..... | P-22 | 13 | 46-55 | 6 | 0 | 1100 30 |
| | 13..... | P-23 | 13 | 46-55 | 4-5 | Str. 1 | 1100 30 |
| | 17..... | P-24 | 18 | 84 | 21-16 | 0 | 1340 30 |
| | 17..... | P-26 | 18 | 84 | 50 | Str. 1 | 1340 30 |
| | 18..... | P-28 | 22 | 11 | 10-0§ | 6 | 2100 - |
| | 18..... | P-30 | 22 | 11 | 3-0 | Str. 1 | 2125 30 |
| | 20..... | P-31 | 1 | 31 | 6 | Str. 1 | 1220 30 |
| | 20..... | P-32 | 1 | 31 | 12 | 0 | 1220 30 |
| | 20..... | P-33 | 1 | 31 | 10 | 6 | 1220 30 |
| | 20..... | P-34 | 1 | 31 | 14 | Str. 1 | 1317 30 |
| | 20..... | P-36 | 1 | 31 | 20 | 0 | 1317 30 |
| Aug. | 10..... | P-41 | 33 | 15 | 10 | 0 | 0910 30 |
| | 11..... | P-42 | 37 | 4 | 1-0 | 6 | 1140 30 |
| | 11..... | P-43 | 37 | 4 | 1-0 | Str. 1 | 1148 30 |
| | 11..... | P-44 | 38 | 2 | 2 | 6 | 1635 20 |
| | 16..... | P-45 | 40 | - | 2-3 | 0 | 1727 30 |
| | 17..... | P-47 | 41 | 240 | 25 | 6 | 1400 60 |
| | 17..... | P-48 | 41 | 240 | 220 | 0 | 1400 60 |
| | 17..... | P-49 | 41 | 240 | 50 | Str. 1 | 1400 60 |
| | 19..... | P-52 | 44 | 80 | 75 | 0 | 1430 40 |
| | 19..... | P-53 | 44 | 80 | 70 | Str. 1 | 1434 36 |
| | 29..... | P-61 | 51 | 45-65 | 3 | Str. 1 | 2100 30 |
| | 29..... | P-62 | 51 | 45-65 | 0 | 0 | 2103 30 |
| 1951 | | | | | | | |
| July | 3..... | P-1 | 301 | 110 | 25 | Str. 1 | 1645 30 |
| | 3..... | P-2 | 301 | 110 | 0 | 18 | 1430 30 |
| | 3..... | P-3 | 301 | 110 | 10 | 6 | 1430 30 |
| Aug. | 4..... | P-16 | 312 | 62 | 17 | 6 | 1000 15 |
| | 4..... | P-17 | 312A | 20 | 13 | 6 | 1209 15 |
| | 7..... | P-19 | 310 | 27 | 15 | Str. 1 | 1130 15 |
| | 14..... | P-21 | 326 | 600 | > 225 | Str. 1 | 1015 60 |
| | 21..... | P-23 | 329 | 180 | 20 | 7 | 1223 20 |
| | 21..... | P-24 | 329 | 180 | 150 | Str. 1 | 1153 50 |

(Cont.)

TABLE 1 (Continued)

| Date | Haul No. | St. No. | Depth (m) | | Net* | Time EST | Duration (min.) |
|--------------|----------|---------|-----------|---------|--------|----------|-----------------|
| | | | St. | Haul | | | |
| 1951 | | | | | | | |
| Aug. 26..... | P-29 | 335 | 320 | 150-220 | Str. 1 | 1855 | 30 |
| 26..... | P-32 | 335 | 320 | 90 | Str. 1 | 2016 | 15 |
| 26..... | P-34 | 335 | 320 | 50 | Str. 1 | 2312 | 15 |
| 26..... | P-35 | 335 | 320 | 90 | Str. 1 | 2312 | 15 |
| 26..... | P-36 | 335 | 320 | 150 | Str. 1 | 2352 | 30 |
| 27..... | P-38 | 335 | 320 | 50 | Str. 1 | 0209 | 15 |
| 27..... | P-41 | 335 | 320 | 250 | Str. 1 | 0407 | 15 |
| 1953 | | | | | | | |
| July 13..... | P-1 | 502 | 22-27 | 20 | 0 | 1515 | 10 |
| 21..... | P-6 | 503 | 65-90 | 33 | 0 | 1420 | 25 |
| 21..... | P-9 | 503 | 65-90 | 16 | Str. 2 | 1600 | 15 |
| 31..... | P-10 | 514 | 20 | 6 | 0 | 1603 | 30 |
| Aug. 4..... | P-12 | 520 | 137 | 85 | 0 | 1150 | 30 |
| 4..... | P-14 | 520 | 137 | 8.5 | 6 | 1250 | 20 |
| 4..... | P-15 | 520 | 137 | 50-25 | Str. 2 | 1515 | 15 |
| 8..... | P-16 | 526 | 53 | 50-0§§ | 6 | 1800 | - |
| 8..... | P-17 | 526 | 53 | 25-0§§ | 6 | 1810 | - |
| 9..... | P-18 | 526 | 53 | 25 | 0 | 0748 | 12 |
| 9..... | P-19 | 527 | 350-415 | 50 | 0 | 1010 | 20 |
| 11..... | P-24 | 531 | 183 | 150-0§§ | 6 | 1530 | - |
| 11..... | P-25 | 531 | 183 | 50-0§§ | 6 | 1545 | - |
| 11..... | P-26 | 531 | 183 | 50 | 0 | 1610 | 25 |
| 17..... | P-30 | 535 | 140-155 | 100-0§§ | 6 | 1200 | - |
| 17..... | P-31 | 535 | 140-155 | 50-0§§ | 6 | 1210 | - |
| 26..... | P-34 | 539 | 65-110 | 50 | 0 | 1050 | 15 |
| 27..... | P-37 | 541 | 65-75 | 38 | 0 | 1115 | 12 |
| 28..... | P-39 | 542 | 13 | 8-10 | Str. 1 | 1740 | 60 |
| Sept. 2..... | P-40 | 544 | 256 | 200-0§§ | 6 | 1230 | - |
| 2..... | P-41 | 544 | 256 | 100-0§§ | 6 | 1245 | - |
| 4..... | P-44 | 549 | 75 | 45-60 | 0 | 1105 | 30 |
| 4..... | P-47 | 549 | 75 | 38 | Str. 2 | 1245 | 15 |

* Numbers refer to bolting silk or nylon grade; "Str. 1" and "Str. 2" mean 1-metre and 2-metre stramin nets respectively.

§ oblique; §§ vertical.

Salinities are typically arctic and coastal, exceeding 33‰ only below 100 m and never reaching 34‰ (the only higher salinities in the whole expedition area were in Cumberland Sound, not included in this paper). July temperatures below 25 m are low, usually below -1°C in Hudson Bay and Foxe Basin, and up to 1.5° in Ungava Bay. In August at 50 m, water may be up to 2° warmer in Ungava Bay than in the rest of the region. The Ungava Bay water at 100 m and below in August is similar in temperature to the water at the same depths in Frobisher Bay, between 0° and -1°C, and about 0.5° warmer than in Hudson Bay, where the deep water is below -1°. The winter

temperature at all depths is close to -1.7° in Hudson Bay and Foxe Basin; the winter temperatures in Ungava and Frobisher bays have not yet been measured, but it is very probable that they are similarly close to the freezing point.

The physical (and chemical) data for Lake Ogac are given below.

Maturity Stages. Russell (1932) and Kramp (1939) both offered systems of classification of the maturity stages in *Sagitta*, which, like all chaetognaths, is a protandric hermaphrodite. The two systems are not incompatible. Russell divided the development to maturity into three stages:

Stage I included all the youngest *Sagitta* in which not a single sperm mother cell was visible lying loose in the tail cavity. Stage II ranged between those individuals with the first appearing spermatocytes and those in which the tail segment was packed with spermatocytes and spermatozoa, but in which the ovaries, while appearing evident, showed little sign of swelling eggs. Stage III contained those individuals in which the ovaries were fully ripe or ripening.

Kramp's system added two more stages, as follows:

| Stage | Male gonads | Female gonads |
|-------|------------------------------------|-------------------------------|
| I | Unripe | Unripe |
| II | Tail containing more or less sperm | All eggs small and alike |
| III | Tail still containing sperm | Some eggs large |
| IV | Sperm mainly or totally evacuated | Ovaries filled with ripe eggs |
| V | Sperm evacuated | Eggs evacuated |

For *Sagitta elegans*, as Kramp himself pointed out, the two systems are essentially the same, because there is considerable overlap between the male and female maturity, and also because, as observed in the present Canadian material, Kramp's stages IV and V are very seldom taken in the plankton, indicating that the period of their existence is very short. For present purposes, therefore, Kramp's stages III, IV and V have been bracketed together as stage III, corresponding to Russell's stage III. The system used here then reads as follows:

- Stage I. No sperm or spermatocytes; seminal vesicles undeveloped; ovaries minute if apparent at all.
- Stage II. Tail segment containing spermatocytes in greater or lesser numbers, seminal vesicles beginning to develop; ovaries small and narrow, all eggs still quite small and undeveloped.
- Stage III. Tail segment full of spermatocytes or spermatozoa, sometimes spent; seminal vesicles fully developed; ovaries stouter and longer, containing at least some enlarged eggs. This stage includes the fully mature female condition.

In practice, stages I and II are often difficult to distinguish, because they grade into each other imperceptibly, whereas the differences between stages II and III are quite marked. For this reason only stage III has been shown separately in the histograms below. The impression gained in working with the material is that the final maturing from stage II to stage III takes place rapidly, followed by spawning and death.

Results. Size frequency distributions for the summer collections from Hudson Bay 1953, Ungava Bay 1947 and 1951, and Frobisher Bay 1951, together with the distribution of stage III individuals, are shown in Figs. 2, 5 and 6. The results from Igloolik (Foxe Basin, 1955-56), prepared by Dr. Grainger, are given in Fig. 3.

It is at once apparent from Fig. 2 that the three broods demonstrated from Baffin Island coastal waters in 1939 and 1940 (Dunbar, 1941) were also represented in northern and northeastern Hudson Bay in 1953. Giving these the same labels as in the earlier work, group A includes the largest individuals, group C the small-size population, and group B the intermediate sizes. The interpretation put upon this distribution is that group A is parental to group C and that group B consists of adolescents which will mature and spawn later, probably in the following year. On this interpretation group C will not spawn until two years later, so that the spawning cycle is of the two-phase or alternating type already found in certain other pelagic invertebrates of similar size in arctic and subarctic water.

The time of appearance of eggs in the plankton agrees with the development of stage III maturity in group A in mid-July. It is not improbable that stage III begins to appear before this time, as the Foxe Basin evidence given below suggests; on the other hand group C individuals, offspring of group A, were not taken until the second week in August.

Group B contains only unripe individuals, stage I being greatly predominant; some develop to stage II later in the summer. It is very unlikely that they would be in spawning condition until the following year, since all growth slows down or stops during the winter. Group B in Fig. 2, therefore, represents the group A of the following year, 1954. However, group A in Fig. 2 (1953) contained large numbers of stage II individuals even in early September, so that spawning must continue into the late autumn at least, perhaps later still.

The growth of Group B during the summer months is also clearly shown in Fig. 2, the modal length of the brood advancing from 13 to 25 mm between mid-July and the end of August. But there is an interesting possibility here that there may be a significant difference in the populations sampled in 1953, so that the growth rate may require a little interpretation. The upper histogram (Fig. 2 a) comes from sts. 501, 502 and 503 (Table I, Fig. 1), in western Hudson Bay; Fig. 2 b is made up of individuals taken at sts. 514 and 520, off Coats and Mansel Islands; Fig. 2 c is from sts. 526, 527 and 531, in

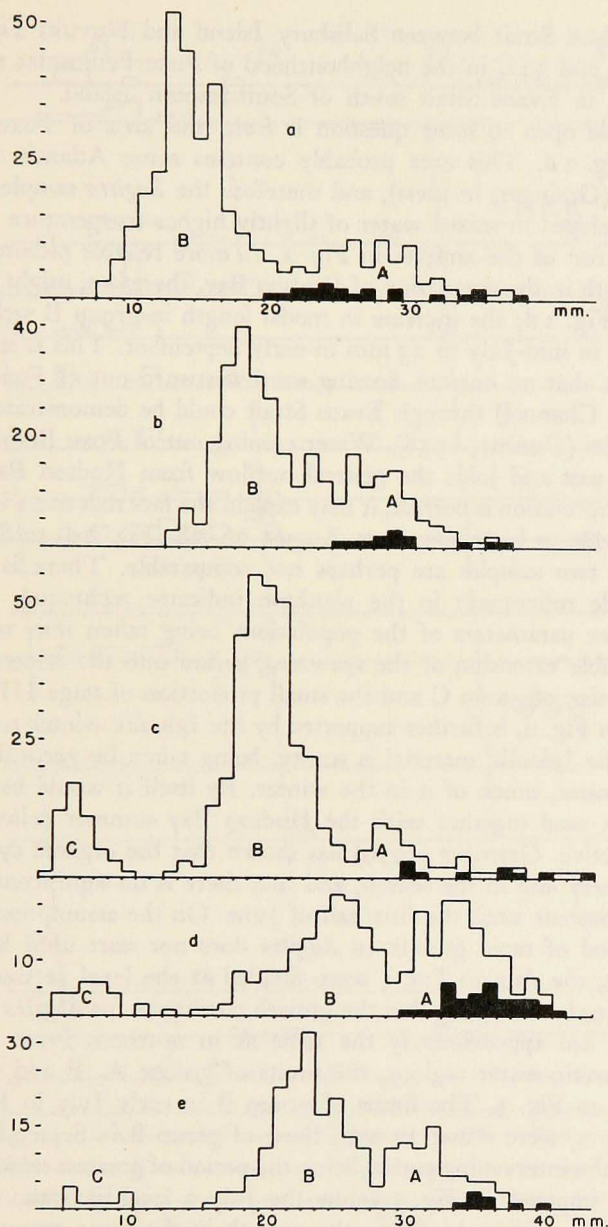


Figure 2. Size frequency distributions and maturity stages, from northwestern Hudson Bay and western Hudson Strait, 1953. a: hauls P-1 (July 13), P-6, P-9 (July 21); b: P-10 (July 31), P-12, P-15 (Aug. 4); c: P-18, P-19 (Aug. 9), P-26 (Aug. 11); d: P-34 (Aug. 26), P-37 (Aug. 27), P-39 (Aug. 28); e: P-44, P-47 (Sept. 4). Size groups A, B, C as described in text. Numbers of individuals on vertical coordinates, pivotal lengths (mm) on horizontal coordinates. White - stages I, II; Black - stage III.

western Hudson Strait between Salisbury Island and Nuvuk; Fig. 2 d from sts. 539, 541 and 542, in the neighbourhood of Foxe Peninsula; and Fig. 2 e from st. 549 in Evans Strait south of Southampton Island.

The sample open to some question is from the area of Foxe Peninsula, shown in Fig. 2 d. This area probably contains some Atlantic water from Davis Strait (Grainger, in press), and therefore the *Sagitta* sample from there probably developed in mixed water of slightly higher temperature than would apply to the rest of the samples in Fig. 2. A more reliable picture of the increase in length in the population of Hudson Bay, therefore, might be obtained by omitting Fig. 2 d; the increase in modal length in group B would then be from 13 mm in mid-July to 23 mm in early September. This is in agreement with the fact that no current flowing southwestward out of Foxe Basin (by way of Foxe Channel) through Evans Strait could be demonstrated from the physical results (Dunbar, 1958). Water coming out of Foxe Basin apparently turns to the east and joins the general outflow from Hudson Bay.

If this interpretation is correct, it may explain the fact that there is in Fig. 2 a decided decrease in body size from August 26-28 (Fig. 2 d) to September 4 (2 e). These two samples are perhaps not comparable. There is implicit in this a possible refinement in the plankton indicator technique, the growth rate and other parameters of the populations being taken into account.

The probable extension of the spawning period into the winter, suggested by the small size of group C and the small proportion of stage III individuals in group A in Fig. 2, is further supported by the Igloolik winter results shown in Fig. 3. The Igloolik material is scanty, being taken by vertical hauls only in 50 m of water, much of it in the winter. By itself it would be difficult to interpret, but used together with the Hudson Bay summer collection it becomes instructive. Grainger (1959) has shown that the organic cycle in Foxe Basin starts very late in the season, and that there is no significant rise in the inorganic phosphate until the first half of June. On the assumption, therefore, that the period of rapid growth in *Sagitta* does not start until late June or early in July, the data in Fig. 3 were divided at the level between June 19 and July 2, 1956. Assuming that the growth conditions for *Sagitta* in northern Hudson Bay are approximately the same as in northern Foxe Basin, both areas being arctic water regions, the limits of groups A, B and C in Fig. 2 were applied to Fig. 3. The limits of group B in early July in Hudson Bay in 1953 (Fig. 2) were 8 and 22 mm; those of group B in September were 16 and 28 mm, the intervening period being the period of greatest seasonal growth. These limits imposed on Fig. 3 below the July 2 level gave the dashed lines shown, which are taken to define the growth in the three groups.

Allowing for some growth during September, the limits for group B at the September 25 level (top line, Fig. 3) were then taken as 17 and 29 mm. Group C, then, in 1955 (group B, 1956), can be taken as everything to the left of the line joining 17 mm at the top, and 22 mm at the level between

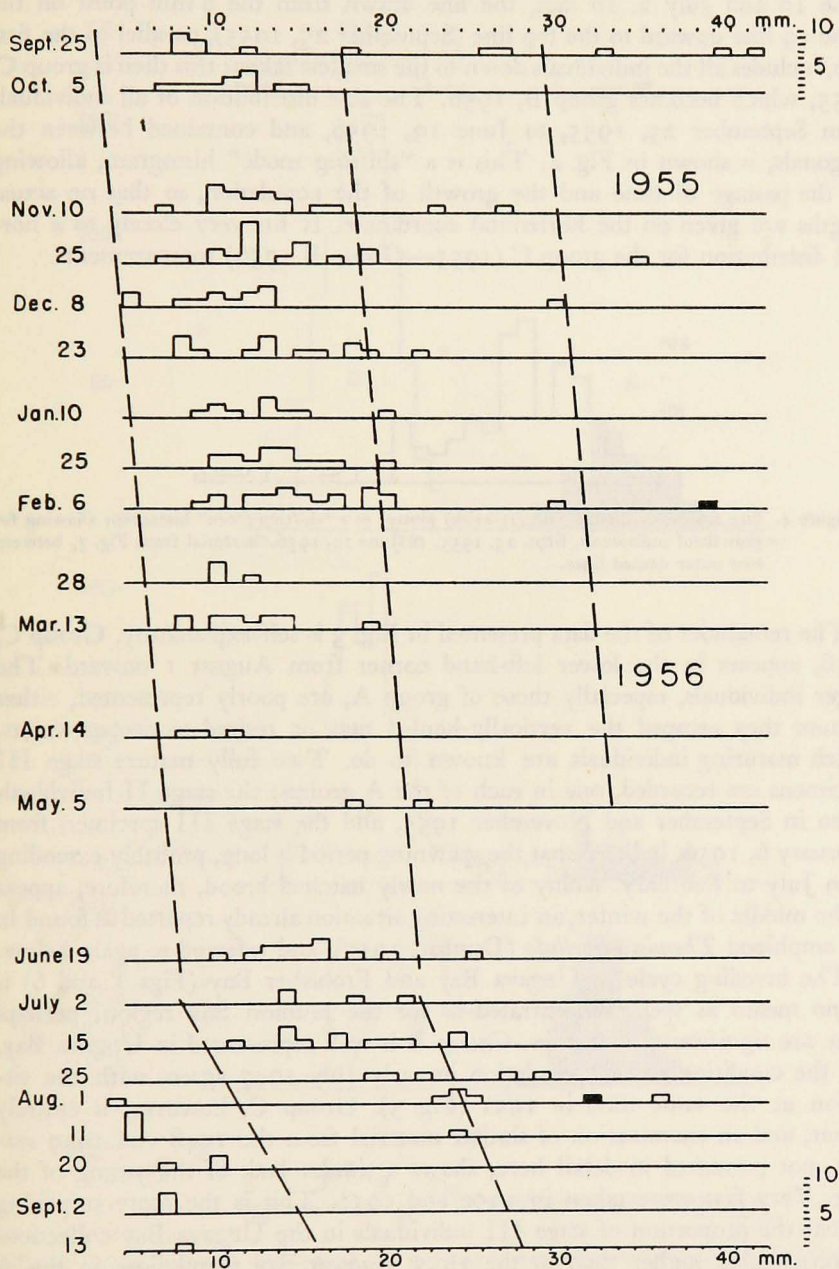


Figure 3. Size frequency distributions and maturity stages, Igloolik, Foxe Basin, 1955 to Sept 1956. Details as in Fig. 2. Also see text. Collections by E. H. Grainger.

June 19 and July 2. In fact, the line drawn from the 8 mm point on the June 19 line upward to the top line (September 25, 1955), parallel to the first line, includes all the individuals down to the smallest taken; this then is group C, 1955, which becomes group B, 1956. The size distribution of all individuals from September 25, 1955, to June 19, 1956, and contained between the diagonals, is shown in Fig. 4. This is a "shifting mode" histogram, allowing for the passage of time and the growth of the population, so that no actual lengths are given on the horizontal coordinate. It fits very closely to a normal distribution for the group C (1955—Group B 1956) measurements.

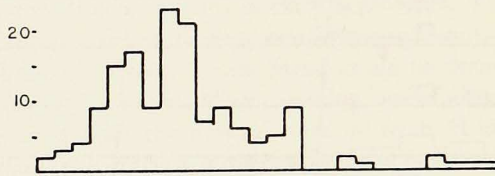


Figure 4. Size frequency distribution (Igloolik) plotted as a "shifting mode" histogram allowing for growth of individuals, Sept. 25, 1955, to June 19, 1956. Material from Fig. 3, between two outer dashed lines.

The remainder of the data presented in Fig. 3 is self-explanatory. Group C, 1956, appears in the lower left-hand corner from August 1 onward. The larger individuals, especially those of group A, are poorly represented, either because they escaped the vertically-hauled nets or retired to deeper waters, which maturing individuals are known to do. Two fully mature stage III specimens are recorded, one in each of the A groups; the stage II individuals taken in September and November 1955, and the stage III specimen from February 6, 1956, indicate that the spawning period is long, probably extending from July to February. Many of the newly hatched brood, therefore, appear in the middle of the winter, an interesting situation already reported as found in the amphipod *Themisto libellula* (Dunbar, 1957), and referred to again below.

The breeding cycle in Ungava Bay and Frobisher Bay (Figs. 5 and 6) is by no means as well demonstrated as for the Hudson Bay region; perhaps there are significant differences. Group B is well represented in Ungava Bay, and the condition of the population in early July 1947 agrees with the situation at the same time in 1951 (Fig. 5). Group C, however, is entirely absent, and an examination of similar material from the 1948 and 1949 seasons, not presented in detail here, shows a similar lack of the young of the year. Very few were taken in 1950 and 1951. This is the more surprising in that the proportion of stage III individuals in the Ungava Bay collections is considerably higher than in the 1953 Hudson Bay population, in the A group. *Sagitta*, in the subarctic mixed water of Ungava Bay, appears to reach maturity a little earlier in the season than in the pure arctic water of Hudson

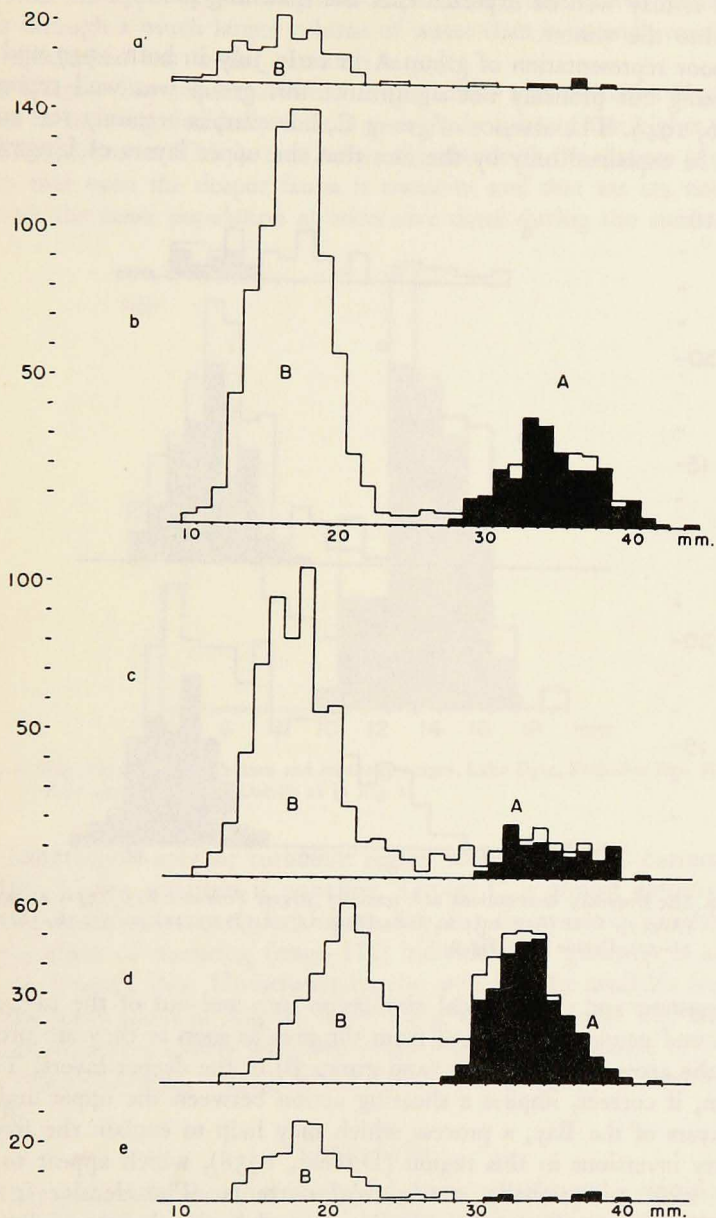


Figure 5. Size frequency distributions and maturity stages, Ungava Bay, 1947, 1951. a: hauls P-11 (July 3); b: P-14, P-15 (July 11), P-19, P-21, P-22 (July 13); c: P-26 (July 17), P-32, P-36 (July 20); d: P-48, P-49 (Aug. 17), P-52, P-53 (Aug. 19)—all a, b, c, d from 1947; e: P-1, P-2, P-3 (July 3, 1951). Details as in Fig. 2.

Bay, and it may well be expected that the spawning period does not extend so long into the winter.

The poor representation of group A in early July in both 1947 and 1951 is interesting but probably not significant; this group was well represented on July 6, 1949. The absence of group C, however, is certainly real and can probably be explained only by the fact that the upper layers of Ungava Bay

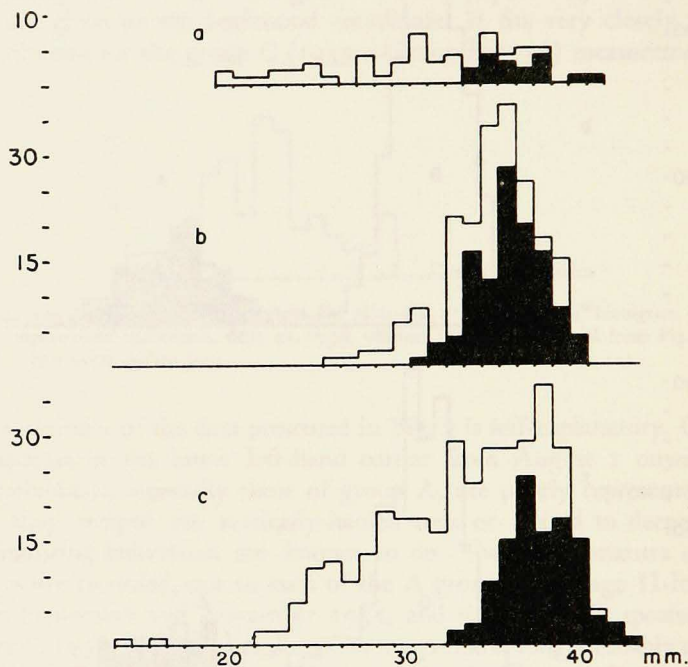


Figure 6. Size frequency distributions and maturity stages, Frobisher Bay, 1951. a: hauls P-19 (Aug. 7), P-21 (Aug. 14); b: P-24 (Aug. 21); c: P-29, 32, 34, 35, 36, 38, 41 (Aug. 26-27). Details as in Fig. 2.

are in constant and violent tidal circulation into and out of the bay, so that the eggs and young are removed from the area as soon as they are produced, leaving the group A individuals (and group B) in the deeper layers. This explanation, if correct, implies a shearing action between the upper and lower water layers of the Bay, a process which may help to explain the frequency of density inversions in this region (Dunbar, 1958), which appear to be associated with exceptionally strong tidal currents. The density inversions themselves offer an additional mechanism to explain the absence of the young-of-the-year in the samples. The inversions are temporary, associated with particular phases of the tide, and they therefore imply vertical exchange of water that constantly tends to re-establish stability. Such vertical exchange

would mix the upper layers with the deeper water, thus scattering the young *Sagitta* through a much larger volume of water than is normal, causing them to be represented less in the plankton samples.

The Ungava Bay results shown in Fig. 5 differ also from the Hudson Bay material in showing decidedly slower growth, in spite of the higher environmental temperatures. This in turn, taken together with the absence of group C, suggests that even the deeper fauna is transient and that we are not dealing here with the same population at successive dates during the summer.

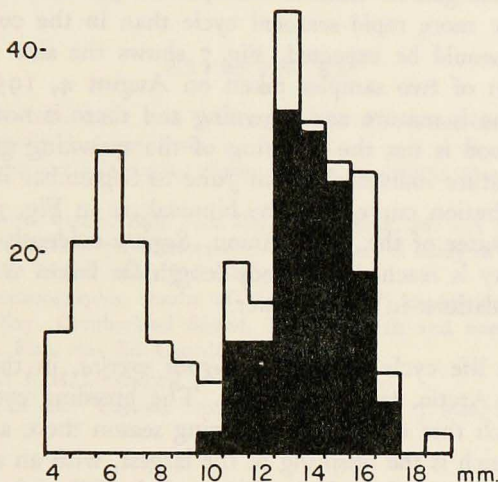


Figure 7. Size frequency distribution and maturity stages, Lake Ogac, Frobisher Bay. Hauls P-16, P-17 (Aug. 4 1951). Details as in Fig. 2.

Frobisher Bay is another turbulent region with strong tidal currents. Here again (Fig. 6) the situation is puzzling. Group C is almost entirely absent. Group B, consistently strong in Ungava Bay, is quite weak in Frobisher Bay. The proportion of maturing (stage III) individuals in group A is almost as high as in Ungava Bay. Unfortunately, the only samples available from Frobisher Bay were taken in August, none being taken in July. The size distribution shown agrees closely with that of the *Sagitta* sample taken in Frobisher Bay in 1940 (Dunbar, 1941), which contained no group C and very few group B.

Ogac Lake

Hydrographic differences, as is shown above, clearly make significant differences in the life cycle of *Sagitta*, and this effect is shown in extreme form in the case of Ogac Lake, a small body of water at the head of New Harbour, Frobisher Bay, which receives sea water over a sill at spring tides only and in which summer temperatures rise above 8°C. There is a layer of fresh water

on top, which probably so insulates the mesolimnion in winter that the temperature fall is slight. Earlier hydrographic data of this area have been amplified recently (Dunbar, 1958) by a much fuller account of both hydrography and biology (McLaren, 1961). The salinity in the middle and lower layers of this lake ranges from about 20–27‰, and at depths below about 30 m the water is anaerobic and stagnant. The depth in the centre of the lake is over 60 m.

In these highly special conditions there lives a population of Atlantic cod from which the lake gets its Eskimo name, and a planktonic flora and fauna which show a far more rapid seasonal cycle than in the cold water in the fjord outside, as would be expected. Fig. 7 shows the size distribution and maturity condition of two samples taken on August 4, 1951. Of the two broods present, one is mature and spawning and there is nothing to suggest that the other brood is not the offspring of the spawning group. McLaren (1961) records mature individuals from June to September in the same lake and his size-distribution curves are also bimodal, as in Fig. 7.

In the warm water of the mesolimnion, *Sagitta* evidently grows very rapidly, and maturity is reached at a body length far below that found in the fully marine populations in arctic water.

Summary. The life cycle of *Sagitta elegans arctica*, in the waters of the Canadian eastern Arctic, takes two years. The breeding cycle is two-phase or alternating, such that during the spawning season there are three broods, the smallest of which is the offspring of the largest, with an adolescent group of intermediate individual size which will spawn the following year, and which is normally reproductively isolated from the others. The spawning period is long, from July into the fall and winter; one mature specimen was taken in February in Foxe Basin.

This habit of breeding in the middle of winter in arctic water has been observed before, in other macroplanktonic species, and it appears to indicate that spawning is not accurately timed to coincide with the maximum abundance of food for the young, but that the slow growth rate at low temperatures, to which there has been no adaptation, determines the breeding cycle.

The hydrographic differences between Hudson Bay and northern Foxe Basin on the one hand, and Frobisher Bay and Ungava Bay on the other, although not great on the global scale, are nevertheless reflected in the biology of *Sagitta*. Maturity seems to be reached earlier in the season in Ungava Bay, where the intrusion of Atlantic water is not inconsiderable. There is some evidence that Atlantic water entering southern Foxe Basin round Foxe Peninsula may cause a discernible difference in the growth rate of *Sagitta*, when compared with the life cycle in Hudson Bay.

It is suggested that strong tidal turbulence, especially in the upper water where the younger *Sagitta* are normally concentrated, removes the younger

stages from Ungava Bay and Frobisher Bay so rapidly that they are not represented in the plankton samples. There is even the possibility that the whole planktonic fauna of these two regions is transient, constantly being swept out and constantly being replaced from outside, so that the interpretation of the samples, and the devising of sampling methods, become difficult.

The *Sagitta* population in the specialized environment of Ogac Lake is typically warm-water; the growth rate is rapid and the breeding cycle is single-phase or nonalternating. Maturity is reached at less than half the body length required in the colder water.

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