

Growth and development of biofouling freshwater bryozoans, Southern Reservoir, Dunedin, New Zealand, November 2000 to June 2004

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Abstract: At the Southern Reservoir water treatment station, Dunedin, New Zealand, freshwater bryozoans *Paludicella articulata* and *Plumatella repens* infest hard surfaces throughout the microstrainers as well as the Reservoir itself, intermittently affecting normal operation of the plant since 1996. Weekly-to-monthly monitoring using settling plates and photographic surveys was carried out between November 2000 and June 2004 (a total of 44 months), resulting in 69 visits and 1300 photos. Bryozoans settled and began to grow each spring (mid- to late October), with coverage of settling plates increasing to 100 % in February to March (mid-summer). Senescence occurred in May (late autumn) each year, with mean annual production of 540 to 1630 kg/y in the water treatment hall. Onset of settlement and senescence appears to be linked to water temperature, with no growth occurring in water less than 9 °C. *Paludicella articulata* settled exclusively on the upper sides of settling plates, and grew more slowly (0.6 mm/day) than *Plumatella repens*, which occupied the under sides and grew at 1.4 mm/day. Biofouling by these two persistent bryozoans may be related to changes in the Reservoir's catchment since 1996. While control of freshwater bryozoans is notoriously difficult, this long-term monitoring of growth and settlement allows for management of the infestation.

Key words: Bryozoa, *Paludicella articulata*, *Plumatella repens*, fouling, Dunedin.

Introduction

Freshwater bryozoans are cryptic but important parts of the New Zealand freshwater fauna (WOOD et al. 1998). When they grow on artificial structures found in water treatment plants or aquaculture facilities, however, bryozoans can become persistent biofoulers (BAILY-BROCK & HAYWARD 1984; APROSI 1988; WOOD et al. 1998, WOOD & MARSH 1999). Control is difficult due to resistant resting stages (statoblasts and hibernacula) which act like a seed bank, allowing re-colonisation when conditions improve.

Southern Reservoir water treatment station is located in Dunedin, New Zealand at 45°55'S, 170°28'E (Fig. 1). An open, concrete-lined reservoir (Fig. 2A, B) of about 40,000 m² leads to an enclosed hall where large rotating microstrainers filter the water before chemical treatment (Fig. 2C). Fresh-

water bryozoans *Paludicella articulata* and *Plumatella repens* grow on submerged hard surfaces throughout the microstrainer hall (Fig. 3). Their presence has become a severe problem since 1996, intermittently affecting normal operation of the plant. When colonies detach from the sides of pipes and walls, they clog microstrainers and cause considerable damage. Waterblasting and hand-scrubbing has proved to be the only way to remove the colonies; statoblasts and hibernacula can never be completely removed. The infestation has increased workloads, decreased efficiency, and reduced water quality at Southern Reservoir. A coordinated programme of study has been implemented to assist the Water Department in planning and management of this biofouling problem (SMITH et al. 2005).

Along with surveys and experimental investigations (SMITH et al. 2005), long-

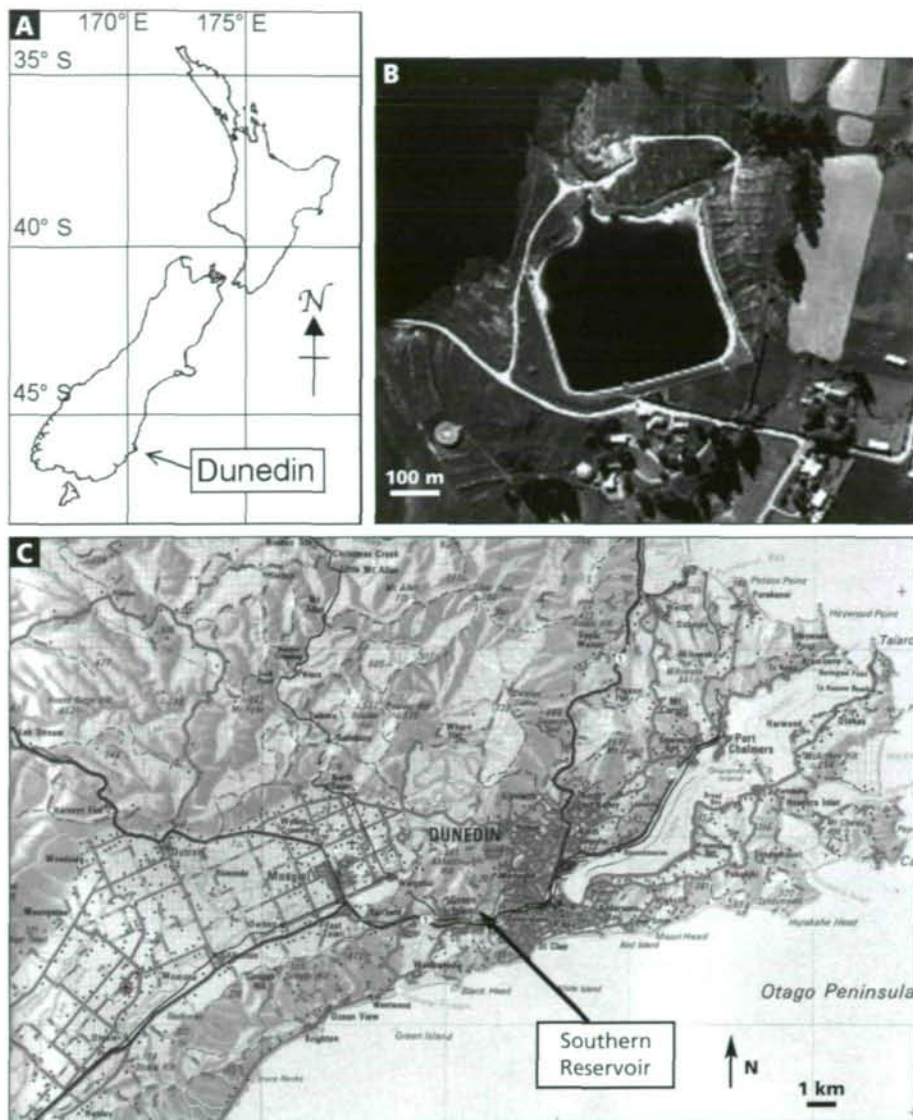


Fig. 1: Location of Southern Reservoir, Dunedin, New Zealand. **A:** New Zealand. **B:** Southern Reservoir from the air. **C:** Southern Reservoir in Dunedin.

term monitoring of the bryozoan populations in the microtrainer hall at Southern Reservoir is essential to understanding growth and development of these biofoulers. Effective management of the problem requires knowledge about when bryozoan colonies settle and begin development, how fast they grow, and when to expect the die-off which causes so many problems. Monitoring over several years also allows investigation of the environmental factors which may affect timing of freshwater bryozoan life cycles at Southern Reservoir.

Methods

On 14 November 2000, a monitoring programme was initiated to describe growth and development of freshwater bryozoans in the microtrainer hall at Southern Reser-

voir, Dunedin. Six settling plates were installed in each of the intake and outflow channels at the microtrainer hall at Southern Reservoir. On 29 November 2000, an additional six plates were installed in a microtrainer chamber, along with a wall-mounted quadrat.

Each settling plate was a 25 x 25 cm square sheet of white PVC plastic with holes drilled in the corners and a number burned into one side. Three plates were tied in a stack using strong cord with a small lead weight at the bottom (Fig. 4A). Each stack of plates was tied to an access ladder and suspended in the water (Fig. 4B). The top plate was immersed about 20 cm, the middle one about 50 cm, and the bottom one about 80 cm below the water surface. At each of the three sites (intake, chamber, and outflow), two stacks of plates were used. One stack was scraped clean each time it was observed, and the other was left to develop all season.

Settling plates were photographed and observed monthly (fortnightly or weekly during periods of rapid growth) during the first year. Both the upper side and the under side of each plate was photographed and described. Percentage cover by bryozoans was visually estimated. Growth on the chamber walls was also recorded. When bryozoan cover was greater than 90 %, the length of bryozoans hanging from the plate was measured (Fig. 4C).

On 29 March 2001 the microtrainer hall was drained for routine waterblasting and maintenance. Bryozoan material was collected from the walls of the microtrainer chambers. Blotted wet weights of bryozoans from a measured area were taken and coverage weights calculated. After maintenance was completed and refilling of the chamber occurred on 11 April 2001, all bryozoan colonies on the settling plates were found to be dead, presumably due to drying out.

A scaled-down monitoring programme was continued in 2002 and 2003. Six settling plates were monitored as before at the only site where bryozoans had grown in 2001: the microtrainer chamber. No plates were cleaned between visits this time. Monitoring was completed on 2 June 2004.

Over the same 4.5 years, water quality measurements were taken almost daily (1585 days of the 1643 between 1 Jan 2000 and 30 June 2004; 97 % of days) by Dunedin City Council Water Department staff. Measured included water temperature, pH, and turbidity.

Results

In total, 69 visits were made to Southern Reservoir in the 44 months between November 2000 and June 2004. General observations made each visit are listed in Table 1. Percent coverage on tops and bottoms of the settling plates ranged from zero in the winter to 100 % in late summer (Tab. 2). A total of 1300 photos were taken to document growth and development.

At the inlet channel site, where water velocity was greatest, there was no bryozoan growth on settling plates until April 2001, at which time coverage with tiny colonies and statoblasts was only 5-10 % (Fig. 4). The outlet channel site was similarly barren until mid-February 2001, when small colonies of *Paludicella articulata* occurred on the top sides of plates. Coverage remained at about 5 % until mid-March when the undersides of the plates began to show small colonies of *Plumatella repens*, and upper surfaces were covered up to 15 % by *Paludicella articulata*. At both these sites, growth of bryozoans on the settling plates was much less than that observed on the channel walls.

In contrast, growth and development in the microtrainer chamber was similar to that on the walls. A brown biofilm developed first on the plates, followed in December 2000 by the settlement of statoblasts of *Plumatella repens* on the undersides of the plates. Worm-shaped larval cases of insects appeared, and by late February 2001 the plates were nearly covered with bryozoans. *Plumatella repens* covered the undersides of the plates, while *Paludicella articulata* was found only on the upper sides. Bryozoan coverage reached its peak in March 2001, with bryozoan density reaching 90-100 %, and *Plumatella repens* beginning to grow over onto the upper sides of the plates.

In the following years, bryozoan settlement and development in the microtrainer

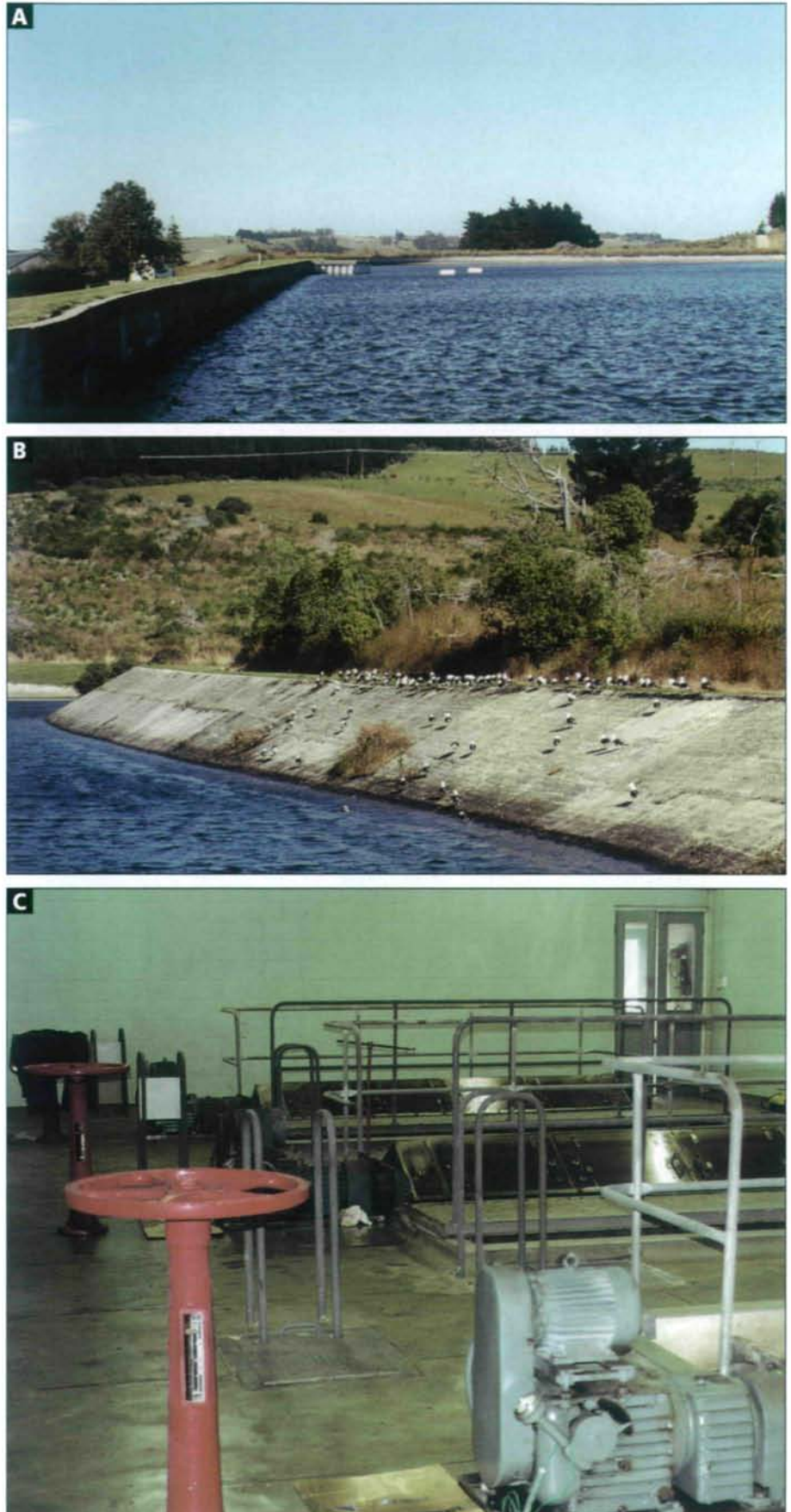


Fig. 2: Southern Reservoir, Dunedin, New Zealand. **A:** View to the west. **B:** Concrete lined walls. **C:** Inside the microtrainer hall.

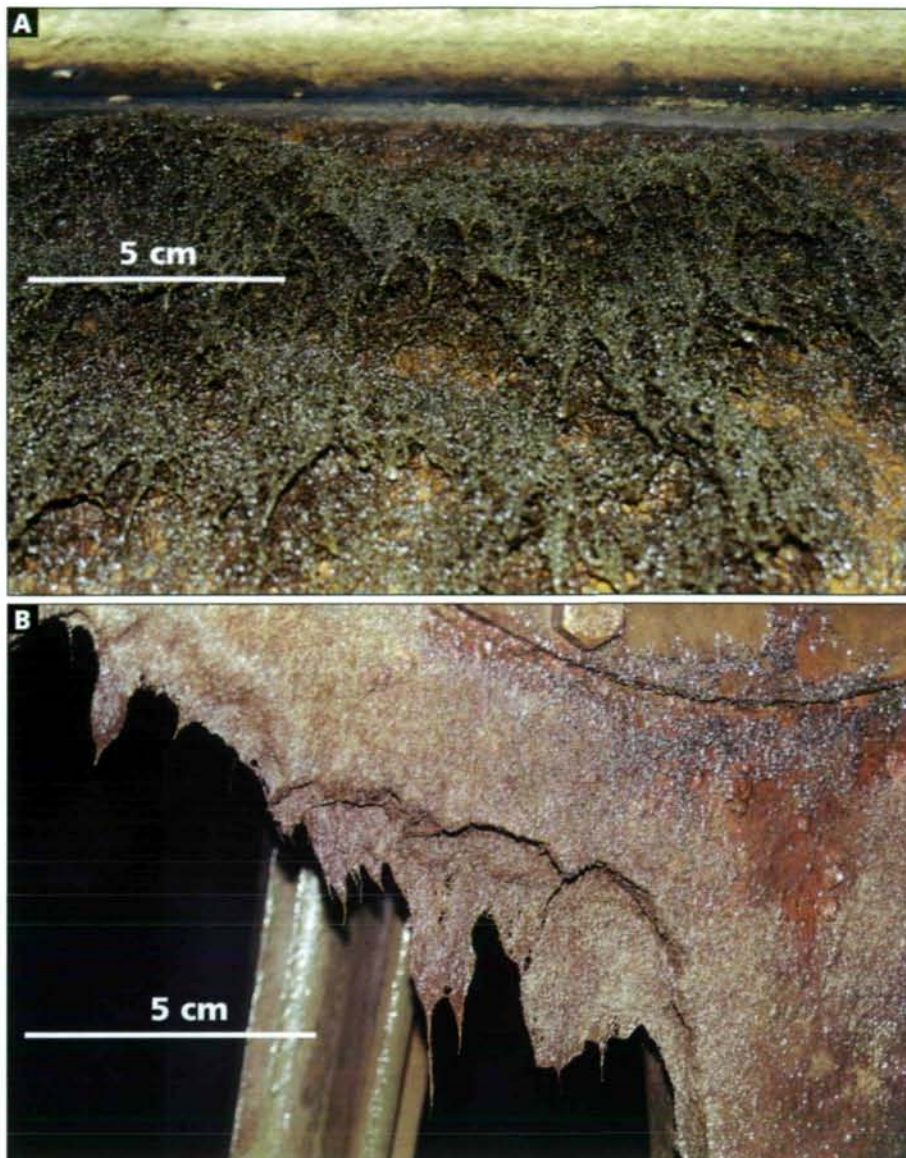


Fig. 3: Degree of infestation by freshwater bryozoans of Southern Reservoir water treatment station. **A:** *Plumatella repens* on the wall of a microstrainer chamber. **B:** *Paludicella articulata* on a wall bracket.

chamber followed a similar pattern. Bryozoans began settling and growing on settling plates in spring, that is, mid to late October (Fig. 6). Coverage of the plates increased in a fairly linear way until almost all space available was occupied (90-100 % coverage). In 2001 and 2002, maximum coverage was reached in March, but in 2003 and 2004, it was reached in February. This late-summer coverage was duplicated on the walls of the microstrainer tanks. Death occurred in May (late autumn) each year, though there was sometimes still some dead bryozoan material remaining on the plates. While this overall pattern was exhibited by both *Paludicella articulata* on the upper sides of the plates and *Plumatella repens* on the undersides, *Plumatella* seemed to grow more variably (Fig. 6).

A large colony of *Paludicella articulata* grew 7 cm (radially) on a settling plate after 60 days, a mean growth rate of 0.6 mm/day. *Plumatella repens* reached 12 cm in 42 days, a radial growth rate of 1.4 mm/day.

Microstrainer walls with a "typical" density of bryozoans (as measured on 29 March 2001) were found to contain 1.4 kg bryozoan material/m². In an area with maximum density, bryozoan coverage was 4.2 kg/m². Calculation of the surface area of the under-water microstrainer chambers, including inlet and outlet channels, gives about 388 m² available for colonization (Tab. 3). At average densities, this would translate to 543 kg of bryozoan material; at maximum densities 1629 kg of bryozoan material could be produced.

The "tideline" of statoblasts (and perhaps some hibernacula) found throughout the microstrainer hall (see Fig. 3E) was 10 cm wide and 3 mm thick, and about 60 m long. There is thus about 18,000 cm³ (18 litres) of statoblast material available for recolonisation in the microstrainer chambers alone.

Water temperature varied from 4 to 6 °C in winter, and from 14 to 18 °C in summer, with an overall mean of 11 °C (Fig. 7A). The pH of water varied from 6.3 to 8.5 with a mean of 7.3. High pH values tended to occur in summer (Fig. 7B), though the cycles are not strictly annual. Turbidity was generally low, with a mean of 1.4 ntu and a minimum of 0.5 ntu. One large turbidity event in winter of 2002 reached 5 ntu, but in general turbidity remained below 2.5 ntu (Fig. 7C).

Discussion

No one has ever closely monitored a freshwater bryozoan population for several years. The advantage of studying a fouling population on artificial substrate is that many natural disturbances are avoided, and detailed water quality measurements are available. Conclusions reached from a "captive" population, however, may not apply to natural populations.

The two species at Southern Reservoir exhibit marked ecological partitioning. Pa-

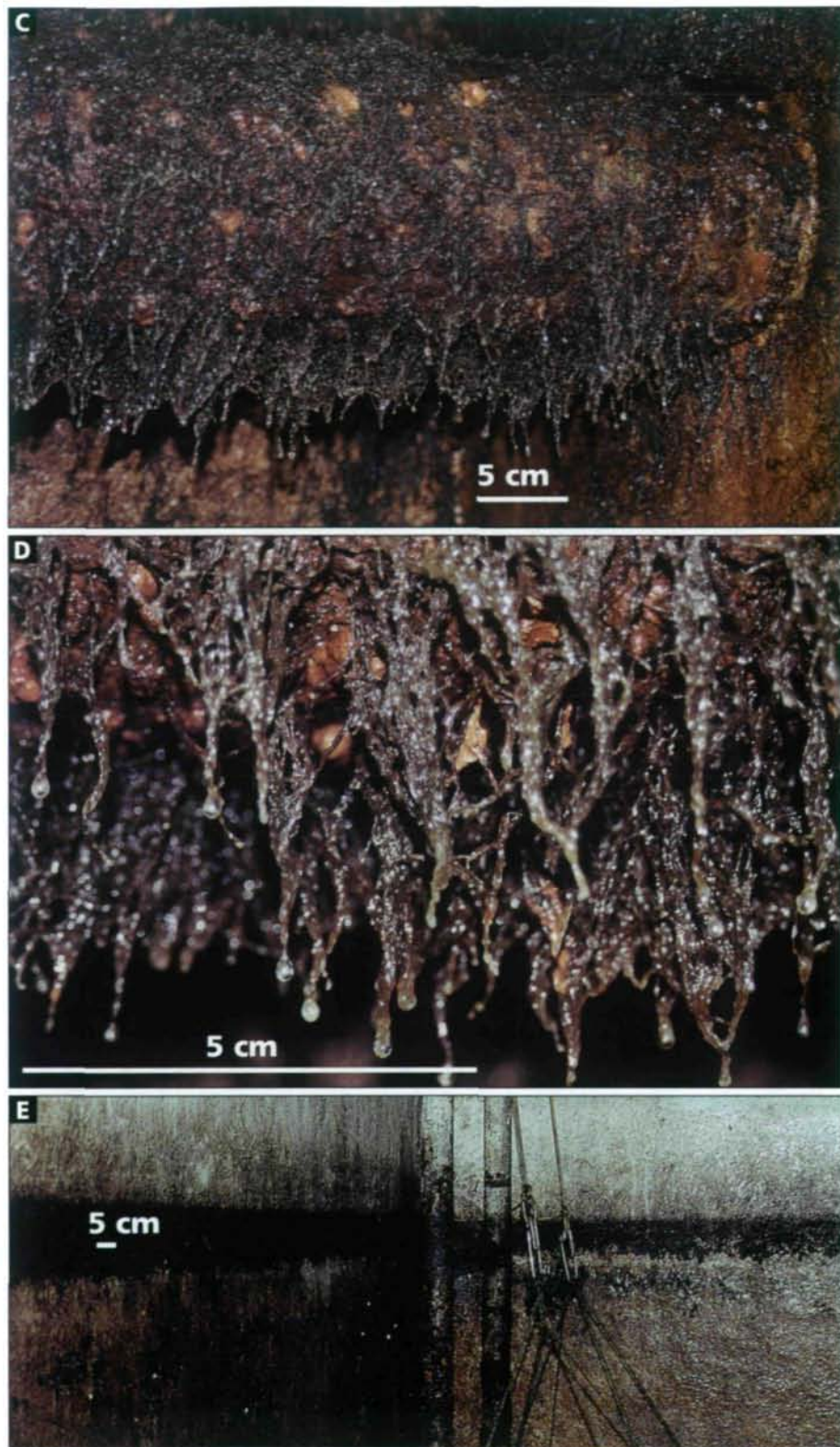
ludicella articulata, which only grows on upper surfaces, exhibits linear seasonal growth. *Plumatella repens*, in contrast, grows mainly on under surfaces, and tends to grow rapidly when conditions are favourable. In some years there was more variability in *Plumatella* coverage over the summer months than that of *Paludicella* (see Fig. 6).

Plumatella repens is a widespread bryozoan, known from all over the world. It has been recorded from tropical to temperate latitudes in both hemispheres, including Hawaii (BAILY-BROCK & HAYWARD 1984), Europe (KAMINSKI 1984; TATICCHI 1989; WÖSS 1996), North America (RICCIARDI & REISWIG 1994), New Zealand (WOOD et al. 1998), Chile (ORELLANA 2003) and elsewhere. It and other phylactolaemate bryozoans (such as *Plumatella emarginata*) are widespread in New Zealand (WOOD et al. 1998; SMITH & BATSON this volume).

In contrast, *Paludicella articulata* is the only freshwater bryozoan in the class Gymnolaemata found in New Zealand (GORDON 1999). It is primarily found in cold temperate northern environments, such as Quebec, Canada (RICCIARDI & LEWIS 1991), Poland (KAMINSKI 1984) and northern Norway (ØKLAND & ØKLAND 2000). We know of no southern hemisphere records for this species.

In New Zealand, *Paludicella* has been reported only from two sites in Dunedin, both of which are water supply reservoirs. About 100 years ago this bryozoan was observed growing profusely in the public water system draining Ross Creek Reservoir (HAMILTON 1902). Almost a century later, WOOD et al. (1998) did not locate any *Paludicella* colonies at Ross Creek in 1995, and SMITH & BATSON (this volume) report none present in their extensive 2002 survey. Meanwhile, *P. articulata* was found at Southern Reservoir by WOOD et al. (1998) in 1995, and fouling in the microstrainer hall began to cause problems in 1996.

The timing and occurrence of *P. articulata* suggests that it may have been accidentally imported into Dunedin about 1900, perhaps in the form of hibernacula glued to piping or other water treatment equipment. Subsequently, equipment used at Ross Creek



may have been involved in the newer Southern Reservoir, thus transferring *P. articulata* to a new environment. Because it is not native to the southern hemisphere, the immigrant bryozoan may not be able to persist under extreme conditions, which may have eliminated the population at Ross Creek.

Fig. 3: Degree of infestation by freshwater bryozoans of Southern Reservoir water treatment station. **C:** *Plumatella repens* draped over a pipe. **D:** Close up of *Plumatella repens*. **E:** "Tide line" of statoblasts (and possibly hibernacula) at water level in the microstrainer chamber.

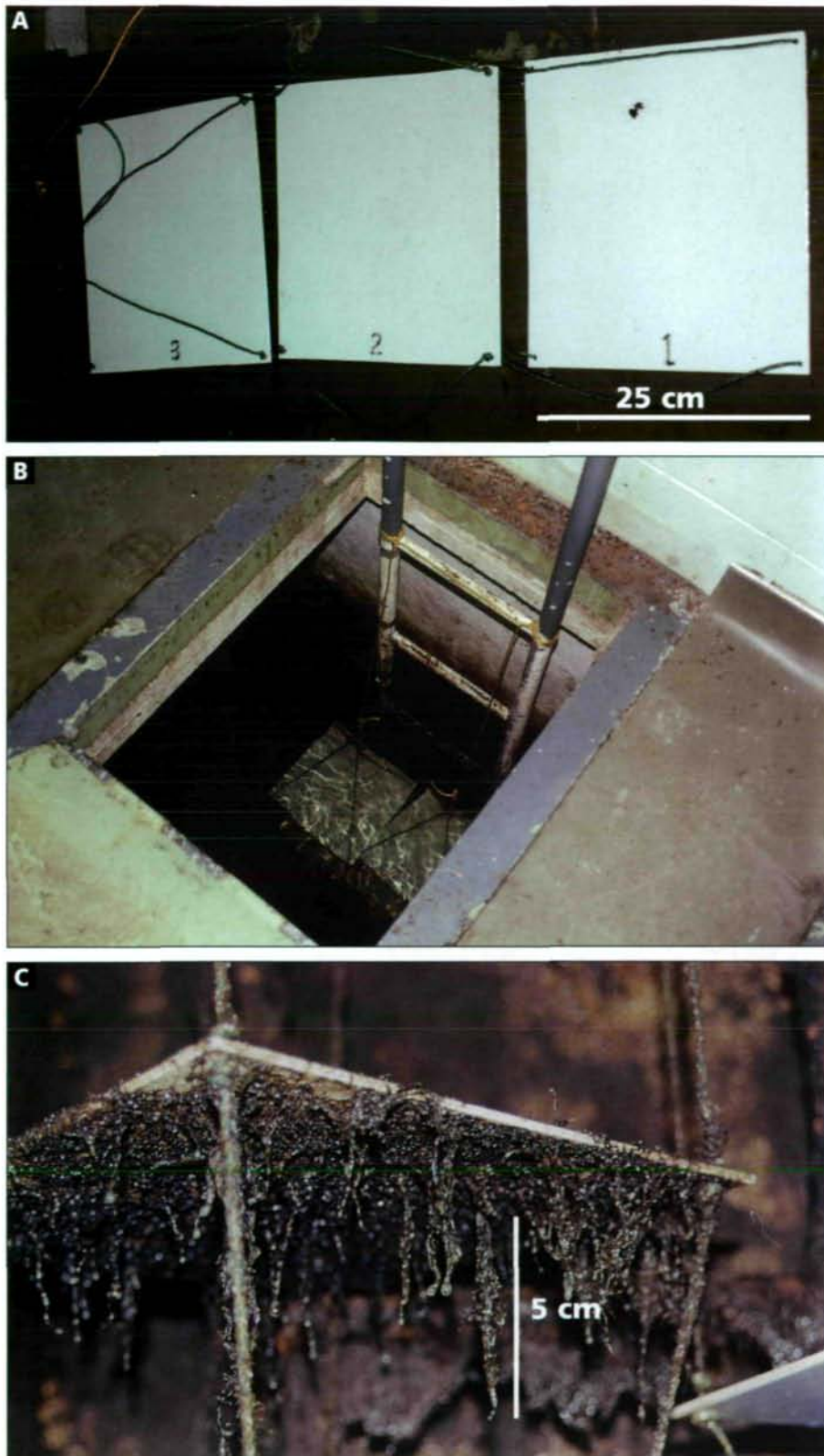


Fig. 4: Settling plates used in monitoring freshwater bryozoans at Southern Reservoir, Dunedin.
A: Stack of three plates, each 25 x 25 cm.
B: Plates immersed in microstrainer chamber. **C:** Measurement of colony length of *Plumatella repens* on undersides of plates during peak infestation.

The benign and consistent conditions of the Southern Reservoir treatment halls may provide just the environment necessary for this potential invader to flourish.

Alternatively, it is possible that *P. articulata* may grow in the southern hemisphere

and remain undetected. There are very few freshwater bryozoologists, and they work and study predominantly in Europe and North America. *Paludicella* is a cryptic organism, and is easily overlooked. Surveys of freshwater bryozoans around the southern hemisphere are few (but see ORELLANA 2003). A genetic study comparing *P. articulata* from the northern hemisphere with the Southern Reservoir population is on-going at the University of Otago, and may provide the data necessary to resolve the bryozoan's origin.

Patterns of settlement and growth in both *P. articulata* and *Plumatella repens* (Fig. 6) are most similar to variations in temperature (Fig. 7). Although there is no particular linear trend when plate coverage is compared with water temperature (Fig. 8), there is a 'cut-off' temperature of about 9 °C for both species. Settlement and growth by freshwater bryozoans at Southern Reservoir cease at water temperatures colder than 9 °C. Natural populations of *Paludicella articulata* tolerate temperatures of 9 to 23 °C (ØKLAND & ØKLAND 2000), but *Plumatella repens* has been found to tolerate a much wider range: 5 to 37 °C (BUSHNELL 1966). At Southern Reservoir, however, *Plumatella* was never found alive at temperatures lower than 9 °C.

During the seven months in which they are growing, the bryozoans produce a great deal of material. Between 500 and 1600 kg of bryozoan material was produced each year in the microstrainer hall at Southern Reservoir, at a mean rate of 2.4 to 7.5 kg/day during the growing season. Highest production occurs during the warmest months. Rapid elongation immediately post-settlement (up to 1.4 mm/day in *Plumatella repens*) allows bryozoan colonies to cover the entire area available during periods with favourable conditions.

Prior to 1996, both species of bryozoans were found at Southern Reservoir (WOOD et al. 1998), but there were no problems with biofouling (and no water quality data were routinely collected). What change occurred to allow proliferation of these bryozoans? Both are tolerant of a wide range of environmental factors (Tab. 4), though drying and disturbance can be lethal.

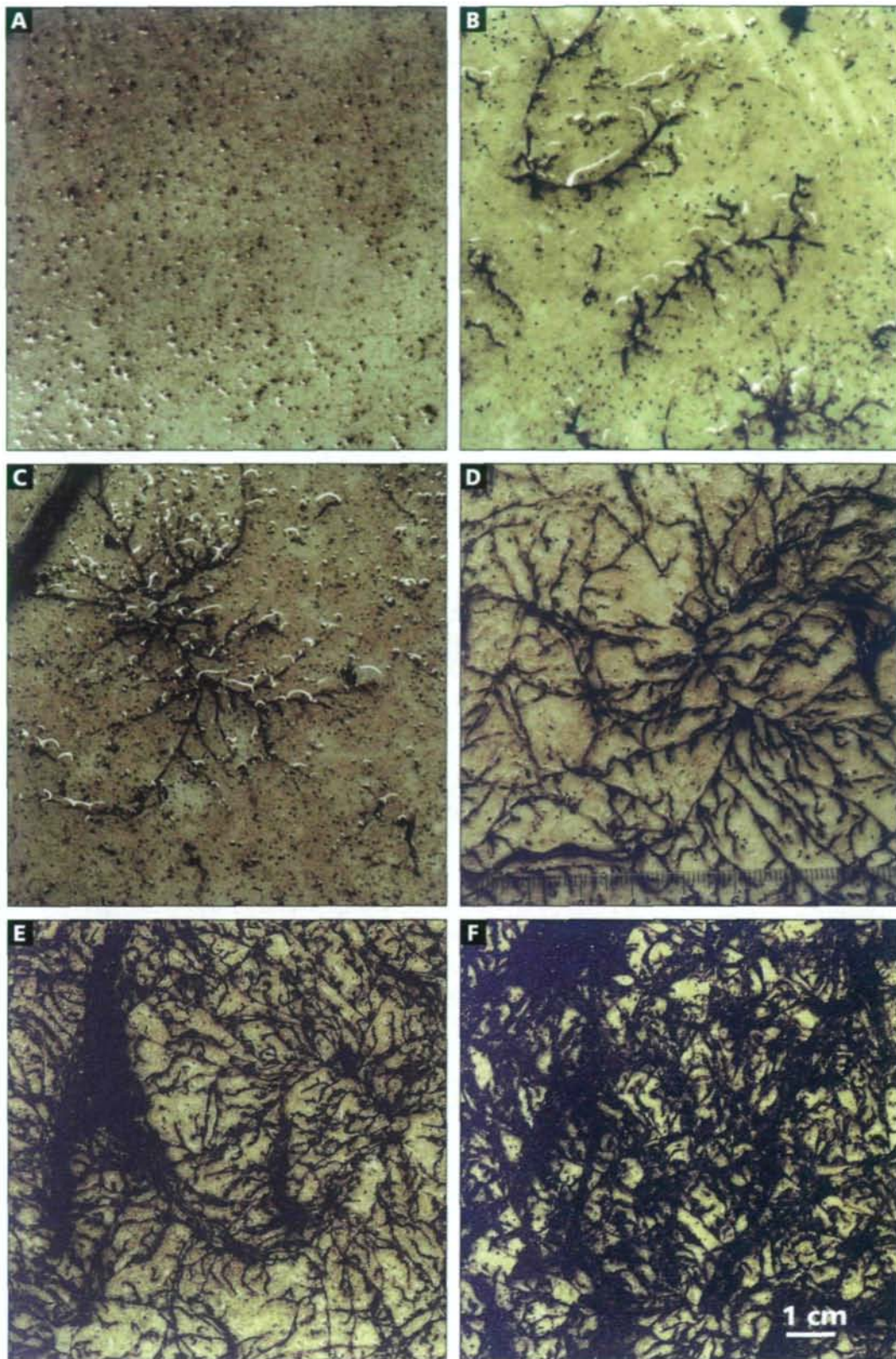


Fig. 5: Growth and development of *Plumatella repens* on the underside of plate 15, microstrainer chamber, Southern Reservoir, Dunedin. **A:** 17 January 2001, statoblasts. **B:** 24 January 2001, small colonies. **C:** 7 February 2001, larger colonies. **D:** 28 February 2001, large colonies coalesce. **E:** 7 March 2001, three-dimensional growth. **F:** 28 March 2001, dense thick mat.

Sometime in 1996-1997, the conifer forest around Southern Reservoir was logged. While some forest remains (Fig. 9), the immediate area surrounding the Reservoir has been cleared. As a consequence, the Reservoir is now more open to the sun, and pre-

sumably supports a greater population of photosynthetic micro-organisms, which may serve as food for bryozoans. Nutrient run-off into the reservoir, too, may have increased due to land clearance. Conifer needles are quite acidic, and removal of the trees

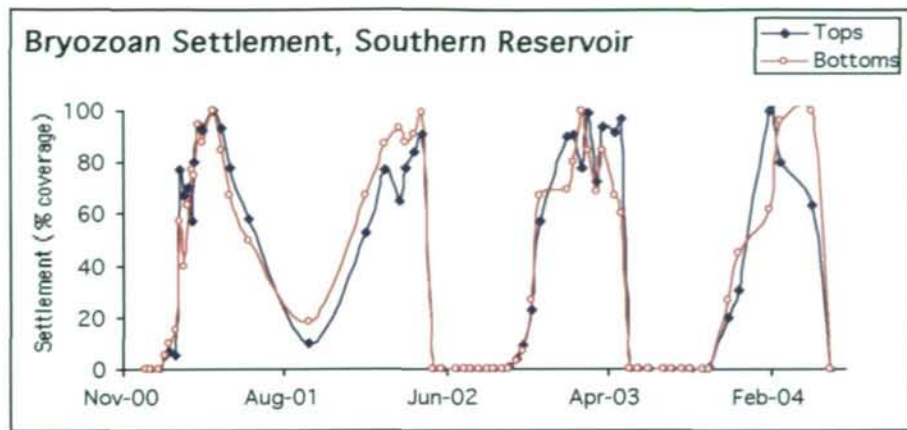


Fig. 6: Patterns of growth and development of freshwater bryozoans at Southern Reservoir, Dunedin over 44 months (November 2000 to June 2004). *Plumatella repens* is found only on the undersides of plates; *Paludicella articulata* dominates the upper sides.

may have allowed the pH of the reservoir to increase enough to allow freshwater bryozoans to thrive. *Plumatella* prefers pH above 7, and *Paludicella* above 6, so a lowered pH could have inhibited their growth and/or settlement. Unfortunately, city records are sparse, and are unable to allow these theories to be supported or refuted.

There are four possible approaches to biofouling problems of this nature: attempts at total eradication, control of adults, control of resting stages, and prevention of further infestation. Given the hardiness and persistence of hibernacula and statoblasts, as well as the cryptic nature of adult colonies, total eradication is impossible. It is likely, however, given experience prior to 1996, that low population densities of freshwater bryozoans do not pose an operational problem. Clogging and filter damage only occur when large clumps of material detach from walls and pipes. Effective control need only keep growth to pre-1996 levels to limit effects on water delivery systems. Killing large colonies will not be effective, as the dead colonies will detach and clog filters. Control must be directed at reducing settlement and growth of young colonies.

Physical removal of colonies by water-blasting and scrubbing occurs at Southern Reservoir, and removes much of the colonial material before it dies and is released into the filters. This method is highly work-intensive and access to all surfaces can be difficult. The data gathered here suggests that physical removal strategies should be concentrated in late summer to early autumn, before water temperatures decrease to 9 °C, so that colonies are large but not yet dead.

Many chemical treatments will kill bryozoans, but most are not allowable in drinking water. The infested areas of microstrainers and associated piping carry untreated water to the chemical treatment facility – bryozoans do not occur in water pipes carrying chlorinated water. Short-term treatments such as desiccation, sonication, and acidification would all discourage growth by bryozoans, but would still allow hibernacula and statoblasts to recolonise the chambers afterwards. An attempt to manage bryozoan biofouling over the next 10 years at Southern Reservoir is to move chemical treatment of drinking water closer to the Reservoir, eliminating the long pipes and large chambers housing untreated water which provide ideal habitat for freshwater bryozoans.

Finally it is necessary to avoid contamination of any additional sites – and there are several other reservoirs in the Dunedin area which could host huge populations of freshwater bryozoans (Smith & Batson this volume). Precautions will be necessary to ensure that equipment, gear, and clothing from Southern Reservoir is thoroughly treated before being used in any other water body.

Experience with other biofoulers suggests that control often requires several different methods over an extended period. Effective biofouling management is an on-going process, requiring active monitoring and carefully designed response procedures, which may vary over seasons or years. The results from this and other studies allow water treatment managers to design control strategies and establish management procedures. Knowledge of settlement and development patterns, growth and production rates, and contributing environmental factors inform that process and promote a responsible but effective solution.

Summary and conclusions

Plumatella repens and *Paludicella articulata* are freshwater bryozoans which cause a major fouling problem at Southern Reservoir, Dunedin, New Zealand. They exhibit ecological partitioning such that *Paludicella* grows on upper surfaces and *Plumatella* on under surfaces. Both species have an annual growth cycle, settling in October, thriving

during the summer months, and dying off in about May. Settlement occurs when water temperatures are greater than 9 °C, and colonies die when water temperatures cool below 9 °C. During the 7 months in which they are growing, bryozoans produce 500 to 1600 kg of material in the microtrainer chambers, at a mean rate of 2.5 to 7 kg/day. Highest production occurs during the warmest months. Resting stages (statoblasts and hibernacula) accumulate along the walls of the chambers; there may be as much as 18 litres of these microscopic propagules in the three microtrainer chambers and associated channels. Bryozoans have only grown at this prolific rate since 1996, which may be related to forest clearance increasing light, nutrient and pH levels. Control of infestation by freshwater bryozoans should focus on limiting and preventing settlement in springtime, as well as avoiding contamination of uninfested sites.

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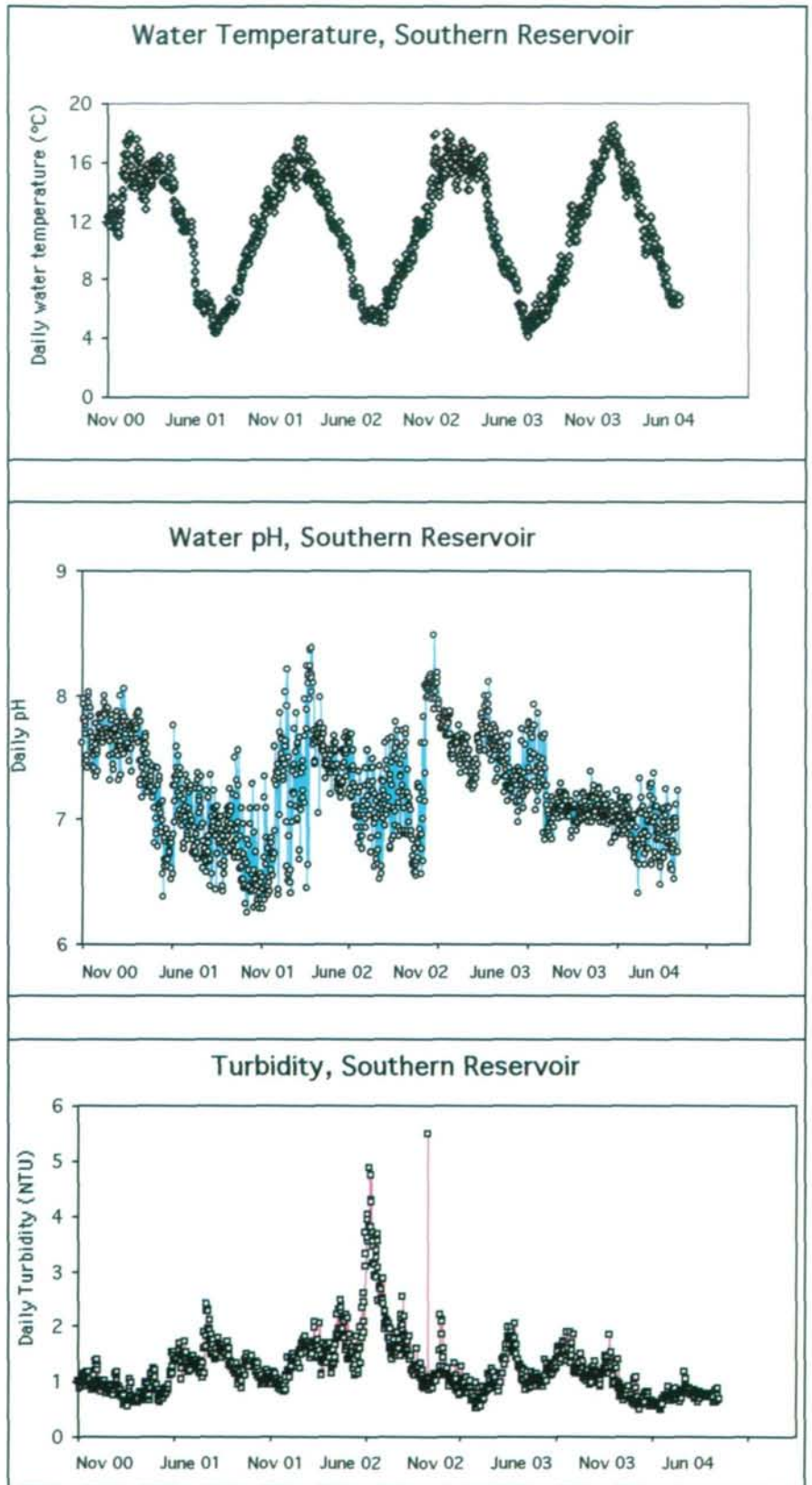


Fig. 7: Measurements of water quality at Southern Reservoir over 4.5 years (November 2000 to June 2004). **A:** Temperature. **B:** pH. **C:** Turbidity.

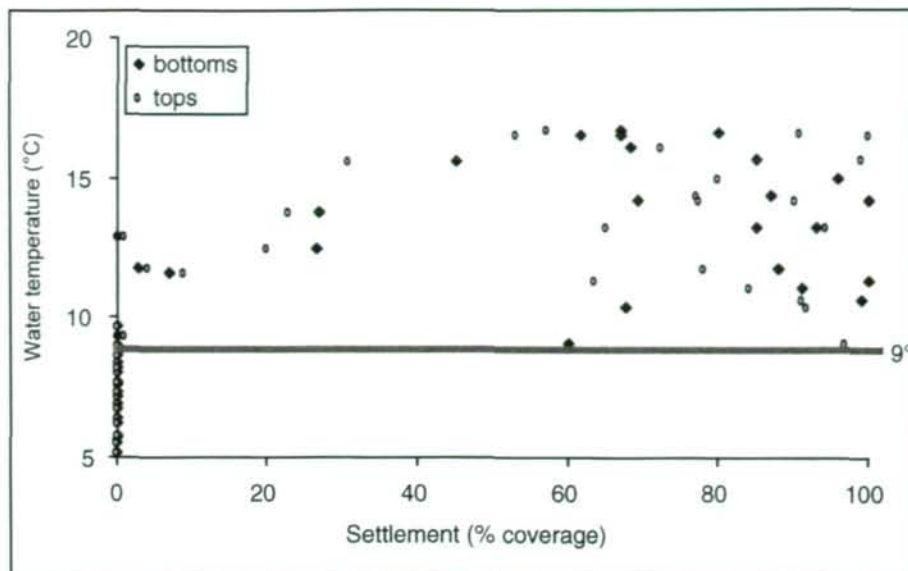


Fig. 8: Bryozoan coverage of settling plates relative to water temperature.

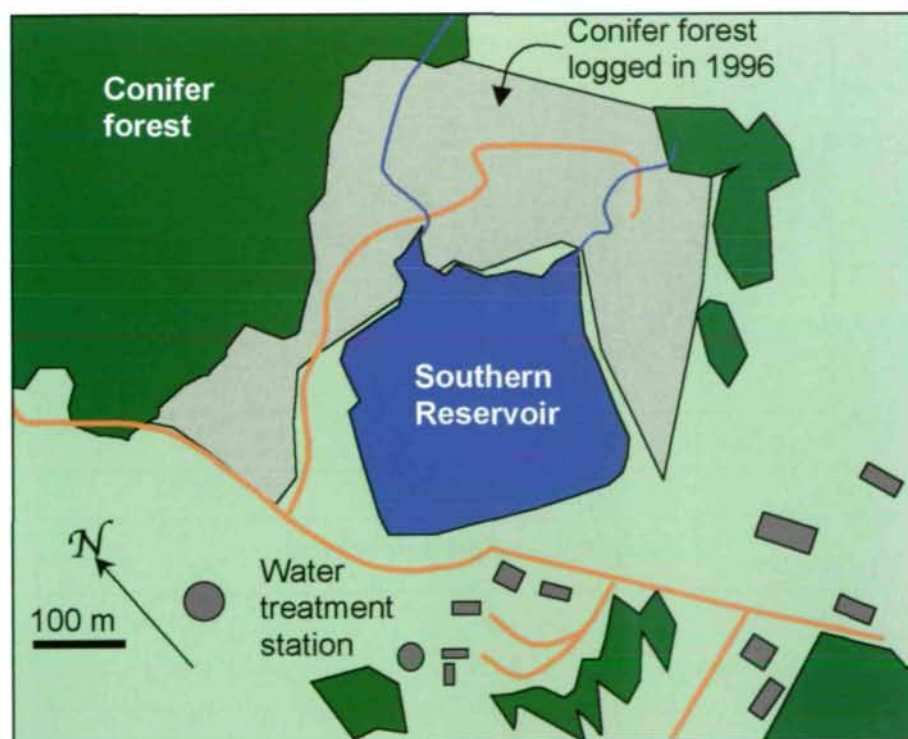


Fig. 9: Southern Reservoir, modified from an aerial photo taken in December 1999, showing extent of forest logged in 1996 (hashed area).

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Tab. 1: Actions and observations at Southern Reservoir, November 2000 to June 2004.

Date	Comment	Photos taken
14-Nov-00	Installed 4x3 settling plates at inlet and outlet sites	0
22-Nov-00	Plates with brown film, no colonies	6
29-Nov-00	Plates with brown film, no colonies, installed wall bracket on waterblasted wall, also 2x3 settling plates at microstrainer tank (MS)	18
13-Dec-00	Plates with brown film, undersides have black "dots"	17
20-Dec-00	Plates with brown film, undersides have black "dots," also larval cases ("worms")	20
6-Jan-01	Plates with thick brown film, black "dots," larval cases ("worms") a few filaments on undersides of plates from MS site, <i>Plumatella</i> abundant on walls, beginning to grow in wall bracket	19
17-Jan-01	Plates with brown film, undersides have black "dots," also larval cases ("worms") one set of plates broken, removed colonies found on undersides of MS site plates <i>Plumatella</i> abundant on walls, beginning to grow in wall bracket	24
24-Jan-01	Plates with brown film, undersides have black "dots," also larval cases ("worms") quite a few small colonies on undersides of plates at MS site	32
7-Feb-01	Plates with thick brown film, black "dots," larval cases ("worms") 10-30 % cover of small <i>Plumatella</i> on undersides of plates from MS site <i>Plumatella</i> abundant on walls of MS tanks	36
14-Feb-01	Installed 1x3 settling plates at inlet site (to replace broken ones) plates with thick brown film, black "dots" at intake site 30-50 % cover of <i>Paludicella</i> on top sides of plates from MS site 50-60 % cover of <i>Plumatella</i> on undersides of plates from MS site one or two tiny <i>Paludicella</i> colonies on topsides of plates from outlet site; <i>Plumatella</i> abundant on walls of MS tanks	50
21-Feb-01	Plates with thick brown film, black "dots" at intake and outlet sites 60-80 % cover of <i>Paludicella</i> on top sides of plates from MS site 40-60 % cover of <i>Plumatella</i> on undersides of plates from MS site wall <i>Plumatella</i> began to clog pipes and filters the inlet chamber was scoured	50
28-Feb-01	Plates with thick brown film, black "dots" at intake and outlet sites 60-80 % cover of <i>Paludicella</i> on top sides of plates from MS site, one or two <i>Plumatella</i> colonies 60-70 % cover of <i>Plumatella</i> on undersides of plates from MS site, one or two <i>Paludicella</i> colonies sampled several buckets of material for detailed identification	40
7-Mar-01	Plates with brown film, no colonies at intake site 60-80 % cover of <i>Paludicella</i> on top sides of plates from MS site, one or two <i>Plumatella</i> colonies 70-80 % cover of <i>Plumatella</i> on undersides of plates from MS site one or two tiny <i>Paludicella</i> colonies on topsides of plates from outlet site abundant statoblasts on undersides of plates from outlet site	42
14-Mar-01	Plates with brown film, no colonies at intake site 70-90 % cover of <i>Paludicella</i> on top sides of plates from MS site, one or two <i>Plumatella</i> colonies 70-80 % cover of <i>Plumatella</i> on undersides of plates from MS site 5-10 % cover of <i>Paludicella</i> on top sides of plates from outlet site <i>Plumatella</i> statoblasts have sprouted on undersides of plates from outlet site	54
21-Mar-01	Plates with brown film, no colonies at intake site 90-100 % cover of <i>Paludicella</i> on top sides of plates from MS site, one or two <i>Plumatella</i> colonies 90-100 % cover of <i>Plumatella</i> on undersides of plates from MS site 5-10 % cover of <i>Paludicella</i> on top sides of plates from outlet site 5-10 % cover of <i>Plumatella</i> on undersides of plates from outlet site	36
28-Mar-01	Plates with brown film, no colonies at intake site 90-100 % cover of <i>Paludicella</i> on top sides of plates from MS site, one or two <i>Plumatella</i> colonies 90-100 % cover of <i>Plumatella</i> on undersides of plates from MS site 5-15 % cover of <i>Paludicella</i> on top sides of plates from outlet site 5-10 % cover of <i>Plumatella</i> on undersides of plates from outlet site	37
29-Mar-01	Microstrainer hall drained for waterblasting Photographs and measurements taken	36
11-Apr-01	Microstrainer hall tanks refilled	
18-Apr-01	All bryozoans dead from drying, no evidence of growth	38
2-May-01	Dead bryozoans covered with biofilm, no new growth	37
16-May-01	Dead bryozoans covered with biofilm, no new growth	37
20-Jun-01	Dead bryozoans covered with biofilm, no new growth	37
10-Oct-01	Dead bryozoans covered with biofilm, no new growth Removed plates from intake and outlet Scraped plates in MS site completely clear	7
14-Nov-01	Plates with brown film, tiny colonies, black dots on top side Plates with thick brown film, black dots, and tiny colonies on underside Photos of emptied microstrainer chamber #3	30
24-Jan-02	Plates with small colonies Ropes and walls covered with <i>Paludicella</i>	18

Tab. 1: continued.

Date	Comment	Photos taken
5-Feb-02	Plates with larger colonies, mostly over 50 % coverage	0
27-Feb-02	Many medium <i>Paludicella</i> on top sides thick cover of <i>Plumatella</i> (5-7 cm long) on bottom sides	0
6-Mar-02	Greater than 50 % cover of <i>Paludicella</i> on top sides 85-95 % cover of <i>Plumatella</i> (5-7 cm long) on bottom sides	0
27-Mar-02	Many <i>Paludicella</i> colonies growing on tops <i>Plumatella</i> thick and long on bottoms	21
10-Apr-02	Many medium <i>Paludicella</i> on tops, a few <i>Plumatella</i> extensive growth of large <i>Plumatella</i> on bottoms	28
24-Apr-02	Mostly dead <i>Paludicella</i> on top sides of plates dead and dying <i>Plumatella</i> (5-7 cm long) on bottom sides	21
8-May-02	Dead <i>Paludicella</i> on top sides dead <i>Plumatella</i> on bottom sides, many black dots	20
29-May-02	MS2 being cleaned, all plates scraped and replaced in MS1	0
12-Jun-02	Traces of biofilm, a few black dots All colonies on the ropes or weights are dead	0
10-Jul-02	Thick biofilm on tops and bottoms, dots on bottoms no growth, no colonies on walls	14
24-Jul-02	Thick biofilm on tops, no colonies thin biofilm plus 1-2 tiny colonies on bottoms no growth, no colonies on walls	14
7-Aug-02	Thick biofilm on tops, no colonies thin biofilm plus 1-2 tiny colonies on bottoms no growth, no colonies on walls	14
21-Aug-02	Thick biofilm on tops, no colonies thin biofilm plus 1-2 tiny colonies on bottoms no growth, no colonies on walls	14
6-Sep-02	Plates moved to MS2 (not sure exact date) thick biofilm on tops, 2-3 small colonies of <i>Paludicella</i> thin biofilm on bottoms	14
18-Sep-02	Thin biofilm on tops and bottoms, no colonies no growth, no colonies on walls	14
2-Oct-02	Thin biofilm on tops and bottoms, no colonies no growth, no colonies on walls	13
16-Oct-02	Plates moved back to MS1 (not sure exact date of transfer) thin biofilm on tops and bottoms, no colonies no growth, no colonies on walls	13
30-Oct-02	Plates moved back to MS2 (not sure exact date of transfer) thin biofilm on tops, a few small colonies of <i>Paludicella</i> no growth, no colonies on walls	14
13-Nov-02	Small <i>Paludicella</i> colonies growing on tops few small <i>Plumatella</i> colonies growing on bottoms	14
27-Nov-02	Moderate to dense growth of <i>Paludicella</i> on tops few small <i>Plumatella</i> colonies growing on bottoms walls have biofilm but no colonies yet	14
11-Dec-02	Plates moved to MS1 (not sure exact date) dense growth of <i>Paludicella</i> on tops moderate to dense growth of <i>Plumatella</i> on bottoms	14
30-Jan-03	Dense growth of <i>Paludicella</i> on tops moderate to dense growth of <i>Plumatella</i> on bottoms, some creeping over	15
11-Feb-03	Plates moved to MS3 (not sure exact date) dense and thick growth of <i>Paludicella</i> on tops moderate to dense growth of <i>Plumatella</i> on bottoms growth 5-6 cm on walls in microstrainers	17
26-Feb-03	Dense and thick growth of <i>Paludicella</i> on tops dense growth of <i>Plumatella</i> on bottoms	0
11-Mar-03	Dense and thick growth of <i>Paludicella</i> on tops dense growth of <i>Plumatella</i> on bottoms, up to 5 cm long	15
26-Mar-03	Some of the dense growth (top and bottom) is sloughing off (too heavy?) thick growth top and bottom	16
9-Apr-03	Dense growth of <i>Paludicella</i> on tops, but no longer thick (some has sloughed off) dense growth of <i>Plumatella</i> on bottoms, but not so long/thick	14

Tab. 1: continued.

Date	Comment	Photos taken
30-Apr-03	Plates moved back to MS2 (not sure exact date of transfer) dense growth of <i>Paludicella</i> on tops, thinning out, perhaps dead already <i>Plumatella</i> on bottoms also thinning, many statoblasts all microstrainers have recently been cleaned, no colonies to see	14
14-May-03	<i>Paludicella</i> dead and mostly gone, just attachment sites left <i>Plumatella</i> dead, thinning, many statoblasts	16
28-May-03	All dead leftovers, thinning	15
11-Jun-03	All dead leftovers, thinning	15
2-Jul-03	Scrubbed plates 13, 14, 15 completely clean for next season removed colonies from plates 16, 17, 18 but left the statoblasts	16
30-Jul-03	Plates moved to MS1 (not sure exact date) biofilm developing	17
13-Aug-03	Thin biofilm on tops and bottoms, dots on bottoms plates 16, 17, 18 have initial colonies beginning to emerge	14
2-Sep-03	Thick biofilm, no colonies top or bottom, no growth in microstrainers	14
17-Sep-03	Thick biofilm, no colonies top or bottom, no growth in microstrainers	15
10-Oct-03	Thick biofilm, no colonies top or bottom, no growth in microstrainers	14
22-Oct-03	Thick biofilm, no colonies top or bottom, no growth in microstrainers	15
26-Nov-03	Plates moved to MS2 (not sure exact date) thick biofilm on tops, a few small colonies of <i>Paludicella</i> thick biofilm on bottoms, a few very small colonies of <i>Plumatella</i>	17
17-Dec-03	Moderate growth of <i>Paludicella</i> on tops moderate growth of <i>Plumatella</i> on bottoms moderate to dense growth on walls of microstrainers	19
10-Feb-04	Every available surface covered with dense mats of <i>Paludicella</i> microstrainer walls 10-15 cm deep in <i>Paludicella</i> , ropes, floats, everything <i>Paludicella</i> is even growing over the old <i>Plumatella</i> colonies on bottoms	15
3-Mar-04	Dense thick growth of <i>Paludicella</i> on tops, ropes, walls, floats thin small colonies of <i>Plumatella</i> on bottoms	1
29-Apr-04	Dense thick growth of <i>Paludicella</i> on tops dense growth of <i>Plumatella</i> on bottoms, up to 7 cm long, some have sloughed off walls still fuzzy with 5-6 cm thick colonies	16
2-Jun-04	All dead	0
69 visits		1300 photos

Tab. 2: Coverage of settling plates at Southern Reservoir by freshwater bryozoans from December 2000 to December 2002. Plates 16, 17, and 18 were cleaned after every visit until January 2002, so are not comparable until after that date. *Paludicella articulata* was always found only on the tops of the plates, and *Plumatella repens* was found mostly on the bottoms, only occurring on the tops when growth was extremely dense.

Date	Tops of plates							Bottoms of plates						
	13	14	15	16	17	18	Mean	13	14	15	16	17	18	Mean
13-Dec-00	0	0	0				0	0	0	0				0
20-Dec-00	0	0	0				0	0	0	0				0
6-Jan-01	0	0	0				0	0	0	0				0
17-Jan-01	5	5	5				5	5	5	5				5
24-Jan-01	10	5	5				7	10	10	10				10
7-Feb-01	5	5	5				5	30	10	5				15
14-Feb-01	70	80	80				77	60	50	60				57
21-Feb-01	80	60	60				67	50	40	30				40
28-Feb-01	80	60	70				70	70	60	60				63
7-Mar-01	60	60	50				57	80	70	80				77
14-Mar-01	90	80	70				80	80	70	75				75
21-Mar-01	100	90	95				95	95	95	95				95
28-Mar-01	100	85	90				92	85	90	90				88
18-Apr-01	100	100	100				100	100	100	100				100
2-May-01	100	100	80				93	85	85	85				85
16-May-01	100	75	60				78	65	65	70				67
20-Jun-01	60	65	50				58	50	50	50				50
10-Oct-01	10	0	20				10	20	25	10				18
24-Jan-02	50	50	60	60	50	50	53	70	60	70	70	70	60	67
27-Feb-02	80	80	70	70	80	80	77	80	90	90	90	90	80	87
27-Mar-02	60	60	70	70	70	60	65	90	90	100	100	90	90	93
10-Apr-02	75	75	80	80	80	80	78	90	90	80	85	90	90	88
24-Apr-02	85	80	80	80	90	90	84	90	90	95	95	90	85	91
8-May-02	95	95	80	90	95	90	91	100	100	95	100	100	100	99
29-May-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Tab. 2: continued.

Date	Tops of plates							Bottoms of plates						
	13	14	15	16	17	18	Mean	13	14	15	16	17	18	Mean
12-Jun-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10-Jul-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24-Jul-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7-Aug-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21-Aug-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6-Sep-02	0	0	0	0	0	0	0	0	2	0	0	0	0	0
18-Sep-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Oct-02	0	0	0	2	0	0	0	0	0	0	0	0	0	0
16-Oct-02	0	0	0	3	0	0	1	0	0	0	0	0	0	0
30-Oct-02	5	2	5	5	5	2	4	2	2	2	5	2	2	3
13-Nov-02	10	10	15	5	10	5	9	5	5	5	5	10	10	7
27-Nov-02	20	30	50	10	15	15	23	30	30	20	20	30	30	27
11-Dec-02	70	50	50	50	60	60	57	70	70	60	70	60	70	67
30-Jan-03	90	95	95	90	85	85	90	65	75	80	50	65	80	69
11-Feb-03	100	90	95	100	80	80	91	75	80	85	75	80	85	80
26-Feb-03	95	100	95	100	35	40	78	100	100	100	100	100	100	100
11-Mar-03	100	100	95	100	100	100	99	80	90	95	80	85	80	85
26-Mar-03	85	80	80	60	70	60	73	50	60	70	70	80	80	68
9-Apr-03	100	95	95	95	90	90	94	70	80	90	70	100	100	85
30-Apr-03	95	90	95	95	85	90	92	40	60	70	60	90	85	68
14-May-03	95	95	100	95	95	100	97	40	50	50	60	80	80	60
28-May-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11-Jun-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Jul-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-Jul-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13-Aug-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Sep-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17-Sep-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10-Oct-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22-Oct-03	1	0	1	0	2	1	1	0	0	0	0	0	0	0
26-Nov-03	40	20	30	20	5	5	20	40	50	60	2	3	5	27
17-Dec-03	60	50	50	10	10	5	31	70	50	70	20	40	20	45
10-Feb-04	100	100	100	100	100	100	100	60	50	75	60	50	75	62
3-Mar-04	100	95	90	80	65	50	80	95	95	90	100	95	100	96
29-Apr-04	70	75	55	75	55	50	63	100	100	100	100	100	100	100
2-Jun-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Tab. 3: Potential size of bryozoan infestation in the microstrainer hall at Southern Reservoir, Dunedin, New Zealand, using average blotted wet weight of 1.4 kg/m² and maximum blotted wet weight of 4.2 kg/m².

	Internal Surface Area				Bryozoan density	
	Width (m)	Length (m)	Depth (m)	Surface area (m ²)	Average (kg bryoz.)	Maximum (kg bryoz.)
Microstrainer One	4.7	4.6	2.7	71.8	100.6	301.7
Microstrainer Two	4.7	4.6	2.7	71.8	100.6	301.7
Microstrainer Three	4.7	4.6	2.7	71.8	100.6	301.7
Inlet Channel	1.0	14.5	1.6	64.1	89.7	269.2
Inlet	1.2	4.7	2.8	38.3	53.7	161.0
Outlet Channel	1.0	14.5	1.1	49.8	69.8	209.3
Ladders, piping (approx)				20.0	28.0	84.0
Total				387.8	542.9	1628.7

Environmental factor	<i>Paludicella articulata</i>	<i>Plumatella repens</i>
Chemical		
Water temperature	9 – 23 °C	5 – 37 °C
Water hardness	0.15 – 10.2 mg/L	7.7 – 120 mg/L
Ca content	0.7 – 56.8 mg/l	unknown
Mg content	0 – 9.5 mg/l	unknown
Water pH	5.9 – 9.5	7.2 – 9.8
Salinity	7 – 292 µs/cm	unknown
Chlorine	killed by chlorination	killed by very high chlorination
Oxygenation	killed by anoxia	killed by anoxia
Water colour	wide tolerance	tolerates colour
Turbidity	prefers clear water	wide range tolerated
Light	avoids direct sunlight	prefers lower light
Physical		
Water velocity	prefers moving water	prefers moving water
Substratum	hard surfaces	hard surfaces
Disturbance	damaged but regrows	damaged but regrows
Drying	killed by drying	killed by drying
Biological		
Nutrient load	prefers oligotrophic	prefers eutrophic
Predation	eaten by fish, mollusks, insects	eaten by fish, insects, birds
Food source	chooses microorganisms	chooses microorganisms
Parasitism	probably some	probably some

Tab. 4: Reported tolerance ranges of adult colonies of *Paludicella articulata* and *Plumatella repens* to environmental factors (HARMER 1913; BUSHNELL 1966; TATICCHI 1989; RICCIARDI & REISWIG 1994; WOOD & MARSH 1999; ØKLAND & ØKLAND 2000).

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