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Growth and mesh selection in the edible cockle (Cardium edule L.)

by

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Introduction

Much work has been done with commercial fish populations on the determination of growth rates and the effects of fishing by nets with different sizes of mesh. The ageing of many species of fish is however not completely straightforward and back interpretation of the rings on otoliths and scales as a way of determining the previous growth histories of individual fish may lead to errors and bias.

In cockles, growth is measured by changes in the dimensions of the shell, in particular its length (Figure 1a), and these are not likely to be subjected to modifying influences with increasing age. Well-defined annual rings occur on the shell in most areas, formed as a result of winter cessation of growth, (Orton. 1926) and these require no back interpretation, but merely direct measurement. Cockles should therefore provide a useful subject for examining the effects of selection at the legal minimum size and for determining the subsequent influence of these effects on the population. The information derived could help towards an understanding of some of the problems relating to growth and mesh selection in fish, many of which are apparently as yet unresolved (Jones 1960). The following report presents a preliminary account of observations which are not yet complete. The seasonal growth pattern has already been described (Hancock 1960) and shows rapid growth during the summer months (May to September) and no increase in shell length during the remainder of the year.

Minimum size regulations

Most cockle fisheries are subject to minimum size regulations, so that separation of the catch into legal and undersized components is necessary. Fishing is usually by hand often using a metal "scrape" to break the surface of the sand, and a rake (Plate 1), and the catch, including dead shells and sand, is riddled through a sieve. Sea Fisheries Committee byelaws sometimes include restrictions on the gauge of the sieving instrument to be used, like that in the South Wales District which reads "No person shall remove from a fishery:- Any cockle that will pass through the gauge of a riddle or like instrument used for the purpose of riddling, sorting or sifting cockles having an aperture of ¾" (19 mm.) square."

Alternatively just a gauge is specified which may or not be square, as by North Eastern Sea Fisheries Committee:- "No person shall remove from a fishery any cockle which will pass through a gauge having an oblong opening of ¾" (19 mm.) in breadth and two inches (51 mm.) in length." (Figure 1b) Sometimes restrictions are placed on the distance between the teeth of fishing rakes, but this is a less effective method of selection. The regulations vary from district to district round the coast of Britain (Figure 2), and the selected minimum size should reflect the average growth rate, which varies considerably from area to area.

Factors affecting average growth rate

Determination of the average growth rate involves a knowledge of the basic factors which influence growth. Being sedentary organisms, the growth of cockles would be expected to exhibit more localised differences than mobile forms like fish, and growth rates have been found to vary between areas separated by only a short distance on the same cockle bed. Growth increments are usually related to the shell length dimension (Figure 1a), and Figure 3 shows how the mean length of two year old cockles varies from East to West across a cockle bed in South Wales. This is in some way influenced by the position relative to the mouth of the river, and to tidal exposure or distance from low water mark as can be seen from the correlations shown in Figure 4. The growth rate is not constant from year to year (Table 1) as a result of variable seasonal conditions which will affect behaviour and the amount of available food, and the average growth rate calculated for an area in any chosen year will be affected by the relative intensity of settlement in fast or slow growing regions. The mean length of cockles attained in the third and subsequent years is of course affected by the size attained in previous years (Table 1). In years of unusually heavy settlement, the effects of competition for space and food include changed shell shape and reduced growth rate in regions of high density.

When calculating the average growth rate for a fishery the previous effects of selection must also be considered, and determination of the true growth rate of year classes subsequent to the age at selection may be difficult. On Llanrhidian Sands selection commences during the summer period of addition of the second growth increment, and throughout the following winter. Soon after growth recommences most of the cockles entering their third year have been fully recruited. There is therefore a longish period of almost one year during which cockles at the selection age, which in this fishery constitute the bulk of the fishable stock, are being heavily exploited. Figure 5 shows the sort of effect this can produce, and the apparent growth rate of cockles surviving after selection is less than the true growth rate. This effect is similar to that described by Lee (1912) in fish, but further observations are necessary before it can be decided whether selection is the only contributory cause (Taylor 1958).

A full understanding of the influence of so many factors on growth rate is necessary before a minimum size can be properly adjusted even for one cockle fishery for one year, and these observations emphasise the difficulty of choosing a single minimum size to cover the large area administered by each Sea Fisheries Committee (Figure 2) and intended to remain in effect for many years. Table 1 shows how small differences in mean shell length from year to year, and small changes in the minimum size, can drastically affect the proportion of the stock which can be fished, and in Figure 3 it can be seen how more than 80% of the stock could be fished in an area of fast growth, while in an area of slow growth as little as 11% would be fishable at the same minimum size.

Practical effects of Minimum size regulations

Although square meshed sieves are sometimes used, a wire meshed builder's or "bar" sieve with oblong apertures (Plate 1) is usually found to be more suitable for redepositing accumulations of dead shells as well as undersized cockles from the catch. The choice of sieve rests with the preference of individual fishermen provided the size of cockle landed conforms with the regulations. To determine the practical effects of a selected minimum size it is therefore necessary to obtain information on selection by both designs of sieve. The standard adopted in fish populations of a 50% retention size is a suitable measure also for cockles. As with fish, we are concerned with interpreting the effects of selection in terms of the length dimension, by which growth is measured, even though this dimension may not be the agent responsible for selection. A trawl net retains only half of the fish at the 50% retention size partly due to variations in mesh size, but also because of the variable girth measurements of fish of the same length, and the girth dimension is the selective agent. With a rigid square-meshed sieve it is easier to obtain and maintain a greater uniformity of aperture than with a net, but differential selection of shells of the same length occurs as a result of variation in the shell width measurement (Figure 1a). Selection by square meshed sieves is dependent on the two dimensions of length and width, and when cockles are sieved, steep ogives are produced with selection over a small length range (Figure 6a). When a bar sieve is used, the shells of the cockles are differently orientated (Figure 1b), and selection is dependent only on the width dimension. Similar selection ogives are produced (Figure 6b), but with selection over a rather greater length range. This is partly because bar sieves are manufactured with rather less accuracy, and the wires are subject to distortion after use. The results of bar-sieving cannot be repeated with the same degree of accuracy as those from square meshed sieves.

Shell length growth pattern

Before considering the immediate and long term effects of selection, the growth pattern requires careful examination. A large sample of 5,259 cockles collected from within an area of only 100 square metres on Llanrhidian Sands cockle beds during the winter months, was measured with vernier callipers to the nearest millimetre below for shell length at each growth check shown on the shell. The measurements were grouped according to age, and Plate 2 shows the relationship between the length of the shell at the completion of the first growing season (l_1, see Figure 1a) and that at the end of the second growing season (l_2) from cockles which were undergoing a growth check during their second winter i.e. rising two years of age. The total frequency distributions for both years recorded from the same shells were virtually symmetrical suggesting that so far there had been little or no selection. Plate 2 shows the wide variations in shell length (l_2) attained by growth of cockles of a single millimetre (l_1) group. Cockles with an l_1 close to the mean value of l_2. Those with an l_1 less than or greater than the mean size grew on average to a respective size less than or greater than the mean value of l_2. This is shown more clearly in Figure 7A. These results are very similar to those obtained by Farran (1928) for herring. The relative positions are maintained through subsequent years (Table 2), at least up to the completion of the fifth growth season, which was the oldest group with numbers sufficient for analysis. A similar pattern was obtained for haddock by Taylor (1958), who averaged growth rates from data accumulated over many years. There is continuous variation in growth in length from year to year as shown in Figure 8, in which the growth rings on 4th winter cockles have been analysed to show the variation produced by growth from the modal l_1 group (14 mm.) - cockles from the mode (24 mm.) of the l_2 distribution so obtained i.e. all of which had an l_1 of 14 mm. also grew with variation and so on to the fourth winter growth check.

The underlying growth pattern is based on the process of natural variation influenced by the time of settlement. In cockles, the main period of settlement is of relatively short duration, lasting about three months from early May until towards the end of July, but with a pronounced maximum in late May (Baggerman 1953), and fairly regularly decreasing numbers before and afterwards. There may occasionally be a separate late settlement in August-September, but these individuals are usually relatively few in number and are clearly distinguishable from those which settled earlier on. By the time the first winter check in growth occurs, cockles have acquired a symmetrical length distribution, and there is no physical indication of whether their time of settlement was earlier or later than average. A suggested pattern of growth behaviour to explain the result obtained in Plate 2 is given in Figure 7. Figure 7A shows the growth of millimetre l_1 groups to l_2 of cockles shown in Plate 2. In Figure 7B the reverse procedure has been applied to millimetre (l_2) groups to demonstrate the range of l_1 from which each group had grown, giving a similar pattern. Both figures show how variation in shell length occurs. This is only partially explained by difference in settlement time and depends also on variation in growth rate. An attempt at representing the probable combination of these two factors in a simple diagrammatic form is shown in Figure 7C. Cockles which have settled in any arbitrary time unit will include those capable of average growth, together with smaller numbers exhibiting slow and fast growth in shell length. As growth proceeds towards the first winter growth check, continuous overlapping of fast and slow growers from the arbitrary settlement time units occurs with the result simplified in Figure 7C. Each l_1 group, here taken as 1 millimetre which is the convenient unit of measurement, thus contains elements for slow, average and fast growth in shell length, in the same manner as demonstrated by Figure 7B. This helps to explain how some cockles with a large l_1 may grow to a smaller l_2 than some which had a smaller l_1 even though on average large l_1's produced larger l_2's (e.g. some 15 mm. cockles only grew to 20 mm. while some at 11 mm. grew to 23 mm (Plate 2)).

Length/width relationship and growth rates

With a knowledge of the distribution of fast and slow growing individuals in the length dimension, the relationship between length and the important selecting agent, width, may be examined. Cole (1956) has already pointed out that young quick-growing cockles have narrower shells than older slow-growing cockles of the same length, and this will result in different 50% selection lengths for cockles of different ages. There is also some evidence that the length/width relationship varies from place to place on the same cockle bed, and certainly between different cockle beds, so that more information than just shell length distribution is necessary when selecting a minimum size.

In Table 3A is shown the variation of width in each l_2 group of cockles measured for Plate 2, and mean shell width increases approximately linearly with shell length. In addition, Table 3B shows how shell width varies for each l_1 group shown on cockles with a selected l_2 length (22 mm.) and it can be seen that the mean shell width increases with increasing l_1 i.e. cockles which added the greatest shell length increment (10→ 22 mm.) were narrower on average than those with the smaller increment (16 → 22 mm.). Whole volumes showed the same trend demonstrated in the following table, but shell heights (Figure 1) remained unchanged.

l_1 mm.	l_2 mm.	Mean volume ml.
10	21	2.6
11	21	2.8
12	21	3.0
13	21	3.0
14	21	3.0
15	21	3.2

Problems arising from selection include not only its effects on observed growth rates and yield prediction, but also its possible influence on inheritable characters, and in view of the variability of shell shape related to differences in growth rate in the length dimension, it is important to be sure whether differences in growth rate within one locality do involve real differences in volume, and are not just the result of a combination of the effect of time of settlement and variation in shell shape.

<u>Effects of selection and their relation to growth rate</u>

Variations in average growth rate between different areas of a cockle bed (Figure 3) involve marked differences in volume, and they are considered to be the result of environmental, not genetical, differences since cockles transplanted from a slow to a fast-growing area adopt the growth characteristics of the new area. The effects of selection will be most marked in the fast growing areas, and there will be an apparent reduction in average shell length and average growth rate for the whole area.

In any chosen locality, sieving will lead to the following effects of selection, (illustrated by reference to the results of sieving a sample of 1,546 of the cockles shown in Plate 2 through a $\frac{5}{8}$" (= 16 mm.) oblong-meshed sieve (Tables 4 and 5)) and this must be regarded as a continuous process while growth proceeds and the smaller l_2 millimetre groups move towards the 50% retention length:-

1. Cockles which had (a) the greatest l_1 all remain on the sieve, e.g. groups 17-19 mm. in Table 5, and (b) the smallest l_1 all pass through the sieve, e.g. groups 9-11 mm. in Table 5. Cockles (a) include those with the greatest l_2 (Table 5) and the greatest width (Table 3A) and would have grown to the greatest l_4 (Table 2), and the effect of removing the larger cockles would be to reduce the mean lengths of l_2 and l_1 of the population, and hence subsequently of l_3, l_4, etc.

2. Each l_1 millimetre group is subjected to the complete removal of its largest resultant l_2's, e.g. cockles which grew from 16 mm. to 25 and 26 mm. at l_2 (Table 5). These are undoubtedly the fastest growers in length as shown in the following example from cockles shown in Table 2 (all in mm.):-

l_1	l_2	Mean l_3	Mean l_4
13	20	24.7	25.6
13	21	25.2	26.1
13	22	26.8	27.8
13	23	27.5	29.0
13	24	28.9	29.9

and the following table (Table 6) shows that the volume increases of cockles which had grown from the same l_1 to the largest l_2's in the second growing season were also greater.

Table 6. Length and volume increments of a selected (13 mm.) l_1 group in subsequent years. The volume of each l_1, l_2 etc. group has been taken as the mean for the group

		$l_1 \longrightarrow l_2$						$l_2 \longrightarrow l_3$			
l_1 mm	l_2 mm	Length increment mm.	% Length Increment	Mean Volume at l_2	Volume Increment	% Volume Increment	l_3 mm.	Length Increment	% Length Increment	Volume Increment	% Volume Increment
13	20	7	54	2.7	2.0	286	24.7	4.7	24	2.15	80
13	21	8	62	3.0	2.3	329	25.2	4.2	20	2.10	70
13	22	9	69	3.3	2.6	371	26.8	4.8	22	2.75	83
13	23	10	77	3.7	3.0	429	27.5	4.5	20	2.85	77
13	24	11	85	4.2	3.5	500	28.9	4.9	20	3.30	79

For cockles which added the smallest length increment in the second season i.e. grew from 13 → 20 mm., the percentage length increments, actual volume and percentage volume increments were also least. The wide differences in actual volume increases show that true growth rate differences are not entirely related to shell shape, i.e. a cockle with l_1/l_2 measurements of 13/20 mm. was presumably a slow growing early settler (Figure 7) with a relatively wide shell, but it grew to only half the volume of a 13/24 mm. cockle which was presumably a fast growing late settler with a relatively narrow shell. At the end of the third growing season ($l_2 \rightarrow l_3$) the magnitude of differences was reduced, only the actual volume increment showing a noticeable increase. This will have been the result of the approach of the shell lengths towards their asymptote, and according to von Bertalanffy's theory (1938) the slower growing cockles should achieve a greater final average length (L_∞) than that of fast growers. This becomes apparent if Walford lines (1946) are plotted for the different growth rates shown above.

The effect of this selection is to remove the fastest growing cockles, i.e. to reduce the mean size of l_1 and l_2 of the population, as in paragraph 1 (above), and reduce the mean size of l_2 related to each millimetre l_1 group (Table 5).

3. As growth proceeds selection also takes place within each l_2 millimetre group as it reaches the 50% retention size, and since the widest cockles are those which had added the smallest length increment, e.g. in Table 3B those which grew from 16 to 22 mm. were wider than those which grew from 10 to 22, the effect is therefore of removing the apparently slower growing cockles, in contrast to the behaviour described in paragraphs 1 and 2 above.

i.e.	l_1	l_2	Mean l_3	Mean l_4
	11	22	27.0	28.7
	12	22	26.8	28.3
	13	22	26.8	27.8
	14	22	26.6	27.5
	15	22	26.0	27.2

In this case however, although the length increment of the wider cockles is smaller, the volume increment is not necessarily so. Care must be taken to compare the volume at l_1 with the related volume at l_2, and not the mean volume at l_2, because as mentioned previously both shell width and whole volume for any selected l_2 group increase with the length at l_1, as in the following example:-

l_1	Whole Volume	l_2	Whole Volume	Volume Increment	% Volume Increment
11	0.5	21	2.8	2.3	82
12	0.6	21	3.0	2.4	80
13	0.7	21	3.0	2.3	77
14	0.8	21	3.0	2.2	73
15	1.0	21	3.2	2.2	69

Allowing for obvious errors in estimation, these volume increments are much the same, but if they had all been calculated from the mean volume for an l_2 of 21 mm. i.e. 3.0 ml., there would have been a definite trend from 2.5 → 2.0 ml. as l_1 increased. The data shown in Table 6 should also have been treated in this way but only the mean values are so far available for the l_2 groups shown there.

Selection in this fashion reduces the mean value of l_1 from which each l_2 millimetre group has grown, but although there appears to be an increased growth rate in length, the volume increment remains relatively unaffected. Again the mean lengths of l_1 and l_2 in the population will both be less after selection.

4. The widest cockles from each l_1/l_2 millimetre group, i.e. in each square on Plate 2 (see also Table 4B), will at some time be selected. From the foregoing observations, these would add on average a smaller length increment than the narrower ones, and selection will leave cockles apparently growing faster in length than average, though as in the previous paragraph the volume differences may be negligible.

Conclusions on selection

The resulting total effect of selection by sieving, an example of which is shown in Table 5, will be to cause a reduction in the mean values of l_1 and l_2 in the population, and the mean growth rate as determined by back measurements of annual rings on the shells of the older cockles will be less than the true growth rate (see also Figure 5). The originally symmetrical frequency distribution of l_2 measurements will now tend towards a skew distribution (Figure 9). In paragraphs 1 and 2 the tendency is demonstrated for cockles shown to be fast growing in shell length and in volume to be selected off. The tendency shown in paragraphs 3 and 4 for narrow shelled apparently fast growing cockles to remain on the beds will have the effect of compensating for part of the reduction in shell length in subsequent years but the length/volume ratio will tend to become increased, and the relatively narrow-shelled faster-growing shells will predominate. This becomes important in yield prediction, which involves a comparison of the weight of cockles at a chosen minimum size with the average weight of individuals larger than the minimum size in the catch (Gulland 1961).

On Llanrhidian Sands, significant egg production does not commence until cockles are nearly two years of age, that is in the early summer following almost a year of intense selection of this year class. The effect of selection on the relative production of larvae from breeding stock in areas of fast and slow growth, and from cockles of variable shape and growth rate should at some time also be discussed.

Difference in selective action between square and oblong-meshed sieves

The selection ogives obtained from square-meshed sieves are steeper with selection over a smaller range of shell length than oblong-meshed sieves (Figure 6). The result is that amongst cockles smaller than the 50% retention size relatively more cockles are retained by an oblong-meshed sieve, and these will consist mostly of wide apparently slow growing cockles (see para. 3 above) which would have passed through a square-meshed sieve of the same 50% retention size (remembering that the square-meshed sieve would have the larger gauge (Figure 6). Conversely amongst cockles larger than the 50% retention size, more narrow, apparently fast-growing cockles, will pass through the oblong-meshed than the square-meshed sieve. This suggests that selection by a square-meshed sieve will cause a greater reduction in mean shell length (l_2), but an oblong-meshed sieve will cause a greater reduction in mean length of l_1 and a greater increase in the length/volume ratio.

Summary and conclusions

Observations on growth rate and selection of cockles by sieves have emphasised the difficulty of choosing a single minimum size to cover a large area of coastline. Where practical each separate fishery of any importance within a Sea Fisheries District should have its own regulations, which should take into account seasonal and spatial fluctuations in growth. The growth pattern of cockles has been analysed and the effects of selection by different types and meshes of sieve examined. The samples examined were collected from a commercial fishery and could already have been affected by selective action though the results obtained showed little evidence of this. It would be possible to repeat these observations either on an unexploited cockle bed, or in an area of a commercial fishery which had been fenced to prohibit fishing. Additional observations on other factors influencing the effectiveness of minimum size regulations, such as mortality resulting from various causes and particularly from the methods of exploitation, should also be employed in deciding on the best application of minimum size regulations.

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Table 1. Mean shell lengths of cockles from a selected locality on Llanrhidian Sands, South Wales during five successive winters, and the percentage of the stock in that locality which could have been fished at various minimum sizes. The size of square gauge is shown in inches and millimetres and the respective 50% retention size (in brackets) in millimetres.

	Mean shell length		% of 2 year old stock which was fishable		
Winter	2 year old	3 year old	5/8" = 16 mm. (19 mm.)	11/16" = 17.5 mm. (21 mm.)	3/4" = 19 mm. (23 mm)
1958/9	24.0	26.8	100	97	74
1959/60	21.2	27.0	95	55	12
1960/1	22.3	25.6	96	81	33
1961/2	22.9	26.7	99	88	49
1962/3	21.0	25.7	90	50	8

Table 2. Relationship between outer shell length (l_4) and length of the first ring (l_1) at the end of the fourth growing season

	Outer shell length (l_4)												
Length of inner ring (l_1)	24	25	26	27	28	29	30	31	32	33	34	Total	Mean of l_4
9			1									1	26.0
10	1		3	1	1							6	26.2
11	3	2	3	2	3	3			1			17	26.9
12	4	7	6	15	12	9	2					55	27.1
13	1	5	8	12	23	17	24	6				96	28.4
14		1	6	13	26	35	19	8	2			110	28.7
15		1	2	3	7	12	10	4	3			42	29.1
16				2	3	5	5	6	2			23	29.7
17						1	2					3	29.7
18										1	1	2	
TOTAL	9	16	29	48	75	82	62	24	8	1	1	355	28.4

Table 3A. Relationship between length and width of two year old cockles shown in Plate 2, from Llanrhidian Sands

Shell length mm. (l_2)	Numbers at shell widths - mm.										Total	Mean width
	11	12	13	14	15	16	17	18	19	20		
15	1										1	11.0
16	1	1									2	11.5
17	2	8	2								12	12.0
18	2	16	29	12							59	12.9
19		2	41	72	16	1					132	13.8
20			27	128	122	8	1				286	14.4
21			1	67	232	132	11				443	15.2
22				12	141	175	35				363	15.6
23					19	97	70	9			195	16.4
24					3	9	19	9	4		44	17.0
25							3	3	1		7	17.7
26										1	1	
27								1			1	
TOTAL	6	27	100	291	533	422	139	22	5	1	1,546	

Table 3B. Relationship between inner ring length (l_1) and width of cockles of 22 mm. shell length (l_2) from above sample.

Length of inner ring (l_1) - mm.	Numbers at shell widths - mm.				Total	Mean width
	14	15	16	17		
10	1	1			2	14.5
11	1	5	2		8	15.1
12	2	35	19	2	58	15.4
13	5	59	74	8	146	15.6
14	2	35	64	19	120	15.8
15	1	5	13	5	24	15.9
16		1	3	1	5	16.0
TOTAL	12	141	175	35	363	15.6

Table 4A. Effect of sieving with a $\frac{5}{8}$ inch (= 16 mm.) oblong meshed sieve on shell length/width relationship shown in Table 3A.

Shell length (l_2) mm.	Numbers at shell widths - mm.																	
	Through sieve									On sieve								
	11	12	13	14	15	16	17	Total	Mean width	15	16	17	18	19	20	Total	Mean width
15	1							1	11.0								
16	1	1						2	11.5								
17	2	8	2					12	12.0								
18	2	16	29	12				59	12.9								
19		2	41	72	16			131	13.8		1					1	
20			27	128	113	4		272	14.3	9	4	1				14	15.4
21			1	67	221	61		350	15.0	11	71	11				93	16.0
22				12	131	82	4	229	15.3	10	93	31				134	16.2
23					17	44	7	68	15.9	2	53	63	9			127	16.6
24					2	4		6	15.7	1	5	19	9	4		38	17.3
25												3	3	1		7	17.7
26															1	1	
27													1			1	
TOTAL	6	27	100	291	500	195	11	1,130	14.7	33	227	128	22	5	1	416	16.4

Table 4B. Effect of sieving on relationship between inner ring length (l_1) of cockles of 22 mm. shell length (l_2) shown in Table 3B.

Length of inner ring (l_1) - mm.	Numbers at shell widths - mm.										
	Through sieve						On sieve				
	14	15	16	17	Total	Mean width	15	16	17	Total	Mean width
10	1	1			2	14.5					
11	1	5	2		8	15.1					
12	2	34	9	1	46	15.2	1	10	1	12	16.0
13	5	55	38	2	100	15.4	4	36	6	46	16.0
14	2	32	24	1	59	15.4	3	40	18	61	16.2
15	1	4	6		11	15.5	1	7	5	13	16.3
16			3		3	16.0	1	0	1	2	16.0
TOTAL	12	131	82	4	229	15.3	10	93	31	134	16.2

Table 5.

Effect of sieving with ⅝ inch (= 16 mm.) oblong meshed sieve on relationship between l_2 and l_1 of cockles shown in Plate 2.

Inner ring length (l_1) mm.	Numbers at shell length (l_2) - mm.																											
	Through sieve															On sieve												
	15	16	17	18	19	20	21	22	23	24	25	26	27	Total	Mean l_2	19	20	21	22	23	24	25	26	27	Total	Mean l_2	Grand Total	Mean l_2
9			1	1	2	3								7	19.0												7	19.0
10			2	10	13	9	7	2						43	19.3												43	19.3
11			3	19	34	38	33	8	2					137	19.8												137	19.8
12	1	2	1	16	48	102	97	46	7					320	20.4	1	3	13	12	8					37	21.6	357	20.5
13			4	9	29	92	164	100	26	3				427	20.9		9	46	46	33	6				140	21.9	567	21.2
14			1	4	5	26	43	59	25	1				164	21.4			25	61	51	10				147	22.3	311	21.8
15						2	5	11	8	1				27	22.0		2	8	13	24	12	3			62	22.7	89	22.5
16							1	3		1				5	22.2			1	2	6	7	3	1		20	23.6	25	23.3
17																				5	3				8	23.4	8	23.4
18																								1	1	27.0	1	27.0
19																						1			1	25.0	1	25.0
TOTAL	1	2	12	59	131	272	350	229	68	6				1,130	20.7	1	14	93	134	127	38	7	1	1	416	22.3	1,546	21.1
Mean l_1	12.0	12.0	11.7	11.6	11.8	12.3	12.6	13.1	13.4	14.0				12.5		12.0	13.1	13.3	13.6	14.0	14.8	16.0	16.0	18.0	13.8			
Grand Total	1	2	12	59	132	286	443	363	195	44	7	1	1	1,546	21.1													
Mean l_1	12.0	12.0	11.7	11.6	11.8	12.3	12.8	13.3	13.8	14.7	16.0	16.0	18.0		12.9													

Figure 1. (a) Shell dimensions of the cockle

(b) Sieving through a square meshed and oblong meshed sieve

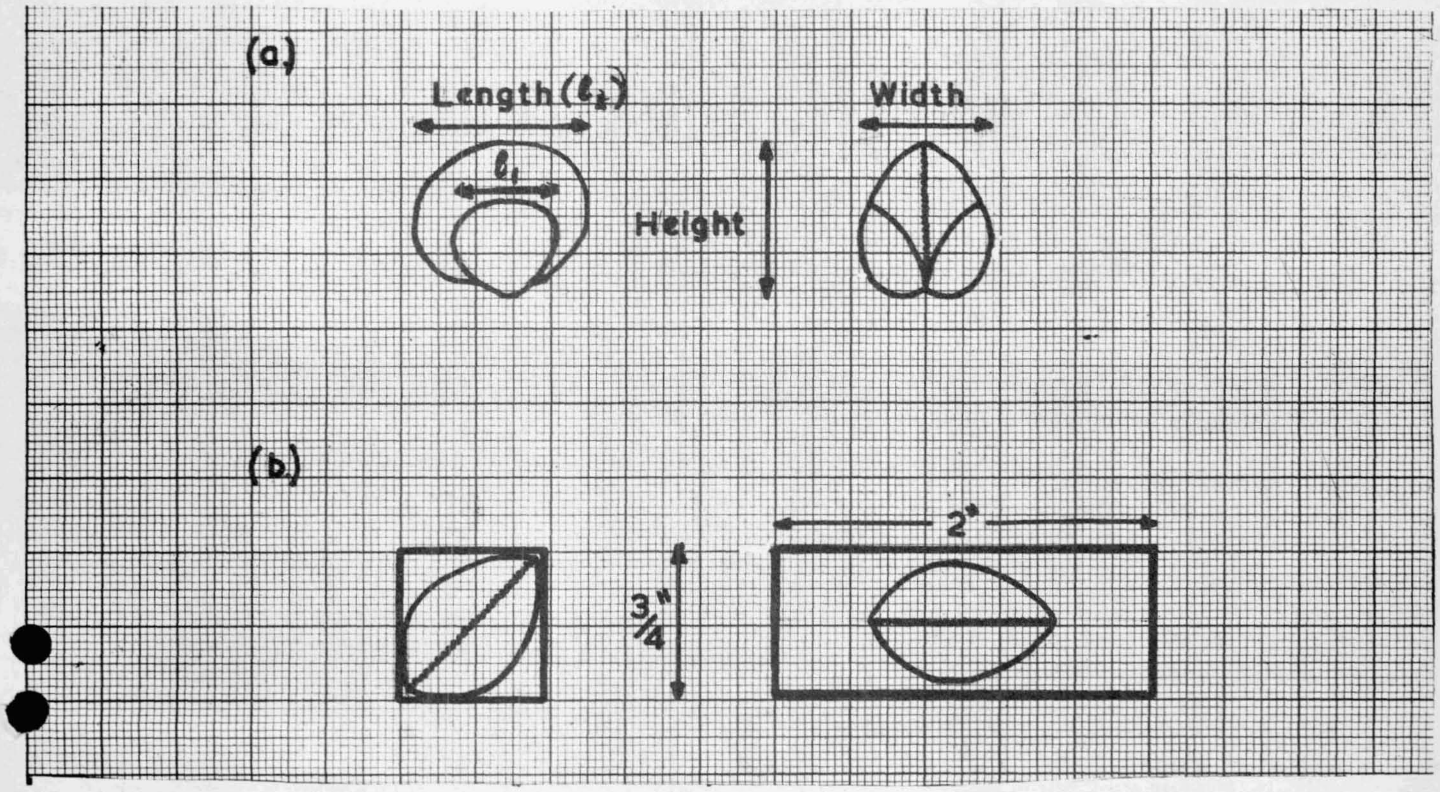

Plate 1. Cockle gathering on Llanrhidian Sands, South Wales, using a metal "scrape" and rake, and an oblong meshed or bar sieve.

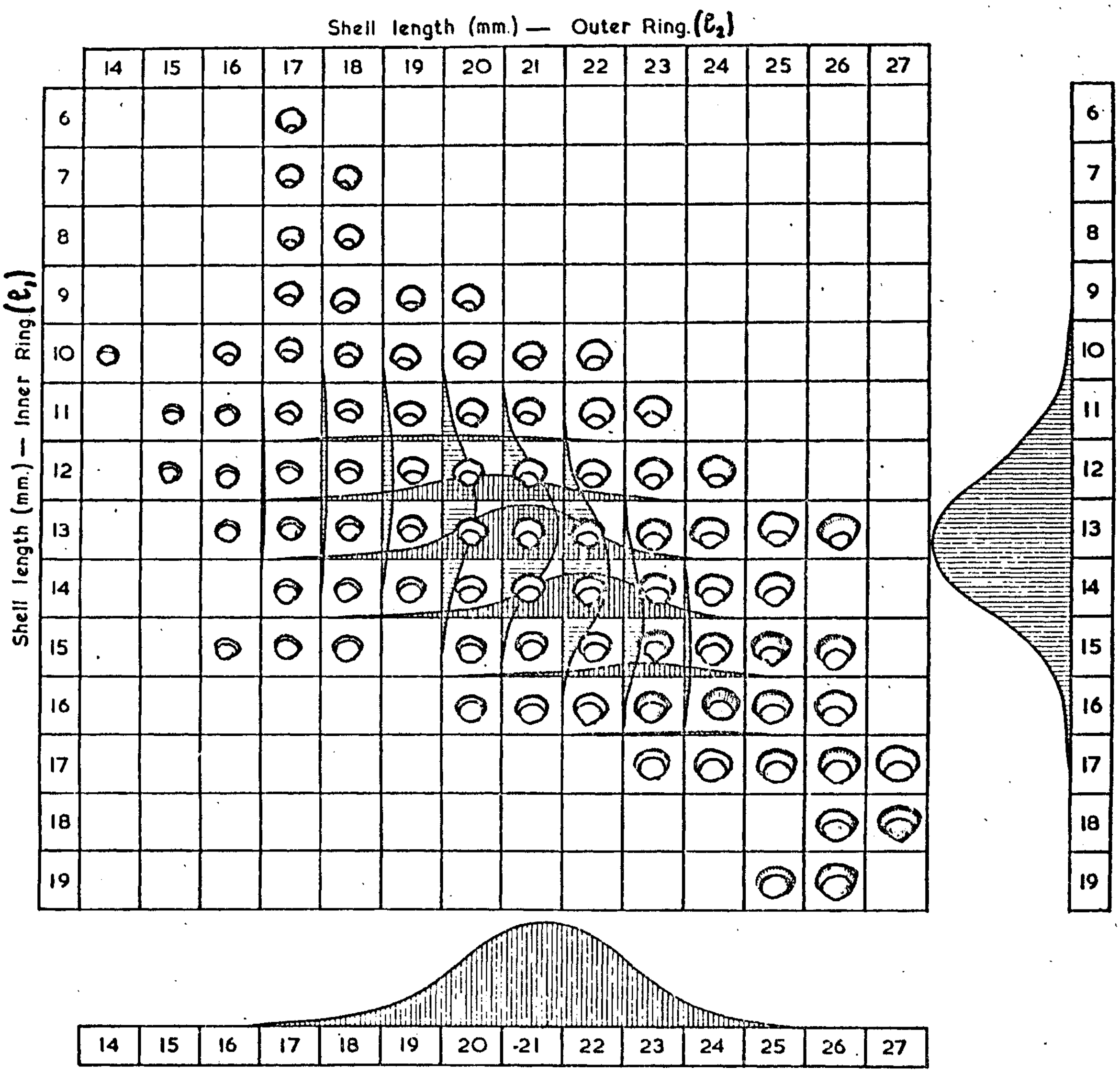

Plate 2 Frequency distributions of l_1 and l_2 measurements of cockles at their second winter growth check from Llanrhidian sands. The frequency distribution of l_2 reached by each millimetre l_1 group is shown, together with the frequency distribution of l_1 from which each millimetre l_2 group had grown.

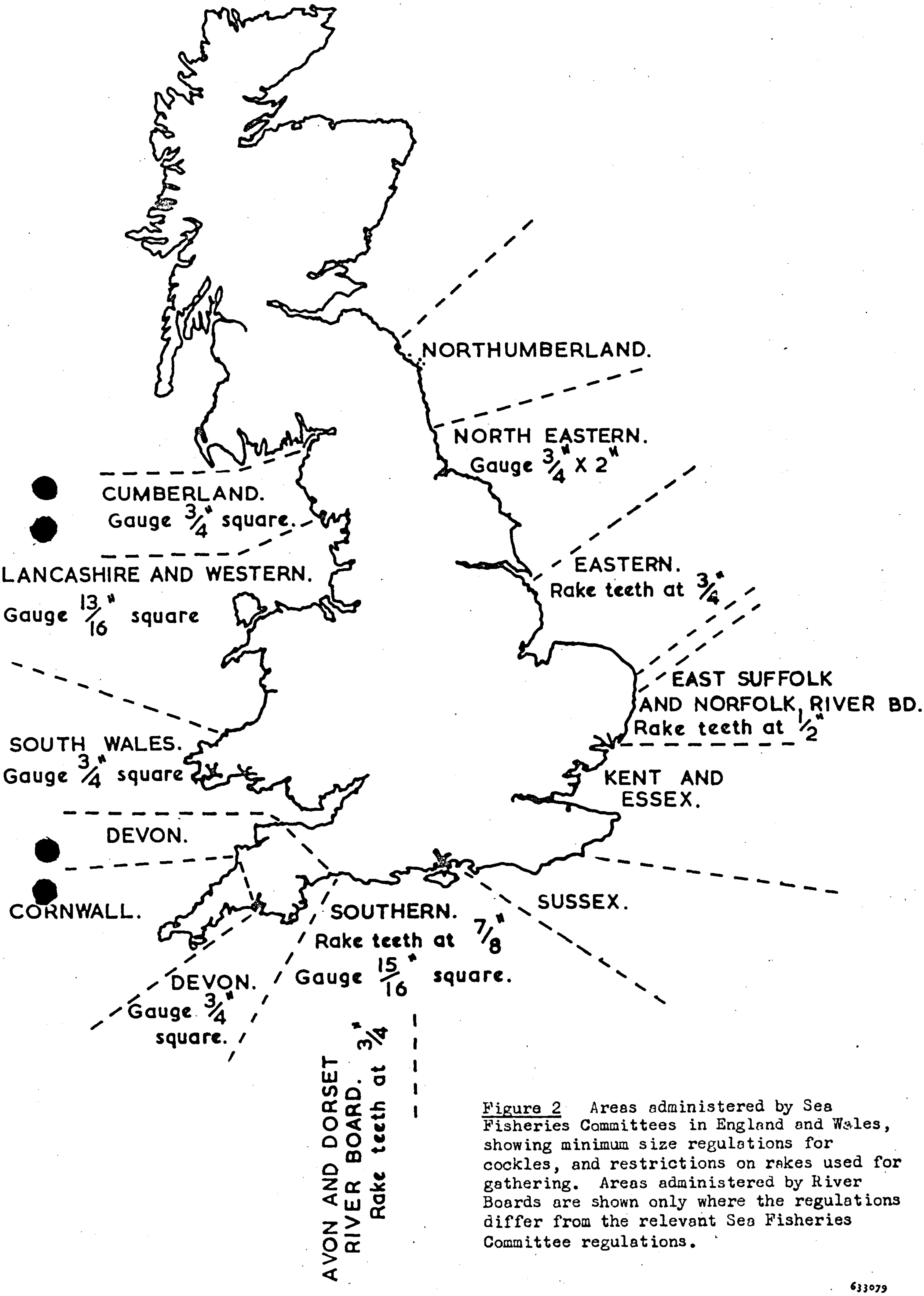

Figure 2 Areas administered by Sea Fisheries Committees in England and Wales, showing minimum size regulations for cockles, and restrictions on rakes used for gathering. Areas administered by River Boards are shown only where the regulations differ from the relevant Sea Fisheries Committee regulations.

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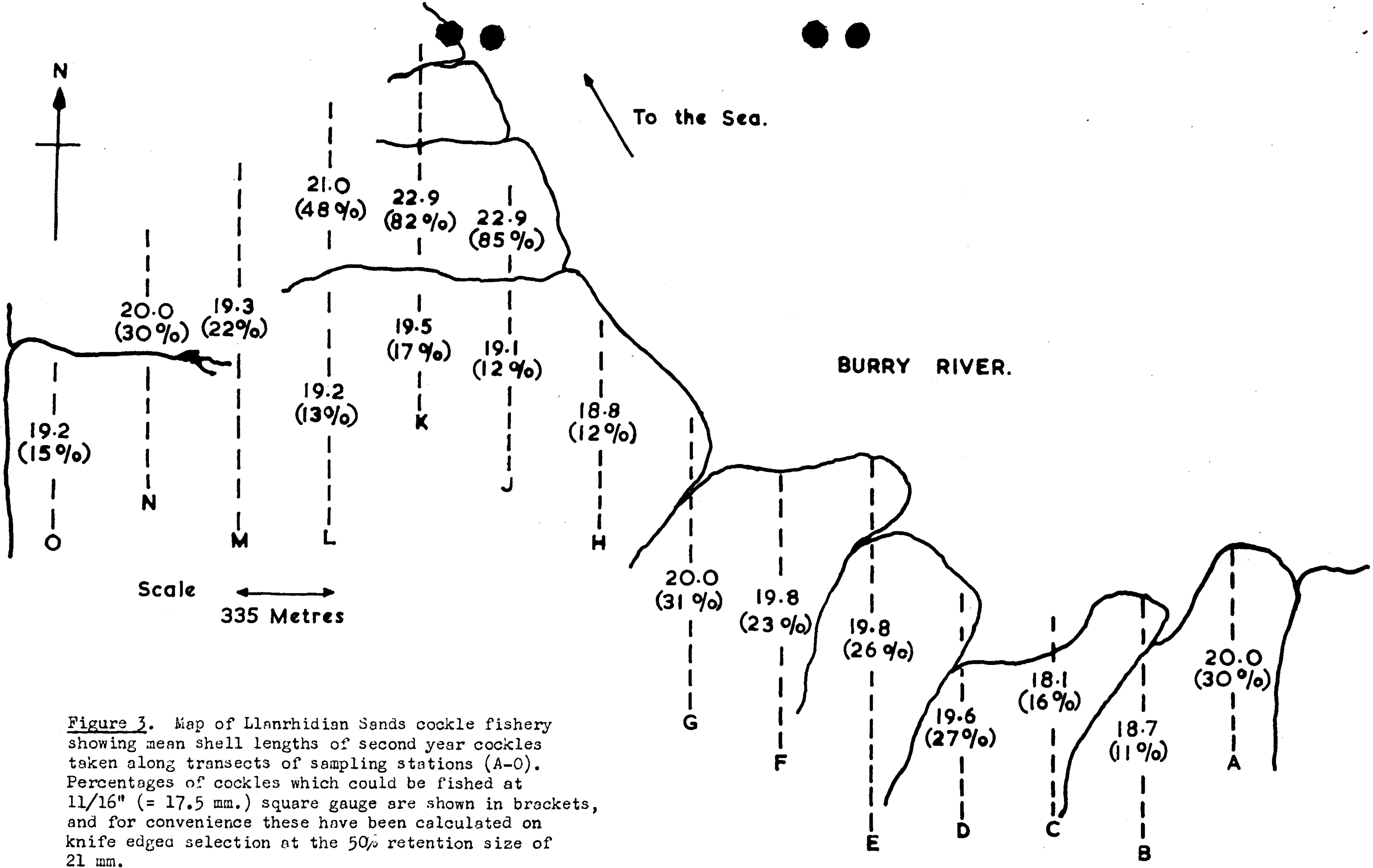

Figure 3. Map of Llanrhidian Sands cockle fishery showing mean shell lengths of second year cockles taken along transects of sampling stations (A-O). Percentages of cockles which could be fished at 11/16" (= 17.5 mm.) square gauge are shown in brackets, and for convenience these have been calculated on knife edged selection at the 50% retention size of 21 mm.

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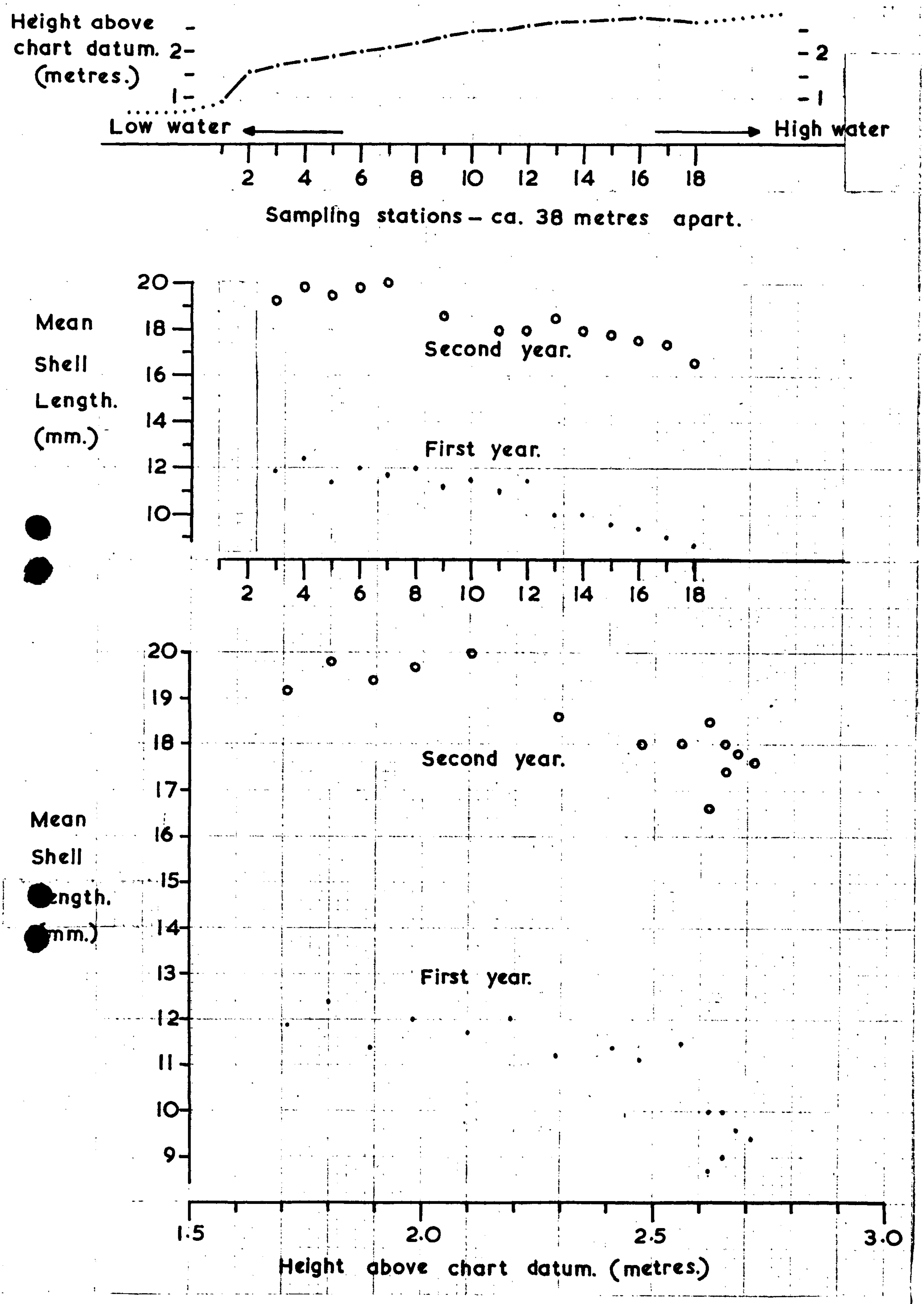

Figure 4. Relationship between mean shell length of cockles and (A) distance from low water mark, and (B) height above chart datum. At the highest and lowest (i.e., below the edge of the bank) levels of the shore densities were too small for useful sampling. Samples were taken along Transect F (Figure 3).

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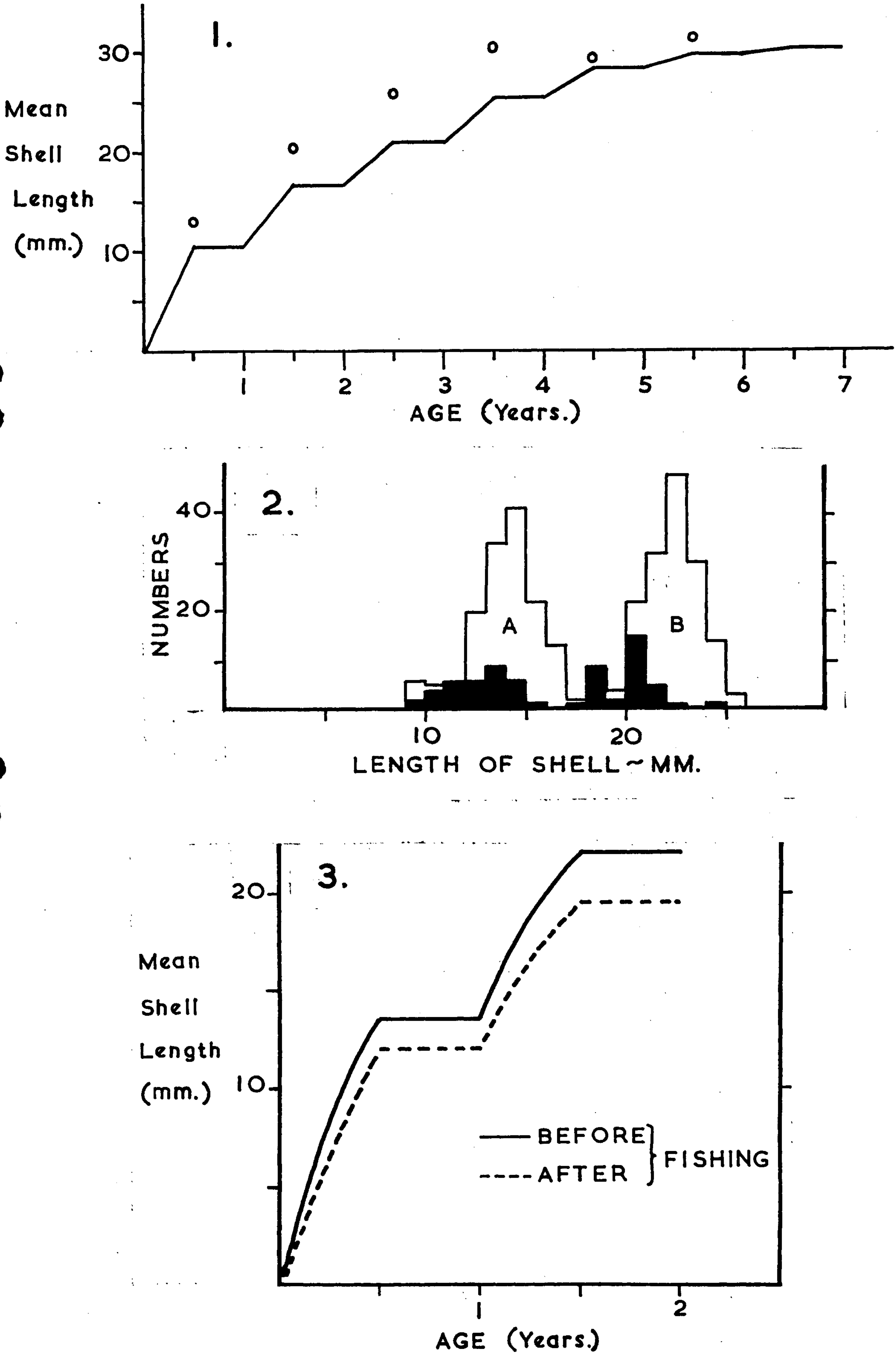
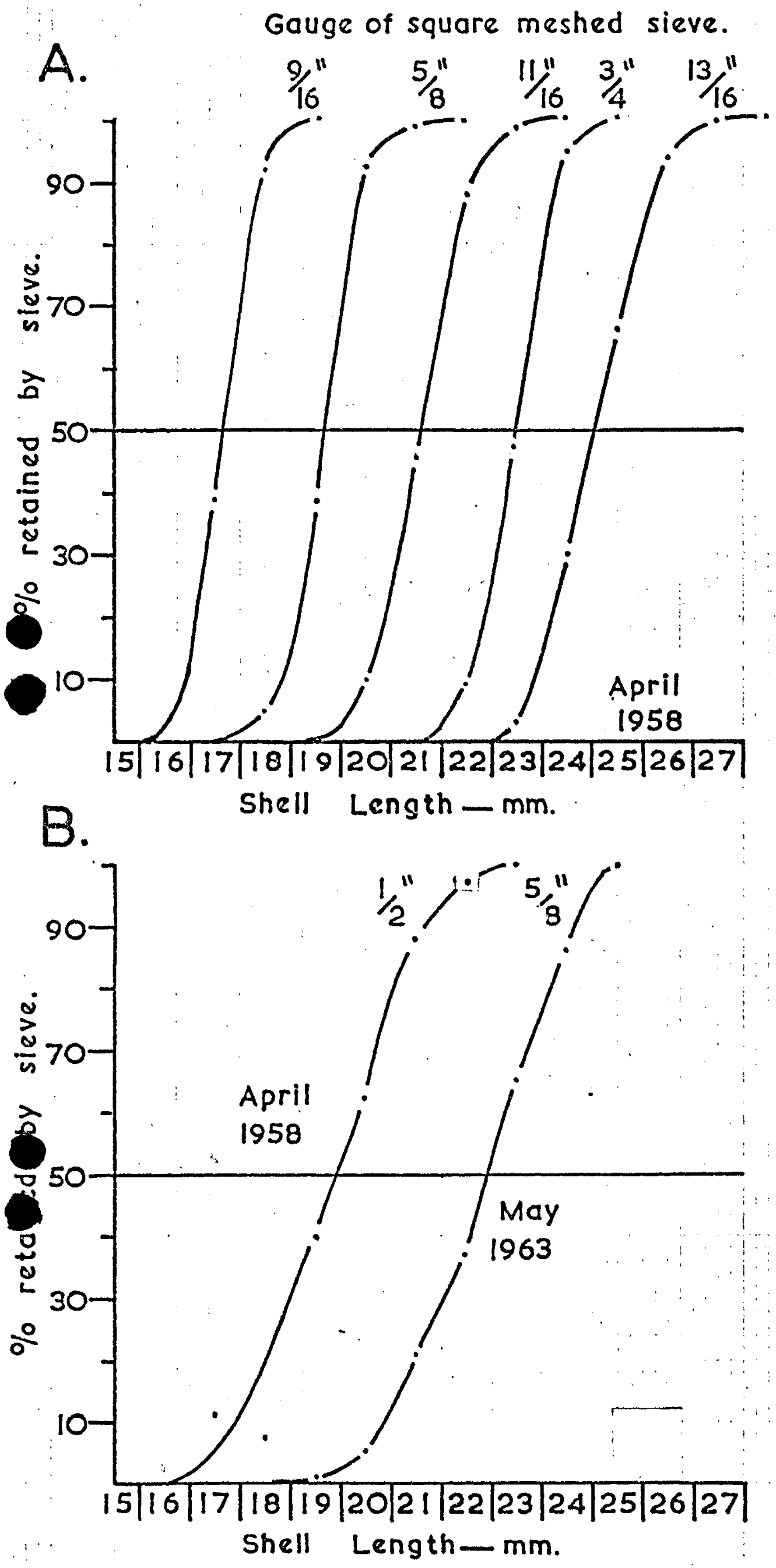


Figure 5. Growth of cockles. Growth curve obtained by measuring the lengths of growth rings on cockles of seven years of age from Llanrhidian Sands, April 1958. Points marked (O) show mean sizes of cockles of each year group collected from the same area. (2) shows the length distribution of 2-ring cockles (B) and the position of their first rings (A), before and after (blocked in) fishing. (3) Growth curves from cockles shown in (2).



50% retention size.

Gauge	Shell length group.
9/16"(=14.5mm.)	17mm.
5/8"(=16mm.)	19mm.
11/16"(=17.5mm.)	21mm.
3/4"(=19mm.)	23mm.
13/16"(=20.5mm.)	24/25mm.

Gauge of oblong mesh.	Shell length group.
ca. 1/2"(=12.5mm.)	19/20mm.
5/8"(=16mm.)	22/23mm.

Figure 6

Selection ogives obtained by sieving cockles from Llanrhidian Sands through (A) square meshed, (B) oblong meshed sieves, of various gauges. Graphs have been constructed from observed values, using in (A) all ages to cover the required shell length range. Only two year old cockles are represented in graph B. The $\frac{1}{2}$" oblong meshed sieve used in (B) was one employed by fishermen, and the meshes were very variable.

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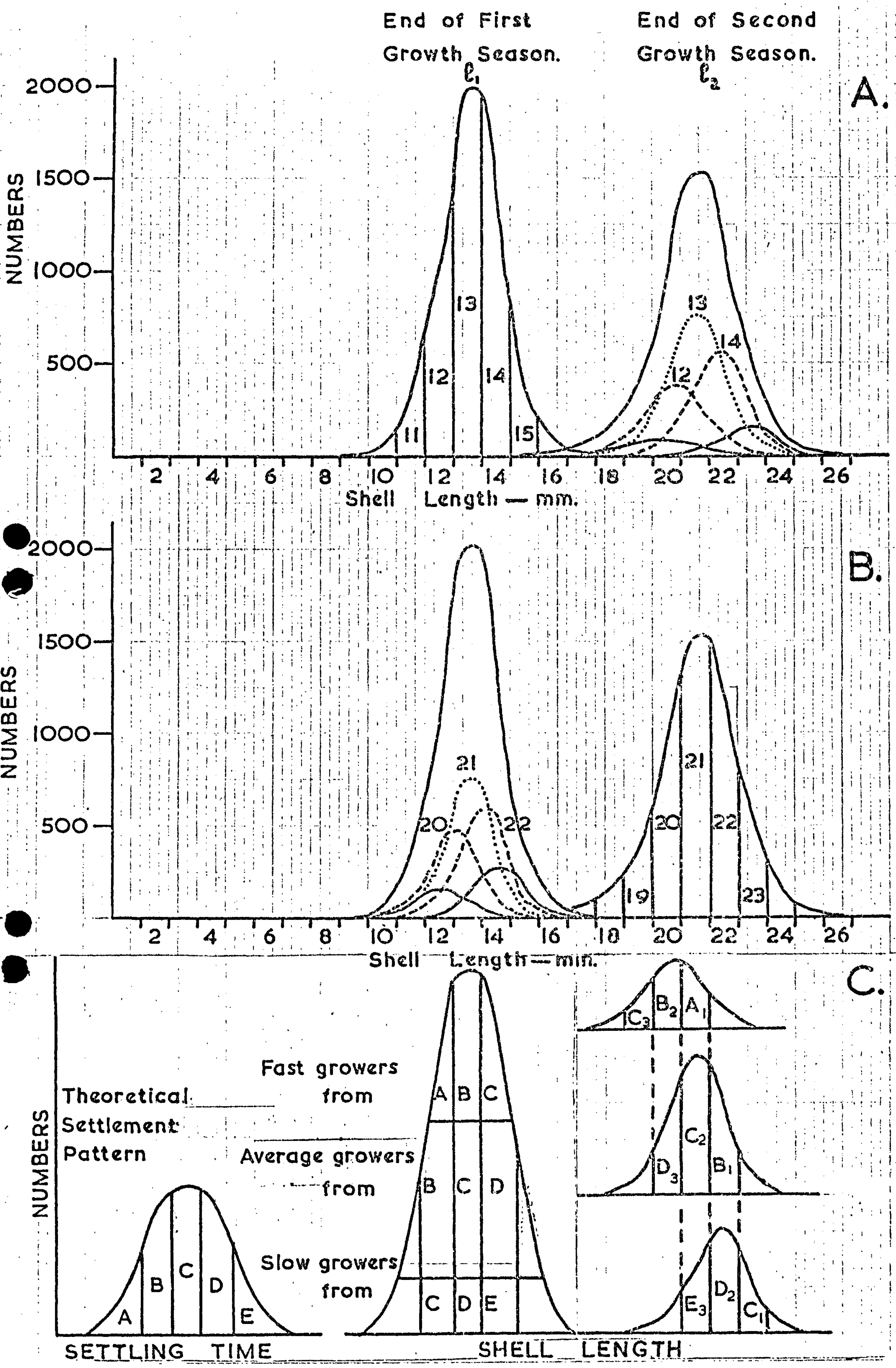

Figure 7 Shell length distribution of cockles shown in Plate 2, showing growth (A) of selected millimetre l_1 groups to l_2 and (B) of selected millimetre l_2 groups from l_1. (C) Diagrammatic representation of cockle settlement, and distribution of l_1 and l_2 measurements resulting from growth of arbitrarily chosen groups A (settled late) to E (settled early), with fast growing (A_1 etc.) to slow growing (A_3 etc.) components.

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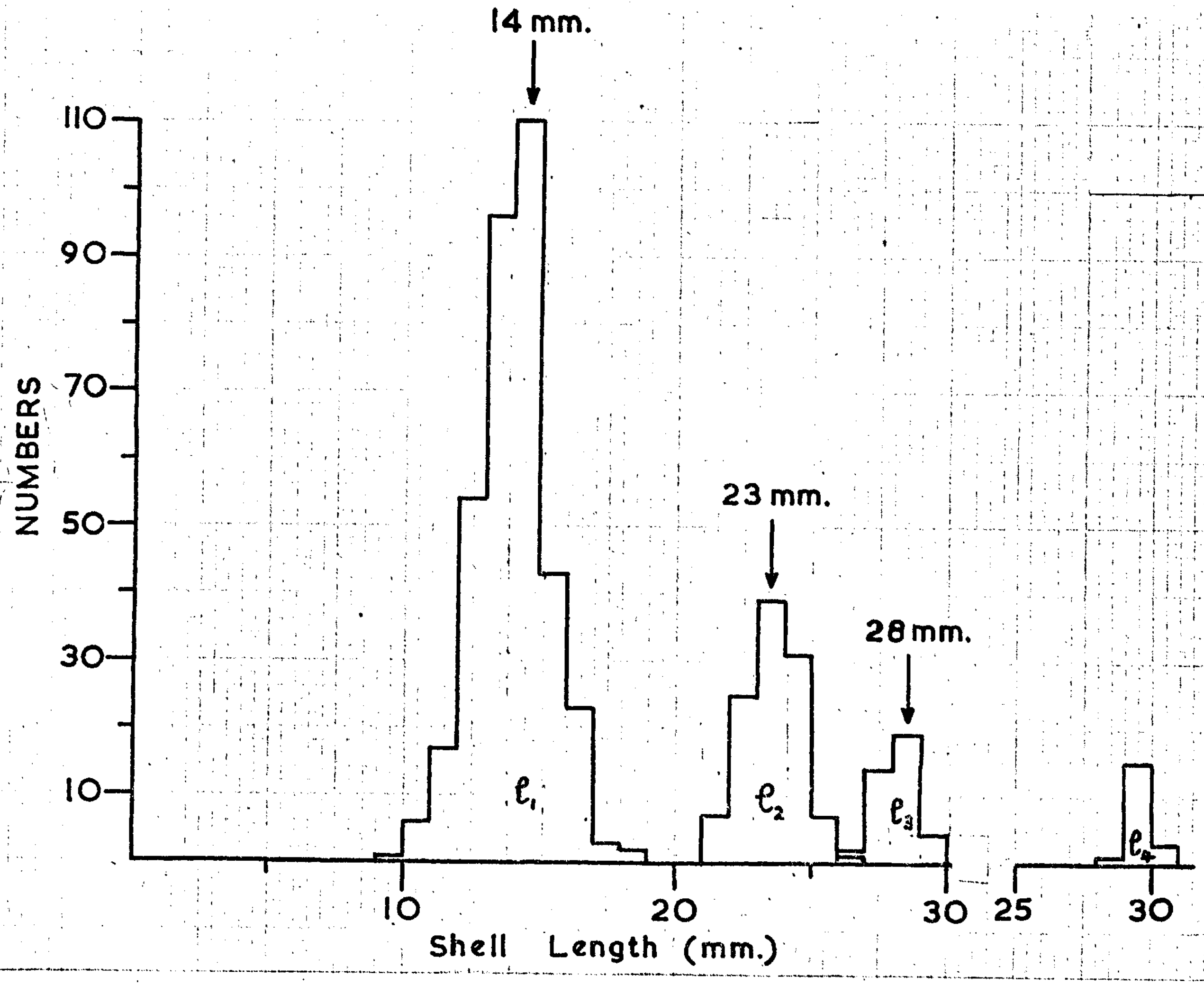

Figure 8. Distribution of l_1 measurements from 4 year old cockles from Llanrhidian sands, showing l_2 distribution of cockles from the mode of l_1, l_3 distribution from their mode at l_2, and l_4 distribution of their mode at l_3.

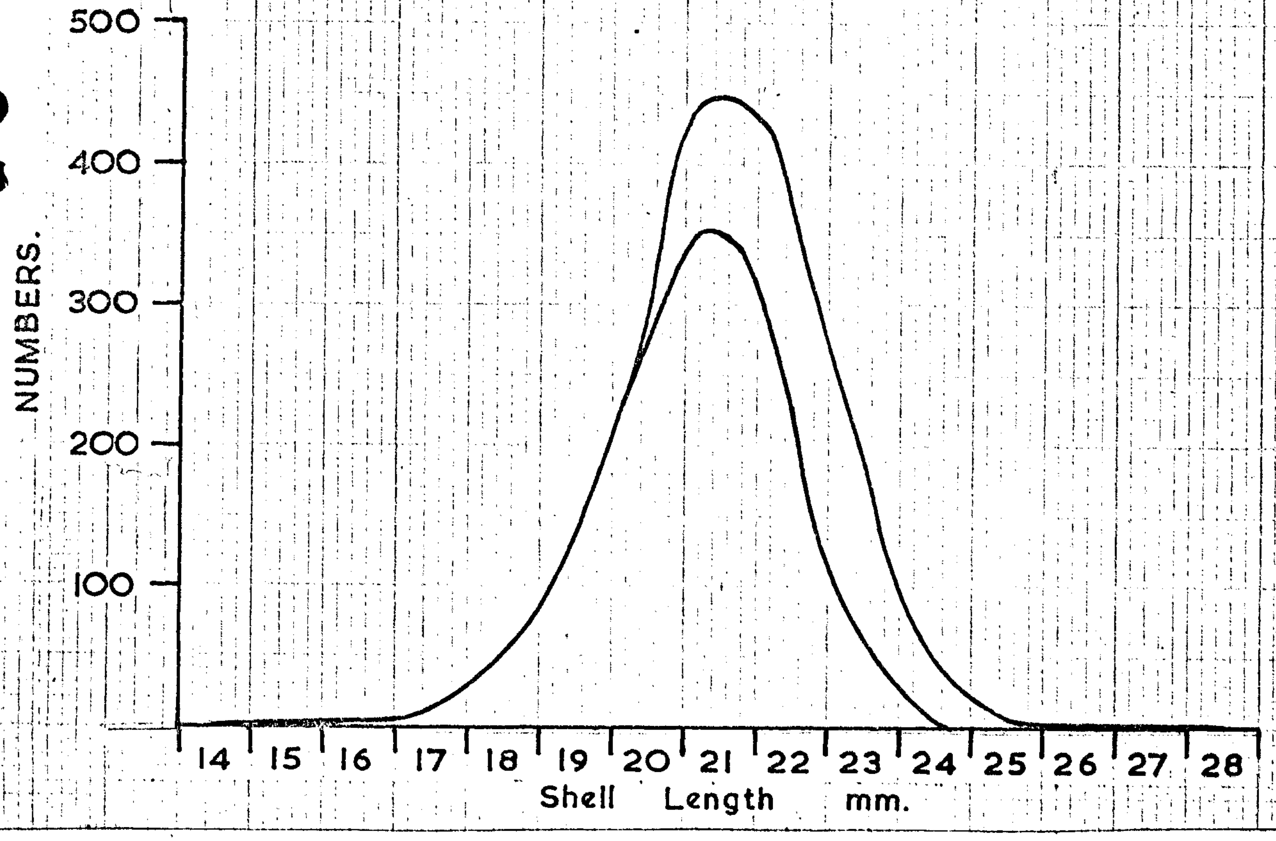

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Figure 9. Frequency distribution of shell lengths of cockles at their second winter growth check before and after sieving through a $\frac{5}{8}$"(= 16 mm.) oblong meshed sieve. (See also Plate 2 and Table 5).