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THE SIZE OF DIATOMS

III. THE CELL WIDTH OF *BIDDULPHIA SINENSIS* GREVILLE FROM THE SOUTHERN NORTH SEA

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(Text-figs. 1–5)

The present contribution deals with the measurements of fifty-two samples of *Biddulphia sinensis* collected by Hensen net hauls from the Ministry of Agriculture and Fisheries research ships *George Bligh* and *Onaway*, working in the southern North Sea between 1932 and 1938. With one exception in which there were only seventy available, the samples consisted of a hundred cells and the unit of measurement was that employed in Part I of this paper (Wimpenny, 1936). The dimension used was the greatest width (apical axis), and care was taken to see that the cells measured were lying flat, to give the true maximum of their elliptical cross-section. For convenience in tabulation and to avoid random fluctuations due to too small grouping of the data, the measurement units have been taken in pairs in the presentation of all the sea results, each arbitrary unit being equivalent to about 8 μ. The measurements from cultures, where the samples were sometimes fewer than a hundred, have been 4 μ units.

The positions of the stations, the mean widths, the population densities and the temperatures and salinities relating to the samples are given in Table I. The individual measurements from which this table has been compiled have been deposited at the Marine Laboratory, Plymouth, whence they may be obtained for consultation on request.

Observations made on cell width

A representative series of size-frequency samples covering the period 1932–38 has been plotted in Fig. 1. This may usefully be compared with Text-fig. 2 in Part II of this work (Wimpenny, 1946). It will be seen at once that the regularly recurring and persistent form of the size distribution shown by *Rhizosolenia styliformis* is absent in *Biddulphia sinensis*, where the width distribution in one year, or indeed on one cruise, may vary as much as it does throughout the whole period.

These big variations within the area of one cruise are, however, more explicable when related to the salinity of the surrounding water, and in Fig. 2 I have shown the surface salinities of two cruises in 1937 in relation to the

TABLE I. POSITION OF STATIONS AND OTHER DETAILS REFERRING TO THE DIAMETER MEASUREMENTS OF *BIDDULPHIA SINENSIS*

Date	Cruise	Station	Depth (fathoms)	Latitude N.	Longitude E.	t° C at 0 m	Salinity at 0 m	Mean diameter in arbitrary units	1000's per m^3
26. x. 32	J	7	15	52° 55′	4° 00′	13·67	34·67	17·6	23·8
28. x. 32	J	17	15	53 45	6 07	12·57	33·40	16·7	30·3
7. x. 33	K	4	13	52 12	3 53	16·70	33·82	16·4	136·5
8. x. 33	K	8	17	53 06	3 02	16·70	34·66	17·4	351·7
8. x. 33	K	10	18	53 26	2 27	16·46	34·62	19·1	1417·2
19. x. 33	L	15	16	53 19	3 07	14·89	34·85	17·8	375·6
20. x. 33	L	22	17	53 45	2 35	14·32	34·73	17·9	6·1
28. viii. 34	J	35	18	52 03	3 15	18·12	34·60	20·1	0·6
28. viii. 34	J	36	28	52 03	2 11	17·03	35·07	14·5	1·8
27. ix. 34	L	24	27	52 00	2 11	16·80	35·09	14·4	470·4
27. ix. 34	L	26	16	51 48	3 15	17·21	34·81	16·4	146·2
28. ix. 34	L	29	14½	53 00	3 12	16·76	34·89	14·8	332·6
20. x. 34	N	2	30	52 20	2 28	15·07	35·10	15·6	300·9
22. x. 34	N	20	15	53 00	3 49	14·17	35·03	14·9	1284·4
1. xi. 34	O	10	24	54 27	4 40	12·74	34·82	16·7	787·5
3. x. 35	O	4	15	51 45	3 18	15·57	34·65	16·9	235·8
4. x. 35	O	11	22	53 54	3 03	14·35	34·62	14·8	1650·0
4. x. 35	O	12	19	53 36	2 21	13·98	34·60	15·6	783·9
25. x. 35	P	13	29	54 10	4 30	12·87	34·76	17·1	124·9
9. xi. 35	Q	24	25	53 44	4 09	11·73	34·83	16·3	428·6
24. xi. 35	R	6	24	54 54	5 17	10·30	34·81	18·9	231·8
27. ix. 36	N	19	17	53 30	2 57	16·12	34·11	20·6	146·2
27. ix. 36	N	20	14	53 30	3 53	16·47	34·40	19·1	166·1
29. ix. 36	N	29	7	51 31	1 24	15·84	34·50	18·1	870·0
29. ix. 36	N	30	14	51 29	0 52	15·39	33·56	18·2	490·5
6. x. 36	O	2	19	52 00	2 06	15·84	34·43	18·2	209·0
11. x. 36	O	20	22	53 17	2 25	14·31	34·28	19·1	2106·8
14. x. 37	M	24	32	54 07	2 25	14·37	34·85	15·4	27·5
15. x. 37	M	25	20	53 43	2 53	14·53	34·14	18·5	1234·1
15. x. 37	M	26	18	53 26	2 11	14·38	34·18	19·6	121·0
27. x. 37	N	4	10	52 42	4 23	13·11	32·03	20·8	138·9
27. x. 37	N	5	15	53 06	4 21	13·21	33·97	25·2	3·0
28. x. 37	N	12	13	53 35	2 14	13·26	34·84	15·9	16·0
28. x. 37	N	13	17	53 35	2 57	13·48	34·13	19·1	1890·0
14. xi. 37	O	8	16	53 32	3 42	11·35	34·14	20·0	165·0
15. xi. 37	O	12	10	53 32	2 20	11·47	34·52	20·9	339·0
15. xi. 37	O	16	17	53 57	2 23	11·77	34·83	16·9	197·5
15. xi. 37	O	17	24	53 58	3 06	12·02	34·65	19·1	384·8
15. xi. 37	O	18	19	53 58	3 47	11·77	34·43	20·1	481·9
16. xi. 37	O	19	21	53 58	4 20	11·69	34·00	19·6	20·6
16. xi. 37	O	21	22	54 23	3 32	11·29	34·93	15·4	547·3
16. xi. 37	O	23	17½	54 20	2 08	11·67	34·70	14·9	7·1
28. xi. 37	P	1	10½	53 32	2 20	9·60	34·48	19·6	384·0
28. xi. 37	P	2	17½	53 32	3 02	9·88	34·66	19·9	23·8
21. x. 38	P	5	13	52 48	4 01	14·39	34·63	25·5	339·8
21. x. 38	P	6	17	52 32	3 25	14·57	34·78	19·3	250·0
22. x. 38	P	7	18	53 14	3 35	14·19	34·88	15·3	28·6
23. x. 38	P	12	19	53 38	3 09	12·38	34·58	15·6	2·2
23. x. 38	P	13	35	54 00	2 34	13·19	34·66	17·1	81·8
11. xi. 38	Q	7	22	54 48	4 32	12·23	34·68	18·0	77·5
13. xi. 38	Q	19	25	57 12	7 38	11·50	—	16·7	420·5
14. xi. 38	Q	20	21	56 08	6 32	12·36	—	19·6	14·9

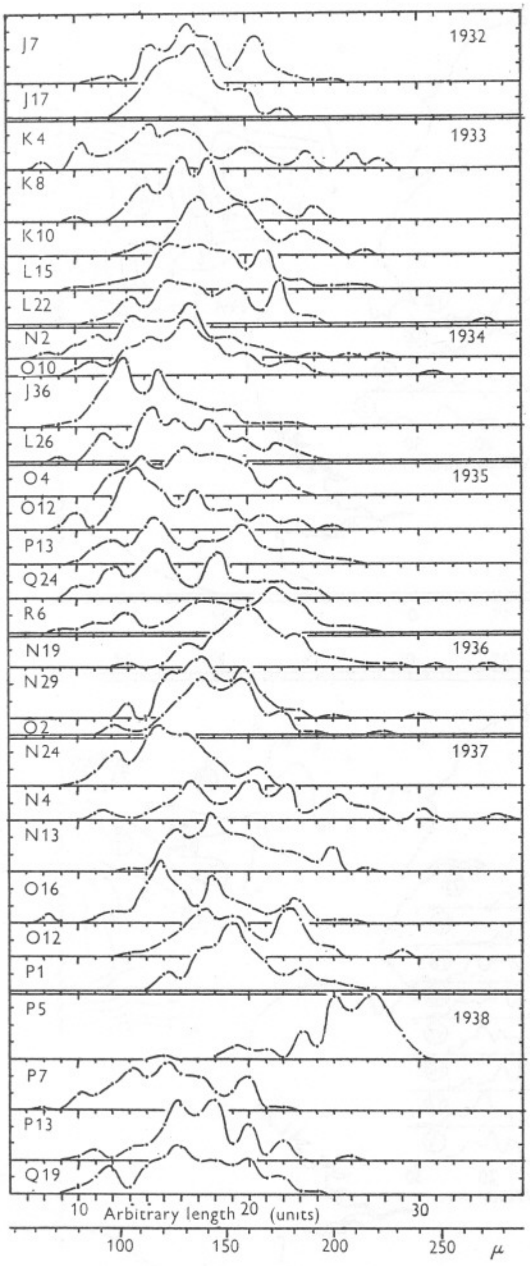

Fig. 1. *Biddulphia sinensis* width frequencies for various stations in the southern North Sea between 1932 and 1938. The ordinate is marked in 5s.

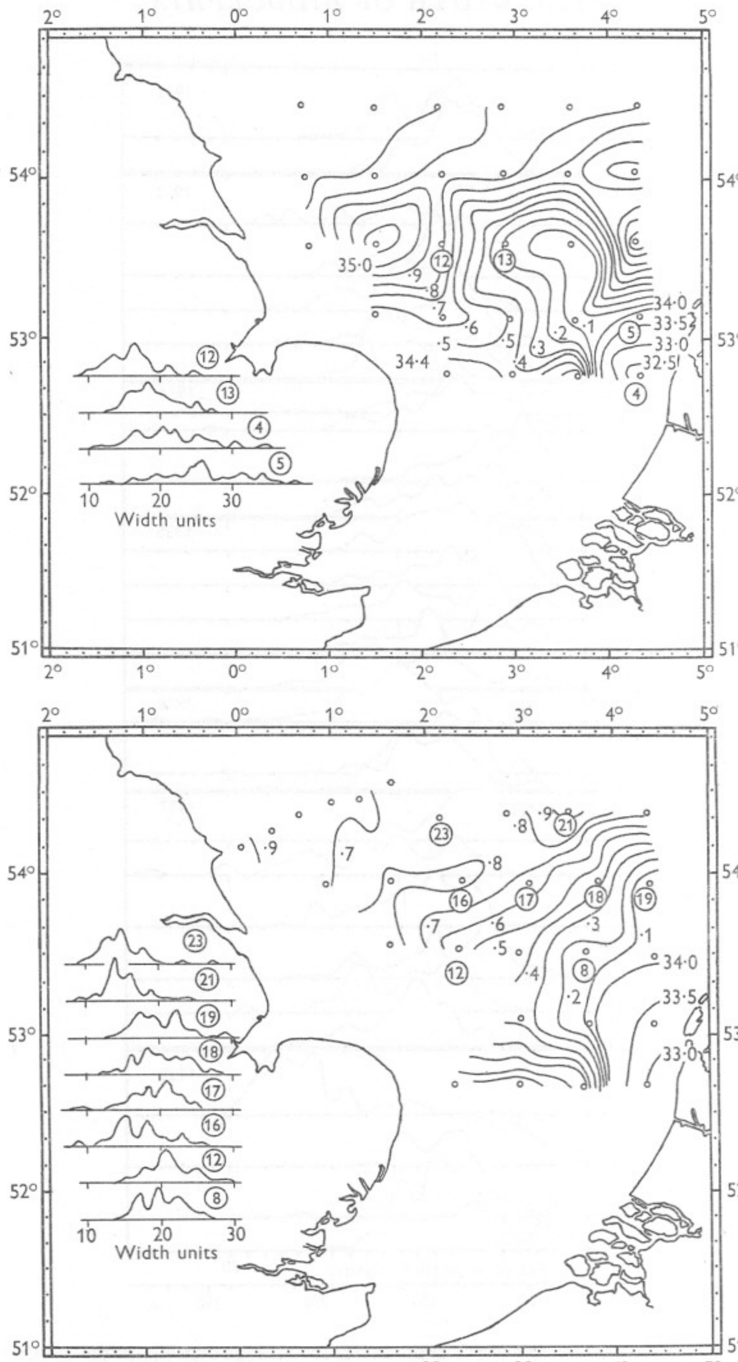

Fig. 2. Surface salinities on Cruise N, 1937 (above) and on Cruise O, 1937 (below) showing stations at which 100 width measurements of *Biddulphia sinensis* were made (ringed figures) and on the left the actual width frequencies from these stations.

positions from which samples were taken and the corresponding width distributions. The relation between surface salinity and cell width seems close in these cases, and even when all the fifty-two samples available over the period 1932–38 are taken together there is a negative correlation with the surface salinity of −0·43. This would happen by chance less than once in a hundred times. Similar correlations with density of population and with surface temperature (−0·06 and −0·17) were found to be of negligible significance.

Lucas & Stubbings (1948), using material from the Hardy continuous recorder in the southern North Sea between 1931 and 1938, measured samples amounting to 20,000 cells, most of them from 1938 material. From their distribution when compared with the data published in the *Bulletin Hydrographique* these workers inferred that the wider cells were found in the water of lower salinity mainly near the continental coast. They distinguish narrow, medium and wide cells in their samples, but on a line from Hull to Bremen in November 1938 they figure (p. 156) what at first appears to be a unimodal population changing abruptly near the Friesian Islands into a bimodal one with subsequent increasing emphasis on the larger mode. This latter appearing in Lucas and Stubbings's results in November seems to correspond with a similar one found by me at Station P 5 in October 1938, 20 miles off the Texel.

Consideration of the facts presented up to this point would make it appear that *B. sinensis* must adjust its width to changes of salinity fairly rapidly so that it would not be possible to follow and identify a population by its size distribution. On the contrary, it is rather more likely to be an index of contemporary salinity, and shows no steady diminution of size over a long period followed by a sudden return to maximum width as a result of the formation of auxospores as happens in *Rhizosolenia styliformis*.

However, when all the samples are grouped together by years (Fig. 3 and Table II), it is seen that there is a sharp rise in the chief mode of the size-frequencies between 1935 and 1936 which is reminiscent of that shown by the individual samples of *Rhizosolenia styliformis* taken in these years. There is also a slight rise in the mean size between 1932 and 1933 which, on account of the poor sampling in 1932, might have been thought of as of no significance if I had not been afforded the opportunity of examining some of Dr Lucas's unpublished measurements. With the latter's kind consent I have prepared Fig. 4 from these data. The figure shows the percentage frequency distribution of *Biddulphia sinensis* for the same general area as my material for the years 1932–38. It will be seen that, in addition to the increase in the modal frequency between 1935 and 1936 there are indications of increases from 1932 to 1933 and 1937 to 1938. It is as if, for *B. sinensis* as for *Rhizosolenia styliformis*, the same law of diminishing division followed by a sudden increase is being observed—if one adds together for each year all the separate samples which in some way appear adjusted in width to their contemporary salinity.

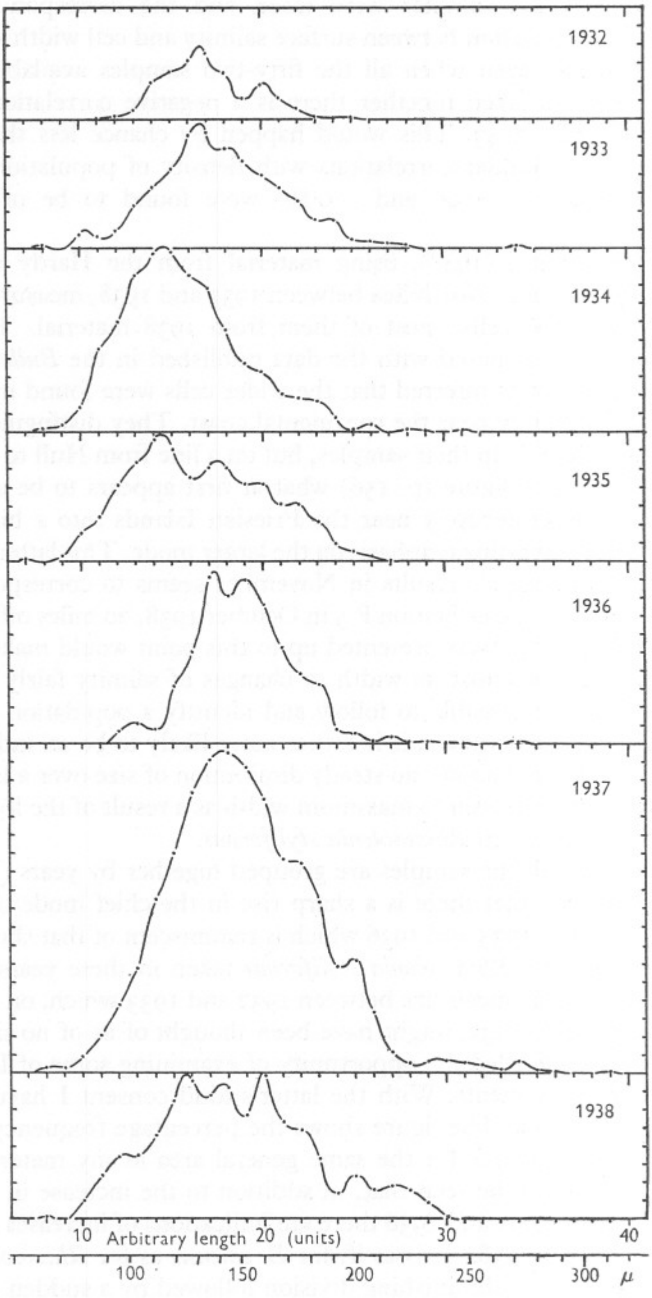

Fig. 3. *Biddulphia sinensis* width frequencies for the whole years 1932–38. The ordinate is marked in 10s.

Table II. Measurements of *Biddulphia sinensis* Diameters, for Separate Years 1932–38

Year	Measurement groups (8 μ units) 8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	Mean
1932	—	—	—	—	2	5	9	25	28	30	35	22	10	23	3	6	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	18·2
1933	—	2	1	8	11	15	31	32	58	71	57	49	43	35	31	18	13	13	4	5	1	1	—	—	—	—	1	—	—	—	—	—	18·7
1934	—	5	7	25	48	82	91	104	88	82	60	55	38	22	18	22	11	3	3	2	1	2	—	1	—	—	—	—	—	—	—	—	16·7
1935	1	1	4	22	27	57	61	53	63	46	56	42	37	46	26	29	14	10	2	3	—	—	—	—	—	—	—	—	—	—	—	—	17·6
1936	—	—	—	—	3	10	8	18	40	77	77	97	89	58	49	32	21	7	2	2	5	2	1	—	1	—	1	—	—	—	—	—	19·9
1937	1	4	4	13	32	39	80	123	137	146	178	172	175	125	120	83	93	64	37	26	7	8	7	6	4	5	4	5	2	—	—	1	19·4
1938	—	1	6	18	25	38	41	48	73	72	71	66	79	61	47	44	20	17	21	17	15	14	6	—	—	—	—	—	—	—	—	—	19·4

Table III. Growth of *Biddulphia sinensis* Cultures shown by Cell Numbers; and Mean Size of Cells

Cultures set up on 11 August 1950 in a north window. Size expressed as mean widths and lengths of samples of 100 cells taken on 15 and 21 August 1950, in units of 4 μ.

Date in August 1950	Sea water with erdschreiber	Sea water with erdschreiber diluted with distilled water of percentage 10	20	30
	Cell numbers			
12	6·75	5·0	4·75	6·5
13	18·75	37·25	22·75	20·75
14	53·5	95·25	80·0	73·5
15	117·5	178·25	153·0	162·75
16*	197·75	253·75	251·5	299·25
17	462·5	650·0	487·5	550·0
18	1,187·5	862·5	1,200.0	1,312·5
19	1,937·5	2,725·0	2,162·5	2,500·0
21*	5,262·5	7,462·5	8,312·5	6,725·0
22	12,500·0	9,375·0	25,625·0	18,125·0
24	37,500·0	51,250·0	54,375·0	63,125·0
26	96,875·0	96,250·0	101,875·0	119,375·0

	Cell shape Width	Length	Width	Length	Width	Length	Width	Length
15	68·5	93·6	70·1	93·9	69·9	92·45	68·3	88·9
21	67·3	93·3	68·0	93·4	66·5	92·5	66·8	88·9

* Subcultured.

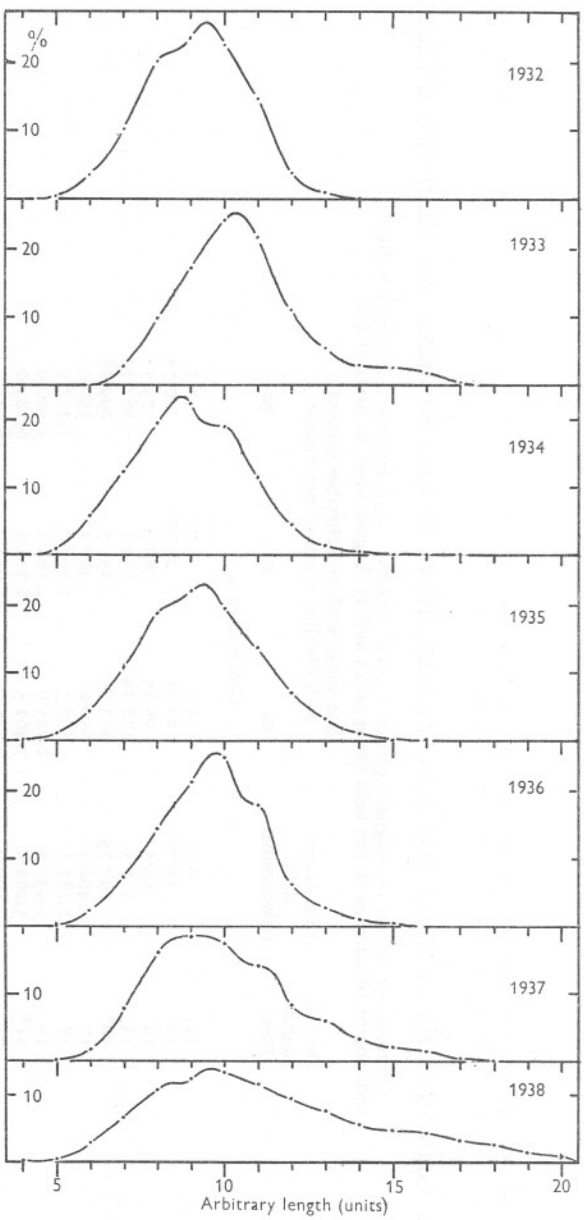

Fig. 4. *Biddulphia sinensis* width frequencies for the whole years 1932–38 in arbitrary units of approximately 12 μ. Lucas and Stubbings's material expressed as percentages along the ordinate.

Egusa (1949), who has worked on this species from a coastal bay in Japanese waters from September 1946 to April 1948, found a large and small diameter group alternating, the former dominating in winter and the latter in summer. No auxospore formation is described and there was no horizontal distribution of the samples which would indicate whether the individuals came from an identical stock. If the cells did in fact come from the same stock these observations suggest the annual formation of an auxospore generation in an environment where there is little change in the salinity.

FACTORS AFFECTING SIZE IN *BIDDULPHIA SINENSIS*

Width adjustment in diatoms is well known to occur downwards by division and upwards and suddenly by auxospore formation, and we may examine how this known method of diminishing growth and auxospore formation could produce the observed situation for *B. sinensis*. First, reference may be made to the work of Schreiber (1931), who figured and observed auxospore formation in *B. sinensis* in material collected off Heligoland on 19 July 1926, and at a time when the salinity—28·6‰—had reached a lower value than the preceding and following days and lower than the July average for 15 years—31·5‰. Schreiber also quotes Mielck as noting that *B. sinensis* is smaller in the northern than the southern North Sea.

In view of the observations on this species at Heligoland and the fact that he was able to produce abundant auxospore formation in *Melosira nummuloides* by lowering the salinity, Schreiber was of the opinion that the greater width in North Sea diatoms is due to more auxospore formation in an area of lower salinity. The correspondence of lower salinity with auxospore formation is also pointed out in Part I of this work (Wimpenny, 1936), where the distribution of *Rhizosolenia alata* is examined, and again in Part II (1946), where it was thought worth noting that a commencement in the lowering of salinities in 1935–36 corresponded with the origin of a new auxospore generation of *R. styliformis* in 1935 and its development in 1936. No auxospore formation has actually been seen in my material, but in a collection taken on the same voyage (Station 23, Cruise P, 1935) as that on which some of the present measurements were collected, what appeared to be newly formed auxospores and detached parent cells were seen. These are reproduced in Fig. 5. They occurred in the same year as did those of *R. styliformis* and, if we lump all the years' samples together, precede a year in which there was a sudden increase of size. This circumstantial evidence then favours the thesis of an auxospore formation in 1935 following populations which were on the whole diminishing in size and preceding a wider population which had also diminished in size by 1937. There is also the suggestion particularly supported by the width distributions communicated to me by Dr Lucas, that there may have been auxospore formation in 1932 or 1933 and possibly in

1938. Unfortunately the observations do not go beyond 1938 so that it cannot be said whether an unusually wide population occurring at Station 5 of Cruise P off the Dutch coast in 1938 could have been the precursor of a new auxospore generation.

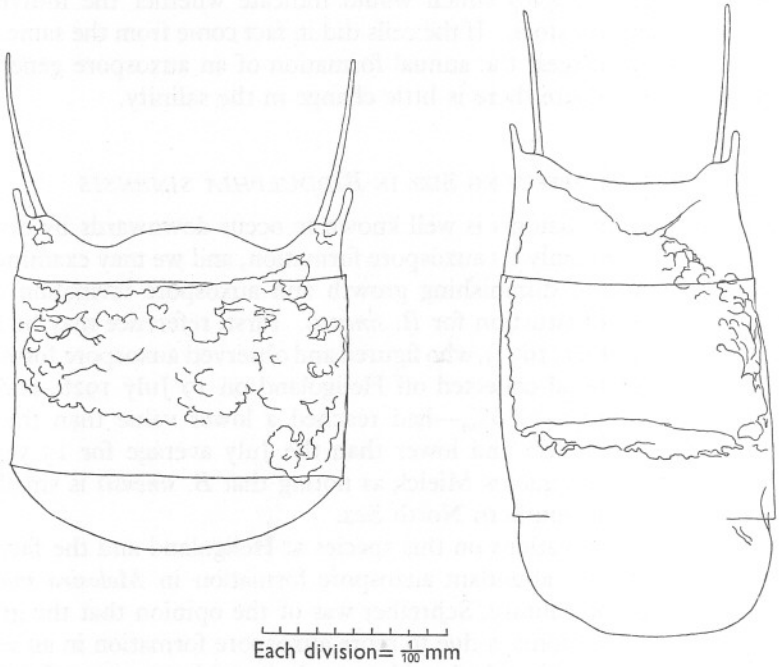

Fig. 5. Drawings of *Biddulphia sinensis* cells from station 23 of *George Bligh* Cruise P, 1935.

It is very puzzling to account for the big differences of widths in the same voyage or season, but three reasons occur to me as affording a possible mechanism. These are: (*a*) the frequent origin of auxospore generations in the less saline water; (*b*) direct and immediate adjustment of cell-size to the salinity of the surrounding water, perhaps by some osmotic action taking place at cell division; and (*c*) differential survival or growth of cells in water of different character, particularly with reference to changes of salinity.

In an attempt to test explanations (*b*) and (*c*), I made some simple experiments in 1950 on a culture of *B. sinensis* which Mr D. Jefferies of the Fisheries Laboratory, Lowestoft, had succeeded in establishing. Unfortunately, the cells of this culture were already similar in width to the wider fraction of those found in the sea, so that the fact that my first series of experiments in which the erdschreiber-enriched sea water was diluted to various degrees (Table III) showed no auxospores may only have meant that auxospore formation is not possible above a certain size. The dilution experiments also showed little or no difference in growth rate over the period of 21 days (about a division a day for most of the time). However, for the first two days it did appear that dilution accelerated the rate of growth, 10% being the most effective and 30% the least. There were no increases in width attributable to osmotic swelling or any other cause. There also appeared to be little or no mortality in this series and the diminishing cell widths suggested that on the average the cell wall might be expected to be about 1·5 μ thick. These experiments were carried out in a room with a north light where the day temperature varied between 18° and 20° C.

TABLE IV. GROWTH OF *BIDDULPHIA SINENSIS*, IN CELL NUMBERS

Cultures set up on 23. viii. 50

Date	In erdschreiber-enriched seawater at 24° C	In erdschreiber-enriched seawater at 10° C
23. viii.	11	15
24. viii.	20	16
25. viii.	27	22
26. viii.	33	38
28. viii.	40	42
29. viii.	42	54
30. viii.	55	62
31. viii.	80	64
1. ix.	78	72
2. ix.	75	92
4. ix.	90	103
5. ix.	—	93
6. ix.	—	85
7. ix.	92	90
8. ix.	91	96
9. ix.	93	101
11. ix.	98	108
12. ix.	95	98
13. ix.	98	101
14. ix.	100	100

TABLE V. LENGTH AND WIDTH OF *BIDDULPHIA SINENSIS* CELLS AT DIFFERENT TEMPERATURES

Measurements in 4 μ units. Light supply 550 Lux

	Parent population	Population at 24° C			Population at 10° C		
	23. viii.	29. viii.	2. ix.	12. ix.	29. viii.	2. ix.	12. ix.
Observations	100	29	50	41	27	46	33
Mean width	66·4	62·0	60·5	62·4	61·2	61·0	56·9
Mean Length	106·2	93·0	97·8	121·4	112	110·9	134·1

In the second series two experiments run at 24° and 10° C (Tables IV and V) showed little difference in growth, which stopped after three divisions, but many morbid cells appeared, more at the higher temperature. Cell measurements indicated that the mortality was selective, the higher temperature culture being left with cells that were wider and shorter than those grown at the lower temperature.

As far as they go, therefore, these experiments do not suggest that immediate swelling or formation of auxospores follows a lowering of salinity where the cells are of the larger size. On the other hand they do suggest that an environmental difference, in this case temperature, can act on cell shape through selective mortality at different values.

Summary

The cell widths of samples of *Biddulphia sinensis* taken from Hensen net hauls made in the southern North Sea between 1932 and 1938 correspond rather closely to the contemporary salinity samples, but not to the density of population or to temperature.

The width distributions of *B. sinensis* do not give a persistent and characteristic guide or mark to populations of this species in the way that is characteristic of *Rhizosolenia styliformis*, but rather give a rough indication of the salinity of the water in which they are found.

There is nevertheless some circumstantial evidence pointing to a 3-year auxospore cycle similar to that shown by *R. styliformis* in the same area. It is, however, much masked and overlaid by other causes of change in cell width.

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