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BIOFOULING OF WASTEWATER TREATMENT PLANTS BY THE FRESHWATER BRYOZOAN, *PLUMATELLA VAIHIRIAE* (HASTINGS, 1929)

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Abstract—We report large growths of a phylactolaemate bryozoan, *Plumatella vaihiriae* [Hastings, A. (1929) Notes on some little-known phylactolaematous polyzoa and description of a new species from Tahiti. Ann. Mag. Nat. Hist., 10(3), 300–311], from three widely separated domestic wastewater treatment plants in the United States. This relatively uncommon species is previously known only from Tahiti, Hawaii, Utah, and Argentina. The bryozoan colonies are capable of plugging pipes and filters. Free statoblasts are suspected of interfering with ultraviolet disinfection of wastewater. Laboratory reared specimens exhibit rapid, aggressive growth and produce vast quantities of free statoblasts which either float or sink. Devising effective control methods is impeded by limited knowledge of bryozoan physiology. Given the widespread distribution of known wastewater treatment facilities affected by the bryozoan, the problem is probably a common one. © 1998 Elsevier Science Ltd. All rights reserved

Key words—bryozoa, Ectoprocta, Phylactolaemata, *Plumattella*, *Hyalinella*, *vaihirial*, biofouling, wastewater, sewage

INTRODUCTION

Several species of freshwater bryozoans are notorious for clogging pipes that carry unfiltered water from rivers and lakes. The branching, tubular animal colonies attach firmly to any solid substrate, often appearing as clumps of brownish moss. In the last century major cities in Europe and the United States regularly experienced disruption of public water service due to blockages by bryozoans (Kraepelin, 1886).

We now report a new bryozoan biofouling threat, this time in domestic wastewater treatment facilities in the United States. Although we are so far aware of only three such occurrences they are over 1200 km from each other and suggest the likelihood of a widespread problem.

Bryozoans are tiny coelomate animals which form coherent colonies, often of surprisingly large size. Most freshwater species belong to the class phylactolaemata, and the species infesting wastewater treatment plants is *Plumatella vaihiriae* (Hastings, 1929). Individual units of the colony, termed zooids, ingest and digest suspended particles from the water. Each zooid is also capable of producing dormant buds, called statoblasts, which can resist harsh environmental conditions for several years. *Plumatella vaihiriae* and other species of the family plumatellidae produce two types of statoblasts: a small floatoblast (Fig. 1) released freely into the water, and a larger sessoblast (Fig. 2) cemented firmly to submerged surfaces. After an obligate period of dormancy these seed-like statoblasts can "germinate" and produce a new generation of colonies. Every floatoblast has a central fenestra surrounded by an annulus of large cells (Fig. 1). The biology of freshwater bryozoans is summarized by Pennak (1990) and Wood (1989, 1991).

Despite its wide geographical range the literature citing *Plumatella vaihiriae* is not extensive. The species was first described as *Hyalinella vaihiriae* from material collected in Lake Vaihiria, a mountain pond in Tahiti (Hastings, 1929). Since then it has been found in Utah (Rogick, 1942), Hawaii (Baily-Brock and Hayward, 1984), and Argentina (Cazzaniga, 1988). Lacourt's (1986) report of *Plumatella vaihiriae* in Australia cannot be confirmed by any known specimen (Wood, in press) and should be considered tentative.

Because *Plumatella vaihiriae* is so poorly known our primary intent in this paper is to document its occurrence with the first full description of the species. We also discuss the implications of what appears to be a serious biofouling hazard. Although we suggest several possible methods for suppressing bryozoan populations, thorough studies on the effectiveness of such measures are still under way.

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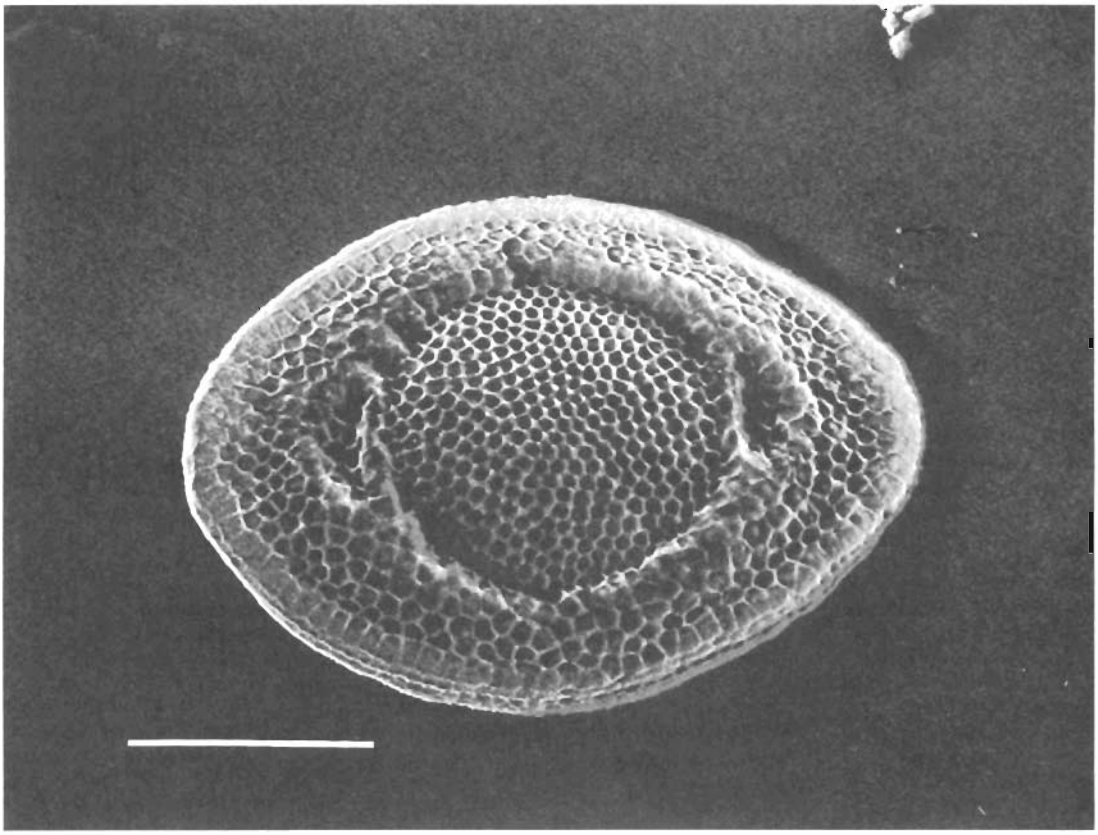

Fig. 1. Floatoblast of *P. vaihiriae*. SEM micrograph of dorsal side. Scale bar is 100 μm.

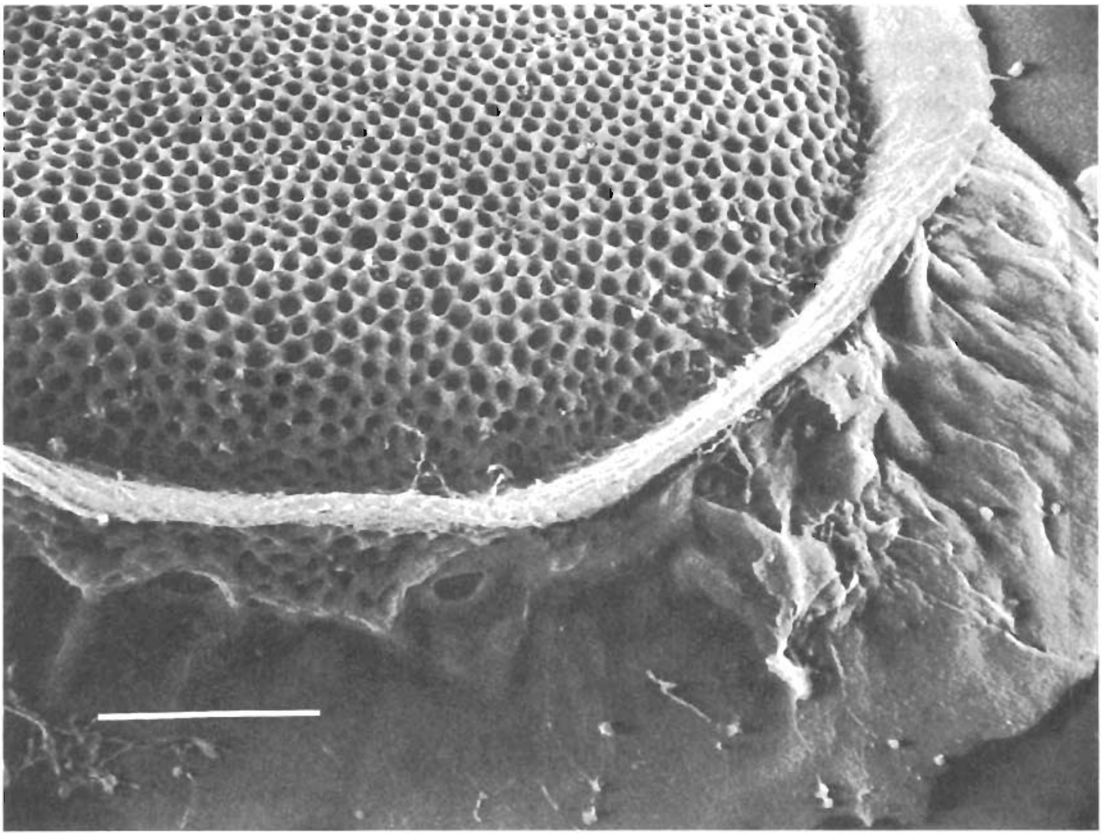

Fig. 2. Sessoblast of *P. vaihiariae*. SEM micrograph. Scale bar is 50 μm.

METHODS

We received both living and preserved specimens of *Plumatella vaihiriae* from wastewater treatment plants in three cities in the United States where fouling problems had been identified. These include facilities in Aiken, South Carolina, Monroe, Wisconsin, and the 28th Avenue Wastewater Treatment Plant in Phoenix, Arizona. All colonies had been collected from secondary clarifiers or from structures immediately downstream of the clarifiers. The Phoenix plant was by far the largest with an average daily flow of 57 million gallons; the Aiken and Monroe facilities currently treat an average of 700,000 and 17,000 gallons per day respectively.

We stored living statoblasts for several weeks in a refrigerator at 3°C, then germinated them at room temperature in reconstituted soft water (American Public Health Association, 1989). Colonies grew in disposable 3.5 cm petri plates in a culture system modified from Wood (1996). For examination by light microscopy we heated statoblasts in a concentrated KOH solution for about 1 min, then placed them in cool deionized water and teased the valves apart with needles. Preparation of statoblasts for scanning electron microscopy (SEM) included vigorous washing in 0.1 M sodium metabisulfite, rinsing in distilled water, freeze drying, then sputtering with gold palladium alloy. For comparison with our material we examined the following museum specimens: *Hyalinella vaihiriae* (paratype), No. 1321, National Museum of Natural History (Leiden, Netherlands); and *Hyalinella vaihiriae*, No. 1874.12.8.3, British Museum (Natural History). We measured floatoblasts with an electronic video digitizer (Fink, 1987) using CODA software by Julian Humphries.

THE FOULING PROBLEM

Although a single bryozoan species fouled all three wastewater treatment plants, the problems they caused were somewhat different in each case. At Phoenix the bryozoan colonies were first noticed blanketing the floors of chlorine contact channels where residual chlorine levels were 3–4 mg/l. They also grew in masses several centimeters thick along the launder walls of secondary clarifiers. Cleaning the clarifiers entailed disposing of truckloads of the moss-like bryozoans. The colonies were a nuisance and a worrisome presence, but they did not noticeably impair the wastewater treatment process.

In Wisconsin the fouling problem was more serious, with colonies completely plugging nozzles of the sand filters whenever the chlorine level was reduced from 7 to 2 mg/l (Gerald Ellifson, 1996, personal communication). Dismantling and chemically cleaning the nozzles proved very labor intensive. The subsequent return of bryozoans after only a few weeks suggested the presence of parent colonies upstream, possibly in a secondary clarifier.

In South Carolina vigorous bryozoan colonies in secondary clarifiers appeared to impair indirectly the ultraviolet disinfection process. It was apparently possible for coliform bacteria to be shielded from ultraviolet radiation by millions of floating seed-like statoblasts produced by the colonies (see below), although the evidence for this is still only circumstantial. The high density of statoblasts corresponded with high levels of viable coliform bacteria in the plant effluent. When bryozoan populations were brought under control the coliform counts in plant effluent returned to normal low levels. The deep recesses on the surface of the free statoblast (Fig. 1) could easily harbor large numbers of coliform and other bacteria.

SPECIES DESCRIPTION

Colonies are tubular and branching, many branches growing free of substrate, twisting, intertwining, and often fusing into ropelike cords. The colony wall is initially transparent and colorless, gradually acquiring a light amber color. There is no furrow or keel, and internal septa are absent. Hastings (1929) describes and illustrates a thick and gelatinous colony wall "not unlike that of (*Hyalinella*) *punctata*". This feature may have resulted from chemical fixation shrinking internal tissues. We do not see the effect in living material.

Floatoblasts are ovoid in outline, tapering to sharply rounded poles to give a pointed appearance. While in most plumatellids the floatoblast annulus is smoothly contoured, in this species the annulus rises abruptly to the fenestra as though pushed outward by a bulging capsule beneath it. This "shoulder" is clearly illustrated in Fig. 3(e) of Hastings (1929) original description. The valves tend to be strongly convex ventrally and nearly flat dorsally resulting in a pronounced lateral asymmetry. However, the Hawaiian floatoblasts are exceptional in having much greater lateral symmetry, so this feature may be variable. Seen with light microscopy the split valves reveal a heavy reticulation which subdivide the fenestra area into five-sided cells. The cells are uniform in size on the dorsal valve, while on the ventral valve they become smaller and more crowded towards the center. On both valves, small, individual tubercles may appear in certain cells around the fenestra periphery. Scanning electron microscopy reveals an equally strong reticulum on the annulus of both valves, the annular cells slightly larger than those of the fenestrae (Fig. 1). The raised, net-like lines stand out in sharp relief on an otherwise smooth surface, with an occasional faint tubercle in the center of certain cells near the ventral fenestra margin. Polar grooves on the dorsal valve are narrow, triangular pits lined with reticulum. Hastings' type specimens have button-like protuberance in the middle of the ventral fenestra, but we have not seen this feature elsewhere. Floatoblast dimensions from the wastewater treatment plants, summarized in Table 1, are consistent with those cited by Rogick (1942) and by Baily-Brock and Hayward (1984).

The sessoblast is ornamented with a dense assortment of holes. As seen by SEM, these appear in some instances to have been formed as interstices in a tight, somewhat ragged lattice; at other times they appear as smoothly bored holes varying slightly in

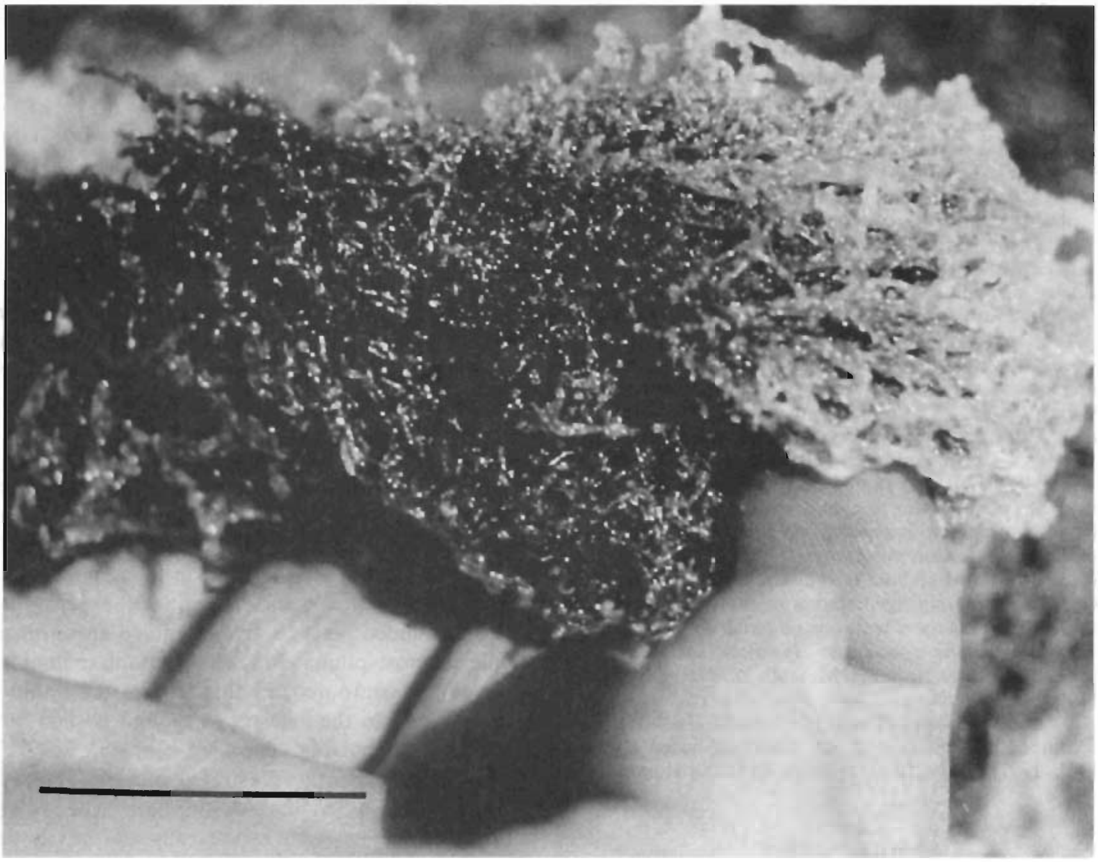

Fig. 3. Colonies of *P. vaihiriae* lifted from the launder walls of a secondary clarifier at the 23rd Avenue Wastewater Treatment Plant in Phoenix, Arizona. Scale bar is 30 mm.

size (Fig. 2). The same pattern of holes is continued on the sides of the sessoblast. A relatively wide lamella bears a faint tracery of raised, reticulated lines.

TAXONOMY

The genus *Hyalinella* is generally considered to include tubular bryozoans having a thick, gelatinous colony wall. *Hyalinella punctata* is an excellent standard bearer with its swollen appearance and stubby zooids. It was on this basis that Hastings (1929) named *Hyalinella vaihiriae*, noting however that "the stout horny structure of the older parts of the colony is rather outside the usual conception of *Hyalinella*...." In fact, we find that even young branches of her specimen colonies are indistinguishable from those of certain *Plumatella* species, including *P. nitens* and *P. repens*. Moreover, there has been some debate over whether the genus *Hyalinella* should include species forming sessoblasts, the current sense being that it should not (Ricciardi and Wood, 1992). *H. punctata* is sufficiently distinct from other known species to warrant a separate genus. We therefore recommend that *H. vaihiriae* be transferred to the genus *Plumatella* based on colony and statoblast features it share with certain other species of this taxon.

Table 1. Critical measurements of *Plumatella vaihiriae* floatoblasts from wastewater treatment plants in Wisconsin, Arizona, and South Carolina. Dimensions are given in micrometers, and 95% confidence limits are expressed for all mean data

Floatoblast measurements	Maximum	Minimum	Mean	Number of measurements
Overall length	356	292	322 ± 3	80
Overall width	255	197	223 ± 2	80
Overall length/width	1.61	1.24	1.45 ± 0.16	80
Dorsal fenestra length	168	133	146 ± 2	49
Dorsal fenestra width	156	124	141 ± 2	49
Dorsal fenestra length/width	1.23	0.91	1.04 ± 0.02	49
Ventral fenestra length	233	201	221 ± 3	31
Ventral fenestra width	196	164	177 ± 3	31
Ventral fenestra length/width	1.36	1.09	1.25 ± 0.03	31

ECOLOGY

The existing literature on *Plumatella vaihiriae*, while sparse, paints a consistent picture of a species characterized by massive colonies and rapid growth. In Tahiti Hastings (1929) found *P. vaihiriae* together with another species, *Plumatella emarginata*, forming "masses all along the shore, 9 in or so thick, besides creeping on sticks fallen into the water". In Utah Rogick reports that "almost every stick and stone pulled from the river was covered with a dense growth of *Hyalinella vaihiriae*". In the Phoenix wastewater treatment plant huge masses of the bryozoan grew in turbulent water on the walls of the launders which carry effluent from the secondary clarifiers (Fig. 3). Our laboratory reared colonies at Wright State University exhibit rapid and aggressive growth. They are capable of doubling in size every three to four days and sending out long branches that readily adhere to any solid surface they contact (Fig. 4). In Hawaiian prawn ponds such solid surfaces apparently included unwary prawns (Baily-Brock and Hayward, 1984). When colony branches adhere to each other the result is a fused mass, which is what plugged the tertiary sand filtration nozzles in the Monroe, Wisconsin wastewater treatment plant.

In *P. vaihiriae* not only are the colonies large, but their floatoblast production exceeds that of any other species in our experience. In the laboratory a single colony occupying an area of 10 cm^2 can release over 250 floatoblasts per day for several weeks. Even at that rate, older portions of the colony become black with retained floatoblasts, which can number more than 200 in a single 5 mm tubule. At the height of production floatoblasts are released with the annulus uninflated, and so they sink to the sediments. At other times, apparently under more crowded conditions when colony growth is retarded, buoyant floatoblasts are produced. We have detected no difference between buoyant and sinking statoblasts with respect to their dormancy or viability. In South Carolina the heavy production of buoyant floatoblasts coincides with abnormally high coliform counts in the plant effluent, suggesting interference with the ultraviolet disinfection process.

Preliminary observations at the Phoenix wastewater treatment plant indicate *Plumatella vaihiriae* colonies are not particularly tolerant of low dissolved oxygen. Without the circulation of aerated water the zooids stop feeding and exhibit signs of respiratory stress. Bryozoan growths have so far not been found in primary treatment areas, although in some species viable statoblasts are known to survive many weeks under anaerobic conditions.

CONTROL OF BRYOZOAN POPULATIONS

Plumatellid bryozoan colonies in the laboratory are generally killed by 5 h exposure to 1 mg/l

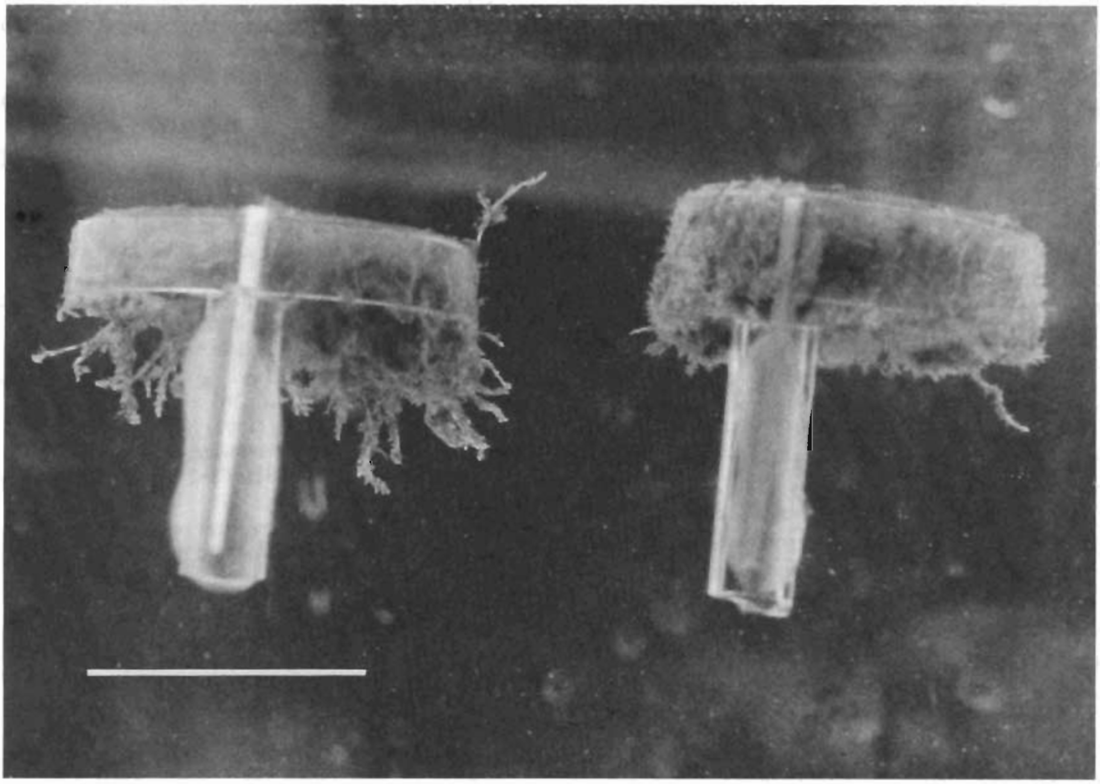

Fig. 4. Bryozoan colonies growing in inverted plastic dishes in laboratory culture, showing differences in colony form: *Plumatella vaihiriae* (left) and the more compact *P. fungosa* (right). Scale bar is 20 mm.

sodium hypochlorite (Wood, unpublished). At the Wisconsin facility a residual chlorine level of 7 mg/l prevents bryozoan growth. Precise tolerance levels of colonies and statoblasts to residual chlorine have not yet been established, although these are likely to vary with the age, size, and condition of both colonies and statoblasts. Spraying hot water or steam over contact surfaces, and the thorough drying of fouled surfaces are suitable methods for temporarily reducing the living biomass of bryozoans. In pipelines carrying water with a moderate BOD it should be possible to kill colonies by allowing anaerobic conditions to develop.

However, killing the colonies is not a long-term solution as long as dormant statoblasts remain to begin a new generation. Dormant viable sessoblasts are firmly cemented to the substrate on which colonies have previously grown, while new free statoblasts enter a sewage treatment plant with incoming wastewater or with visiting waterfowl. Statoblasts are notoriously resistant to chemical treatments. Working with *Asajirella gelatinosa*, Mukai (1977) found silver, mercury, and copper ions to be highly toxic to statoblasts after 2 h of exposure, but various sodium salts, nitrates, and chlorides had little impact. Curiously, Mukai was able to retard statoblast germination with 0.5 M and 1 M concentrations of various acids and alkalis, but found no effect with higher or lower concentrations. We have found hydrogen peroxide to be particularly effective at destroying statoblasts, but it is seldom practical on a large scale.

An alternative to killing statoblasts outright would be to control bryozoan populations at the colony level with scheduled maintenance treatments using shock chlorination or another appropriate toxin yet to be identified. Biological control is a future possibility, especially one using microsporidium or myxosporidium parasites known to disable bryozoans (Canning *et al.*, 1997). Unfortunately our knowledge of the host–parasite relation is currently too meager to carry this idea very far.

CONCLUSIONS

(1) The phylactolaemate bryozoan fouling three wastewater treatment plants in the United States is *Plumatella vaihiriae* (Hastings, 1929).

(2) Fouling properties of this species are enhanced by rapid colony growth, high statoblast production, and the tendency of free branches to adhere to any surface they contact.

(3) The transfer of this species from *Hyalinella* to *Plumatella* is prompted by the relatively thin, cuticular colony wall and the formation of sessoblasts.

(4) Preliminary studies suggest colonies are killed by exposure to sodium hypochlorite at 1 mg/l for no less than 5 h. Field experience shows a free residual chlorine level of 7 mg/l sufficient to keep bryozoan colonies under control, but the dynamics of chlorine toxicity have yet to be established. Colony control may also be possible through desiccation, elevated temperatures, or anaerobic conditions. Effective and appropriate means of killing statoblasts at various stages in their dormancy have yet to be explored.

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