Seasonal Variations in the Metabolism of Lipids and Glycogen in the Scallop, Patinopecten yessoensis (JAY) I. Biochemical Studies

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journal or publication title	Tohoku journal of agricultural research
volume	22
number	2
page range	114-133
year	1971-11-20
URL	http://hdl.handle.net/10097/29612

Tohoku Journal of Agricultural Research
Vol. 22, No. 2, August 1971
Printed in Japan

Seasonal Variations in the Metabolism of Lipids and Glycogen in the Scallop, *Patinopecten yessoensis* (JAY)

I. Biochemical Studies*

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(Received, May 27, 1971)

Summary

1. The seasonal variations in the metabolism of lipids and glycogen in the Japanese scallop, *Patinopecten yessoensis* (Jay), were chemically analized. Scallops, cultivated in Onagawa Bay, Miyagi Prefecture, Japan, by the hanging method, were used as the materials for the study.
2. High concentrations of lipids were found in the digestive diverticula and of glycogen in the adductor muscle.
3. In the digestive diverticula, lipids were detected in large quantities in summer, but they showed a marked fall in amount at the beginning of sexual maturation. However, their total amount proved to increase rapidly as sexual maturation proceeded. During this period, the body growth of the scallops was remarkable and the adductor muscle especially showed a marked increase in weight.
4. The glycogen content in the adductor muscle increased as sexual maturation proceeded. This increase was not more marked than that of the lipid content in the digestive diverticula.
5. The seasonal changes in the content of lipids in the digestive diverticula, and glycogen in the adductor muscle, were generally in parallel with those of lipids and glycogen in the entire soft body.
6. From the results obtained in the present study, it appears that the digestive diverticula is the main organ for lipid metabolism, and the adductor muscle the main organ for glycogen metabolism.
7. These findings on the seasonal change in the content of lipids in the digestive diverticula of scallops cultivated in Onagawa Bay agree well with those obtained by us on scallops from Mutsu Bay, Aomori Prefecture.

Scallop fisheries for *P. yessoensis*, in Japan are found mostly from Mutsu Bay and northward. Recently, their culture has been extensively carried on in not only

* The oral presentation of this report was given at the Annual Meetg. of Japan. Soc. Sci. Fish., Tokyo, April 1, 1968, and at the Autumn Meetg. of the same society, Fukuoka, October 12, 1968.

these regions, but also on the coast of the Sanriku district which lies to the south of Mutsu Bay. All of this production does not necessarily mean that the method for culture has been the object of much scientific research. We feel that physiological studies on the metabolism of scallop is needed as one of the biological bases for culture management.

There have been many reports concerning seasonal variations in the chemical composition of the entire soft body (meat) of bivalves, but relatively little is known about that of the separate body components, namely, parts that can be conveniently separated from one another by dissection. Ashikaga (1) investigated biochemically the chemical composition of the separate body components of the pearl oyster, *Pinctada martensii*, in connection with the season and age. On the other hand, Mori et al. (2) carried out biochemical and histochemical studies on the distribution of glycogen and lipids in the Japanese common oyster, *Crassostrea gigas*, with special reference to sexual maturation and spawning. In the former report, however, the relation to the reproductive cycle was not described in detail, and in the latter, the growth of each tissue was not discussed.

Scallops can locomote by the rapid contraction of the well-developed adductor muscle, while oysters attach themselves to many kinds of hard or semihard surfaces as larvae, and remain immovable all their lives. The adductor muscle of the scallop contains a large quantity of glycogen (3), while that of the oyster has only a small quantity of this substance and shows no clear seasonal variation in the content (4, 5). Further, it is observed that the degree of organ differentiation is higher in the scallop than in the oyster. From these facts, it may be assumed that these two kinds of bivalves differ in their metabolic activities.

The growth of the Japanese scallop was followed by Nishikawa et al. (6) and Maru and Obara (7), and the gonadal development was observed by Yamamoto (8) and Wakui and Obara (9). These results indicate that the rate of growth and the reproductive period vary from place to place, depending on the conditions of the environment. Accordingly, we strongly feel that physiological studies on the metabolism of scallop will require simultaneous detailed investigations of growth and gonadal development of the experimental animals.

The purpose of this study was to follow biochemically the seasonal variations in the metabolism of lipids and glycogen in the scallops, *P. yessoensis*, cultivated in Onagawa Bay, and to clarify the correlation between the aforementioned variations and the growth and reproductive cycles. In addition, the scallops from Mutsu Bay were investigated for comparison.

Materials and Methods

The experiments were carried out each month from July in 1967 to August in 1968. One or two year old scallops cultivated at a depth of 6 m in Onagawa Bay, Miyagi Pref., by the hanging method, were used as the experimental materials. The juveniles of these scallops which had been hatched out of fertilized eggs in May, 1966, at the Mohne laboratory of the Oyster Research Institute near Kesennuma City, Miyagi Pref. (10), were transfered to Onagawa Bay at the end of April in 1967 for this study.

First the length and height of shell, and the weight of the entire soft body (meat) and separate body components, namely, the gonad, digestive diverticula, adductor muscle, and gill and mantle of 10 to 16 scallops were measured in every experiment. Then, the lipids, glycogen and protein of the entire soft body and separate body components were extracted with ethyl ether using Soxhlet's extractor, and determined by the method of Kemp et al. (11) and by the micro-Kjeldahl method of nitrogen determination, respectively. These biochemical data were given in percentage of dry weight.

For histological observation of the gonadal development, pieces of the gonad were fixed in Zenker-formol solution and embedded in paraffin. Six micron sections were made and stained with hematoxylin-eosin.

Results

Sexual cycle and growth

1. Gonadal Development

Water temperature and gonad index

In Fig. 1 are shown the seasonal changes in noon-time water temperatures observed in the vicinity where scallops were cultivated, and the respective gonad index (gonad weight/soft body weight$\times$100). The highest temperature (23°C) was recorded from the middle to the latter part of August in 1967, while the lowest (6°C) was measured in the middle of February in 1968. The seasonal change in the gonad index was negligible before December in 1967, but a sharp increase was found in and after December when the sexes of scallops became distinctly separable with the naked eye. The highest index was seen in the middle of February in 1968 during the period of lowest temperature. After that, the index fell with the rise of water temperature. In short, there was a reciprocal relationship between water temperature and gonad index. Also, it was noticed, in relation to the spawning, that the widest range in the index was obtained in March, 1968, and that a considerable fall in the index was seen from April to May.

Seasonal variations in the histological condition of gonads

During the period from August till the beginning of October in 1967, the lumina of the follicles in the ovary and spermary were almost empty, and there were considerable wide spaces between follicles (Figs. 2 and 3). The sexes of

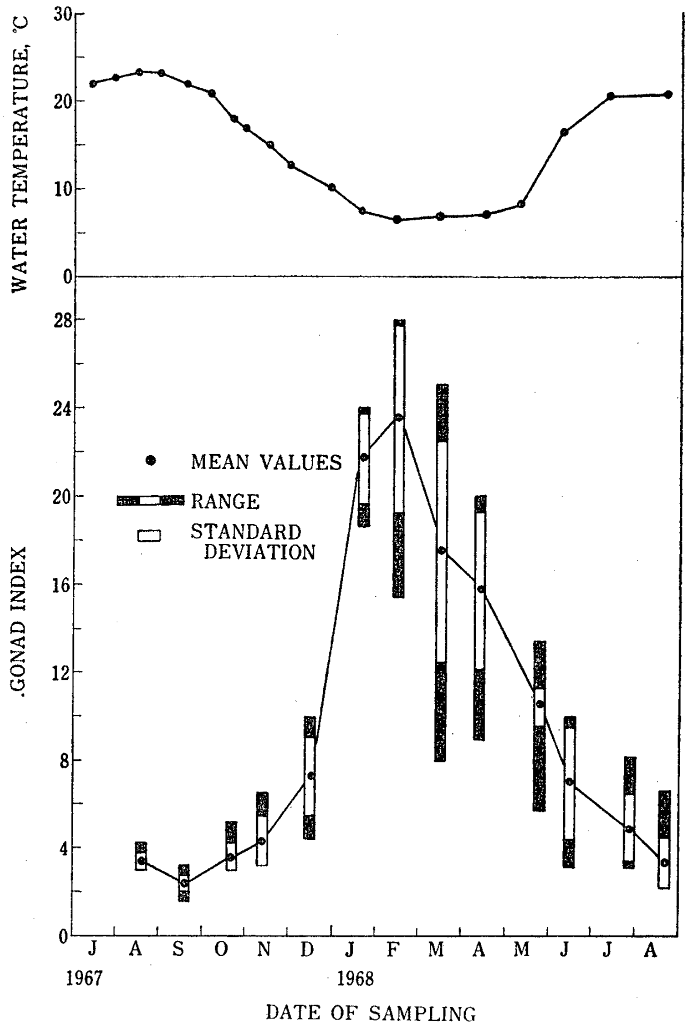

FIG. 1. Seasonal changes in the noon-time water temperatures (6 m in depth) observed in the vicinity where scallops were cultivated, and the respective gonad index (gonad weight/soft body weight ×100).

scallops were not identifiable with the naked eye. These observations indicate that the gonads during this period were in the resting stage.

From the latter part of October till November, the division of spermatogonium commenced in the spermary. Only a few scallops had a small number of spermatozoa. On the other hand, ovogonia and young ovocytes were observed to line the wall of the follicle in the ovary.

Toward the end of December, the spermatogonia, spermatocytes and spermatids were packed in the follicle of the spermary, and spermatozoa were found in the central part of the lumen (Fig. 4). In the ovary, ovocytes increased in size and the distal part, grossly enlarged and rounded, protruded into the lumen of the follicle (Fig. 5). The sexes of scallops became easily separable by gonad coloration.

Gonadal development proceeded rapidly with the fall of water temperature.

From the middle of January till the middle of February in 1968, spermatozoa predominated and were closely packed in the follicle of the spermary (Fig. 6). The ovocytes which were either free or connected to the wall with stalks were closely packed in the follicle of the ovary (Fig. 7).

In the middle of March, a very slight spawning was observed to have occurred in a few scallops of both sexes. It seemed that the most active discharge of sex cells occurred about the middle of May in the case of the female, and about the middle of June in the case of the male, because their numbers were found to be very small toward the end of each given month (Figs. 8 and 9).

Toward the middle of July, only a few mature sex cells were retained, indicating that spawning was complete (Figs. 10 and 11). It was very difficult to distinguish the sexes of scallops by observing gonad coloration at this point.

2. Growth

Body growth

In Fig. 12 are shown the seasonal changes in the shell length and the dry weight of the entire soft body (meat). The shell length showed a considerable increase from mid-Juy to mid-August in 1967, from mid-December in 1967 to mid-February in 1968, when the gonadal development proceeded rapidly, and from mid-June to mid-August in 1968 after spawning. From mid-August to mid-December in 1967, and from mid-April to mid-June in 1968 during spawing, the shell growth was very slow or had stopped. The variation of weight of soft body

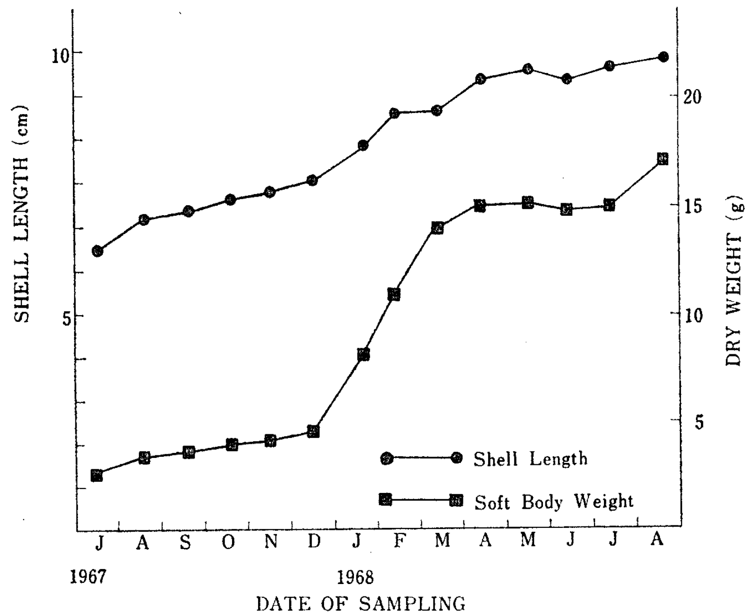

Fig. 12. Seasonal changes in the shell length and the dry weight of the entire soft body of scallop.

was similar to that of shell length. A sharp increase in weight was noted especially from mid-December to mid-February.

Growth of separate body components

The seasonal change in the dry weight of separate body components is shown in Fig. 13. From mid-August to mid-November in 1967, when no change in weight was found in the gonad, no significant change was recognized in other tissues either. On and after mid-December when the sexes of scallops became

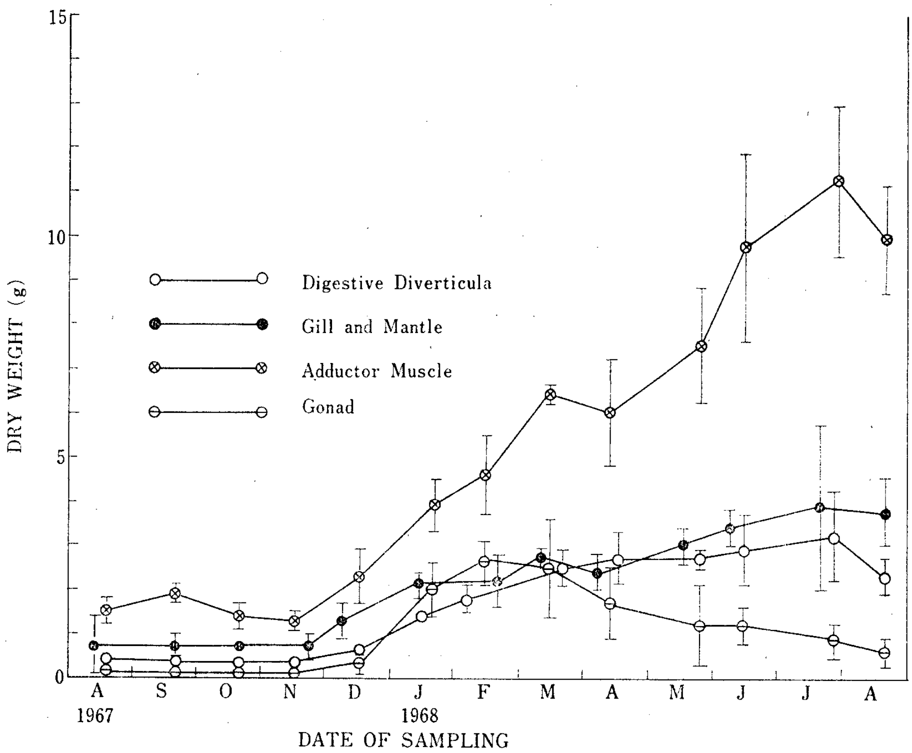

Fig. 13. Seasonal change in the dry weight of separate body components of scallop. The circles are the mean values and the vertical lines are the 95% confidence limits.

distinctly separable with the naked eye, the gonad showed a sharp increase in weight as sexual maturation proceeded rapidly. The other tissues also exhibited marked increase in weight during this period. The increase was especially marked in the adductor muscle. From mid-January in 1968 onward, the growth of gill and mantle stopped or was slow. During the period of spawning from March to June, the growth of the digestive diverticula almost stopped. However, the adductor muscle exhibited marked increase in weight.

Seasonal variations in the chemical composition

1. Chemical Composition of the Entire Soft Body

The seasonal change in the chemical composition of the entire soft body is

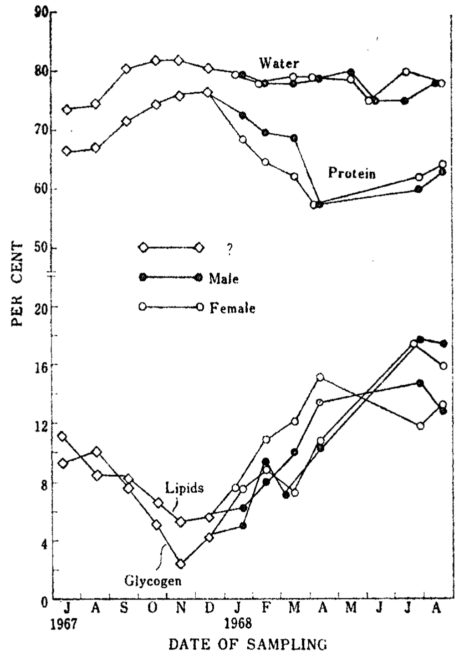

FIG. 14. Seasonal change in the chemical composition of the entire soft body of scallop; ordinate, % of soft body wet weight for water, % dry weight for other components. ?: The sexes were not identifiable with the naked eye.

shown in Fig. 14. No definite trend in the change of the water content could be detected. There was no appreciable difference between males and females. The lipid content showed a tendency to decrease from mid-July to mid-November, and was lowest (about 5%) in mid-November when sexual maturation started. From this time on, it increased in both the female and the male as sexual maturation proceeded rapidly, and did not decrease after spawning. Although the glycogen content exhibited a tendency to increase slightly from mid-July to mid-August, its seasonal variation was generally parallel to that of the lipid content from this period on. In contrast with lipids or glycogen, protein increased in content from mid-August to mid-November and then decreased with the sexual maturation of the scallops. The content was usually higher in the male than in the female.

2. Chemical Composition of Separate Body Components

Water content

In Fig. 15 is shown the seasonal variation in the water content of separate body components. No significant difference was found between the females and males in any tissue examined. The gonad showed a decreasing water content as sexual maturation proceeded, and an increasing one after spawning. The digestive diverticula, containing the lowest percentage of water, exhibited a decrease with the occurrence of spawning. However, no seasonal change was recognized in other tissues.

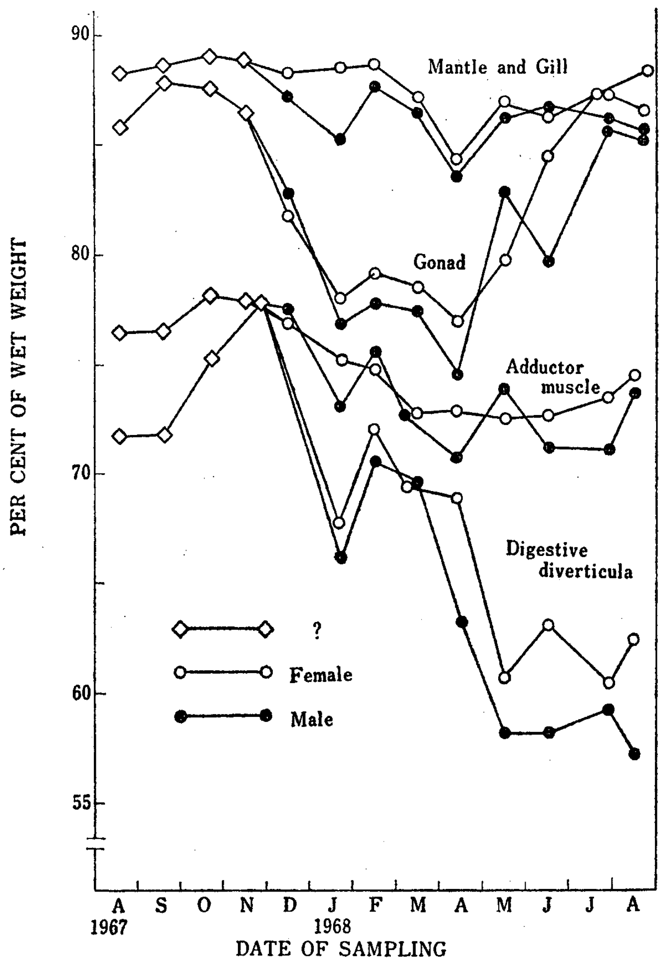

FIG. 15. Seasonal variation in the water content of separate body components of scallop.
?: The sexes were not identifiable with the naked eye.

Lipid content

In Fig. 16 is shown the seasonal variation in the lipid content. The content differed considerably among tissues. In the ovary, there was a rise in the content with the gonadal development and no clear decrease was found even after spawning. In the spermary, on the other hand, there was no variation with sexual maturation but a tendency to increase was seen after spawning.

In the middle of August when the water temperature reached the maximum, the lipid content of the digestive diverticula was 48% of the dry weight. This percentage corresponds to 79% of the total lipids contained in the entire soft body sampled at the same time. But, it decreased rapidly with the fall in the water temperature and reached 22 % late in November when sexual maturation had just commenced, and late in December when the sexes of scallops became separable with the naked eye. The percentage (22 %) is lower than half of the content determined in mid-August, and it corresponds to 58 % of the total lipids contained in the entire soft body sampled at the same time. After mid-December, the lipid

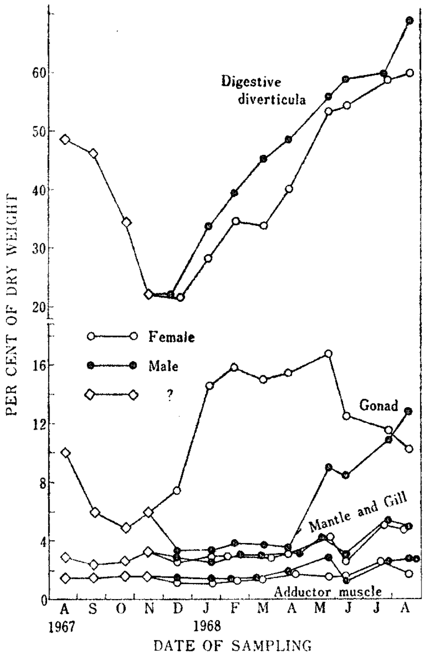

Fig. 16.

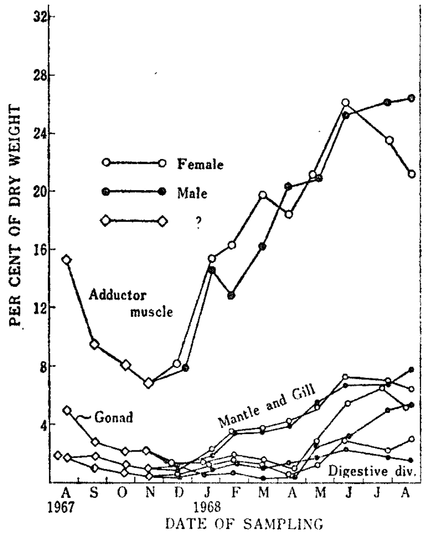

Fig. 17.

Fig. 16. Seasonal variation in the lipid content of separate body components of scallop. ?: The sexes were not identifiable with the naked eye.

Fig. 17. Seasonal change in the glycogen content of separate body components of scallop. ?: The sexes were not identifiable with the naked eye.

content increased markedly as sexual maturation proceeded rapidly, and showed a tendency to increase also during the period of spawning. After spawning when the experimental scallops became two years old, the content increased slowly. In mid-August, 1968, when the experiment finished, it was 60 % in the female and 69 % in the male. It was found that the seasonal change in the content of lipids in the digestive diverticula was generally parallel to that of lipids in the entire soft body.

In other tissues determined, the lipid content was very low and showed no clear change throughout the season.

Glycogen content

The seasonal change in the glycogen content is shown in Fig. 17. Glycogen, like lipids, differed considerably in content among tissues. In the adductor muscle where the lipid content was very low and showed no seasonal change, the glycogen content was 15 % of the dry weight in mid-August. This percentage corresponds to 90 % of the total glycogen contained in the entire soft body sampled at the same time. After mid-August, it decreased to about 7 % in mid-November. The percentage is half of the content obtained in mid-August, and it also corresponds to 90 % of the total glycogen. Like lipids in the digestive diverticula, it increased with sexual maturation and showed a tendency to increase both during the period of spawning and after. In mid-August, 1968, when the experiment ended, it was 21 % in the female and 27 % in the male. It was recognized that the seasonal change in the glycogen content in the adductor muscle mentioned above was similar to that in the entire soft body.

In the gill and mantle, a tendency to increase was found during the stages of sexual maturation and spawning. In the gonad also, a similar tendency was observed after spawning. In the digestive diverticula where the lipid content showed a marked seasonal change, the glycogen content was very low and exhibited no significant variation through a year.

Protein content

The seasonal change in the protein content is shown in Fig. 18. The content in the adductor muscle of both sexes, in contrast with glycogen, reached the maximum (84 %) in mid-December and fell gradually during the periods of sexual maturation and spawning. The content in the digestive diverticula, in contrast

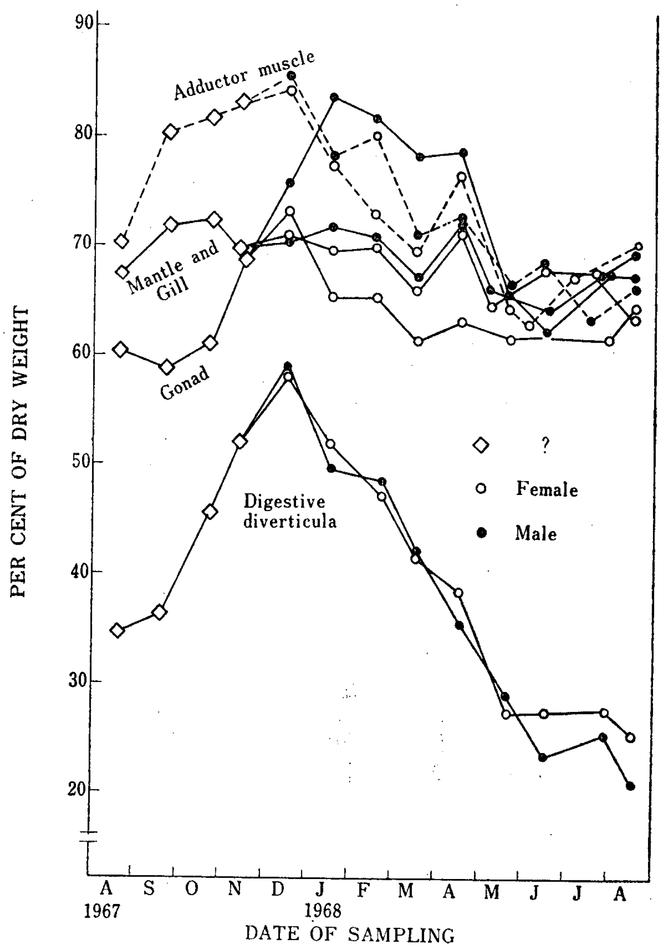

FIG. 18. Seasonal change in the protein content of separate body components of scallop.
?: The sexes were not identifiable with the naked eye.

with lipids, increased markedly after mid-August and reached the maximum (58 %) in both sexes in mid-December. But, it showed a decline with sexual maturation. The contents in the ovary and spermary were considerably different. In the spermary, the content increased with sexual maturation and decreased after the spawning period. In the ovary, on the other hand, there was a slight decrease during the period of sexual maturation. In the gill and mantle, there was no seasonal change in the content, except for sporadic fluctuations.

Discussion

From the chemical analysis, high concentrations of lipids were found in the digestive diverticula and of glycogen in the adductor muscle. The seasonal changes in the contents of lipids in the digestive diverticula and of glycogen in the adductor muscle were generally parallel to those of lipids and glycogen in the entire soft body (Figs. 14, 16 and 17). From these results, we can regard the digestive diverticula as the main organ for lipid metabolism, and the adductor muscle as the main organ for glycogen metabolism.

It is not obvious whether the seasonal changes in the contents of lipids in the digestive diverticula and glycogen in the adductor muscle are characteristic of the scallops cultivated in Onagawa Bay or whether they are to be regarded as physiological phenomena proper to *Patinopecten yessoensis* itself. In order to make this point clear, scallops from Mutsu Bay were also investigated for comparison concerning lipids in the digestive diverticula.

In Mutsu Bay, there was a considerable difference between cultivated and natural scallops concerning the gonadal condition early in May. In the former, spawning was completed and it was difficult to separate the sexes of the scallops from each other with the naked eye (Figs. 19 and 20). In the latter, the bulk of each gonad was observed to be made up of fully developed ova or sperms which filled up the lumina of the follicles, although a very slight spawning was found to have occurred in a few scallops (Figs. 21 and 22). In the former the lipid content of the digestive diverticula was 50% in the male and 47% in the female, while in the latter it was 37% in the male and 33% in the female. Early in August when the gonad was in the resting stage (Figs. 23 and 24), it was 50% in the former and 54% in the latter, indicating no significant difference in content. From these results, it is evident that the content varies with the gonadal development. The abovementioned results on the scallops from Mutsu Bay agree well with those cultivated in Onagawa Bay. From this fact, it may be concluded that the seasonal change in the content of lipids in the digestive diverticula is a physiological phenomenon proper to *P. yessoensis* itself.

Acknowledgement

The authors wish to express their thanks to the late Dr. T. Imai and other members of the staff of the Mohne Laboratory of the Oyster Research Institute for many courtesies and accommodations offered, and to the entire staff of the Aquaculture Center of Aomori Prefecture for supplying samples of scallops from Mutsu Bay.

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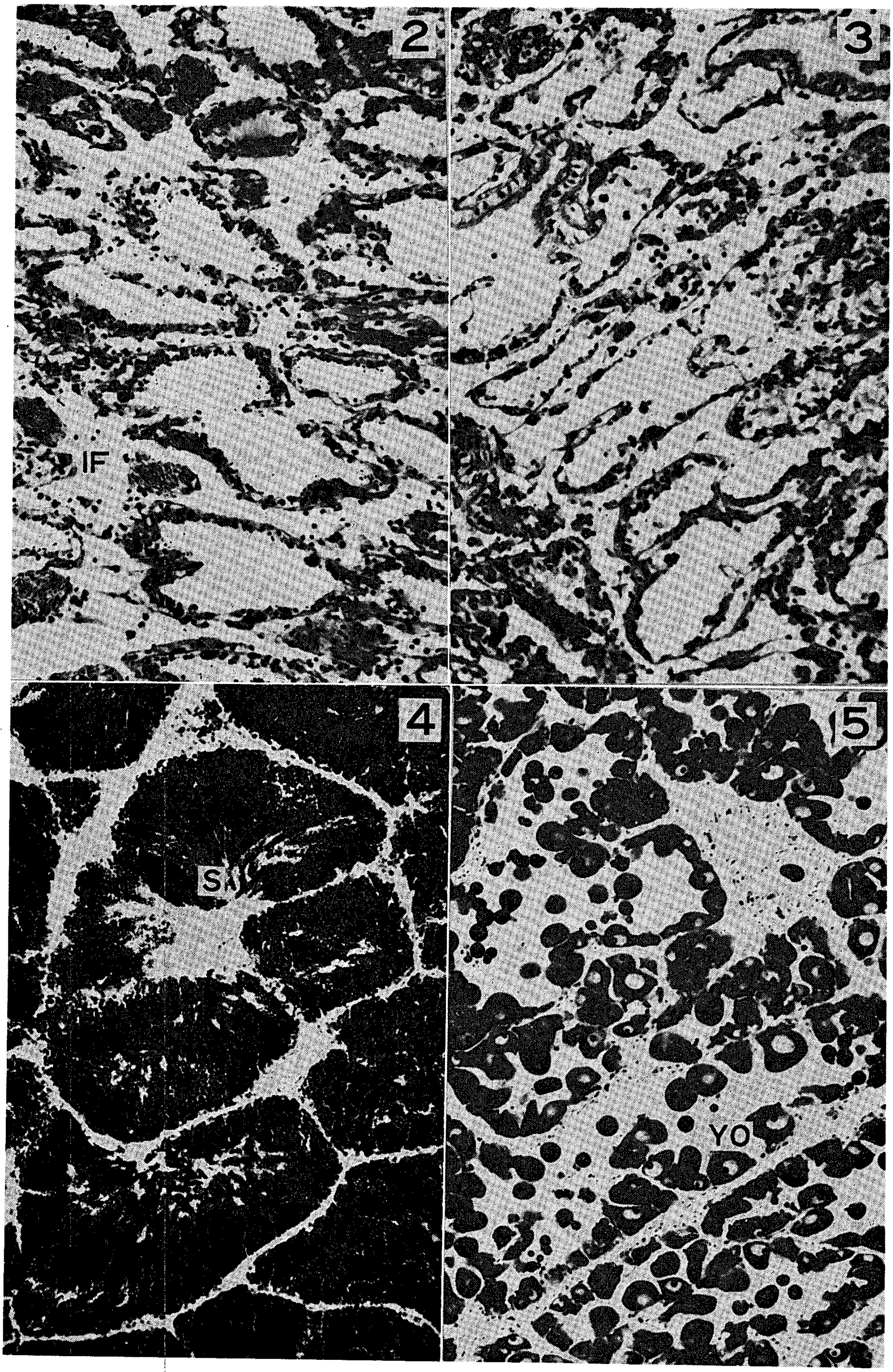
Plate 1

Explanation of the Figures

FIGS. 2 and 3. Gonads in the resting stage (late August, 1967). The lumina of the follicles are almost empty and there are considerably wide spaces among follicles (IF). Fig. 2, spermary. Fig. 3, ovary. Hematoxylin-eosin (H-E) stain. ×150.

FIG. 4. Spermary (late December, 1967). The spermatogonia, spermatocytes and spermatids are packed in the follicle, and spermatozoa are found in the central part of the lumen (S). H-E stain. ×150.

FIG. 5. Ovary (late December, 1967). Ovocytes show an increase in size (YO) and the distal part, grossly enlarged and rounded, protrudes into the lumen of a follicle. H-E stain. ×150.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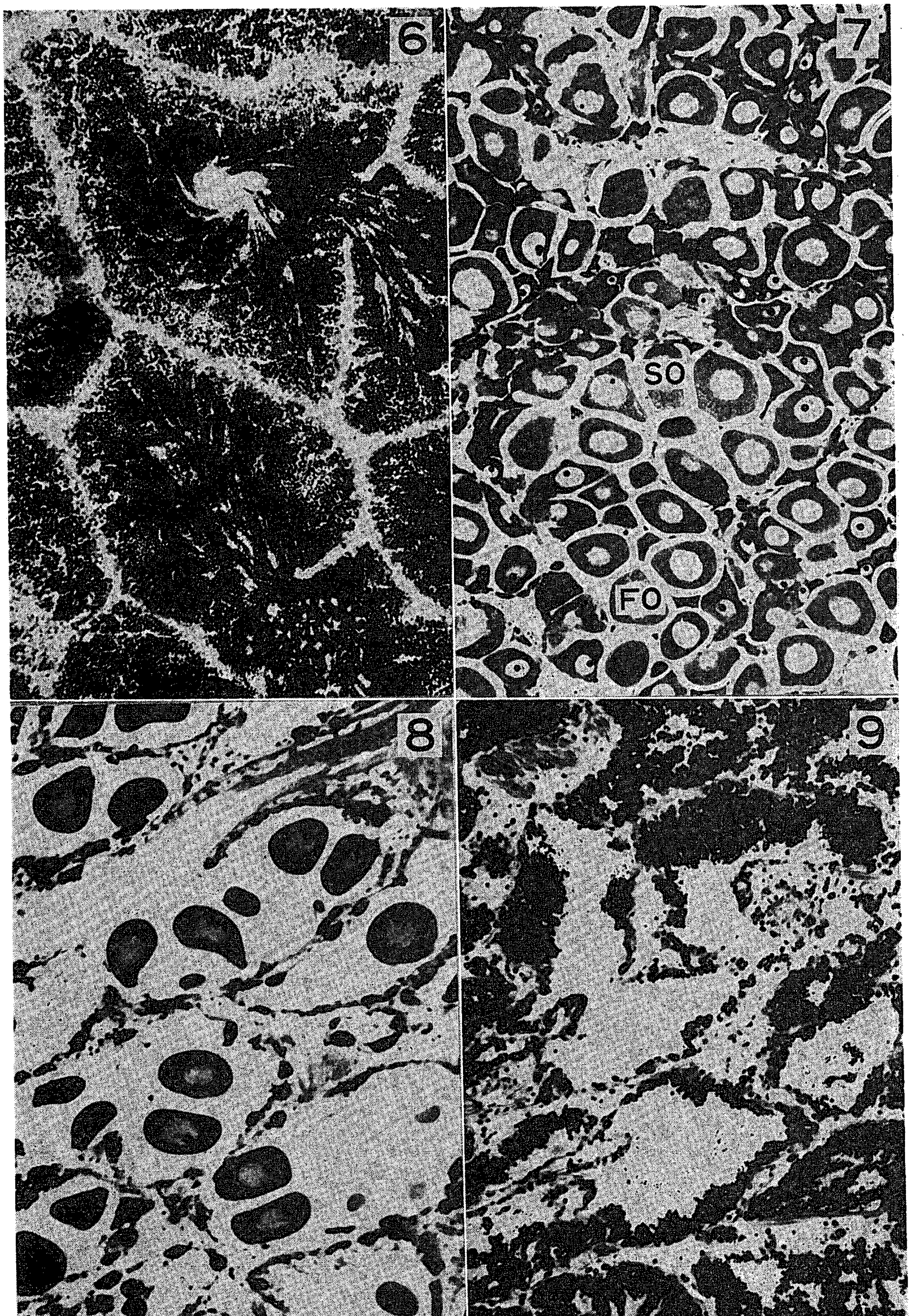
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FO
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Plate 2

Explanation of the Figures

FIG. 6. Spermary (late February, 1968). Spermatozoa predominate and they are closely packed in the follicle of the spermary. H-E stain. ×150.

FIG. 7. Ovary (late February, 1968). The ovocytes which are either free (FO) or connected to the wall with stalks (SO) are closely packed in the follicle of the ovary. H-E stain. ×150.

FIG. 8. Ovary (late May, 1968). A small number of sex cells are retained after the active discharge. H-E stain. ×150.

FIG. 9. Spermary (late June, 1968). The lumina of some follicles are almost empty after the active discharge of sex cells. H-E stain. ×150.

Plate 3

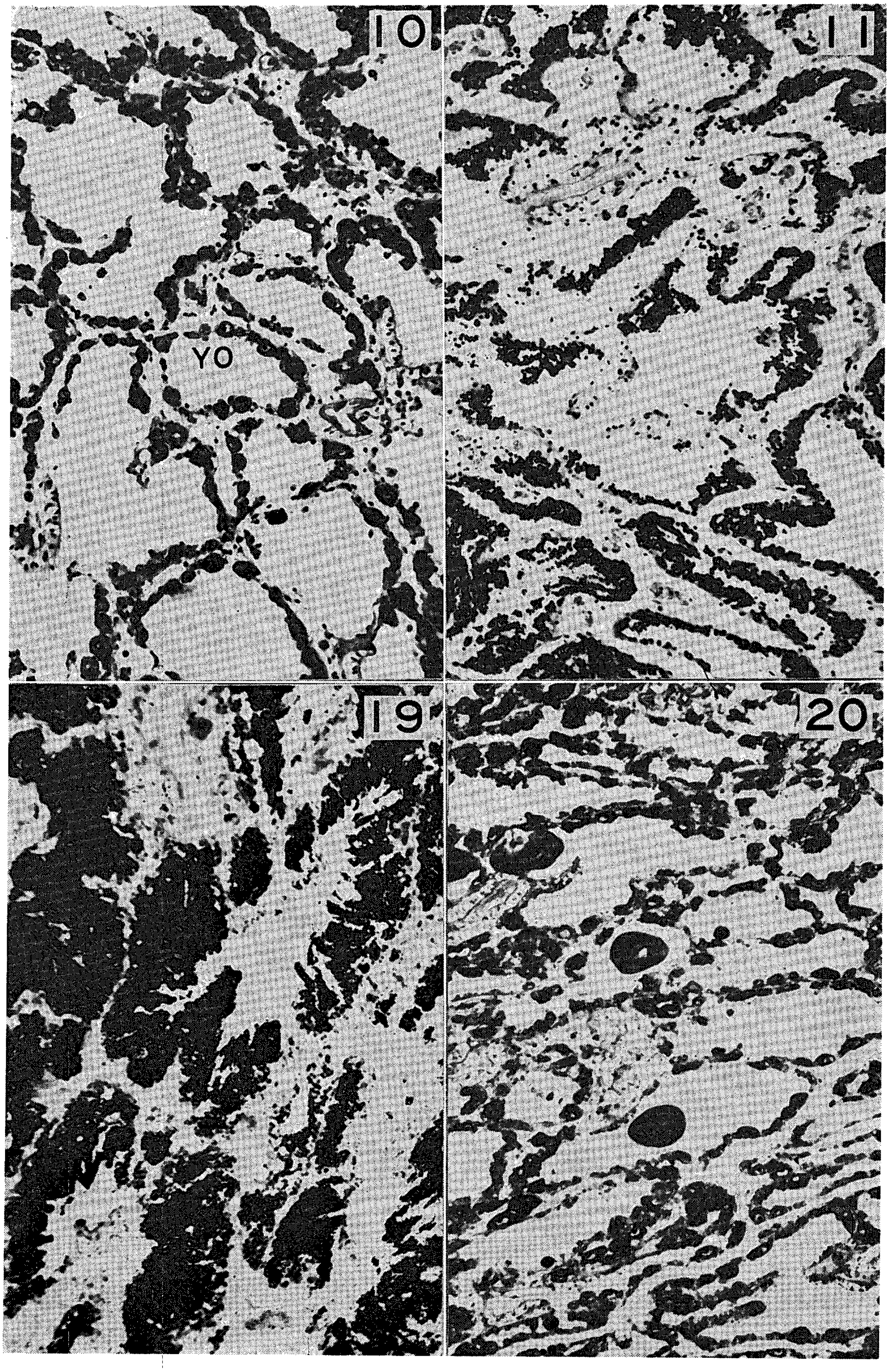
Explanation of the Figures

FIG. 10. Ovary (late July, 1968). The lumina of all follicles are almost empty. A few young ovocytes (YO) are observed to line the follicle wall. H-E stain. ×150.

FIG. 11. Spermary (late July, 1968). The lumina of all follicles are almost empty. H-E stain. ×150.

FIG. 19. Spermary (early May) of a scallop cultivated in Mutsu Bay. It is observed that spawning has been almost completed. H-E stain. ×150.

FIG. 20. Ovary (early May) of a scallop cultivated in Mutsu Bay. It is observed that spawning has been completed. H-E stain. ×150.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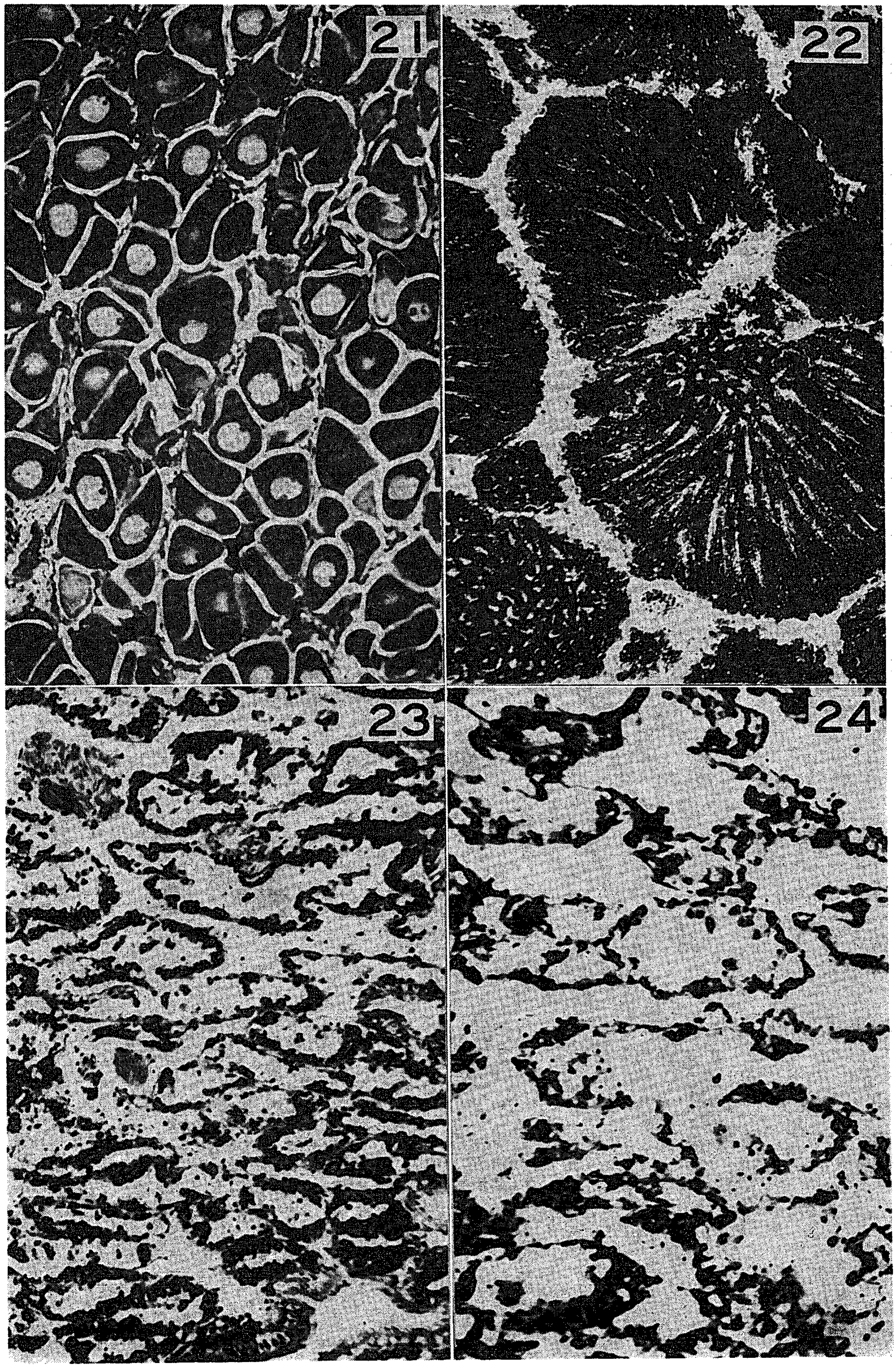
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Plate 4

Explanation of the Figures

FIG. 21. Ovary (early May) of a natural scallop from Mutsu Bay. The bulk of an ovary is observed to be made up of fully developed ova which fill up the lumina of the follicles. H-E stain. ×150.

FIG. 22. Spermary (early May) of a natural scallop from Mutsu Bay. The bulk of a spermary is observed to be made up of fully developed sperms which fill up the lumina of the follicles. H-E stain. ×150.

FIG. 23. Gonad (early August) of a scallop cultivated in Mutsu Bay. It is in the resting stage. H-E stain. ×150.

FIG. 24. Gonad (early August) of a natural scallop from Mutsu Bay. It is in the resting stage. H-E stain. ×150.