A Study of the Diatom Assemblages in Grazing Marsh Ditches: Application to Assessment of Ecological and Conservation Status

Part 1: Gwent and Somerset Levels

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The views expressed in this report are those of the author and do not necessarily represent those of Buglife.

This study forms part of a programme of surveys being carried out by Buglife - The Invertebrate Conservation Trust to assess the condition of the aquatic biota of grazing marsh ditches in England and Wales. This report forms the first phase of the work, and was carried out in 2007/8.

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1. Summary

A survey of the periphytic diatoms of selected ditches on the Gwent and Somerset Levels was undertaken in the summer of 2007. Fifty sites were sampled. The majority of diatom species recorded were typical of those commonly found in rivers. Drawing upon indices obtained from river flora, various metrics were derived from species compositional data.

The DARLEQ tool for rivers was applied to the ditch diatom flora to obtain estimates of the ecological status of the ditches. Only one site was assigned to the High status category, indicating only minimal anthropogenic input, and a further five were considered to be of good ecological status. Good matches were found between the ditches with good or high ecological status as predicted by the diatom species and the submerged macrophyte flora. There was a reasonably good fit between diatom and macrophyte data for sites given a poor ecological status. Relatively more nitrogen heterotrophs and species tolerant to low oxygen levels were present in the ditches dominated by free floating macrophytes.

It was possible to distinguish between *Lemna* dominated sites and sites with mixed submerged and free-floating macrophytes based on their diatom composition. Significant differences were found between the Somerset Levels and Gwent Levels for a number of biotic indices derived from the diatom data and some abiotic indices.

2. Background and aims

This study of diatom assemblages in grazing marsh ditches has four aims:

1) to extend the present knowledge of diatom communities in ditches
2) to explore possible relationships between diatom, macrophyte and invertebrate assemblages in ditch systems
3) to act as a surrogate for the programme of water chemistry analysis
4) to constitute a pilot study for extending the Water Framework Directive assessment methodology to diatoms of ditch systems

This study forms part of a programme of surveys being carried out by Buglife – The Invertebrate Conservation Trust, to assess the condition of the aquatic biota of grazing marsh ditches in southern England, South Wales, East Anglia and Anglesey. It is hoped that the diatom study will be a three-year programme. So far, funding has been secured for the first year, to cover sites in Somerset and Gwent.

The Water Framework Directive's (WFD), (European Union, 2000) Programme of Measures (PoM), will be applied to Natura 2000 sites, some of which (e.g. Nene Washes, Ouse Washes, Norfolk Broads) contain ditch systems. A WFD compliant assessment methodology is required for the phytobenthos of ditches. In the UK, we have recently developed a conceptual model and predictive tool (DARLEQ) to assess changes in the assemblage of phytobenthos as a measure of the ecological status of rivers and lakes along a pressure gradient of eutrophication (nutrients and organic pollution), (Yallop & Kelly, 2006; Kelly *et al*., 2008). The DARLEQ tool enables assessments to be made of the ecological status of rivers (formerly called the DARES tool) and lakes (formerly referred to as the DALES tool). The tool assesses changes in the biodiversity of the attached diatoms communities, which play a key role in the primary productivity of inland aquatic ecosystems. Diatoms are used as proxies for the phytobenthos in the tool. The application of this tool to ditch ecosystems will be assessed during this study. The river based tool was applied based on the assumption that rivers represent the most appropriate analogy to the ditch ecosystems.

3. Study sites in 2007

In 2007, diatoms were sampled from a number of sites with approximately 20% of the samples collected from the Gwent Levels: Wentlooge (WLL) and Caldicott Level (CCL), and 80% from Somerset Levels (Kenn Moor (KNM), Nailsea Moor (NSM), King's Sedgemoor (KSM), Moorlinch (MLH), Pawlett Hams (PWH), Southlake Moor (SLM), Tealham and Tadham Moors (TTM), West Sedgemoor (WSM), Chilton and Catcott Heaths (CCH), and two miscellaneous sampling sites (OWEN). The sampling locations (Appendix 1) within each site were chosen to cover the range of vegetation types present in each grazing marsh. Each ditch has matched invertebrate and macrophyte data with the exception of samples from Southlake Moor, for which there are only matched macrophyte and diatoms samples. Diatom biofilms were removed from *Phragmites* or *Sparganium* stems where possible, and preserved on site. In the absence of either of these substrata, samples were collected from other plant stems including *Eleocharis*, *Glyceria*, *Typha*, *Equisetum*, *Bulboschoenus*, *Berula*, *Juncus,* and *Carex.*

4. Sample processing

Subsamples of the diatom biofilms were cleaned to digest the organic matter following a standard protocol (for detailed methodology see: http://craticula.ncl.ac.uk/dares/methods.htm). A slide was made up for each sample and over 300 diatom valves identified in each sample by reference to standard works (Krammer & Lange-Bertalot, 1986-2004). The percentage relative abundance of each species was determined. Each diatom species in the DARLEQ database has been assigned a sensitivity (s) value according to its tolerance to nutrients (Kelly *et al*., 2008). There are five groups with s values ranging from 1 (very nutrient sensitive) through to 5 (very nutrient tolerant).

Metrics were derived from the data set, including:

- Trophic Diatom Index, (TDI), which is a measure of nutrient/organic pollution status varying from 1 – 100 where 100 indicates hypereutrophic
- Ecological Quality Ratio (EQR) ranging from 0 – 1 and measuring deviation from reference site where no deviation = 1
- % motile valves (an indication of silt and biofilm maturity)
- % organic pollution tolerant valves
- % of nutrient sensitive and very nutrient sensitive species (i.e. those with s values or 2 and 1)
- % nutrient tolerant and very nutrient tolerant species (i.e. those with s values of 4 and 5)
- Species richness
- Evenness and diversity (Shannon-Wiener as $\log_e$)
- Salinity (H) ranging from 1 = fresh, to 4 = brackish
- Oxygen tolerance (O) where 1 = can only tolerate high oxygen and 5 = tolerates low oxygen
- pH (R), 1 = acidophile to 5 = alkalibiontic
- N (nitrogen uptake metabolism), where 1 = N autotroph to 4 = obligate N heterotroph, dependent on sources of organic N.

The values for H,O,R and N were assigned after van Dam & Mertens, (1993) and weighted by the relative abundance of each species in a sample.

Detrended Correspondence Analysis (DCA) was used to examine spatial patterns in the data set. Relative abundance values were square-root transformed prior to analysis and rare taxa were down-weighted. The DCA was performed on a reduced dataset where all species that were present in two or fewer samples and with a relative abundance of less than 1% were removed. Correlations (Spearman's rank) were undertaken to compare the samples scores of the first four axes of the DCA with a number of environmental variables and other derived biotic metrics. Analysis of variance (or the nonparametric form, Kruskal-Wallis) was carried out to explore differences between selected metrics in the different marshes.

The DARLEQ diatom tool was used to calculate the TDI. Ecological Quality Ratios (EQR) were produced by comparing the observed TDI with that expected to be obtained if the site was at reference conditions i.e. in the absence of any eutrophication pressure (Kelly *et al*., 2008). Alkalinity values were required to compute the EQR values. A regression equation was used to obtain estimates of the ditch alkalinity values derived from matched alkalinity/conductivity from UK river sites

(regression equation used y = 0.339x-7.7395, r^2 = 0.82, where x = conductivity µS cm^{-1}; Kelly, unpublished data).

5. Results and discussion

5.1 *Diatom species composition and environmental preferences*

A total of 176 diatom species were identified from the ditches sampled in Gwent and Somerset levels (see Appendix 2). The percentage frequency of each species is recorded along with the maximum relative abundance recorded for each species (Table 1). Most of the species recorded were typical of those found in UK rivers. However, a few species were recorded that have not been recorded in the DARLEQ database (1051 river sites) including *Anomoneis sphaerophora, Navicula pseudoarvensis* and *Nitzschia solita.*

Species richness ranged from 9 (WSM13) to 40 species (SLM2, WSM10, and PWH8) (Table 2). Other sites with a relatively low species richness included TTM21 (with 11), MLH6c (with 14 species) and WLL22 (15 species). In each of the cases where richness was low, the sample was dominated by a single species, resulting in low evenness and diversity (Table 2).

In the cases of TTM21 and WLL22, the dominant organism was *Lemnicola hungarica*, a common epiphyte on *Lemna* species. TTM21 and WLL22 are both *Lemna* dominated ditches (Nick Stewart, pers. com.). In samples from WSM13 and MLH6c, the dominant species was *Cocconeis placentula* var *lineata*. WSM13 was the only sample taken from the macrophyte *Juncus subnodulosus* which is a species that doesn't get particularly deep into the water and this ditch was quite open having been cleaned in the previous winter (Nick Stewart, pers. com.). The biofilm from MLH6c was on *Typha*, rather late in the season and possibly getting senescent with the potential for plant exudates to influence the species composition of the attached diatom assemblage. Domination by *Cocconeis placentula* var *lineata* could, however, be due to a number of other reasons including: snail herbivory (Steinman et al., 1996); scouring effects (Peterson & Stevenson, 1990); or because the substrate may be recently colonised. The pioneer species on newly colonised substrates tend to be *Achnanthidium minutissimum* and *Cocconeis* varieties (Yallop & Kelly, 2006). *Achnanthidium* was rare in all of these samples but is a species more easily removed by grazing, as it is attached to the substrate by a short mucilage pad. Varieties of *Cocconeis* are, however, attached to the substrate along the entire valve and therefore they are far more resistant to scour and grazing. Further samples may help to elucidate which factor(s) are responsible for the reduced biodiversity in these samples.

Some species were common, being recorded in over half of the sites and making up over 20% of the sample (Table 1) including *Cocconeis placentula* vars *euglypta, placentula* and *lineata*, *Epithemia adnata, Lemnicola hungarica*, *Planothidium frequentissimum*, *Rhoicosphenia abbreviata Gomphonema clavatum* and *G. parvulum* var *exilissimum*. Two motile species *Navicula radiosa* and *N. minima* were also very common across the sites.

Sites in which species with low s scores (1 and 2), (Table 1), were relatively more abundant are characteristic of UK river reference sites. Over 23% of all species recorded were those that are common in reference conditions, with thirteen species with s values of 1 and twenty-nine species with s values of 2. The representation of the groups in each sample is shown in Table 3. Species assigned a score of 3 do not

indicate a strong nutrient preference and those with scores of 4 and 5 are typical of more eutrophic to hypereutrophic sites, though they can be found in waters with low nutrients. *Gomphonema parvulum* var *exilissimum* is indicative of very low nutrients and has been assigned an s value of 1. It made up over a fifth of the valves in SLM2. Interestingly this species is common on plant material obtained from herbarium specimens of plants collected prior to 1930, before the effects of agricultural intensification were realised (Yallop, unpublished data). Another species in this group, *Gomphonema gracile*, was recorded at over 5% RA in the sample TTM12.

Species in Group 2 that were well represented in some samples were *Gomphonema clavatum* (19.6 %) in WSM16, *Achnanthidium minutissimum* (14 % in CCL61 and *Eunotia bilunaris* var *bilunaris* (14% in SLM2). The Group 3 epiphytic diatom *Cocconeis placentula* var *lineata* was recorded in almost all of the sites and was well represented in many sites, with a maximum relative abundance of 83.4 % in WSM13, 67% in KSM9 and 64% in SLM8. Species with s values of 4 were well represented in two of the Pawlett Hams sites, PWH5 and PWH8, with 50% and 54% of valves in the samples. *Rhoicosphenia abbreviata* was recorded in 40% of the sites. The latter species is frequently found as an epiphyte on the green filamentous algae such as *Cladophora* spp,.(blanket weed), and typifies electrolyte-rich to brackish waters, tolerating pollution. This species made up about one third of the sample in PWH8 and one quarter of the sampled in PWH5. PWH5 and PWH8, had good submerged plant floras, but also abundant filamentous algae (Nick Stewart, pers. com.). Furthermore, these samples both had a reasonable representation of Group 2 species, also indicating a better water quality. The presence of a good submerged plant flora coupled with a 'diatom index' of higher nutrients, indicating eutrophication, might seem anomalous, in the first instance. However, plants have many self-stabilising mechanisms that allow them to continue to grow in relatively high nutrient concentrations. According to the 'Alternative Stable States' hypothesis (Scheffer, 1998) a clear water, vegetation-dominated state is possible over a wide range of nutrient levels in shallow lakes (Morris et al., 2003), rivers (Dent et al., 2002), ponds and ditches (Portielje et al., 1995).

A common Group 5 species was *Lemnicola hungarica*, recorded in 86% of the sites and dominating one of the samples (TTM21 at 60% RA). This species is frequently found growing on *Lemna* spp. This diatom species was very common at a number of other sites including WLL22 (> 40% RA), CCL51 (27% RA) and NSM5 (22% RA). TTM21, WLL22 and CCL51 were all ditches with floating *Lemna* dominant, but NSM5 had a mix of floating *Lemna* species, *Lemna trisulca* and emergent plant species, all scored as abundant (Nick Stewart, pers. com.). Presence of a relatively large number of valves of *L. hungarica* could indicate contamination from *Lemna* or could mean that a dense surface layer of *Lemna* has formed on the ditch and diatom valves from *Lemna* could act as an inoculum for colonisation on other plants.

Epithemia adnata, also a Group 5 representative, was common in MLH6d (>48% RA) and on two other plants at the same site: MLH6c (25% RA) and MLH6a (18.5% RA). It was also common at TTM3 (19% RA) and WSM16 (16.7%). This diatom species is often associated with nitrogen deficient waters or where there is a low N:P ratio in the water column. The possession of cyanobacterial endosymbionts, which can fix atmospheric nitrogen, provide it with a source of nitrogen. However, this species rarely occurred in the river samples included in the DARES data base (Kelly et al., 2008). The s values calculated for the DARES database are primarily determined using the relative abundance of diatoms sampled from epilithon. *Epithemia* is commonly part of the epiphyton and is frequently recorded as a dominant species on emergent plants and it is possible that the s value for this species needs to be revised. Free-floating plants depend on high nutrient concentrations as a

consequence of their growth form, whereas rooted vegetation has access to a much larger nutrient pool in the sediments (Scheffer et al., 2003). Field studies show that concentrations of ortho-phosphate remain unchanged or even increase with increasing macrophyte cover whilst submerged nitrogen concentrations can be below detection levels (van Donk et al., 1993). Diatom samples dominated by both *Lemnicola* and *Epithemia* may be a good indication of nitrogen-limited growth in ditches supporting dense vegetation of both submerged and free-floating species.

Theory predicts that further nutrient enrichment will ultimately result in a switch to an alternative phytoplankton dominated state (in the case of shallow lake ecosystems) or a floating plant dominated state (in the case of ditches) and field-based evidence and modelling provides evidential support for this (Janse & Van Puijenbroek, 1998; Scheffer et al., 2003). In this survey, sites where nitrogen and phosphorus inputs are both relatively high are more likely to be in the alternative free floating macrophyte dominated state as opposed to the mixed submerged and free-floating state, and the diatom species composition may be useful as an indication of the nutrient status of these ditches.

Some species that have been recorded in marine samples or can tolerate saline conditions were found, including *Achnanthes delicatula, Amphora commutata, Ctenophora pulchella, Tabularia fasciculata, Navicula arvensis, Navicula digitoradiata* var *rostrata, Nitzschia incognita, Gyrosigma macrum, Navicula gregaria*, *Navicula radiosfallax, Nitzschia solita, Pinnularia subgibba, Nitzschia tubicola, Nitzschia sublinearis* and *Stauroneis salina*. The sites where diatoms indicated a possible saline influence included WSM10, PWH5, CCL26, CCL35, KSM15 and WSM21, with PWH5 and CCL26 showing the greatest signal. PWH5 and CCL35 are both close to the sea wall and have conductivities of 990 and 1190 µS cm^{-1}, but the other ditches are not obviously saline, having conductivities below 600 µS cm^{-1}. A number of these other sites are main ditches and share common features in terms of their depth, breadth, poor water quality and a regular cleaning programme (Nick Stewart, pers. com.).

Species of the genus *Eunotia* were present in some samples. *Eunotia* is particularly common in areas that are electrolyte-poor and with low pH and can thrive in very acidic waters e.g. from acid mine drainage (Whitton & Diaz, 1981). Over 13% RA of *Eunotia bilunaris* was recorded in SLM2 and three other species of this genus were recorded in the site. *Eunotia* was present in a number of other sites CCL35, WWL5, WSM16, NSM5, TTM12 and CCH13, though the relative abundance of this genus was lower, hence there was not a strong indication of acidity in these samples.

A number of species of *Navicula* occurred in the samples. They are generally part of the silt flora and could indicate heavy siltation or water carrying a high silt load. *Navicula gregaria*, *N. cryptotonella* and *N. menisculus* were recorded at a relative abundance of circa 10% in CCL26, CCL31, and CCL51, in PWH15, OWEN 90 and MLH3. One of the most abundant species in this genus was *Navicula minima*. This species was recorded at a high relative abundance in MLH3, MLH12 and MLH13, forming between 17 and 30% of the total diatom counts; in CCL26, 41, 51, 56 and 61, forming between 17 and 42% of the total diatom count; and in TTM3 (22%) and SLM4 (31%). This diatom is widespread in a range of nutrient conditions and is tolerant of low oxygen; it may be associated with organic influx (Cox, 1996). *Navicula radiosa* was well represented in just one site (CCH17), forming 23% of the sample, though it was frequently present in others sites at a low abundance. This species is relatively common in oligosaprobic standing waters and is fairly sensitive to organic pollution, not tolerating an oxygen deficit greater than 50% (Cox, 1996). Little is known about its tolerance to pH or nutrients, and it is not commonly recorded in

rivers. The macrophyte community of CCH17 is indicative of good status with frequent *Utricularia* and occasional *Chara*. *Navicula saprophila* is common in strongly eutrophic water with high organic loading and is tolerant of polysaprobic conditions (oxygen deficit of > 90%). This species was relatively common in only one site, CCL56. This ditch was *Lemna* dominated with patchy emergents. There were no obvious signs of pollution, though the ditch was bordered by a maize crop on one bank and improved pasture on the other (Nick Stewart, pers. com.), hence it may receive agrichemicals or other organic inputs.

The motile diatom *Nitzschia amphibia* was common in a number of sites including CCL31 (14% RA), KSM24 (13% RA) and NSM9 (13% RA). *Nitzschia amphibia* is often associated with organic pollution being a tolerant species, as is *Amphora veneta*, which was also relatively common in CCL31 (10% RA). The former species typically is part of the silt flora and is often abundant in recovery zones close to sewage treatment works. CCL31 was *Lemna* dominated (Nick Stewart, pers. com.), and a site that is potentially subject to periods of low oxygen, which these diatom species can tolerate.

The only other species that was very well represented across the moors and present in relatively high abundance in some samples was *Planothidium frequentissimum*. This species is a common epiphyte and is found in both flowing and standing waters. It prefers circum-neutral to alkaline waters and can tolerate a wide range of nutrient concentrations. It can also withstand intermediate levels of organic pollution.

5.2 *Overall assessment of water quality of the ditches*

The Trophic Diatom Index, based on the river TDI, of each site was determined (Table 4). The values of this index range from 1 to 100, where 100 is very hypereutrophic. The values for this index ranged from 30.3 at site SLM2 to a maximum of 79.8 at site TTM21. Other sites with a relatively low TDI value included WSM13 (46.7), CCH13 (47.8), CCL61 (50.1), KSM9 (50.6) and SLM4 (52.1). Other sites with a relatively high TDI included MLH6d (76.5), WLL22 (73.7) CCL31 (73), CCL51 (72.1), and NSM5 (69.1).

To derive EQR values estimated alkalinity values were used and the latter values were predicted using field site measurements of conductivity (Stewart, unpublished data). There was a strong correlation between conductivity and alkalinity for conductivity values lower than 600 µS cm^{-1} ($p = < 0.001$). A few of the conductivity values measured on site were over 1000 µS cm^{-1} and it is possible that the estimates for alkalinity at these sites are unreliable. However, it is not thought that the predicted TDI/EQR values would be affected by this. Sites with high conductivity values may reflect a higher salinity. The EQR values, derived from the ratio of the Expected TDI/Observed TDI, indicate deviation from reference condition flora. A value of 1 indicates no change from the reference state. The EQR represents a gradient of ecological status and results indicate that sites spanned the range from High to Poor status (Table 4). No ditches were considered to fall into the Bad category. Only one site SLM2 was placed in the High category indicating ‘reference’ or at least only minor impact from anthropogenic influences. Five sites fell into the Good status category (CCH13, CCL61, KSM9, SLM4, and WSM13). Six sites were deemed to fall into the poor category (CCL31, CCL51, NSM5, MLH6d, TTM21 and WLL22). All of the other sites were estimated to be of moderate ecological status.

A provisional comparison with the macrophyte flora suggests that the better diatom scores match sites with good to moderate macrophyte interest (e.g. presence of

species such as *Hottonia*, *Hydrocharis* or *Chara*). The poor scoring diatom sites include a site with moderately good submerged macrophytes but also with floating *Lemna minor* and *Lemna trisulca* (NSM5), and a site with *Lemna* domination but also *Hydrocharis* (MLH6d). Co-existence of poor scoring diatoms with submerged macrophytes could indicate a mixed macrophyte community where there is intense competition between submerged macrophytes and floating plant species for nutrients available in the water column. The diatoms indicate that these sites, at least in the water column itself, are P replete (species with high s values) but potentially N deplete (presence of relatively high abundance of *Epithemia* spp.) Mismatches between the diatom flora status and that of the macrophytes could also be explained by consideration of the s values assigned to one of the diatom species. In the revised version of the TDI, a rescaling procedure was adopted to revise the existing s values for each diatom species (Kelly et al., 2008). Less confidence can be placed on the s values where there are limited records on the species as was the case for *Epithemia adnata.* It is possible that the variety of this species found on plant material is a different ecotype, potentially with a lower tolerance to phosphorus and therefore would have a lower s score. Given the uncertainty of the tolerance of this species, the TDI scores for sites where this species is abundant (MLH6a, MLH6c,MLH6d, TTM3, WSM16, KSM23, CCH5, CCH17) may need to be revised. This could result in an improvement in the estimates for ecological status of these sites.

The remaining sites in the poor category (TTM21, CCL31, CCL51 and WLL22) had no submerged flora and were *Lemna* dominated and *Epithemia* was rare or absent in these samples. These latter sites could potentially be examples of the 'floating plant' dominant alternative stable state (Scheffer et al., 2003). In such sites, submerged macrophytes have been out-competed by floating plants, possibly as a result of high concentrations of both nitrogen and phosphorus in the water column, though the possibility of light limitation cannot be ruled out. The switch to total domination by free floating macrophytes may be higher in deeper ditches with a greater potential for light limitation and/or in ditches with a higher silt carrying capacity. Anoxic conditions may occur under beds of floating plants, which can accelerate the decline in the submerged plant community. Certainly in the case of CCL31, the presence of the low oxygen tolerant species *Nitzschia amphibia* and *Amphora veneta* lend support to this theory. In the three other ditches, *Lemnicola hungarica* was the dominant species, providing further evidence of free floating plant domination. Scores for the metrics N and O were some of the highest in these four ditches, indicating low oxygen and potentially the ability to utilise organic nitrogen sources. However, to date, there is insufficient information on a species by species basis to place too much reliance on the van Dam metrics (van Dam & Mertens, 1993). Following the requirements of the WFD to achieve good ecological status in all water bodies by 2015 (Article 4, clause 1) then only six sites would fit the requirement. However, due to the natural variation of microbial communities there is a degree of uncertainty associated with the assessment of ecological status and this would need to be taken into account before a site can be considered to truly fall within a status class. Uncertainty estimates were not shown for this study, as the estimates of ecological status were based on only one sample, but could be calculated for each site by pooling samples.

Another useful indication of the ecological status of the water bodies can be obtained by an examination of the proportion of nutrient tolerant and nutrient sensitive valves (Table 3). The sites with the highest percentage relative abundance of very nutrient sensitive species were SLM2 (30.25% RA) and TTM12 (8.66% RA). The sites with the highest scores of nutrient sensitive species were SLM2 (37% RA) and WSM16 (30.68% RA). Sites at West Sedgemoor (WSM13), King's Sedgemoor (KSM9) and Wentlooge Level (WLL5) were almost exclusively supported by Group 3 species. Group 4 species were well represented in two of the Pawlett Hams sites, PWH5 and

PWH8, with 50% and 54% of valves in this nutrient tolerant group. Overall the Group 3 valves were the dominant valves in 40 of the ditches surveyed.

5.3 *Spatial patterns in species composition across sites*

A DCA was carried out to identify sites with a similar species composition and to examine trends in spatial groupings. Figure 1 shows the distribution of sites and Figure 2 the distribution of species. The eigenvalues for Axis 1 and 2 were 0.177 and 0.155 respectively and the first three Axes explained 21.1 % of the cumulative percentage variance of the species data. The gradient length of the first axis was relatively short at 1.7. Sites were well distributed within the ordinal space along the first two axes. Sites from the same moor were clustered in a similar location in some cases (e.g. King's Sedgemoor sites located in a cluster to the right along Axis 1 and assessed as either Good or Moderate ecological status, with TDI's ranging from 51-66). The Moorlinch site is quite small and all ditch samples were situated close to each other in ordinal space, reflecting that they experience a similar environmental regime. All of these sites were assessed as moderate, with the exception of MLH6d, which was graded as Poor.

Four of the diatom samples were taken from the same ditch (MLH6a, b, c and d) but from different plants: *Sparganium erectum*, *Bulboschoenus maritimus*, *Typha latifolia* and *Eleocharis palustris* respectively. The purpose of these replicate samples was to address the subject of host specificity. Two of the samples had TDI values of 63, one scored 64 and the sample from *Eleocharis palustris* had a higher TDI of 77. These four samples show a degree of spatial segregation on Axis 2 of the DCA (Figure 1) reflecting species differences. There was a difference in the composition in the dominant species with *Cocconeis placentula* var *lineata* and *Epithemia adnata* present in all of the samples but there was a switch in dominance from *C. placentula* var *lineata* in a, b and c to *E. adnata* in d. As the latter species has an s value of 5 and the former an *s* value of 3, the TDI value is higher for MLH6d. These particular samples were taken very late in the season on 23/10/07. Towards late autumn, the plants may be senescing, and differences in their biofilm composition may reflect differences in the leaching of substrates from the plants. These nutrients could be used by diatoms in the biofilm. Some evidence supports the view that plants can provide nutrients to support their attached biofilm communities and potentially the 'diatom signal' of the surrounding water quality may be masked (Burkholder, 1996). However, it is also considered that the uptake of nutrients from the host substrate may only be critical in relatively oligotrophic environments (Eminson & Moss, 1980). The four samples taken from this site were taken in relatively uniform conditions. However, the biofilm on *Eleocharis* was not well developed, and difficult to collect because of the flexibility of the stems (Nick Stewart, pers. com.). Further replicate samples, taken during the period June-September, when the plants are healthy, would be beneficial. It is also possible that the tolerance of *Epithemia adnata* is lower than present estimates would indicate. The higher TDI for site MLH6d may just be a reflection of the greater abundance of this species in the sample.

The samples from Kenn Moor and Nailsea Moor are situated towards the centre of the ordination and all lie in close proximity, but slightly displaced from the Moorlinch sites. All of the sites from Wentlooge lie to the left of the ordination though they are spread along Axis 2. Two of the sites from Chiltern and Catcott Heath are placed close to the sites from Kenn and Nailsea Moor (CCH17 and CCH23) in the ordination, whilst the other two are displaced to the right along Axis 1 (CCH13 and CCH5). The different positioning was due a higher relative of abundance of *Lemnicola hungarica* in sites CCH17 and CCH23, more *Navicula radiosa* in CCH17

and more *C. placentula* var *lineata* in CCH13 and CCH5. Possibly there was some *Lemna* contamination in sites CCH17 and CCH23. Site CCH13 was assigned to a higher ecological status class than the other three sites, which were all assigned a TDI between 59 and 64 and given a moderate ecological status. All of the sites had varieties of *Cocconeis placentula*, but in site CCH13 a different variety, *C. placentula* var *placentula*, was also common. This variety is less tolerant to high nutrients.

Two of the sites from Pawlett Hams were situated to the far left of the ordination and the other two were located to the mid centre on Axis 1, but were separated on Axis 2, indicating larger differences in the environmental conditions of these sites. The main reason for the displacement is that PWH5 and PWH8 have a relatively greater abundance of the epiphyte *Rhoicosphenia abbreviata*, which is typically associated with the filamentous alga *Cladophora* spp. (Hardwick et al., 1992). The latter species is often associated with more enriched sites, and in rivers, is an indication of a change in the structure and function of the river and can be a sign of degradation. However, there are many diatom species present in the samples that are not tolerant of very high nutrient concentrations. Furthermore, PWH5 and PWH8 both have moderately good macrophyte floras (Nick Stewart, pers. com.). In UK rivers, *Rhoicosphenia* is most common in sites with moderate ecological status, though it is common in good and poor sites also. The epiphyte *Rhoicosphenia abbreviata* also occurs on other species of filamentous algae e.g. *Oedogonium*, the latter being more common in water bodies with a lower nutrient concentration. Filamentous algae are suppressed by dense floating *Lemna* cover, and the presence of significant growths of filamentous algae cannot therefore be used as an indicator of high nutrients (Nick Stewart, pers. com.). It is possible that there may be different 'ecotypes' of *Rhoicosphenia abbreviata* with some forms preferring less nutrient rich environments, and the s value assigned, may be too high for the ditch variant of this species.

The different sites from Southlake Moor were well separated in the ordination with the 'best' site in terms of ecological status being placed to the left, close to the PWH sites 5 and 8. SLM2 is an unusual site and is striking due to the presence of a number of different *Eunotia* species indicating acidic conditions. It is also characterised by the absence of *Lemnicola hungarica*. SLM4 was also of good ecological status. SLM2 is a shallow ditch dominated by *Glyceria fluitans* – and the presence of *Hottonia* in this ditch indicates good quality (Nick Stewart, pers. com.). It is not particularly acidic, as Southlake is a clay moor, so the reasons underlying presence of acidic species are not obvious.

The remaining samples from Caldicott Levels and West Sedgemoor are very spread out in the ordination showing no obvious associations (Figure 1). A number of the sites from the Caldicott levels are situated to the top of the ordination (41, 26, 56 and 51) whilst one other (CCL27) is the most southerly site on the ordination, with the remaining sites taking an intermediate position to the centre of the ordination. Site CCL27 had a lot of submerged plant species, distinguishing it from the rest of the ditches sampled for diatoms on the Caldicott Levels. Hence the diatoms and macrophytes complement each other indicating relatively good water quality in CCL27. Clearly, there is a strong gradient along Axis 2 resulting in the spread of sites. There is an indication of lower oxygen conditions in the northerly sites due to the presence of small *Navicula minima* and *N. saprophila* and three sites (but not CCL56) have a relatively high abundance of *L. hungarica*. The most southerly site (CCL27) was overwhelmingly dominated by varieties of *C. placentula*. Such a skewed composition could indicate grazing, scour or a recent colonisation (see above). The most notable sites at West Sedgemoor are WSM16 and WSM13, situated in the ordination close to the CCL27 site and also dominated by a relatively

high abundance of adnate species including *Cocconeis placentula* varieties. Caldicott Level is a large area with widely scattered samples across several hydrological units, hence a higher degree of spatial variation is not unexpected (Nick Stewart, pers. com.).

The DCA samples scores from Axis 1 and 2 were correlated with selected variables to account for the distribution in sites and to look for gradients accounting for the changes in species composition between sites. Correlates included the % organic tolerant valves (inferring organic pollution), % motile valves indicating silt deposition or high silt carrying load, conductivity, pH, and the van Dam metrics H (salinity, where high is more saline), N (nitrogen metabolism, where high is more organic N enriched), R (where high is more alkaliphilic species) and O (tolerance to low oxygen is high). Biotic indicators of diatom species richness and diversity (H´) were also included. There was a positive correlation on Axis 1 with the van Dam pH metric R ($p = 0.003$). This is supported by the presence of a number of acid tolerant species of the genus *Eunotia* towards the left of the ordination (Figure 1b). There was also a negative correlation between Axis 1 and the Shannon's diversity index (H') and species richness. A positive correlation between Axis 1 sample scores and the field based measurements of pH was not found. The R measurements determined by the diatom species may give a better reflection of the long term pH profile, as the biofilms may have been present for a number of weeks.

Axis 2 sample scores were weakly positively correlated with TDI (0.043). Axis 2 was strongly positively correlated with the % of motile and organic tolerant valves and with the van Dam metrics O and N, ($p = < 0.001$). Some of the sites towards the top of the ordination had a number of species (e.g. *Navicula minima* and *Navicula saprophila*) that indicated a tolerance to lower oxygen conditions, which could reflect heavy *Lemna* domination. The increase in N heterotrophs could indicate a source of organic nitrogen pollution. Frequently, sites with higher nutrients are associated with a higher oxygen demand and it is not possible at this stage to tease out differences between higher inorganic inputs or high organic nutrient contamination.

Axis 3 of the DCA sample scores (figure not shown) indicated a positive salinity gradient ($p = < 0.001$) as measured using the van Dam metric H. An examination of the species composition of sites indicated that PWH5 had the best representation of saline tolerant species, and was situated close to the sea wall. One difficulty in making assessments is that many species can cope with both freshwater and salt water to some extent (e.g. *Navicula gregaria* and *Navicula menisculus*), though the latter species was not abundant in the ditches surveyed. Therefore, the presence of this species does not necessarily indicate a more saline habitat. Furthermore, if these species are made up of a number of 'ecotypes' they may have different tolerances to nutrients.

5.4 *Comparisons between the different moors in diatom derived metrics.*

Sites within each moor were grouped for further analysis. No significant differences were observed between the % motile valves or the % of organic tolerant valves, or the R, O, N and H metrics between any of the moors. This is a reflection of the greater intra-site variability in some of the Moors, particularly Chilton & Catcott Heaths and King's Sedgemoor.

The mean TDI values ranged from 46.2 ± 13.9 (Southlake Moor) to a mean of 64.65 ± 11.14 (Tealham and Tadham Moor). However, there was considerable variation in

some of the Moors and there was no significant difference between the mean TDI values at each of the Moors.

No differences were observed in the percentage of very nutrient sensitive valves between the moors, though there were considerably more valves at 11.3 ±16.5 % RA in Southlake Moor than elsewhere. The next highest record was for Tealham and Tadham Moor at 2.4 ± 4.2 % RA. However, there was a significant difference between the percentage of the nutrient tolerant Group 4 valves between moors (ANOVA, $F_{10,39}$ 2.72, p = 0.012). *Post hoc* Tukey tests indicated that the percentage of Group 4 valves in the sites at Pawlett Hams was considerably greater at 40.3 ± 13.7 % than the percentage of valves in Chilton and Catcott Heaths (11.2 ± 5.3), Moorlinch (12.5 ±7.7), Tealham and Tadham Moor (12.4 ± 8.5) and King's Sedgemoor (10.9 ± 4.5). No differences were observed in any other nutrient categories.

5.5 *Comparisons between the Somerset and Gwent Levels*

The sites in the Gwent Levels were located at the periphery of the ordination (Figure 1) whereas those from the Somerset Levels are located largely in a band in the middle of the ordination, with just a few exceptions (TTM8, WSM16 and WSM13). This spatial segregation indicates that there may be differences in the ditches from these two Levels. All the sites from Somerset were assigned to one category and the sites from Gwent to another, in order to investigate whether there were differences in selected abiotic and biotic variables in this subset of ditches. There were no significant differences in the species richness, species diversity, evenness, percentage of diatoms in any of the 5 categories of nutrient sensitivity, the van Dam metrics of R (pH) and S (salinity), or in the TDI metrics derived from analysis of the diatoms between the Gwent and Somerset ditches. There were significant differences in other biotic variables measured. The metrics N and O were significantly higher on the Gwent Levels (p = < 0.01), Table 5). The mean sample score for DCA Axis 1 of the ordination was significantly lower for the Gwent ditches compared with the Somerset ditches. In terms of abiotic measures, the ditches sampled for diatoms were significantly deeper on the Gwent Levels (p = < 0.001) (Table 5), and silt depth was significantly shallower (p < 0.05). Conductivity (p= < 0.05) and pH levels (p =< 0.001) were significantly lower on the Gwent Levels.

6. Summary and conclusions

1. The diatom species composition of the Somerset and Gwent Level ditches reflect high species richness overall and over 170 different species of diatom were recorded. The biota from a total of 50 sites was examined. The vast majority of the diatom species found were typical of UK rivers and lakes and therefore we already have strong indications of their ecological preferences, particularly for nutrients.

2. As a consequence of our extensive knowledge of the environmental preferences of most of the species of diatom found in the ditches, it was possible and appropriate to apply the DARLEQ tool to assess the ecological status of the ditches.

3. In applying the predictive tool, an estimate for alkalinity was made. It is recommended that existing databases are examined to find matched data for

alkalinity and conductivity in sites with conductivity values over 600 µS cm^{-1}, to provide better predictions of alkalinity at these electrolyte-rich sites.

4. Given the temporal and spatial variability in any waterbody and in order to give reliable predictions of the ecological status, it is recommended that a minimum of three samples is taken over time (e.g. one each year) before a reliable assessment of the ecological status can be provided for any one site (Yallop & Kelly, unpublished data). Pooling samples from different locations in any of the Moors will improve the reliability of the ecological status indicator.

5. Preliminary indications, using the DARLEQ tool for rivers, show that a limited number of sites fall within the high or good status and a few are considered to be of poor quality. Most of the sites are of moderate ecological status. However, it is possible that different ecotypes of diatoms may vary in their tolerance to nutrients e.g. *Epithemia adnata* and *Rhoicosphenia abbreviata.* The s scores have primarily, with a few exceptions, been calculated using data obtained from epilithic samples for the river predictive tool. Diatoms that are growing epiphytically may have a different tolerance to nutrients. Reassigning nutrient sensitivity values for species that are very common or abundant in the ditch ecosystems would lead to a revision of the ecological status.

6. A significant difference in the percentage of nutrient tolerant valves was found between some of the moors. A more detailed analysis of the management regimes between these sites would be of high utility.

7. Although many substrates were used to collect the diatom samples there were no indications of strong substrate specificity. Replicate samples from one of the sites at Moorlinch indicated a very similar diatom composition, with the exception of one of the sites where the samples was taken from *Eleocharis palustris.* However, these samples where taken late in the season when host plants may senesce and leach nutrients. It is recommended that in future sampling programmes, the samples are restricted to a tighter window of collection from June to September to ensure that the diatoms give a good indication of the ambient water quality.

8. The dominance of *Lemnicola hungarica* at some sites could indicate contamination of the sample by *Lemna* spp., as this diatom has shown a strong specificity for *Lemna*. However, there was no obvious sign of contamination in these samples and extra care was taken to eliminate the plant in the field. It is more likely that this diatom species was growing on the plant stems too. Domination by *Lemnicola hungarica*, with low diversity and species richness of diatoms, could indicate that a ditch is in the 'stable free-floating macrophyte dominant' alternative stable state. Other associated diatom species indicated low oxygen conditions and possible contamination with organic nitrogen sources in these sites.

9. The application of ordination techniques indicated that all of the ditches on some moors shared a similar species flora (e.g. Moorlinch), whilst others were more disparate in their species composition (e.g. Caldicott Levels and West Sedgemoor).

10. Correlations of the DCA sample scores with selected metrics indicated there were some gradients across the moor sites (acidity, salinity, oxygen, organic nitrogen and phosphorus). Many of the variables are correlated with each

other (e.g. TDI, % motile valves, % O, and % organic tolerant valves) and it is not possible at this stage to give a clear indication of the major drivers at any one site. It is likely that sites are impacted by a number of pressures.

11. Differences in the diatom species composition was evident in ditches with only a free-floating canopy of macrophytes compared with sites with a mixture of free-floating and submerged macrophyte species. The TDI/EQR scores obtained using the DARLEQ river tool showed a good match with plant indicators of good water quality. There was a reasonable match between ditches with a poor submerged plant community. Whilst most of the diatom species were common to rivers and ditches, it is possible that there may be ecotypes which vary in their tolerance to specific pressures. Comparisons between the diatom ditch flora and nutrient concentrations will allow determination of their response to pressure gradients for comparison with sensitivity values obtained using river data. It is considered that any existing nutrient data would be invaluable to support further validation of the DARLEQ tool for application in ditch ecosystems.

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10. List of Tables

9. List of Figures

Table 1

Taxon	s value	% frequency	max
Achnanthes delicatula	5	2	0.53
Achnanthidium minutissimum	2	86	14.47
Amphora commutata	4	4	1.66
Amphora inariensis	4	38	13.01
Amphora libyca	4	16	2.20
Amphora normannii	5	2	1.39
Amphora oligotraphenta	5	4	2.87
Amphora ovalis	5	2	1.04
Amphora pediculus	5	16	3.41
Amphora veneta	5	66	9.87
Anomoeoneis sphaerophora	1	6	0.54
Caloneis bacillum	4	8	2.72
Caloneis molaris	4	4	1.34
Caloneis silicula	4	6	1.05
Cocconeis pediculus	4	14	2.22
Cocconeis placentula v. euglypta	4	48	33.91
Cocconeis placentula v. lineata	3	96	83.38
Cocconeis placentula v. pseudolineata	3	16	4.35
Cocconeis placentula v. placentula	2	78	21.91
Craticula accomoda	3	4	0.28
Craticula halophila	3	36	3.20
Ctenophora pulchella	2	6	5.93
Cymatopleura solea	5	2	0.28
Cymbella microcephala	2	6	0.59
Denticula subtilis	3	2	0.28
Diadesmis contenta	4	2	0.28
Diatoma tenuis	1	4	0.83
Encyonema minuta	2	2	2.23
Epithemia adnata	5	74	48.55
Eunotia bilunaris v. bilunaris	2	36	13.90
Eunotia bilunaris v. linearis	2	6	1.14
Eunotia bilunaris v. mucophila	2	2	1.36
Eunotia faba	1	6	3.70
Eunotia formica	2	2	1.04
Eunotia intermedia	2	2	0.26
Eunotia minor	2	24	5.23
Eunotia monodon	3	2	0.29
Eunotia praerupta	3	2	0.56
Eunotia rhomboidea	1	2	1.91
Eunotia sudetica	1	4	0.28
Eunotia girdle views	2	16	2.60
Fallacia pygmaea	5	4	0.26
Fragilaria bidens	3	6	0.87
Fragilaria capucina (Fig. 110, T 22)	1	2	2.04
Fragilaria capucina v. capucina	1	8	1.11
Fragilaria capucina v. gracilis	1	8	1.67
Fragilaria capucina v. mesolepta	3	6	2.55
Fragilaria capucina v. rumpens	2	4	0.83
Fragilaria fasciculata	4	32	5.93
Fragilaria nanana	1	2	0.25
Fragilaria neoproducta	2	2	0.26

Fragilaria parasitica	5	2	0.58
Fragilaria vaucheriae	2	8	2.22
Fragilaria virescens	2	2	0.54
Frustulia vulgaris	2	6	0.54
Gomphonema acuminatum	2	18	1.57
Gomphonema clavatum	2	70	19.60
Gomphonema gracile	1	32	5.77
Gomphonema minutum	4	8	0.32
Gomphonema olivaceum	3	2	0.28
Gomphonema parvulum	3	56	5.94
Gomphonema parvulum v. exilissimum	1	28	23.16
Gomphonema parvulum v. parvulius	3	8	2.21
Gomphonema pumilum	3	4	0.29
Gomphonema truncatum	3	26	1.66
Gyrosigma acuminatum	5	4	0.54
Gyrosigma attenuatum	5	4	0.28
Gyrosigma macrum	3	2	0.29
Hantzschia amphioxys	4	6	0.31
Lemnicola hungarica	5	86	60.06
Luticola cohnii	3	2	0.27
Luticola ventricosa	3	2	0.28
Navicula agrestis	5	4	1.17
Navicula arvensis	5	2	0.59
Navicula atomus	4	44	2.82
Navicula bryophila	3	10	5.16
Navicula capitata	4	26	2.62
Navicula capitata v. hungarica	5	16	4.13
Navicula capitatoradiata	4	8	10.19
Navicula cincta	4	16	2.82
Navicula clementis	4	2	0.64
Navicula cryptocephala	3	30	12.15
Navicula cryptocephala v. exilis	3	2	1.09
Navicula cryptotenella	4	70	12.96
Navicula cryptotenelloides	4	8	2.28
Navicula difficilima	3	10	7.62
Navicula digitoradiata v. rostrata	5	4	0.52
Navicula eidrigiana	4	10	1.38
Navicula exilis	4	14	2.90
Navicula gregaria	4	38	9.16
Navicula joubaudii	4	12	2.52
Navicula lacunolaciniata	3	2	1.06
Navicula lanceolata	4	6	0.96
Navicula laterostrata	2	2	0.28
Navicula menisculus	4	46	4.69
Navicula menisculus v. upsaliensis	4	12	3.05
Navicula minima	3	98	42.15
Navicula molestiformis	5	44	6.74
Navicula parsura	4	6	3.98
Navicula pseudoarvensis	4	6	0.79
Navicula radiosa	3	50	23.16
Navicula radiosafallax	5	28	6.48
Navicula recens	5	2	0.28
Navicula reichardtiana	4	8	1.55

Navicula rhyncocephala	3	2	0.32
Navicula rhynchotella	4	16	1.09
Navicula saprophila	3	42	9.97
Navicula schroeteri	5	2	0.52
Navicula slesvicensis	3	12	1.08
Navicula striolata	4	2	0.28
Navicula subminuscula	4	4	1.13
Navicula tenelloides	4	10	1.05
Navicula tridentula	4	2	0.63
Navicula tripunctata	5	6	0.82
Navicula trivialis	4	8	13.81
Navicula trivialis v. oligotraphenta	4	2	0.82
Navicula veneta	4	72	6.81
Navicula viridula	4	4	0.55
Neidium ladogensis	3	2	0.27
Nitzschia amphibia	5	38	13.69
Nitzschia angustiforaminata	4	2	0.27
Nitzschia archibaldii	2	32	6.04
Nitzschia capitellata	4	8	1.28
Nitzschia debilis	4	2	0.55
Nitzschia denticula N. kuetsingii	3	24	10.33
Nitzschia dissipata	3	6	0.55
Nitzschia dubia	5	2	1.09
Nitzschia fonticola	4	14	2.54
Nitzschia frustulum	3	8	3.39
Nitzschia frustulum v. bulnheimia	3	16	5.15
Nitzschia gracilis	3	8	0.59
Nitzschia hantzschiana	2	12	2.18
Nitzschia incognita	3	6	0.79
Nitzschia inconspicua	4	12	8.47
Nitzschia lacuum	2	2	0.52
Nitzschia liebetruthii	1	2	0.52
Nitzschia linearis	4	4	0.51
Nitzschia linearis v. subtilis	4	4	1.66
Nitzschia linearis v. tenuis	4	2	1.36
Nitzschia palea	4	8	1.29
Nitzschia palea v. debilis	3	50	11.05
Nitzschia paleacea	3	20	4.24
Nitzschia paleaeformis	3	24	9.59
Nitzschia perminuta	3	34	6.40
Nitzschia pusilla	4	20	1.09
Nitzschia recta	4	4	1.09
Nitzschia sigmoidea	4	2	0.55
Nitzschia sociabilis	4	8	1.03
Nitzschia solita	5	2	0.27
Nitzschia sublinearis	4	4	1.78
Nitzschia tubicola	4	2	0.27
Nitzschia sp.	3	2	1.55
Pinnularia gibba	2	6	1.09
Pinnularia lagerstedtii	1	2	0.27
Pinnularia rupestris	3	2	0.26
Pinnularia sinistra	2	2	0.56
Pinnularia subgibba v. hustedtii	2	4	0.53

Pinnularia girdle views	2	2	1.09
Planothidium ellipticum	3	4	2.30
Planothidium frequentissimum	3	92	67.73
Planothidium lanceolatum	4	14	3.27
Planothidium rostratum	5	4	3.49
Rhoicosphenia abbreviata	4	40	34.88
Sellaphora pupula	4	18	2.76
Sellaphora seminulum	4	78	17.13
Stauroenis anceps	2	4	0.54
Stauroneis kriegerii	2	14	1.63
Stauroneis phoenicentereon	4	2	0.27
Stauroneis salina	3	2	0.51
Staurosira construens	3	2	0.28
Staurosirella leptostauron	4	2	0.55
Staurosirella pinnata	4	4	0.52
Surirella angusta	3	4	0.28
Surirella brebissonii	3	10	0.56
Synedra ulna	2	20	1.28
Tryblionella fasiculata	4	6	1.55
Tryblionella hungarica	4	6	0.82

Table 2

Site	Index	Evenness	Number of Species
CCH5	2.266	0.666	30
CCH13	1.773	0.626	17
CCH17	2.691	0.776	32
CCH23	2.716	0.791	31
CCL26	2.377	0.653	38
CCL27	1.936	0.683	17
CCL31	2.965	0.821	37
CCL35	2.422	0.693	33
CCL41	2.783	0.76	39
CCL51	2.202	0.723	21
CCL56	2.475	0.728	30
CCL61	2.751	0.774	35
KNM15	1.933	0.586	27
KSM15	2.19	0.719	21
KSM23	2.296	0.754	21
KSM24	2.31	0.701	27
KSM9	1.318	0.465	17
MLH3	2.646	0.771	31
MLH6a	2.094	0.677	22
MLH6b	2.542	0.763	28
MLH6c	1.118	0.424	14
MLH6d	1.943	0.648	20
MLH12	2.582	0.759	30
MLH13	2.335	0.708	27
NSM1	2.537	0.726	33
NSM5	2.434	0.788	22
NSM9	2.913	0.819	35
OWEN90	2.03	0.639	24
OWN240	1.879	0.627	20
PWH5	2.743	0.791	32
PWH7	2.267	0.688	27
PWH8	2.758	0.748	40
PWH15	2.659	0.754	34
SLM2	2.876	0.78	40
SLM4	2.497	0.721	32
SLM8	1.66	0.516	25
TTM3	2.252	0.691	26
TTM8	2.21	0.632	33
TTM12	3.065	0.837	39
TTM21	0.93	0.388	11
WLL5	1.41	0.471	20
WLL8	2.065	0.62	28
WLL14	2.585	0.721	36
WLL22	1.533	0.566	15
WSM3	1.38	0.453	21
WSM10	2.783	0.755	40
WSM13	0.647	0.295	9
WSM16	2.256	0.753	20
WSM19	2.604	0.758	31
WSM21	2.924	0.81	37

Table 3

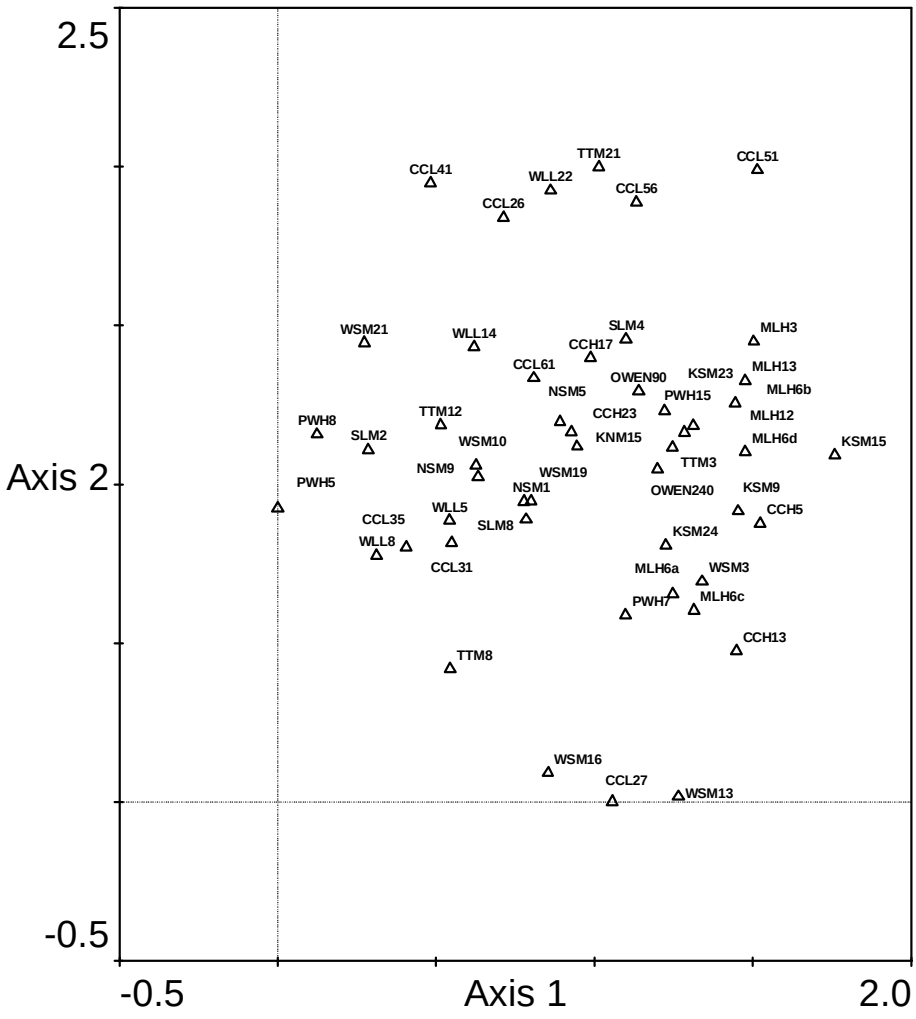
Moor	% Group 1	% Group 2	% Group 3	% Group 4	% Group 5
CCH5	1.06	8.78	64.36	9.57	16.22
CCH13	4.01	**29.32**	50.00	5.56	11.11
CCH17	0.54	4.90	60.22	11.44	22.89
CCH23	0.50	12.94	53.73	18.16	14.68
CCL26	0.00	2.88	68.59	14.40	14.14
CCL27	0.58	10.14	37.39	41.74	10.14
CCL31	1.27	7.32	26.43	31.85	33.44
CCL35	4.72	10.28	55.28	11.39	18.33
CCL41	2.04	4.59	58.16	15.82	19.39
CCL51	0.00	1.47	49.56	17.30	31.67
CCL56	0.00	6.93	70.36	16.90	5.82
CCL61	2.11	25.26	51.05	14.21	7.37
KNM15	0.00	6.45	69.09	6.45	18.01
NSM1	0.82	5.99	56.68	29.16	7.36
NSM5	2.21	11.05	28.73	24.31	33.70
NSM9	1.34	26.08	44.62	14.78	13.17
KSM9	0.00	12.31	**77.85**	5.23	4.62
KSM15	0.58	13.66	71.80	11.34	2.62
KSM23	1.15	6.32	53.74	16.09	22.70
KSM24	0.55	4.99	55.96	10.80	27.70
MLH3	0.27	4.89	54.62	22.01	18.21
MLH6a	5.04	6.72	49.86	9.24	29.13
MLH6b	0.00	8.82	55.08	19.52	16.58
MLH6c	0.00	2.73	66.97	0.61	29.70
MLH6d	1.74	13.37	21.51	5.52	**57.85**
MLH12	0.00	12.50	62.77	16.58	8.15
MLH13	0.57	9.94	65.63	13.64	10.23
OWEN90	0.58	9.86	67.54	19.13	2.90
OWN240	0.59	2.35	**75.07**	9.38	12.61
PWH5	1.13	16.38	28.53	**50.00**	3.95
PWH7	0.00	4.07	58.27	26.29	11.38
PWH8	1.55	8.53	23.77	**54.01**	12.14
PWH15	0.00	2.54	51.83	30.99	14.65
SLM2	**30.25**	**37.06**	17.71	14.99	0.00
SLM4	2.39	16.76	59.84	14.36	6.65
SLM8	1.11	3.32	**75.35**	13.02	7.20
TTM3	0.00	2.32	56.23	19.71	21.74
TTM8	0.83	9.64	59.50	17.36	12.67
TTM12	**8.66**	27.30	26.25	12.07	25.72
TTM21	0.00	2.52	36.79	0.63	**60.06**
WLL5	0.29	7.27	**78.20**	8.43	5.81
WLL8	2.72	5.45	56.13	34.60	1.09
WLL14	2.60	4.17	64.32	18.49	10.42
WLL22	0.00	1.24	46.89	10.25	41.61
WSM3	0.29	9.14	75.52	2.95	12.09
WSM10	1.02	14.72	33.76	23.35	27.16
WSM13	0.31	14.46	**83.69**	1.23	0.31
WSM16	1.14	**30.68**	34.94	16.48	16.76
WSM19	2.22	14.13	51.25	23.55	8.86
WSM21	0.83	6.08	33.43	43.65	16.02

Table 4

Site	TDI	EQR	Ecological Status	Alkalinity
CCH5	59.6	0.67	Moderate	291
CCH13	47.8	0.84	Good	67
CCH17	64	0.6	Moderate	193
CCH23	58.6	0.69	Moderate	229
CCL26	62.6	0.62	Moderate	148
CCL27	63.8	0.6	Moderate	179
CCL31	73	0.45	Poor	263
CCL35	57.7	0.7	Moderate	396
CCL41	62.4	0.62	Moderate	104
CCL51	72.1	0.46	Poor	108
CCL56	56	0.73	Moderate	233
CCL61	50.1	0.83	Good	220
KNM15	59.2	0.68	Moderate	244
NSM1	59.3	0.68	Moderate	328
NSM5	69.1	0.52	Poor	339
NSM9	54	0.77	Moderate	250
KSM9	50.6	0.82	Good	233
KSM15	54.1	0.76	Moderate	193
KSM23	63.5	0.61	Moderate	315
KSM24	65.8	0.57	Moderate	219
MLH3	64.5	0.59	Moderate	280
MLH6a	62.7	0.62	Moderate	267
MLH6b	62.5	0.62	Moderate	267
MLH6c	64.3	0.59	Moderate	267
MLH6d	76.5	0.39	Poor	267
MLH12	56.7	0.72	Moderate	308
MLH13	56.4	0.73	Moderate	335
OWEN90	54.3	0.76	Moderate	162
OWN240	57.9	0.7	Moderate	241
PWH5	60	0.67	Moderate	329
PWH7	62.3	0.63	Moderate	172
PWH8	66.9	0.55	Moderate	145
PWH15	68.5	0.53	Moderate	247
SLM2	30.3	1	High	209
SLM4	52.1	0.8	Good	216
SLM8	56.1	0.73	Moderate	206
TTM3	66	0.57	Moderate	291
TTM8	57.9	0.7	Moderate	203
TTM12	54.9	0.75	Moderate	193
TTM21	79.8	0.34	Poor	189
WLL5	53.2	0.78	Moderate	135
WLL8	56.4	0.73	Moderate	162
WLL14	58.3	0.69	Moderate	155
WLL22	73.7	0.44	Poor	240
WSM3	54.5	0.76	Moderate	328
WSM10	66.5	0.56	Moderate	203
WSM13	46.7	0.89	Good	199
WSM16	55.3	0.75	Moderate	203
WSM19	56	0.73	Moderate	396
WSM21	67.7	0.54	Moderate	199

Table 5

Variable	Somerset Levels (mean ± SD)	Gwent Levels (mean ± SD)	Significance: * = 0.05; ** = 0.01; *** = 0.001
Water Depth (cm)	55.92 ± 15.06	82.08 ± 17.64	ANOVA***
Silt Depth (cm)	71.84 ± 37.46	42.08 ± 28.88	ANOVA*
Conductivity (µS cm^{-1})	737.90 ± 191.4	598.30 ± 241.50	ANOVA*
pH (Spring values)	7.70 (median)	7.07 (median)	KRUSKAL-WALLIS***
Nitrogen Heterotrophs (N)	2.03 ± 0.20	2.25 ± 0.25	ANOVA**
Oxygen tolerance (O)	2.93 (median)	3.12 (median)	KRUSKAL-WALLIS**
DCA Axis 1	1.02 ± 0.42	0.74 ± 0.42	ANOVA*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Axis 2
-0.5
Axis 1
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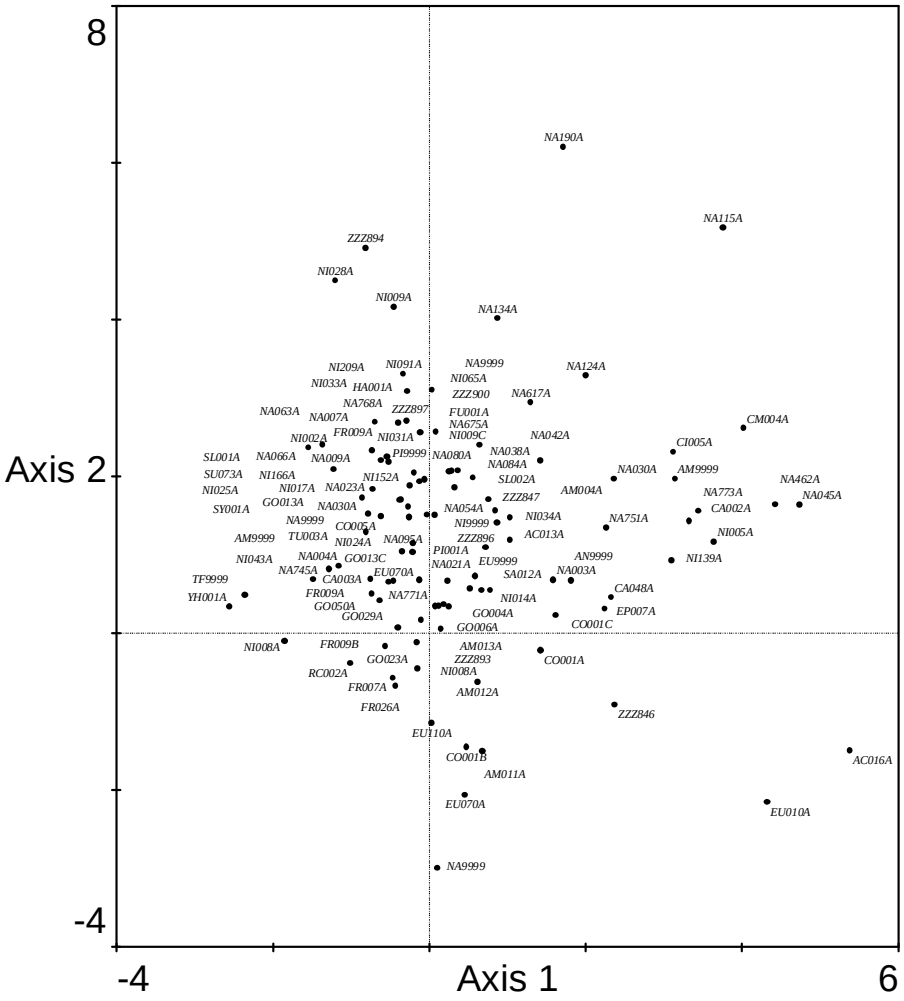
CCL41
WLL22
CCL56
CCL26
WSM21
WLL14
SLM4
MLH3
CCH17
CCL61
OWEN90
KSM23
MLH13
NSM5
PWH15
MLH6b
TTM12
CCH23
MLH12
PWH8
SLM2
WSM10
KNM15
MLH6d
KSM15
NSM9
TTM3
WSM19
PWH5
NSM1
OWEN240
KSM9
WLL5
CCH5
CCL35
SLM8
KSM24
WLL8
CCL31
MLH6a
WSM3
PWH7
MLH6c
CCH13
TTM8
WSM16
CCL27
WSM13

Figure 1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Axis 2
-4
Axis 1
6
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NA115A
ZZZ894
NI028A
NI009A
NA134A
NI209A
NI091A
NA9999
NA124A
NI033A
HA001A
NI065A
ZZZ900
NA617A
NA768A
ZZZ897
FU001A
NA675A
NA063A
NA007A
FR009A
NI031A
NI009C
NA042A
CM004A
NI002A
CI005A
SL001A
NA066A
NA009A
PI9999
NA080A
NA038A
NA084A
NA030A
AM9999
SU073A
NI166A
NI152A
SL002A
NA462A
NI025A
NI017A
NA023A
AM004A
NA773A
NA045A
GO013A
ZZZ847
SY001A
NA030A
NA054A
NI034A
CA002A
NA9999
NI9999
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CO005A
AM9999
TU003A
NI124A
NA095A
ZZZ896
AC013A
NI005A
PI001A
NI043A
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GO013C
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AN9999
NI139A
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CO001A
RC002A
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FR007A
AM012A
FR026A
ZZZ846
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CO001B
AC016A
AM011A
EU070A
EU010A
NA9999

Figure 2

Appendix 1

Site	Grid reference	Sampling date
CCH5	ST37684176	09/08/2007
CCH13	ST40834305	07/08/2007
CCH17	ST40354253	07/08/2007
CCH23	ST39904075	08/08/2007
CCL26	ST36398528	01/10/2007
CCL27	ST37718551	01/10/2007
CCL31	ST36998266	01/10/2007
CCL35	ST39388343	28/09/2007
CCL41	ST42308476	02/10/2007
CCL51	ST43908635	03/10/2007
CCL56	ST40048543	28/09/2007
CCL61	ST42018639	03/10/2007
KNM15	ST43046882	06/10/2007
KSM9	ST39673378	20/10/2007
KSM15	ST38393467	14/08/2007
KSM23	ST40883271	20/10/2007
KSM24	ST39863361	14/08/2007
MLH3	ST39613555	17/10/2007
MLH6	ST38513629	23/10/2007
MLH12	ST39063631	17/10/2007
MLH13	ST39053603	17/10/2007
NSM1	ST43517030	09/09/2007
NSM5	ST44797060	09/09/2007
NSM9	ST45067119	06/10/2007
OWEN90	ST50423731	15/10/2007
OWEN240	ST37184537	14/10/2007
PWH5	ST26474300	03/08/2007
PWH7	ST27284133	02/08/2007
PWH8	ST27234219	02/08/2007
PWH15	ST27714346	03/08/2007
SLM2	ST36523019	21/10/2007
SLM4	ST36173045	23/10/2007
SLM8	ST37313007	20/10/2007
TTM3	ST40424593	14/10/2007
TTM8	ST41594576	14/10/2007
TTM12	ST42214497	08/10/2007
TTM21	ST42984377	08/10/2007
WLL5	ST25057962	10/10/2007
WLL8	ST26178043	10/10/2007
WLL14	ST26998136	05/10/2007
WLL22	ST30088165	26/09/2007
WSM3	ST34212486	04/09/2007
WSM10	ST34482477	04/09/2007
WSM13	ST35842517	03/09/2007
WSM16	ST36572519	01/09/2007
WSM19	ST37562612	01/09/2007
WSM21	ST38182708	01/09/2007

Appendix 2

Species Code	Diatom species list
AC016A	*Achnanthes delicatula*
AC013A	*Achnanthidium minutissimum*
AM9999	*Amphora commutata*
AM013A	*Amphora inariensis*
AM011A	*Amphora libyca*
AM005A	*Amphora normannii*
AM9999	*Amphora oligotraphenta*
AM001A	*Amphora ovalis*
AM012A	*Amphora pediculus*
AM004A	*Amphora veneta*
AN9999	*Anomoeoneis sphaerophora*
CA002A	*Caloneis bacillum*
CA048A	*Caloneis molaris*
CA003A	*Caloneis silicula*
CO005A	*Cocconeis pediculus*
CO001B	*Cocconeis placentula v. euglypta*
CO001C	*Cocconeis placentula v. lineata*
ZZZ846	*Cocconeis placentula v. pseudolineata*
CO001A	*Cocconeis placentula v. placentula*
CI002A	*Craticula accomoda*
CI005A	*Craticula halophila*
YH001A	*Ctenophora pulchella*
CL001A	*Cymatopleura solea*
CM004A	*Cymbella microcephala*
DE9999	*Denticula subtilis*
DA005A	*Diadesmis contenta*
DT004A	*Diatoma tenuis*
EY011A	*Encyonema minuta*
EP007A	*Epithemia adnata*
EU070A	*Eunotia bilunaris v. bilunaris*
EU070A	*Eunotia bilunaris v. linearis*
EU070B	*Eunotia bilunaris v. mucophila*
EU010A	*Eunotia faba*
EU018A	*Eunotia formica*
EU108A	*Eunotia intermedia*
EU110A	*Eunotia minor*
EU008A	*Eunotia monodon*
EU003A	*Eunotia praerupta*
EU011A	*Eunotia rhomboidea*
EU021A	*Eunotia sudetica*
EU9999	*Eunotia girdle views*
FA001A	*Fallacia pygmaea*
FR026A	*Fragilaria bidens*
FR009A	*Fragilaria capucina (Fig. 110, T 22)*
FR009A	*Fragilaria capucina v. capucina*
FR009A	*Fragilaria capucina v. gracilis*
FR009B	*Fragilaria capucina v. mesolepta*

FR009G	*Fragilaria capucina v. rumpens*
SY013A	*Fragilaria nanana*
FR9999	*Fragilaria neoproducta*
SY004A	*Fragilaria parasitica*
FR007A	*Fragilaria vaucheriae*
FF001A	*Fragilaria virescens*
FU001A	*Frustulia vulgaris*
GO006A	*Gomphonema acuminatum*
GO029A	*Gomphonema clavatum*
GO004A	*Gomphonema gracile*
GO050A	*Gomphonema minutum*
GO001A	*Gomphonema olivaceum*
GO013A	*Gomphonema parvulum*
GO013C	*Gomphonema parvulum v. exilissimum*
GO013A	*Gomphonema parvulum v. parvulius*
GO080A	*Gomphonema pumilum*
GO023A	*Gomphonema truncatum*
GY005A	*Gyrosigma acuminatum*
GY001A	*Gyrosigma attenuatum*
GY9999	*Gyrosigma macrum*
HA001A	*Hantzschia amphioxys*
ZZZ900	*Lemnicola hungarica*
LU002A	*Luticola cohnii*
LU009A	*Luticola ventricosa*
NA190A	*Navicula agrestis*
NA038A	*Navicula arvensis*
NA084A	*Navicula atomus*
NA045A	*Navicula bryophila*
NA066A	*Navicula capitata*
NA004A	*Navicula capitata v. hungarica*
NA745A	*Navicula capitatoradiata*
NA021A	*Navicula cincta*
NA050A	*Navicula clementis*
NA007A	*Navicula cryptocephala*
NA007A	*Navicula cryptocephala v. exilis*
NA751A	*Navicula cryptotenella*
NA771A	*Navicula cryptotenelloides*
NA115A	*Navicula difficilima*
NA060A	*Navicula digitoradiata v. rostrata*
NA9999	*Navicula eidrigiana*
NA9999	*Navicula exilis*
NA023A	*Navicula gregaria*
NA462A	*Navicula joubaudii*
ZZZ976	*Navicula lacunolaciniata*
NA009A	*Navicula lanceolata*
NA147A	*Navicula laterostrata*
NA030A	*Navicula menisculus*
NA030A	*Navicula menisculus v. upsaliensis*
NA042A	*Navicula minima*
NA124A	*Navicula molestiformis*
NA9999	*Navicula parsura*
NA038A	*Navicula pseudoarvensis*

NA003A	*Navicula radiosa*
NA773A	*Navicula radiosafallax*
NA762A	*Navicula recens*
NA768A	*Navicula reichardtiana*
NA008A	*Navicula rhyncocephala*
ZZZ847	*Navicula rhynchotella*
NA617A	*Navicula saprophila*
NA764A	*Navicula schroeteri*
NA080A	*Navicula slesvicensis*
NA9999	*Navicula striolata*
NA134A	*Navicula subminuscula*
NA675A	*Navicula tenelloides*
NA9999	*Navicula tridentula*
NA095A	*Navicula tripunctata*
NA063A	*Navicula trivialis*
NA063A	*Navicula trivialis v. oligotraphenta*
NA054A	*Navicula veneta*
NA027A	*Navicula viridula*
NE9999	*Neidium ladogensis*
NI014A	*Nitzschia amphibia*
NI192A	*Nitzschia angustiforaminata*
NI065A	*Nitzschia archibaldii*
NI028A	*Nitzschia capitellata*
ZZZ985	*Nitzschia debilis*
NI9999	*Nitzschia denticula N. kuetsingii*
NI091A	*Nitzschia dissipata*
NI018A	*Nitzschia dubia*
NI002A	*Nitzschia fonticola*
NI008A	*Nitzschia frustulum*
NI008A	*Nitzschia frustulum v. bulnheimia*
NI017A	*Nitzschia gracilis*
NI034A	*Nitzschia hantzschiana*
NI209A	*Nitzschia incognita*
NI043A	*Nitzschia inconspicua*
NI198A	*Nitzschia lacuum*
NI203A	*Nitzschia liebetruthii*
NI031A	*Nitzschia linearis*
NI031A	*Nitzschia linearis v. subtilis*
NI031A	*Nitzschia linearis v. tenuis*
NI009A	*Nitzschia palea*
NI009C	*Nitzschia palea v. debilis*
NI033A	*Nitzschia paleacea*
NI139A	*Nitzschia paleaeformis*
NI005A	*Nitzschia perminuta*
NI152A	*Nitzschia pusilla*
NI025A	*Nitzschia recta*
NI046A	*Nitzschia sigmoidea*
NI166A	*Nitzschia sociabilis*
NI206A	*Nitzschia solita*
NI024A	*Nitzschia sublinearis*
NI048A	*Nitzschia tubicola*
NI9999	*Nitzschia sp.*
PI001A	*Pinnularia gibba*

PI9999	*Pinnularia lagerstedtii*
PI056A	*Pinnularia rupestris*
PI9999	*Pinnularia sinistra*
PI9999	*Pinnularia subgibba v. hustedtii*
PI9999	*Pinnularia girdle views*
ZZZ894	*Planothidium ellipticum*
ZZZ896	*Planothidium frequentissimum*
ZZZ897	*Planothidium lanceolatum*
ZZZ893	*Planothidium rostratum*
RC002A	*Rhoicosphenia abbreviata*
SL001A	*Sellaphora pupula*
SL002A	*Sellaphora seminulum*
SA001A	*Stauroenis anceps*
SA012A	*Stauroneis kriegerii*
SA006A	*Stauroneis phoenicentereon*
SA9999	*Stauroneis salina*
SR001A	*Staurosira construens*
SS003A	*Staurosirella leptostauron*
SS002A	*Staurosirella pinnata*
SU001A	*Surirella angusta*
SU073A	*Surirella brebissonii*
SY001A	*Synedra ulna*
TF9999	*Tryblionella fasiculata*
TF015A	*Tryblionella hungarica*