

**A STUDY OF THE ECOLOGY OF BENTHIC ALGAE USING
ARTIFICIAL SUBSTRATES IN AN IRRIGATION CANAL OF THE
BREEDE RIVER, WESTERN CAPE, SOUTH AFRICA.**

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**ABSTRACT:**

The viability of using artificial substrates (plastic petri-dishes) for sampling benthic algae, in a Breede River irrigation canal was investigated and in so doing the general ecology of these alga was investigated. Sampling took place between March and September. The effect environmental conditions (water temperature, water speed, conductivity, pH and turbidity), time of exposure, water level and texture of substrates had on the number of species, algal cover and the number and abundance of different algal forms was investigated. Canonical correspondence analysis was used to identify the most important conditions affecting samples. It was found that temperature and conductivity were the most important factors determining community structure. Small diatoms were the most common algal form. The cover and species number of samples differed between sites, and at different water levels, most probably both differences as a result of varying turbidity. Samples exposed for a month had higher algal cover, but lower number of species than those exposed for two weeks. Sanding the petri-dishes resulted in an overall decrease in number and abundance of species. However, filamentous algae (mostly *Sitgeoclonium*), increased in abundance on roughened surfaces. Using artificial surfaces for sampling benthic algae in these canals appears to be feasible and, although the community sampled may not be representative of the natural community, this may be a very useful tool in studying the biology of these alga.

INTRODUCTION:

Water is a valuable commodity, especially in arid and semi-arid countries such as South Africa. Organisms associated with this resource may affect, or give an indication of the water quality (Stevenson et al., 1996). Benthic algae for example are excellent indicators of the condition of most aquatic ecosystems (Stevenson et al., 1996).

Benthic algae are algae that live on, or in association with substrata. These consist mostly of diatoms (Bacillariophyta), blue-green algae (Cyanophyta), green algae (Chlorophyta) and red algae (Rhodophyta) (Stevenson, 1996). These algae are important primary producers, and, as a link between the chemical-physical and biotic components in the food web (Stevenson, 1996; Biggs, 1996; Lowe and Pan, 1996), they are ideal organisms to use in monitoring water quality. In addition the primarily sessile nature and short life cycles of benthic algae allow them to respond directly and rapidly to environmental changes and the large number of species found in a small area provides much information for monitoring (Lowe and Pan, 1996).

Benthic algae may also have a more direct affect on water quality. By converting inorganic chemicals into organic forms, benthic algae are considered important nutrient sinks (Stevenson, 1996; Biggs, 1996) and may help purify streams (Vymazal, 1988; Uehlinger, 1991). Water quality is not always positively affected by benthic algae. Under favourable conditions certain "weedy" species proliferate. These algal blooms may disrupt the functioning of water systems by negatively affecting other natural biota of the system, impeding the flow of water and blocking irrigation jets. In South Africa, limited knowledge has frustrated attempts at controlling these problem species and control is costly and usually only temporary. A better understanding of the ecology of weedy species may make it possible to predict and anticipate these problem growths and facilitate the development of better control methods (Joska and Bolton, 1994).

Increasing our knowledge of benthic algae may help improve many aspects of water management and as a result these organisms have been intensively studied in many countries (Stevenson et al., 1996), however, unfortunately South Africa has been slow to follow this trend (Joska and Bolton, 1994). In spite of this increased attention on benthic algae, there are still large gaps in our understanding of these organisms. This may be largely due to the problems involved with sampling (John and Moore, 1985) as there is a clear need to simplify and standardise methods (Cazaubon, 1991).

The study of benthic algal communities or species is complicated by patchiness of the substrata (Rott, 1991) in an unstable and often very heterogenous environments (John and Moore, 1985). The surface, composition, texture, gross shape, size and orientation and depths of natural substrata is variable (Austin et al., 1981). Natural substrates are also not ideal for studying benthic algae because of the difficulty in removing the organisms from the surface. Prostrate green algae for example break easily when attempting to remove them from natural substrates (John and Johnson, 1991). This may cause a bias toward species like diatoms which are less easily damaged during sampling (John and Johnson, 1991; Rott, 1991).

In order to overcome these problems artificial substrates have been widely used in sampling (Oemke and Burton, 1986; Biggs, 1996; Lowe and Pan, 1996). These surfaces make it easy to standardise potentially influencing variables such as light, current and nature of substrate (Austin et al., 1981; Lowe and Pan, 1996). This makes replication possible (Austin et al., 1981; John and Johnson, 1991; Rott, 1991). In some situations, for example in canals where there is a shortage of natural surfaces, artificial substrates are one of the few practical ways to sample and detect microalgae (John and Johnson, 1991).

Although widely used, there is still much debate over the validity of using artificial substrates for sampling. There is some uncertainty concerning the relationship between the communities that develop on the artificial substrates and those

found on natural substrata (John and Johnson, 1991). Ideally the artificial substrate should provide a fair representation of the natural population and should not influence the growth dynamics or be biased against any particular organisms (Austin et al., 1981). The results of using artificial substrate are however often only partially representative of communities found on natural substrata (Lowe and Pan, 1996).

Methods of using artificial substrates should not alter the environmental variables in any way (Austin et al., 1981). Suitable artificial substrates should also be transparent, inconspicuous, inexpensive, disposable, easily manipulated and positioned in the river and tough enough to withstand the conditions it will be placed in (John and Johnson, 1991).

Within these criteria there is a need for well-defined and widely accepted methods and standardised apparatus for sampling benthic algae (Austin et al., 1981). Glass slides are commonly used (Hoagland et al., 1982; John and Moore, 1985; Austin et al., 1981), but polythene or plastics have also been used with success (eg Backhaus, 1967, Klasvic, 1974, Williams, 1978, Antoine and Benson-Evans, 1985, 1986, Thorpe and Williams 1980, John et al., 1990 cited by John and Johnson, 1991; John and Moore, 1985).

The aim of this study is to test the suitability of using polystyrene petri-dish covers (as suggested by John and Moore (1985)) as an artificial substrate in canal systems of the Breede River, South Africa, and in so doing gain a preliminary insight into the benthic algal ecology of this habitat. The sampling dishes were placed at different levels in the water column, exposed for different lengths of time, and sanded or left smooth to determine, which, if any treatments would be best to use in future studies.

STUDY SITE:

The area of the Breede River valley is semi-arid and the Breede River Irrigation Scheme is used to provide water to the farms in the area. The Breede River Irrigation Scheme consists of 4 canal systems, which obtain water from the Breede River at various

points between the Worcester District and Bonnivale (Joska and Bolton, 1994). Initially two sites along each of the of the La Chasseur and Sandrift canals were chosen. Maintenance work on the Sandrift canal resulted in it being dry for a large portion of the study period, so only data from the La Chasseur canal is used in this analysis. Site A in the La Chasseur Canal was situated near the source while site B was positioned at the lower end of the canal system. Maintenance work on this canal also meant that it was periodically dry, with site A empty when visited on the 11 July, and site B dry between the 26 June and 11 July and on the 7 August.

During the dry summer months water from the Kwaggaskloof Dam is supplied to the Breede river to maintain water flow in the canals (Joska and Bolton, 1994). The Kwaggaskloof canal inlet to the La Chasseur canal was closed on the 17 April in the year this study took place. The Brandevlei pump station which pumps water into the Breede river was stopped on the 31 May.

METHODS:

Sampling methods:

As suggested by John and Moore, (1985), the bases of 9 cm diameter plastic (polystyrene) petri-dishes were used as artificial substrates. Half of each dish was sanded and the rest left smooth in order to determine if this would affect colonisation. The petri-dishes were attached to a perspex sheet by means of bolts through holes made in the centre of the dish. The sampling dishes were positioned in two rows (of six dishes each) 20 centimetres apart. Once positioned in the water, the upper level of dishes was approximately 15 cm away from the water surface. However, this level was not constant as the water level fluctuated constantly. The entire apparatus was placed in the water and anchored by looping a chain, attached to the board, around a stake, or one of the poles that run across the canal. Care was taken to position and secure the board against the canal wall, at right angles to the direction of flow. This was done by means of bricks attached to the perspex board.

Sampling took place every two weeks between March and September

1996. At each site the surface illumination and the illumination at both levels of petri dishes was measured using a Skye Quantum Sensor. The pH was determined using pH paper (Merck Spezialindikator pH-Indikatorstäbchen), while a YSI Conductivity Meter was used to measure conductivity and temperature. The surface water speed was estimated by measuring the time that an apple took to float 10 meters. This was repeated three times, and the values averaged to obtain the mean surface water velocity. Rainfall data for the area was obtained from the South African Weather Bureau.

In order to determine the most suitable period of immersion and how exposure time affects the communities, half (3) of the dishes at each level were removed every two weeks, while the rest were removed after a month of submergence. All removed dishes were replaced with new ones.

Once removed, samples were placed in a cooler box in separate plastic bags and returned to the laboratory where they were kept in water in a 20°C room until they could be examined. The petri-dishes were washed gently under a tap to remove excess loose debris and the undersides were cleaned thoroughly. Each half (sanded or smooth) was examined separately. The percentage cover was estimated. Identification of most of the smaller algae, especially the diatoms, requires expertise and experience, and many small green algae require culturing before positive identification can be made (John and Johnson, 1991). Unidentified species were given arbitrary labels which were used throughout the sampling period. All separate taxa were noted and their abundance was estimated on a scale of 1-9 (with 1 being present, 5 being common and 9 being dominant).

Statistical analysis:

To determine if the environmental conditions (temperature, water speed, turbidity, conductivity and pH) differed between the two sites a Paired T-test was used to compare the measurements taken at the different sites, but on the same date. Correlation coefficients were calculated in order to determine if there was

a linear relationship between species number and cover, and the environmental conditions that were measured.

Because the data was non-parametric, the Wilcoxon Matched Pairs Test was used to ascertain if sanding, level and time of exposure affected the overall number of species and cover of benthic algae. The samples were then divided up into those from sites A and B and the Wilcoxon Matched Pairs Test was repeated the same as above. A Wilcoxon Matched Pairs Test was also used to determine if the species number and cover differed between the two sites.

The algal taxa were divided up into large diatoms (greater than 40 μm), small diatoms (smaller than 40 μm), filamentous green algae, non-filamentous green algae, and blue-green algae and once again the Wilcoxon Matched Pairs Test was used to ascertain whether position, sanding, time of exposure and site affected the number of species found in each group and their overall abundance.

TWINSPAN analysis and Canonical Correspondence Analysis (CCA) were used in order to determine if the sites were grouped and if so, what was most important in causing this trend. The tests were conducted using the abundance values of each species identified at each site under each treatment (ie sanding, level, time of exposure). (The average value of the 3 replicates for each treatment was used). An Unrestricted Monte Carlo Test was used to test if the environmental variables were significantly correlated with the CCA data.

RESULTS:

Environmental conditions:

Of all the environmental variables recorded, only turbidity (measured as the proportion of light reaching the level) differed significantly between the two sampling sites. The lower level of site A was found to be more turbid than that of site B ($t = -2,688$; $df = 5$; $p = 0,0434$), while the top levels were not significantly different. Within sites A and B the proportion light reaching the upper levels was significantly higher than that reaching the lower levels ($t = 5,918$; $df = 10$; $p = 0,00015$

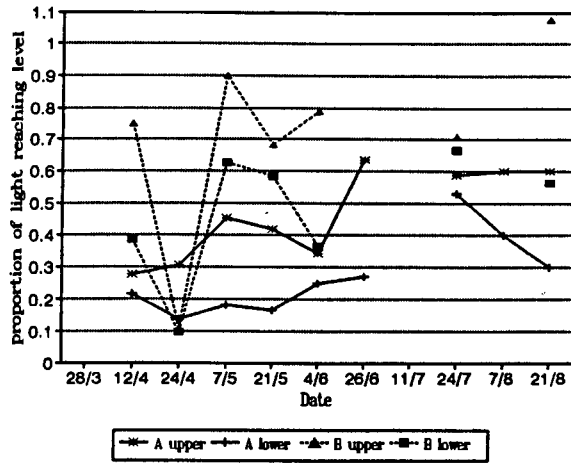


Figure 1: Seasonal variation in water turbidity, measured the proportion of light reaching different levels sites A and B.

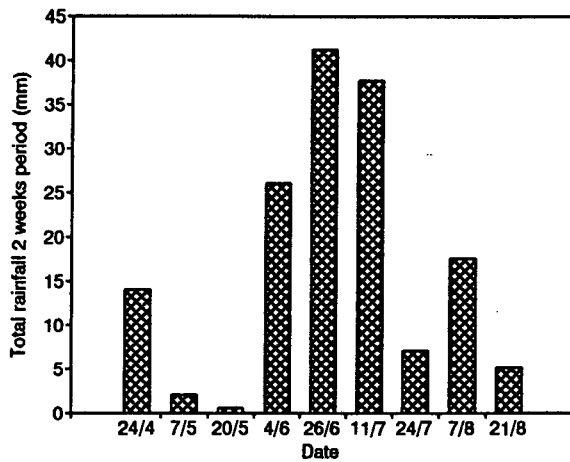


Figure 2: Total rainfall for the that fell in the study area in the two weeks prior to the given date.

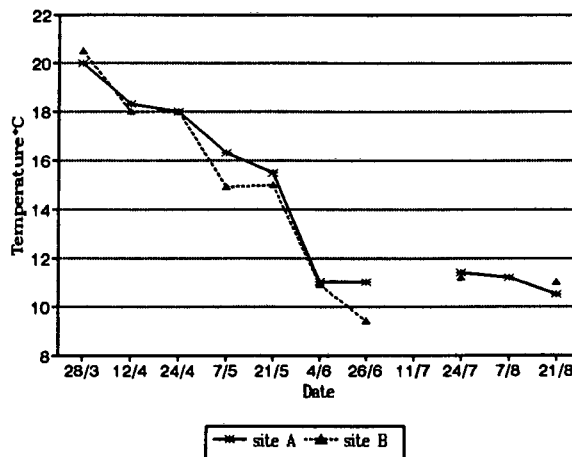


Figure 3: Seasonal variation in temperature at sites A and B.

and $t = 3,599$; $df = 8$; $p = 0,0070$ for sites A and B respectively). The change in the turbidity over time is illustrated in Figure 1, which clearly illustrates these differences with the notable exception on the 24 April when the turbidity at site B increased markedly (the proportion of light reaching that level decreased) to a level higher than that of site A.

Figure 2 summarises the rainfall that occurred in the study period. This shows a dramatic increase in rainfall from the two weeks leading up to the 4 June, followed by a significant decrease in rainfall after the 11 July.

The water temperature decreased rapidly from approximately 20°C to 11°C between the start of the study (28 March) and 4 June, after which the temperature levelled out at roughly 11°C (illustrated in Figure 3). In contrast conductivity (shown in Figure 4) showed a general trend to increase up to the 26 June, following the gap in the data on the 11 July, conductivity fell.

Both pH and water speed changed little over time (Figure 5 and 6 respectively). The water was found to be acidic with a mean pH of 5,38 (std = 0,214) and the surface water velocity had a mean of $1,824 \text{ cm.s}^{-1}$ (std = 0,205).

General trends:

Figures 7 and 8 illustrate the trends in overall species number and cover respectively. Both measures showed a marked decrease occurring between 20 May and 26 June for monthly sampling, and 4 June and 26 June for bimonthly sampling. Excluding this anomaly there was a general trend of increasing species number over the period of study, while algal cover fluctuated, but showed no distinct trend. The trends in the average number of species in each algal group are shown in Figure 9, while Figure 10 illustrates the change in the average abundance values of each group over time. Both graphs clearly show that the small diatoms, were dominant in both abundance and number and contributed largely to the overall pattern described above. The filamentous green algae also showed the dramatic dip in abundance, but as

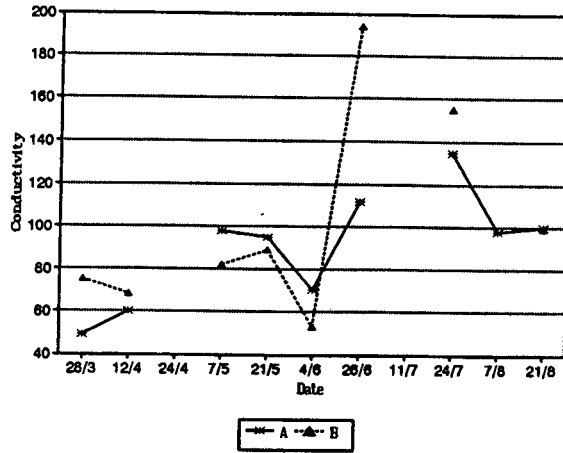


Figure 4: Seasonal variation in conductivity at sites A and B.

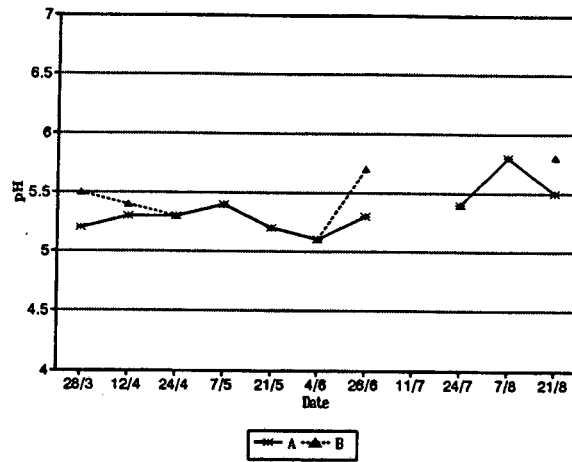


Figure 5: The range of pH recorded over the study period.

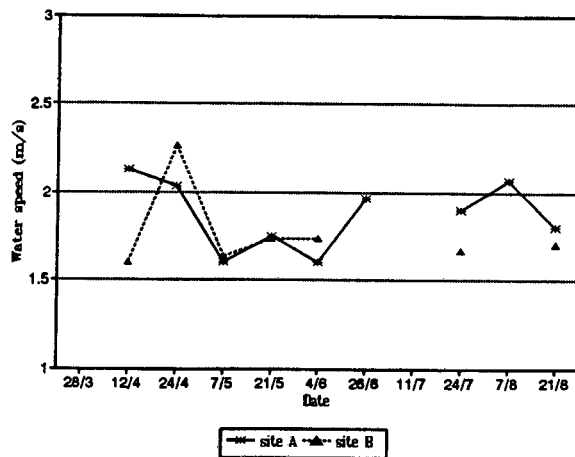


Figure 6: The range of water speeds recorded at sites A and B.

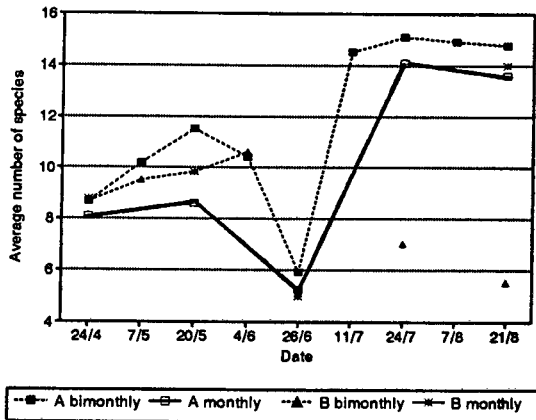


Figure 7: The seasonal variation in the average number of species found on bimonthly and monthly samples in sites A and B.

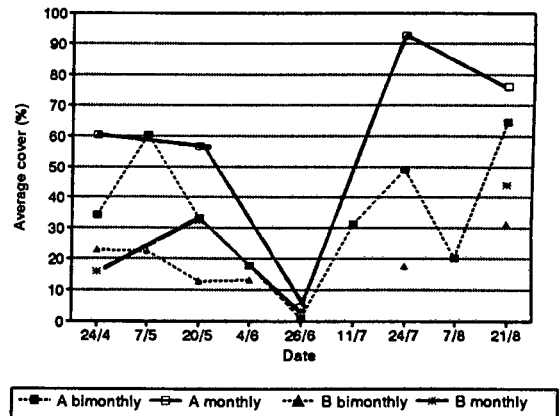


Figure 8: The seasonal variation in the average algal cover found on bimonthly and monthly samples in sites A and B.

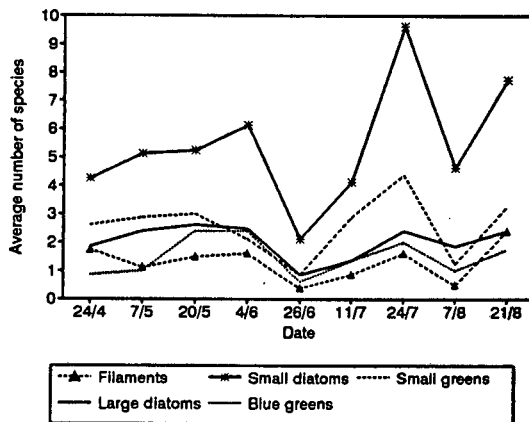


Figure 9: The seasonal variation in the average number of species found in each of the 5 algal form groups.

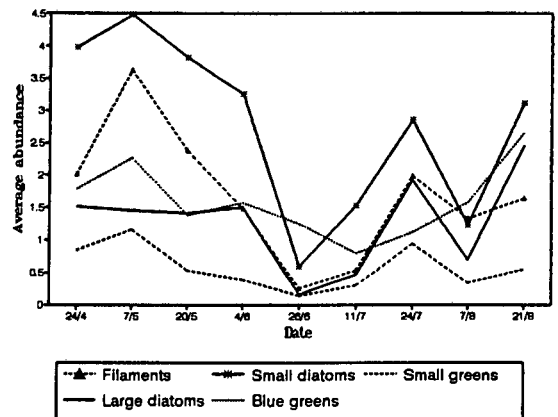


Figure 10: The seasonal variation in the average abundance value in each of the 5 algal form groups.

with most other groups the average number of species remained low and constant. The large diatoms followed a similar, but less dramatic trend in abundance to that of the filamentous green algae. The blue-green and non-filamentous green algae had the most constant abundance, although the number of species of non-filamentous green algae did not fluctuate significantly more than that of other groups excluding the small diatoms.

The small diatom group was characterised by generalist species such as *Cocconies*, *Navicula* and *Fragilaria*, and were found in most sites throughout the sampling period. The large diatom group had few species and consisted mostly of *Rhopaloidia*, *Gyrosigma* and *Pinnularia* species, which occurred in low numbers throughout the year. Small, non-filamentous algae included a few desmids, colonial cells, all of which occurred sporadically. *Stigeoclonium* was the most common filamentous algae observed and this species occurred throughout the sampling period, if only as basal cells. *Oedogonium* was also found fairly regularly, while the only other filamentous species found were *Rhizoclonium* and *Enteromorpha*, which appeared only in one sample in March. The blue-green algal group was also small and species rare with the most common species being *Oscillatoria*, and an unidentified thin filamentous form.

Table 1 shows that of the environmental factors measured, % cover was most strongly correlated with pH and weakly correlated with conductivity and water velocity. Species number was found to be most strongly correlated with pH and conductivity and weakly correlated with water speed and turbidity.

The results of the TWINSpan analysis and CCA showed that the sites were separated primarily by the date of sampling. Samples taken before the 26 June were found to be most different from those taken after that date. In some cases sites A and B were grouped separately within the major divisions. Although the results of the CCA (summarised in Table 2 and Figure 11) showed the groupings to be weak (eigenvalues: axis 1 = 0.219; axis 2 = 0.0187) the Unrestricted Monte Carlo Test showed that the environmental variables were significant in explaining the data

Table 1: Correlation coefficients for environmental variables vs algal cover and number of species (* represents significant correlations).

	Cover	Species no.
Temperature	0.01	0
Conductivity	0.36*	0.7*
pH	0.52*	0.6*
Speed	0.38*	0.3*
Turbidity	-0.1	0.2*

Table 2: Eigenvalues and canonical coefficients of the first and second axis of the CCA.

	Axis 1	Axis 2
Eigenvalues	0.219	0.087
Environmental variables: coefficients		
Turbidity	0.11	0.27
pH	0.72	0.37
Conductivity	0.62	-0.41
Current velocity	0.46	0.21
Temperature	0.72	0.22
Rainfall	0.12	-0.16
Exposure time	-0.04	0.44
Sanding	-0.05	0.21
Level	0.01	0.02

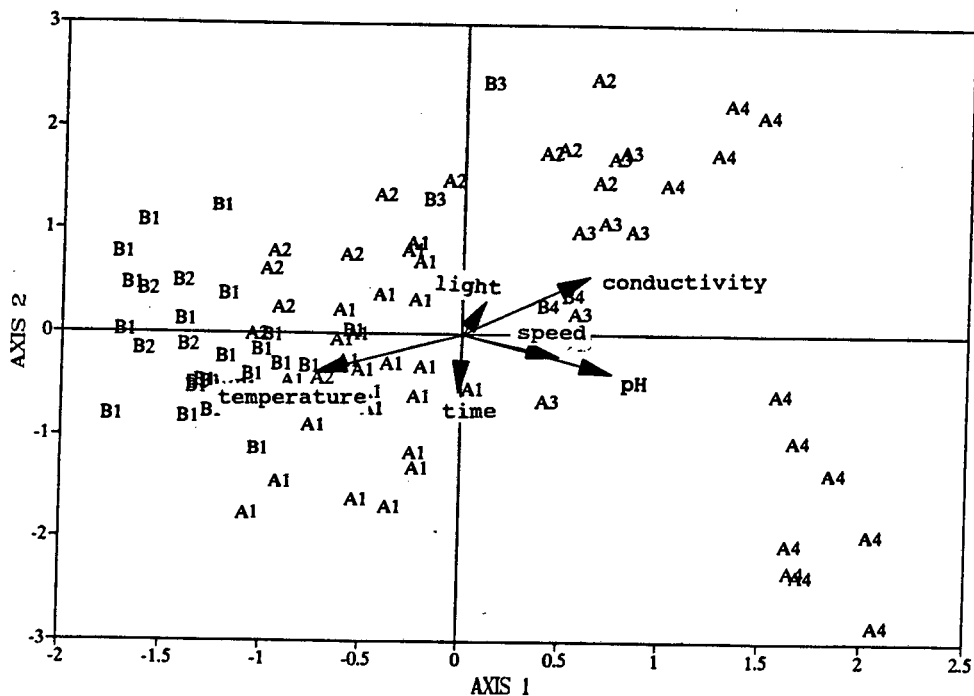


Figure 11: A CCA ordination diagram of sample and environmental biplot scores.

KEY: A - site A
 B - site B

Dates removed:
 1 - 24/4-4/6
 2 - 4/6-11/7
 3 - 11/7-24/7
 4 - 24/7-21/8

(eigenvalue = 0.22; F-ratio = 13,48; p = 0.01). Conductivity, pH, current velocity and temperature were all found to be well correlated with the axes, unlike exposure time, position on apparatus (level) and rainfall.

The effect of site:

Table 3 summarises the results of the Wilcoxon Matched Pairs Test comparing the total algal cover, number of species and the abundance and number of species in groups of algae found at sites A and B. The total cover was significantly different between the two sites. This is illustrated in Figure 8 which shows that the percentage cover was higher at site A than site B. These differences were largely as a result of the large and small diatoms and the green filaments. Figure 12 clearly shows that at site A the small diatoms were more abundant and the large diatoms less abundant than at site B. Figure 13 shows that although significantly different between the two sites, the abundance of filamentous algae was not consistently higher at either site.

The total number of species found at each site was not found to be significantly different. However the number of species in the blue-green, filamentous, and both diatom groups were significantly different between sites A and B. Although significantly different, the filamentous or blue-green groups were not favoured by either site in terms of species number. The number of diatom species was significantly higher in site A than in site B for both the large and small diatom groups as depicted in Figure 14.

The effect of immersion time:

Table 4 shows the results of the Wilcoxon Matched Pairs Test, comparing samples immersed for two weeks with those immersed for a month in terms of the total number of species, percentage algal cover, and abundance and number of species each algal group. Both the overall number and cover of algae differed significantly with exposure time, largely due to the large differences at site A. Site B showed no significant difference in either overall cover or species number. Figure 7 shows that the number of species was

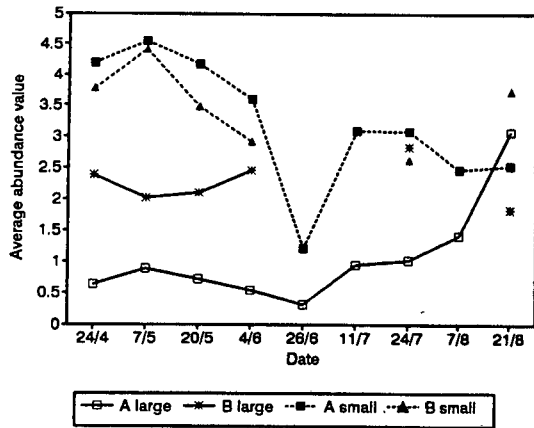


Figure 12: The average abundance of small and large diatoms at sites A and B.

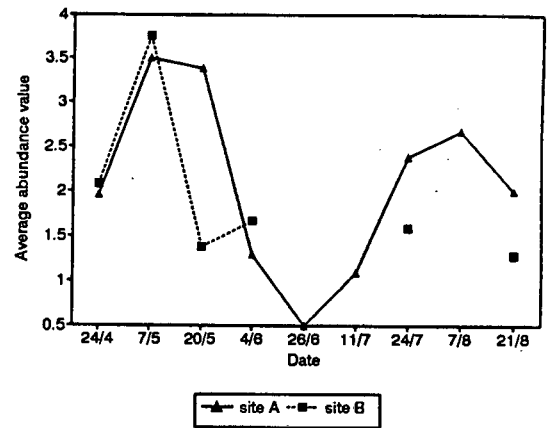


Figure 13: The average abundance of filamentous green algae at sites A and B.

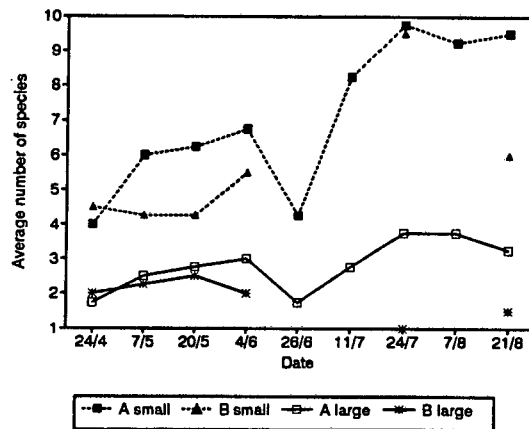


Figure 14: The average of number of species of small and large diatoms in sites A and B.

Table 3: Differences between sites A and B - results of the Wilcoxon Matched Pairs Test. (** denotes $p < 0.01$; * denotes < 0.05 ; and - means "not significant")

	ALL SITES	
	Cover	Number
TOTAL	**	**
Blue-greens	-	**
Filaments	**	*
Large diatoms	**	**
Small diatoms	**	**
Small greens	-	-

Table 4: Differences between species number and abundance after a month vs two weeks of immersion - results of the Wilcoxon Matched Pairs Test (** denotes $p < 0.01$; * denotes < 0.05 ; and - means "not significant").

	ALL SITES		SITE A		SITE B	
	Cover	Number	Cover	Number	Cover	Number
TOTAL	**	**	**	**	-	-
Blue-greens	-	**	-	**	**	**
Filaments	**	**	**	**	-	-
Large diatoms	*	-	**	**	-	-
Small diatoms	*	-	-	**	**	**
Small greens	-	-	-	-	-	-

higher after two weeks compared to a month, while the cover (Figure 8) was generally higher after a month of exposure.

Both the filaments and both size groups of diatoms had significantly higher overall abundance values after a month of exposure. However, broken down to site level, the small diatoms show significant changes with exposure time at site B only, while the filaments and large diatoms differed significantly at site A only. Interestingly the abundance of blue greens differed significantly at both site A and B, but showed no significant difference overall.

The overall decrease in species number with longer exposure time was affected by the blue-green and filamentous algal groups, the former differed significantly at both sites, while the latter differed only at site A. All groups except the non-filamentous green algae has significantly higher numbers after bimonthly samples at site A, while the abundance of small diatoms was also significantly different at site B

The effect of water level:

The water level in the canal fluctuated largely which meant that the dishes were not at a constant distance from the water surface. The fluctuation also meant that the upper level was exposed on occasion. Table 5 summarises the results of the Wilcoxon Matched Pairs Test comparing the total algal cover, number of species and the abundance and number of species of groups of algae found at different water levels. The overall percentage algal cover was significantly different, mostly as a result of the significant differences at site B. Figure 15 illustrates that at site B the algal cover was significantly higher in the lower level, while site A showed no significant difference in cover between the two levels. Overall the abundance of non-filamentous green algae differed significantly (illustrated in Figure 16) with the abundance higher in the lower levels of both sites. Interestingly this difference was not significant at either site A or B. The abundance of small diatoms found at the two levels at site B were found to differ significantly, contributing largely to the effect of higher cover

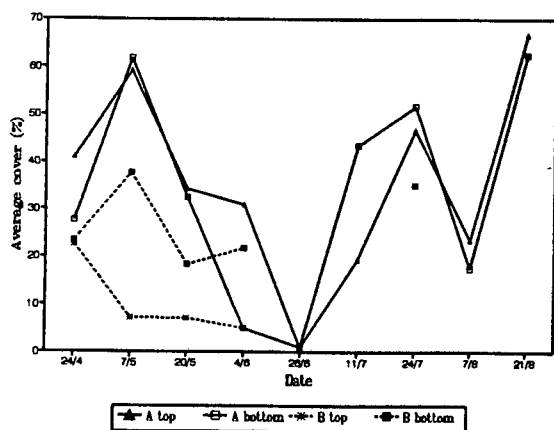


Figure 15: The average algal cover at the different water levels at sites A and B.

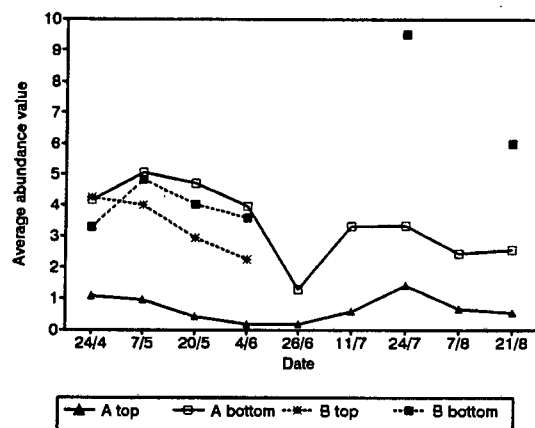


Figure 16: The average abundance of non-filamentous green algae found at different water levels at sites A and B.

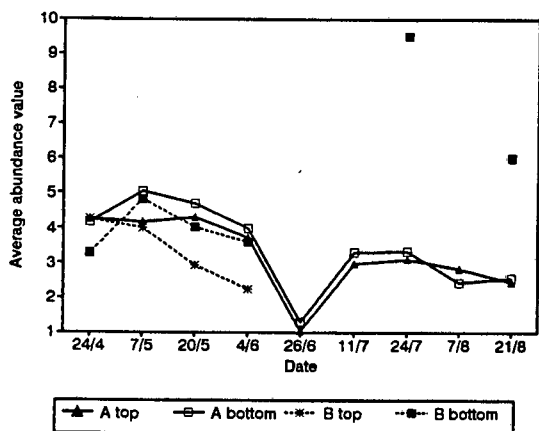


Figure 17: The average abundance value of small diatoms found at different water levels at sites A and B.

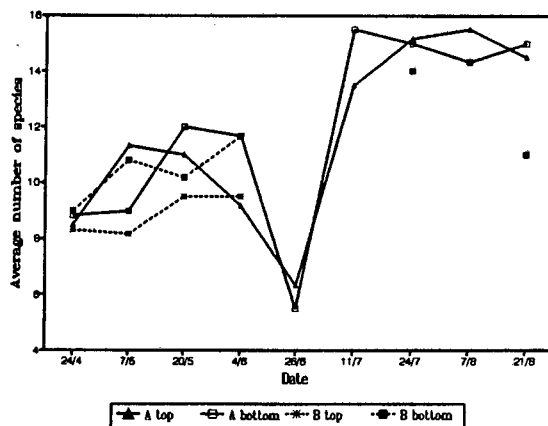


Figure 18: The average number of species found at different water levels at sites A and B.

Table 5: The effect of water level on species number and abundance in samples at positioned at different water levels - results of the Wilcoxon Matched Pairs Test (** denotes $p < 0.01$; * denotes < 0.05 ; and - means "not significant").

	ALL SITES		SITE A		SITE B	
	Cover	Number	Cover	Number	Cover	Number
TOTAL	*	-	-	-	-	*
Blue-greens	-	-	-	-	-	-
Filaments	-	-	-	-	-	-
Large diatoms	-	-	-	-	-	-
Small diatoms	-	-	-	-	**	*
Small greens	*	-	-	-	-	-

in the lower level (shown in Figure 17).

Overall, the number of species did not differ significantly between the two levels, but once again site B had significant differences, with more species found at the lower level (Figure 18). This difference was largely as a result of differences in the number of small diatom species.

The effect of sanding:

The results of the Wilcoxon Matched Pairs Test, comparing the total number of species, percentage algal cover and abundance and number of species each algal group that were found on sanded and smooth surfaces, are shown in Table 6. Overall, and at both sites, the percentage cover and total number of species was found to be significantly different on the two surfaces, with the smooth surface having both higher species number and cover (Figures 19 and 20 respectively).

All algal form groups contributed to the overall difference in cover. It is however interesting to note that while all other groups increased in abundance on the smooth surfaces (Figure 21), the filamentous green algae increased in abundance on the rough surface (Figure 22).

At site A the abundance of blue-greens was not significantly affected, while at site B the abundance of both large diatoms and non-filamentous green algae were not affected.

Of the algal form groups, only the filamentous algae did not have significantly different number of species on the different surfaces at all the sites. The overall significant difference in the number of species found in all other groups was largely due to differences in site A as, only the large diatoms differed significantly at site B.

DISCUSSION:

General trends:

The general trend of increasing species number over the study period was disrupted by a large anomalous drop in the number of

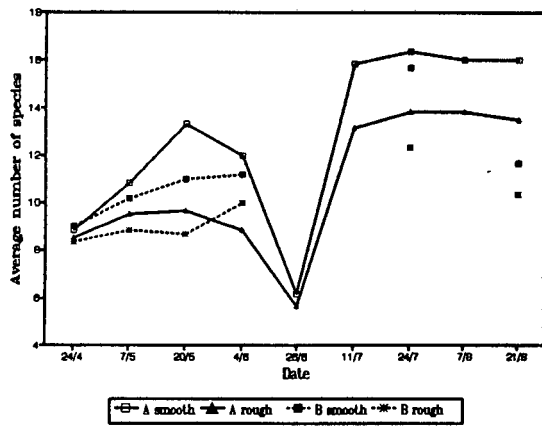


Figure 19: The average number of species found on rough and smooth surfaces at sites A and B.

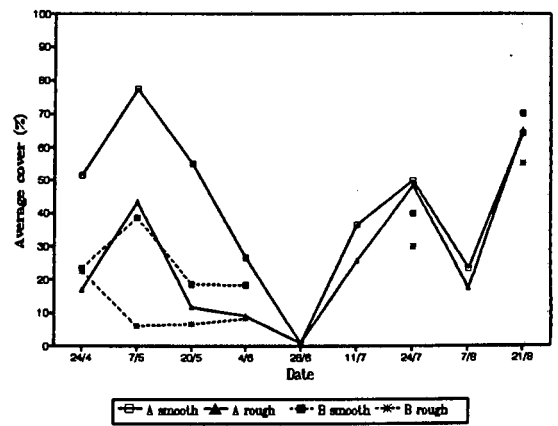


Figure 20: The average algal cover on rough and smooth surfaces at sites A and B.

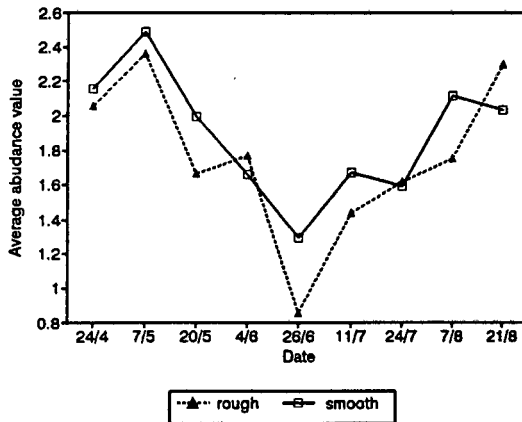


Figure 21: The average abundance of algal form groups (excluding green filaments) found on rough and smooth surfaces.

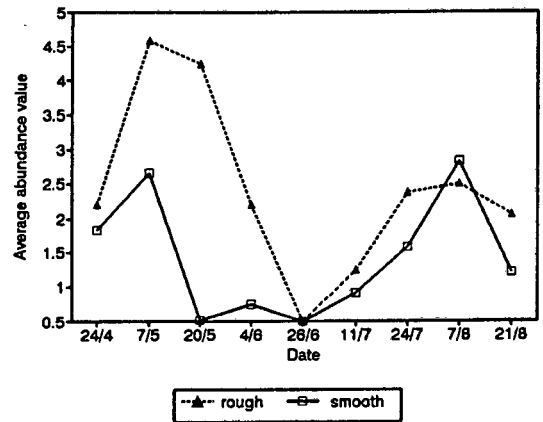


Figure 22: The average abundance of filamentous algae found on rough and smooth surfaces.

Table 6: The effect of sanding petri-dishes on species number and abundance in samples at positioned at different water levels - results of the Wilcoxon Matched Pairs Test (** denotes $p < 0.01$; * denotes < 0.05 ; and - means "not significant").

	ALL SITES		SITE A		SITE B	
	Cover	Number	Cover	Number	Cover	Number
TOTAL	**	**	**	**	**	**
Blue-greens	**	**	-	**	**	-
Filaments	**	-	**	-	**	-
Large diatoms	**	**	**	**	-	**
Small diatoms	**	**	**	**	**	-
Small greens	*	*	*	*	-	-

species found the on samples removed on the 26 June. Similarly, algal cover observed on samples removed on this date were also exceptionally low. Excluding this point however, algal cover showed no clear trend over the study period. The small diatom form group, the group with the largest number of species and average abundance, contributed significantly to these trends.

The general trends in species number and cover may be accounted for by pH, water speed and conductivity which were well correlated with these values. Conductivity particularly, may explain the general increase in species number, as these two factors follow similar trends. Conductivity is also a possible explanation of the anomalous dip, as the as conductivity showed marked fluctuations around this time. Conductivity is however positively correlated with species number and cover, which would imply that the peak in conductivity should result in a peak, not a drop in species number and algal cover. The communities may have been negatively affected due to the sudden large change in conductivity. pH and water speed are also unlikely to account for the anomalous dip observed as these factors showed little variation.

It is possible that there is a non-linear relationship with the environmental conditions and that the dip is as a result of crossing over a threshold of conditions. This is supported by the results of the TWINSPAN analysis which showed that the major division of the samples occurred at the 26 June, which indicated that a shift in the community composition occurred during this point. Similar seasonality was observed in the macroalgae in the same canal system (Privett, 1994) and in another river in the western Cape (Guthrie, 1992). The CCA showed that pH, conductivity and current velocity and explained much of the variance in the community composition at different sites, but once again the small variance in these variables makes this relationship is unlikely in reality. It is however possible that these factors give an indication of the levels of some other, unmeasured factors, possibly nutrient status, which may vary greatly with small changes in pH, conductivity or water speed.

The CCA also showed that temperature explained a significant amount of the variation in taxa, with the sites removed before 26 June characterised by high temperatures, while the sites sampled after this date typical of cold water. Temperature is known to be an important environmental factor in aquatic ecosystems and it is thought that temperature may cause shifts in lotic periphyton community composition (DeNicola, 1996). Temperature is therefore a more likely explanation for the changes observed in the algal community. Although not well correlated with species number or cover, the temperature decreased steadily until it reached about 11°C on the 11 June after which it stabilised at this temperature. It is possible that the community changed from a warm water adapted community to one more tolerant of cold waters as the temperature levelled out. The dip in number may have occurred if these warm water species were intolerant of the cold temperatures, and the cold water species were slow to proliferate and facilitate the recovery.

A problem in the above argument is that the both the TWINSPAN analysis and CCA showed that the communities were only partially different (all analysis had low eigenvalues). This means that there would not have been a complete change-over from warm to cold tolerant communities - leaving no explanation for the size of the dip in species number and cover.

Another explanation may be that the increased rainfall and the closing of the Brandevlei pump station on the 31 May (which pumps water into the Breede river to maintain a constant flow) may have altered the nutrient status and availability of propagules in the water, and this together with the temperature change, may have been enough to cause the rapid decrease in algal abundance and species number. Later stabilization of conditions may have allowed the recovery of a slightly differently community.

The effect of position along the canal and within the water column:

Turbidity was poorly correlated with species richness and cover and little of the variance in the samples was explained by this

environmental factor. Turbidity was however the only environmental factor measured that differed significantly between sites A and B, with site A (the site nearest the source) being more turbid. Turbidity is therefore the only factor measured that could explain the significant difference in algal cover between the two sites. It is however possible that the differences are a result of other, unmeasured factors.

Site A had a higher overall algal cover than B, largely as a result of the abundant small diatoms whose growth and abundance may have been favoured in the more turbid waters of site A. This theory is supported by the fact that at site B the abundance and number of species of small diatoms is higher on the lower, more turbid level and by the fact that the abundance of small diatoms in site B showed a slight peak on dishes taken out on the 7 May, corresponding to the dip in the illumination that was measured when the dishes were placed in the water (24 April). These findings confirm many previous reports that diatoms may be better adapted to growing in environments with low irradiances (Richardson et al, 1983 and Langdon, 1988 both cited by Hill, 1996). *Cocconeis*, for example, found in most of this studies samples, is able to proliferate in low light densities (Goldsborough and Robinson, 1986)

Although the number of species in the large diatom group was lower in the more turbid site A, their abundance was significantly higher in site B, which would not be expected if the above findings applied to all diatoms. The overall abundance of these organisms was too low to affect the overall pattern. It is interesting to note that the pattern of abundance of these organisms does not follow the same trends as turbidity does, which may indicate that the difference in abundance between the two sites may be as a result of other factors. Large diatoms are certainly not as susceptible to changes in turbidity, as their abundance and number did not significantly differ at the two levels in the water column.

The non-filamentous green algae were more abundant in the lower level of sampling dishes, however they were not significantly

affected by differences in turbidity between the two sites. This may be because the non-filamentous green algal communities (but not the number and abundance of species) were different between the two sites and adapted to the particular light conditions found there and as a result the abundance and number of species between these sites was similar.

The difference in abundance of filamentous algae may be as a result of turbidity, although within sites their abundance does not differ with level. Like the small diatoms, the abundance of filamentous green algae found in site B peaks on dishes taken out on the 7 May, corresponding to the dip in the proportion of light reaching the dishes measured on the 24 April. Chlorophyta, both filamentous and non-filamentous) found in this system therefore appear be favoured by low light intensities (turbid conditions).

Although the difference in turbidity between the levels within a site was not as great as the difference in turbidity between the sites, this difference may have caused the general trend of the upper levels having lower algal cover than lower ones. The number of species found at site B was also significantly higher at the lower level. This may be because at high levels of irradiance photosynthesis, biomass accumulation (Hill, 1996) and species diversity may be reduced by photoinhibition. Species diversity has been shown to be low near the water surface (as seen in the upper level), peak slightly deeper (the lower level) and then decrease once again (Austin et al., 1981). The more turbid water in site A may have meant that the optimum light intensity was closer to the surface and extended across both levels therefore causing little differentiation between the two levels. The clear water of site B may have meant that the optimum level of light intensity was lower, near, or between the two levels causing the significant differences observed.

The communities found at different levels within a site were not as markedly different as those between the sites. This may be because the difference in illumination was not great enough between the levels as the distance between the levels may have been too small to cause difference in the communities. This is

unlikely as the proportion of light reaching the two levels was found to be significantly different. The water quality, for example, the nutrient levels between the sites may also have been different, compounding the effects. Another likely cause is that the water level in the canals fluctuated greatly (pers. obs.) causing the amount of light reaching the levels to fluctuate and therefore causing the overall growth conditions between the two levels to be more similar than would be expected.

While the CCA showed that environmental variables were more important in determining community structure that sanding and time of exposure were, these treatments definitely did have an effect on the communities that developed.

The effect of sanding:

Contrary to the observation of John (1996 pers comm.) who found that sanding the petri-dishes had no effect on the algal samples, the results of this study found that sanding most definitely affected the colonisation. Compared to the dishes left smooth, the sanded petri-dishes had a lower total algal cover and fewer species. These differences seen in all algal form groups except the filaments. The number of filamentous species did not differ significantly on the different surfaces (probably because most of the filamentous algae recorded was *Stigeoclonium*, often only its basal cells which occurred on both rough and smooth surfaces). Interestingly however, the abundance of filamentous algae was higher on the sanded substrates.

An explanation for the phenomena of lower overall cover and abundance on rough surfaces may be that the smaller algal groups accumulated in the grooves formed by sanding, making identification and abundance assessments difficult. This would not however explain why there is a significant difference in the number of large diatom species which were larger than most of the grooves and therefore clearly visible. In fact this group appears to be exceptionally sensitive to the different surfaces, being the only algal group in site B to have significantly different number of species.

Another, more plausible theory is that the rough surface disrupts

the boundary layer where the low current velocities usually enables small algae lying close to substrate to avoid the shear stress of strong currents (Round, 1965; Stevenson, 1996). Although the flow in most of the boundary layer is turbulent, immediately adjacent to the substrate the flow is laminar (Stevenson, 1983). Irregular surfaces however increase turbulence in the boundary layer which changes the rate of flow near the substratum (Round, 1965; Stevenson, 1983). Stevenson et al (1996) therefore predicted that the initial colonisation on surfaces exposed to direct currents will be reduced if the surface is roughed, which is what was observed in this study.

Stigeoclonium is heterotrichous, with a well developed basal attachment system, which forms a broad expanse over the substrate (Stevenson, 1996). This may mean that it is able to withstand the increased turbulence on the roughened surface which also provides many grooves into which the basal cells can grow and anchor the plant. This may explain why filamentous algae are more abundant on the roughened surfaces.

The effect of immersion time:

The amount of time a substrate is exposed to the water is an important determinant of species community structure (Oemke and Burton, 1986). There is however little agreement on the length of time that substrates should be exposed in order to obtain a representative sample of the community. Suggestions generally range between two weeks and a month (Lowe and Pan, 1996; Oemke and Burton, 1986; John and Moore, 1985). This lack of agreement may be due to the fact that environmental factors vary and influence the pattern and rate of colonisation. The length of time taken to reach a mature community may therefore vary from stream to stream, and so a standard exposure time, that could be applied to all water systems, may not exist (Oemke and Burton, 1986; Rott, 1991).

In this study it was found that increasing the exposure time from two weeks to a month resulted in an increase in overall algal cover, but a decrease in species number. This may indicate that the sample exposed for a month are closer to the climax, which

is often characterised by a sub-maximal species diversity. The overall differences were largely due to the differences in site A, as the species number and cover did not differ significantly in site B. These differences may once again be due to difference in turbidity. As mentioned earlier, the turbid water of site A may favour growth and reproduction, which could increase the rates of colonisation, and therefore result in marked changes in the extra two weeks that dishes sampled every month had. In site B the less turbid conditions may have slowed algal growth and colonisation, so here the community may not have had enough time to develop such pronounced differences between the two periods of immersion.

CONCLUSIONS:

One of the most important questions to ask when using artificial substrata is: is the community growing on the artificial substrate representative of the natural community? The answer in this situation is probably not. The small diatoms seem to be favoured by the substrate, while blue-green and non-filamentous green algae appear to be under-represented. This may be a seasonal phenomenon in which other algal groups are naturally rare during the study period. However, although samples were not taken from natural substrates for comparisons, certain species (for example blue-greens) that were observed on the canal walls were not found on the sampling dishes. Other studies have also shown that certain species, common on natural substrates, were absent or are on artificial surfaces (eg John and Moore, 1985; Lowe and Pan, . 1996). It seems clear that the artificial surfaces are selective, favouring initially opportunistic species (especially diatoms) (John and Moore, 1985) while green and blue-green algal species are often under-represented (Cattaneo and Amireault, 1992 cited by Lowe and Pan, 1996).

This does not however mean that artificial surfaces should not be used. Despite their shortcomings they are for example convenient means of studying the structure and reproduction of small algae that may be overlooked or difficult to obtain by other sampling methods (John and Moore, 1985). The objective of the study must however be borne in mind when using artificial

substrates. If the aim of a study is to compare communities which are growing on the same substrate, and these communities do not have to represent the entire natural community, artificial substrates would be very useful (Lowe and Pan, 1996).

In addition to the advantages of being able to replicate samples, another advantage of using substrates, at least in the Breede River canals, is that to a certain degree one can selectively sample for specific algal types by making slight changes in the sampling method. In this study it was found that the changes in the community resulting from the different sampling treatments was small and certain environmental conditions were much more important in determining community structure. However, the number and abundance of species sampled with slightly different methods were significantly affected, which could influence the choice of method used. If for example the area of interest is diatoms, say for monitoring water quality, I would advise that the artificial substrates are left smooth and immersed for approximately two weeks. Diatoms are rapid colonisers (Biggs, 1996; John and Moore, 1985) and a high species richness should be observed after this period. If substrates are exposed for much longer, identification of these organisms becomes difficult due to their high abundance (pers. obs) and the number of species is reduced as they are replaced by later successional stages (Peterson and Stevenson, 1990; Hoagland et al., 1982; John and Johnson, 1991). The increase in biomass with exposure time also increases the risk of sloughing of the thick biofilm (Oemke and Burton, 1986; Roemer et al., 1984). Another reason that the substrate should not be left in the water for too long is that the larger algal forms may overgrow the surface. The larger algae may out-compete the smaller algae and cause the accumulation of sediment.

Sanded petri-dishes, immersed for a month, will favour the growth of filamentous algae, (especially *Stigeoclonium*), which are among the last organisms to colonise a surface (Peterson and Stevenson, 1990; Hoagland et al., 1982 (Hoagland et al., 1982)).

In conclusion it can be seen that there both advantages and disadvantages to using artificial substrates for sampling benthic

algae. This method, like any other, should not be used blindly, but with a clear understanding and a bit of thought, it could be a very valuable tool.

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