STUDIES ON THE REPRODUCTIVE ORGANS OF RED ALGAE

IV. On *Dumontia simplex* COTTON*

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The genus *Dumontia* comprises two species, viz., *D. incrassata* (Müller) Lamouroux and *D. simplex* Cotton, both of which are distributed in Japan in northern regions, the former in Hokkaido while the latter from Iwate Prefecture in northeastern Honshu northwards. Developments of the reproductive organs of *D. incrassata* were already studied thoroughly by Dunn (1916, 1917), Rosenvinge (1917) and Kylin (1917), and those of *D. simplex* were described by Okamura (1928) rather briefly and by Kawashima (1959) quite thoroughly. However, the male plant has been left undiscovered in *D. simplex* by the last mentioned authors. One of the writers, Komatsu, was fortunate enough to discover a number of male individuals among his collections of *D. simplex* during his ecological and morphological studies of the alga at Oshoro Bay, Otaru City, in 1943, and the other of the junior writers, Kaneko, was able to collect them at Moheji, near Hakodate City, in 1962. In addition, three herbarium specimens of *D. simplex* collected at Paramushiru Island, the North Kuriles, on June 27, 1935, were examined and revealed by the senior writer, Tokida (1954, p. 155), to be the male plant. The writers' observations on the ecology and morphology of the alga are, of course, identical in general with Kawashima's, but not without a few differences. So the writers wish to report here the results of their studies.

Materials and Methods

At Oshoro Bay, ecological observations and collections of the materials were made monthly from January through June by Komatsu in 1943. The materials were fixed with weak chromo-acetic-osmic solution, cut 20 μ thick by paraffin

* After completion of the manuscript, the writers happened to notice in the latest number of British Phycological Bulletin (Vol. 2, No. 4, 10th October, 1963) the obituary of Mr. Arthur Disbrowe Cotton, the author of *Dumontia simplex*, telling his passing on December 7th, 1962, at the age of 83. The writers wish to dedicate this short paper to him in memory of his contributions to the knowledge of marine algae in early days (1904–1915) including some Oriental species such as *Dumontia simplex* from Korea (1906), "Tosakanori" from Japan (1914), etc.

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method, and stained with Heidenhein's haematoxylin. Other kinds of fixatives, such as formalin acetic alcohol, Allen-Bouin solution, and Boveri's picric-acid solution, were also tried but with no satisfactory results.

At Moheji, collections of the materials were made several times by Kaneko, in 1962, from January through March. After they were fixed with 2 percent formalin sea-water or with Navashin's solution, the materials were squashed and stained with anilin blue, or cut 4–10 μ thick by paraffin method and stained with Heidenhein's haematoxylin.

Ecology

1. At Oshoro Bay: *Dumontia simplex* grows densely on the rocky reefs in the littoral and sublittoral belts. The frond is usually 10–30 cm, sometimes up to 50 cm in length, and 1–5 cm in width. Larger individuals are more common in the littoral belt. The plants growing in the Bay are usually broader than those growing outside the Bay. Color of frond is from dark red to yellowish brown; it is more pale and yellowish in sunny places.

The tetrasporophytes are usually larger than the gametophytes. The largest tetrasporiferous specimen collected on March 22nd was 50 cm in height by 5 cm in width. However, a smaller specimen, 12 cm high, was also found already fertile. The height and width of frond are markedly variable. The female individuals were 9–34 cm in height by 1.7–3 cm in width. They attained the maximum height when the carpogonial branches were formed. After they had grown to a certain extent, no marked difference in their frond size was detected with the advance of the season. The specimens dotted all over the surface with ripe cystocarps were collected on May 23rd (Pl. I, Figs. A & B). A few male individuals were collected on May 22nd; they were all dwarf, 6–10 cm high by 0.2–1.0 cm wide, and almost colorless (Pl. I, Fig. C). The male plants might have escaped from Komatsu's collections in earlier seasons on account of their dwarf fronds and in later seasons on account of their nearly decayed fronds.

Seasonal variation of growth in *Dumontia simplex* can be summarized from the present research as follows. This alga is annual, growing in Oshoro Bay from October to late June or even to early July of the next year; reproductive organs begin to be formed in November, and fully grown individuals are already observed from December to February.

2. At Moheji: *Dumontia simplex* grows densely on the littoral rocky reefs but not so densely in the sublittoral rocks. Mature fronds of the tetrasporiferous, male and female plants are all observed from early December. Most of the fronds are found dead in late June. The frond is generally smaller than that of

the plant growing in Oshoro Bay; it is 12–33 cm in height by 1–2 cm in width. On the other hand, the Moheji plant is somewhat larger than the dimensions given by Cotton (1906), Okamura (1928), and Kawashima (1959). The present species seems to be fairly variable in frond size according to habitat.

Morphology

The fronds are membranous, fleshy and gelatinous, lanceolate, sometimes twisted once or twice and provided with a few wrinkles on surface in later stages of growth, simple but rarely divided once in the lower portion, attenuated below into short cylindrical stipe, and attached to substratum by a small discoid holdfast. The inner structure is composed of two tissues, namely medulla and cortex. The medulla consists of long filamentous cells with thick walls running longitudinally with rather large intercellular spaces or rarely even with a large central hollow. The cortex consists of cell branches arising from the medullary cells and consisting of anticlinal rows of short cells (Pl. II, Fig. 1). Some of the superficial cells are observed to bear a non-septate hair (Fig. 2).

The tetrasporangia are immersed among the outer cortical cells and scattered all over the frond surface except only the basal portion. They are formed from the upper part of the frond downwards, arising as a side branch from the inner cortical cells (Fig. 3). The sporangium is cruciately partite, being divided at first by a wall parallel to the frond surface (Fig. 4), and then by a wall perpendicular to the former (Fig. 5). The mature sporangium is ellipsoidal, up to $64 \times 75\,\mu$. The tetraspores are liberated with the decay of the surrounding tissue.

The male plant of the present species has not been reported in Japan to date as far as the writers are aware. Fortunately the writers could collect a few antheridial specimens at Oshoro in May and at Moheji in January, as already mentioned. The antheridia are scattered on the frond surface, being cut off by oblique walls from their mother cells among the superficial cells (Fig. 12).

The carpogonial branch is formed as a side branch from an inner cortical cell. It is usually five or six-celled but rarely seven-celled. The terminal cell of the branch or the carpogonium bears a spiral trichogyne which projects outside the frond surface. The upper portion of the branch is so strongly curved that the carpogonium lies close to both the third cell and the fourth of the branch as counted from above. The cells of the carpogonial branch are usually uninucleate, but the second cell and the third from the base are sometimes observed to contain two to three nuclei, as observed by Kylin in *D. incrassata*. The carpogonium is always uninucleate. The carpogonial branch is covered as a whole with a thick membrane.

The auxiliary branch is formed in the same way as the carpogonial branch. It consists of four or five cells which are usually uninucleate but rarely binucleate. At first it is not clear which cell of the branch will play the role of the auxiliary cell, but later it becomes possible to tell the cell from others by the fact that it stains well with anilin blue. The auxiliary cell is the second cell from below in a four-celled branch while it is the third cell from below in a five-celled branch (Figs. 17 & 18). Fertilization could not be proved cytologically but a male nucleus was once observed within the trichogyne (Fig. 8). After fertilization, the carpogonium gives rise downward to a process which always fuses with the fourth cell of the carpogonial branch as counted from above, which is namely the nutritive auxiliary cell, and they form an irregularly shaped fusion-cell. Rarely one more cell, the fifth from above, participates in the formation of the fusion-cell (Fig. 15). Then, from the fusion-cell arise two to five, or sometimes more, non-articulate connecting filaments, and the fusion-cell becomes poor in content staining very faintly with haematoxylin (Figs. 13–15). Those primary connecting filaments run toward all directions in search of the auxiliary cells; they are quite rarely found to be branched (Fig. 16). After fusion with one of the connecting filaments, the auxiliary cell gives rise to the gonimoblast-initials and also to one or two secondary connecting filaments which are of the same morphological and functional characters as the primary ones (Figs. 18–21). The auxiliary cell which has fused with one of those secondary connecting filaments gives rise again to gonimoblast cells and connecting filaments (Fig. 22). Thus a single fertilization may result in the development of gonimoblasts from many auxiliary cells. Most of the gonimoblast cells on each auxiliary cell produce carpospores which are grouped in a small spherical cystocarp (Fig. 23). The cystocarps embedded in the outer cortex of the thallus are visible to the naked eye as minute reddish dots scattered over nearly all the thallus surface. The ripe carpospores are spherical, up to about 22 μ in diam. (Figs. 19 & 23). Their shedding is associated with the decay of the thallus.

Discussion

The above described results of the present study agree in general with the observations of *D. simplex* by previous investigators. However, the writers' specimens are markedly different from those observed by Kawashima in having a 5–7-celled carpogonial branch in contrast with the 3–4-celled of the latter, and in that the nutritive auxiliary cell is the second to fourth cell of the carpogonial branch as counted from below, or invariably the fourth cell as counted from above, while it is observed by Kawashima to be the first cell or the basal of the branch which is the third or fourth cell as counted from above. On the other hand, the auxiliary branch in Kawashima's plant is described to be 4–5(-6)-celled and its second cell (in the 4-celled branch) or the third (in the 5- or 6-celled branch) from below to play the role of the auxiliary cell. In these latter respects, Kawashima's plant coincides with the writers' except for the rare occurrence of the 6-celled auxiliary branch. The connecting filament was observed by Kawashima to be always unbranched and to have never continued its growth toward other auxiliary cells after fusion with an auxiliary cell, while the writers could observe that the connecting filament was rarely branched and that the secondary connecting filaments were produced anew, not as a continuance of growth of the primary filament, from the auxiliary cell that had fused with a primary connecting filament.

In short, Kawashima's plant, as compared with the writers', seems to be characterized in having smaller fronds, shorter carpogonial branches, basal nutritive auxiliary cells, unbranched connecting filaments, and no secondary growth of connecting filaments. His plant is considered from these characters to represent an ill-developed form of the species. As a matter of fact, Kawashima's material came from near the southern limit of distribution of *Dumontia simplex* along the coasts of Japan. Here is an interesting example of a plant's response to environmental factors expressed not only in morphological changes of vegetative structures but also of female reproductive organs.

Summary

In this paper are reported the ecological and morphological descriptions of *Dumontia simplex* Cotton collected in Hokkaido, Japan, including the details of the female reproductive organ and the gonimoblast development. The male plant of *D. simplex* is described and illustrated herein for the first time. A comparison between the results of the present study and the report of Kawashima (1959) is discussed.

Literature

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Explanation of Plates

PLATE I

Photographs of herbarium specimens of
Dumontia simplex Cotton

Fig. A. Female specimens with ripe cystocarps, collected by Komatsu at Oshoro on May 23, 1943

Fig. B. Partly decayed female specimens from the same collection as above

Fig. C. Male specimens collected by Komatsu at Oshoro on May 22, 1943

Fig. D. Tetrasporiferous narrower specimens, collected by Komatsu at Oshoro on March 22, 1943

Fig. E. Tetrasporiferous specimens, collected by Kaneko at Moheji on January 21, 1962

(Pl. I, Figs. A–D photographed by Komatsu, Fig. E by Kaneko; Pl. II, Figs. 1–8, Pl. III, Figs. 18, 19 & 21 drawn by Komatsu, Pl. II, Figs. 9–12, Pl. III, Figs. 13–17, 20, 22 & 23 by Kaneko)

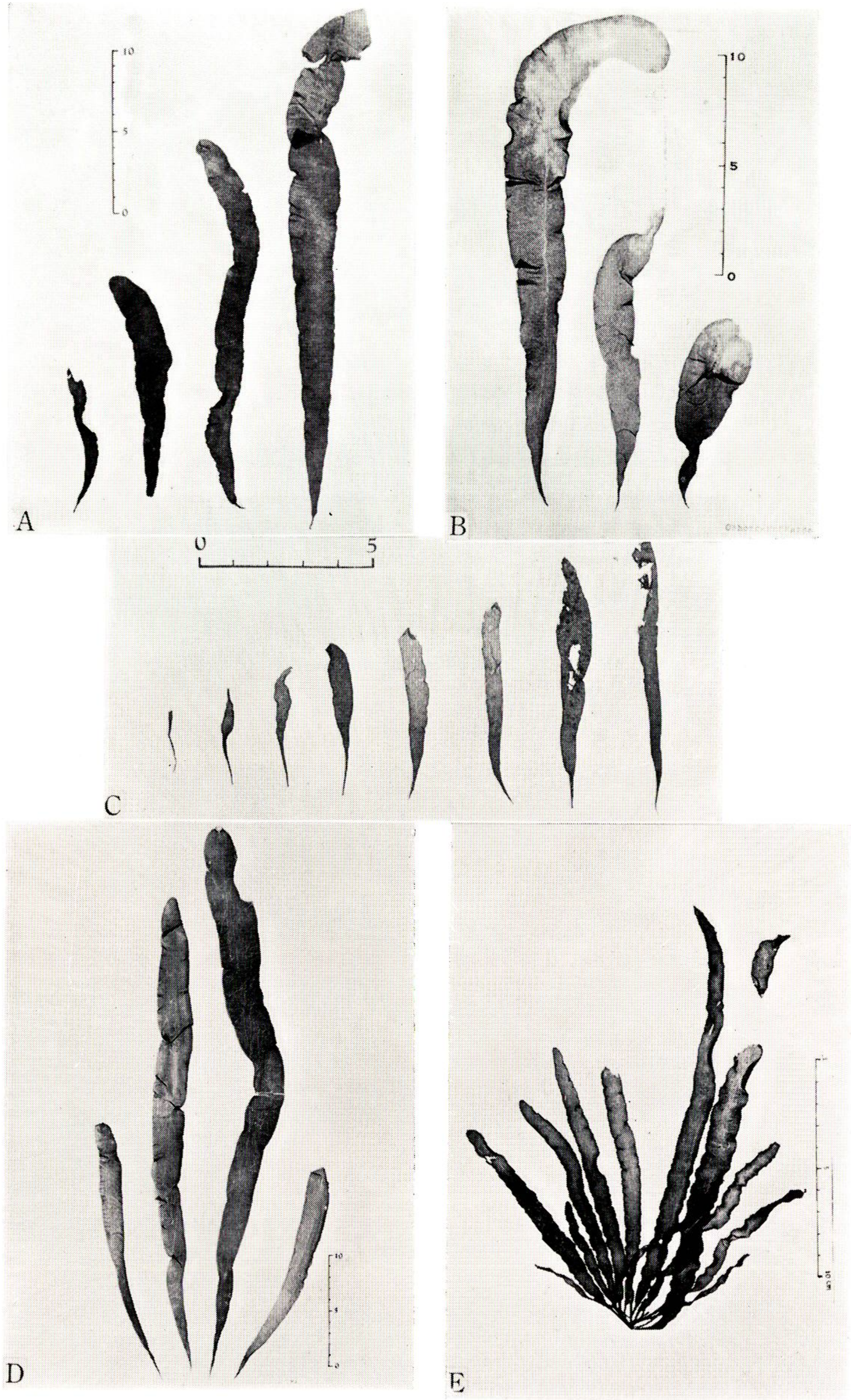

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PLATE II

Dumontia simplex Cotton

Fig. 1. Part of longitudinal section of a female frond showing a young auxiliary branch on an inner cortical cell

Fig. 2. Part of cortical tissue in section of thallus showing an uni-nucleate hair cell

Figs. 3–5. Development of tetrasporangium

Fig. 6. Part of longitudinal section of female frond showing a 5-celled carpogonial branch

Figs. 7–10. Carpogonial branches, five-celled (Figs. 7 & 8), six-celled (Fig. 9) and seven-celled (Fig. 10); in Fig. 8 is shown that the trichogyne contains its own nucleus near the center and a male nucleus near the apex and that the carpogonium has a process growing toward the second cell of the branch

Fig. 11. Two auxiliary branches, four-celled and five-celled

Fig. 12. Part of cortical tissue in a longitudinal section of male frond showing spermatangia and their mother cells

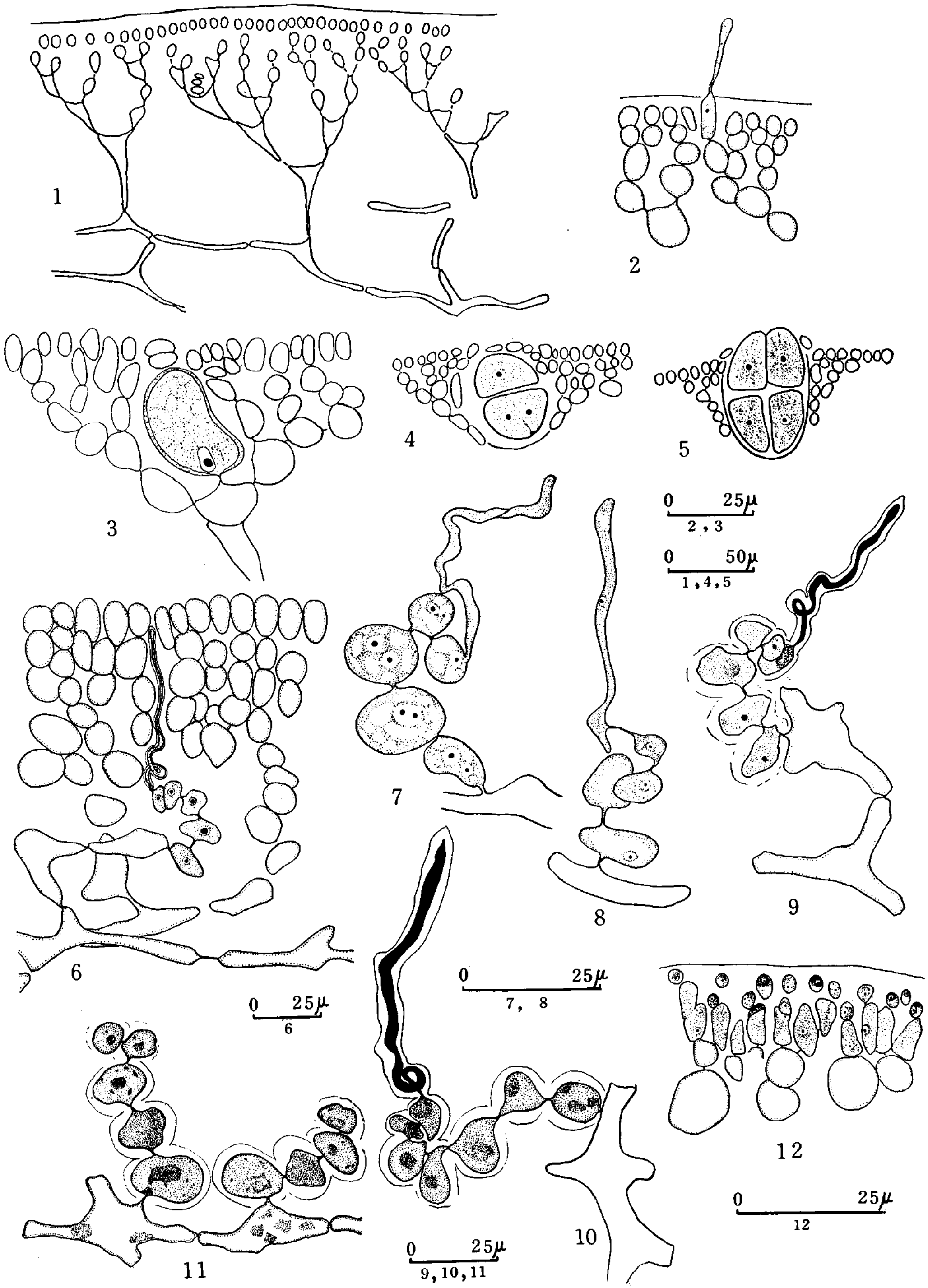
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PLATE III

Dumontia simplex Cotton

Fig. 13. Carpogonial branch, six-celled, after fertilization, showing two connecting filaments issued from the fusion-cell

Fig. 14. The same, showing three connecting filaments issued from the fusion-cell

Fig. 15. The same, showing four connecting filaments issued from the fusion-cell which is formed from the fourth and fifth cells from above of the branch

Fig. 16. Part of a branched connecting filament

Fig. 17. Auxiliary branch, four-celled, just after fusion between the short process from the auxiliary cell (the second cell of the branch) and a connecting filament

Fig. 18. The same, five-celled, showing the early development of gonimoblast from the auxiliary cell (the third cell of the branch) fused with a connecting filament

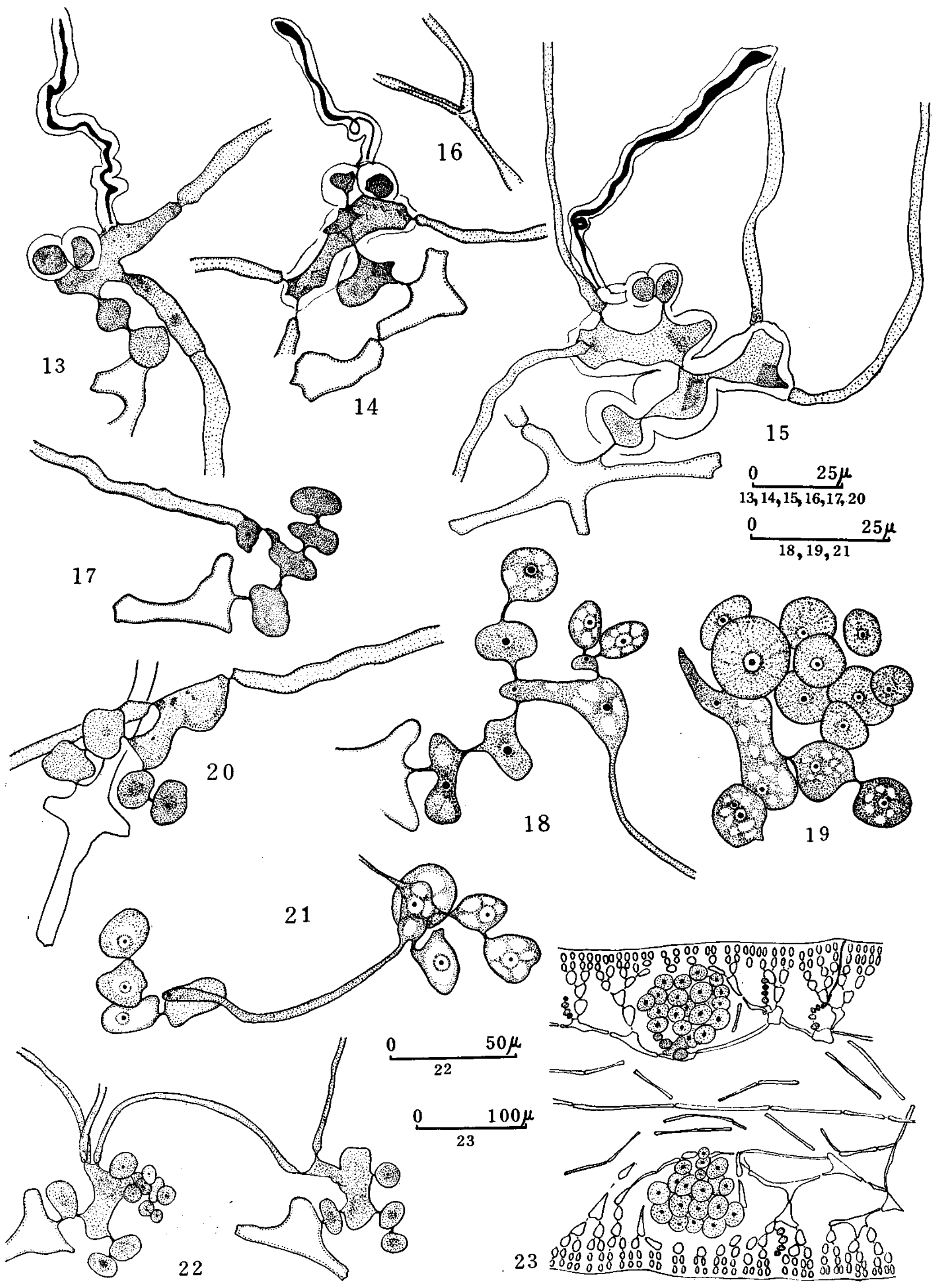
Fig. 19. The same, four-celled, showing part of mature gonimoblast on the auxiliary cell (the second cell of the branch)

Fig. 20. The same, five-celled, showing a secondary connecting filament produced from the auxiliary cell (the third cell of the branch) that has fused with a connecting filament

Fig. 21. Two auxiliary branches, five-celled and four-celled, showing a secondary connecting filament just before fusion with the auxiliary cell (the second cell of the four-celled branch)

Fig. 22. Two four-celled auxiliary branches connected with a secondary connecting filament

Fig. 23. Longitudinal section of mature female frond, showing a carpogonial branch, three auxiliary branches, and two cystocarps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