THE OCCURRENCE AND BREEDING OF *SAGITTA ELEGANS* VERRILL AND *SAGITTA SETOSA* J. MÜLLER IN PARTS OF THE IRISH SEA

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(Text-figs. 1–2)

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INTRODUCTION

Investigations in recent years have recognized the fact that certain species of *Sagitta* are associated with particular bodies of water, and that when these species are swept by currents into foreign water masses they exist there for limited periods of time. The relatively large size of *Sagitta* makes them convenient to handle and increases their value as representatives of their respective localities.

There has been no previous prolonged examination of the *Sagitta* in Liverpool Bay with respect to the present classification of the species. Russell (1935, p. 323) has recorded *S. setosa* J. Müller and *S. elegans* Verrill from the north of Ireland and from Port Erin. The present investigation has demonstrated that the *Sagitta* present in Liverpool Bay are *S. elegans* and *S. setosa*. The latter species had not been recorded before from this region. During the period of my study it was the dominant form in these coastal waters.

The work of Russell (1932*a*, *b*, 1933*a*, *b*, 1935), Meek (1928), Wimpenny (1936), and others, on the life history and distribution of the species of *Sagitta*, has placed emphasis on the importance of data from other areas. As a result of their work and of the discovery of *S. setosa* in Liverpool Bay, the problem on which this paper is based is the distribution and relative abundance of *S. setosa* and *S. elegans* in parts of the Irish Sea, and the number and periodicity of their reproductive cycles.

I am indebted to Prof. J. H. Orton for general supervision of my work and for helpful advice. Mr F. S. Russell verified the maturity and classification of a number of specimens sent him. Dr Jenkins, chairman of the Lancashire and Western Sea Fisheries Committee, kindly enabled me to collect from the fishery cutters in Liverpool Bay. Mr Nicholson, operator of the cutter at Liverpool, assisted by making many tow-nettings for me. Dr R. J. Daniel, Director of Port Erin Laboratory, and members of the staff at that station, made it possible for me to study plankton samples from Port Erin. Finally, I wish to thank the various other persons who have aided me in the collection and preparation of this material.

Collecting Stations and Apparatus

Collections were obtained once a week from each of three localities, namely: Pier Head, Liverpool Docks, Liverpool; the outer Mersey Channels; and Port Erin harbour, Isle of Man.

The Pier Head station at the mouth of the Mersey River was selected because it was easily reached, would furnish a plankton sample from estuarine conditions and *Sagitta* were known to be available from there. Two nets were used: a $\frac{1}{2}$ m. stramin net sunk with a weight to an approximate depth of 6 m.; and a fine silk net (104 meshes per inch) $\frac{1}{2}$ m. in diameter suspended just beneath the surface. Both nets were allowed to remain in an ebb tide for $\frac{1}{2}$ hr. The tide at this point flowed at the rate of 1 knot.

The outer Mersey Channels include an area which extends 14 miles into the Bay from the mouth of the river. The samples were usually taken 7 or 8 miles from the mouth of the Mersey in the Queen's and Crosby Channels. Two nets were used: a $\frac{1}{2}$ m. stramin net towed at a depth of 6–8 m. (occasionally in shallower water it was towed just 3 or 4 m. deep); and a $\frac{1}{2}$ m. silk net (64 meshes per inch) towed just below the surface. The period of towing was $\frac{1}{2}$ hr. at the rate of approximately 1 knot.

In both the above stations the depth of the water and the diurnal vertical migration of the *Sagitta* were the chief factors considered in selecting the depth at which the stramin nets were towed. The vertical movement of *Sagitta* has been recorded by several investigators (Michael, 1911; Bigelow, 1924; Russell, 1935). Several tests were made to determine the extent of this movement in the comparatively shallow waters of the outer Mersey Channels. The surface towings made during these trials contained relatively few *Sagitta*. Below a few metres it was difficult to determine at what depth the animals were most numerous. I believe this rather scattered distribution was due to the continual mixing of the water layers by the strong tides in these channels. The water was always heavily silted and of low transparency. I have found on several occasions at the Pier Head, where the water was even more muddy and turbulent than farther out in the Bay, that I have captured almost equal numbers in both nets during one haul.

The third regular station from which weekly collections were obtained was the harbour at Port Erin, Isle of Man. Here two silk nets, 36 cm. in diameter with 64 and 125 meshes per inch respectively, were towed across the harbour behind a rowing boat. These towings were taken just below the surface for a period of 20 min.

Stages of Maturity

Sagitta is hemaphroditic with ovaries in the posterior portion of the body cavity and testes extended in two narrow bands, one on either side of the tail cavity. The testes mature first, filling the tail cavity with clusters of sperm cells in various degrees of development. The early indications of maturity in the ovary are an increase in size accompanied by an apparent increase in the number of eggs. In the final stage the eggs increase rapidly in size, a few at a time becoming distinctly larger than the remainder in the ovary.

Several investigators have recognized stages in the development of the germ cells which may be determined visually in the whole animal. Kramp (1917, p. 37) and Wimpenny (1936, p. 17) have each defined four main stages in the development of the gonads. These stages, though differing in some details, are very similar. Russell (1932*a*, p. 134) has simplified Kramp's divisions, describing three stages of maturity in place of four. Russell's descriptions have appeared to me to be the more suitable and I have classified my specimens according to the stages recognized by him.

These stages, designated as I, II and III, represent progressive sexual development from the young immature individual, through an intermediate form, to the adult and fully mature animal. Quoting from Russell (1932*a*, p. 134): "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" (e.g. contained one or more eggs very much enlarged).

Treatment of Material

Sampling. The *Sagitta* were placed in 10% formalin shortly after capture. Later the total number was counted, the stage of maturity determined and each specimen measured. If the weekly collection exceeded fifty specimens a representative fraction containing about forty individuals was separated for maturity determinations and measuring. The measurement of the body length did not include the caudal fin which is delicate and easily damaged.

Staining. In order to ascertain accurately the maturity of the sperm and ovary it was necessary to stain the animal. A successful method for staining large numbers of *Sagitta* was as follows: groups of specimens (20–30) were transferred gradually from the 10% formalin to 75% alcohol and placed in

small glass tubes ($\frac{1}{2} \times 2$ in.). Three or four drops of a concentrated solution of borax carmine were added to the tubes and gently mixed. A day later the borax carmine solution was poured off and replaced by 75 % alcohol and one drop of concentrated hydrochloric acid. The *Sagitta*, now a light red, were kept in the acid alcohol until by inspection the body wall appeared translucent (20–30 min.); the ovary and testes were still red. At this point the acid alcohol was replaced with 75 % alcohol. A second change was sometimes given if continued fading was noticed. The advantages of this method are that large numbers of specimens can be handled with a minimum of effort, and little or no shrinkage or distortion of the *Sagitta* will take place.

Port Erin *Sagitta*

Port Erin material, 1928–34. The data for *S. elegans* at Port Erin for 1928–34 inclusive, are shown in Table I and Fig. 1. The weekly catches during

Table I. Percentages of *S. elegans* Grouped in Stages I, II and III

Taken from Port Erin 1928–34

Month	Stage I %	Stage II %	Stage III %	No. counted from sample
Jan.	4	69	27	89
Feb.	5	49	46	120
Mar.	14	41	45	46
Apr.	27	50	23	105
May	52	47	1	84
June	60	40	0	122
July	82	16·5	1·5	209
Aug.	91	9	0	192
Sept.	94	3	3	135
Oct.	98	2	0	120
Nov.	78	22	0	108
Dec.	37	63	0	128

these years had been combined in fifty-two grouped samples. Each sample contained the plankton collected in that week for all of the years under consideration. These weekly catches have, for brevity and clarity, been graphed in monthly units.

Fig. 1 presents the relative occurrence of the three maturity stages and their relative percentage frequency. Length (mm.) is plotted on the ordinate of the graph and percentage frequency on the abscissa. Stages I, II and III have been treated separately in each month. The absence of a particular stage in the graph for any month is evidence that such a stage is scarce or wanting in the plankton for that period. A similar graph (Fig. 2) has been drawn of the weekly plankton catches of *S. setosa* taken in the outer Mersey Channels during 1937. The appearance of *S. setosa* at Port Erin and *S. elegans* in the outer Mersey Channels was too sporadic to graph in this manner; however, for a short period in the year they became relatively abundant (Pierce & Orton, 1939).

The graph of *S. elegans* from Port Erin (Fig. 1) shows that the main spawning period is during the months of January, February, March and

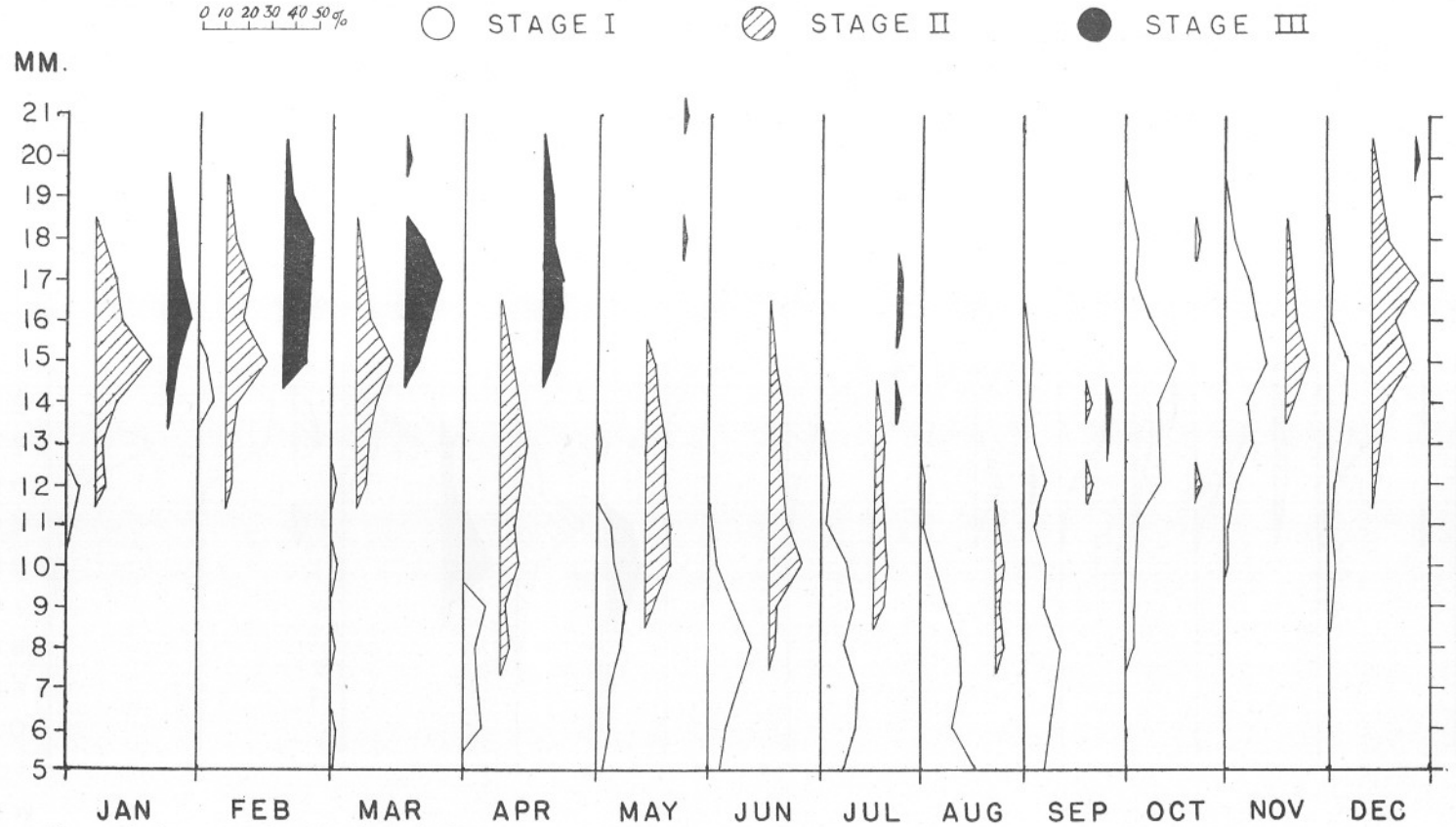

Fig. 1. *S. elegans* caught at Port Erin during 1928–34. Length (mm.) is plotted on the ordinate of the graph and percentage frequency on the abscissa. Stages I, II and III have been treated separately for each month.

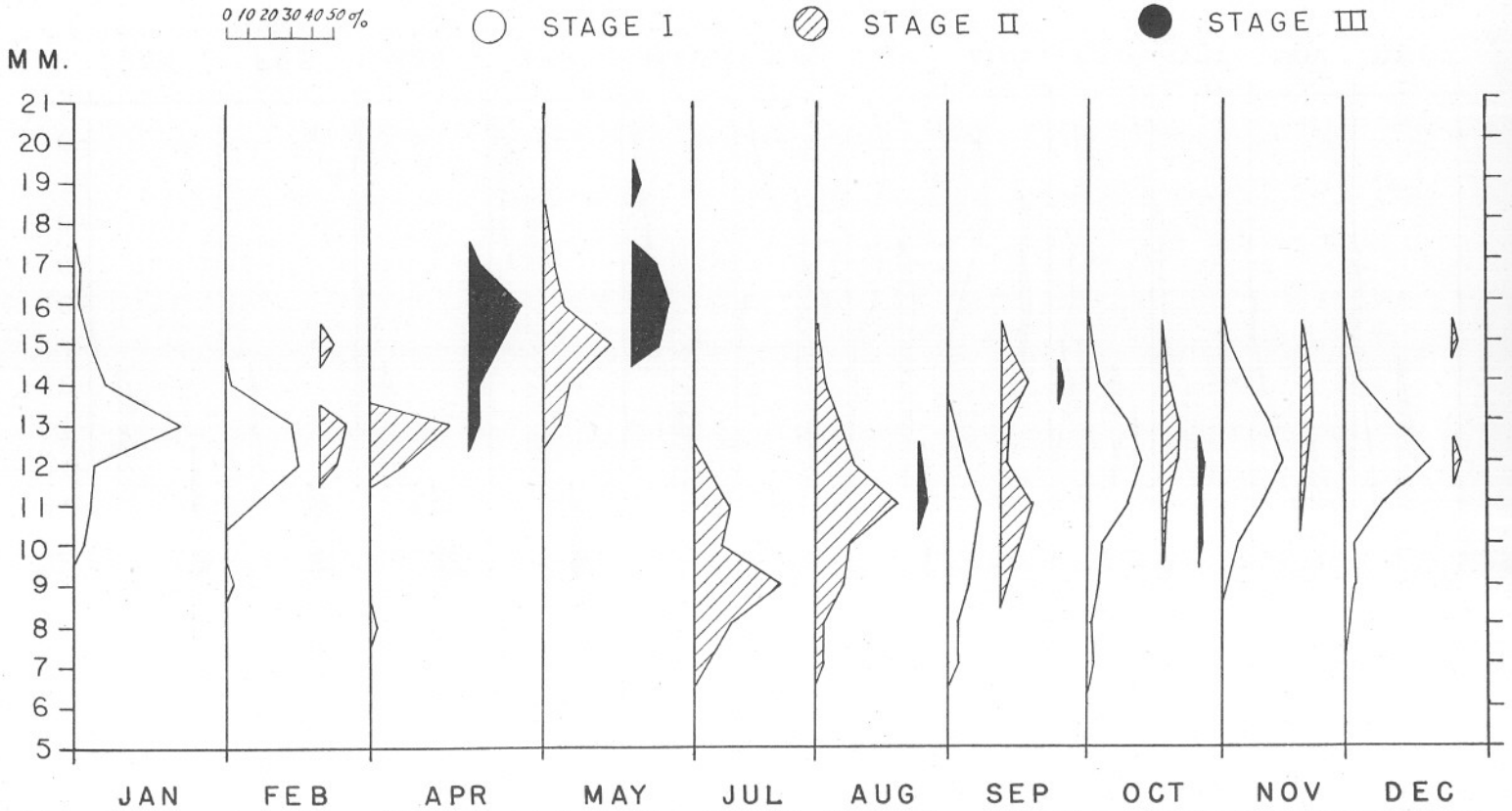

Fig. 2. *S. setosa* caught in the outer Mersey Channels in 1937. Length (mm.) is plotted on the ordinate of the graph and percentage frequency on the abscissa. Stages I, II and III have been treated separately for each month.

April. The stage III *Sagitta* increase from less than 1 % in December to 27 % in January, 46 % in February, and 45 % in March, and decrease to 23 % in April and 2 % in May. Table I contains the complete annual percentages for all three stages. A few mature individuals, as indicated by the small black areas on the graph, were found at scattered intervals throughout the grouped years. Their numbers in these instances were too small to permit recognition of a definite spawning season.

The first young appeared in large numbers in April and from then onward they increased, outnumbering the individuals in the other two stages through November. In November, stage II became noticeable (22 %) and increased to 63 and 69 % in December and January respectively. As indicated above many of the *Sagitta* have become mature by January which thus completes the breeding cycle for the year.

Port Erin material, 1937. Table II of the *S. elegans* collected at Port Erin in 1937 agrees closely with the grouped data for the years 1928–34. A scarcity of specimens in March and October gave few records for those months; however, this does not seriously impair the sequence of the data in the table.

In this year the spawning season began a month later (February) when 18 % of the specimens were mature, and extended through May. The stage II individuals attained their maxima of 73 % in January and 80 % in February, as in 1928–34. The October data are scarce, but the abundance of stage II in November (68 %) indicates that the *Sagitta* began maturing in October, developing into mature individuals in numbers in February and the succeeding months. This completes their annual breeding cycle.

TABLE II. PERCENTAGES OF *S. ELEGANS* GROUPED IN STAGES I, II AND III

Taken from Port Erin in 1937

Month	Stage I %	Stage II %	Stage III %	No. counted from sample
Jan.	23	73	4	66
Feb.	2	80	18	90
Mar.	—	—	—	—
Apr.	4	35	61	138
May	33	33	34	126
June	57	36	7	275
July	94	4	2	87
Aug.	85	12	3	36
Sept.	94	3	3	29
Oct.	89	11	0	9
Nov.	32	68	0	49
Dec.	7	93	0	57

Discussion. In view of the possibility of discrepancies in sampling such a shifting population the close agreement of the data from the grouped samples from 1928–34 and for the single year 1937 is noteworthy. The maxima and minima for stages I, II and III fall in every case within a month of each other. A comparison of Tables I and II reveals a gradual increase and diminution of the individuals in each group. There are no exceptionally large populations

in any month which are not in agreement with the appearances of the *Sagitta* in both the preceding and following months. These are important features, because they substantiate the validity of the sampling methods and support the conclusion that there is but one main season of reproduction for *S. elegans* in the Port Erin region.

Additional collections of *Sagitta* were examined from Port Erin for the years 1935 and 1936. The data from these samples are in essential agreement with the material already discussed and permit of the same conclusions. This information appears useful chiefly as an additional check on the 1928–34 and 1937 breeding cycles and will not be discussed further here.

Russell's data (1932*a*) have indicated four main breeding periods a year for this species in the Plymouth area. These occur in February, May, June-July and September. A comparison of his results with mine reveals that a spawning period in February coincides. After that date and through September no additional breeding periods were identified, as recorded by Russell. In October, November, December, January and February the stages in development appear very similar.

Wimpenny (1936) collected *Sagitta* from the south-west portion of the North Sea. He places one of the breeding periods of *S. elegans* between January and February, which agrees with Russell's and my results; also his data indicate a spawning period between April and August and another tentative breeding in October, which in general is similar to the reproductive periods at Plymouth. In contrast the one long spawning period from January-February to April-May evidenced by my results from Port Erin does not correspond completely with the observations of either Wimpenny or Russell. The great discrepancies appear to lie in the long breeding period from winter to spring of the Port Erin species and the lack of another in the succeeding summer.

Liverpool Bay *Sagitta*

Outer Mersey Channels. The *Sagitta* collected in the outer Mersey Channels in 1937 were with few exceptions *S. setosa*, and the graph (Fig. 2) includes only that species. During January and February this species comprised 95 and 58% respectively of the total number of the two species. Owing to a mishap to the fishery cutter the March data are missing. For the remainder of the year the entire catch consisted of *S. setosa* (Pierce & Orton, 1939).

The first spawning of the year, as indicated in the graph (Fig. 2) occurred in April, May and probably June. During April stage III amounted to 48% of the catch and in May 40% (Table III). In June the presence of the alga *Phaeocystis* in great quantities plus large numbers of the ctenophore *Pleurobrachia pileus* rendered the plankton nets almost useless; moreover, the *Sagitta* themselves appeared very scarce.

Following the April-May spawning the young produced in June must have started maturing rapidly, because all individuals collected were in stage II

in the latter part of July when the first *Sagitta* for that month were obtained in the outer Mersey Channels. By August the first mature individuals from the April-May spawning appeared. The occurrence of these stage III forms, followed by the appearance of numerous stage I specimens, is evidence of a second breeding period despite the scarcity of mature *S. setosa*. During October, November and December stage I continued to increase in relative frequency and by January comprised 100% of the catch. The testes started maturing during February and large individuals ready for spawning appeared in April and May, completing the annual cycle.

It is to be noted that the stage II individuals from February to May (first brood) are larger than the stage II specimens taken between July and November (second brood). The former attained an average length of 13·4 mm. in February, 13·2 mm. in April and 16·0 mm. in May. In the second generation the male stage was first noted in July, when an average length of 9·4 mm. was recorded. By August this had increased to 11·1 mm., in September to 12·0 mm., to 12·6 mm. in October and 13·1 mm. in November. The stage II specimens had almost vanished from this locality by December. The increase in body length found during the colder months (i.e. February, April and May) agrees with the records of Russell (1932*a*) and Bigelow (1924), who have noted a relation between length and temperature; the greater length being found during the colder months. Similar conclusions hold for the stage III *S. setosa* taken; however, in view of the small numbers collected in the summer, details of average length have been omitted.

Pier Head samples. Throughout the year 1937 weekly plankton samples were collected from a pier at the mouth of the Mersey River. Usually the numbers of *Sagitta* caught here were small (Table III). These samples are valuable largely because they confirm the results of the collections taken farther out in the Bay (Fig. 2).

It is of interest to note that during February when mixed catches of *S. setosa* and *S. elegans* were caught in the outer Mersey Channels a similar mixed catch was obtained from the Pier. In March, when the fishery cutter was disabled, towings from the Pier were obtained. The first on March 18 contained a single *S. elegans*. The second sample on March 30 contained nine *S. elegans*; no *S. setosa* were caught during that month. This record agrees with the record of *S. elegans* obtained in Morecambe Bay in March. The remainder of the year produced only *S. setosa*. Collecting at Pier Head was discontinued after the first week in December 1937.

Comparison with previous data. Russell (1932*b*) at Plymouth finds at least six generations of *S. setosa* per year. There is a greater similarity between his results and mine than may at first appear. He records a generation in April and May, and another in June. I believe, in the Liverpool region, that *S. setosa* spawn continuously for these three months, thus combining two of his breeding seasons in one. There was a dearth of mature individuals in July, but there is evidence for a breeding season in August extending into September. This

is also similar to the July-August and September spawnings indicated by Russell. Little evidence was found for a breeding season in October and February, such as he records.

Wimpenny (1936) finds two spawning seasons for *S. setosa* in the south-western portion of the North Sea. The first was in April and the second in July. The earlier season corresponds to that indicated by Russell's data and my own. The July spawning agrees with Russell's records for a brood in July-August and appears to correspond with my evidence for a spawning in August.

Additional Samples

Morecambe Bay. A number of plankton samples were obtained from Morecambe Bay during March and April 1937. The number of *S. setosa* taken is listed briefly as follows: March, stage I, 1 specimen; stage II, 86 specimens; April, stage II, 6 specimens; stage III, 5 specimens.

A graph of the March 1937 collection of *S. setosa* would readily fit between the February and April results from the outer Mersey Channels (Fig. 2), as is evident from the above data. The small April collections agree with those taken in the outer Mersey Channels in the same month.

The number of *S. elegans* found was: March, stage II, 34 specimens; stage III, 105 specimens. None were taken in April. These data agree very well with the 1928–34 and 1937 records from Port Erin.

Anglesey. During the first week in May a trip was made around Anglesey on Board the Lancashire and Western Sea Fishery steamer *Charles MacIver.* Although plankton towings were made completely around the island and in the Menai Strait, *Sagitta* were obtained only from the northern coast in the vicinity of Point Lynas and Moelfre. Relatively few *Sagitta* were taken even here. The total number caught was fifty-eight; of these thirty-eight were *S. elegans* and twenty were *S. setosa.* The large majority of the thirty-eight *S. elegans* were stage III individuals; the remainder were stage II. These specimens are similar both in length and development to the *S. elegans* taken in April and May 1937 from Port Erin (see also Fig. 1). In both species there is a preponderance of stage III forms, indicating a spawning.

There were thirteen stage III specimens as compared to the seven stage II forms among the twenty *S. setosa* caught. These data, though scanty, agree with the May records of the species taken from the outer Mersey Channels some 50 miles east.

Range of *S. setosa*

S. setosa and *S. elegans* are evidently distributed along the west coast of England and Wales from Morecambe Bay to Anglesey, for at least portions of the year. In view of Russell's records (1936, Fig. 6) of *S. setosa* and *S. elegans* from the vicinity of Land's End, and additional records of these two species from the north coast of Ireland, it appears probable that they extend along the entire coast of England and Wales bordering the Irish Sea.

Formerly, *S. setosa* was believed to be indigenous only in the English Channel, North Sea and neighbouring waters. Also it appears that the *Sagitta* at Port Erin, Morecambe Bay, outer Mersey Channels and Anglesey are members of a more or less related population whose breeding periods for each species are approximately the same.

Numbers of *Sagitta* Collected per Month

Table III records the number of *Sagitta* taken per month for the year 1937 at Port Erin, Pier Head and the outer Mersey Channels. Plankton catches from Port Erin taken with a surface tow-net as a rule produced the greatest number of specimens during the summer. This was the period when the young forms were comparatively numerous; later, as winter approached, the catches decreased somewhat, reaching a minimum in January and February. These results are merely indications of the actual quantity of *Sagitta* present during this time. Larger collections taken with nets at greater depths will be required before even general quantitative conclusions may be drawn.

Table III. Total Number of *Sagitta* Caught per Month in 1937

Month	Port Erin	Pier Head	Mersey Channels
Jan.	66	2	69
Feb.	205	19	72
Mar.	—	10	—
Apr.	138	9	75
May	126	3	90
June	590	2	7
July	87	9	57
Aug.	36	4	90
Sept.	34	11	140
Oct.	—	60	1399
Nov.	269	126	377
Dec.	57	16	70

Certain general trends in the increase and decrease of the *Sagitta* in the outer Mersey Channels were more discernible. In June 1937 *S. setosa* had practically vanished from this region. A marked scarcity continued until the latter portion of July when fifty-seven specimens were secured. The noticeable increase in September was due to the presence of the young *Sagitta*. This increase reached a peak in October. After October, although *S. setosa* was present in numbers, no very rich hauls were obtained. The trend from then onward appeared to be one of decrease which would result in a similar scarcity the following summer.

Summary

An investigation has been made of the species of *Sagitta* present in parts of the Irish Sea, their relative occurrence, and the annual number of reproductive cycles of each species. Three stages of maturity as described by Russell (1932*a*) have been used. To determine the maturity the *Sagitta* were transferred to a solution of 75% alcohol and stained with borax carmine.

S. elegans Verrill and *S. setosa* J. Müller were collected in Liverpool Bay and in Port Erin harbour, Isle of Man. The former species was predominant at Port Erin. The coasts of Liverpool Bay have been added to the permanent range of *S. setosa*.

At Port Erin there appears to be but one chief spawning period for *S. elegans* which extends generally from January through May. Following May the young forms appear in numbers and gradually mature through December to repeat the annual cycle.

There appear to be two main breeding seasons for *S. setosa* in the outer Mersey Channels. The first and most noticeable begins in April and extends into June. There is evidence for a second breeding period in August.

Both species were found in the samples taken from Morecambe Bay and Anglesey. The stage of maturity of these agreed with the *Sagitta* caught at the same time at Port Erin and Liverpool.

The total monthly catches of *Sagitta* from Port Erin and the outer Mersey Channels have been recorded.

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