Gunderboom Fouling Studies in Bowline Pond July 2001

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1. Introduction

The Gunderboom is a structure made from a geotextile matting that is hung as a curtain across a cooling water intake to stop the entrainment of planktonic animals, particularly fish eggs and larvae. Because power stations pump considerable volumes of water, and in order to be effective the Gunderboom must have a low flow per unit area, a Gunderboom curtain must offer a large surface area to the flow. Before any new structure can be introduced we need to consider if it will be effective in reducing entrainment and also ensure that it does not create other, as yet, unanticipated ecological impacts. There are a number of potential problems with respect to the use of Gunderbooms that are briefly described below. These problems are linked to the development of biofouling communities on the fabric, which is why the development of fouling and the effect on permeability is the subject of this report.

First, fouling of the surface might reduce the area through which water can flow leading to velocity 'hot spots' where delicate animals may be pinned or pulled through the mesh. There was clear evidence that fouling by macro-algae does occur. In the Lovett 1999 report it is stated "The airburst system was not effective at removing algal growth from the boom". Even if they are not pulled through the filter, there is the possibility that contact with a surface may be damaging to planktonic stages that are not adapted to withstand contact with any surface. This type of problem, whether it results from passage through the filter or simply contact, can be termed mesh damage.

A second effect of increased flow resistance is the tendency of water to force another path across or around the barrier. There are three alternative pathways available to the water. (i) The water may tunnel under the bottom of the boom by displacing the sand or mud sediments; (ii) The boom may be pulled underwater resulting in flow over the boom; and (iii) The material may rip resulting in a flow via holes. Overtopping, tunnelling and rips have been observed during testing. For example, in the Lovett evaluation report for 1999 it is stated that " the divers documented a substantial gap along the bottom of the boom …. the gap extended along the bottom of the boom for approximately 3 m and ranged in depth from 0.5 to 0.6 m" . Further, E. W. Radle in direct testimony for the Athens plant stated that -" establishing a complete seal may be difficult". However, the diver surveys in the Lovett 2000 report indicated that a good seal was maintained. The problem of water not flowing through the barrier is termed mesh avoidance. Mesh damage is particularly difficult to detect as entrainment monitoring at the intakes may not detect organisms that are killed and broken. Mesh avoidance is detectable, as animals will be found in intake water samples, it is clear from the Lovett 2000 report that it does occur as there is clear evidence in the report of a gradual increase in the proportion of the available animals that become entrained through time.

A third major class of potential problem relates to the establishment of a predatory community that feed on any small animals drawn close to the mesh. A fouling community adapted to feed upon any organisms drawn onto the filter may develop. If the flow is maintained at very low levels this may be unimportant, but if flow differentials become established then weakly swimming or non-swimming life stages may become held against or close to the surface for sufficient time to be attacked.

Further, if water movement does not quickly carry away plankton from the surface of the filter, they will tend to concentrate in front of the boom. This may then become a favoured hunting zone for their predators. Fish are frequently attracted to structures and it is possible to envisage a situation where they patrol along the boom picking off larval and juvenile organisms and other forage as they are drawn in.

The fourth and final area of concern relates to the general ecological impact of the boom. The area inside the boom is essentially lost to the natural ecosystem. Many species will be excluded and an unnatural community will form. Thus a Gunderboom has a footprint. For small volume intakes this will probably be of little significance, but may become more so for large stations where the area within the boom may become an appreciable proportion of the local littoral and immediately sub-littoral habitat. Further, the boom itself and anchoring system represents a considerable structure which will offer unusual ecological niches possibly resulting in the establishment of animals and plants that are new to the area. While such changes may be quite acceptable, we need to ensure that they have been considered as there are numerous examples of damaging ecological consequences from human intervention.

Only a short period in the spring and summer of 2001 was available for the present study so it was not possible to study all aspects of the potential impact of Gunderbooms and their working efficiency. However, the Lovett 2000 study gave useful information with which to focus our study as it suggests that the ability of the Gunderboom to reduce entrainment declined through time (Fig 10 page 18). Direct experiments on eggs and larval fish which are difficult and time consuming to undertake and can only take place at particular times of year were not possible in 2001. However, there was still much useful insight that could be gained from focussing on biofouling. This holds the key to the entire assessment of Gunderboom efficiency. If biofouling occurs then mesh damage or mesh avoidance is likely or even inevitable and differences in flow rate across the fabric are likely. Further, if a biofouling community develops, we have the potential for the development of a predatory fouling community and general changes in the local community. Thus, all four potential impact categories listed above require the establishment of a biofouling community.

A working Gunderboom is designed with an air-burst cleaning system to remove dead, principally inorganic, sediment from the mesh. It can also be anticipated to affect the development of the biofouling community. The main series of fouling tests reported here were carried out on static panels through which no water was pulled and which were not subject to air burst cleaning. To ensure that the results were of relevance, it was agreed that Mirant would run contemporaneously a biofouling test rig which used flow and air-burst cleaning. If this test material produced similar results to those obtained with the static pest panels it would increase confidence that the fouling and permeability changes observed would be likely in an installed Gunderboom. It is unlikely that air-burst will remove biofouling as it has already been reported that it cannot remove fouling organisms on deployed Gunderbooms.

If it is accepted that biofouling is a key issue then there is much that we can achieve this year. Put simply we need to discover if and at what rate a Gunderboom fouls and what impact this fouling has on the flow resistance.

2. Methods

2.1. Plate set up

The pieces of Gunderboom fabric, 5 inches by 4 inches, were fixed to stainless steel plates with a hole cut in the centre (Fig 1). Spacers and bolts were used to attach the plates together in pairs to mimic the two layer structure of a working Gunderboom (Fig 2). A neoprene sleeve was attached to stop light penetration between the plates. Six ropes were hung from the oil boom in front of the power station intakes in Bowline Pond. Three plates were positioned, vertically, on each rope at 3, 9 and 15 feet from the surface. Three of the six ropes had single control plates attached at each depth. The control panels were a coarse nylon mat commonly used for fouling studies and known to readily foul

2.2. Plate Removal

Plates were removed at 11, 20 and 29 days (2nd, 11th and 20th July 2001). On each occasion, two ropes were removed containing a total of 6 Gunderboom plates (2 from each depth) and 3 control plates (1 from each depth). The plates were lifted gently to the surface of the water. Each plate was tied to the boat and bottom cable ties removed. While still in the water, a bag was dipped under the plate and both were lifted out of the water. The ropes were removed and the plates were double bagged and placed in a waterproof box.

2.3. Gunderboom Fabric Removal

The Gunderboom was removed from the steel plates in the laboratory as each one was used for the analysis. One sheet was used for the permeability testing and biofouling inspections. The other sheet was halved and a 1cm^2 piece taken from the centre of each half sheet for use in the microbiology, the rest of the sheet was preserved in formaldehyde to be investigated under an electron microscope in the UK.

Water from the plastic bags in which the plates had travelled to the lab was drained though a fine mesh net and retained.

2.4. Permeability Testing

The permeability was measured using a piece of equipment designed based on the ISO 11058:1999 for testing the geotextiles. A constant head apparatus was used in which the head differential across the fabric is adjustable. Head loss was measured in mm using two transparent tubes, one from each side of the fabric, placed over a graduated scale. To allow for any head loss through the side of the fabric, the adjustable side of the apparatus was set so that no water flowed into the collection vessel. Ideally, with no flow there should be no head loss with no flow. In practice the head loss with no flow across clean fabric this was 2 mm and with fabric exposed for 29 days the head loss never exceeded 1 mm. Adjustments were made to the head to allow for this head loss. For example to run the clean Gunderboom at a head differential of 10 mm required a measured head of 12 mm.

Six sets of plates were run in total, each set consisting of three individual pieces of Gunderboom fabric, one from 3, 9 and 15 feet. Two sets of plates were removed on each visit.

The mat was kept in water at all times, in order to keep wetting issues and gas bubble problems to a minimum. Water temperatures used ranged from 20 to 21.9ºC, with dissolved oxygen never getting above 7.75mg/l.

The panel was divided into 6 parts of similar area, two of which were randomly chosen for testing. The plates were placed on the permeability rig with the exposed outer surface of the fabric towards the flow as would be the case for the material on the front surface in a working boom. This seemed the best procedure as most of the fouling was anticipated to occur on the outer (river) surface of a working boom. Starting with the smallest head and working to the largest the permeability was measured twice with head differences of 10, 20, 25 and 35 mm. For each determination the water passing across the fabric was collected in a measuring cylinder for 60 seconds. Controls to measure the flow of clean, unexposed, Gunderboom were taken at regular intervals during each period of measurement.

The flow velocity across the test panel at 20 °C was calculated using the equation

$$f_{20} = \frac{VR}{At}$$

where :

V was the measured water volume passing across the fabric (m^3),
R is a correction factor to a water temperature of 20 °C (not applied in this case as the temperature was always in the range 20-21 °C),
A is the exposed specimen area (m^2) and
t is the time measured to achieve the volume V.

For each test panel the flow velocity was calculated for a head loss of 10, 20, 25 and 35 mm. The flow velocity for a head loss of 25 mm for each panel was then estimated by plotting the flow velocity against the head, fitting a line by linear regression and then obtaining the predicted value for a head of 25mm.

2.5. Epi-flora and fauna

Different testing methods were used depending on the type of fouling that was discovered on the fabric. To estimate the number of holes blocked by tube building amphipods, the number of holes blocked in 10 randomly picked rows of 25 holes were counted. In order to avoid edge effect errors where the Gunderboom had been in contact with the steel plate, only the area of the panels inside of the panel attachment points was used. Following a visual search of both sides of the panels at x 12 magnification, descriptions of the general fouling on both sides of the fabric were recorded and photographs taken. An estimate of the total proportion of the panel surface covered by fouling organisms was made and the number of attached mussels recorded. The water in the bags holding the panels was drained via a net and any animals present retained for examination.

For subsequent electron microscope examination, the test fabric was fixed in 10% formaldehyde solution then placed in a sealed bag. These were then double bagged and placed in an airtight container. Back at the laboratory in England they were stored

in 4% buffered formaldehyde. The fabric samples used for permeability testing and all other exposed panels were preserved.

Selected pieces of fabric were examined under a scanning electron microscope. A piece of fabric, approximately 1 cm^2, was taken from the center of one mid-water (9 feet deep) panel on days 11, 20 and 29. On day 29, additional samples were taken from the top and bottom panels. A small number of additional samples were prepared to investigate unidentified objects of interest on the surface.

Electron microscopy was undertaken at the Southampton Oceanographic Centre on 26/7/01 using a Leo 1450 VP scanning electron microscope. The samples were dehydrated, and splatter coated with gold for four minutes. Each piece of fabric was photographed under x450 magnification to give a general record of the amount of encrusted fouling present. Interesting observations were photographed under varying magnifications, particularly as aids to identification of the fouling present.

2.6. Microbial Examination

2.6.1. Dip-slide Method

Bacteria, general fungi and yeast levels in the mat were monitored using 'Easicult Combi Dip-slides' which are slides containing multi nutrient agar selective for bacteria on one side and rose bengal agar the other side, selecting for yeasts and other fungi.

Two $1cm^2$ pieces of Gunderboom fabric were removed from the center of the panel to avoid any edge effects. One $1cm^2$ piece was placed in a tube with 15mls of sterile water and shaken vigorously for 5 minutes. Any water then left in the square of fabric was drained into the tube and removed. A clean dip-slide was then placed into the water for 7 seconds, removed, drained and incubated at 25^oC. The second $1cm^2$ piece removed from the Gunderboom was treated in a similar way, but underwent a serial dilution to ensure the organism density was in the range of measurement of the dip-slide. The dip-slides were checked regularly for bacterial and fungal growth. Final readings were taken at 48 hrs for bacterial levels and 84 hrs for fungal and yeast levels.

Previous experiments had shown that a $1cm^2$ block of Gunderboom holds an average of 0.295mls of water. Therefore, control dip-slide experiments were run, consisting of 0.295mls of river water diluted into 15mls of sterile water. These control dip-slides never showed more than two colonies indicating that bacterial levels in the water were far lower than 10^3 bacterial cells per ml. This shows that microbes extracted from the Gunderboom were not predominately from the river water held within the fabric, but were from bacteria actually attached and living within the Gunderboom fabric.

2.6.2. Gunderboom Filament Method

Filaments from the Gunderboom material were removed, washed in sterile water and placed on multi nutrient agar. These were incubated at 25^oC and regularly checked for bacterial and fungal growth. This method was used to demonstrate that the bacteria were attached to the fibres and not free living in the interstitial spaces within the fabric. This was not used as a quantitative method.

2.6.3. Live Bacterial Counts

Water remaining from the undiluted dip-slide tests was used for a live bacterial count using a haemocytometer. The number of rod-shaped bacteria was recorded for two slides with 15 squares counted per slide. The squares were selected using a random walk method, using a random number chart.

2.6.4. Staining Method

0.1mls of water remaining from the undiluted dip-slide tests was placed onto a sterile microscope slide and allowed to air dry. These were then fixed by passing the slide through a Bunsen flame a few times, smear side up. The slide was then flooded with 0.1% methyl blue and left to stain for 3-5 minutes. The stain was then washed off and the slide was blotted dry using clean paper. The slides were then examined under the microscope and a count of bacteria was made using an eyepiece graticule. For each slide, six fields of view were selected randomly and the same 5 squares were counted within each field of view. If the randomly selected field of view was at the edge of the drop, another field of view was randomly chosen to avoid any edge effect of the drop.

3. Results

3.1. Permeability

3.1.1. Panels not exposed to flow or air-burst cleaning

Statistical analysis using an ANOVA showed that there was no significant difference in the flow across panels submerged at different depths. It was therefore possible to combine observations from all the individual test panels when analysing the change in permeability through time. Table 1 gives the flow rate in millimetres per second across all the tested panels. As can be seen there is a large, statistically significant, decline in mean permeability through time. The rate of change of permeability is not constant and almost no change was observed after the initial 11 days exposure. Between 11 and 20 days exposure an almost 50% reduction in flow was observed. Subsequently, the rate of decline was reduced. This general pattern of change could be described by a sigmoid curve as shown in Fig 3. After 11 days of exposure the average flow was 21.8 mm/s, which is effectively identical to that of the clean material. After 20 days exposure, average flow was reduced to 11.1 mm/s, which is 50.7% of the flow of clean fabric. After 29 days exposure, the average flow was reduced to 8.35 mm/s which is 38% of the flow through clean material.

Table 1 Flow velocity of Gunderboom material after different periods of submersion. The flow is given in mm/s at a standard head difference of 25 mm.

	Exposure time			
Replicate	Control	11 days	20 days	29 days
1	26.08	21.09	7.22	7.21
2	21.79	24.67	12.99	11.88
3	25.29	24.61	14.59	14.60
4	19.53	18.86	16.52	15.57
5	17.78	19.52	9.68	9.83
6	20.32	25.03	11.68	5.23
7	27.14	26.72	10.13	6.24
8	17.67	25.69	11.40	4.38
9		18.76	13.58	4.08
10		22.04	7.05	5.52
11		16.05	9.38	6.93
12		18.49	9.11	8.73
Mean	**21.95**	**21.79**	**11.11**	**8.35**
SD	**3.77**	**3.48**	**2.91**	**3.88**

3.1.2. Panels with flow and air-burst cleaning

Table 2 gives the measured flow at a standard 25 mm head difference across the test panels after 29 days of exposure. The front panel had an average flow of 0.86 mm/s, which is only 3.9 % of the flow through a clean panel. The back panel, which is not directly in contact with the river, had an average flow of 3.27 mm/s, which is 14.9 % of the flow through a clean panel (See Table 1). Some areas of these panels were so highly covered with animals that no flow at all occurred with a 10 mm head difference.

Table 2 Flow velocity of Gunderboom material exposed in the test rig where water was pumped through the material and air-blast cleaning was applied to simulate normal operating conditions. The flow is given in mm/s at a standard head difference of 25 mm. Results are given for both the front and back panels.

Replicate	Front	Back
1	0.26	2.86
2	0.67	2.34
3	0.57	2.56
4	0.29	3.48
5	2.01	4.20
6	1.35	4.20
Mean	**0.86**	**3.27**
SD	**0.69**	**0.81**

3.2. The development of the fouling community

3.2.1. A general description of the development of the fouling community on the fabric

The fouling community gradually developed over the 30 days of the study and there was a steady increase in fouling on the surface (Plates 1, 2 & 3) and at a smaller scale

in encrusted material on the fabric fibres (Plates 13,14 & 15). Plants were mostly filamentous algae (Plate 11) and diatoms. Typical examples of surface living diatoms observed on the surface after 29 days of exposure are shown in Plates 20 & 21. Single celled animals observed on the surface included both mobile ciliates and attached forms such as *Vorticella* (Plate 10). Dominant multicellular animals within the community included bryozoans, hydroids (Plate 12), copepods, ostracods (Plate 9), *Corophium* species (Plate 4), *Gammarus* species, mussels (Plate 8) and chironomids (Plate 7). A brief description of each type of organism is given in Table 3.

Table 3 Brief descriptions of the organisms found on the fabric

Organism	Description
Corophium	A tube-living crustacean which grows to about 1cm in length.
Gammarus	A free living crustacean of about 1 cm.
Chironomids	Insect larvae, sometimes tube building, 1.5 cm length
Mussels	Bivalve mollusc that attaches itself to a substrate with threads. Can grow to several cm in length.
Ostracods	Small free living crustaceans with a bivalve carapace between 0.3 and 4 mm long.
Ciliates	Small, single celled, free living, predators.
Vorticella	Small, single celled, attached ciliate.
Bryozoans	Colonial animals that form plant or coral like structures.
Copepods	Free living crustaceans that form part of the plankton in the river.
Hydroids	Colonial animals that form plant or coral like structures.
Filamentous algae	Aquatic plants that grow in long filaments. Often mat forming.
Diatoms	Small single celled plants

A brief account of the development of the fouling community follows.

By day 11 the fabric had been colonised by *Corophium* and *Gammarus* spp with about 5% of the surface showing evidence of colonisation. Tube building *Corophium* spp had colonised the 1 mm holes in the fabric (Plate 6 &17). Many holes were completely filled. Smaller *Corophium* used part of a hole as a base for building a tube. By day 20 the fabric had started to be colonised by several additional organisms including mussels, chironomids and small amounts of filamentous algae. Approximately 30% of the fabric surface showed evidence of colonisation. *Corophium* continued to colonise the 1mm holes and their tubes were widely dispersed over the surface of the panels. These surface tubes were bound under the outer filaments of the fabric and the surface of the fabric was becoming looser (Plate 5 &18). Some chironomid tubes were found. Copepods were observed moving across the surface of the fabric. By day 29, obvious colonisation had increased to 70% of the available surface area. Many *Corophium* surface tubes were observed and most of the 1 mm holes in the fabric were occupied. Holes were now only occupied by large *Corophium*, which completely filled the holes with their tubes. A large number of chironomid tubes were present on the upper panels exposed at a depth of 3 feet. The community had increased in diversity to include several predatory organisms including ostracods and ciliates. Other groups included the vorticellids, hydroids and bryozoans.

3.2.2. Number of holes blocked by Corophium tubes

The 1 mm holes through the fabric were found to be used by the tube building amphipod, *Corophium* sp (see Plates 6 & 17). The percentage of holes on each piece of fabric that were blocked are given in appendix 2. Table 4 gives a summary of the data and demonstrates that there was little difference in the percentage of blocked holes from panels exposed at 3, 9 and 15 feet. In the first sample, after 11 days, there were more tubes blocking holes in the lower panels than the top or middle panels. This difference had disappeared by the second and third samples.

Table 4 - The percentage of blocked holes with depth after different exposure times

	Day 11	Day 20	Day 29
Top - 3 feet deep	9	30.2	86.4
Middle - 9 feet deep	9.2	25	72
Bottom - 15 feet deep	16.2	30	75.4

Table 5 gives the average percentage of blocked holes for all panels, irrespective of depth. The percentage of blocked holes increased rapidly after day 20 (Fig 4).

Table 5 - Percentage of holes blocked in the Gunderboom after different exposure times

Days	% blocked
0	0
11	11.46667
20	28.4
29	77.93333

3.2.3. The development of Mussels

From day 20 onwards, young mussels were found attached to the fabric (Plate 8). All mussels found on either side of the fabric were noted (appendix 3). Table 6 shows the number of mussels found at each depth. The number of mussels was lowest near the surface (Fig 5a).

Table 6 - The average number of mussels found at different depths on both side of the fabric after different exposure times

Days	0	11	20	29
Top – 3 feet deep	0	0	1.5	8
Middle – 9 feet deep	0	0	2	13.75
Bottom – 15 feet deep	0	0	5	14

As shown in Table 7, there were more mussels attached to the front of the fabric (Fig 5b).

Table 7 - The average number of mussels found on the front and back of the Gunderboom fabric after different exposure times

Days	0	11	20	29
Front	0	0	3.50	16.33
Back	0	0	1.20	7.50

Table 8 shows the general increase in the number of attached mussels through time. The number increased rapidly between days 20 and 29 (Fig 5c). No significant difference in the number of mussels attaching to the Gunderboom and control fabrics was found.

Table 8 - Comparison of the average number of mussels found on a side of the Gunderboom and control fabric.

Days	0	11	20	29
Gunderboom fabric	0	0	2.83	11.92
Control material	0	0	2.67	11.67

3.3. Results of Microbial Analysis

Four different methods were used to analyse the levels of bacteria in the Gunderboom material over time. 1 cm^2 of mat was shaken in 15mls of sterile water for 5 minutes in order to extract bacterial, fungal and yeast cells, which were then grown on dip-slides. This water was also used for a live count of rod-shaped bacteria and bacterial counts were made of fixed slides stained with methyl blue. Lastly, filaments were extracted from the Gunderboom panels, washed in sterile water and placed onto multi-nutrient agar plates in order to show bacterial growth directly on the hair.

3.3.1. Bacterial Dip-slide Results

After 11 days exposure, the average abundance of bacteria extracted from the Gunderboom panels was $7x10^3$ bacterial cells per ml. This increased to $2.2x10^5$ cells per ml after 20 days and to $2.02x10^6$ cells after 29 days. While the bacterial dip-slide analysis showed an overall increase in bacterial numbers over the 29 day period, the bottom panels showed a decrease from day 20 to day 29. Figure 6 plots the trends observed, the data are shown in Table 9.

Table 9 - Number of bacterial cells indicated by the dip-slide method (cells/ml)

	Days of Exposure		
	11 Days	20 Days	29 Days
Top - 3 feet deep	10000	505000	5050000
Middle - 9 feet deep	5500	55000	1000000
Bottom - 15 feet deep	5500	100000	10000
Mean	**7000**	**220000**	**2020000**

Throughout the experiment the top panels gave higher bacterial counts than the middle and bottom panels.

A typical dip-slide showing bacterial colonies is shown in plate 22.

3.3.2. Fungal Dip-slide Results

There were very few fungal colonies cultured from the Gunderboom panels. After 11 days there was light fungal growth from one of the bottom panels and after 20 days, light fungal growth was observed from one of the top panels. After 29 days, no fungal growth was visible. No trends were observed.

A typical dip-slide showing fungal growth on the rose bengal agar is shown in Plate 23.

No yeast was cultured from any of the Gunderboom panels (or the control panels) at any point during the experiment.

3.3.3. Live Count Results

Figure 7 shows the results of the live counts of rod-shaped bacteria extracted from the Gunderboom panels. After 11 days the average number of bacteria per ml was 4806. By 20 days this had dropped slightly to 3922 bacteria per ml, followed by an increase to 10006 bacteria per ml by day 29 (Table 10).

Table 10 Number of rod-shaped bacteria found by the live count method (cells/ml)

	Days of Exposure		
	11 days	20 days	29 days
Top - 3 feet deep	5633	5133	9000
Middle - 9 feet deep	4700	3483	9717
Bottom - 15 feet deep	4083	3150	11300
Mean	**4806**	**3922**	**10006**

There was an overall increase in bacterial numbers between 11 to 29 days of exposure, despite the numbers falling slightly from day 11 to day 20. No trends between panel depth and bacterial number were observed.

3.3.4. Stained Slide Results

After 11 days the average number of bacteria observed on the slides was 13138 per mm^2. This increased progressively to 31511 after 20 days and then to 61159 cells per mm^2 after 29 days (Table 11).

Table 11 Number of bacterial cells observed per mm^2 of slide

	Days of Exposure		
	11 days	20 days	29 days
Top - 3 feet deep	16373	59467	65947
Middle - 9 feet deep	14560	16987	64800
Bottom - 15 feet deep	8480	18080	52731
Mean	**13138**	**31511**	**61159**

The stained slide method showed an overall increase in bacterial numbers through time on the Gunderboom material, at all depths. The average trend is plotted in Fig. 8. No relationship between panel depth and bacterial number was detected.

3.3.5. Agar Plate Results

This method was used purely to observe the presence of bacteria growing on the Gunderboom filaments and was not used as a quantitative method. Filaments that were removed, rinsed and placed on agar plates showed clear bacterial growth along the length of the filaments at all depths throughout the duration of the experiment. Bacterial colonies were clearly visible surrounding Gunderboom filaments as shown in plates 24 and 25. These results suggest that bacterial colonisation may be linked to the development of encrusting material on the individual fibres (See Plate 19).

4. Discussion

This study clearly demonstrates that the permeability of the Gunderboom fabric exposed to the environment in Bowline Pond progressively declines and that this decline is linked to the growth of a biological community on the surface. When the study was first proposed it was hypothesised that the static test panels would exaggerate the level of fouling and loss of permeability that would occur in material exposed to designed levels of flow and air-burst cleaning. Instead, air-burst and flow actually enhanced the level of fouling and resulted in an extremely severe reduction in permeability so that the flow after 29 days was less than 4% of that found in the clean material. This likely occurred because the boundary layer effects offered a static region in which the community could attach while the flow allowed the delivery of oxygenated water and possibly food. In any flowing medium there is a narrow layer of fluid close to the surface that is almost static. The thickness of this boundary layer is linked to the surface roughness and offers a region in which microorganisms can attach and grow, even when there is a very rapid and powerful flow nearby. Once established, it is almost impossible to remove microorganisms from the surface by mechanical means, which is why biocides such as chlorine or antifouling paints are used. A fouling community, as it grows, extends the boundary layer outwards so that in a narrow orifice it can eventually completely block the flow, even when exposed to high forces. The vulnerability of any filter medium such as the Gunderboom is related to the very high surface area that can become colonised. The more rapid colonisation of the panels through which water was pulled compared with the static panels might be related to superior oxygenation with flow. Other possible reasons include the flow drawing more potential colonisers onto the surface and bringing in more food for filter feeders.

The Gunderboom fabric with 1 mm holes offers a near perfect environment for small freshwater and marine organisms to colonise. The surfaces of individual fibres offer habitat to bacteria and algae such as diatoms. Larger insects and crustaceans can burrow between the fibres and use the fibres to attach their tubes. Perhaps most importantly for the effect on permeability, tube-building *Corophium*, which are small crustaceans, rapidly invaded and inhabited the 1 mm holes in the fabric.

For the panels not exposed to air-burst and flow, permeability had declined after 29 days to an average of only 38% of that observed in the clean material. An important question that arises from this result is whether the permeability and fouling would get

even worse if the experiment had continued for longer? All the evidence suggests that it would. First the panel exposed to flow and air-burst was considerably more heavily fouled and given sufficient time the static panels might have developed to this level. By the end of the experiment the encrustation on the individual fibres was still increasing and it seems inevitable that all the 1 mm holes would eventually have been blocked by *Corophium* tubes. Permeability was determined by both flows through the body of the fabric and via the 1 mm holes. By day 29, with many of the holes blocked, much of the flow was probably via the fabric. If the individual fibres were to become ever more fouled, as seems likely, then permeability may have declined much further.

The trends in the numbers of some organisms leave little doubt that we were observing the early stages of colonisation. For example, the mussel population would have almost certainly increased further. Further, we would expect the mussel biomass to increase much faster than number as the individuals that have settle continue to grow. Some of the mussels observed on day 29 time were considerably bigger than those found on day 20.

As the colonisation progressed, there was a gradual increase in active, potentially predatory organisms such as the ostracod, *Cypriodopsis vidua* and gammarids. Gammarids became highly abundant; they moved rapidly over the surface of the fabric, entering any unblocked holes and tucking themselves under loose fibres. Such animals are potential predators to fish eggs and larvae that are drawn onto the surface. Other potential predators of plankton include large protozoans. At day 29 even a small catfish was caught living on one panel.

These results clearly demonstrate that the permeability of Gunderboom fabric can be seriously reduced by the development of a fouling community. Further, the community that develops is species rich and diverse. The development of such a community suggests that there is considerable doubt as to whether a Gunderboom installed in Bowline Pond would effectively prevent ichthyoplankton entrainment. Further, the development of an extensive fouling community might have unplanned or unacceptable ecological consequences such as the development of predator populations preying on the plankton and the colonisation of the area by species more typical of other habitats.

Figure 1 – The metal plates used for mounting the Gunderboom material.

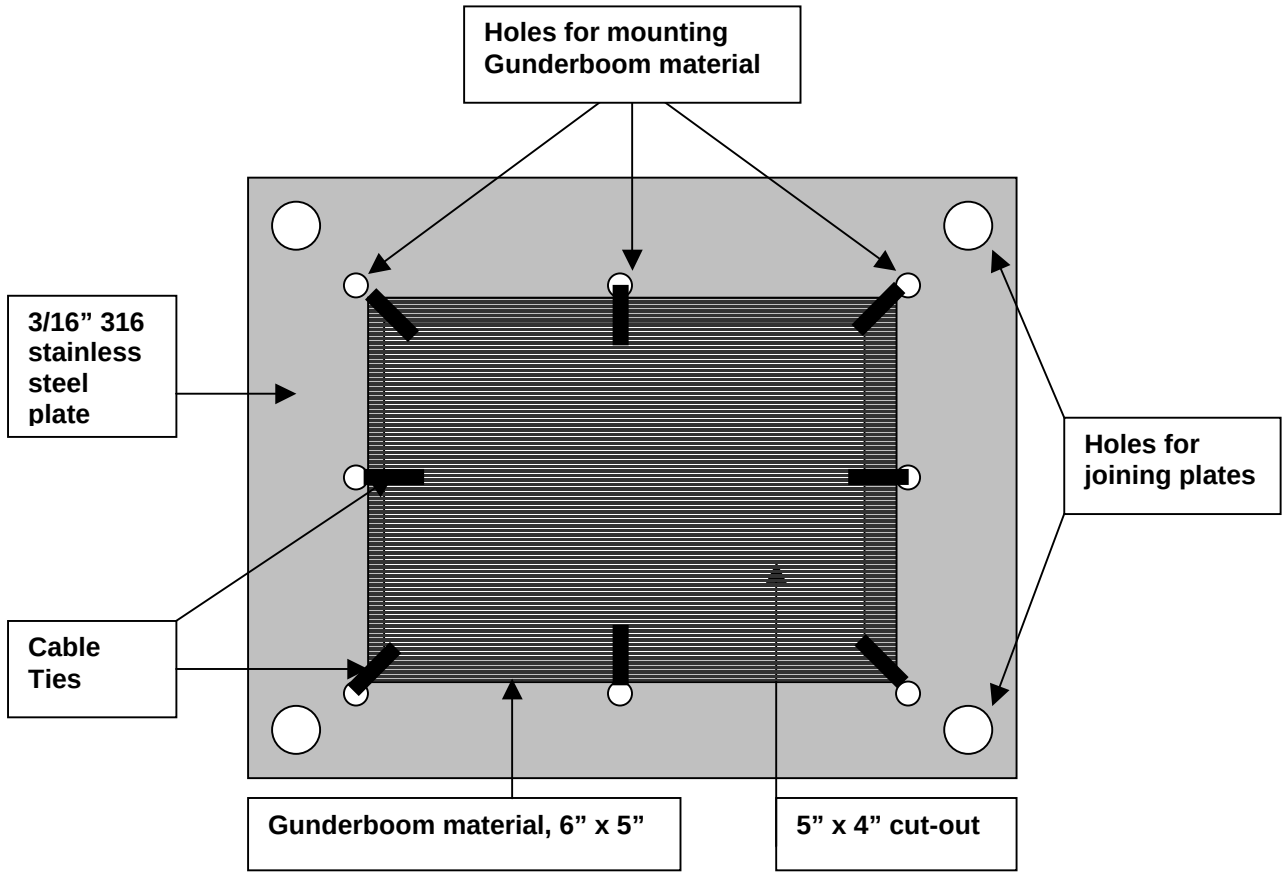
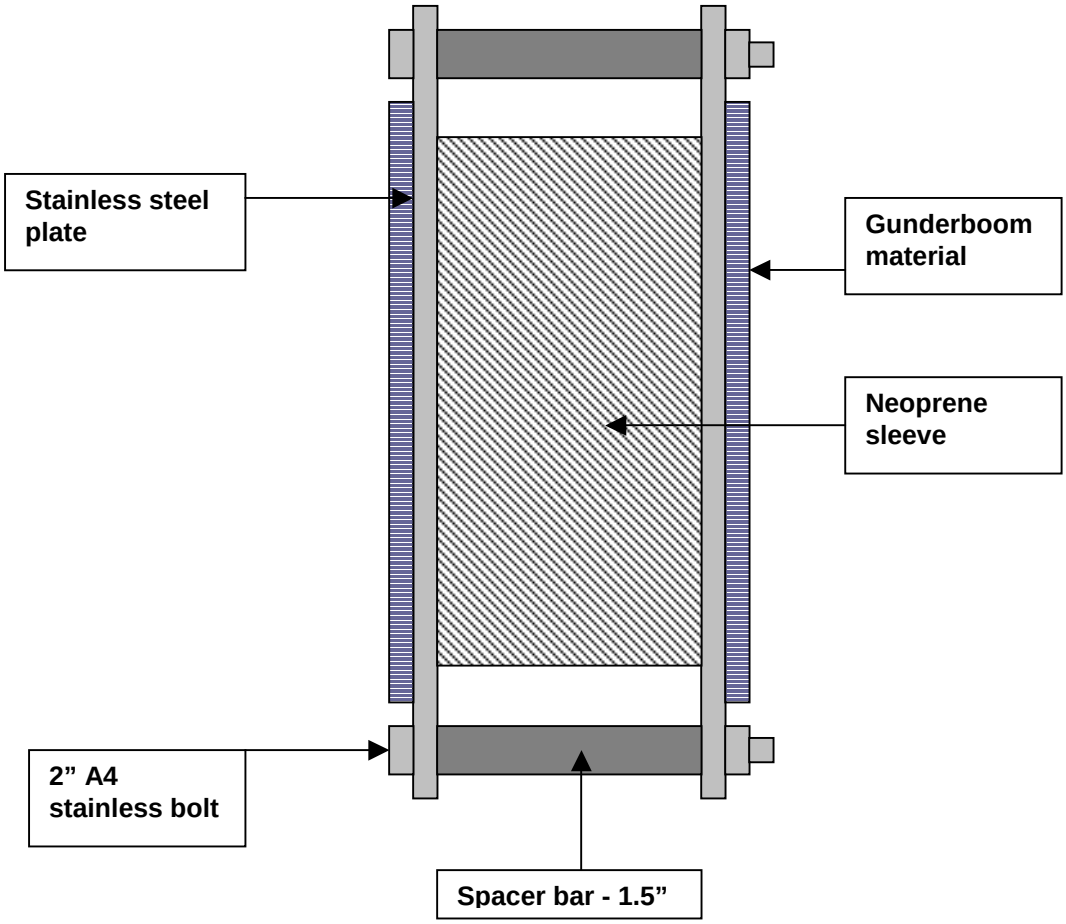


Figure 2 - Side view of a pair of plates.



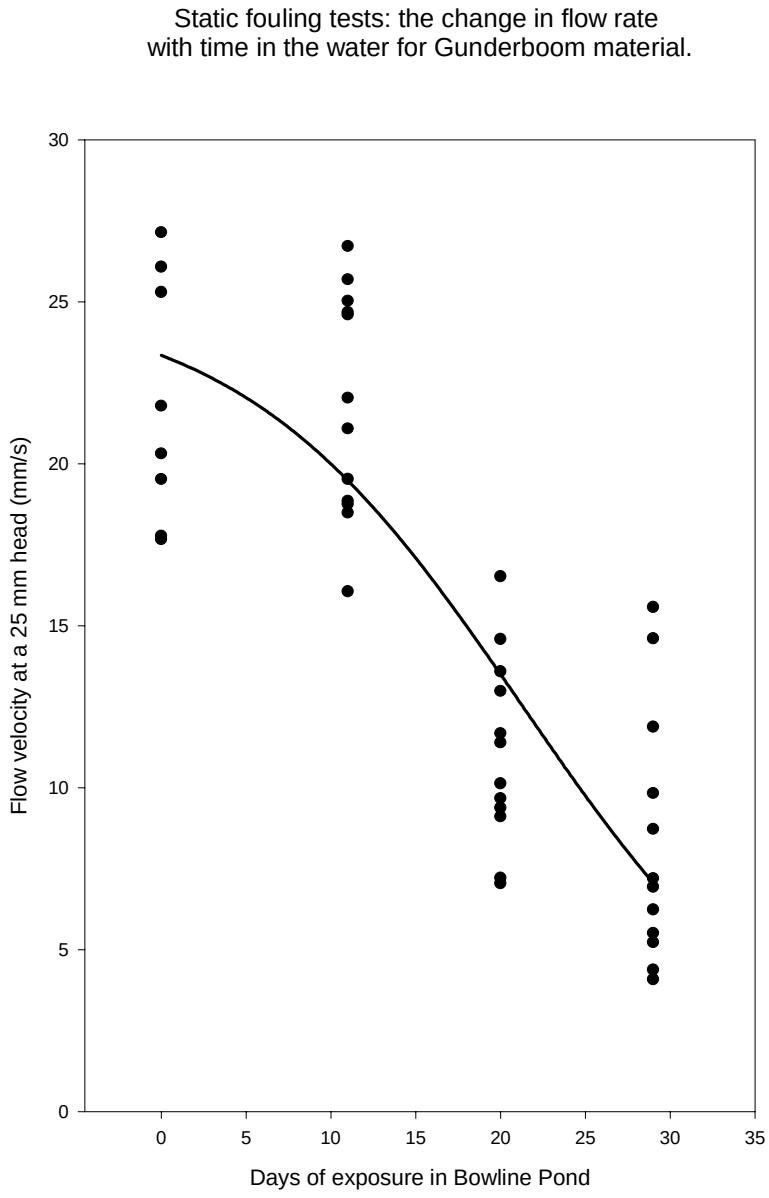


Figure 3 - Change in permeability through time

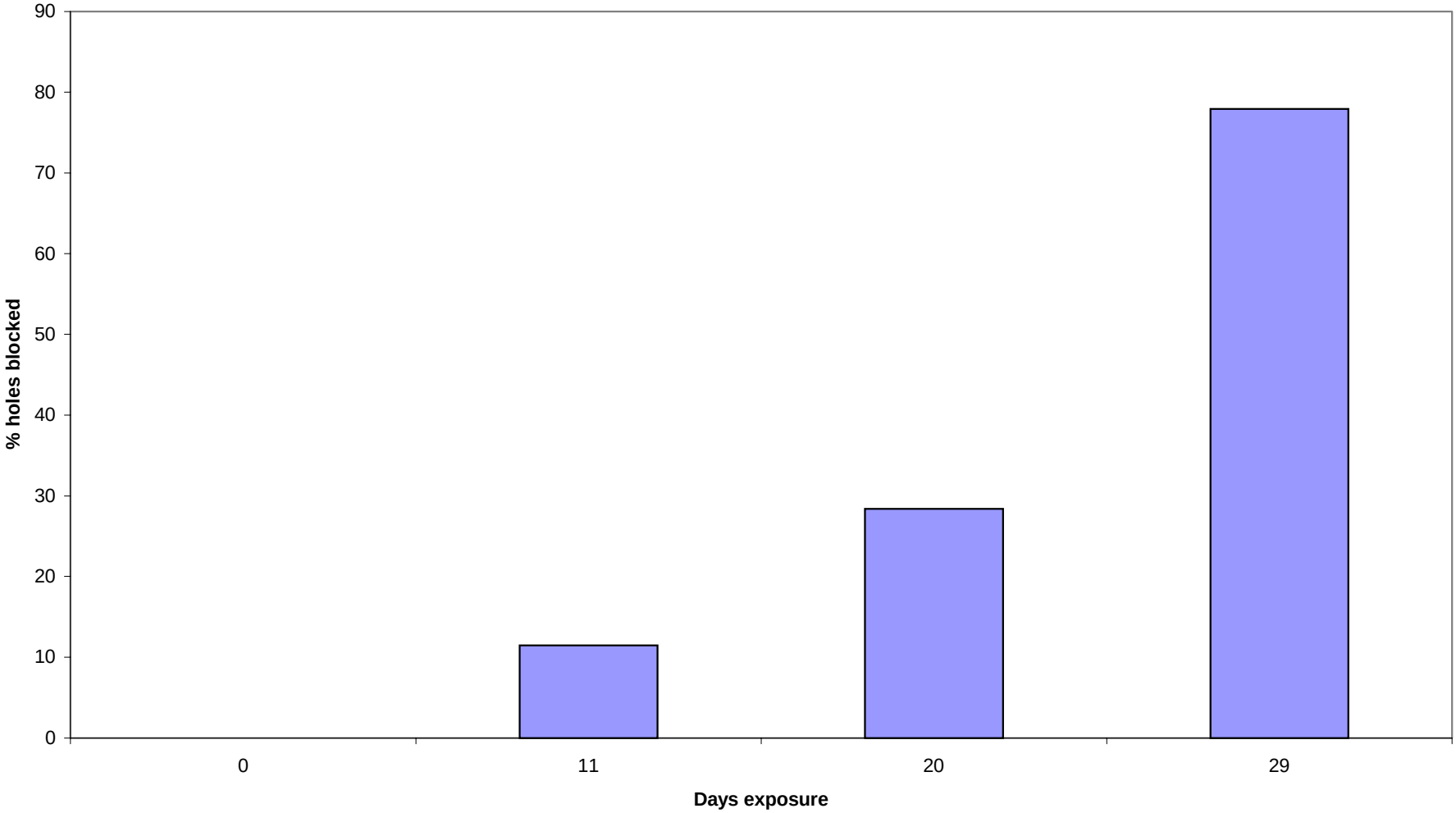
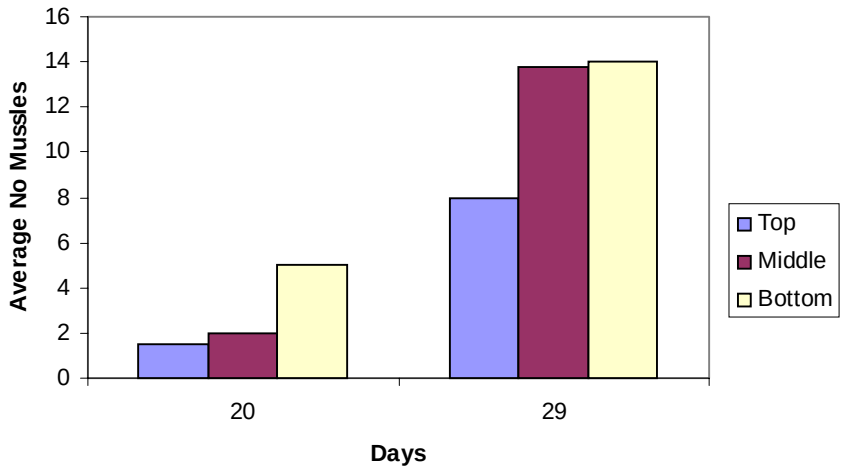
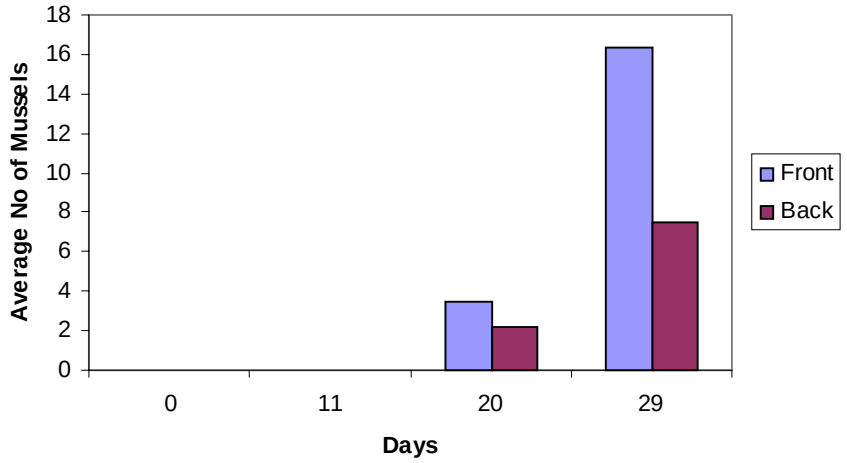


Figure 4 - Percentage of holes blocked in the Gunderboom after different exposure times

a)



b)



c)

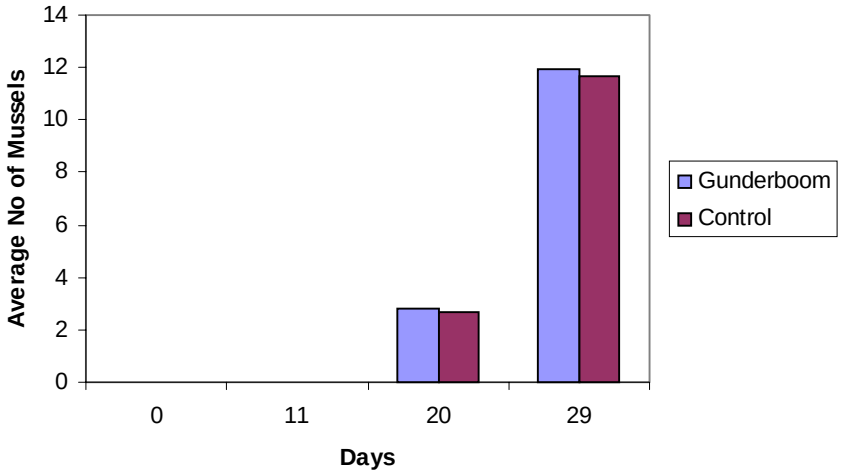


Figure 5

a) Average number of mussels found on the Gunderboom panels at different depths over time.

b) Average number of mussels on the front and back of a Gunderboom panel over time.

c) Average number of mussels found on the Gunderboom and control panels over time

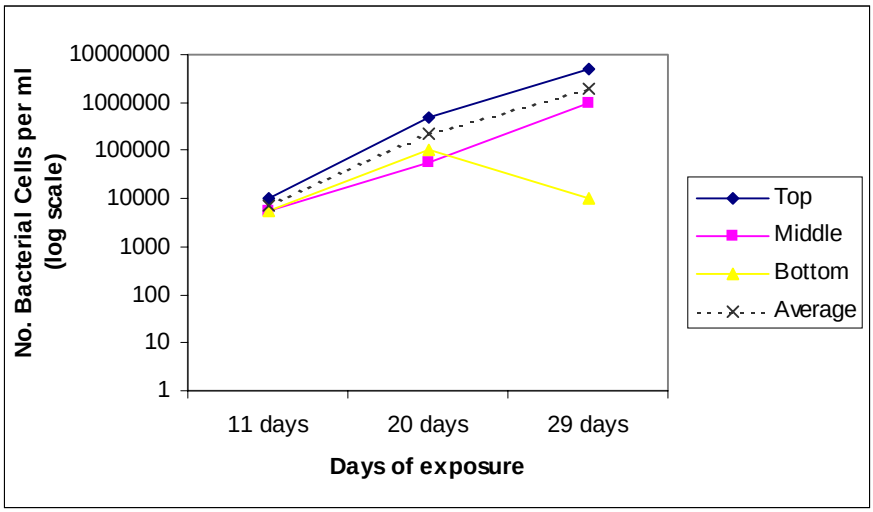


Figure 6 - Bacterial Dip-slide Results for Gunderboom Panels

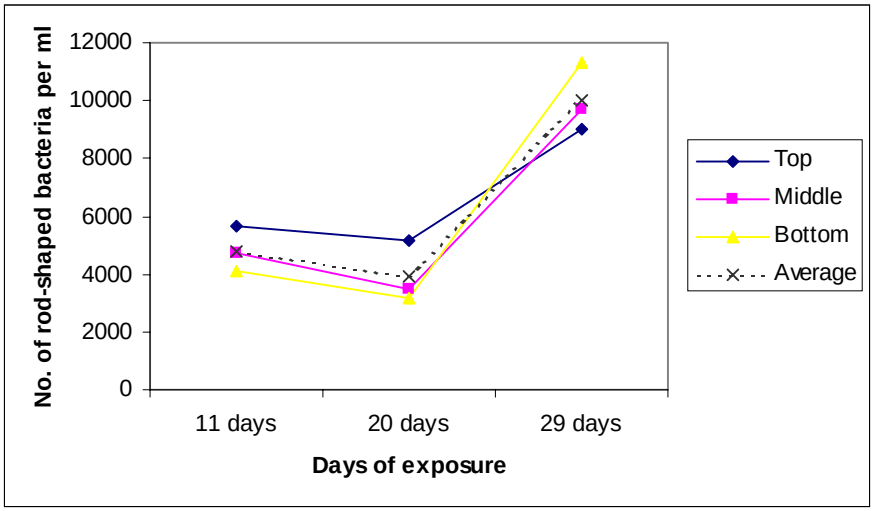


Figure 7 - Live Count Results for the Gunderboom Panels

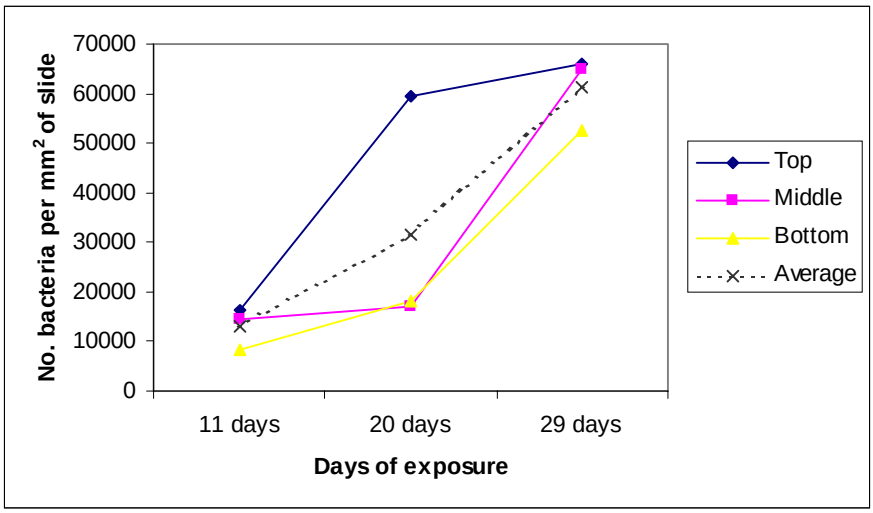


Figure 8 - Stained Slide Count for the Gunderboom Panels

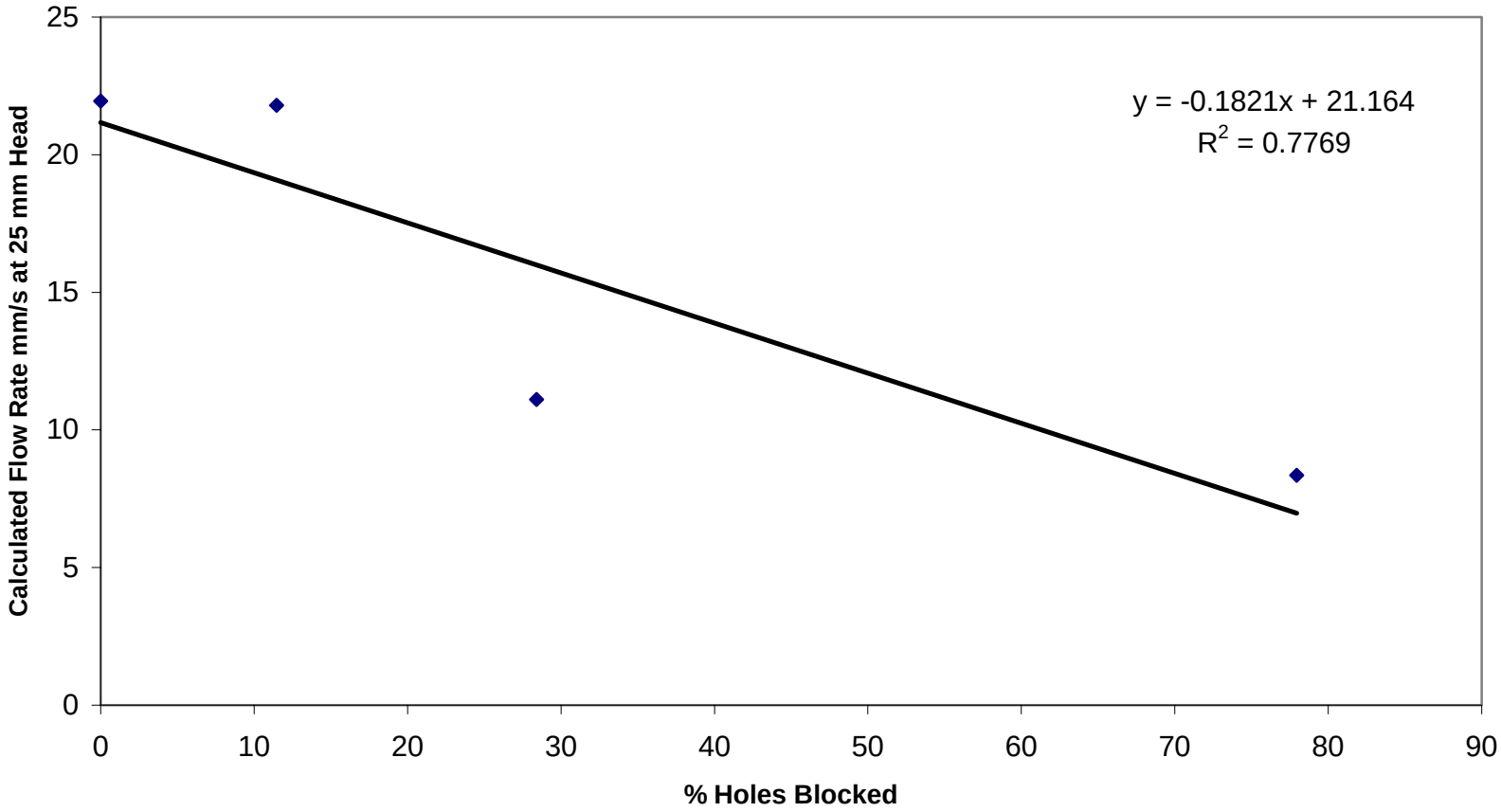


Figure 9 - Calculated flow through the Gunderboom fabric (mm/s) and the percentage of holes blocked

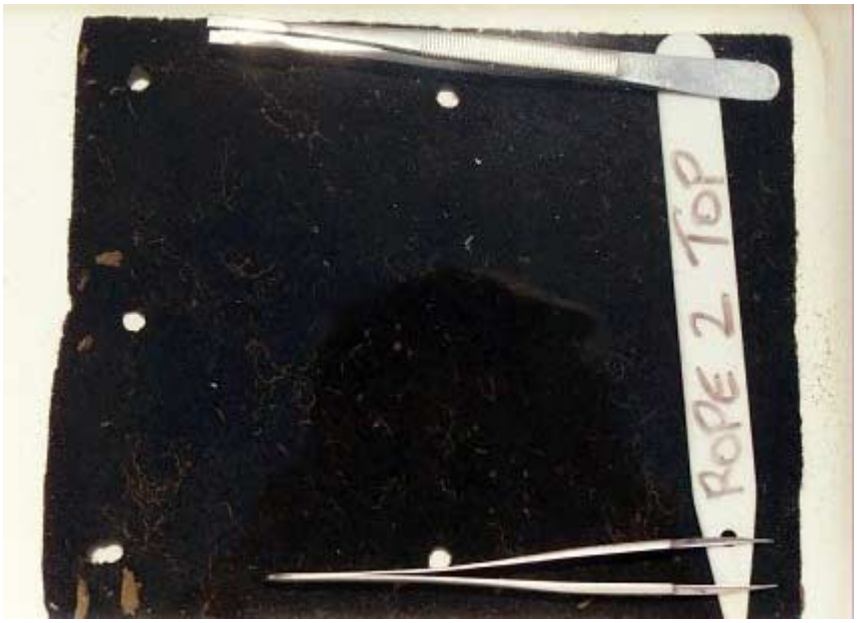


Plate 1
P1T
Gunderboom that has been in Bowline pond for 11 days at a depth of 3 feet

Plate 2
P4T
Gunderboom that has been in Bowline pond for 20 days at a depth of 3 feet

Plate 3
P6T
Gunderboom that has been in Bowline pond for 29 days at a depth of 3 feet

Plate 4
Corophium (x6)
A tube-dwelling amphipod.

Plate 5
Corophium tube (x6)
A surface tube showing the use of fibres to bind the *Corophium* to the fabric.

Plate 6
Corophium tube (x6)
A tube passing through one of the pre-made hole in the fabric.

Plate 7
Chironomid (x12)
An insect larva which sometimes builds tubes.

Plate 8
Mussel (x25)
A bivalve mollusc that attaches itself to substrates using threads.

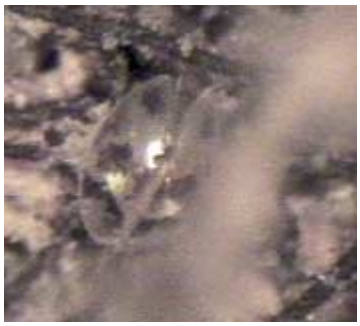


Plate 9
Ostracod (x25)
A small crustacean

Plate 10
Vorticella (x50)
An attached ciliate

Plate 11
Filamentous Algae (x50)
Two strands of the algae which have twisted together

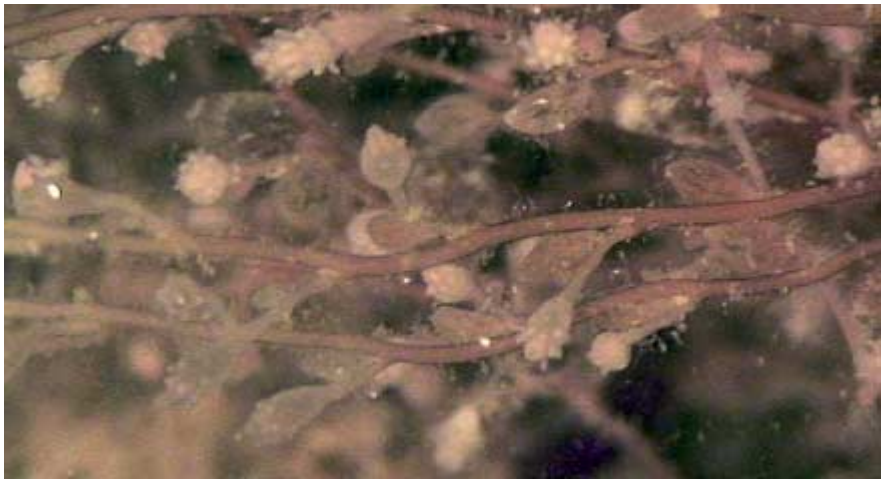


Plate 12
Hydroid (x6)
Colonial animals forming plant or coral-like structures

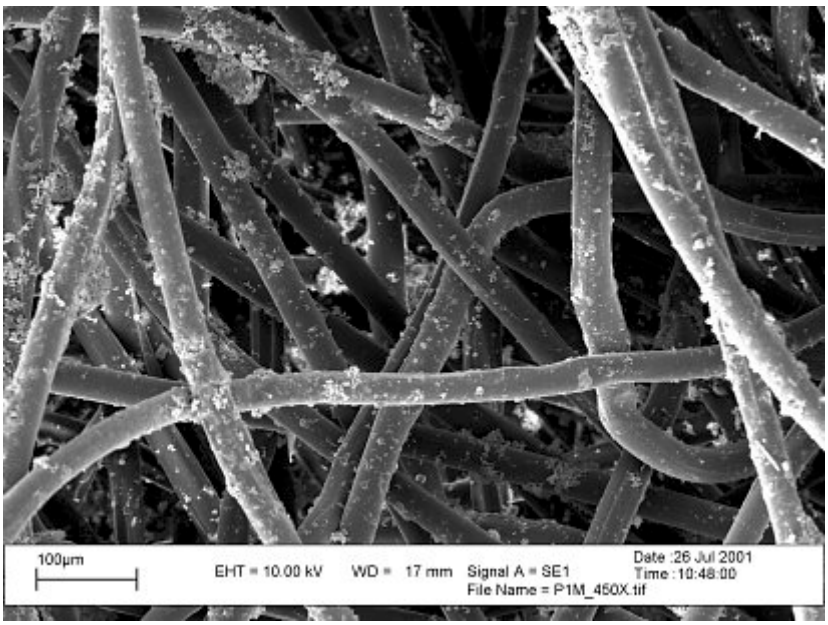


Plate 13
450X magnification
An electron micrograph of the fibres of the Gunderboom after 11 days of exposure at 9 feet.

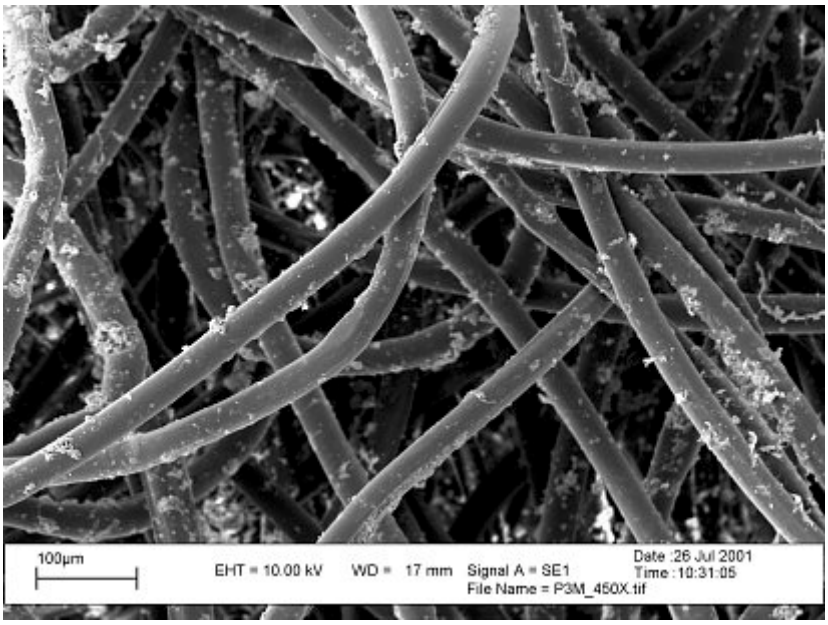


Plate 14
450X magnification
An electron micrograph of the fibres of the Gunderboom after 20 days of exposure at 9 feet.

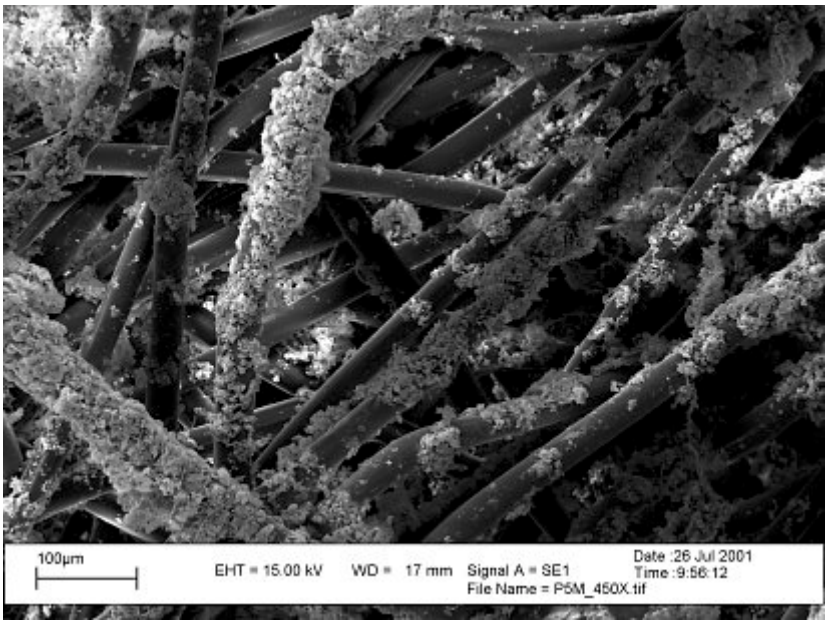


Plate 15
450X magnification
An electron micrograph of the fibres of the Gunderboom after 29 days of exposure at 9 feet.

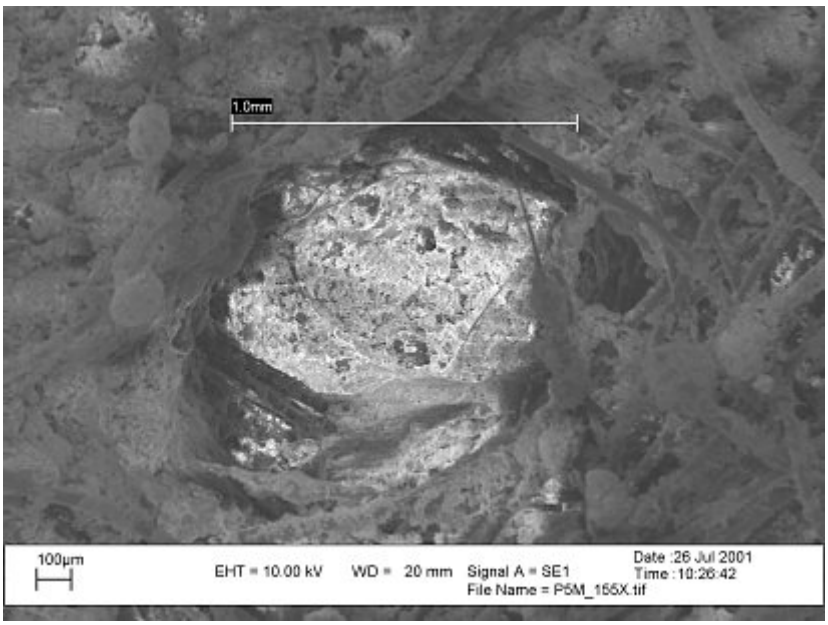


Plate 16
155X magnification
View down a blocked pre-made hole of the Gunderboom after 29 days of exposure at 9 feet

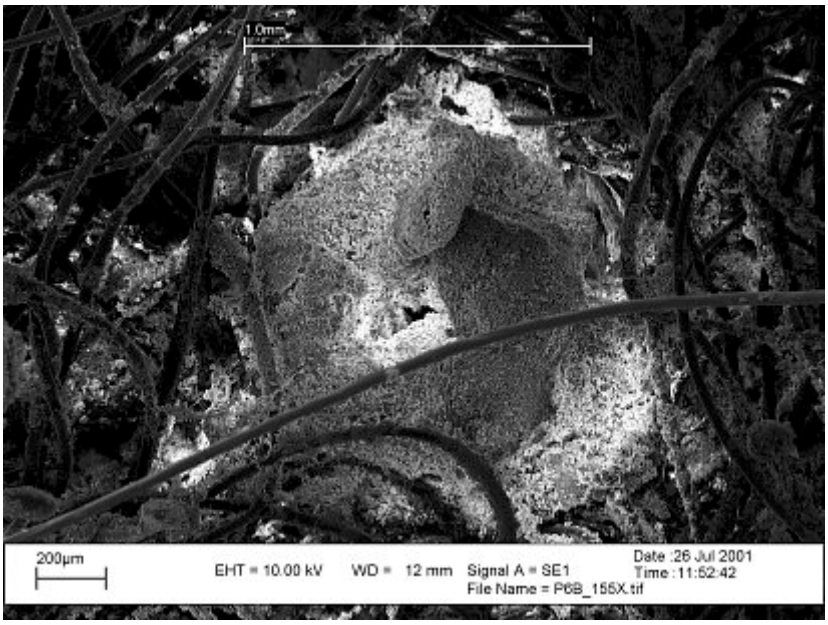


Plate 17
155X magnification
View down a blocked pre-made hole in the Gunderboom caused by a *Corophium* tube. 29 days exposure at 9 feet

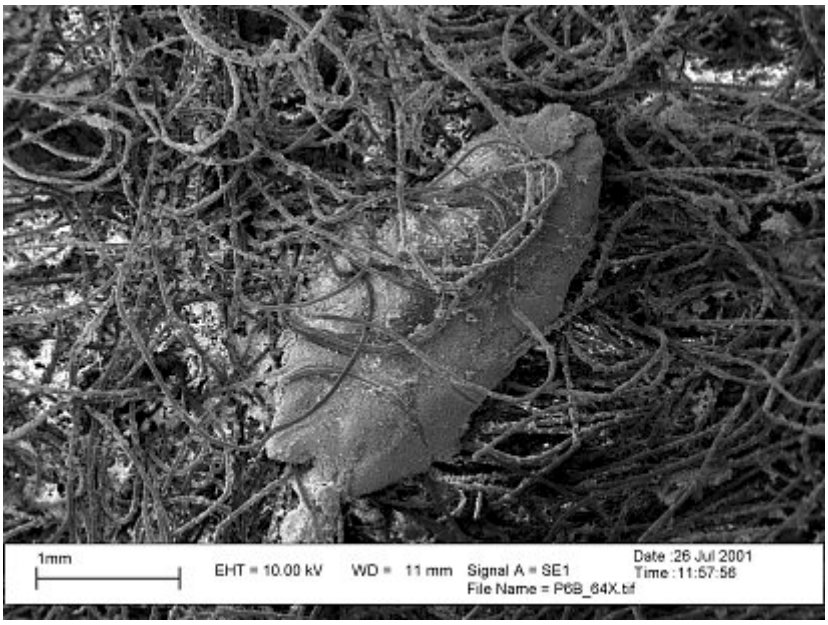


Plate 18
64X magnification
A large *Corophium* tube across the surface of the fabric. 29 days exposure at 9 feet

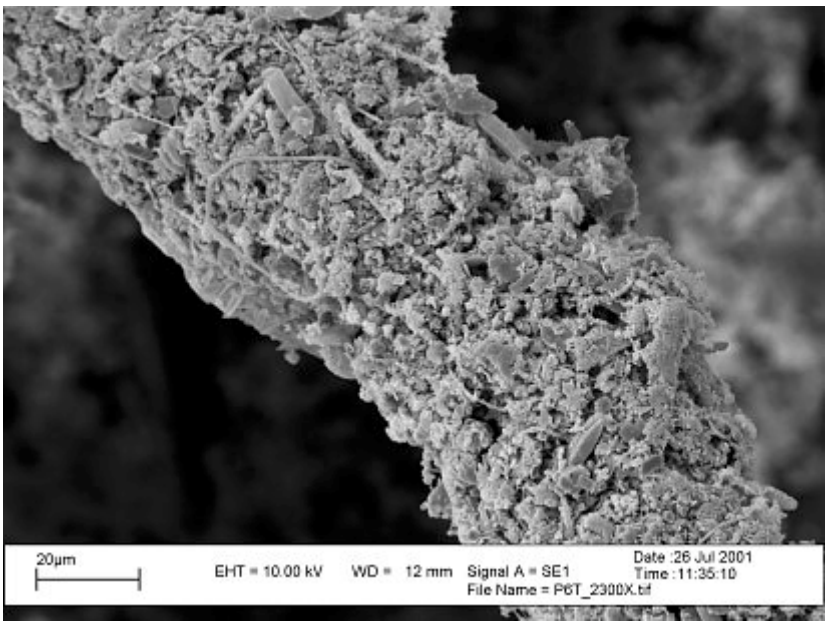


Plate 19
2300X magnification
High magnification of a fouled fibre showing encrusting organisms. After 29 days exposure at 3 feet

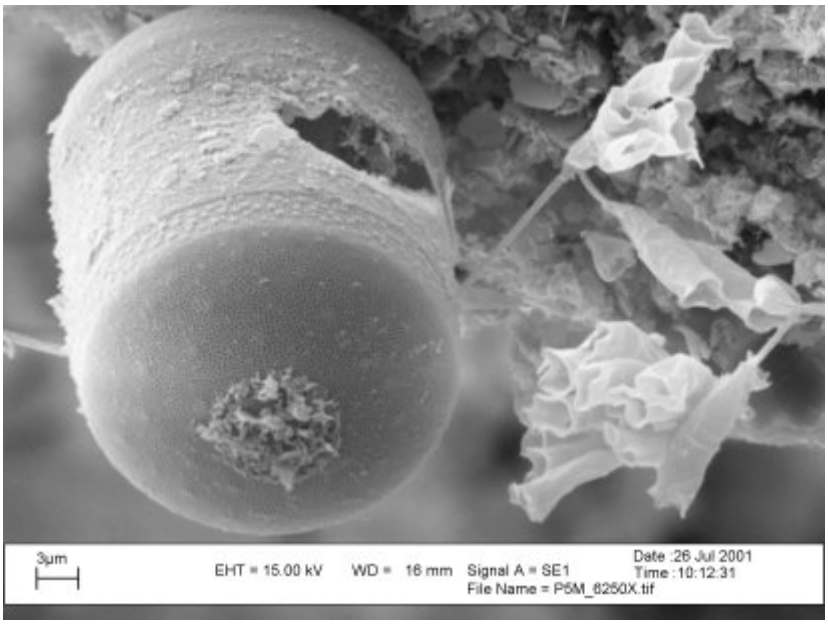


Plate 20
6250X magnification
High magnification
Diatom. 29 days exposure at 9 feet.

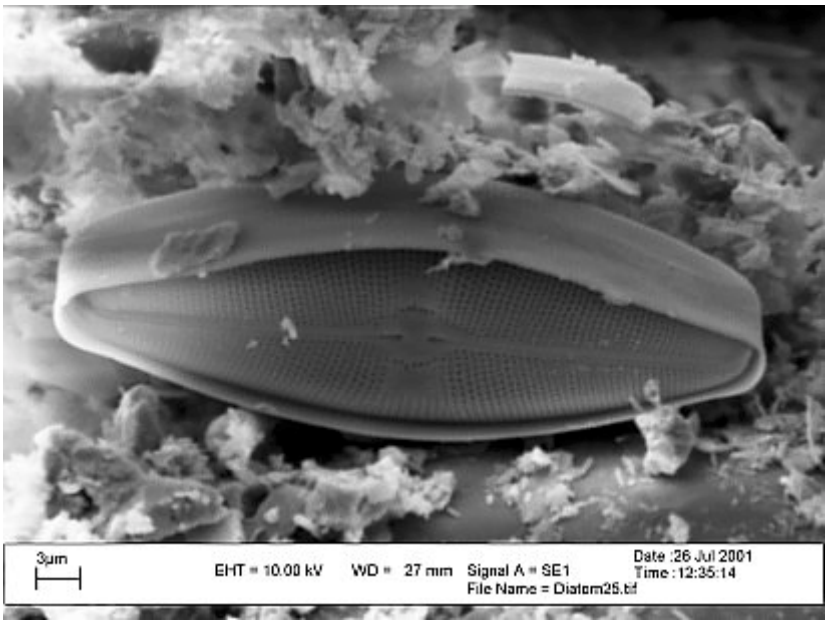


Plate 21
6250X magnification
High magnification
Diatom. 29 days exposure at 3 feet

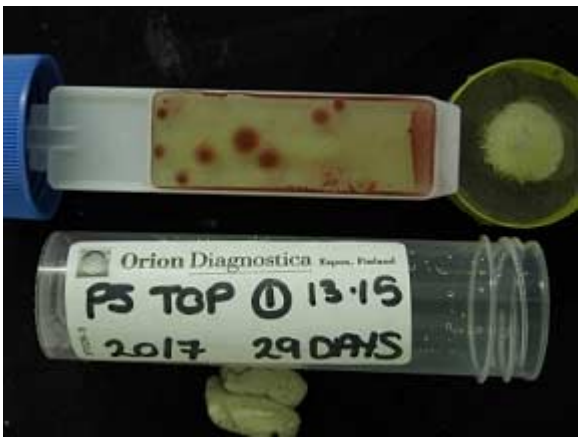


Plate 22
3 feet deep
29 days exposure
A typical dip-slide showing bacterial colonies

Plate 23
5 feet deep
11 days exposure
A typical dip-slide showing a fungal colony

Plate 24
29 days exposure
The top half of the agar plate shows bacterial colonies surrounding fibres from Gunderboom at 3 feet deep, the bottom half from 15 feet deep

Plate 25
9 feet deep
29 days exposure
Gunderboom fibres removed and placed on an agar plate; bacterial colonies can clearly be seen following the fibres.

Appendix 1

Permeability Raw Data: all measurements are given in ml/minute.

Control run on clean Gunderboom fabric throughout the trial.

Point No.	Date	Head								Blocked
		10	10	20	20	25	25	35	35	
		Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	
1	02/07/01	950	895	1040	1070	1380	1360	1780	1780	0
2	02/07/01	1010	990	1760	1740	1850	1820	2300	2260	0
3	02/07/01	650	510	990	960	1160	1140	1700	1620	0
4	11/07/01	1170	1110	1460	1430	1630	1650	2210	2210	0
5	11/07/01	920	930	1250	1170	1220	1220	1720	1600	0
6	11/07/01	810	710	890	940	1160	1130	1570	1540	0
7	20/07/01	1250	1210	1700	1650	1710	1700	2110	2130	0
8	20/07/01	1350	1260	1560	1280	1400	1370	1670	1660	0

Results of the two pieces of Gunderboom tested after 11 days exposure (02/07/01)

P1, Rope 2

	Point No.	Head								Blocked
		10	10	20	20	25	25	35	35	
		Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	
Top	1	532	538	1164	1175	1440	1415	2010	2005	9
3 feet	2	830	840	1510	1495	1720	1720	2135	2110	2
Middle	1	1150	1170	1590	1535	1720	1620	1970	1960	7
9 feet	2	1150	1120	1160	1180	1320	1110	1610	1320	14
Bottom	1	590	600	1180	1160	1300	1260	1840	1730	5
15 feet	2	850	860	1480	1500	1860	1870	2110	2050	5

P2, Rope 3C

	Point No.	Head								Blocked
		10	10	20	20	25	25	35	35	
		Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	
Top	1	810	790	1710	1660	1980	1940	2320	2140	7
3 feet	2	1020	960	1640	1640	1770	1740	2150	2120	8
Middle	1	530	580	1140	1130	1340	1300	1670	1620	15
9 feet	2	680	690	1450	1410	1550	1510	1890	1850	7
Bottom	1	650	570	980	920	1210	1120	1340	1330	17
15 feet	2	690	680	1050	1030	1280	1240	1660	1630	12

Results of the two pieces of Gunderboom tested after 20 days exposure (11/07/01)

P3, Rope 1C

	Point No.	Head								Blocked
		10	10	20	20	25	25	35	35	
		Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	
Top	1	340	330	450	430	470	460	610	610	54
3 feet	2	540	580	610	590	740	740	1360	1270	45
Middle	1	390	380	770	780	990	990	1400	1400	36
9 feet	2	580	580	1110	1110	1180	1130	1350	1330	20
Bottom	1	580	570	840	700	700	540	660	630	25
15 feet	2	610	520	820	800	780	720	910	920	25

P4, Rope 3

	Point No.	Head								Blocked
		10	10	20	20	25	25	35	35	
		Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	
Top	1	530	530	820	670	640	600	770	770	87
3 feet	2	550	540	870	830	720	680	870	890	72
Middle	1	900	820	910	860	830	800	1070	1040	28
9 feet	2	200	190	340	350	450	460	710	710	42
Bottom	1	500	470	680	600	620	590	720	730	98
15 feet	2	480	480	670	580	630	580	690	680	94

Results of the two pieces of Gunderboom tested after 29 days exposure (20/07/01)

P5, Rope 1

	Point No.	Head								Blocked
		10	10	20	20	25	25	35	35	
		Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	
Top	1	150	180	400	400	540	520	670	650	107
3 feet	2	320	320	640	720	920	870	1080	990	87
Middle	1	560	560	850	930	1030	1010	1250	1200	79
9 feet	2	500	500	930	930	1080	1090	1390	1340	80
Bottom	1	440	450	820	760	760	640	700	600	120
15 feet	2	240	250	400	370	380	340	400	360	119

P6 Rope 2C

	Point No.	Head								Blocked
		10	10	20	20	25	25	35	35	
		Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	
Top	1	230	230	430	420	460	430	500	480	110
3 feet	2	240	240	420	360	290	260	340	300	117
Middle	1	290	280	400	310	270	210	260	240	113
9 feet	2	220	230	430	390	400	340	430	410	102
Bottom	1	330	340	510	470	480	440	540	510	111
15 feet	2	370	370	580	630	590	560	710	680	102

FTA Gunderboom test 29 days

	Point No.	Piece Used	Side	Head								Blocked
				10	10	20	20	25	25	35	35	
				Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	
Middle	1	Pan 1	Front	0	0	14	13	20	19	26	27	120
	2			18	19	38	38	45	47	61	61	114
Middle	3	Pan 1	Back	110	110	170	170	190	190	250	250	94
	4			90	80	130	130	160	160	210	210	100
Middle	5	Pan 2	Front	15	15	29	31	37	44	54	52	118
	6			0	0	16	17	23	22	27	28	120
Middle	7	Pan 2	Back	85	80	150	150	180	180	220	230	100
	8			110	130	200	210	240	240	310	300	89
Lower	9	Pan 3	Front	80	80	120	120	140	140	170	170	100
	10			50	50	80	80	100	90	110	120	100
Lower	11	Pan 3	Back	180	170	260	260	290	280	350	350	81
	12			150	150	250	270	280	280	360	370	76

Appendix 2

Number of blocked holes in the Gunderboom fabric.

Ten randomly chosen rows were counted, each row consisted of 25 holes.

Count		1	2	3	4	5	6	7	8	9	10	Average	% Filled
11 Days													
P1	Top 3 feet deep	3	1	3	1	3	3	7	2	2	1	2.6	10.4
Rope 2	Middle 9 feet deep	2	2	1	1	1	3	3	4	1	2	2	8
	Bottom 15 feet deep	3	4	5	2	1	3	3	1	2	1	2.5	10
P2	Top 3 feet deep	1	2	1	3	2	1	3	0	5	1	1.9	7.6
Rope 3C	Middle 9 feet deep	5	3	4	1	4	2	3	2	1	1	2.6	10.4
	Bottom 15 feet deep	5	7	5	3	6	6	4	6	5	9	5.6	22.4
20 Days													
P3	Top 3 feet deep	4	6	9	10	7	7	4	6	4	7	6.4	25.6
Rope 1C	Middle 9 feet deep	7	6	4	4	5	5	8	6	5	8	5.8	23.2
	Bottom 15 feet deep	5	11	5	3	8	6	6	8	5	10	6.7	26.8
P4	Top 3 feet deep	5	15	4	3	7	8	10	14	10	11	8.7	34.8
Rope 3	Middle 9 feet deep	5	10	8	4	5	9	5	6	9	6	6.7	26.8
	Bottom 15 feet deep	7	12	7	8	12	10	7	6	8	6	8.3	33.2
29 Days													
P5	Top 3 feet deep	22	20	21	18	18	19	25	18	12	15	18.8	75.2
Rope 1	Middle 9 feet deep	17	17	10	16	22	19	21	19	17	18	17.6	70.4
	Bottom 15 feet deep	22	13	20	18	18	21	10	22	22	21	18.7	74.8
P6	Top 3 feet deep	23	24	22	25	25	25	25	25	25	25	24.4	97.6
Rope 2C	Middle 9 feet deep	16	23	19	15	18	16	18	27	18	14	18.4	73.6
	Bottom 15 feet deep	17	15	20	19	22	19	20	19	19	20	19	76

Appendix 3

Number of mussels found on the Gunderboom Fabric

Only one control panel was counted on each visit

		Day 11			Day 20			Day 29		
		P1	P2	C1	P3	P4	C2	P5	P6	C3
Top 3 feet deep	Front	0	0	0	0	4	3	10	10	10
	Back	0	0	0	2	0	-	6	6	-
Middle 9 feet deep	Front	0	0	0	1	7	3	12	27	15
	Back	0	0	0	0	0	-	10	6	-
Bottom 15 feet deep	Front	0	0	0	5	4	2	13	26	10
	Back	0	0	0	4	7	-	13	4	-

11 Days	Gunderboom Panel 1			Gunderboom Panel 2			Control Panel 1			Sterile Water		
Dip1	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	SW1	SW2	SW3
12hrs	x	x	x	x	x	x	x	x	x	x	x	x
24hrs	$<10^3$	x	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	x	x	x
30hrs	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	x	x	x
36hrs	10^3	$<10^3$	$<10^3$	$<10^3$	10^3	10^3	$<10^3$	$<10^3$	$<10^3$	x	x	x
42hrs	10^3-10^4	$<10^3$	$<10^3$	10^4	10^4	10^3	10^3	10^3	10^3	x	x	x
48hrs	10^4	10^3	10^4	10^4	10^4	10^3	10^3	10^3-10^4	10^3	x	x	x
54hrs	10^4	10^3	10^4	10^4	10^4	10^3	10^3	10^4	10^3	x	x	x
60hrs	10^4	10^3	10^4	10^4	10^4	10^3	10^3	10^4	10^3	x	x	x
72 hrs	10^4	10^3	10^4	10^4	10^4	10^3	10^3	10^4	10^3	x	x	x
84 hrs	10^4	10^3	10^4	10^4	10^4	10^3	10^3	10^4	10^3	x	x	x

	Gunderboom Panel 1			Gunderboom Panel 2			Control Panel 1		
Dip2	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
12hrs	x	x	x	x	x	x	x	x	x
24hrs	x	x	x	x	x	x	x	x	x
30hrs	x	x	x	x	x	x	x	x	x
36hrs	x	x	x	x	x	x	x	x	x
42hrs	x	x	x	x	x	x	x	x	x
48hrs	x	x	x	x	x	x	x	x	x
54hrs	x	x	x	x	x	x	x	x	x
60hrs	x	x	x	x	x	x	x	$<10^3$	x
72hrs	x	x	x	$<10^3$	x	x	x	$<10^3$	x
84hrs	$<10^3$	x	x	$<10^3$	x	x	x	$<10^3$	x

	Gunderboom Panel 1			Gunderboom Panel 2			Control Panel 1		
Dip3	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
12hrs	x	x	x	x	x	x	x	x	x
24hrs	x	x	x	x	x	x	x	x	x
30hrs	x	x	x	x	x	x	x	x	x
36hrs	x	x	x	x	x	x	x	x	x
42hrs	x	x	x	x	x	x	x	x	x
48hrs	x	x	x	x	x	x	x	x	x
54hrs	x	x	x	x	x	x	x	x	x
60hrs	x	x	x	x	x	x	x	x	x
72hrs	x	x	x	x	x	x	x	x	x
84hrs	x	x	$<10^3$	x	x	x	x	x	$<10^3$

11 days - Bacterial Dipslide Results

Dip 1 - 15mls of sterile water, shaken with 1cm^2 of fabric.

Dip 2 - 15mls of sterile water, shaken with 1 cm^2 of fabric and then had 4 serial dilutions performed by a factor of 10.

Dip 3 - water from dip 2 which had a further 4 serial dilutions performed by a factor of 10.

These dilutions would mean that if results from dip 1 showed 10^7 bacteria per ml, dip 2 results should show 10^3. As none of the results showed 10^7 bacteria per ml from dip 1, any bacteria growing in dips 2 and 3 are assumed to be contaminants resulting from the slides being inspected regularly.

Top - 3 feet deep
Middle - 9 feet deep
Bottom - 15 feet deep

20 Days	Gunderboom Panel 3			Gunderboom Panel 4			Control Panel 2			Sterile Water			Diluted River Water		
Dip1	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	SW1	SW2	SW3	1	2	3
12hrs	$<10^3$	x	x	x	x	x	x	x	x	x	x	x	x	x	x
24hrs	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	x	x	x	x	x	x	x
30hrs	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	$<10^3$	x	x	x	x	x	x
36hrs	10^3	10^3	10^4	10^3	10^3	10^{3}-10^4	10^3	10^4-10^5	$<10^3$	x	x	x	x	x	x
42hrs	10^3	10^3	10^4	10^3	10^3	10^{3}-10^4	10^3	10^4-10^5	$<10^3$	x	x	x	x	x	x
48hrs	10^6	10^5	10^5	10^4	10^4	10^5	10^5	10^6	10^3	x	x	x	$<10^3$	$<10^3$	$<10^3$
54hrs	10^6	10^5	10^5	10^4	10^4	10^5	10^5	10^6	10^3	x	x	x	$<10^3$	$<10^3$	$<10^3$
60hrs	10^6	10^5	10^5	10^4	10^4	10^5	10^5	10^6	10^3	x	x	x	$<10^3$	$<10^3$	$<10^3$
72 hrs	10^6	10^5	10^5	10^4	10^4	10^5	10^5	10^6	10^3	x	x	x	$<10^3$	$<10^3$	$<10^3$
84 hrs	10^6	10^5	10^5	10^4	10^4	10^5	10^5	10^6	10^3	x	x	x	$<10^3$	$<10^3$	$<10^3$

	Gunderboom Panel 3			Gunderboom Panel 4			Control Panel 2		
Dip2	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
12hrs	x	x	x	x	x	x	x	x	x
24hrs	x	x	x	x	x	x	x	x	x
30hrs	x	x	x	x	x	x	x	x	x
36hrs	x	x	x	x	x	x	x	x	x
42hrs	x	x	x	x	x	x	x	x	x
48hrs	x	x	x	x	x	x	x	x	x
54hrs	x	x	x	x	x	x	x	x	x
60hrs	x	x	x	x	x	x	x	x	x
72hrs	x	x	x	x	x	x	x	x	x
84hrs	x	x	x	x	x	x	x	x	x

20 Days Bacterial Dipslide Results

Dip 1 - 15mls of sterile water, shaken with $1cm^2$ of fabric.

Dip 2 - 15mls of sterile water, shaken with 1 cm^2 of fabric and then had 4 serial dilutions performed by a factor of 10.

Diluted River Water - 0.295mls of river water (the average amount held by $1cm^2$ of Gunderboom) added to 15mls of sterile water.

Top - 3 feet deep
Middle - 9 feet deep
Bottom - 15 feet deep

29 Days	Gunderboom Panel 5			Gunderboom Panel 6			Control Panel 3			Sterile Water			Diluted River Water		
Dip1	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	SW1	SW2	SW3	4	5	6
12hrs	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
24hrs	10^3	10^3	$<10^3$	$<10^3$	$<10^3$	$<10^3$	x	x	$<10^3$	x	x	x	x	x	x
30hrs	10^3	10^3	$<10^3$	$<10^3$	$<10^3$	$<10^3$	x	x	$<10^3$	x	x	x	x	x	x
36hrs	10^4	10^4	10^3	10^3	10^4	10^3	10^3	10^3	10^3	x	x	x	x	x	x
42hrs	10^5	10^4	10^3	10^4	10^4	10^3	10^4	10^4	10^3	x	x	x	x	x	x
48hrs	10^7	10^6	10^4	10^5	10^6	10^4	10^5	10^4	10^3	x	x	x	x	x	x
54hrs	10^7	10^6	10^4	10^5	10^6	10^4	10^5	10^4	10^3	x	x	x	x	x	x
60hrs	10^7	10^6	10^4	10^5	10^6	10^4	10^5	10^4	10^3	x	x	x	x	x	x
72 hrs	10^7	10^6	10^4	10^5	10^6	10^4	10^5	10^4	10^3	x	x	x	x	x	x
84 hrs	10^7	10^6	10^4	10^5	10^6	10^4	10^5	10^4	10^3	x	x	x	x	x	x

	Gunderboom Panel 5			Gunderboom Panel 6			Control Panel 3		
Dip2	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
12hrs	x	x	x	x	x	x	x	x	x
24hrs	x	x	x	x	x	x	x	x	x
30hrs	x	x	x	x	x	x	x	x	x
36hrs	x	x	x	x	x	x	x	x	x
42hrs	$<10^3$	x	x	x	x	x	x	x	x
48hrs	10^3	$<10^3$	x	x	x	x	x	x	$<10^3$
54hrs	10^3	$<10^3$	x	x	x	x	x	x	$<10^3$
60hrs	10^3	$<10^3$	x	x	x	x	x	x	$<10^3$
72hrs	10^3	$<10^3$	x	x	x	x	x	x	$<10^3$
84hrs	10^3	$<10^3$	x	x	x	x	x	x	$<10^3$

29 Days - Bacterial Dipslide Results

Dip 1 - 15mls of sterile water, shaken with 1cm^2 of fabric.

Dip 2 - 15mls of sterile water, shaken with 1 cm^2 of fabric and then had 4 serial dilutions performed by a factor of 10.

Diluted River Water - 0.295mls of river water (the average amount held by 1cm^2 of Gunderboom) added to 15mls of sterile water.

Top - 3 feet deep
Middle - 9 feet deep
Bottom - 15 feet deep

11 Days	Gunderboom Panel 1			Gunderboom Panel 2			Control Panel 1			Sterile Water
Live Count	**Top**	**Middle**	**Bottom**	**Top**	**Middle**	**Bottom**	**Top**	**Middle**	**Bottom**	**SW1**
First count	3	4	20	4	5	3	3	1	11	0
	11	2	0	2	2	0	1	1	1	0
	6	6	1	3	2	7	0	1	4	0
	5	6	26	2	7	12	0	3	2	0
	3	6	3	4	6	0	3	0	1	0
	2	4	5	6	5	1	2	2	5	0
	26	19	2	4	2	16	2	31	4	0
	10	2	2	3	5	3	4	4	6	0
	7	2	1	3	2	4	0	8	0	0
	8	7	0	5	2	0	1	4	3	0
	9	1	1	1	1	3	1	3	3	0
	6	4	2	2	0	6	2	3	7	0
	3	5	4	0	2	8	7	5	1	0
	6	4	3	9	3	3	2	0	2	0
	21	2	2	4	4	13	3	2	6	0
Average	**8.4**	**4.93333**	**4.8**	**3.46667**	**3.2**	**5.26667**	**2.06667**	**4.53333**	**3.73333**	**0**
Second count	10	11	3	4	8	1	14	6	1	0
	3	7	1	11	2	2	0	6	9	0
	4	29	0	3	3	5	0	9	0	0
	2	1	2	2	3	7	5	1	2	0
	0	8	15	12	8	1	1	3	0	0
	5	1	0	2	2	1	0	8	0	0
	3	2	2	2	1	1	2	3	2	0
	19	0	0	2	6	1	0	2	9	0
	10	3	5	7	2	2	3	4	2	0
	1	5	6	5	2	2	0	7	4	0
	3	8	3	4	1	10	1	7	4	0
	9	0	1	1	2	3	2	2	1	0
	13	4	0	5	13	3	2	4	3	0
	4	2	3	6	8	6	5	2	2	0
	6	2	2	2	16	6	1	2	5	0
Average	**6.13333**	**5.53333**	**2.86667**	**4.53333**	**5.13333**	**3.4**	**2.4**	**4.4**	**2.93333**	**0**

Live Count Results
(Number of rod-shaped bacteria per square).

All live counts were made from water left over after dip 1 (15mls of sterile water, shaken with 1cm^2 of fabric).

20 Days	Gunderboom Panel 3			Gunderboom Panel 4			Control Panel 2			Diluted River Water			Sterile Water
Live Count	**Top**	**Middle**	**Bottom**	**Top**	**Middle**	**Bottom**	**Top**	**Middle**	**Bottom**	**DRW 1**	**DRW 2**	**DRW3**	**SW1**
First Count	6	2	3	2	5	7	0	0	1	0	0	0	0
	10	1	1	5	4	0	2	0	0	0	0	0	0
	6	2	2	10	2	1	1	10	1	0	0	0	0
	3	6	0	1	6	6	0	0	2	0	0	0	0
	2	1	4	2	6	3	0	2	0	0	0	0	0
	4	0	1	3	8	2	6	1	0	0	0	0	0
	8	0	2	2	6	4	0	1	1	0	0	0	0
	5	3	2	5	2	2	0	3	0	0	0	0	0
	9	5	4	0	0	1	3	0	1	0	0	0	0
	0	3	2	1	0	0	4	4	0	0	0	0	0
	7	1	6	8	4	2	2	3	0	0	0	0	0
	0	2	13	1	4	7	0	2	0	0	0	0	0
	2	1	1	4	2	3	3	0	2	0	0	0	0
	3	1	2	1	6	2	1	1	6	2	0	0	0
	2	1	17	4	5	0	0	2	1	0	0	0	0
Average	**4.4667**	**1.93333**	**4**	**3.266667**	**4**	**2.66667**	**1.466667**	**1.933333**	**1**	**0.1333333**	**0**	**0**	**0**
Second count	1	2	0	4	3	1	0	1	0	0	0	0	0
	13	0	1	5	1	2	0	1	2	0	0	0	0
	2	2	2	43	2	1	3	2	5	0	0	0	0
	6	3	11	3	5	2	0	0	3	0	0	0	0
	21	4	6	3	42	2	0	2	1	0	0	0	0
	2	0	5	0	0	3	1	8	0	0	0	0	0
	1	2	3	9	3	3	0	1	2	0	0	0	0
	8	1	1	6	3	2	0	2	1	0	0	0	0
	3	1	0	2	1	4	0	3	5	0	0	0	0
	10	0	1	7	6	3	0	6	11	0	0	0	0
	4	1	4	3	12	4	2	1	1	0	0	0	0
	4	0	3	0	4	0	2	2	1	0	0	0	0
	9	2	6	1	11	2	4	2	0	0	0	0	0
	13	0	3	3	6	4	0	1	0	0	0	0	0
	4	0	4	2	3	6	2	3	0	0	0	0	0
Average	**6.7333**	**1.2**	**3.333333**	**6.066667**	**6.8**	**2.6**	**0.933333**	**2.333333**	**2.133333**	**0**	**0**	**0**	**0**

29 Days	Gunderboom Panel 5			Gunderboom Panel 6			Control Panel 3			Diluted River Water			Sterile Water
Live Count	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	DRW 4	DRW 5	DRW 6	SW1
Count 1	21	12	17	2	8	14	5	2	3	1	1	0	0
	4	17	8	15	2	40	13	5	1	4	0	3	0
	1	3	51	10	0	13	8	1	17	3	0	0	0
	5	8	12	4	6	10	5	1	2	5	1	0	0
	4	22	9	2	3	3	10	6	5	0	2	0	0
	15	1	15	15	3	5	7	9	6	0	1	0	0
	13	8	7	5	2	6	5	5	20	4	0	0	0
	19	10	4	6	6	4	8	5	15	3	1	0	0
	15	10	12	4	5	10	4	6	6	4	1	0	0
	7	9	17	35	12	7	4	5	4	3	3	2	0
	25	8	28	9	5	11	9	7	7	3	0	2	0
	9	8	7	12	13	7	7	7	9	5	2	1	0
	9	18	13	5	33	10	8	7	2	1	0	1	0
	5	55	7	2	11	8	13	15	4	2	2	1	0
	14	7	14	19	4	3	3	3	4	1	2	2	0
Average	**11.0667**	**13.0667**	**14.7333**	**9.66667**	**7.53333**	**10.0667**	**7.26667**	**5.6**	**7**	**2.6**	**1.0667**	**0.8**	**0**
Count 2	2	16	11	8	15	6	4	6	2	3	1	1	0
	13	6	15	4	3	5	2	2	2	0	0	2	0
	9	3	5	2	1	16	4	3	3	0	0	3	0
	4	1	9	6	5	7	3	4	5	0	0	6	0
	2	8	20	5	25	25	12	0	6	0	0	4	0
	4	6	25	5	1	9	25	5	3	2	0	4	0
	2	7	16	2	1	10	8	5	4	18	1	0	0
	3	12	9	2	21	6	6	1	5	2	0	4	0
	9	16	6	44	3	8	7	10	7	1	0	4	0
	6	14	7	7	2	11	2	1	1	0	5	6	0
	1	22	22	9	0	4	18	15	2	1	0	0	0
	5	13	19	3	2	12	8	5	2	1	0	0	0
	9	20	15	13	28	5	9	20	3	0	2	0	0
	22	11	6	8	3	4	2	15	3	1	1	2	0
	10	6	8	10	3	5	8	0	10	3	1	2	0
Average	**6.73333**	**10.7333**	**12.8667**	**8.53333**	**7.53333**	**8.86667**	**7.86667**	**6.13333**	**3.86667**	**2.13333**	**0.7333**	**2.53333**	**0**

Stained Slide Count - 11 Days

Gunderboom Panel 1	1st count	2nd count	3rd count	4th count	5th count	6th count
Top	6	11	22	11	3	13
	13	30	31	15	13	12
	5	10	13	18	9	16
	19	6	40	15	5	13
	10	19	13	16	12	14
Average	**10.6**	**15.2**	**23.8**	**15**	**8.4**	**13.6**
Middle	5	4	7	1	0	35
	3	5	4	4	0	49
	6	3	5	3	1	27
	6	1	1	4	3	21
	14	2	13	11	5	10
Average	**6.8**	**3**	**6**	**4.6**	**1.8**	**28.4**
Bottom	4	6	9	3	3	33
	1	4	4	1	6	9
	2	3	9	1	0	5
	3	0	5	7	6	10
	3	1	11	3	7	8
Average	**2.6**	**2.8**	**7.6**	**3**	**4.4**	**13**

Gunderboom Panel 2	1st count	2nd count	3rd count	4th count	5th count	6th count
Top	7	24	3	9	3	3
	3	5	6	0	18	9
	5	6	4	1	1	1
	6	13	0	17	2	5
	5	9	2	9	2	3
Average	**5.2**	**11.4**	**3**	**7.2**	**5.2**	**4.2**
Middle	16	3	3	12	3	16
	15	6	26	14	13	8
	9	6	23	5	4	0
	9	8	17	3	5	13
	11	5	15	9	3	13
Average	**12**	**5.6**	**16.8**	**8.6**	**5.6**	**10**
Bottom	5	7	9	2	7	12
	0	3	9	5	4	6
	0	1	4	6	2	1
	17	0	2	5	8	8
	7	4	5	2	3	7
Average	**5.8**	**3**	**5.8**	**4**	**4.8**	**6.8**

Control Panel 1	1st count	2nd count	3rd count	4th count	5th count	6th count
Top	6	28	3	7	0	6
	1	15	6	6	1	2
	0	9	1	9	8	4
	0	3	6	2	1	5
	6	9	7	13	6	1
Average	**2.6**	**12.8**	**4.6**	**7.4**	**3.2**	**3.6**
Middle	2	3	3	32	1	15
	1	3	0	2	16	18
	3	0	2	2	3	14
	2	0	7	1	6	4
	11	5	1	2	23	0
Average	**3.8**	**2.2**	**2.6**	**7.8**	**9.8**	**10.2**
Bottom	25	12	4	23	2	7
	2	14	12	15	3	3
	4	3	6	13	2	6
	8	14	7	13	3	4
	23	15	13	17	3	12
Average	**12.4**	**11.6**	**8.4**	**16.2**	**2.6**	**6.4**

Stained Slide Results (Number of bacteria per square of eyepiece graticule)

All stained slide counts were made using the water resulting from dip 1 (1cm^2 block of Gunderboom shaken in 15mls of sterile water).

Stained Slide Count - 20 Days

Gunderboom Panel 3	1st count	2nd count	3rd count	4th count	5th count	6th count
Top	29	10	19	8	70	45
	15	8	4	3	6	5
	65	5	8	15	6	7
	10	8	22	14	11	4
	6	30	16	250	7	7
Average	**25**	**12.2**	**13.8**	**58**	**20**	**13.6**
Middle	70	2	11	2	5	55
	3	0	12	2	3	5
	2	2	1	11	0	8
	5	8	3	6	0	0
	4	10	21	13	1	2
Average	**16.8**	**4.4**	**9.6**	**6.8**	**1.8**	**14**
Bottom	2	7	14	62	2	15
	9	9	10	3	44	9
	7	3	48	4	6	8
	5	6	4	2	29	23
	6	16	3	9	1	12
Average	**5.8**	**8.2**	**15.8**	**16**	**16.4**	**13.4**

Gunderboom Panel 4	1st count	2nd count	3rd count	4th count	5th count	6th count
Top	19	300	17	13	13	0
	11	300	50	6	2	3
	6	150	4	18	6	6
	9	300	4	16	5	14
	48	150	13	9	4	21
Average	**18.6**	**240**	**17.6**	**12.4**	**6**	**8.8**
Middle	16	8	14	0	9	1
	7	9	17	8	2	9
	21	17	5	2	4	19
	7	13	12	65	11	37
	17	10	8	4	9	9
Average	**13.6**	**11.4**	**11.2**	**15.8**	**7**	**15**
Bottom	15	3	1	13	24	3
	4	9	6	32	5	7
	6	5	8	5	17	2
	10	3	5	17	15	4
	19	31	11	1	10	9
Average	**10.8**	**10.2**	**6.2**	**13.6**	**14.2**	**5**

Control Panel 2	1st count	2nd count	3rd count	4th count	5th count	6th count
Top	5	25	13	2	10	5
	1	0	5	33	13	14
	14	29	4	2	5	25
	4	45	6	3	6	7
	2	13	7	5	3	12
Average	**5.2**	**22.4**	**7**	**9**	**7.4**	**12.6**
Middle	8	19	9	5	5	3
	58	16	9	14	6	9
	16	35	10	5	8	10
	3	14	16	4	8	5
	17	9	7	4	5	4
Average	**20.4**	**18.6**	**10.2**	**6.4**	**6.4**	**6.2**
Bottom	15	4	12	5	7	45
	3	1	13	4	21	9
	4	1	6	13	8	22
	2	9	12	46	5	27
	5	3	8	8	5	62
Average	**5.8**	**3.6**	**10.2**	**15.2**	**9.2**	**33**

Stained Slide Count - 29 Days

Gunderboom Panel 5	1st count	2nd count	3rd count	4th count	5th count	6th count
Top	11	19	4	125	15	23
	100	18	61	150	60	20
	84	23	25	22	14	150
	76	11	31	19	5	22
	16	15	20	70	14	30
Average	**57.4**	**17.2**	**28.2**	**77.2**	**21.6**	**49**
Middle	45	105	29	3	44	35
	33	23	70	12	75	21
	32	25	13	11	18	60
	75	75	80	25	75	25
	23	75	25	33	150	19
Average	**41.6**	**60.6**	**43.4**	**16.8**	**72.4**	**32**
Bottom	25	25	44	20	17	25
	62	8	21	40	18	75
	5	140	180	25	30	16
	25	140	22	14	31	15
	30	30	25	17	11	300
Average	**29.4**	**68.6**	**58.4**	**23.2**	**21.4**	**86.2**

Gunderboom Panel 6	1st count	2nd count	3rd count	4th count	5th count	6th count
Top	15	150	15	10	8	11
	26	20	17	300	7	8
	40	150	60	13	14	4
	18	5	27	33	19	16
	75	15	75	40	9	20
Average	**34.8**	**68**	**38.8**	**79.2**	**11.4**	**11.8**
Middle	110	40	18	24	50	4
	8	14	8	40	4	10
	22	16	0	0	16	30
	16	28	56	8	6	14
	6	4	140	300	46	58
Average	**32.4**	**20.4**	**44.4**	**74.4**	**24.4**	**23.2**
Bottom	60	35	80	14	20	7
	5	8	10	10	70	12
	18	100	14	17	40	48
	12	20	200	150	30	11
	20	24	100	18	22	225
Average	**23**	**37.4**	**80.8**	**41.8**	**36.4**	**60.6**

Control Panel 3	1st count	2nd count	3rd count	4th count	5th count	6th count
Top	30	30	17	12	17	85
	13	23	26	21	35	27
	300	14	40	12	35	75
	22	25	75	11	27	25
	65	10	24	15	17	5
Average	**86**	**20.4**	**36.4**	**14.2**	**26.2**	**43.4**
Middle	8	70	16	75	10	75
	4	25	22	26	35	100
	27	60	8	19	30	23
	21	17	100	75	15	11
	5	40	20	40	75	8
Average	**13**	**42.4**	**33.2**	**47**	**33**	**43.4**
Bottom	300	3	100	75	275	10
	39	24	200	275	15	27
	45	14	70	300	17	12
	14	17	150	150	10	200
	8	275	12	150	15	150
Average	**81.2**	**66.6**	**106.4**	**190**	**66.4**	**79.8**