

The Folliculinids (Protozoa) of Ago Bay, Japan, and Their Relation to the Epifauna of the Pearl Oyster (*Pinctada martensii*)¹

DONALD C. MATTHEWS²

ALTHOUGH THE PEARL OYSTER (*Pinctada martensii*) is widely dispersed throughout Japanese waters, that portion of Honshu south of Toba, in the many bays of Ise peninsula, excels as a favorable production center. This is largely because the cold Oya Shio (current) flowing south from the Kurile Islands meets the warm Kuro Shio between 35° and 40° N, sinks, and passes under it to well up again farther south, bringing an abundance of plankton. Thus, protected bays such as Ago, Matoya, and Gokasho provide an excellent environment for oysters and other filter-feeders to multiply. However, as the number of animals in the epifauna increases, available attachment sites decrease, and a sequential, complex epifauna develops on any suitable surface, whether glass plates or *P. martensii* imbricate scales.

Whereas some 50 species embracing many taxa (Protozoa, Porifera, Coelenterata, Nemertini, Nematoda, Polychaeta, Ostracoda, Harpacticida, Cumacea, Amphipoda, Decapoda, Pycnogonida, Bryozoa, Mollusca, Echinodermata, and Tunicata) comprise this complex epifauna, the Polychaeta in particular, by the number and depth of their burrows, seriously affect the oysters' well-being.

Korringa (1951) working on the epifauna of *Ostrea edulis* in the Oosterschelde, Holland, mentioned in his annotated list of species that folliculinids are among the first to appear, and he reasoned that because their growth and reproduction are so rapid they "... may be important as basic food for many members of the oysters' epifauna." Although Miyazaki (1938) made an extensive study of fouling organisms on shell-strings hung from rafts of Japanese oyster farms, interrelationships of species were not studied in detail.

The purpose of this paper is twofold: (A) to report the occurrence of folliculinids in Ago Bay, and (B) to determine whether folliculinids serve as food for *P. martensii* epifauna.

FOLLICULINIDS IN AGO BAY

Materials and Methods

In a combination of the methods of Moebius (1887), Miyazaki (1938), and Matthews (1962), shell collectors were suspended at various depths in Ago Bay from June through November, 1965, and sequential fouling periodically examined. Concurrently, folliculinids in the epifauna of living *P. martensii*, *Pinna attenuata*, and *Chlamys nobilis* suspended in baskets approximately one meter below oyster rafts of Ago Bay were similarly studied. Those readily identifiable folliculinids were figured and recorded, others were preserved and shipped to Honolulu for subsequent identification.

Results

The following folliculinids were obtained:

Ascobius siléni Hadzi, 1951, Slovenica Biology 2:114-122.

Folliculina simplex (Dons) Silén, 1947, Ark. Zool. 39(12):53-56, figs. 62-65.

Figure 1A represents a ventral view of *A. siléni* taken at Ago Bay, June 21, 1965 from narrow cracks in the shells of *Spirorbis* sp. In such restrictive sites, the dorso-ventrally flattened lorica (*f*) seems attached throughout its length by a rather copious collectoderm (*d*). The lorica tapers rather gradually from its mouth (*c*) (almost devoid of collar) to the rounded and rather broad proximal end. Figure 1B represents a lateral view (left side) of *A. siléni* taken at the same time from spiral "chimneys" of the delicate, coral-like Bryozoan, *Bugula dentata* (Lamouroux) (see Utinomi, 1961:33, pl. 17, fig. 6) and from the smooth, "vertical" sides of *Spirorbis* sp. where attach-

¹ This study was supported in part by Grant No. G.F. 200 from the National Science Foundation. Manuscript received April 13, 1967.

² Department of Zoology, University of Hawaii, Honolulu, Hawaii 96822.

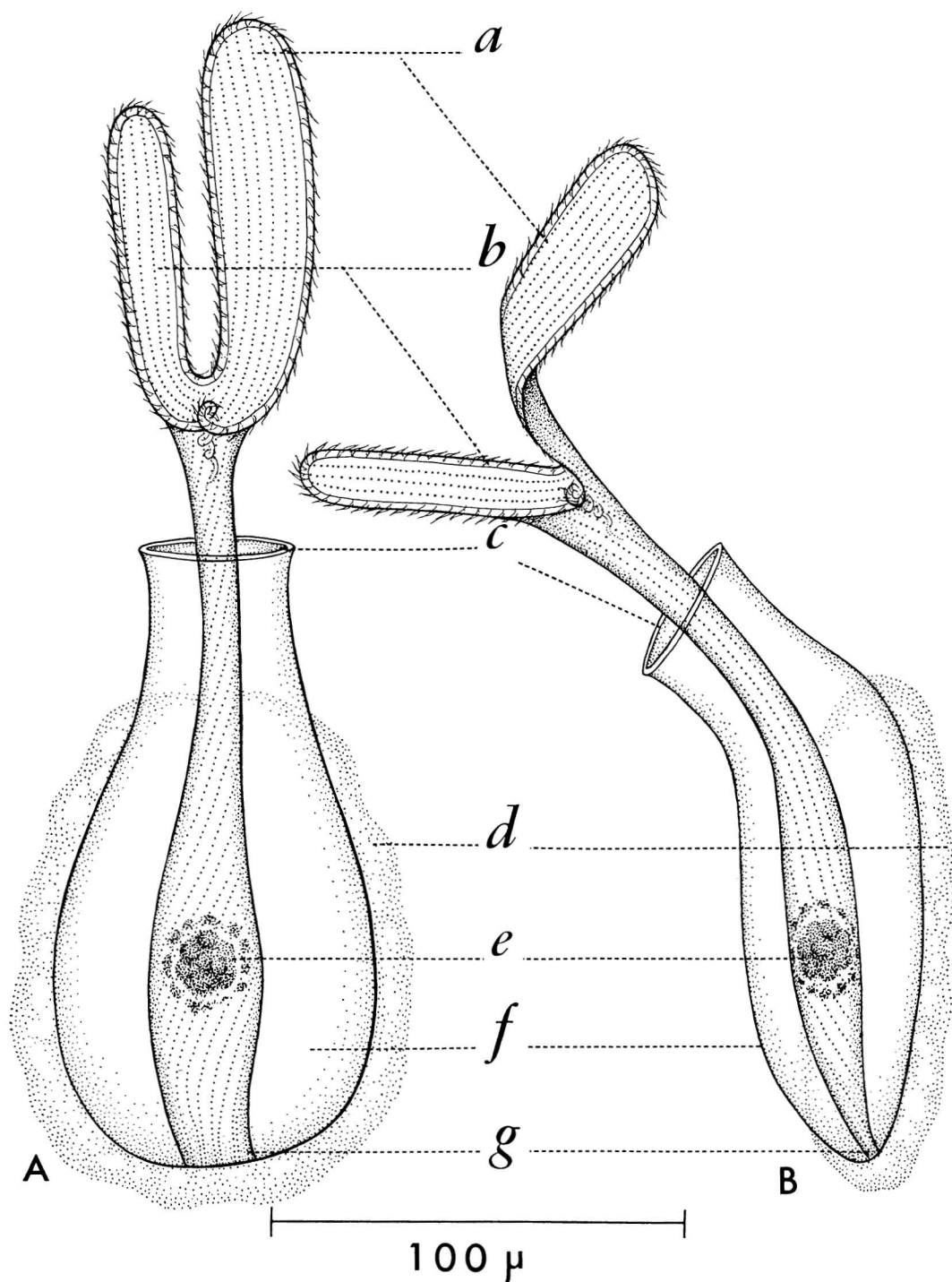


FIG. 1. *Ascobius sileni*.

A, As viewed ventrally showing: *a*, left peristomal lobe; *b*, right peristomal lobe; *c*, mouth of lorica; *d*, collectoderm; *e*, spherical nucleus; *f*, lorica; *g*, spatulate foot.

B, As viewed from left side showing: *a*, position of left peristomal lobe; *b*, position of right peristomal lobe; *c*, collar; *d*, collectoderm; *e*, nucleus; *f*, lorica; *g*, non-spatulate-looking foot.

ment sites are not restrictive. In such instances, the lorica (Fig. 1B, *f*) is only slightly dorso-ventrally flattened and appears to be only partially attached throughout its length by the collectoderm (*d*). Thus, a short free neck is held above the substratum.

The length of the neck is difficult to measure since valves demarking neck from sac are absent. There are no longitudinal stripes, spiral whorls, rings, or extensions.

The species is further characterized by peristomal lobes of unequal length and breadth; the left (Fig. 1A, *a* and B, *a*) is always broader and longer than the right (*b*). Moreover, the left (Fig. 1B, *a*) is usually held at right angles to the longitudinal axis, whereas the right (*b*) is usually held vertically. In the hundreds of specimens observed, no finger-like projections were seen on the peristomal lobes.

The nucleus (*e*) is always spherical and appears as a mass of rather large granules in the posterior half of the extended body.

In specimens taken from restrictive areas (Fig. 1A) the dorso-ventrally flattened lorica (*f*) accentuates the spatulate nature of the foot (Fig. 1A, *g*), i.e., as the body contracts into a flattened lorica, the foot (*g*) is spread thinly into a broad spatula. However, when the lorica is not so dorso-ventrally flattened, the contracted body has more space and the foot (Fig. 1B, *g*) appears less spatulate.

Color: light greenish-blue through grey to colorless.

Eufolliculina lignicola Hadzi, 1951, Slovenica Biology 2:20.

Folliculina lignicola Fauré-Fremiet, 1936, Mém. Mus. Hist. Nat. Belg. (Sér. 2) 3:1129-1175.

Eufolliculina lignicola (Fig. 2) was first taken July 7, 1965 at Tatokushima from abandoned bamboo poles of oyster rafts. Although the smooth, hard surface of the internodes affords little opportunity for heavy *Limnoria* sp. infestations, the nodes are riddled with their tortuous burrows and in these, but not restricted to them (see Matthews, 1963:438) were fully extended folliculinids. In every respect these resembled those obtained from Douglas fir (*Pseudotsuga taxifolia*) frames (Matthews,

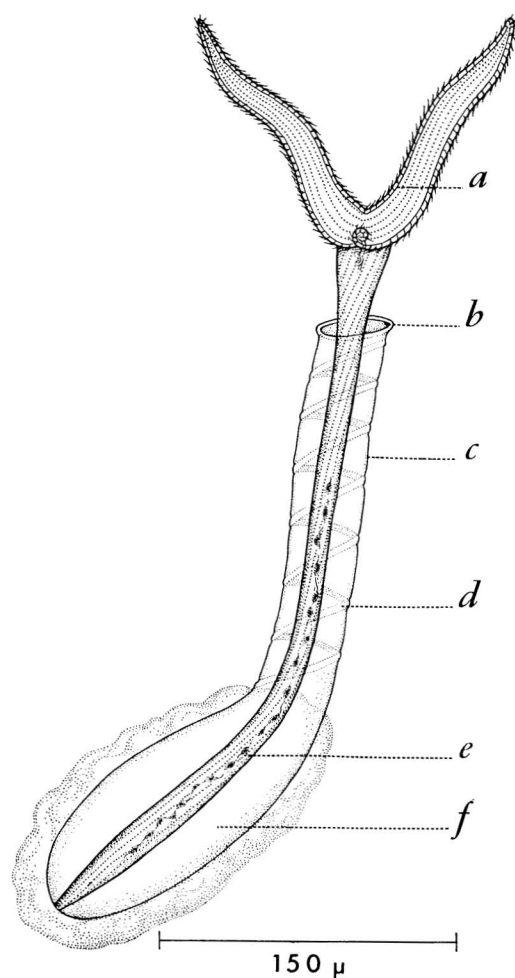


FIG. 2. *Eufolliculina lignicola*, as viewed from the ventro-lateral surface showing: *a*, left peristomal lobe; *b*, mouth of lorica; *c*, neck; *d*, spiral whorl; *e*, monili-form nucleus; *f*, sac of lorica.

1962). Again, sac length, width, and height vary with site conditions. Crowding usually results in an abnormally shaped lorica whose sac (*f*) (up to 170 μ) is often as long as the neck (*c*). And again, the neck, least affected by space restrictions, varies only between 130 μ and 170 μ with 5-7 spiral whorls (*d*). The nuclear components (*e*) vary widely; from what appears to be a more or less compact, spherical mass of 5 or 6 large granules to a "broken" string of 12 to 14 small beads. As in the Hawaiian representatives of this species, *E. lignicola* in Ago Bay is a deep wine-red in reflected light and

bottle-green in transmitted light. The peristomal lobes (*a*) are long (up to 118μ), without finger-like projections and are carried high above the almost collarless (*b*) distal end of the neck.

Folliculinopsis annulata Fauré-Fremiet, 1936, Mém. Mus. Hist. Nat. Belg. (Ser. 2) 3:1136–1137, fig. 2.

Alexandrina karagjorgjevici Hadzi, (1937) 1938, Acta Adriat. 2(1):8–25, figs. 1–5.

Folliculina karagjorgjevici Hadzi. Silén, 1947, Ark. Zool. 39(12):49–53, figs. 52–61.

Folliculinopsis annulata (Fig. 3*A* and *B*) was first taken at Tatokushima, July 6, 1965 on and in the calcareous tubes of *Spirorbis* sp. Whether free or crowded, all taper gradually from a rounded proximal end (*f*) to the distal end of the neck (*a*), resulting for the most part in a long, tube-like lorica with, superficially, no sharp line of demarcation between sac and neck. While certain necks are curved in conformity to attachment sites, most are surprisingly straight and held at an angle above the substrate.

What at first appears to be a cone is, in reality, two valves (*d*) shaped like a roof, whose ridge-pole (marking the position of closure) runs diagonally across the lorica, separating sac (*f*) from neck (*b*, *c*). The sac length is almost uniformly 275μ ; the length of the neck varies only from 475μ to 500μ . Neck widths vary from 38μ to 50μ . Although no collars, longitudinal stripes, or spiral whorls are observed, the neck is characterized by light, "clean" bands (*b*) and dark, "dirty" bands (*c*), the latter formed by an accumulation of foreign, adhering grains.

The animal is further characterized by its long, narrow, peristomal lobes which, even in the contracted condition often reveal prominent, finger-like projections (*e*). However, none of these projections terminates in swollen drop-like bodies (Silén, 1947:50, fig. 59*a*). Size differences are frequently observed but the left peristomal lobe is as frequently reduced as the right.

The nucleus (*g*) is always moniliform and consists of 7–9 components.

The foot (*b*) is non-spatulate. Color varies from grey-green to almost colorless; however,

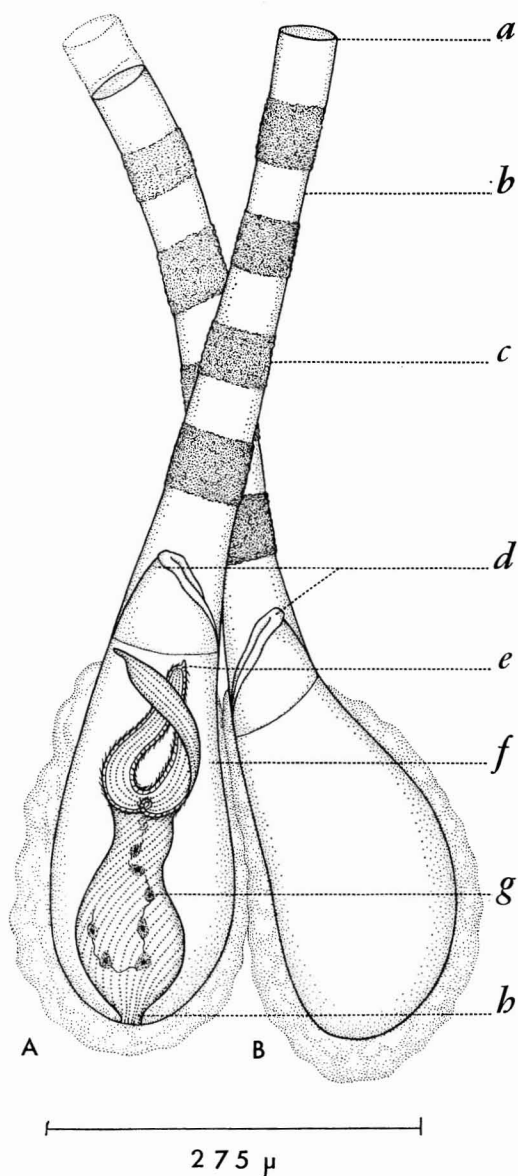


FIG. 3. *Folliculinopsis annulata*.

A, As viewed ventrally showing: *a*, distal end of neck; *b*, "clean" bands of neck; *c*, "dirty" bands of neck; *d*, diagonal valves; *e*, peristomal-lobe projections; *f*, sac; *g*, moniliform nucleus; *h*, non-spatulate foot.

B, As viewed ventro-laterally showing empty lorica with valves *d*.

both body proper and peristomal lobes possess pigment granules which may appear either red or green, depending on the light source used.

Halofolliculina annulata (Andrews, 1944)
Hadzi gen., 1951, Slovenica Biology 2:
152-153, fig. 25.

Parafolliculina annulata Andrews, 1944,
Trans. Am. Microscop. Soc. 63:321-325,
fig. 3.

Halofolliculina annulata (Fig. 4) was first taken at Tatokushima, July 9, 1965 from the valves of *P. martensii* and the calcareous tests of the acorn barnacle, *Balanus amphitrite* Brock. The Ago Bay representatives of this species follow in almost every respect the specific characteristics set forth by Andrews (1944). The lorica is dorso-ventrally flattened. The length of the sac (*f*) is up to 200 μ ; its width, 150 μ . The height of the sac rarely attains 50 μ . The lorica, exclusive of the neck, is well cemented to the substratum by a rather extensive collectoderm (*i*). A narrow collar (*a*) is all that marks the rather plain neck (*b*). Unlike the one figured by Andrews (1944:323, fig. 3), no rings or spiral whorls are present. The

ventral valve (*d*) is larger and better developed than the dorsal valve (*c*).

The peristomal lobes (*e*) lack finger-like projections and end rather bluntly. The nucleus (*g*) is non-moniliform and varies from 10 μ to 13 μ . The foot (*b*) is non-spatulate.

The living animal and its lorica vary from colorless to a rather deep brown. Old, empty loricae are invariably dark.

Diafolliculina rotunda Hadzi, 1951, Slovenica Biology 2:161-165, fig. 27.

Diafolliculina rotunda (Fig. 5A and B) was first taken at Tatokushima, July 10, 1965 on the scales of *P. martensii*. Not until some weeks later, however, was positive identification made. It is easily confused with the genus *Halofolliculina* which, as previously seen, also possesses about the same general body shape, a spherical nucleus, no vestibule and well-developed valves.

The anterior end of *D. rotunda* viewed ventrally (Fig. 5A) discloses a rather broad collectoderm (*a*) and a short, almost circular neck (*b*) with valves (*c*, *d*). However, since the diameter of the neck may be only 30 μ , valve determination (i.e., which is dorsal, which is ventral) is difficult. In Figure 5B (a lateral view of the right side) the valves are clearly seen. The rather short, thick, ventral valve (*f*) lies above the thin dorsal one (*g*) which often curves posteriorly. In related species (*D. similis*) the dorsal valve is often folded, but this condition is not seen in *D. rotunda* from Ago Bay.

The peristomal lobes are irregular, of average length and breadth, and without finger-like processes. The nucleus is spherical and measures up to 27 μ in length and up to 24 μ in breadth—a very prominent nucleus for such a small folliculinid.

As is true for many of the small folliculinids, the lorica and body vary from colorless to very light green.

Lagotia expansa (Levinsen, 1893) Hadzi, 1951, Slovenica Biology 2:55-73, fig. 6a.

Lagotia expansa (Fig. 6) was first observed at Tatokushima, June 19, 1965 on the shell of the large Japanese oyster, *Pinna attenuata*. Literally thousands of folliculinids together with other species comprise the vast epifauna of this oyster. The genus *Lagotia* here contains

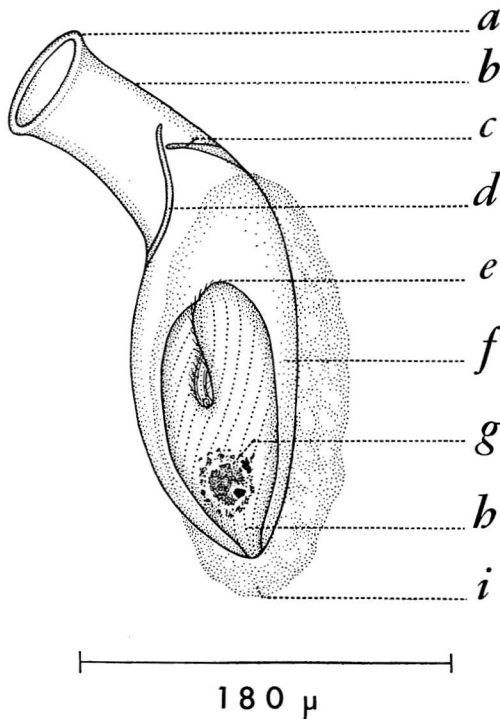


FIG. 4. *Halofolliculina annulata*, ventro-lateral view of left side showing: *a*, narrow collar; *b*, neck; *c*, dorsal valve; *d*, ventral valve; *e*, peristomal lobe; *f*, sac; *g*, spherical nucleus; *h*, foot; *i*, collectoderm.

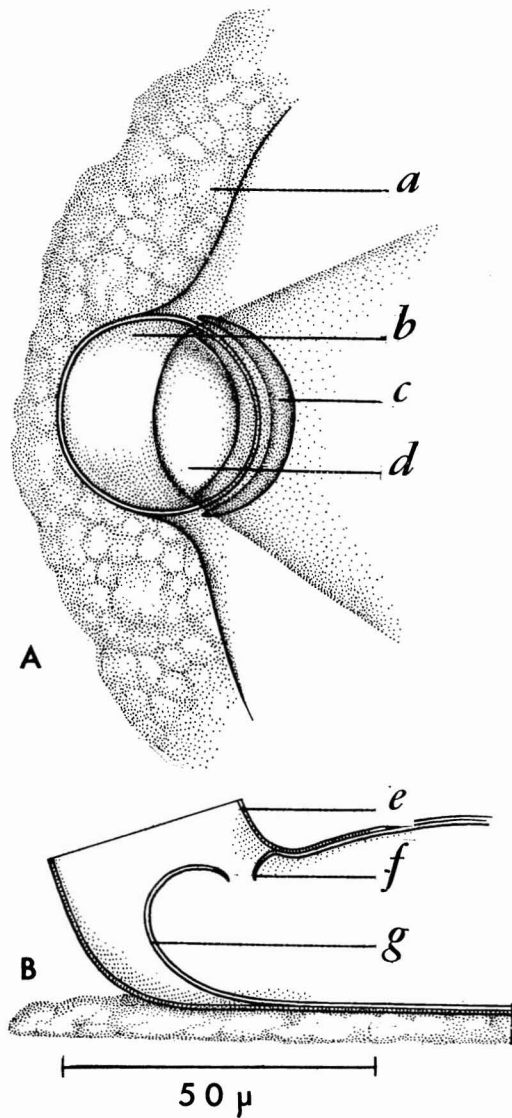


FIG. 5. *Diafolliculina rotunda*.

A, Ventral view of anterior portion of lorica showing; *a*, collectoderm; *b*, neck opening; *c*, ventral valve; *d*, dorsal valve.

B, Lateral view of anterior portion of lorica (right side) showing; *e*, neck; *f*, ventral valve; *g*, dorsal valve.

many closely related species which appear together in great abundance.³

³ Silén (1947:47) stresses that species can only be determined by a study of abundant living material and Hadzi (1951:37) says, "We have, however, in practice, often only a few empty lorica and preserved in-

The lorica (Fig. 6*e*) is approximately 500 μ long of which perhaps half could be considered neck. Because no valves separate sac from neck, only 4 or 5 very indistinct spiral whorls (*d*) indicate where one leaves off and the other begins. The lorica therefore tapers only gradually from a rounded, attached, proximal end (*g*) to a morning-glory shaped distal end. The wide, delicate flare (*a*) is strongly marked by light and dark longitudinal stripes (*b*) which become indistinct posteriorly. No neck extensions are present. The width of the sac is 150 μ , its height, 100 μ .

The peristomal lobes (*c*) are long, even, and terminate bluntly without finger-like projections. The nucleus (*f*) is spherical, measuring up to 38 μ in diameter. The foot (*b*) is non-spatulate.

The color, characteristic of members of this genus, is a deep blue-green. In reflected light the animal is bright red.

Lagotia expansa var. *depressa* Hadzi, 1951:78.

Lagotia expansa var. *depressa* was first taken at Tatokushima, June 19, 1965 on shells of the large Japanese oyster *Pinna attenuata*. More precisely, it was commonly found between the sacs and actually in the necks of *Lagotia gigantea*. Figure 7*A* shows *L. expansa depressa* (*b*) on the calcareous shell of *Spirorbis* sp. and on the operculum (*a*) of the living animal. To my knowledge, this is the first time that a folliculinid has been reported attached to a moving part of a serpulid. Figure 7*B* is a ventral view and 7*C*, a ventro-lateral view. Both show the flattened lorica (*d*) with smoothly rounded proximal ends and typical longitudinal stripes (*b*) on short, distally flaring necks (*a*). The length, breadth, and height of the lorica fall well within the limits of those given by Hadzi (1951:81).

The peristomal lobes (*c*) are of even length and end bluntly without finger-like projections.

dividuals to work with. It is then not remarkable that today we still have not distinguished sharply all species and are unable to name them uniformly." The problem is probably even more complex. Recent observations on the dimorphism of the macronucleus (Uhlir, 1963:115–121, fig. 3*a* and *b*) place in serious doubt the validity of certain taxonomic characters used to distinguish folliculinid genera. However, until the reliability of characters is studied in many genera, these species are assigned to the genus *Lagotia*.

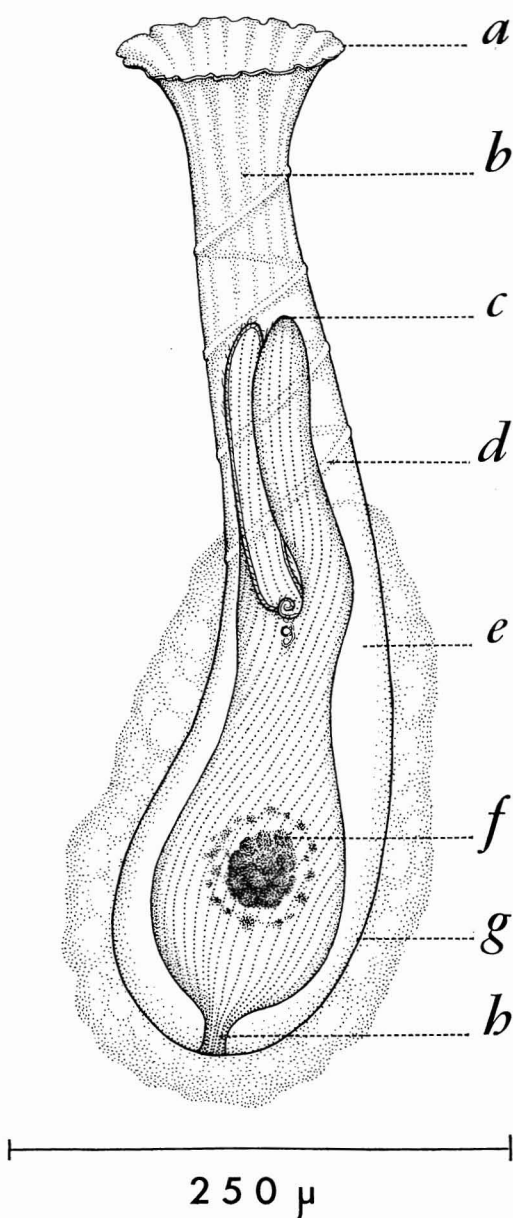


FIG. 6. *Lagotia expansa*. Ventral view of partially contracted animal showing: *a*, delicate flare of collar; *b*, longitudinal stripes; *c*, peristomal lobe; *d*, spiral whorl; *e*, lorica; *f*, spherical nucleus; *g*, rounded, proximal end of lorica; *h*, non-spatulate foot.

Because of the overlying pigment, the nucleus (*e*) though up to 20μ in diameter is difficult to see. The foot (*f*) is non-spatulate. The color of the lorica and animal is a deep blue-green.

Lagotia gigantia (Dons, 1913), Dons 1934 gen. (Hadzi, 1951:81).

Although this may prove to be a form of *L. expansa*, certain characteristics of the Tatokushima material taken June 19, 1965 seem to set it apart. The sac (Fig. 8 *e*) although 350μ long seems too small for the long, almost perpendicular neck which may be up to 1038μ long and 138μ wide. Although as many as 4 spiral whorls (*d*) may be present, they are usually indistinct. Both the neck and its extension (*c*) possess wide, delicate flaring collars (*a*) up to 188μ in diameter, and light and dark longitudinal stripes (*b*). The peristomal lobes (*f*) vary widely. They are of equal size and may possess a single, almost median finger (*i*), a lateral finger (*j*), or a combination of one large and two or three small projections (*k*), or two large, finger-like projections (*l*).

The nucleus (*g*) is a spherical mass $15-20\mu$ in diameter and again, because of intense overlying pigment, is difficult to see. The foot (*h*) is non-spatulate.

The color, so far as I could ascertain, was precisely like that of *L. expansa*—a very deep blue-green.

Lagotia spirorbis (Dons, 1927:7) (see Hadzi, 1951:96).

Folliculina spirorbis Dons, 1912:73, figs. A-B, pl. 5; Fauré-Fremiet, 1936:1155, fig. 11.

Angustofolliculina spirorbis (Dons) (see Silén, 1947:63, figs. 77-82).

Representatives of this unique species (Fig 9A and B) were first taken at Tatokushima, September 13, 1965 on the shells of *Spirorbis* sp. Later, they were taken from many different habitats: *P. martensii*, *Pinna attenuata*, and *Chlamys nobilis*. These folliculinids are placed in the genus *Lagotia* simply because of the shape and form of the lorica (*f*) and the spherical nucleus (*e*). Otherwise, there is considerable doubt whether the absence of a collar (*b*) and the presence of but one peristomal lobe (*a*) justifies this determination, especially when other *Lagotia* characters are lacking, i.e., color and longitudinal stripes, etc.

The necks of the specimens from Ago Bay, unlike those described and figured by Silén (1947:62, figs. 77-81), narrow gradually from

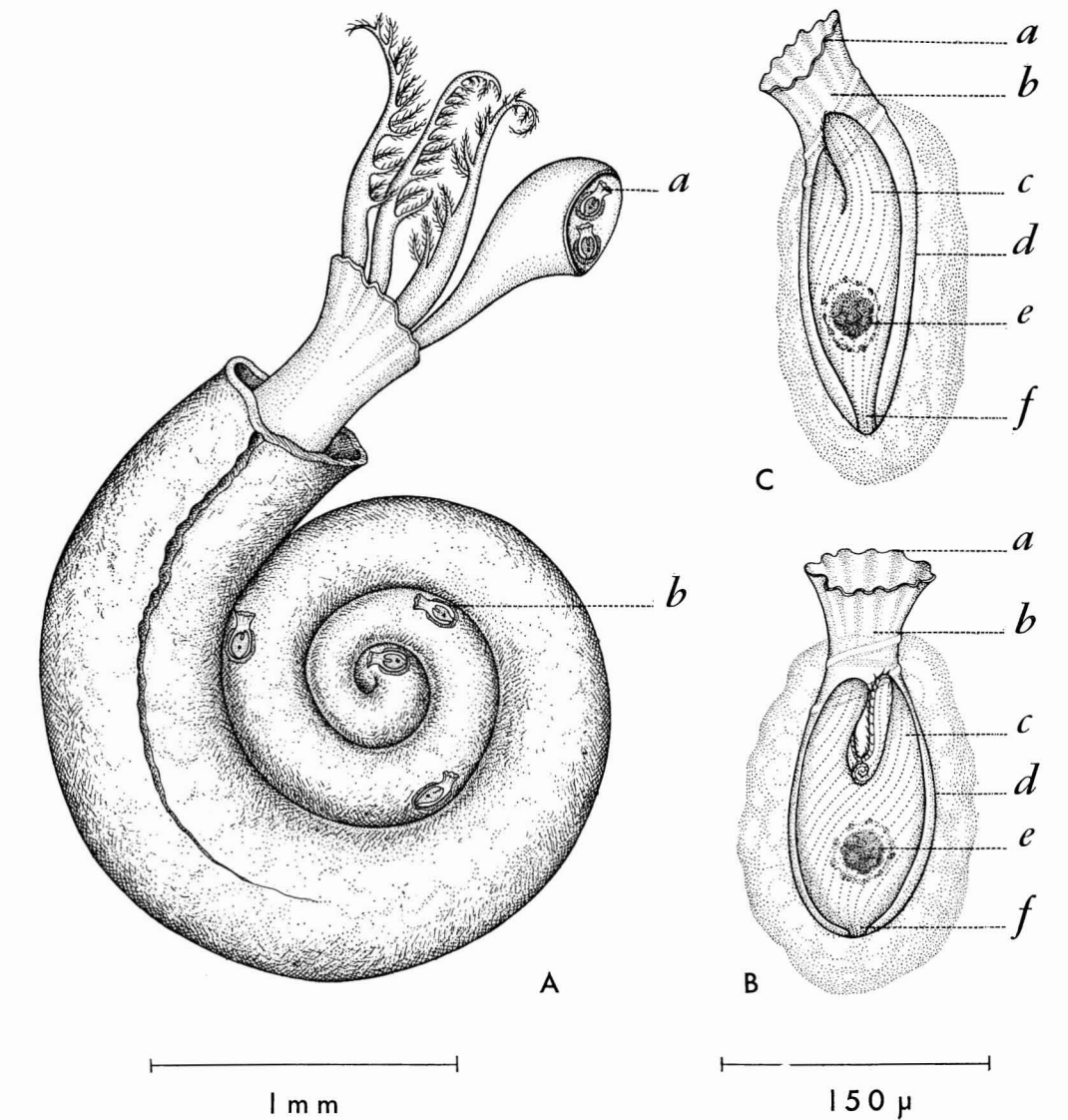


FIG. 7. *Lagotia expansa* var. *depressa*.
A, a, Operculum of *Spirorbis* sp.; b, calcareous shell.
B, Ventral view showing: a, delicate flare of collar; b, longitudinal stripes; c, peristomal lobe; d, flattened lorica; e, nucleus; f, non-spatulate foot.
C, Ventro-lateral view of same structures.

75μ to 48μ (Fig. 9A, d). Only 4 or 5 spiral whorls (c) are present which mark off the neck region (d) from the rest of the lorica (f). The overall length of the lorica is 250μ of which the neck usually makes up about half. No valves are present.

In every instance, only the left peristomal

lobe (a) is present. This measures about 125μ long when fully extended and varies from 12 to 25μ in width. There are no peristomal projections. In the contracted animal (Fig. 9B) the peristomal lobe (a) is often curved. If the condition of but one peristomal lobe proves to be only a transitional stage, then these specimens

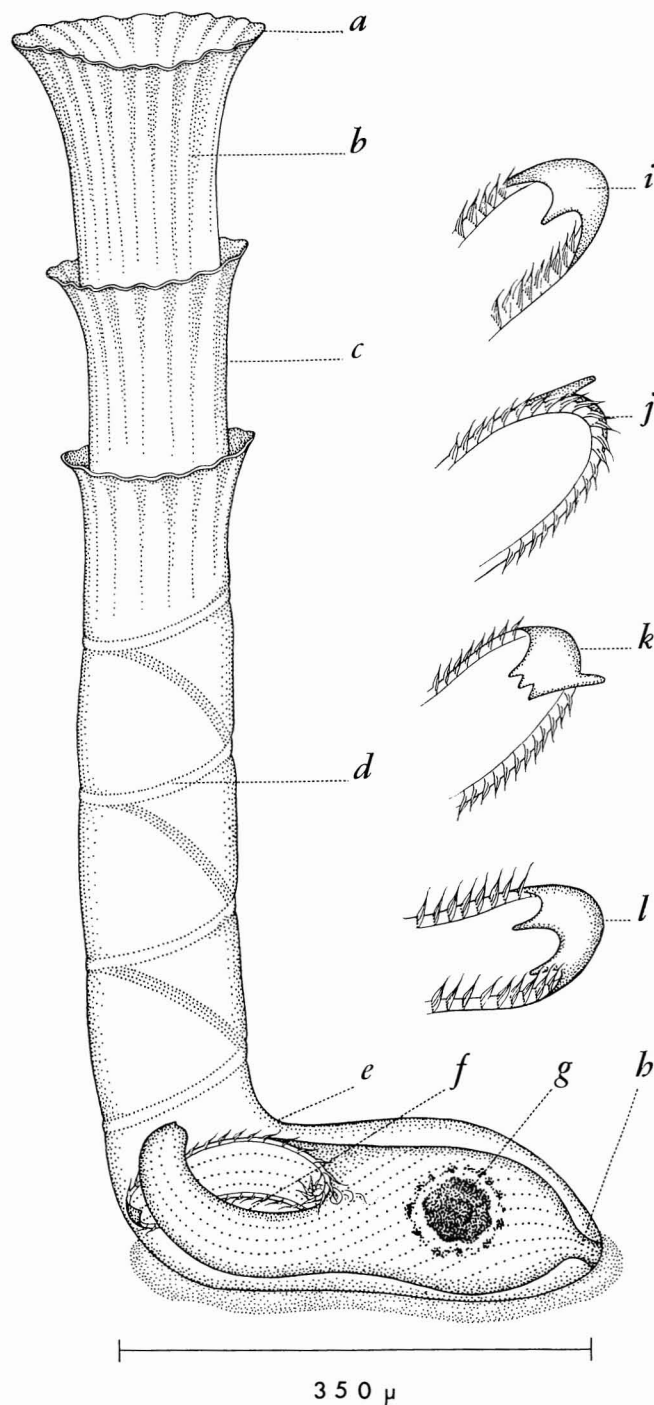


FIG. 8. *Lagotia gigantia*. Lateral view of right side and enlarged peristomal projections showing: *a*, delicate, flaring collar; *b*, longitudinal stripes; *c*, neck extension; *d*, spiral whorl; *e*, sac; *f*, peristomal lobe; *g*, nucleus; *h*, foot; *i*, *j*, *k*, *l*, variations of finger-like projections.

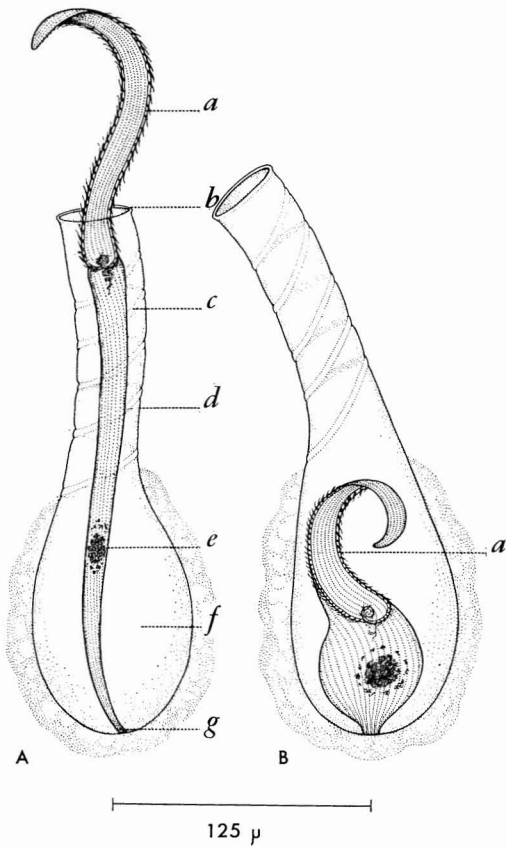


FIG. 9. *Lagotia spirobis*.

A, Ventral view of relaxed animal showing: a, left peristomal lobe; b, collarless neck; c, spiral whorl; d, neck; e, spherical nucleus; f, lorica; g, foot.

B, Ventral view of contracted animal showing: a, curved, left peristomal lobe.

may rightfully belong to the genus *Lagotia*, if not, Silén (1947:63) is justified in creating his new genus (*Angustofolliculina*).

The nucleus (Fig. 9A, e) is spherical and the foot (g) is non-spatulate. As previously stated, this material is not a deep blue-green but rather a light grey-green to almost colorless.

Lagotia viridis Wright, 1858. Amend. Hadzi, 1951:35–42.

Folliculina viridis Fauré-Fremiet, 1936:1152, fig. 9.

Folliculina ampulla Dons, 1912:81, fig. C.

Semifolliculina boeckii Dons, 1913:65.

Lagotia viridis (Fig. 10A and B) was first taken at Tatokushima, June 19, 1965 from the

surface of *P. martensii* and the calcareous tests of the acorn barnacle, *Balanus amphitrite* Brock. The size and shape of the lorica fall well within the limits previously prescribed for this species (Hadzi, 1951:37). The rather perpendicular neck (d) usually has 2 or 3 spiral whorls (c) ending just short of the narrow collar (b) but no longitudinal stripes.

The peristomal lobes (Figs. 10A and B, a) are equal, without finger-like projections and usually held quite high above the open neck. The nucleus (e) is spherical and the foot (f) non-spatulate even in highly contracted animals (Fig. 10B).

The color is the typical blue-green of this genus.

Metafolliculina andrewsi Hadzi, 1938, Acta Adriat. 2(1):1–46.

Metafolliculina andrewsi was first collected at Tatokushima, July 19, 1965 on shells of *Spirorbis* sp. comprising part of the epifauna of *P. martensii*. Later they were found on the valves of *Pinna attenuata* and *Chlamys nobilis* also taken in Ago Bay.

Figure 11 is a lateral view of the left side of *M. andrewsi* taken from the epifauna of *P. martensii*. Although measurements vary considerably from one population to another, none are as large as those described by Hadzi (1938) nor as small as those described by Andrews (1950) for his Carrum Creek (Australia) material. Most fall well within the limits observed by Matthews (1953) for this species taken at Waimanalo Creek, Bellows Field, Oahu.

In the Ago Bay material, the sac (Fig. 11 f) is up to 136μ long and lies attached to the substratum. The neck (d), which rises some 200μ almost perpendicularly from the sac, is reinforced by 6 or 7 well-developed spiral whorls (c). The collar (b) is only slightly developed and beneath it are no indications of longitudinal stripes. No valves are present. Extensions are common. Common also are the presence of “new” swimmers locating in “abandoned” loricae; and it was not uncommon to see two or three completely metamorphosed folliculinids occupying the same lorica.

The peristomal lobes (a) are long and slender and for the most part not provided with finger-like processes. When present, these projections

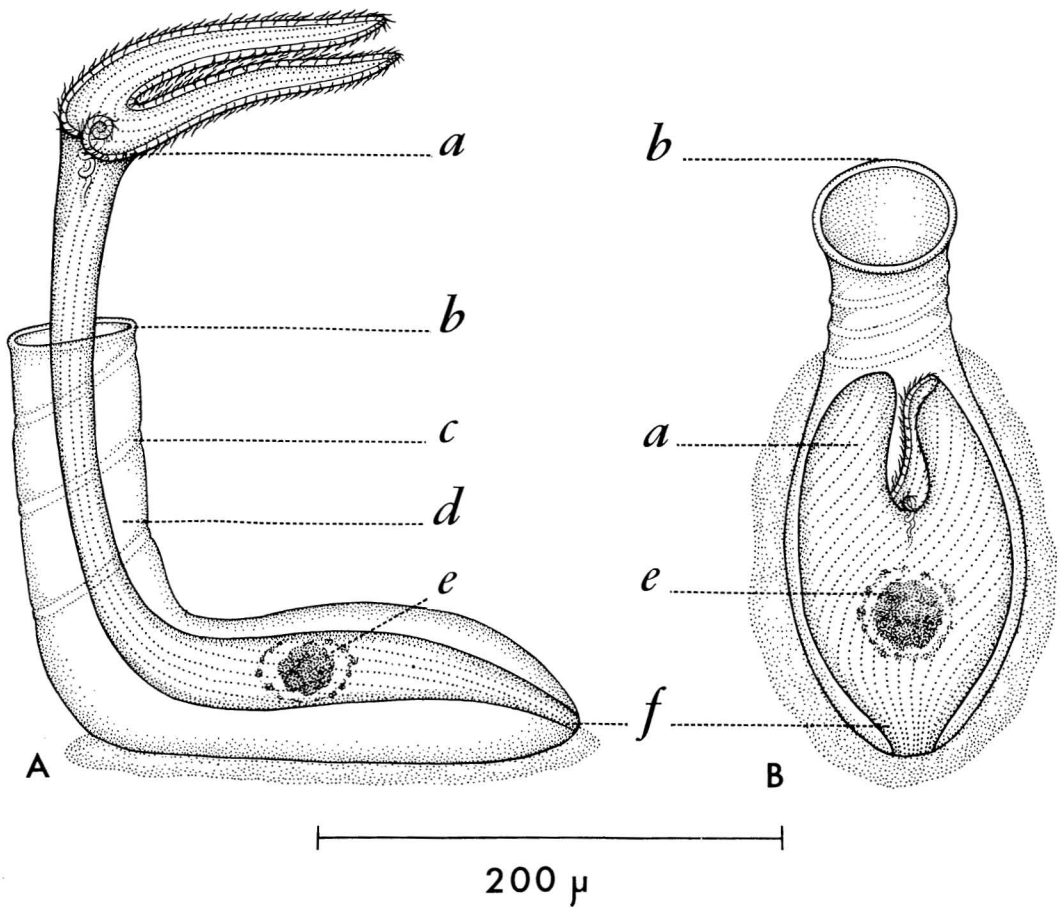


FIG. 10. *Lagotia viridis*.

A, Lateral view of right side of extended animal showing: a, peristomal lobe; b, collar; c, spiral whorl; d, neck; e, spherical nucleus; f, foot.

B, Ventral view of contracted animal showing same structures.

are small and not well developed. The nucleus (e) both in unstained and stained material is moniliform, with up to 20 small (3 or 4μ) beadlike components. The foot (g) is non-spatulate.

The color of the body is grey-green; the lorica, very light green to colorless. In no sense do even the darkest specimens approximate the deep blue-green of members of the genus *Lagotia*.

Mirofolliculina limnoriae (Giard, 1883) Dons, 1927 (see Hadzi, 1951:28-29).

Freya limnoriae Giard, 1883, Bull. Sci. France et Belg. II, 15:264-265.

Folliculina limnoriae (Giard) Bull. Sci. France et Belg. III, 19:310-317, 1888

Mirofolliculina limnoriae was first taken at Tatokushima, July 7, 1965 from *Limnoria* sp. living in the riddled nodes of abandoned bamboo poles of oyster rafts. Figure 12 is a ventral view of an extended animal and its lorica with lateral pouches (d). Although *M. limnoriae* from Ago Bay falls well within the limits of variation held for this species (Silén, 1947:57 and Hadzi, 1938:29), their position on *Limnoria* sp. and the degree of lorica branching differ from previously published accounts. Of 100 *Limnoria* sp. taken at random, only 16% had *M. limnoriae* on their exoskeletons. One of

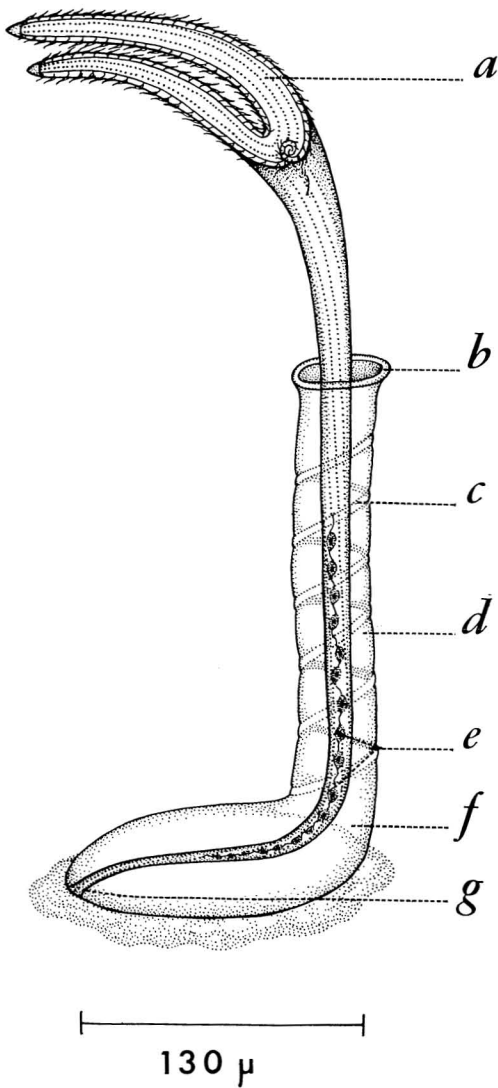


FIG. 11. *Metafolliculina andrewsi*. Lateral view of left side showing: *a*, peristomal lobe; *b*, collar; *c*, spiral whorl; *d*, neck; *e*, moniliform nucleus; *f*, sac of lorica; *g*, foot.

these had 4 *M. limnoriae* in a single row on the dorsal left side of the head with neck openings (*b*) pointing toward the mid-line and another had 2 *M. limnoriae* on the dorsal, right side of the head, with neck openings also pointing toward the mid-line. On still another, *M. limnoriae* was present on the dorsal, posterior margin of the head as well as on the dorsal surface of the pleotelson, and on 13 *M. limnoriae* was attached only to the dorsal surface

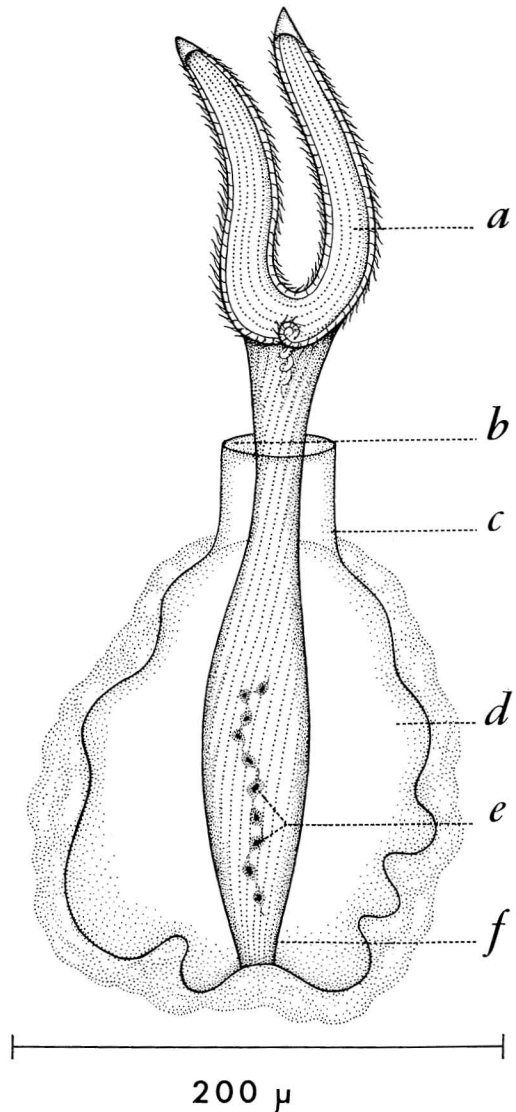


FIG. 12. *Mirofolliculina limnoriae*. Ventral view of extended animal showing: *a*, peristomal lobe; *b*, collarless neck; *c*, neck; *d*, lateral pouch of lorica; *e*, moniliform nucleus; *f*, non-spatulate foot.

of the pleotelson, but here again, their arrangement was random, affording only slight feeding advantage when the peristomal lobes (*a*) were extended above the short neck (*c*).⁴ Thus, the commonly held notion that the larval swimmer "selects" a site advantageous for the subsequent

⁴ This applies also to thousands of *M. limnoriae* examined from Hawaii.

metamorphosed, adult, sessile feeder, is placed in serious doubt. Perhaps the pleotelson, acting as a bulkhead, blocks the easy access of negatively phototropic swimmers and provides a suitable surface for lorica formation. But to date, this is mere conjecture. Only about 50% of the lorica had extensive lateral pouches.

The peristomal lobes (*a*) are without finger-like projections but, as mentioned by Silén (1947:59) are frequently bent forward. The nucleus (*e*) is always moniliform, although the number and size of beads vary considerably. The foot (*f*) is non-spatulate.

The color varies according to the amount and distribution of pigment grains, but in general it is a light, almost grey-green. The peristomal lobes when extended often appear rosy-pink.

Pachyfolliculina gunneri (Dons, 1927) Hadzi, 1951:33–35.

Folliculina gunneri Dons, 1927:5

Folliculinopsis gunneri Fauré-Fremiet, 1936: 1140.

Pachyfolliculina gunneri was first taken at Tatokushima, July 7, 1965 from the ventral

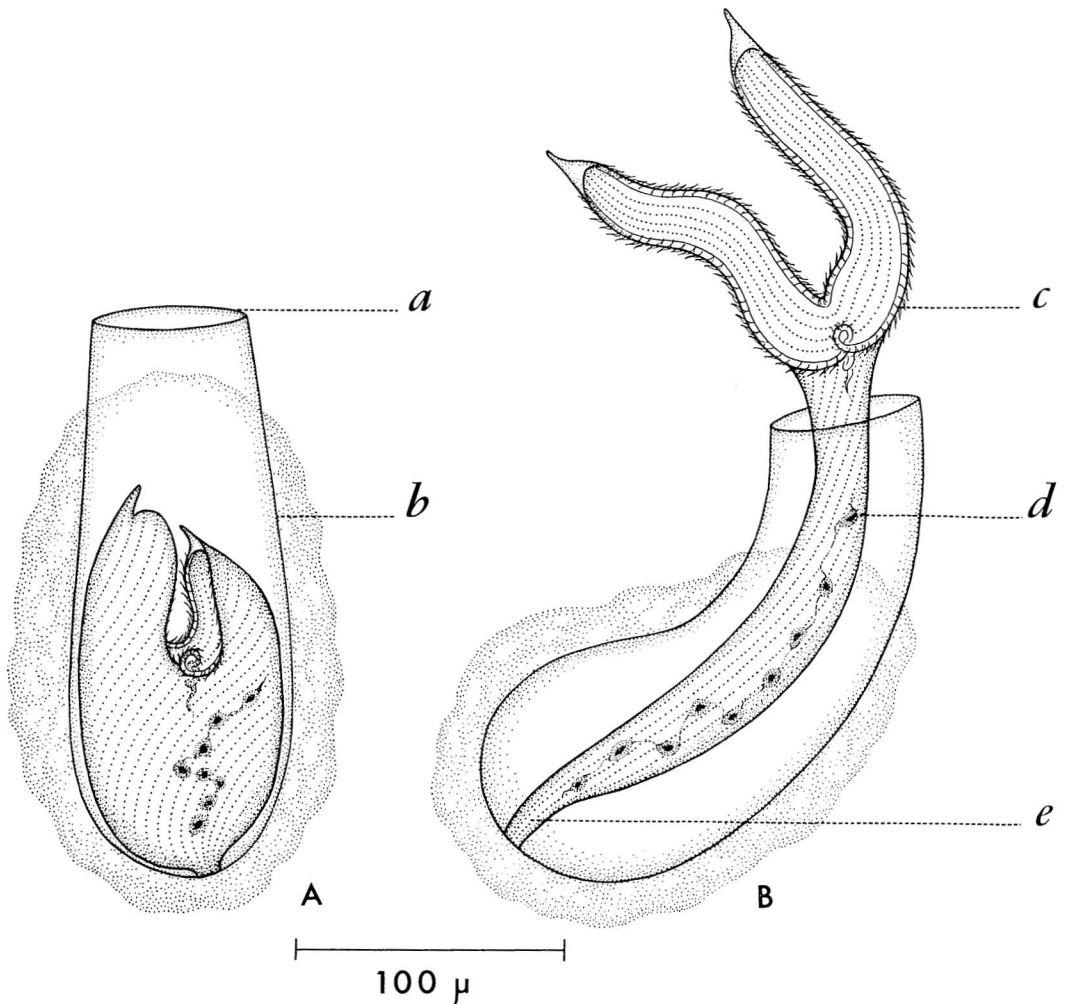


FIG. 13. *Pachyfolliculina gunneri*.

A, Ventral view of contracted animal showing: *a*, collarless neck; *b*, cylindrical lorica.

B, Ventro-lateral view of left side showing: *c*, peristomal lobe; *d*, moniliform nucleus; *e*, non-spatulate foot.

side of *Limnoria* sp. living in the riddled nodes of abandoned bamboo poles of oyster rafts. Later, they were taken from the surface of *Spirorbis* sp. which formed part of the epifauna of *P. martensii*.

Figure 13A is a ventral view of a contracted animal taken from the unrestrictive surface of a *Spirorbis* sp. shell. In such instances, the lorica is cylindrical and terminates in a broad neck (*b*) and wide mouth (*a*). No collar, spiral rings, longitudinal stripes, or bands are present.

Figure 13B is a ventro-lateral view of the left side of an extended animal taken from a restrictive surface of a *Spirorbis* sp. shell. Here, the otherwise cylindrical lorica is bent in compliance to the restricted area; otherwise the general proportions are the same. In no instance did the lorica ever stand vertically (see Silén, 1947:48) as is usually the case in *Parafolliculina violaceae*.

The peristomal lobes are usually equal, but sometimes the left (*c*) is slightly longer and perhaps broader than the right; finger-like projections are present. The nucleus (*d*) is always moniliform and composed of 8 or 9 beads of varying size. The foot (*e*) is non-spatulate.

The color varies from grey-green to bottle-green. The lorica may be yellowish-green to dark brown.

Parafolliculina amphora Dons, 1913 (see Hadzi, 1951:170–179, figs. 29 a–b, e–g and Silén, 1947:64–65, figs. 83–86).

Parafolliculina amphora (Fig. 14) was first taken at Tatokushima, September 22, 1965 on the interzoocelial boundaries of the Bryozoan, *Schizoporella oenochros* Ortman.

The measurements of the Ago Bay material fall well within the limits set for this species by other workers. Figure 14 represents a ventral view of a relaxed *P. amphora* taken from an unrestrictive lorica site. The division of the lorica into a short neck (*b*), vestibule (*c*) with valves (*d*), and sac (*e*) is clearly discernible. Especially significant is the extent of the collectoderm (*i*) which holds the lorica in a horizontal position, not vertical as in *P. violaceae*.

The peristomal lobes (*a*) are of equal size and length and bear short, finger-like projections at their gradually tapering ends. The nucleus (*f*) is spherical.

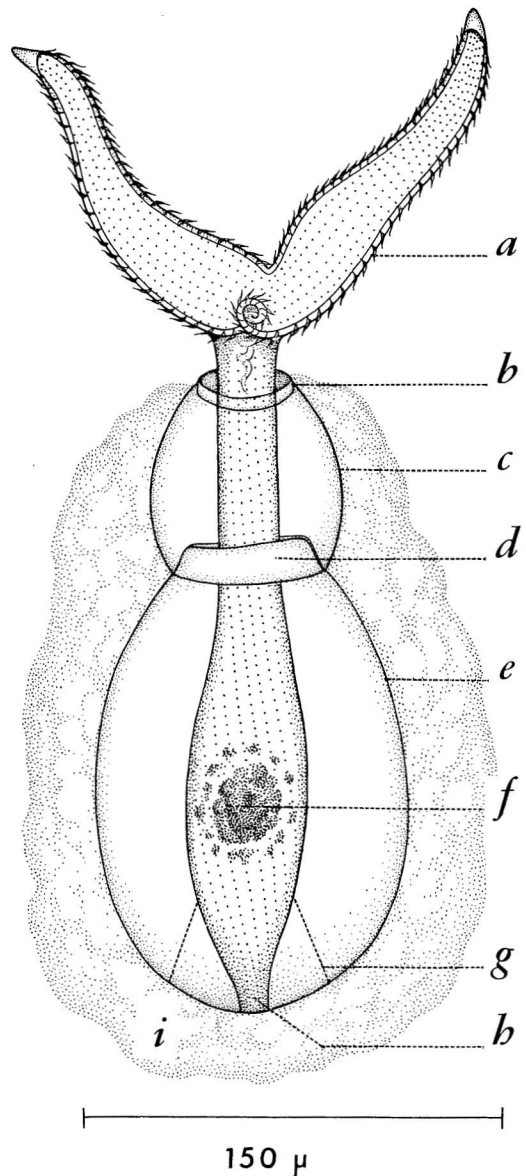


FIG. 14. *Parafolliculina amphora*. Ventral view of partially extended animal showing: *a*, peristomal lobe; *b*, short collar; *c*, vestibule; *d*, valves; *e*, lorica; *f*, nucleus; *g*, extent of foot (dotted area) when lorica excessively flattened; *h*, foot; *i*, collectoderm.

Silén (1947:25) mentions that in *P. amphora*, "the breadth of the attachment of the animal varies very much; it may be broad or as narrow as in most Folliculinidae (Figs. 83, 84)." Although Hadzi (1951:173) takes Silén to task for these figures, the width of the foot

(b) does increase as the building sites become more restrictive. In my Figure 14 the area within the dotted outline indicates the extent of the broadened foot (g). This type of foot attachment is encountered when the lorica is excessively dorso-ventrally flattened.

The color is light-green to grey-green.

Parafolliculina violaceae (Giard, 1888), Dons gen. (see Hadzi, 1951:188 and Silén, 1947:66).

Folliculina violaceae Giard, 1888:315.

Parafolliculina violaceae Dons, 1913.

Parafolliculina violaceae was first observed at Tatokushima, June 19, 1965 on practically everything collected, and, moreover, it was the most abundant folliculinid in Ago Bay. Because *P. violaceae* has been adequately described by many workers, only findings pertinent to the present study will be given here. Wide variations were observed in peristomal lobes (Fig. 15a) mouth (b), vestibule (c), valves (d), nucleus (e), and lorica attachment (f), and these variations seemed to be as much the result of the site chosen as the age of the "colony." As will be discussed subsequently, *P. violaceae* was one of the first organisms to appear on shell collectors and in such instances, even when space was not at a premium, the position assumed was always vertical.

The intense, deep red of this species in reflected light has been mentioned by other workers.

Pebrilla paguri Giard, 1888: Pl. 20.

Folliculinopsis (*Pebrilla* Giard) *paguri*,
Fauré-Fremiet, 1936:356, fig. 6.

Pebrilla paguri (Fig. 15A and B) was first taken at Tatokushima, September 13, 1965 from the dorsal side of the telson, uropods, and last two abdominal segments of the hermit crabs *Pagurus lanuginosus* de Haan, 1849, and *Pagurus samuelis* (Stimpson, 1857).⁵ These hermit crabs, at least for the month of September, were heavily infested (approximately 85%). In such cases of especially heavy infestation, folliculinids were also found attached to the inner, upper region of the shell of *Tegula*

⁵ Kindly identified by Dr. S. Miyake, Kyushu University, Faculty of Agriculture, Fukuoka, Japan.

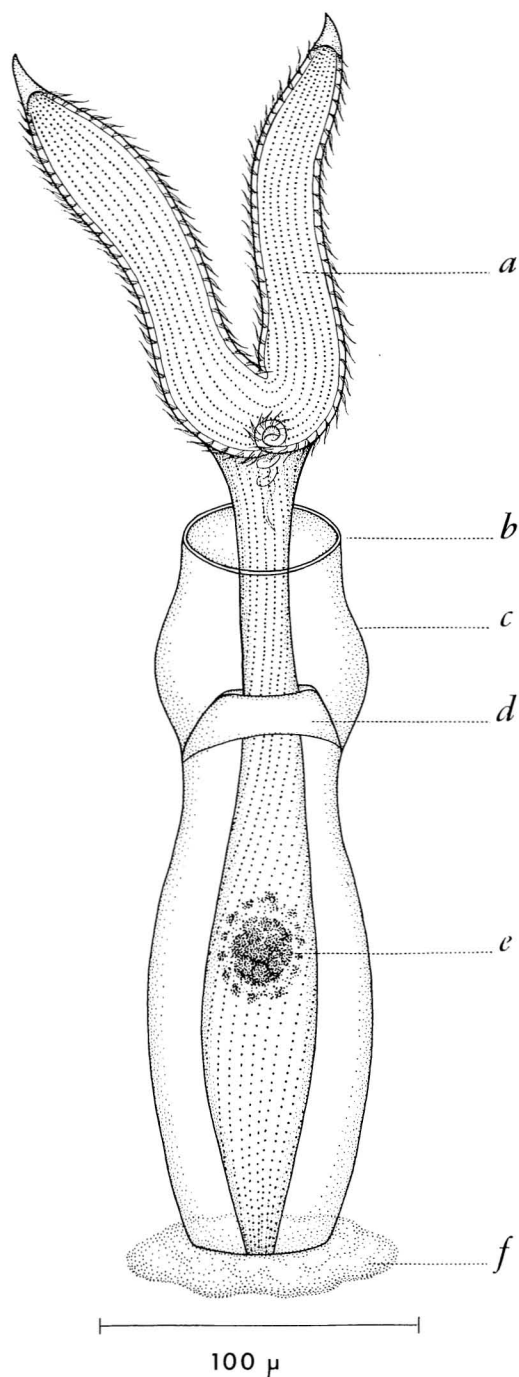


FIG. 15. *Parafolliculina violaceae*. Ventral view of partially extended animal showing: a, peristomal lobe; b, collarless opening of neck; c, vestibule; d, valves; e, spherical nucleus; f, collectoderm.

rustica and, although a few were taken near its large opening, most were far removed from the opening, indicating that swimmers of this species, as well as attached adults, prefer little light.

Figure 16A is a ventral view of *P. paguri* showing the division of the horizontally attached lorica into a distal vestibular portion (*e*) with short neck (*d*) and wide collar (*c*), and a proximal portion (*b*) with a strong spur (*i*). Generally the length of the distal portion, including neck and collar, about equals the proximal portion including the spur, but occasionally either one may surpass the other. Almost without exception, the proximal portion is wider than the distal portion. Both Giard (1888:Pl. 20) and Fauré-Fremiet (1936:356, fig. 6) mention and figure a pronounced, transverse median wrinkle separating distal from proximal portions of the lorica. Superficially the loricae of the Ago Bay material likewise seem to be so demarked. However, a lateral view (Fig. 16B) drawn from many hundred specimens shows that the left, heavily reinforced invagination of the lorica (*f*) does not continue, even as a slight depression, across the ventral surface of the lorica. And while this disparity may one day justify the creation of a new species, perhaps it is best for the present to wait until the presence of this groove in previously described material is actually demonstrated.

The short but well-developed neck (*d*) possesses no longitudinal stripes, spiral whorls, bands, or closures.

The peristomal lobes taper distally and terminate bluntly without finger-like projections. When extended, the left (Fig. 16A, *a*) is commonly held at right angles to the longitudinal axis of the body, whereas the right (*b*) is commonly carried over the ventral surface, parallel to the longitudinal axis of the body.

The nucleus is moniliform and usually consists of 11 or 12 rather easily observed beads (*g*).

The non-spatulate foot is always attached at the bottom of the well developed spur (*i*) whose walls, like those of the lateral invaginations, are often strongly reinforced.

The living animal is bottle-green. The peristomal lobes and distal portion of the body are often lighter than the proximal portion. Espe-

cially is this evident in contracted, alcohol-preserved material.

FOLLICULINIDS AS FOOD FOR THE EPIFAUNA OF *P. martensii*

Material and Methods

Of the folliculinids forming a part of *P. martensii* epifauna, the following were suspect, *prima facie*, of prey-predator relationships:

Ascobious siléni

Bugula dentata, *Spirorbis* sp.

Folliculinopsis annulata

Spirorbis foraminosus

Lagotia expansa *Heterotanaïs* sp.

L. expansa var. *depressa*

Spirorbis foraminosus, *Heterotanaïs* sp.

L. spirorbis *Spirorbis foraminosus*

L. viridis *Heterotanaïs* sp.

Metafolliculina andrewsi

Balanus amphitriti, *Heterotanaïs* sp.

Parafolliculina amphora

Cymodoce japonica

P. violaceae

Spirorbis sp., *Balanus amphitrite*,
Heterotanaïs sp.

With two possible exceptions (*Heterotanaïs* sp. and *Cymodoce japonica*) the suspected predators were all filter-feeders. And, although these could not conceivably prey on the adult, sessile, lorica-protected folliculinids with which they were so closely associated, the possibility still remained that motile "swimmers" of folliculinids might be swept into the feeding currents of filter-feeders. With the exception of *P. violaceae* (to be described subsequently) "swimmers" of these folliculinids were not available for feeding experiments. Therefore, living, attached folliculinids were removed from their lorica by gently tapping or applying pressure to the proximal end of the sac (Matthews, 1964:229). These were broken into tiny pieces and teased directly into the currents of suspected filter-feeders.

Most folliculinid pigment granules are easily discernible using low power, light microscopy, and their presence in digestive tract smears would clearly indicate predation. To this end, larger, suspected predators were dissected and the contents of their digestive tracts smeared

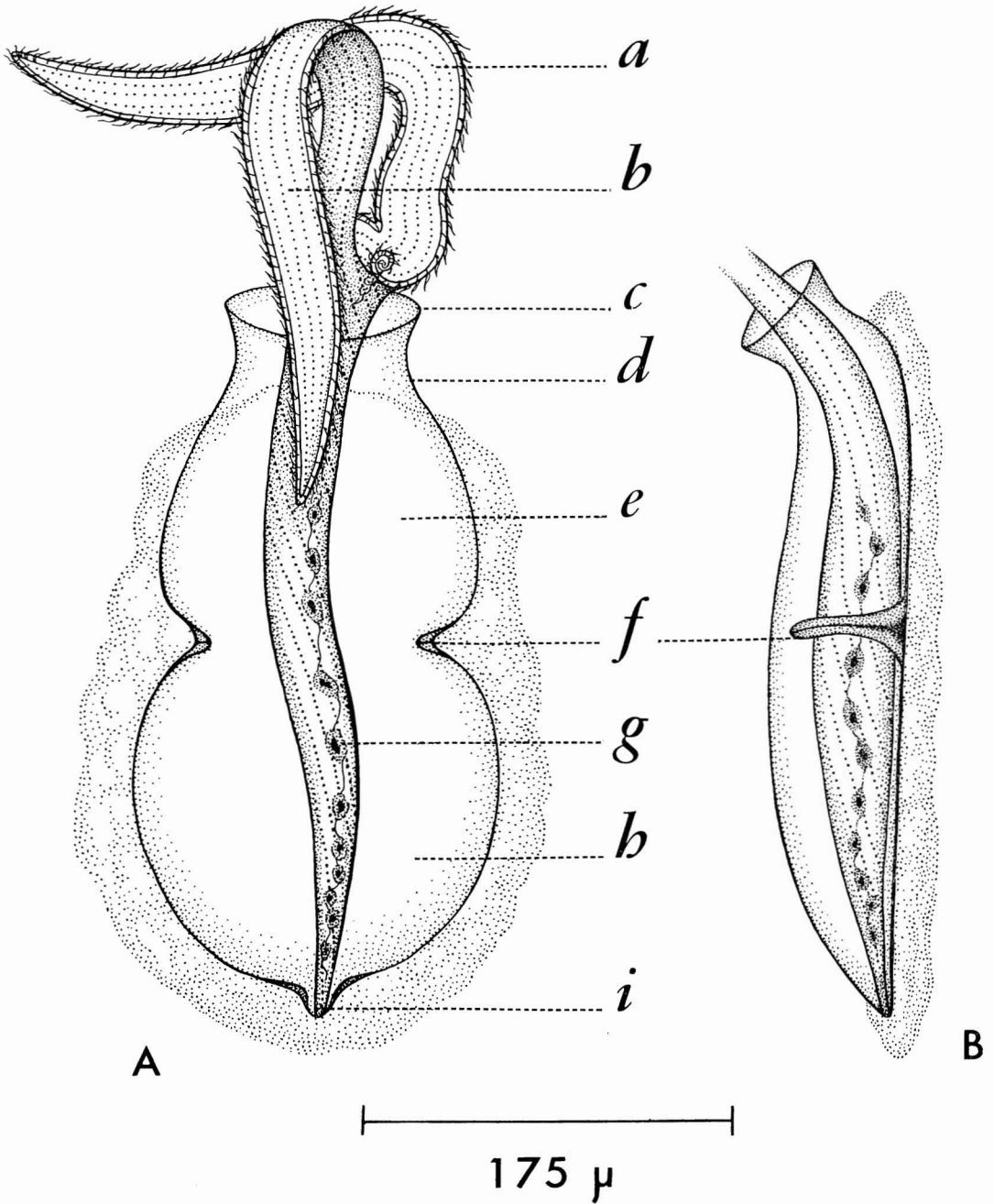


FIG. 16. *Pebrilla paguri*.

A, Ventral view of extended animal showing: *a*, left peristomal lobe; *b*, right peristomal lobe; *c*, collarless neck; *d*, neck; *e*, distal portion of lorica; *f*, lateral invaginations of lorica; *g*, component of moniliform nucleus; *h*, proximal portion of lorica; *i*, spur of lorica.

B, Lateral view of left side of empty lorica showing: *f*, strengthened lateral invagination of lorica not complete ventrally.

and examined for pigment granules. Most, however, were too small to be dissected without micro-manipulators (which were not available) so the entire animal was squashed and examined under the microscope. No stains were employed and no permanent mounts were made.

Results

In every instance these tiny pieces were quickly carried toward the region of the mouth of a suspected predator but were as quickly rejected. Likewise, smears of digestive tract contents of large, dissected animals and squashes of entire animals too small to be conveniently dissected all failed to reveal folliculinid pigment granules. While it is true that the size of the pieces offered as food were probably too large to be accepted, smear and squash techniques should have disclosed "naturally" occurring granules had such been present. Not once in any of the suspected predators were folliculinid pigment granules observed.

Even in *P. violaceae*, whose swimmers are among the first organisms to appear, no pigment granules were ever recovered.

At first sight, the situation seemed quite different in *Heterotanis* sp. (a voracious isopod which temporarily abandons its mucous tube to search for food and then quickly returns to it for protection). It would accept the empty lorica quite as readily as the lorica-free body and quickly pull either into its mucous tube. However, digestive tracts of these animals failed to reveal either pieces of lorica or pigment granules, and only after days of searching were both found cemented together with debris in the wall of the mucous tube.

Even the large *Umisemi*, *Cymodoce japonica* (which the Japanese call the "locust of the sea," for they eat everything) fails to utilize either *P. violaceae* or *P. amphora*, both of which occupy the same position on *C. japonica* that *Microfolliculina limnoriae* occupies on the gribble. In no instance, were folliculinid pigment granules recovered from their digestive tract contents.

CONCLUSIONS

Folliculinids, newly reported in Japan, are abundant in the epifauna of the Pearl Oyster,

Pinctada martensii from Ago Bay, Japan, but while these may profit by their association with different types of filter-feeders it is doubtful if other members of the epifauna use folliculinids as food.

ACKNOWLEDGMENTS

I wish to thank my sponsor, Dr. N. Kawamoto, who arranged housing accommodations at the National Pearl Research Laboratory, Kashikojima, and its director, Mr. Ohta, who provided research facilities at the Tatokushima Laboratory, Ago Bay. I am also grateful to the research staffs of these laboratories for their many kindnesses during these investigations. Credit is also due Mrs. Sally Oshiro, department secretary, who typed the manuscript and Mrs. Barbara Downs, department artist, who prepared the plates from my laboratory sketches.

REFERENCES

- ANDREWS, E. A. 1944. A folliculinid from the Hawaiian Islands. *Trans. Am. Microscop. Soc.* 63:321-325.
- 1950. Folliculinids in Australia. *Trans. Am. Microscop. Soc.* 69(4):413-421.
- DONS, C. 1912. Folliculina-Studien, I-III. *Arch. Protistenk.* 27:73-93.
- 1913. Folliculina-Studien, IV. *Tromsø Mus. Aarsh.* 35/36.
- 1927. Neue und wenig bekannte Protozoen. *K. Norske Vidensk. Selsk. Skr.* 1927 (7):1-17.
- 1934. Übersicht der Folliculiniden. *K. Norske Vidensk. Selsk. Forh.* 7(10):31-32.
- FAURÉ-FREMIET, E. 1936. La famille des Folliculinidae (Infusoria-Heterotricha). *Mém. Mus. Hist. Nat. Belg. (Sér. 2)* 3:1129-1175.
- GIARD, A. 1883. Sur les infusoires de genre *Freya*. *Bull. Sci. France et Belg.* II, 15.
- 1888. Fragments biologiques. XIII. Sur les genres *Folliculina* et *Prebrilla*. *Bull. Sci. France et Belg.* III, 19.
- HADZI, J. 1938. Beitrag zur Kenntniss der adriatischen Follikuliniden (Inf. Heterotricha), 1. Subfam. Eufolliculininae. *Acta Adriat.* 2(1):1-46.

- . 1951. Studien über Follikuliniden. *Academia Scientiarum et Artium, Slovenica Biology* 2:1–390.
- KORRINGA, P. 1951. The shell of *Ostrea edulus* as a habitat. *Arch. Néerl. Zool.* 10(1):32–152.
- MATTHEWS, D. C. 1953. New Hawaiian records of folliculinids (Protozoa). *Trans. Am. Microscop. Soc.* 72:344.
- . 1962. Additional records of folliculinids (Protozoa) in Hawaii. *Pacific Sci.* 16(4):429–433.
- . 1963. Hawaiian records of folliculinids (Protozoa) from submerged wood. *Pacific Sci.* 17(4):438–443.
- . 1964. Recent observations on neck extensions in folliculinids (Protozoa). *Pacific Sci.* 18(2):229–235.
- MIYAZAKI, I. 1938. On the fouling organisms in the oyster farm. *Bull. Jap. Soc. Sci. Fish.* 6(5):223–232.
- MOEBIUS, K. A. 1887. Das Flaschenthierchen: *Folliculina ampulla* beschrieben und abgebildet. *Abh. Naturwiss. Hamburg* 10:1–14.
- SILÉN, L. 1947. On Folliculinidae (Ciliophora, Heterotricha) from the west coast of Sweden. *Ark. Zool.* 39(12):1–68.
- UHLIG, VON GOTRAM. 1963. Untersuchungen über die Folliculiniden (Ciliata; Heterotricha) der Deutschen Bucht. Veröffentlichungen des Instituts für Meeresforschung in Bremerhaven. Drittes meeresbiologisches Symposium, pp. 115–121.
- UTINOMI, HUZIO. 1961. Colored Illustrations of Sea Shore Animals of Japan. Hoikusha Publ. Co., Osaka, Japan. I–XVII + 167 pp.