Journal of the Marine Biological Association of the United Kingdom Vol 31 No 3 1953

OBSERVATIONS ON *NUCULA TURGIDA* MARSHALL AND *N. MOOREI* WINCKWORTH

By J. A. Allen

Zoology Department, The University, Glasgow, and the Marine Station, Millport

(Plate I and Text-figs. 1–8)

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INTRODUCTION

In 1950 a study of the specific differences and growth rates of the British species of *Nucula* (Mollusca, Protobranchiata) was commenced. Winckworth (1932) lists five species which, with the exception of *N. turgida* and *N. moorei*, can be readily distinguished from each other. The present observations on over 2500 specimens of *N. turgida* and *N. moorei* show that the diagnostic characters differentiating the two species are not valid, and as no new differences have been found it is proposed that they should be recombined as one species, *Nucula turgida* Marshall 1875, this being the first available name.

Until 1930, *N. turgida* and *N. moorei* were considered to be one species under the name *N. nitida* Sowerby. Then Winckworth (1930) pointed out that the name *N. nitida* was preoccupied and proposed *N. nitidosa* instead. Two papers by Leckenby & Marshall (1875) and Marshall (1893) had been overlooked in which a dark unrayed form of *N. nitida* was described as variety *turgida* and a form having coloured rays as variety *radiata*.[1] Jeffreys (1879) described another variety under the name *ventrosa* from the Mediterranean (*Porcupine* Expedition, 1870); this was considered by Marshall (1893), however, to be his variety *turgida*. After examination of Marshall's specimens from the Dogger Bank and from the work of Moore (1931 *a*, *b*) on the faeces of the rayed and unrayed forms, Winckworth (1931) considered the two

[1] Not to be confused with *N. radiata* Hanley which is now known as *N. hanleyi* Winckworth.

varieties (*turgida* and *radiata*) distinct and renamed them *N. turgida* Marshall, and *N. moorei* Winckworth. The two species were diagnosed as follows:

Nucula turgida

Shell glossy, with olive-green periostracum, somewhat inflated, anterior margin distinctly prominent, posterior margin evenly rounded; growth lines form distinct wrinkles on the anterior third and the extreme posterior. Faecal pellets subcircular in section, with seven grooves.

Nucula moorei.

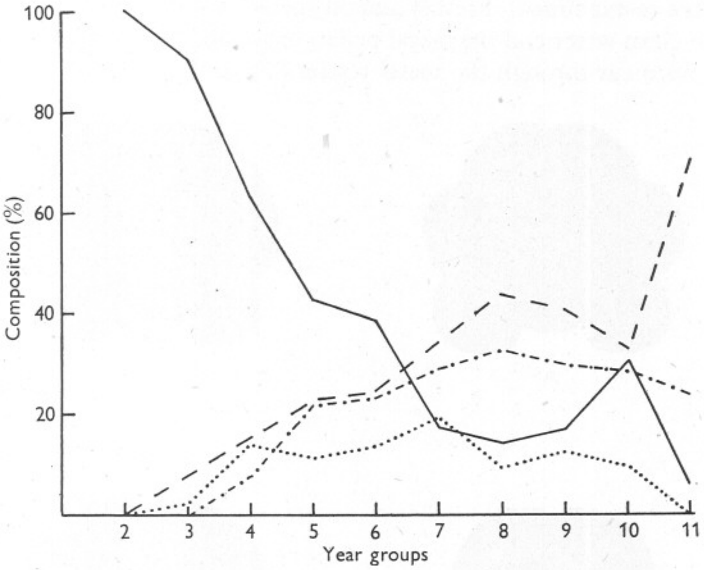
Shell usually more glossy, with a pale green periostracum, streaked with coloured rays (usually obvious but exceptionally they may be only just visible), anterior margin almost straight, posterior margin arched; growth lines much finer and wrinkles slight. Faecal pellets quadrate oval in section, with five grooves.

N. nitida is a widely distributed species ranging from Sweden to the Mediterranean. Forbes & Hanley (1853) and Jeffreys (1865) state that it can be taken in sand and sandy silt at low spring tides and at depths ranging from the latter mark to 86 fathoms (157 m.) Both radiate (*N. moorei*) and non-radiate (*N. turgida*) forms are present together throughout the Clyde Sea Area, but there is no record of them being taken at low-water mark. In a survey of the sublittoral fauna in 1949 and 1950 they were taken from sandy silt at 10 m. to fine mud at 180 m. The densest populations occurred in muddy silt (80–90 m. depth) in company with *Corbula gibba*, *Abra alba*, *Cuspidaria cuspidata* and *Nucula sulcata*. The material for the present investigation was obtained from the fauna survey and additional large samples from the Cumbrae Deep off the east coast of Bute and from the Minnard Narrows, Loch Fyne.

Shell Markings

The colour of the shell has been variously described as pale green, olive-green and yellow. The ground colour of the periostracum of specimens from the Clyde Sea Area is yellow, on which purple-grey markings may be superimposed. These markings can completely mask the yellow ground giving the non-radiate dark form which Marshall called the variety *turgida*. The purple-grey colour is not always laid down continuously and banded forms are found with the bands running parallel to the lines of growth. It can also take the form of radiations at right angles to the lines of growth. These latter forms vary from those that are heavily radiate to those in which the radiations are hardly visible (Plate I, figs. 1, 2). These markings, also, may not be laid down continuously, being often limited to bands parallel to the lines of growth.

Examination of the specimens obtained showed that it was possible to group them into (1) those with markings, and (2) those without markings. Group (1) was then further divided into (*a*) those in which radiate markings could be seen with the naked eye, and (*b*) those in which the markings were not obviously radiate. On microscopic examination group (*b*) was again divided into (i) those that were probably radiate, and (ii) those which were probably non-radiate (Pl. I, fig. 2). The group that was probably non-radiate included the dark non-radiate form and the banded non-radiate form. In a large sample of over 1400 specimens dredged from the Cumbrae Deep 35·3% were found to be non-radiate, 12·4% probably non-radiate, 29·5%



Text-fig. 1. Percentage composition of the year groups. —, non-radiate; ···, probably non-radiate; —·—, radiate; — —, probably radiate.

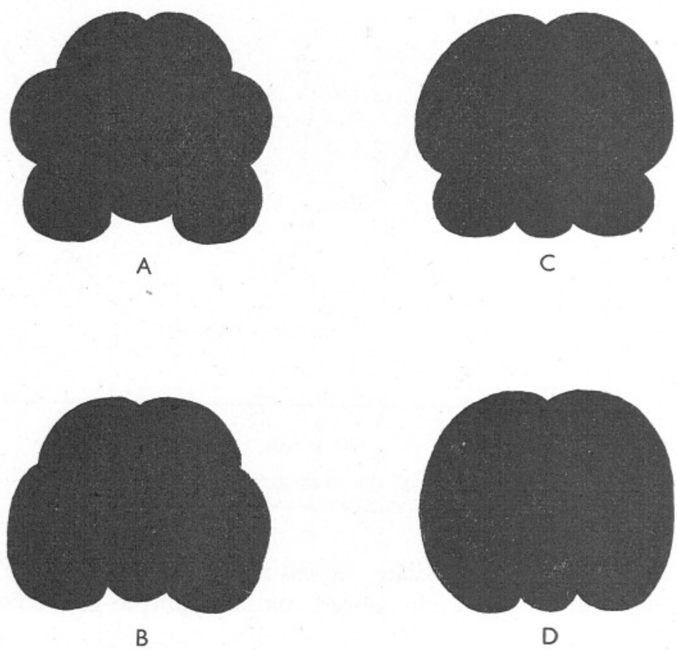
probably radiate and 22·8% radiate. It was found possible to make a graded series ranging from those which showed complete purple-grey coloration to those without markings.

This sample shows that the purple-grey markings are not visible until the animal is approximately 3 mm. long (in its third year) and that the first clearly radiate specimen is 3·6 mm. long. This is shown in Text-fig. 7 in which individual length is plotted against numbers in the four groups. In larger shells with purple-grey radiations there is an area in the region of the umbo corresponding to early shell growth that is not marked. Text-fig. 1, which plots the percentage composition for each year group of this population, shows clearly that the number of shells with markings increases with age.

Examination of the growth lines shows a considerable amount of variation in both radiate and non-radiate forms. In both, distinct wrinkles may be formed on various parts of the shell, but this feature could not be used for classification.

Faeces

Moore (1931 *a*, *b*) points out that the form of the faecal pellets is of value in the specific identification of various molluscan families. He describes their form in the British species of *Nucula* and differentiates the non-radiate form from the radiate form by this means. He states that the former has seven grooves and the latter five grooves (Text-fig. 2, A and B). The faeces of the two forms were re-examined. Freshly caught specimens were placed separately in vessels of clean water and the faecal pellets examined. In addition, transverse sections were cut through the rectal region (Table I; Pl. I, fig. 3).



Text-fig. 2. Faecal pellet types (end view); A, non-radiate form (Moore); B, radiate form (Moore); C, and D, other forms.

It will be seen from Table I that the present observations do not agree with those of Moore. Of fifty-six specimens examined, fifty-one had the non-radiate type of faeces (seven grooves) and only three had the radiate type (five grooves). Only one of these three corresponds to an animal with radiate shell markings and one to a shell that was probably radiate. Pl. I, fig. 3, is a photomicrograph of a transverse section of the rectum of an animal with a radiate type of shell. This shows a faecal pellet with seven ridges which Moore states is found in the non-radiate form. In addition, two other variations in the form of the faecal pellets were noted (Text-fig. 2, C and D).

TABLE I

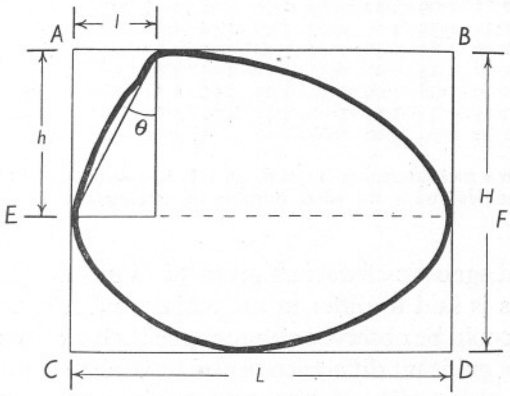
Shell markings	Number examined	Faecal pellets: Radiate form	Non-radiate form	Other forms
Radiate	14	1	12	1*
Probably radiate	7	1	6	—
Non-radiate	20	1	18	1†
Probably non-radiate	15	—	15	—
Totals	56	3	51	2

* See Text-fig. 2C. † See Text-fig. 2D.

Although the two forms as described by Moore exist, it is clear from this examination that they cannot be used as a means of differentiating the two species.

SHELL MEASUREMENTS

Measurements shown in Text-fig. 3 were taken for all British species of *Nucula*. The shell was placed on a grid (*ABCD*) divided into squares of side 1 mm. so that a line through the points *E* and *F* was parallel to the lines *AB*



Text-fig. 3. Diagram to show the shell measurements taken. For explanation of the symbols see text.

and *CD*. The measurements were taken with the aid of a travelling microscope the magnification being $\times 8$. The measurement *W*, the greatest width of the shell (pair of valves), was also taken. The measurements h and l were taken so that the angle θ could be calculated, as it was found that this angle differed in the different species of *Nucula*. In addition, neglecting the curvature of the shell margins, the values l and $L-l$ and h and $H-h$ define the outline of the shell and therefore are likely to be the best values from which discriminant functions can be calculated. Comparisons have been made mainly from the measurements of definitely radiate and non-radiate forms, particularly those from the large sample taken from the Cumbrae Deep.

Comparison of the radiate and non-radiate forms in which mean measurements for height (H) and width (W) were plotted against length (L) show that, except for high shell measurements where numbers are low and the variations in shell shape are the greatest, there is no significant difference between the two forms. Further comparisons of the mean shell measurements of each year group indicate even more strongly that there is no difference between the radiate and non-radiate forms even in the older age groups (Table II, Text-figs. 4 and 5). In addition, it is seen that the variations themselves show identical ranges. It would be possible to obtain identical curves even though the angle θ differed in the two forms. From Table II it is seen that the shell angle does not so differ.

TABLE II

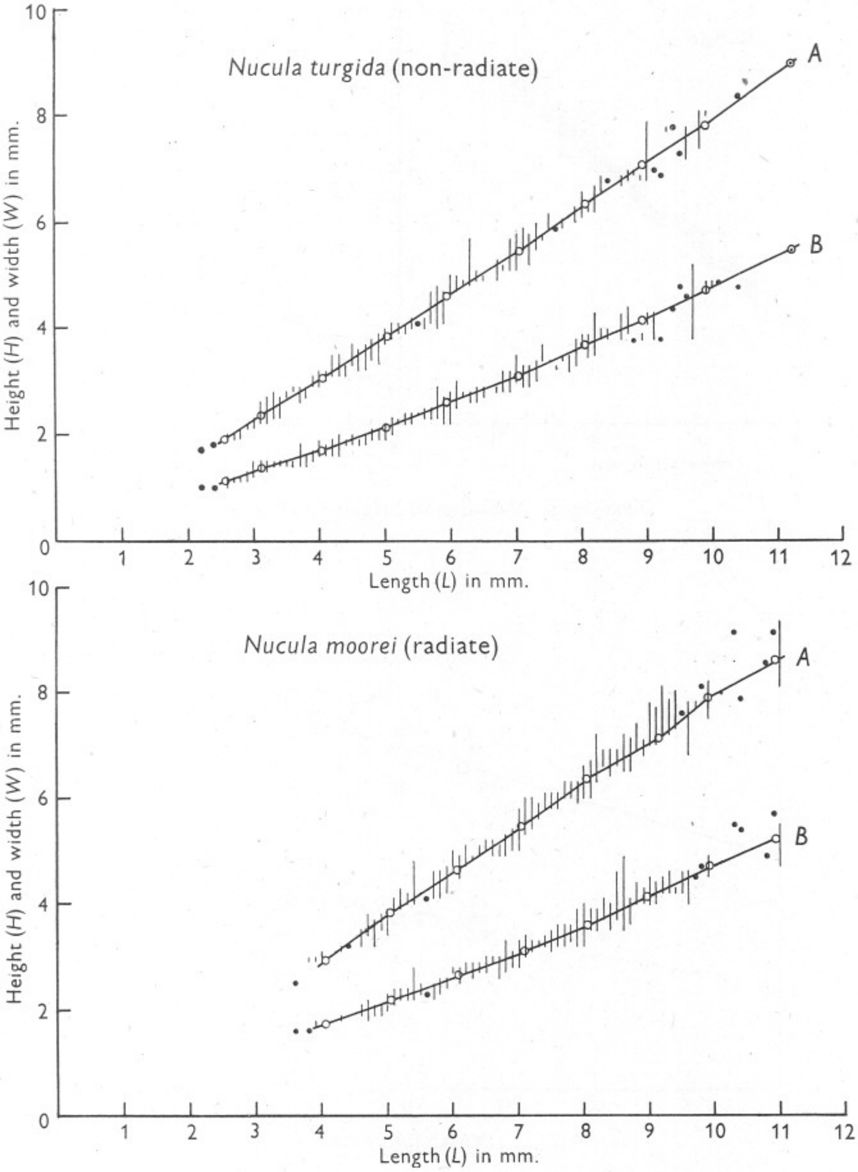
Year group	L		l		H		h		W		θ		Nos./yr. group	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1	2·55	—	0·70	—	1·90	—	1·01	—	1·10	—	34° 43′	—	11	—
2	3·11	—	0·83	—	2·33	—	1·21	—	1·33	—	34° 27′	—	81	—
3	4·04	4·05	0·98	0·98	3·05	2·94	1·65	1·69	1·68	1·74	30° 43′	30° 07′	109	13
4	5·02	5·04	1·11	1·09	3·82	3·84	2·06	2·06	2·12	2·17	28° 19′	28° 53′	107	54
5	5·97	6·08	1·32	1·35	4·60	4·63	2·49	2·54	2·58	2·65	28° 04′	28° 01′	99	61
6	7·04	7·05	1·56	1·63	5·46	5·47	3·04	3·04	3·09	3·10	27° 10′	28° 12′	47	78
7	8·05	8·04	1·87	1·83	6·35	6·33	3·61	3·55	3·69	3·63	27° 23′	27° 16′	35	82
8	8·92	8·94	1·99	1·98	7·09	7·12	4·00	4·06	4·14	4·12	26° 27′	26° 00′	23	41
9	9·88	9·90	2·15	2·23	7·81	7·91	4·42	4·63	4·72	4·73	29° 00′	25° 41′	13	12*
10	11·20	10·93	2·30	2·60	9·00	8·60	5·10	4·73	5·50	5·20	24° 17′	28° 48′	1	4*

Comparison of shell measurements (in mm.) of (A) non-radiate and (B) radiate forms.
* Discrepancies due to the small number of specimens in the year groups.

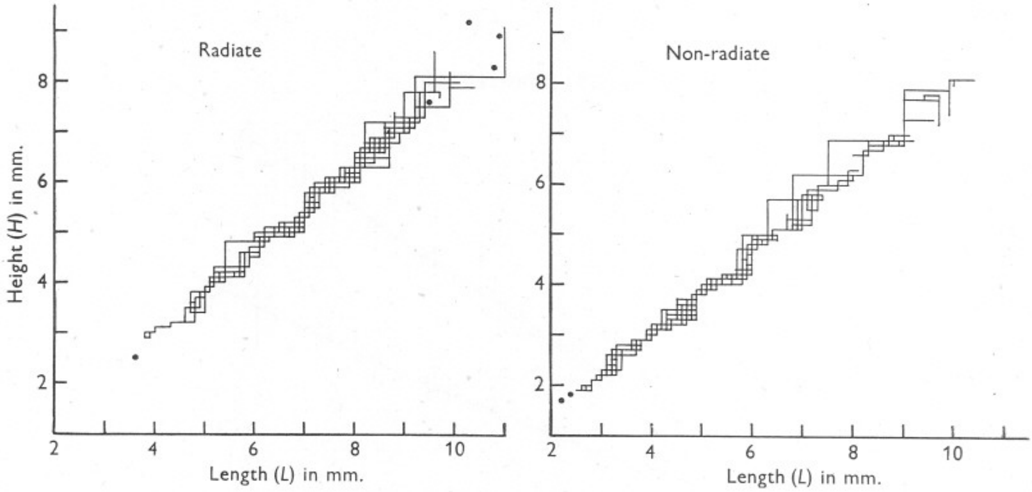
In the list of diagnostic characters given by Winckworth the curvature of the shell margins is said to differ in the radiate and non-radiate forms. No such distinction could be observed although the shell outlines were compared.

As there is no significant difference between the shell measurements and no difference in the shell outline of the two forms, it is not necessary to calculate discriminant functions. Values of t calculated for L, H, W, l and h are 1·59, 0·47, 0·97, 0·87, and 1·34 respectively. All these are considerably lower than the value 2·447 for t (corresponding to a probability $P=0{\cdot}05$) given in Fisher & Yates' (1948) tables. Therefore the means of the values in the radiate and non-radiate groups do not differ significantly from one another.

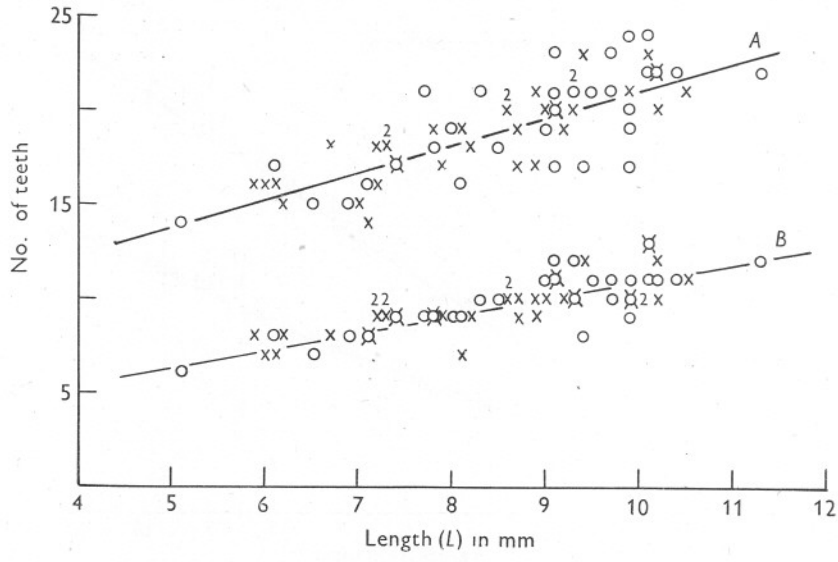
In addition to the measurements listed above the numbers of hinge teeth in the two forms were compared (Text-fig. 6). Although there is a considerable variation in the numbers of teeth in each form for a particular shell length, comparison of the numbers of anterior and posterior teeth at different shell lengths in the radiate and non-radiate forms shows that no distinction can be made by using this character. Both show a similar increase in the number of teeth with increasing shell length.



Text-fig. 4. Comparison of mean values of height (H) and width (W) with length (L) for each year group and the range of values for height and width with length. A, height/length; B, width/length.



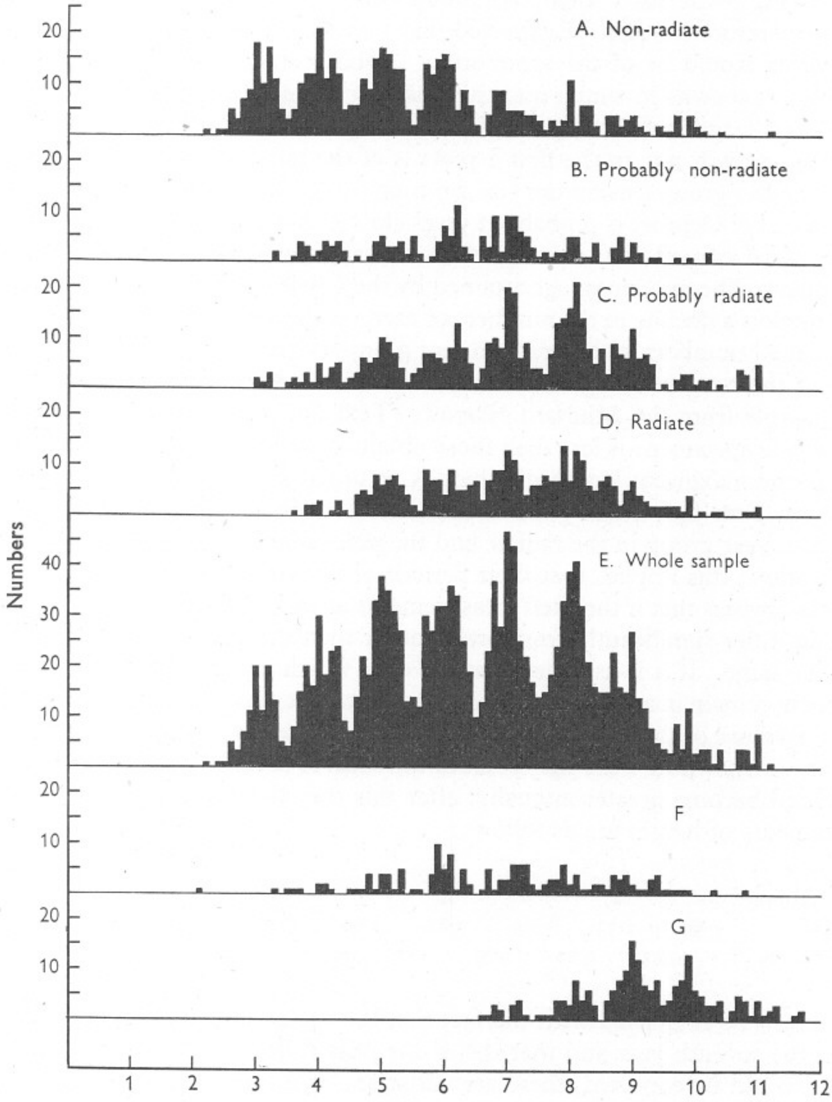
Text-fig. 5. Variation of height with length.



Text-fig. 6. Comparison of the numbers of anterior (A) and posterior (B) teeth at different shell lengths in the radiate and non-radiate forms. $\times$, radiate; $\bigcirc$, non-radiate; the numerals indicate the number of coincident readings.

Age and Growth

It can be seen that the samples fall into distinct groups (Text-fig. 7); these are presumably year groups though actual proof is lacking. The range in shell length of each group is identical in the four colour groups examined. The



Text-fig. 7. Population histogram of three samples. A–E, Cumbrae Deep, 31. x. 50.; F, Cumbrae Deep, 17. vi. 51.; G, Minnard Narrows, 27. vii. 51.

undulations of the ranges of variations in Text-fig. 4 also indicate the year groups and again show no difference between the radiate and non-radiate forms. Lebour (1938) reports that the egg diameter of *N. nitida* is 90 μ and that of *N. nucleus*, a species that grows to a similar size, 100 μ. Both species have a very short larval life, but no measurements of the larvae are given. A drawing by Bernard (1896) of a prodissoconch of *N. nucleus* measures 180 μ long, therefore it might be expected that the size of the newly settled spat of *N. nitida* would be of the same order. Lebour states that *N. turgida* from Plymouth spawns in winter and that she successfully reared fertilized eggs to the larval stage in February. If the spawning times at Millport are the same and the growth rate in the first 2 years is of the same order as the following, the smallest group (maximum size 2·7 mm.) of the Cumbrae Deep haul taken at the end of October is probably 2 years old. Although no successful fertilizations were carried out, ripe sperm and ova were present from October to February. The maximum age attained by the Clyde specimens is 10–11 years, but there is a decline in the numbers of each year group after the seventh year. The small numbers in the first two year groups is due to the fact that the mesh size of the net was too great to retain the smaller shells; this also applies to the sample from the Minnard Narrows (Text-fig. 7). The maximum size of the Clyde specimens is less than those obtained by Marshall from the Dogger Bank, the maximum length of which is recorded as from 13·0 to 13·75 mm.

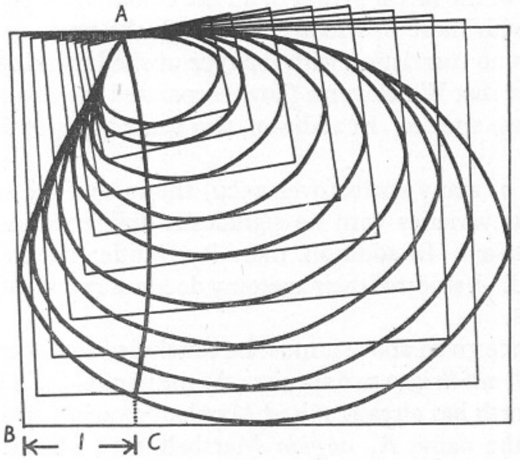
From Text-figs. 4 and 7 it is seen that the shapes of the population curves for each year group in the radiate and the non-radiate forms correspond with each other; this implies that their periods of spawning are the same.

It is obvious that if the shell measurements at various ages in the two groups do not differ significantly from one another then the rates of growth of each are the same. If it is assumed that the cells which lay down the purple-grey pigment remain in a constant position on the mantle edge then the rays indicate the curvature of the growth. Thus the successive yearly increments of growth will be as shown in Text-fig. 8. Until the sixth or seventh year, increments to the shell become greater annually, after this they decrease. Thus the annual increments of height are as follows:

Year groups...	1		2		3		4		5		6		7		8		9
Height	1·90		2·33		3·05		3·82		4·60		5·46		6·35		7·09		7·81
Increments		0·43		0·72		0·77		0·78		0·86		0·89		0·74		0·72	

This may be correlated with the fact that the age groups decline in numbers after the seventh year and that this is the peak followed by senescence.

As would be expected, there are variations in the shape of the shells, and the minimum and maximum values from the mean shell values increase with age. From Text-figs. 4 and 5 it has been seen that the minimum and maximum values are of the same order in both the radiate and non-radiate types.



Text-fig. 8. Shell growth calculated from the mean shell measurements of each year group. *AC* is a ray which passes from the umbo to a point on the shell margin where *BC* is the measurement *l*.

Discussion and Conclusions

Observations have been made on a large number of specimens of the two alleged species *N. turgida* and *N. moorei*. In particular, those characters listed by Winckworth as being diagnostic have been studied. These are of three types: the colour of the shell, the shape of the faeces, and the shape of the shell.

The basic colour is yellow. This may or may not have purple-grey markings. *N. moorei* is differentiated from *N. turgida* by having these markings in the form of rays. *N. turgida* includes the unmarked form and those shells in which the markings are not in the form of rays. It was found that the shells could be arranged in a continuous series from a form that was so heavily marked that the radiations have merged into one another to give a dark unrayed shell through forms with varying degrees of radiate markings to those that have none at all. The shell markings are not necessarily laid down continuously, and shells with coloured bands parallel to the lines of growth are found. A study of a large sample shows that the purple-grey colour does not appear until the end of the second year and that the percentage of unmarked forms decreases with age. These facts indicate that there are not two species but one which exhibits a continuous series of colour varieties. The increase in the number of specimens which show this coloration as their age increases suggests that the purple-grey colour is a waste product produced by the metabolic activities of the animal. Comfort (1951) points out that 'the shell pigments of the lower bivalves are secreted into the shell as a means of disposal, being derived from the diet or unmanageable metabolic residues'.

Examination of the faecal pellets of all the colour varieties gave results that did not agree with those of Moore. Although the types listed by him were found there was no correlation with the type of shell markings. It was mainly on this character that Winckworth (1931) separated the two colour varieties of *N. nitida* into two species. In addition, two other types of faecal pellets were noted.

Examination of many shells (over 2500) shows that the shape is the same in all the colour varieties with no significant difference in any of the shell measurements taken. In addition, there is no difference in growth rate and spawning period. A study of their anatomy does not reveal differences between the colour types.

On the evidence given above it must be concluded that there are no grounds for separating *N. nitida* into two species. As the name *N. nitida* is preoccupied, and as Winckworth has already raised Marshall's variety to specific rank, it is proposed that the name *N. turgida* Marshall 1875 should be applied and *N. moorei* a synonym of it.

I would like to express my thanks to Prof. C. M. Yonge, F.R.S., for his help and encouragement and for reading and criticizing the manuscript. I would also like to thank Dr R. B. Pike for his interest and encouragement and Mr M. V. Brian for his help in the statistics. I am grateful to the Director and Staff of the Marine Station, Millport, for their help and to Mr S. McGonigal for taking the photographs.

This work was made possible in the first place by a grant from the Browne Fund of the Royal Society and later by a Research Grant from the Development Commission.

Summary

In the course of a study of the British Nuculidae the specific characters of a large number of specimens of *N. turgida* and *N. moorei* were re-examined. It was found that no distinction could be made between the two.

Examination of variation in shell colour showed that it was not possible to differentiate into two distinct types. There was a continuous graded series from a dark purple-grey in which the basic yellow colour was almost completely masked, through a series with decreasing numbers of purple-grey radiations, to shells in which the markings could not be differentiated as rays, and finally to shells without purple coloration. The purple-grey colour is not necessarily laid down continuously, and it does not develop until the end of the second year. As the shells get older an increasing percentage of them become coloured.

Although the two types of faecal pellets described by Moore were found they could not be associated with the radiate and non-radiate shell types. The five grooved faeces that he claimed were typical of the radiate variety, were

found in only three of the fifty-six specimens examined. Only one of them was from a definitely radiate shell.

Shell measurements and growth rates were studied, and no feature was found on which two forms could be separated. Samples show that reproduction takes place at the same time in the rayed and unrayed shells.

As the name *N. nitida* Sowerby is preoccupied it is suggested that the name *N. turgida* Marshall should now be used with *N. moorei* a synonym of it.

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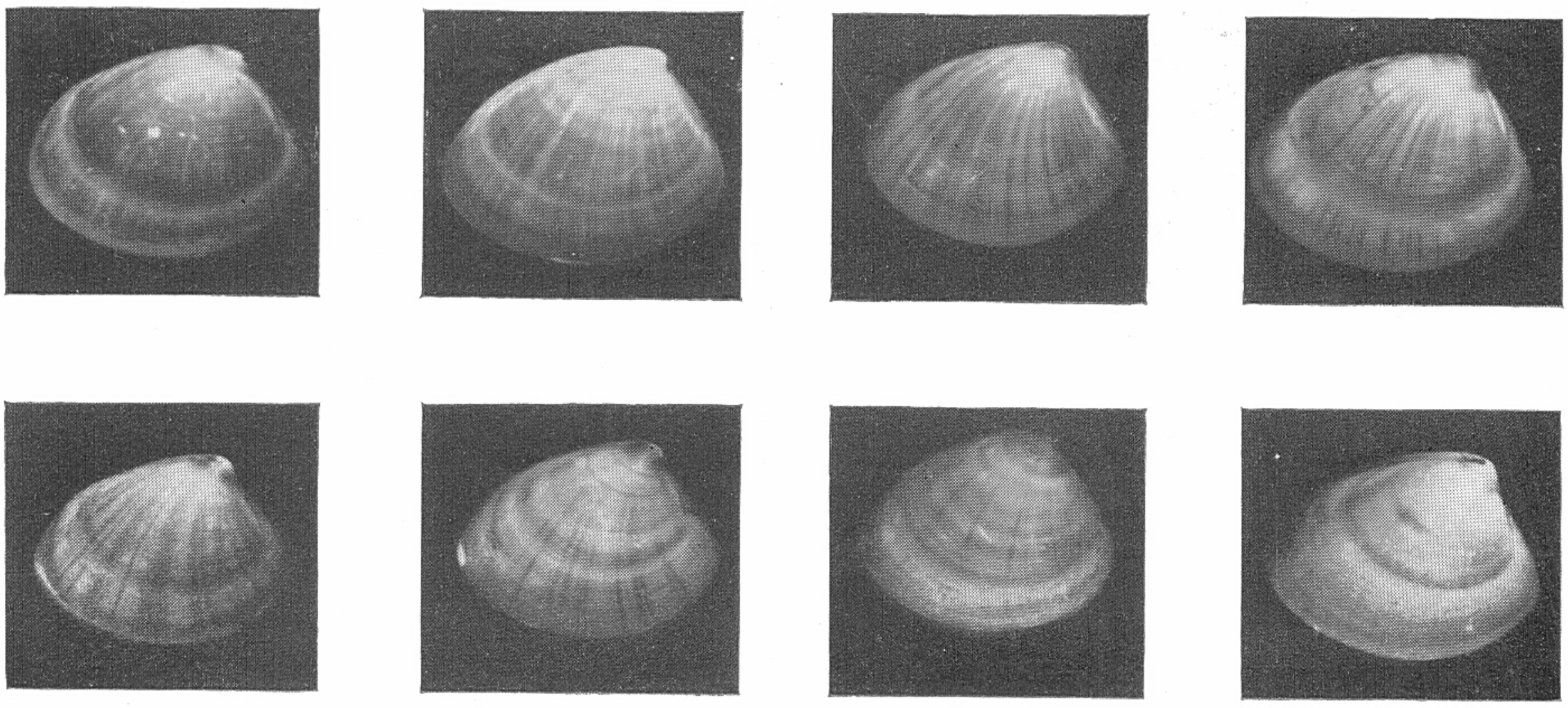
EXPLANATION OF PLATE I

Fig. 1. Series showing the change from a heavily radiate shell to a non-radiate shell. (Some show the sculpturing of the shell, this should not be confused with the purple-grey markings.)

Fig. 2. Left and centre: probably radiate shells; right probably non-radiate shell. These also show shell sculpturing.

Fig. 3. Transverse section of rectum of a radiate shell showing a seven-grooved faecal pellet.



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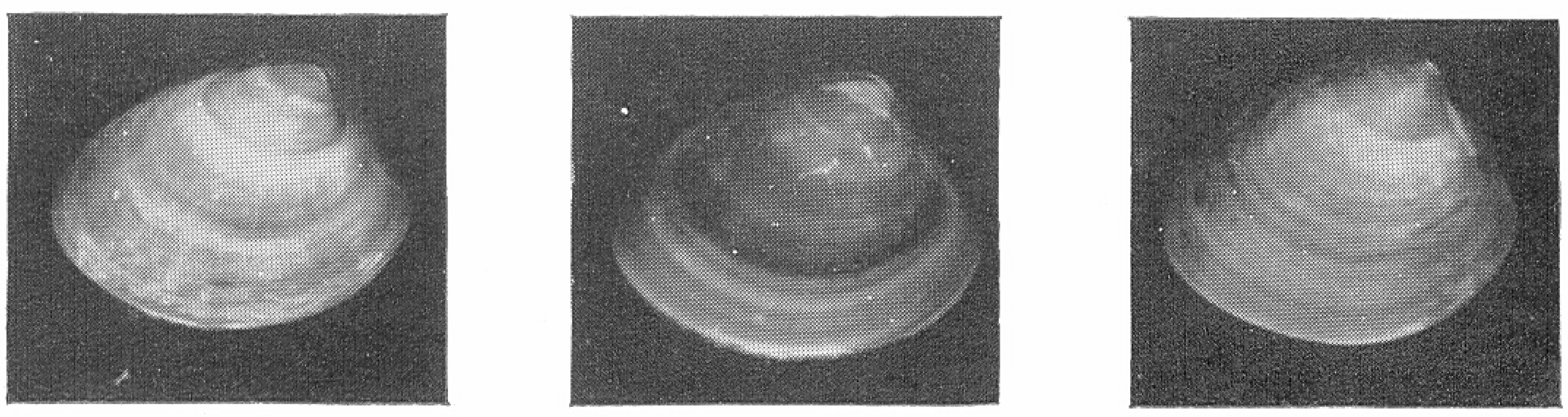

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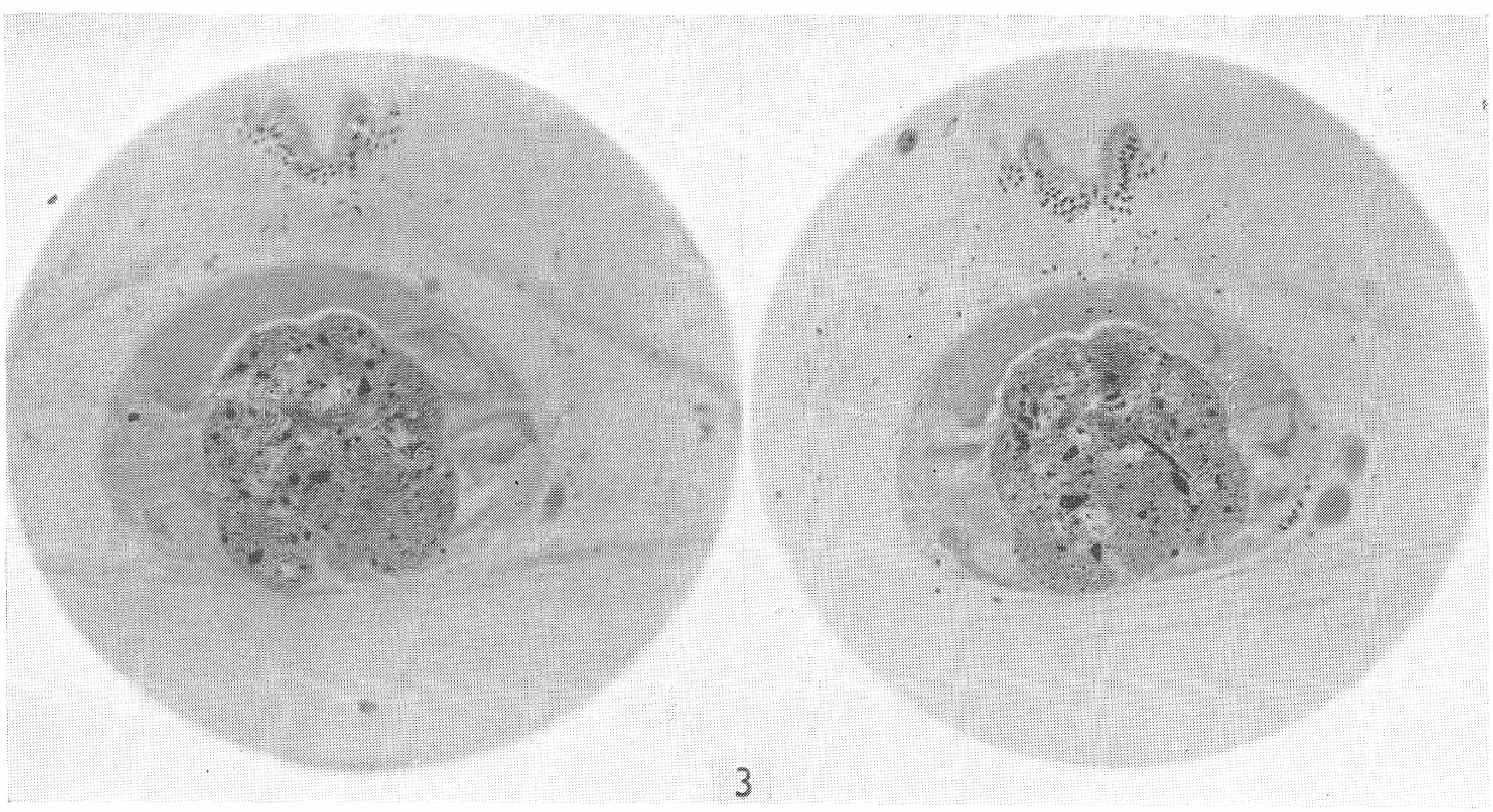

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