RATE OF GROWTH IN SPAT AND YEARLINGS OF THE INDIAN BACKWATER OYSTER *OSTREA MADRASENSIS* PRESTON

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Introduction

Apart from brief reports by Hornell (1910) and Paul (1942) there exists no detailed account of the rate of growth in the Indian backwater oyster, *Ostrea madrasensis* Preston, which is an important species of shell-fish of commercial value in the country. Hornell's (1910) account is based on an examination of a few lots of spat-collectors placed in Ennur backwaters, near Madras, during the months of the north-east monsoon of the year 1908, to ascertain the principal determining factors in oyster-spawning; his observations on the rate of growth were only incidental. Paul's (1942) study of the growth of this species, among other animals, deals with material from the Madras harbour. Although this species occurs in fair numbers and breeds well under the almost marine conditions of the harbour, it remains stunted and does not grow to the maximum size usually reached in estuaries and backwaters (*vide* Rao, 1951). Since it is well known that oysters of the same brood from the same locality exhibit a wide range of growth (Orton, 1937; Havinga, 1928 and Korringa, 1953) the maximum growth-rate alone, as given by previous workers for this species, will be of little significance. An attempt has been made here to study the maximum and the mean rates of growth of the spat and yearlings of the oysters in their natural environs, together with the possible effects of the fluctuating environmental factors upon the rate of growth.

We have great pleasure in offering our sincere thanks to Dr. N. K. Panikkar, for going through the manuscript and suggesting improvements.

Methods of Study

The rate of growth of the spat and yearlings of *Ostrea madrasensis* was studied from weekly random samples collected during the years 1953–55 from an experimental oyster bed in the shallow waters of the Adyar estuary† near its northern bank, at a distance midway between the Elphinstone Bridge to its west and the shore line of the Bay of Bengal to its east. Bricks, bits of plaster, tiles and other

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† For a detailed account of the environment Panikkar and Aiyyar, 1937 may be referred.

masonry material, stones, and shells of dead oysters were used as culch for collecting the spat. They were deposited in heaps, periodically removed, examined, cleaned and replaced. The surfaces of the stones on the embankment near the experimental bed were scraped and cleaned at the commencement of observations, and the spat which subsequently settled on them were studied. From the time of setting, weekly samples of spat were collected and measured by means of sliding callipers. The data were arranged in size-groups with class intervals of 3 mm., taking height as a standard of measure for estimating the rate of growth. Measurement of width was also considered for determining its relationship to growth in height. 'Height' is defined here as the maximum distance between the hinge and the opposite end of the shell, and 'width' as the greatest dimension of the antero-posterior axis. Size-frequency diagrams were drawn separately for the weekly samples in the first few months after the setting of spat, but during the periods when there was no setting of fresh spat or when there was little or no growth of the spat already set, the weekly samples were combined and the population was represented by a single diagram for each month. Owing to the great variation in the rate of growth among individual members of the same brood, it was not found possible to estimate, especially in the yearlings, the average growth by the shifting of the mode values in the frequency diagrams for different months. Hence, the maximum and mean rates of growth were determined separately. Spat was also raised from grown-up larvæ collected in the plankton and reared in finger bowls under laboratory conditions, for studying the rate of growth in the first few days after setting. As the chemical conditions of the waters in the estuary were found to differ from place to place and from season to season, weekly records of salinity and pH were maintained for the inshore sea-water, waters near the bar and waters over the oyster beds, during the entire period of investigation. Arrest in growth, formation of a distinct ring, and reawakening of growth activity observed in the oysters in different periods during the year were studied in relation to the changes in the environmental conditions.

SALINITY, HYDROGEN-ION CONCENTRATION AND TEMPERATURE OF THE WATERS

Fluctuations in salinity of the waters of the Adyar estuary for the years 1948–49, previously recorded by one of us (Rao 1951 *a* and *b*), were attributed to (1) the intermittent closing and opening of the sand bar at the river mouth, (2) the dilution of waters by floods after the rains in the monsoon, and (3) the concentration of salts by evaporation in summer months. During the present investigations from October 1953 to Feburary 1955 the waters at the river mouth were in communication with the sea twice, *viz.*, from 17th October 1953 to the first week of March 1954, and again from 19th October to 26th February 1955; for the rest of the period, however, the bar remained closed.

Salinity of the inshore waters of the sea.—The salinity was moderate from the second week of October 1953 till the end of January 1954, ranging from 22·7 to 30·6‰ (Fig. 1 *a*). In February 1954 there was a slight increase from 31·9 to 33·4‰ and it remained thereafter fairly steady up to the end of September 1954 varying within limits of 33·6 to 35·2‰. In the period from October 1954 to December 1954 it again came down and ranged between 20·3 to 28·1‰.

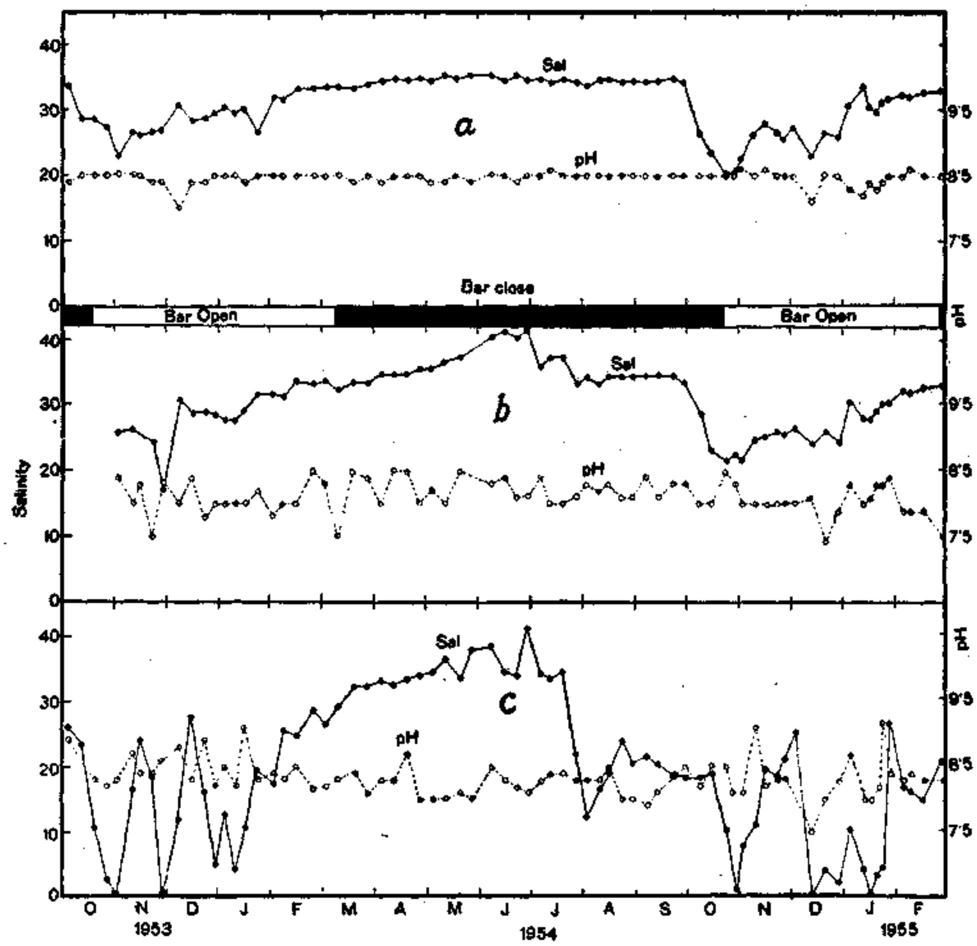

FIG. 1. Fluctuations in salinity (parts ‰) and pH of the inshore sea-water (*a*), of the stuarine waters near the bar (*b*) and of estuarine waters over the oyster beds (*c*) in the eriod from October 1953 to February 1955.

Salinity of estuarine waters near the bar.—The salinity was very low to moderate in November 1953, ranging from 17·1 to 26·4‰ (Fig. 1 *b*). From December 1953 to June 1954 there had been almost a gradual rise within limits of 27·6‰ and 41·1‰. May and June 1953 had the record of the highest salinities of 38·0‰ and 41·1‰ respectively. An appreciable fall in the month of July was noticed due to occasional rains, but the salinity was still fairly high up to September 1954, ranging between 33·1‰ and 37·4‰. From October to December 1954 the salinities ranged moderate between 21·5‰ and 26·8‰. From January to February 1955 there was a gradual increase from 28·0 to 32·8‰.

Salinity of the waters over oyster beds.—From October 1953 to the end of the first week of March 1954, the salinity was low to moderate, varying over a very wide range of 0·3 to 28·5‰ (Fig. 1 *c*). From the second week of March 1954 till the end of June 1954 there was a gradual increase up to 41·1‰. In July 1954 there was a sharp fall to 34·3‰ at which it remained steady for a few weeks, followed by a steeper fall by the end of the month. From August 1954 to February 1955 the salinity was low to moderate ranging from 1·4 to 26·8‰. In general the salinity values for waters over the oyster beds are comparatively lower than those for waters near the bar for the corresponding periods.

During the months when the bar is open, the waters near the bar and those over the oyster beds are subject to the influence of the ebb and flow of tides, with the result that the salinity values do not remain constant even during the course of the same day, as shown by the analysis of samples collected on 21st and 27th January 1955 (Fig. 2).

The varying environmental conditions of the estuary may be grouped in the following three periods, for convenience:

(1) *October to end of February or the first week of March.*—During this period the bar remains open establishing communication with the sea, the waters are subject to the influence of tides, and fluctuations in salinity are very marked even at short intervals, with a maximum not exceeding that of the sea-water. Growth in fresh spat is extremely good, and formation of shell-shoots indicating fresh growth in the yearlings and older oysters is vigorous.

(2) *March to June or about the beginning of July.*—In this period, the bar being closed, there is no tidal effect and drought conditions prevail, as a consequence of which the salinity of the estuarine water gradually increases to concentrations much higher than the sea-water. Growth rate of the spat and the older oysters is good in the first one month or so, but slackens considerably thereafter.

(3) *July to September.*—In this period, the bar being closed, the estuarine waters are not under tidal influence, and the flood waters entering the river considerably bring down the salinity, and such low salinity conditions last for a fairly long time. There seems to be little or no growth in the oysters, evidenced by the formation of an interruption-ring on the shell.

Hydrogen-ion concentration

The sea-water during the period of study did not show any appreciable change in pH, which fluctuated only between 8·0 and 8·6 (Fig. 1 *a*).

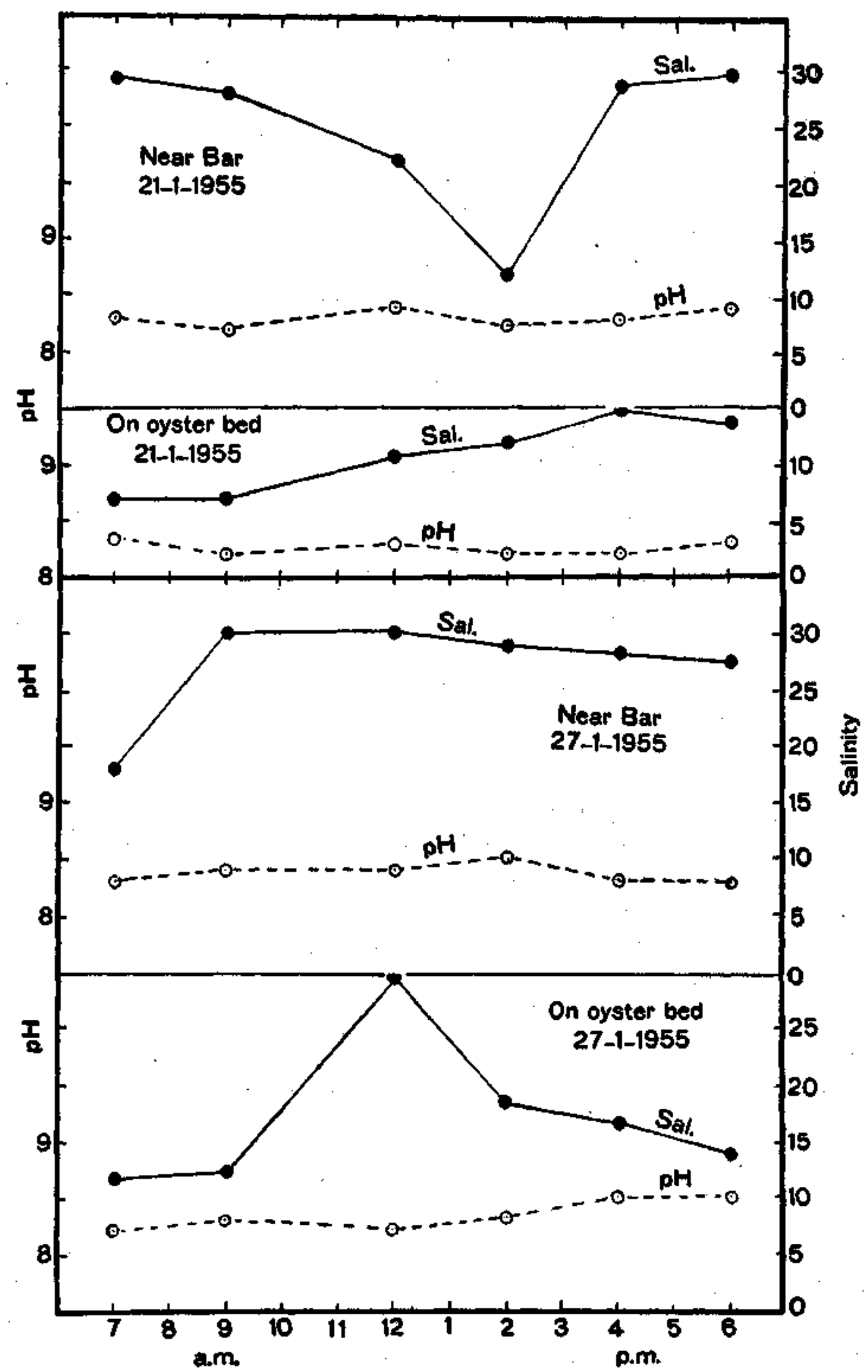

FIG. 2. Fluctuations in salinity (parts ‰) and pH in different samples of water collected between 7 a.m. and 6 p.m. at intervals of 2 hours on 21st and 27th January 1955. The wide fluctuations occurring in very short intervals due to tidal action may be noted.

The estuarine waters near the bar showed a range of pH from 7·4 to 8·5 during the periods when the bar was open and from 8·0 to 8·5 when the sea was not in communication with the estuary (Fig. 1 *b*).

The range of variation in pH of the waters over the oyster beds was very wide, from 7·5 to 9·1 (Fig. 1 *c*). Fluctuations in pH were in general more marked during the periods when the bar was open than when it remained closed.

Changes in pH in the course of the same day were also observed, as shown in figure 2.

Temperature of waters over oyster beds

Fluctuations in water temperature recorded during the period of study showed a minimum of 26·0° on 23rd December 1954 and a maximum of 31·0° on 23rd August 1954 (Table I). Water temperatures in general were low from November to February and high from March to October.

SPAWNING AND SETTING OF OYSTERS

From the field and laboratory observations on *Ostrea madrasensis* it has been ascertained earlier that at Adyar the oysters have a principal spawning season from November to December, followed occasionally by a feeble one in March–April, and that the spatfalls set in only when the bar is open admitting sea-water into the estuary (Rao, 1951 *a*). The results obtained in the present investigations are in almost entire agreement with the previous findings. From the examination of the gonads it was seen that spawning had commenced, in both 1953 and 1954, late in the month of October and had continued up to December. In 1953 the bar opened on the 17th October and the first set of spat was obtained on 23rd November; in 1954 it opened on the 19th October and the first set of spat was obtained on 15th November. It is therefore clear that setting had occurred during the periods when the sea was in communication with the estuary.

In the earliest set obtained on 23rd November 1953, the spat ranged from very small ones up to those with a height of 7·5 mm., and in that obtained on 15th November 1954 they ranged up to a maximum of 6·0 mm. It has not been found possible, by direct observation, to fix the exact date of first setting in either 1953 or 1954. Paul (1942) has observed that the early spat attain sizes of 0·8, 4·4, 6·3, 6·5 and 12·0 mm. in length (= height) in 3, 10, 13, 16 and 19 days respectively. Hence, the maximum sized spat observed in the first set of 23rd October 1953 would be 16 to 19 days old, and those of 15th October 1954 are 10 to 13 days old. From this it is inferred that the earliest setting had occurred between 4th and 7th November in 1953 and between 2nd and 5th November in 1954.

TABLE I

The mean temperatures of waters over Adyar oyster beds in different months from October 1953 to February 1955

Month	Temperature °C.	Month	Temperature ° C.	Month	Temperature° C.
October 1953 ..	29·6	April 1954 ..	..	October 1954 ..	28·0
November 1953 ..	28·2	May 1954 ..	28·2	November 1954 ..	27·4
December 1953 ..	27·2	June 1954 ..	28·2	December 1954 ..	26·8
January 1954 ..	27·3	July 1954 ..	29·5	January 1955 ..	26·5
February 1954 ..	27·3	August 1954 ..	29·8	February 1955 ..	27·8
March 1954 ..	28·7	September 1954 ..	28·3		

Spat raised under laboratory conditions in finger bowls and fed with planktonic organisms had shown a growth rate of 0·7, 0·8, 0·9, 1·9, 2·6, 5·0, 5·9 and 10·3 mm. in height in 1, 2, 3, 5, 10, 15, 21 and 61 days respectively after setting. Thus, the rate of growth had been found in general to be very poor under artificial conditions. It may yet be seen that in the first week after setting the spat increased in size to more or less the same extent as observed by Paul (1942) in the harbour; but thereafter the disparity in growth rates under field and laboratory conditions became wider.

Rate of Growth of Spat and Yearlings

In the year 1953 the earliest spat should have occurred between the 4th and 7th November as stated earlier. The sample of the first set, observed on 23rd November, had individuals measuring up to a maximum of 7·5 mm., with a mean size of 4·5 mm., and the majority of them were in the size-group with a mid-point of 4·5 mm. By the end of November 1953 when the earliest set was three weeks old the population had attained a maximum size of 8·5 mm. and a mean size of 4·05 mm. with a modal value of 4·5 mm. as seen in Figs. 3 and 6 and Table II.

In the weekly samples of December 1953, there was a gradual increase in the maximum and the mean sizes and the mode in the size-frequency diagrams had shifted to higher values. By the end of December 1953 when the spat were about 1 month and 3 weeks old they had attained a maximum size of 35 mm., a mean size of 18·0 mm. with the highest frequency size-group at 13·5 mm. Spat setting, commencing in about the second week of November 1953, has been observed to have a very short duration of about five weeks only, as no fresh spat have been obtained in samples from the second week of December 1953 (Figs. 3 and 6 and Table II).

The samples examined in January 1954 showed a further increase in size. At the end of the month, when they were about 2 months and 3 weeks old, the maximum, mean and the highest frequency sizes were 45 mm., 26·0 mm., and 22·5 mm. respectively (Figs. 4 and 6 and Table II). The samples of February 1954 conformed more or less to those of the previous month. By March and April, when they were 5 and 6 months old, they had considerably increased in their maximum size to 54·0 mm. and 61·0 mm. and in the mean size to 30·4 mm. and 36·8 mm. respectively. From May to September, although there was but very little increase in the maximum size, the mean size had gone up to 48·35 mm. From April on, the samples showed a great variation in their rate of growth with the result that each is represented by more than one mode in the size-frequency diagrams. However, the highest frequency size-groups are

TABLE II

The maximum, minimum and mean height and modal values of the populations of oyster spat in samples examined during 1953–55

Date	Min. Height (mm.)	Max. Height (mm.)	Mean Height (mm.)	Modal Height (mm.)	Date	Min. Height (mm.)	Max. Height (mm.)	Mean Height (mm.)	Modal Height (mm.)
November 1953									
23rd	2·0	7·5	4·5	4·5	June 1954	24	57	36·2	40·5
30th	1·5	8·5	4·1	4·5	July 1954	26	61	45·4	40·5
December 1953					August 1954	26	65	48·4	49·5
7th	3·1	12·5	7·8	7·5	September 1954	27	65	46·4	52·5
14th	2·0	25·0	9·3	7·5	October 1954	27	84	50·6	55·5
21st	6·0	24·2	13·9	10·5	November 1954				
28th	10·0	35·0	18·0	13·5	1953 Yr. Cl. 15th	25	96	55·5	52·5
January 1954					1954 Yr. Cl. 15th	1·5	6·0	4·2	4·5
6th	10·0	32·0	19·6		1954 Yr. Cl. 22nd	1·5	10·0	5·2	4·5
27th	8·0	37·0	20·9	22·5	1954 Yr. Cl. 29th	1·5	22·5	7·6	7·5
29th	15·0	45·0	26·6		December 1954				
February 1954					1953 Yr. Cl.	31·5	102	57·9	52·5
1st	13·0	28·0	21·8		1954 Yr. Cl. 7th	2·5	25·2	12·1	13·5
15th	17·0	38·0	25·7	22·5	1954 Yr. Cl. 13th	1·5	33·0	9·6	10·5
26th	15·0	40·0	26·3		1954 Yr. Cl. 20th	4·0	32·0	13·2	10·5
March 1954					1954 Yr. Cl. 27th	2·5	30·0	14·6	19·5
1st	17·0	50·0	28·8		January 1955				
8th	20·0	36·0	27·1	28·5	1953 Yr. Cl.	23·0	107·0	60·5	61·5
22nd	21·0	48·0	33·4		1954 Yr. Cl. 3rd	7·0	32·0	15·2	
29th	27·0	54·0	34·2		1954 Yr. Cl. 10th	4·0	31·0	15·1	
April 1954					1954 Yr. Cl. 17th	8·0	30·0	16·1	13·5
5th	17·0	42·0	29·4		1954 Yr. Cl. 24th	6·0	32·0	16·4	
12th	23·0	57·0	39·2	40·5	1954 Yr. Cl. 31st	2·0	33·0	13·8	
19th	18·0	55·0	40·4		February 1955				
26th	28·0	61·0	39·2		1953 Yr. Cl.	32·0	109·0	63·7	No. Def. Mode
May 1954									
3rd	22·0	52·0	30·5		1954 Yr. Cl. 7th	0·5	29·0	12·4	
10th	27·0	50·0	38·4	43·5	1954 Yr. Cl. 14th	3·5	41·0	23·1	
17th	22·0	56·0	42·7		1954 Yr. Cl. 21st	8·0	31·0	21·3	22·5
25th	30·0	53·0	37·4		1954 Yr. Cl. 28th	10·0	49·0	24·4	

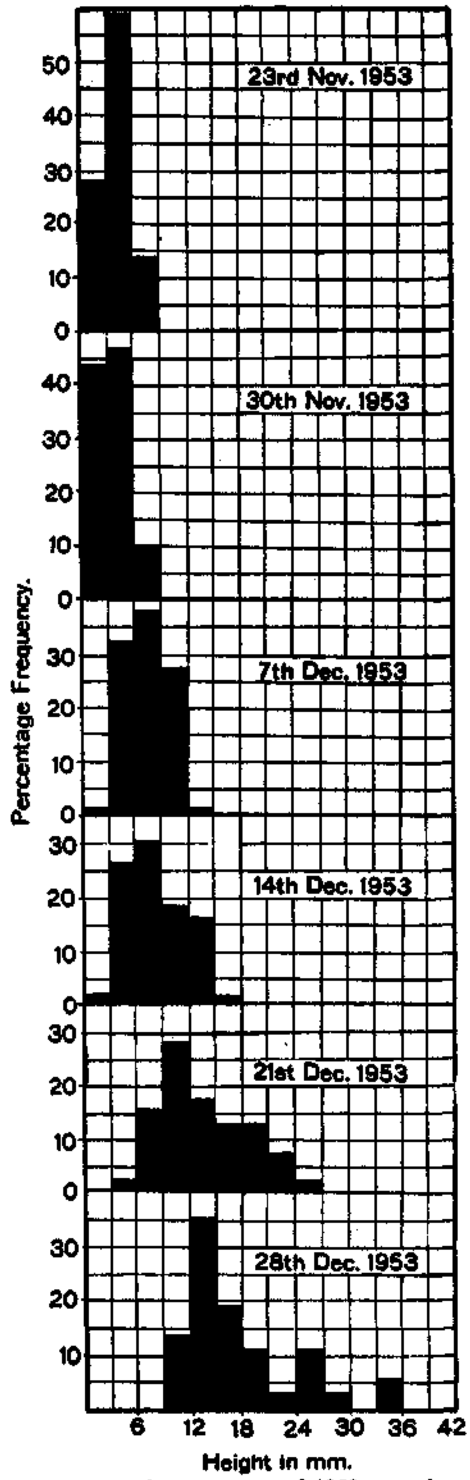

FIG. 3. Size-frequency diagram of oyster spat of 1953 year-class in different samples in November and December 1953.

43·5 mm., 40·5 mm., 40·5 mm., 49·5 mm. and 52·5 mm. for the months from May to September (Figs. 4 and 6 and Table II).

In October 1954, soon after the bar had opened the yearlings then nearing completion of one year were observed to put forth quite fresh shoots from their shell margins, showing a sudden increase in growth rate. Even the stunted oysters were observed to put forth new and quite prominent shell shoots. By the end of October, the yearlings showed a maximum size of 84 mm. and a mean size of 50·6 mm. The mode of the population has shifted to 55·5 mm. from 52·5 mm. observed in the previous month (Figs. 4 and 5 and Table II).

On the 15th of November 1954 spat of a new year-class (1954 year-class) varying from 1·5 mm. to 6·0 mm. were obtained in the samples, with a mean value of 4·16 mm. and a majority size-group of 4·5 mm. The earliest setting of this year-class should have occurred in the first week of this month as observed earlier. At the end of one month the maximum size attained by the new year-class was 22·5 mm. and the mean 7·58 mm., with the highest frequency value at 7·5 mm. The older year-class (1953 year-class) at the end of this month had reached a maximum of 96 mm. and a mean size of 55·5 mm. The mode value, however, has remained the same as in the previous month (Figs. 5 and 6 and Table II).

In December 1954, January and February 1955 oysters showed considerable increase in growth, the new year-class having reached 2, 3 and 4 months in age with maximum sizes of 14·6 mm., 16·4 mm. and 24·4 mm. and the old year-class having completed 14, 15 and 16 months with maximum sizes of 102, 107 and 109 mm. (Figs. 5 and 6 and Table II). Setting which started in the first week of November 1954, had lasted for over 3 months, up to the first week of February 1955, a duration which was very much longer than that observed in the previous year.

Fig. 7 shows the mean rate of increase in height of spat in different months during the period of study. The values plotted in this figure are derived from the mean growth curve in Fig. 6. In the period from November 1953 to March 1954, the values at the end of the respective months, as read from the mean curve, are 6, 15, 22, 28 and 33 mm. and the monthly rates of increase therefore are 6, 9, 7, 6 and 6 mm. respectively. It may be seen that growth was comparatively better during this period than in the two other succeeding periods. In the next period, from April to June, growth rate was moderate as the mean values were 37, 40 and 43 mm. and the rates of increase were 4, 3 and 3 mm. The period from July to September 1954 showed the poorest growth rate: the mean growth values were 45, 47 and 49 mm. with an increase of 2 mm.

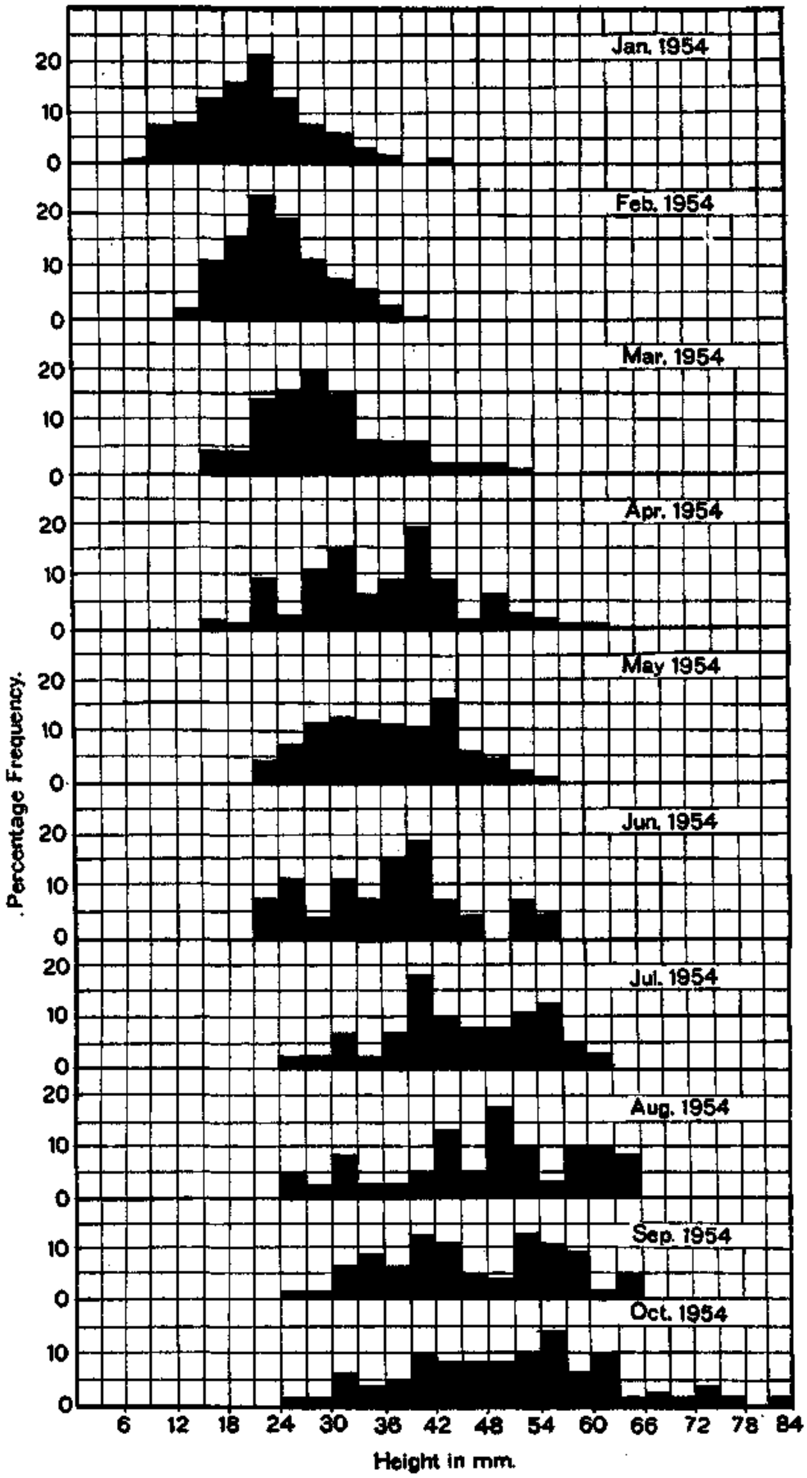

FIG. 4. Size-frequency diagram of oyster spat of 1953 year-class in different samples from January to October 1954.

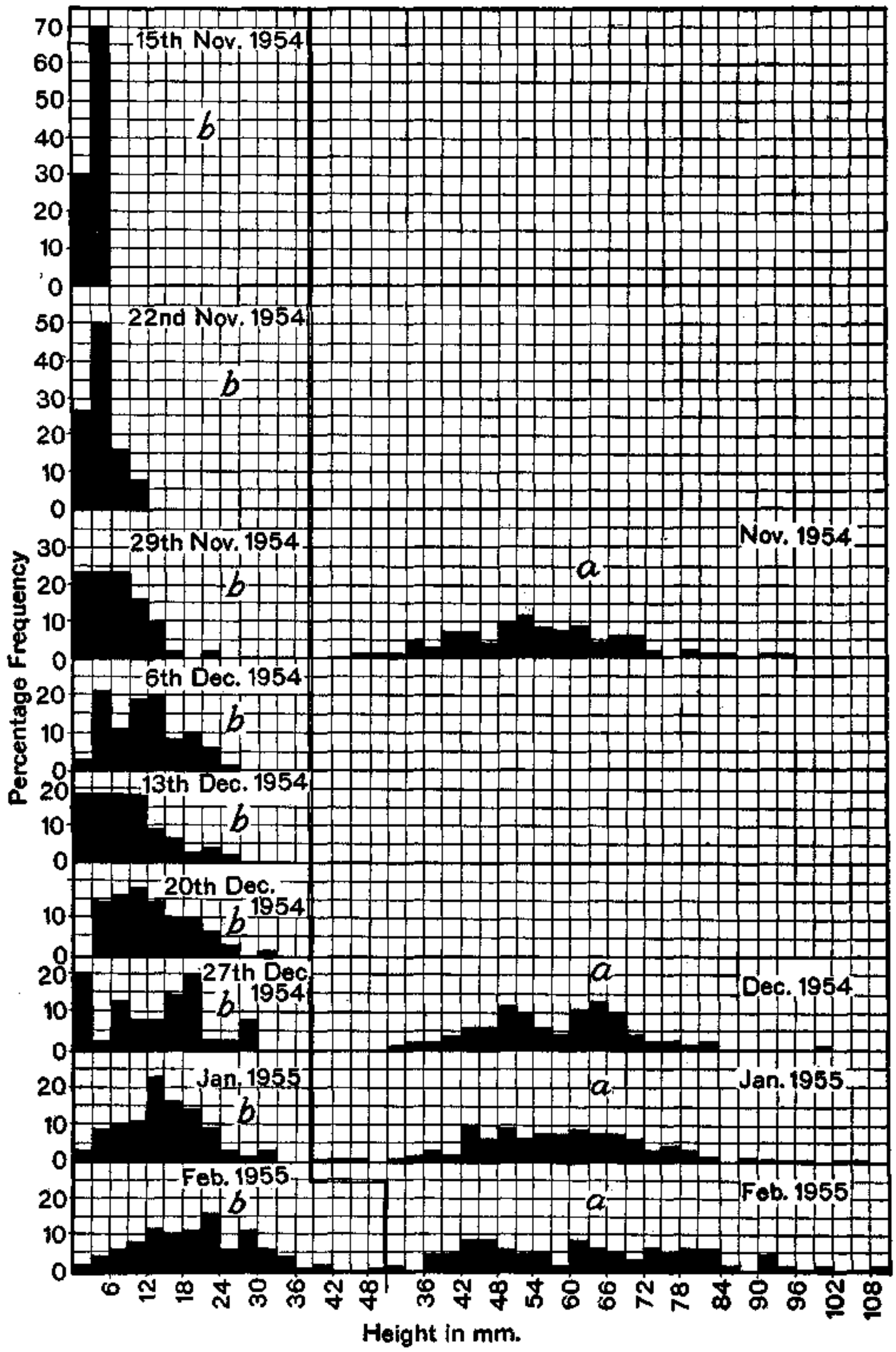

FIG. 5. Size-frequency diagram of oysterlings of 1953 year-class (*a*) and spat of 1954 year-class (*b*) from November 1954 to February 1955.

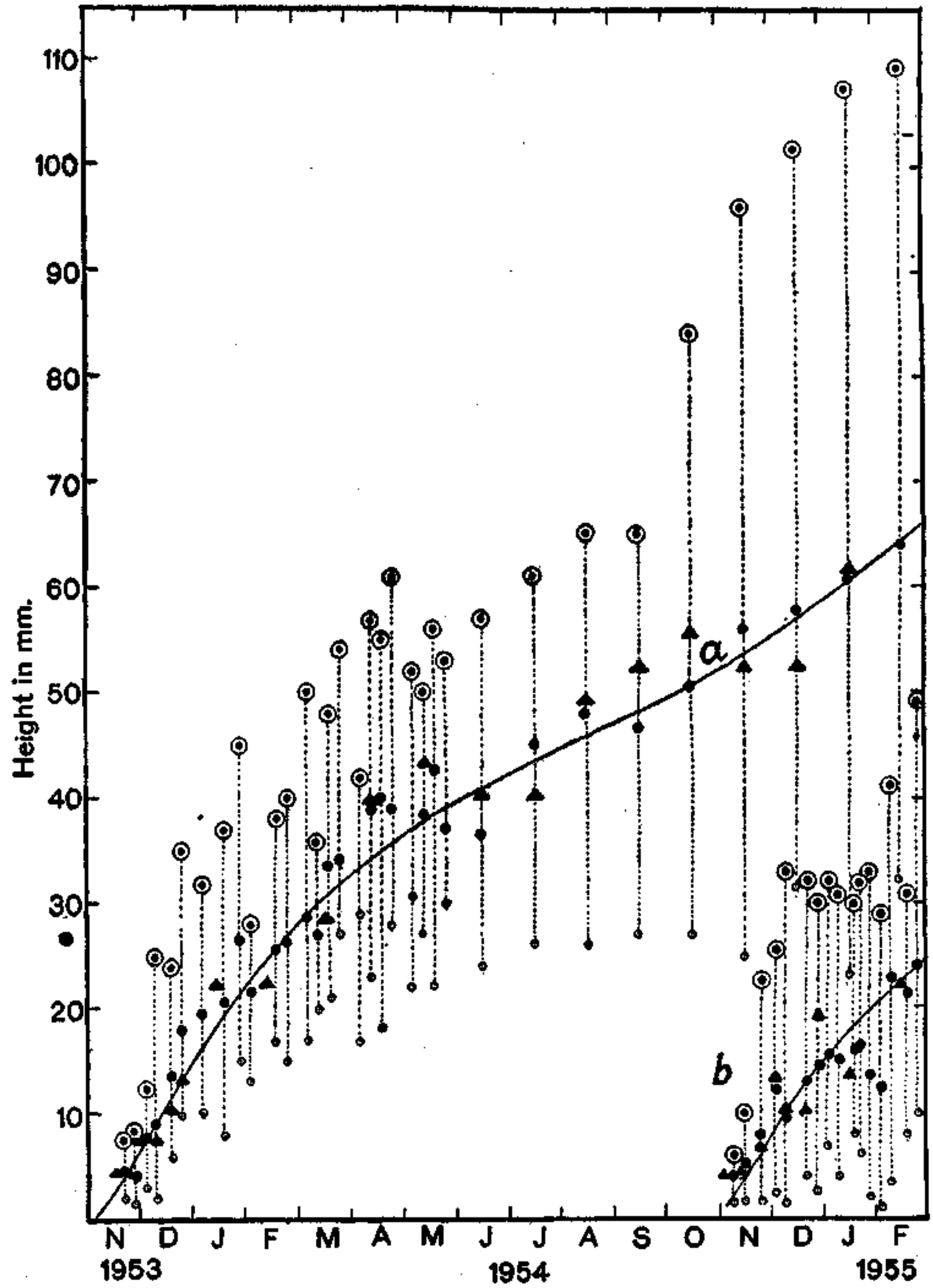

FIG. 6. Mean growth curves in height of oyster spat of 1953 year-class (*a*) and of 1954 year-class (*b*). Large hollow circles with solid centres indicate the maximum size; small hollow circles for the minimum size; small solid circles for the mean size and solid triangles for the highest frequency size-group of each sample, the range of which between the minimum and the maximum sizes is indicated by a dotted line.

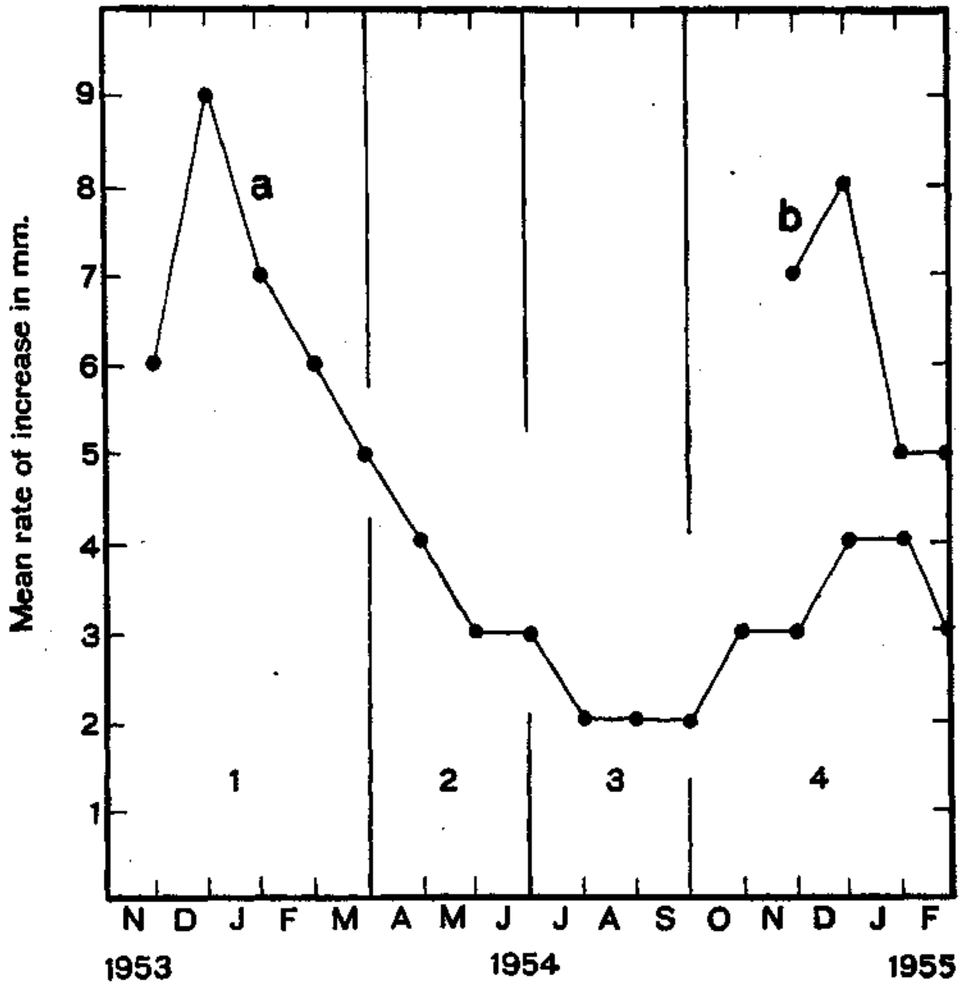

FIG. 7. Rate of increase in mm. in different months of the populations of 1953 year-class (*a*) and of 1954 year-class (*b*). 1 and 4 indicate the periods of rapid growth and 2 and 3 indicate the periods of moderate and slackened growth respectively.

in each month. That growth was reawakened was evident from the upward trend of the curve from October 1954. In the period from October 1954 to February 1955 the mean rates of growth of the population of 1953 year-class for the respective months were 52, 55, 59, 63 and 66 mm. showing an increase of 3, 3, 4, 4 and 3 mm. respectively. The population of the 1954 year-class, being younger, showed naturally a higher rate of growth than the 1953 year-class during this period. In the first 4-month period, from November 1954 to February 1955, this new year-class showed a mean rate of growth of 7, 15, 20 and 25 mm. with an increase of 7, 8, 5 and 5 mm. in the respective months, a rate of increase which was more or less similar to that observed in the 1953 year-class for the corresponding period.

From the foregoing account it is evident that the period of spat setting which occurs in the beginning of November follows a few weeks after the opening of the bar at the river mouth. Setting lasts for a period varying from a few to several weeks. No spat is set after the bar is closed. Growth, though uneven in individual spat, is fairly rapid, the population attaining a maximum size of about 60 mm., with a mean of 40 mm., when it is 6 months old. When they are one year old the maximum size attained is 84 mm. and the mean size is 51 mm. At the end of one year and four months the maximum size attained is 109 mm. and the mean size 63·7 mm. The rate of growth is rapid during the period from October to March, moderate from April to June and slow from July to September. Conditions seem to be conducive for growth during the period when the bar is open and the sea in communication with the estuary.

Formation of Growth Rings and Extent of Growth during October 1954 to January 1955

In oysters of 1953 year-class, collected during or after the opening of the bar in October 1954, distinct zonation has been noticed on the shells, a whitish zone of earlier formation and a darkish one of recent formation. The two are separated by a well-defined growth interruption line or ring. Plate II shows these rings and the extent of the zones in a sample of 12 oysters obtained in January 1955, the measurements of which are given in Table III. In each individual oyster, the height and width of the zone of earlier formation, measured within the limits of the ring, have been deducted from the corresponding measurements of the specimen as a whole to obtain the extent of height and width in the zone of recent formation. The extent of fresh growth in height and width are in each case expressed as percentages of height and width of the earlier formation. In the small sample examined, the percentage increase in height ranges from 38·1 to 87·5 and that of width from 51·6 to 163·1, depending upon the size of the individuals, the samller ones showing a greater extent of growth than the larger.

In Fig. 8 the total height and width for respective measurements within the zone of earlier formation are plotted separately for 88 specimens of a random sample obtained in January 1955. Mean values for growth of size-groups of 10 mm. range in height have been calculated and shown in Table IV and Fig. 8. Separate curves have been fitted to the mean values of height and width to show the extent of growth during the period. It may be seen that oysters of 20 mm., 30 mm., 40 mm., 50 mm. and 60 mm.

TABLE III

Individual measurements of oysters in Plate II with extent of recent growth

No.	Zone of earlier formation		Specimen as a whole		Percentage increase	
	Height mm.	Width mm.	Height mm.	Width mm.	Height mm.	Width mm.
1	26	15	46	36	76·9	140·0
2	28	16	43	38	53·5	137·5
3	29	18	56	41	75·8	127·7
4	32	24	60	46	87·5	91·6
5	43	17	64	39	48·8	129·4
6	42	19	71	50	69·0	163·1
7	33	31	53	54	60·6	74·1
8	43	22	63	44	46·5	100·0
9	55	36	76	55	38·1	52·7
10	44	31	67	47	52·2	51·6
11	53	33	75	53	41·6	60·6
12	49	34	76	56	75·5	64·7

in height at the beginning of the growth period in October 1954 would attain 40 mm., 50 mm., 62 mm., 74 mm. and 88 mm. by January 1955. Similarly, oysters having a width of 20 mm., 30 mm., 40 mm. and 50 mm. at the commencement of growth period would attain 37 mm., 44 mm., 53 mm. and 61 mm. respectively by January 1955. Table IV also shows percentage increase in height or width for the period of growth within size-groups of 10 mm. range. It may be seen here, as in the 12 specimens of Plate II, that smaller oysters show a higher percentage in growth than the larger ones.

AGE AT WHICH OYSTERS REACH MARKETABLE SIZE

In the sample of the 1953 year-class obtained in January 1955, at the age of 16 months, of a total of 136 oysters, it was found that only 32, *i.e.*, 23·5%, were of marketable size, being 70 mm. and above in height. In the same month a small collection of individuals of marketable size from a place

TABLE IV

Th extent of growth in Adyar oysterlings in the period from October 1954 *to January* 1955

Height in zone of earlier formation in size-groups (mm.)	Mean total height (mm.)	Percentage increase	Number examined	Width in zone of earlier formation in size-groups (mm.)	Mean total width (mm.)	Percentage increase	Number examined
21–30	45·2	80·8	26	11–20	34·8	132	20
31–40	57·4	64·0	29	21–30	41·6	66·4	38
41–50	67·8	49·5	21	31–40	50·64	44·6	25
51–60	75·8	37·8	12	41–50	55·50	23·3	6
TOTAL ..			88	TOTAL ..			88

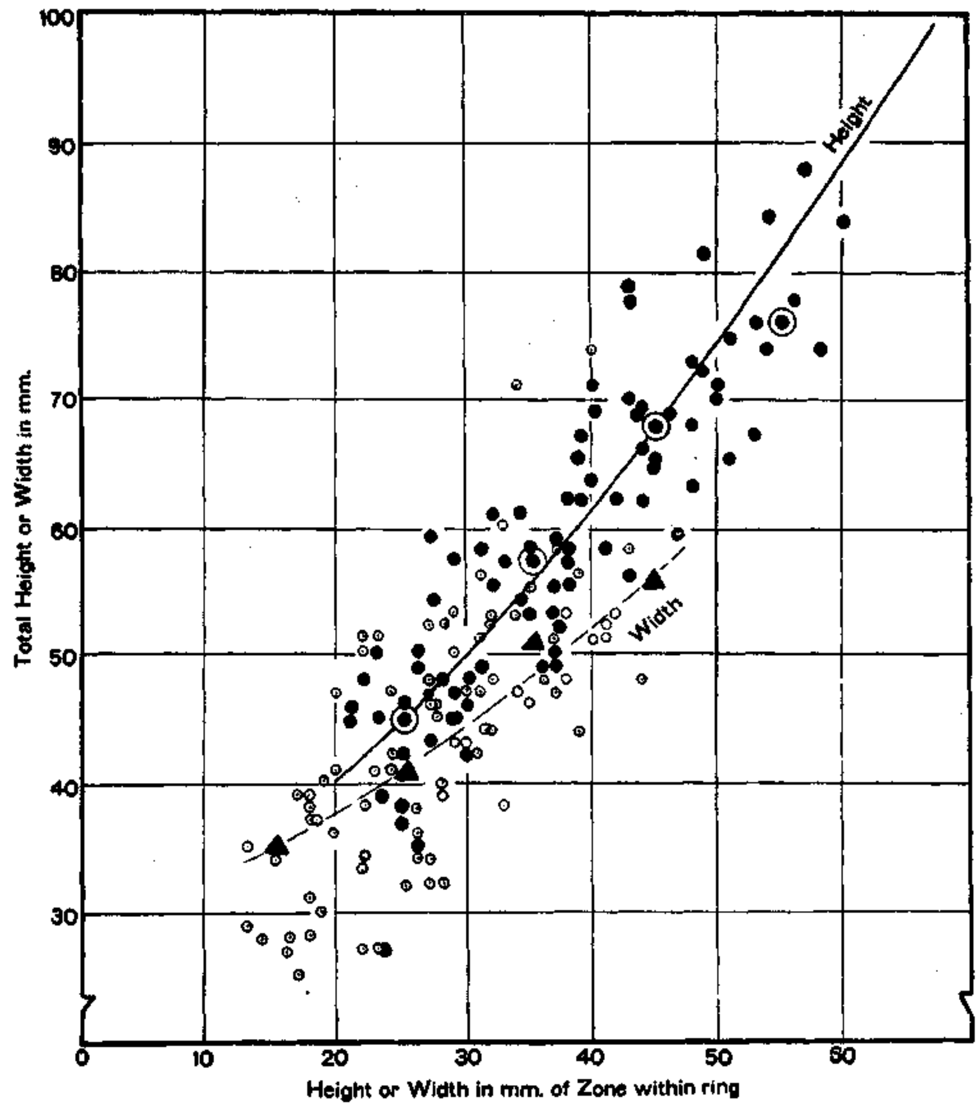

FIG. 8. Extent of growth in height and width in a sample of 88 yearlings during the period of October 1954 to January 1955. Solid circles indicate the height and hollow circles the width. Large hollow circles with solid centres and solid triangles represent mean values in height and width respectively in different size-groups of 10 mm. intervals.

adjacent to the experimental bed, revealed the presence of 2 interruption rings and 3 zones in each. Measurements of these specimens are given in Table V. Based on our observations that these rings are annual and that setting commences about November of every year in this estuary, this lot of individuals showing two rings must be older than the 1953 year-class by one year and is presumably two years and four months old. Despite the fact that a small lot of individuals are ready for the table when they are almost in the middle of the second year of their life, the majority reach a marketable size only when they have completed two years and are in the middle of their third year.

TABLE V

Measurements of height and width of the oysters in their third year of life

Whole oyster		Within Ring 2		Within Ring 1	
Height (mm.)	Width (mm.)	Height (mm.)	Width (mm.)	Height (mm.)	Width (mm.)
97	59	77	46	51	35
130	77	114	68	65	58
110	89	73	69	51	53

HEIGHT-WIDTH RELATIONSHIP IN OYSTER SPAT AND YEARLINGS

It is well known that oysters in general vary a great deal in shape, even within the same species. Since they are fixed to one spot, cemented by their left valves, the shape they assume as they grow depends to a large extent upon the nature of the substratum where they settle after a period of early larval life. Those settling on flat surfaces assume a flat shape and others falling on uneven surfaces conform to the contours of their substrata. Overcrowding results in the assumption of a variety of crooked forms. Besides, environmental factors such as " salinity, current velocity, wave action, depth and exposure " may lead to variation in shape (Korringa, 1953). To ascertain the general form at different sizes a large number of spat were measured for their height and width.

In Fig. 9 the height-width relationship of 612 spat and yearlings of varying sizes are plotted. Mean values have also been calculated for members within size-groups of 10 mm. intervals as given in the table. A curve has been constructed to fit the mean values of the size-groups, from which it is possible to read the approximate height or width an oyster may attain when either of the measurements is known. The deviation of the actual values from the mean values increases with the size of the oysters. It may be seen (Table VI) that in size-groups up to 25 mm., height tends to be the same as width, with the result that the spat are orbicular in form. In size-groups

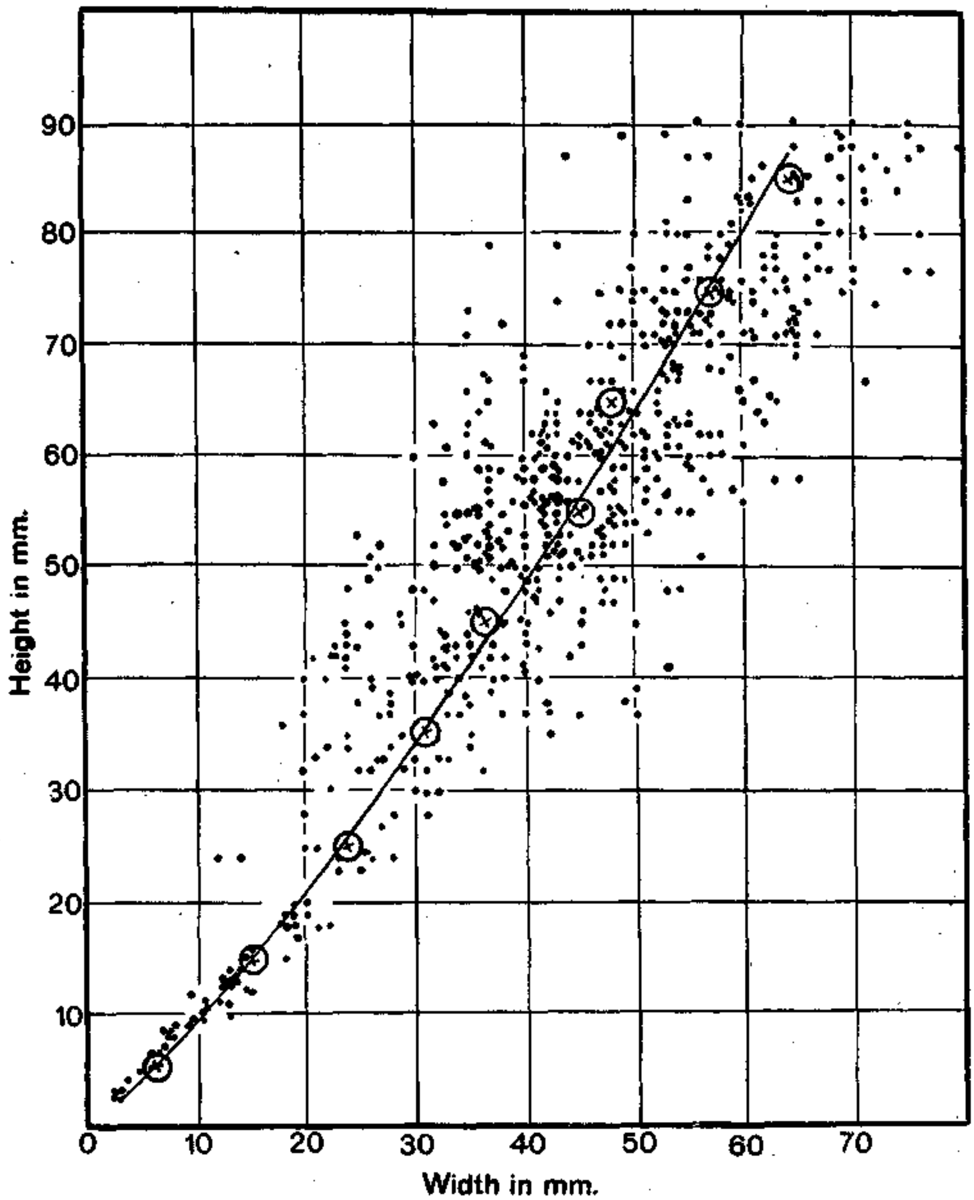

FIG. 9. Height-width relationship of oyster spat. Circles with a cross in each denote the mean values in width of individuals for size-groups of 10 mm. intervals in height.

35 to 55 mm. they assume an oval form in which the width is a little less than the height. In size-groups of 65 mm. and above, the general contour is distinctly elongate, the width approximating to about three-fourths of the height.

TABLE VI

Height-width relationship of oyster spat and yearlings from Adyar estuary

Height in size-groups (with mid-points) (mm.)	Mean width (mm.)	Number examined	General shape
0 -10 (5)	6·6	24	Orbicular
11-20 (15)	15·4	29	
21-30 (25)	24·3	18	
31-40 (35)	31·3	56	Oval
41-50 (45)	36·5	93	
51-60 (55)	45·3	131	
61-70 (65)	48·0	110	Elongate
71-80 (75)	57·2	104	
81-90 (85)	64·7	47	
TOTAL ..		612	

GENERAL CONSIDERATIONS

Rapidity of growth-rate of oyster spat in Adyar estuary.—Hornell (1910), based on Moore's (1898) report, states that in France the oyster spat which settle in July grow to a diameter of about 1·8 cm. by October when they are 3 months old, and that growth-rate in England and Holland is still slower, whereas in the warm sounds of North Carolina in America, it is more rapid, a length of about 3·8 cm. being attained in 3 months. In the American oyster, *Ostrea virginica*, from the warm waters of Apalachicola Bay in Florida, Ingle (1950) records the remarkably rapid growth of 4·5 mm. at the age of 1 week, 8 mm. in 2 weeks, 62·4 mm. in 15 weeks and 104 mm. in 31 weeks. Menzel (1951) states that the same oyster in Louisiana waters grows to a diameter of 50 mm. in 2 months, 75 mm. in 4 or 5 months and 100 mm. within 9 months after setting. For the Madras oyster, Hornell's (1910) observations which are confined to growth in the first two months after setting, show that in about 1¾ months the spat attain a length of 2·7 cm., a rate which is 2½ times more rapid than that observed in France. That the spat reach a maximum height of 8·5 mm. in 3 weeks, 61 mm. in 6 months, 84 mm. in 13 months, 96 mm. in 14 months, 102 mm. in 15 months and 109 mm. in 17 months as revealed by the present study, indicates a much faster rate of growth in the Madras waters than on the coasts of France or England, but about the same as that observed in the bays of Florida and Louisiana in the United States of America. The maximum growth recorded here in this oyster from the Adyar estuary, *viz.*, 35 mm. in one month and 3 weeks (51 days) and 61 mm. in six months (180 days) as against 21·5 mm. in 44 days and 66 mm. in 243 days observed by Paul (1942) in spat from the Madras harbour, shows that growth in this species is better in an environment which is estuarine than in one which is more or less marine.

Although a very rapid rate of growth is inferred from the maximum size attained by some individuals, the samples obtained in different months present a wide range in size as pointed out earlier. At the end of a 12-month period the individuals varied in height from 24 to 84 mm. with an average of 51 mm. A similar variation in the size-range of about 5 to 35 mm., with an average of 19·6 mm. in a 12-month old population of *Ostrea edulis*, from the Thames estuary oyster beds in 1914, has been observed by Orton (1926, 1937). The mean size is also found to vary in different years, even in the same beds and in spat of approximately of the same age, for in the year 1922, which had been preceded by one unusually warm resulting in good spat falls, a higher average of 27·4 mm. was recorded in a population 13 months old. The mean size of 51 mm. attained at the end of one year by the Madras oyster, is very much higher than that observed in *Ostrea edulis* even under favourable conditions.

Factors influencing growth-rate in oysters.—Korringa (1953) states that shell growth is limited to warm months, at least in temperate regions as this is, like many other activities of the oyster, dependent upon water temperatures. Orton (1937) observed that on English oyster beds growth is confined to summer and autumn. Loosanoff and Nomejko (1949) report that in waters north of and in Chesapeake Bay, growth takes place only during summer and stops in winter. Kobayashi (1948), as referred to by Cahn (1949), observes that in *Pinctada martensii* growth is restricted to the months when water temperatures are high, followed by a period of rest when the temperature drops and the oysters hibernate. Almost all the workers who have studied oysters and other shell-fish from the temperate waters have found that growth is confined to the periods when the water temperatures are high. The experimental observations of Loosanoff (1950), Hopkins (1951), Nelson (1921), Galtsoff (1928) and Elsey (1936) on *Ostrea virginica* and *Ostrea gigas* show the extent to which low temperatures adversely effect the opening of the valves and the circulation of water current to secure the organisms forming the food of the oyster. The rate of growth is dependent not only upon the availability of food in the environment but also upon the ability of the organism to secure it. Very low temperature conditions in winter either considerably slacken or prevent water circulation resulting in very poor or altogether no growth in the temperate regions. About 9° C. has been found to be the minimum temperature for shell growth in *Ostrea gigas* (Quale, 1952). Ranson (1949) observed good shell growth in *Gryphæa angulata* on the coast of the Isle of Oleron between 10° and 25° C. Such very low temperature conditions as would hinder the normal activities of the oyster are never obtained in tropical waters. During the period of observations from October 1953 to February 1955 the temperature has been found to fluctuate between a minimum of 26° C. and a maximum of 30·5° C. There being practically no difference in the range of temperature in the periods of rapid growth from October to March (26·0 to 30·4° C.), of moderate growth from April to June (28·0 to 28·5° C.) and of little or no growth from July to September (28·3 to 30·5° C.), it is not probable that this small fluctuation can be a determining factor for growth in the Madras oyster.

The question whether too low or too high salinities produce any adverse effects on oysters has always been controversial. Though they can tolerate short spells of very low salinities by closing their valves, they cannot withstand immersion for prolonged periods. Ranson (1943) has observed in *Gryphæa angulata* a gradual degeneration of tissues in waters of salinity below 7‰. Butler (1949) found an inhibition of gametogenesis in 90% of *Ostrea virginica* in an area of salinity below 6‰ and this he attributed to the starvation of oysters because of their inability to feed under low salinity conditions. Chestnut (1946) states that in Delaware Bay, at stations where high salinity prevailed throughout the tidal cycle, the oysters have been found to feed at any time, but at stations under low salinity round about the low tide, feeding has been temporarily suspended for the duration of such low salinity conditions. The experiments of Loosanoff (1950 *b*) on *Ostrea virginica* show that the species is capable of withstanding sharp changes from low to high salinities without serious physiological injuries, but not prolonged immersion in water of very low salinity which results in tissue starvation proving ultimately fatal. Cole and Hepper (1954) in their study of filtration rates in mussels by the use of neutral red solution, state that low salinity has a much greater depressing effect than has been generally realised. It is, however, observed that the adverse effects of low salinity revealed by their experiments are probably due to the mussels used for the purpose having been obtained from the higher reaches of Conway estuary where high salinities usually prevail and that a different behaviour would not be unlikely if mussels more frequently and regularly exposed to low salinity are used instead.

In Adyar estuary salinity, unlike temperature, has been found to fluctuate over the very wide range of 0·3 to 41·1‰ during the period of observations from October 1953 to February 1955. It may be recalled that the period of rapid growth has been observed to be from October to March, of moderate growth from April to June and of poor growth from July to September. It is seen from the data in Table I and from the rate of increment in different months shown in Fig. 7, that growth rate is not affected in any way by short spells of low salinity occurring during a tidal cycle when the bar is open, that it is retarded to some extent under salinities remaining constantly high during drought conditions and that it is considerably slackened by prolonged sojourn under low salinity conditions when the estuary is flooded with river water. There is also, probably, a more abundant supply of suitable food organisms in the estuary during the periods when the bar is open than when it remains closed to account directly for the differences in the rate of growth of the oysters in the different periods. Unfortunately, there is no satisfactory method of determining seasonal fluctuations in the abundance of the kind of food which the oyster requires for its nourishment.

There seems to be no relation between the fluctuations in pH values of waters over the oyster beds given in Fig. 1 and the mean rate of increase in spat and yearlings in different months shown in Fig. 7. Loosanoff and Tommers (1947) have found that the oysters normally pump at a pH of 7·75 and that their pumping rate is adversely affected below 7·0. At a pH of 4·14, it has been noted that their pumping rate has decreased to 10% of the normal rate. During the period of present observations the pH of the waters over the oyster beds never fell below 7·0 so as to hinder the normal rate of pumping and thus affect the growth-rate.

Validity of growth-checks in age-determination.—The determination of age by the interpretation of growth-interruption lines on the shells in various bivalve molluscs, of both the temperate and tropical waters, has been briefly discussed by Rao (1951) and Nayar (1955). Recently, Gokhale *et al.* (1954) have based the age determination in *Pinctada* sp., on the measurement of rings and have attempted correlation between the number of rings and peak values in the size-frequency distribution of their samples, taking thickness of the oyster as a standard of measure. They have found that growth ceases in *Pinctada* sp., in the Gulf of Kutch, during summer months, resulting in the formation of rings owing to some as yet undetermined internal biological factor. Nayar (1955) states that in *Donax cuneatus* of Palk Bay there is cessation of growth leading to ring formation in November–December, probably as a result of a reduced level of nutrition because of the disturbed condition of the beds during the north-east monsoon. In *Katelysia opima*, from the same environment as the present species, a definite correlation has been found between the data from the size-frequency studies and the measurements of growth rings (Rao, 1951). Both in *Katelysia* and the oyster there is little or no growth during the period from about July to September, and this cessation of growth is indicated by the interruption lines on their shells.

It is worthwhile mentioning here Sewell's (1924) observations on the remarks of Petersen (1908 and 1918) and Massy (1913) regarding the question whether the age of an oyster can be determined by the number of rings on its shell. While Petersen has expressed that a " practised observer can estimate roughly the age from the outer appearance of the shell", Massy has concluded that it is not of much use to apply the study of rings to the age determination of an oyster. Sewell, examining the same data given by Massy, has found that although there is no exact correlation between the number of rings and the age of the oyster, the average number of rings for any given size is fairly constant. The ring on the shell being an indication of a period of cessation of growth preceded by one of active growth, the reason given for a varying number of rings in the samples examined by Massy has been that such periods of activity through which a given individual oyster may pass in any given time may vary enormously. In the Madras oyster, studied from the Adyar estuary, the interruption lines are annual and they do give an indication of the age of the shell-fish, the cause of their formation being the regular recurrence of prolonged periods of unfavourable growth, year after year, when the bar remains closed.

The formation of interruption rings in some bivalves is attributed by certain workers to an arrest of growth during spawning. Belding (1910) in the bay scallop, *Pecten irradians*, and Coe (1947) in the Pismo clam, *Tivela stultorum*, have observed that growth diminishes appreciably during the spawning season. In the backwater clam *Meretrix casta* from Adyar, Abraham (1953) has noticed a number of interruption-rings of varying intensity, from slender lines to deeply marked grooves, appearing in a cyclical manner apparently corresponding to the spawning peaks. A post-spawning cessation of growth does not seem to be a feature of universal occurrence. Belding (1912 and 1931) in the hard-shell clam, *Venus mercenaria*, and the soft clam, *Mya arenaria*, Coe (1947) in the California Bay mussel, *Mytilus edulis diegensis*, Rao (1951 *b*) in the estuarine clam, *Katelysia opima*, and Nayar (1955) in the wedge clam, *Donax cuneatus*, have observed growth during the spawning period. In respect of growth in oysters in relation to spawning activity, similar conflicting statements have been made by different workers. In *O. virginica*, while Needler (1941) finds that growth stops during the period of reproductive activity, Loosanoff and Nomejko (1949) observe that it is continued throughout the period extending from April to November without interruption during spawning. Ranson (1949) observes, in oysters (*G. angulata*) kept in the claires or fattening ponds, practically continuous growth, but not in those in the parks where growth is interrupted in the period of spawning. Korringa (1953) considers that in waters rich in food, spawning hardly leads to interruption of growth, but in waters constantly or temporarily poor in it the older oysters do show an interruption of shell growth during the season of reproduction. As the period of rapid growth overlaps that of spawning, the interruption lines on the shell of the Madras oyster have no relation to the reproductive activity.

Determination of age by indicators other than rings on the shells has been attempted by Nelson (1942) in the Delaware Bay oysters (*O. virginica*) which, according to him, shift their ligaments posteriorly once every winter, leaving one line per year on the ligament scar. We have not, however, been able to make use of, in the present study, growth lines on ligament-scars for determining the age of the Madras oyster.

Summary

(1) The rate of growth of spat and yearlings of the backwater oyster, *Ostrea madrasensis*, has been sudied by the size-frequency method in random samples collected from the Adyar estuary during the period, October 1953 to February 1955.

(2) Spawning of the oysters has been observed in the November–December period of both the years 1953 and 1954, and the setting of spat only when the estuarine waters over the oyster beds are in communication with the sea.

(3) The spat reach a maximum height of 8·5 mm. in 3 weeks, 61 mm. in 6 months, 84 mm. in 13 months, 96 mm. in 14 months, 102 mm. in 15 months and 109 mm. in 17 months. The mean heights attained for the corresponding periods are 4·5, 39·2, 50·6, 55·5, 57·9, 60·5 and 63·7 mm. The majority of the individuals attain marketable size when they have completed 2 years and are in their third year of life.

(4) The rate of growth is vigorous from October to February, moderate from March to June and poor in July to September. Widely fluctuating environmental conditions seem to account for the differences in the rate of growth in the different periods. Prolonged immersion of spat or yearlings under very high or very low salinity conditions, as when the sand bar cuts off communication of the estuary with the sea, has an adverse effect on the growth-rate. Growth of spat under laboratory conditions has been found to be extremely poor.

(5) There is a distinct zonation on the shell surface, with well-defined rings indicating periods of cessation of shell growth. The rings seem to be annual, the cause of their formation being the regular recurrence of prolonged

unfavourable environmental conditions, as a consequence of the bar periodically remaining closed.

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Explanation of Plates

Plate I. Fig. 1. Spat collected on 15th November 1954. Minimum size (height) 1·5 mm.; Maximum size 6·0 mm.; Mean size 4·2 mm. The largest spat are 10 to 13 days old. Fig. 2. Spat collected on 27th December 1954. Minimum size (height) 2·5 mm.; Maximum size 30·0 mm.; Mean size 14·6 mm. The largest spat about 8 weeks old. Fig. 3. Spat collected on 30th January 1955. Minimum size (height) 2·0 mm.; Maximum size 33·0 mm.; Mean size 13·8 mm. The largest spat about 12 weeks old. Fig. 4. Spat collected on 14th February 1955. Minimum size (height) 3·5 mm.; Maximum size 41·0 mm.; Mean size 23·1 mm. The largest oysterlings 14 weeks old.

Plate II. Fourteen-month-old oysterlings showing distinct regions of old and recent growth on shell (data as in Table III).

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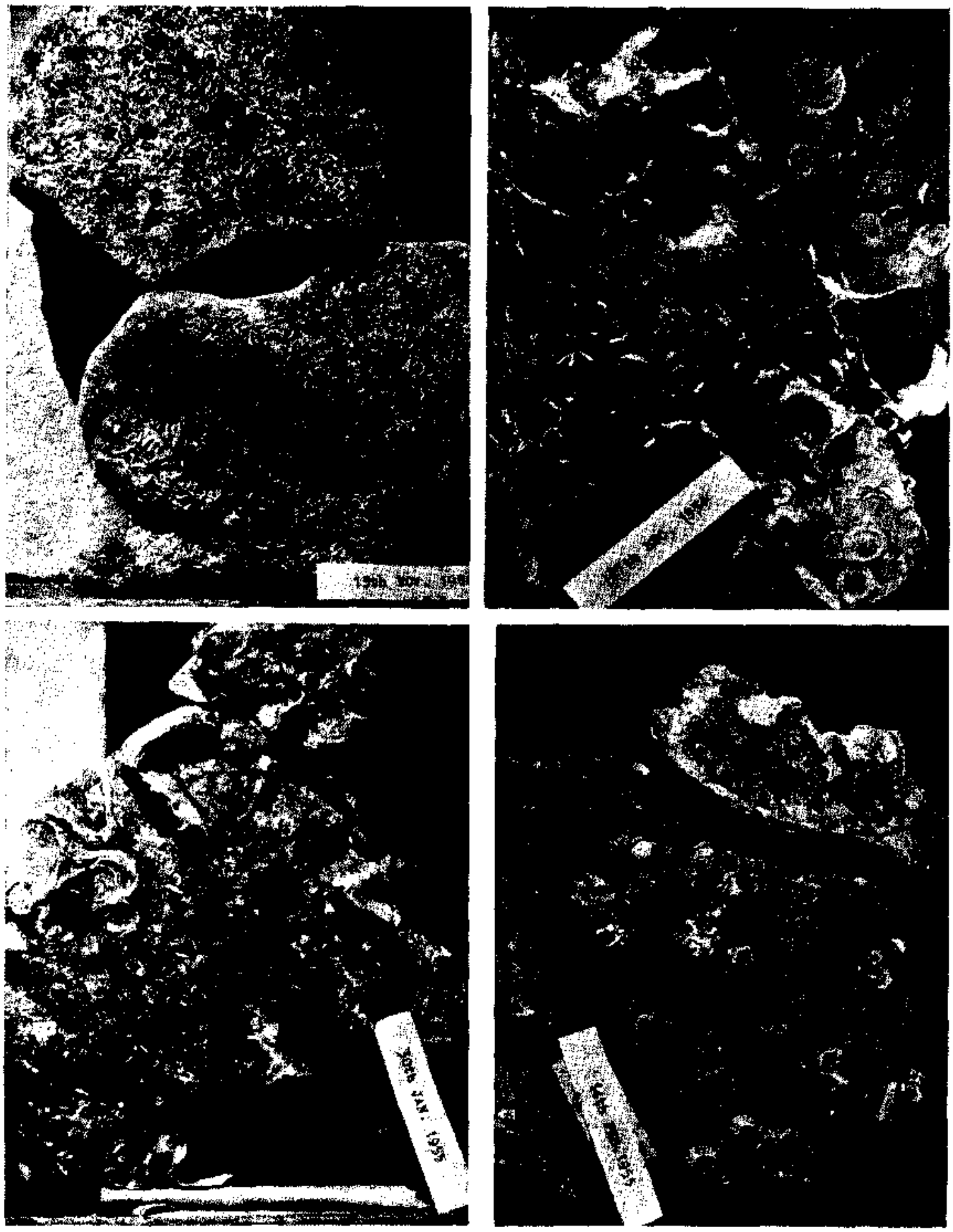

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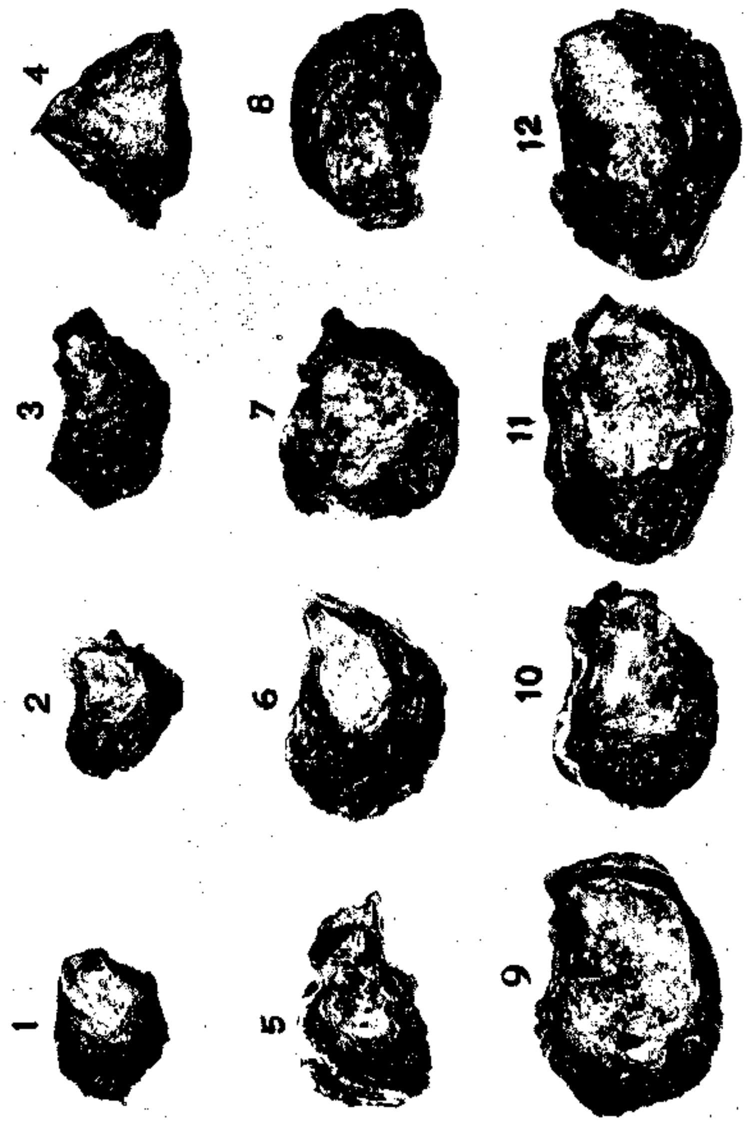
FIGS. 1–4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