Environment Agency

Evidence

A streamlined taxonomy for the Trophic Diatom Index

Report – SC070034/TR1

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Miranda Kavanagh

Director of Evidence

Executive summary

This study investigates different approaches for streamlining the taxon lists used in the Trophic Diatom Index (TDI). The objective is to develop a shorter taxon list that has a similar ability to recognise the boundary between good and moderate ecological status of water bodies as the current taxon list, and to assess any implications for data precision.

Redundancy in the species lists and data were explored by comparing various modifications of the TDI with the current version. The modifications all involve taxa complexes that are time consuming to identify to species or variety, and all are consistent with EU conventions.

The recommendations are as follows:

1. Reduce the taxon list to only those taxa recorded as having a maximum relative abundance ≥2% in samples, and implement a series of taxonomic merges.
2. Use this streamlined TDI for routine surveillance monitoring, but retain an option to use the current TDI for case studies associated with investigative monitoring where fine-level taxonomy can be of benefit, and noting local differences in floras may yield further insights.
3. Apply a trigger for special protocols developed for use in acid-sensitive sites.

Acknowledgements

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Contents

1 Introduction

DARLEQ (Diatom Assessment of River and Lake Ecological Quality) was developed as part of a toolkit of methods to aid the UK's implementation of the Water Framework Directive (WFD). A key assumption during its development was that the technique would be suitable for use by the UK's regulatory agencies. Most diatom-based indices are taxonomically intensive, incorporating recent advances in fine-level taxonomy. The assumption underlying these indices is that many diatoms have narrow ecological niches, shaped primarily by their chemical habitat, making them ideal for monitoring water quality (Telford *et al*. 2006). Ecological status, as defined by the WFD is, however, a subtly different concept, reflecting the 'structure and function of aquatic ecosystems'. Applying narrow niche concepts can be problematic: some species (e.g. *Achnanthidium minutissimum*) appear to fulfil the role of ecological 'generalists' with broad environmental tolerances.

It is possible that cryptic species, each with their own ecological preference (Potapova and Hamilton 2007, Poulíčková *et al*. 2008) exist within complexes, in which case the apparent 'generalist' strategy is illusory, although distinguishing between forms using traditional light microscopy is difficult even for expert taxonomists (Mann *et al*. 2008, Trobajo *et al*. 2009). On the other hand, a widely distributed 'generalist' taxon such as *A. minutissimum*, because it is often abundant, implying a significant contribution to ecosystem functioning, may be a better indicator of ecological status than a 'specialist'. Even if *A. minutissimum* were, in fact, an aggregate of a number of genetically distinct but morphologically (and physiologically) similar taxa, then this argument would still apply.

The limitations of conventional diatom-based indices for WFD assessments, and the operational needs of UK ecological appraisal teams, suggests that detailed taxonomic data may not translate into information valuable to ecological decision-making. The Indice Diatomique Generique (IDG: Rumeau and Coste 1988), an early attempt to simplify the taxonomy required for diatom-based indices, has worked well in some instances (Kelly *et al.* 1995, Growns 1999) but with less resolution in others (Smucker and Vis 2009). The principle of taxonomic simplification was also adopted for the first version of the TDI (Kelly and Whitton 1995) and for the Indice Biologique Diatomées (IBD: Lenoir and Coste 1994), both of which have been widely used in Europe, though the taxonomically intensive Indice de Polluosensibilité Specifique (IPS: Coste, in CEMAGREF 1982) is the most widely used index for WFD assessments (Kelly *et al*. 2008c).

Lavoie *et al*. (2009) evaluated the effect of excluding diatom taxa and reducing taxonomic resolution in stream bioassessment based on application of the Eastern Canadian Diatom Index (IDEC). Removing 40% of the taxa with a maximum relative abundance (RA) of less than 2% did not change the IDEC significantly, although removal of taxa based on their frequency of occurrence did affect ordination structure. More recently, the EU phytobenthos intercalibration group examined the prospect of taxa streamlining to reduce variation due to different taxonomic conventions and found merging those complexes of diatoms most prone to cause problems for analysts had little effect on index calculations (Kahlert *et al*., in press, Kelly and Ector, in press).

This project investigates different approaches for streamlining the taxon lists used in the current TDI (Kelly *et al*. 2008a). The objective is to develop a taxon list with a similar ability to recognise the boundary between good and moderate status as the version described in Kelly et al. (a), and to assess any implications for data precision. Diatoms are used as proxies for 'phytobenthos' which, along with macrophytes, are treated as a single biological quality element in the WFD.. Consequently, analysis of a single diatom sample needs to be considered in a broader context. Previous work has also demonstrated how ecological status assessments need to take temporal variability into account (Kelly *et al*. 2009a). The proposal of this project is that the benefit accruing from the effort applied to a single sample is likely to decrease exponentially, so that it may be better to analyse a number of samples using a streamlined analytical approach rather than to make a detailed analysis of a single sample that does not necessarily add to an understanding of the ecological status of the site. This is a rational basis for surveillance monitoring, although, for local-scale investigations, the ability to recognise finer-scale shifts in assemblage structure may still be useful.

2 Methods

Analyses are based on two datasets: that used in Kelly *et al*. (2008a) to develop the current version of the TDI, and a further dataset, described in more detail below, collected as part of an ongoing ring test scheme in the UK and Ireland. The database of Kelly *et al*. (2008a) consists of 6500 samples from streams and rivers in the UK, containing 548 taxa. This was used to calculate ecological quality ratios (EQRs) as described in Kelly *et al*. (2008a), which also describes how boundaries between ecological status classes were determined.

Redundancy in this dataset was explored by comparing various modifications of the TDI with the version described in Kelly *et al*. (2008a). The modifications all involve taxa complexes that can be difficult to identify to species or variety (Table 3.1), and is consistent with the conventions adopted in an EU exercise (Kahlert *et al*. in press, Kelly and Ector in press), though the latter also include *Achnanthidium minutissimum* complex which is not addressed in the TDI. Analyses were performed using queries in an Access 2000 database. The modifications were evaluated in three ways:

1. By computing the coefficient of determination (r^2), where $r^2 = 1.0$ indicates perfect agreement between the original and modified versions of the TDI method (a) in Figure 2.1).

2. By comparing the proportion of samples that gave the same ecological status classification by the two methods. As the boundary between good and moderate status is the most important boundary from the point of view of regulation, the proportion of samples that were classified as either ‘good status or better’ or as ‘moderate status or worse’ by both methods was computed (method (b) in Figure 2.1). Again, perfect agreement would result in a value of 1.0.

3. By computing the percentage of samples whose TDI values change by >7 TDI units. This value is based on studies of within-site variability at UK stream sites. The average standard deviation between three replicate analyses of a single sample for the TDI was 3.49. Two standard deviations (which approximates to the 95th percentile of the distribution) is, therefore, $6.98 \approx 7$ (Kelly *et al*. 2007). Our objective in using this criterion is to keep changes to the TDI within the limits of expected sample uncertainty.

The effect of the modifications to the index on the precision of estimates was evaluated using data from the UK Diatom Ring Test Scheme. This is an ongoing quality assurance exercise for diatom-based ecological assessments in the UK. Five slides per year are sent to all participants, who then analyse these according to a standard protocol. The mean TDI value of analyses submitted by an ‘expert panel’, composed of six experienced analysts, provides the target for other analysts, whose own results should fall within two standard deviations of this value. For the present exercise, the standard deviations for both expert panel and other participants were computed using both the original and modified TDIs.

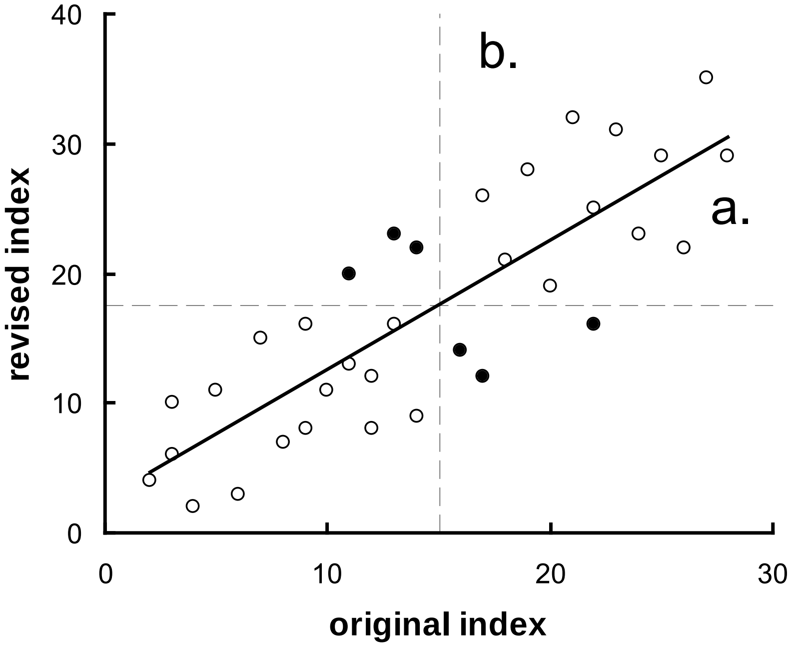


Figure 2.1 Measuring the effectiveness of indices for evaluating ecological status. Effectiveness can be measured either by the strength of the relationship between the two axes, evaluated by the coefficient of determination of the regression (a), or by the proportion of samples that are correctly classified as either 'good or better' (b) (top right quadrant) or 'moderate or worse' (bottom left quadrant) status. In this case, six samples (indicated by closed circles) are classified differently depending on the method used (top left and bottom right quadrants)

3 Results

3.1 Taxonomic composition of database

Of the 548 taxa recorded in the database, 210 (38%) were present in >1% of samples and 100 (18%) were present in >5% of samples (Figure 3.1). Also, 148 taxa (27%) were never present at >1% relative abundance in the sample while 290 taxa (53%) were never present at >5% relative abundance.

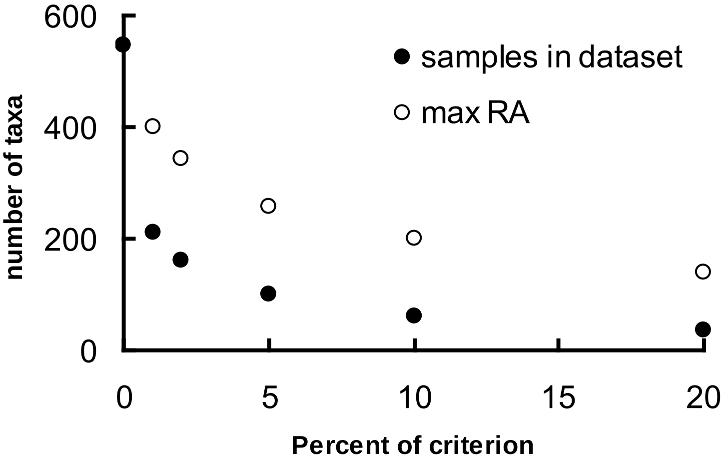


Figure 3.1 Distribution of taxa in the DARLEQ database, according to (a) percentage of samples in which a taxon is present (closed circles) or (b) maximum relative abundance (RA) of a taxon in the database (open circles)

3.2 Effect of removing ‘rare’ taxa

Access queries were used to eliminate taxa based on their frequency in the dataset or their maximum relative abundance in the dataset or the sample. Removing taxa based on their frequency in the dataset had little effect on any of the properties examined (r^2, agreement or change >7 TDI units for taxa represented in less than about 10% of the samples, after which there was a steep decrease in r^2 agreement and an increase in the proportion of samples that changed by >7 TDI units (Figure 3.2)). Removing taxa based on their maximum relative abundance in the database had less effect; even removing taxa with <40% maximum relative abundance had little effect on the properties examined. in contrast, removing taxa based on their relative abundance in the sample had little effect at <1%, but when taxa present at <2% were removed all the properties examined changed dramatically, with r^2 falling to 0.41 and the percentage of samples changing by >7 TDI units increasing to 35.9.

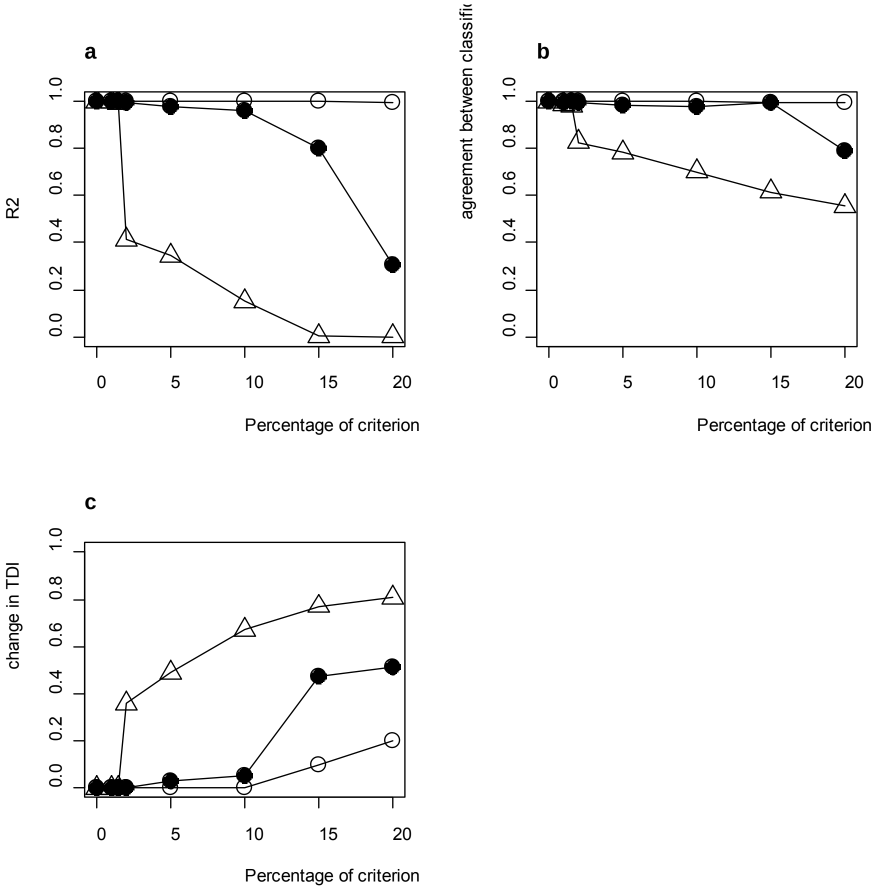


Figure 3.2 Effect of removing taxa from TDI calculations on (a) coefficient of determination (r^2); (b) agreement between classification results (good status or better versus moderate status or worse) and (c) proportion of samples changing by >7 TDI units. Three methods for reducing taxa numbers are used: removing taxa based on the number of records in the database in which the taxon occurs (closed circles), removing taxa based on the maximum relative abundance of the taxon in the database (open circles) and removing taxa based on the maximum relative abundance of the taxon in the sample (open triangles)

3.3 Effect of merging 'difficult' taxa

As many analysts report difficulty differentiating between closely related taxa, the effect of merging morphologically similar species and varieties into a single taxonomic unit was explored. The stages of this process are described in detail for *Cocconeis placentula*, then summarised for other taxa.

A preliminary investigation demonstrated that *Cocconeis placentula* varieties had no clear separation along a nutrient axis (Figure 3.3). *C. placentula* var. *euglypta* did appear to be more tolerant of high nutrients than other varieties but it was present at a high relative abundance along the entire gradient. In the TDI, each variety has its own sensitivity value and here we test the effect of adjusting all sensitivity values to the weighted mean sensitivity, calculated as the average sensitivity score, weighted by the number of records of each variety. For *C. placentula* agg. the revised weighting was 3.1. When the EQR is re-calculated using this value and plotted against the original relationship (Figure 3.4), the coefficient of determination (r^2) is 0.985, with 98.8% of samples giving the same classification with both calculations, and only 2.4% of samples having a difference of >7 TDI units.

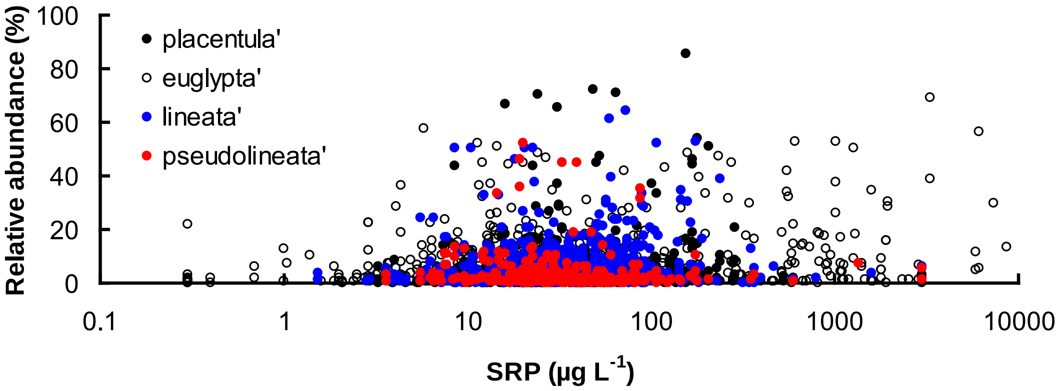


Figure 3.3 Distribution of *Cocconeis placentula* varieties along a nutrient gradient (expressed as soluble reactive phosphorus, SRP). Due to the manner in which the UK database records taxonomic categories, '*placentula*' refers to both taxa explicitly identified as *C. placentula* var. *placentula* and taxa identified only as *C. placentula*

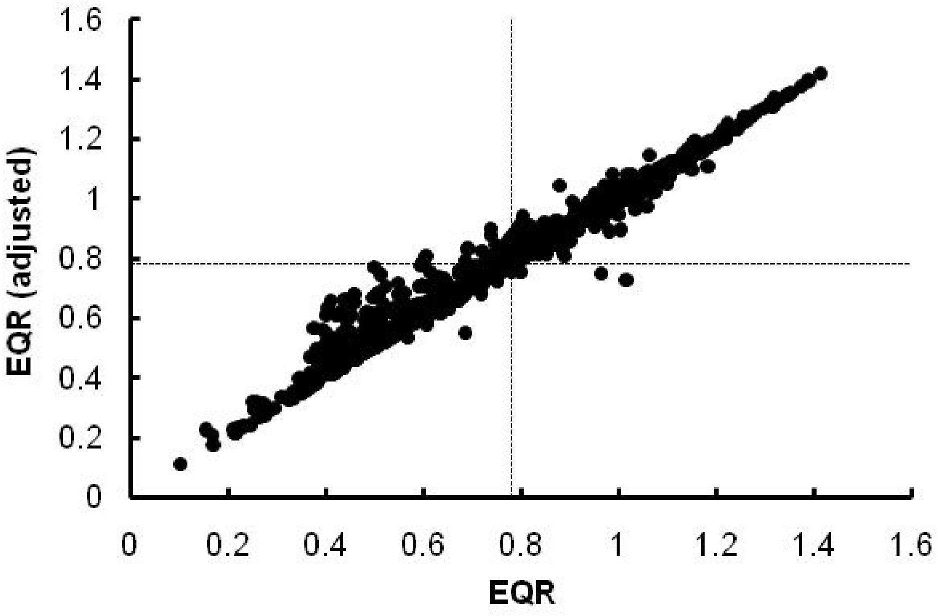


Figure 3.4 Effect of combining *Cocconeis placentula* varieties on EQR values in the UK dataset

This exercise was repeated for the taxa groups listed in Table 3.1, and results are summarised in Table 3.2. Of these changes, merging *Cocconeis placentula* varieties had the greatest effect, although there was still 99% agreement in terms of final classifications produced by original and revised indices, and only 2.4% of samples changed their TDI value by >7 TDI units. Merging *Eunotia* and *Pinnularia* had very little effect on final outcomes but this reflects the largely circumneutral nature of the dataset (only 15% of samples pH <6.5). Combining all of these changes resulted in 98% agreement between original and revised indices, and 4% of samples changing by >7 TDI units.

Table 3.1 Taxonomic groups which cause identification problems for TDI analysts, along with ranges of original sensitivity values and weighted sensitivity, based on occurrence of constituent taxa in the database

Taxon group	Constituents	Original sensitivity values	Weighted sensitivity
Amphora pediculus ‘agg.’	*Amphora fogediana, A. inariensis, A. indistinct, A. pediculus*	4–5	5
Brachysira vitrea/neoexilis	Brachysira vitrea, B. neoexilils	1	1
Cocconeis placentula	All varieties	2–4	3.1
Encyonema ‘ventricosa’	Species that would have been included in *Cymbella ventricosa* in Hustedt (1930): *Encyonema minutum*, *E. silesiacum*, *E. reichardtii* and related taxa (see Krammer 1997a)	2–3	2.6
Eunotia	All representatives of genus	1–3	1.4
Fragilaria capucina	All taxa in ‘sippencomplex’ described in Krammer and Lange-Bertalot (1991a) except *F. vaucheriae*	1–3	1.2
Fragilaria vaucheriae	*Fragilaria vaucheriae, F. vaucheriae* var. *capitellata*	2–3	2
Fragilariforma	All representatives of genus	1 – 5	2.5
Fistulifera/Mayamaea	All representatives of genera	3–4	3.9
Pinnularia	All representatives of genus	2–5	2.2
Gomphonema ‘intricatum’ group	*Gomphonema angustum, minutum, pumilum* and relatives	3–4	3.6
Gomphonema parvulum	All varieties	1–3	3.0
Nitzschia palea	*N. palea* + var. *debilis*	3–4	4.0

Pseudostaurosira/Staurosira	All representatives of genera	3–4	3.7
Reimeria	All representatives of genus	3–4	3.0
Tabellaria	All representatives of genus	1–2	1.0

Table 3.2 Effect of taxon merges and removing rare taxa on performance of the TDI, evaluated using the same criteria as in Figure 3.2

Merge category	r^2	Agreement	Change>7
Small *Amphora*	1.000	1.000	0.0
Cocconeis placentula	0.985	0.988	2.4
Encyonema 'ventricosa'	0.998	0.992	0.2
Eunotia	0.999	1.000	0.1
Fragilaria capucina complex	0.995	0.993	0.9
Fragilaria vaucheriae	1.000	1.000	0.0
Fragilariforma	1.000	0.999	0.0
Pinnularia	1.000	1.000	0.0
Gomphenema 'intricatum' complex	1.000	0.998	0.0
Gomphonema parvulum	0.996	0.991	0.5
Mayamaea/Fistulifera	0.998	0.998	0.4
Nitzschia palea	1.000	0.999	0.0
Pseudostaurosira/Staurosira	0.998	0.999	0.3
Reimeria	1.000	0.998	0.0
Tabellaria	1.000	1.000	0.0
All taxon merges	**0.976**	**0.970**	**4.0**

3.4 Combination of taxon merges and removal of rare taxa

Removing taxa that are 'rare' and which only occur at low relative abundances in the database as a whole had no appreciable additional effect on the overall risk of misclassification (Table 3.3) and, based on the criterion of 95% of samples changing index values by <5%, a combination of taxon merges and restricting the taxa list to those taxa with a maximum relative abundance of 2% or above in the database is recommended. The relationship for the recommended approach is shown in Figure 3.5.

Table 3.3 Effect of taxon merges and removing rare taxa on the performance of the TDI.

Merge category	r^2	agreement	change>7
Taxon merges and taxa in >10% of samples	0.941	0.958	10
Taxon merges and taxa in >5% in database	0.95	0.962	9.2
Taxon merges and taxa with max RA >10%	0.971	0.967	5.6
Taxon merges and taxa with max RA >5%	0.974	0.971	5
Taxon merges and taxa with max RA >2%	**0.976**	**0.970**	**4.0**
Taxon merges, taxa with max RA > 2% and >1% in sample	0.967	0.963	5.7
Taxon merges, taxa with max RA >2% and >2% in sample	0.398	0.82	38.8

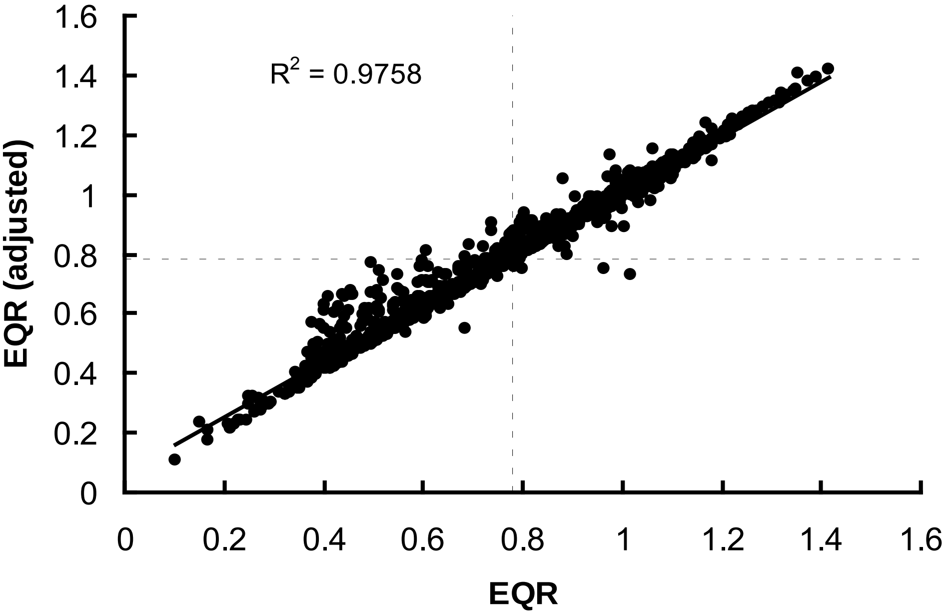


Fig. 3.5. Comparison between EQR values computed for all taxa (x axis) and EQR calculated on a reduced taxa list, comprising taxa found at ≥ 2% on at least one occasion, and with the appropriate taxa complexes merged (y axis). The vertical and horizontal dashed lines show the position of the good/moderate boundaries for the two metrics calculated in the same way, indicating that the number of re-classified sites is minimal.

3.5 Effect of taxon streamlining on data precision

As before, results will be described in detail for one example slide (‘slide 2’), then all other results will be summarised in a table. The slide chosen for detailed analysis is one which contained a high relative abundance of *Cocconeis placentula*, most of which was assigned by the expert panel to *C. placentula* var. *euglypta,* but other varieties were also present and it was difficult to assign all valves to a variety with confidence as some had characteristics that overlapped two varieties.

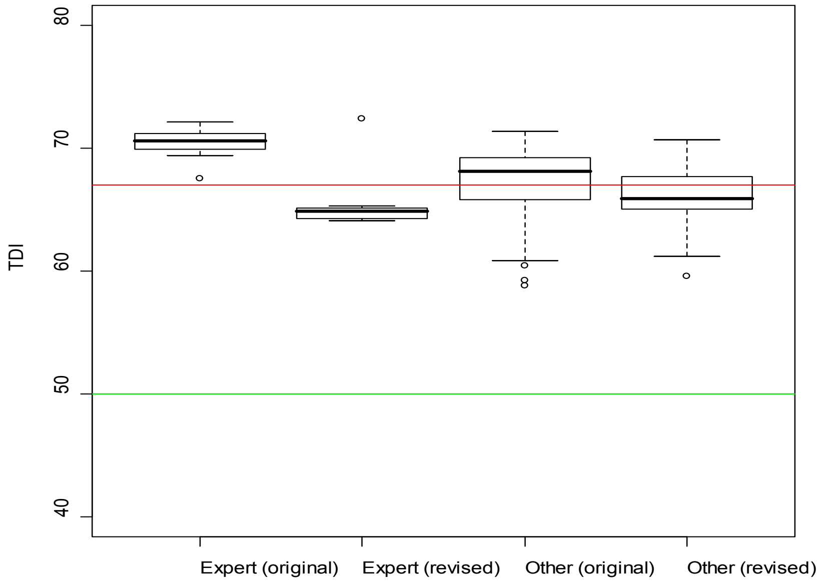
As the expert group recognised *C. placentula* var. *euglypta* as the most abundant diatom, the effect of ‘lumping’ *C. placentula* varieties was to change the mean value of the TDI by 1.8 units, without affecting the status designation, while at the same time slightly decreasing precision (standard deviation rose from 1.51 to 2.94: Figure 3.6). Other participants with a range of experience had more difficulty identifying *C. placentula* varieties and, consequently, the precision was lower. Merging *C. placentula* varieties again had a small effect on the mean TDI value and, this time, a slight increase in precision.

Outcomes for other slides are shown in Table 3.4. In general, the effect on both mean TDI and precision was small, probably because the effects of taxa merges was compensated for by those taxa which were abundant in the samples and which remained unchanged. The exception was slide 7, which had poor precision using the original TDI (caused by difficulty differentiating *Gomphonema parvulum* varieties) and where the revised TDI (with *G. parvulum* varieties merged) had much better precision. This sample was subsequently re-analysed using clearer criteria for distinguishing varieties (slide 7a); while the precision of both ‘expert’ and ‘other’ participants using the original TDI was better, that using the revised TDI changed little. Overall, the average precision was little affected by the revisions to the TDI, and there was no consistent trend of greater or lesser precision.

Table 3.4 Effect of streamlined TDI on ring test results. ‘Experts’ = expert panel (six experienced analysts); ‘Others’ = Environment Agency, Scottish Environment Protection Agency, Northern Ireland Environment Agency and Environmental Protection Agency staff plus contractors who participate in the ring tests. Values in bold indicate increases in mean TDI >5 or >1 standard deviation; values in italics indicate equivalent decreases in TDI and standard deviation

	Experts				**Others**			
	Mean		**Std dev**		**Mean**		**Std dev**	
Slide	**TDI**	**TDI-adj**	**TDI**	**TDI-adj**	**TDI**	**TDI-adj**	**TDI**	**TDI-adj**
1	17.5	17.2	0.64	0.69	17.5	17.1	3.68	4.0
2	70.3	65.9	1.66	3.21	67.2	66.0	3.20	2.24
3	85.3	84.8	1.66	1.50	85.2	84.7	3.50	3.50
4	65.3	64.8	*3.91*	*2.83*	65.1	64.6	3.07	2.94
5	18.2	17.9	5.36	5.12	18.2	17.9	5.14	5.14
6	60.5	59.1	2.40	2.76	60.8	59.3	3.34	3.34
7	**18.8**	**30.1**	*11.43*	*6.89*	**19.0**	**30.5**	*12.26*	*6.68*
7a	**13.1**	**26**	**2.41**	**5.99**	**13.2**	**26.2**	**6.35**	**7.78**
8	79.8	79.2	5.45	5.35	79.8	79.3	5.69	5.5
9	67	67.5	2.52	3.38	66.8	67.3	4.22	4.17
10	47.8	51.6	**5.86**	**8.65**	45.7	46.0	**2.30**	**4.84**

Figure 3.6 Box-and-whisker plots showing effect of streamlining TDI taxonomy on the results of a ring test slide dominated by *Cocconeis placentula*. The upper and lower limits of the boxes represent 25th and 75th quartiles and the solid line is the median; the vertical lines show the largest and smallest observations within 1.5 times the box size from the nearest hinge. Additional points are 'outliers'. 'Expert' refers to analyses by the expert panel. Horizontal lines indicate the position of the good/moderate (green) and moderate/poor (red) status class boundaries



3.6 Effect of taxon streamlining on classification of sites

Site classifications are based on multiple samples per site and, therefore, the effect of the streamlined metric was also tested on a dataset of replicate samples from sites on the River Wye. The scale of within-site variability of EQR estimates based on the TDI has already been established (Kelly *et al*. 2000a); this analyses assesses whether repeated samples from a single site reinforces or reduces the differences between the original and streamlined metrics.

Sites were selected to cover a transect down the River Wye, from soft-water upland headwaters (Marteg) to a hard-water site close to the tidal limit (Florence Hotel). Each site was represented by between 9 and 12 samples collected between 2002 and 2006, a period during which there were no known major changes in water quality. Significant changes in EQR were recorded at five of the six sites, all showing an increase in EQR using the revised TDI (Figure 3.7). In three of these there was a change in status class, although the magnitude of shift, when viewed in terms of the entire EQR scale, was generally small. Where status class changed, this was because the original EQR was close to a boundary and, therefore, would have been reported with a high risk of misclassification. That the revised EQRs tended to be higher may be a consequence of the abundance of *Cocconeis placentula* var. *euglypta* in the river – 'lumping' this taxon would have reduced TDI and caused the increase in EQR.

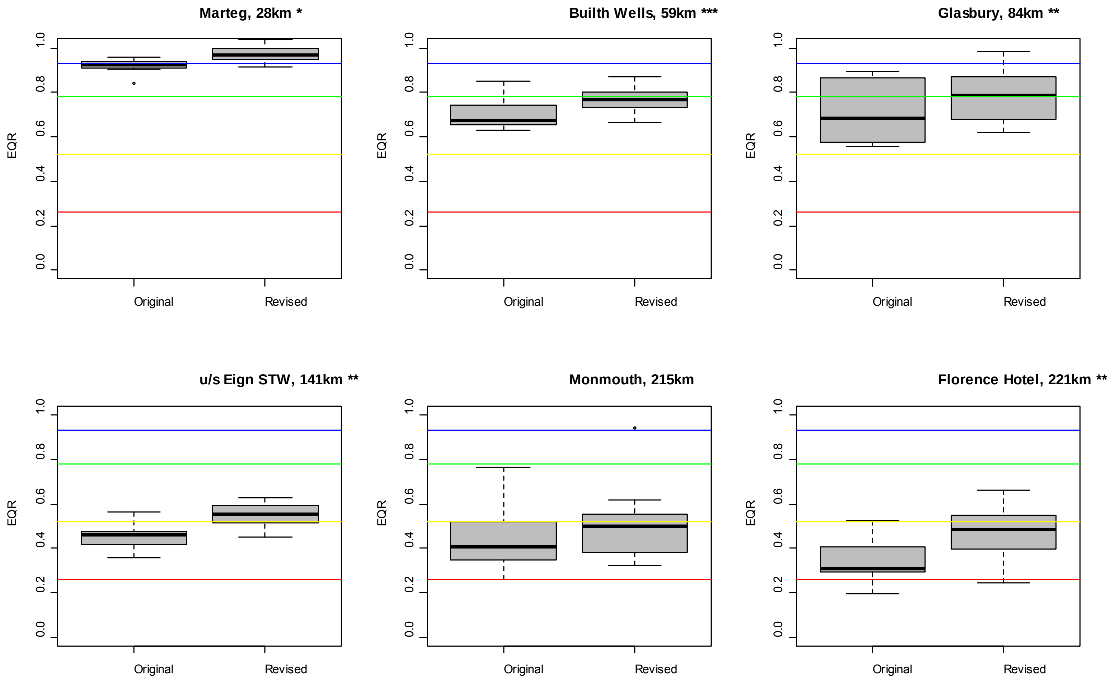


Figure 3.7 Box-and-whisker plots showing the change in classification using the original and revised versions of the TDI at six sites on the River Wye, sampled between 2002 and 2006. Coloured lines show the positions of the high/good (blue), good/moderate (green), moderate/poor (yellow) and poor/bad (red) ecological status class boundaries. The significance of two-tailed paired sample t-tests is indicated by * (p <0.05), ** (p <0.01) or * (p <0.001)**

4 Discussion

Biological monitoring can be “data-rich but information-poor’’ (Ward et al., 1986), and based on an assumption that the greater the effort invested, the greater the sensitivity of the analysis. Though this may be a valid approach when cataloguing biodiversity, its validity can be challenged in diatom-based ecological status assessments, recognising:

(a) that diatoms provide, at best, a proxy measurement of ‘phytobenthos’ (Kelly 2006, Kelly *et al*. 2008b, 2009b) which, in turn, needs to be combined with evaluations of macrophytes in order to fulfil the requirements of the WFD;

(b) results from a single sample cannot account for all the temporal variation in diatom assemblages at a site (Kelly *et al*. 2009a) and it is preferable to invest time in doing more samples with less detail;

(c) the formal definition of ecological status emphasises ‘structure and functioning of aquatic ecosystems’ (European Union 2000) and, as diatom assemblages are often dominated by a few taxa, it is fair to conclude that an understanding of the inter-relationships among these and between these and other trophic levels should be sufficient to derive the status of a water body and the benefits of proposed improvements;

(d) focussing on extracting the key information from the taxa present is cost effective.

4.1 Reasons for the observed effects

Although considerable advances have been made in freshwater diatom taxonomy (e.g. Krammer 1997a, b, Lange-Bertalot 2001, Mann *et al*. 2008), the results presented here suggest that these advances do not have major consequences for diatom-based monitoring. There may be a number of reasons for this, including the fact that only a limited amount of taxonomic harmonisation was possible during the creation of the DARLEQ database from a number of data sources. This is further complicated by potentially ambiguous morphological descriptions provided in some of the key texts for the taxa that are more difficult to identify (e.g. *Fragilaria capucina* sippenkomplex: Krammer and Lange-Bertalot 1991a*; Achnanthidium minutissimum*: Krammer and Lange-Bertalot 1991b), and by data precision issues common in nationwide monitoring programmes (Prygiel *et al*. 2002, Kahlert *et al*. 2008). These may be resolvable by implementing additional quality assurance processes, but the relatively small effects of taxa streamlining on data precision (Figure 3.5, Table 3.3) suggests other factors (e.g. counting protocols) might be equally as important as taxonomy as sources of uncertainty.

An alternative explanation is that the advances in diatom taxonomy have not resulted in significant advances in understanding of the ecology of the taxa concerned. For instance, Lange-Bertalot (2001) is a valuable monograph on the taxonomy of *Navicula sensu stricto*, yet ecological comments are, for the most part, limited to their nutrient and saprobic preferences, along with some general comments on habitat. This is the same for other taxonomic works (e.g. Krammer 1997a, b) while there are few detailed accounts of the autecology of particular taxa along the lines of Jewson and Lowry (1993) for *Cymbellonitzschia diluviana* and Whitton *et al*. (2009) for *Didymosphenia geminata*.

This implies that there is still a need for an understanding of the linkages between trophic levels which may be detrimental when using diatoms as part of an assessment of ecological status. For instance, understanding the relationship between the varieties of *Cocconeis placentula* may enable better discrimination, however, there is also evidence that this taxon, which thrives in heavily grazed environments (Stevenson and Peterson 1989) and as an epiphyte on filamentous algae such as *Cladophora* (Malkin *et al*. 2009), fulfils many characteristics of a 'ruderal' species (Biggs *et al*. 1998). It may be that water quality is not the primary factor explaining the success of *Cocconeis placentula* and a simplistic interpretation of nutrient or organic pollution sensitivity itself contributes to the variations observed when diatom assemblages are used to evaluate ecological status.

Finally, interpretations of results must also be set in a statistical context. The weighted-average equation of Zelinka and Marvan (1961), which is used for the TDI and for many other diatom-based indices, gives greatest emphasis to the most abundant taxa in samples. While the *Sellaphora pupula* complex has been studied extensively (Mann *et al*. 2008) and individuals within this complex have different ecological preferences (Poulíčková *et al*. 2008), *S. pupula* agg. is found in <5% of samples in the DARLEQ database, but most of these records are <1% relative abundance, spread along the nutrient gradient. Any 'signal' from *S. pupula* agg. is overcome by more abundant taxa in the weighted-average indices, while the low relative abundances hinder characterisation of the relationship between members of this complex. There is a conflict between understanding the ecological niche of representatives of *S. pupula* agg. and the statistical pragmatism of recognising limitations in the ability to evaluate this from the data available.

4.2 Consequences for monitoring

Analyses presented here suggest that simplifying the taxonomy behind the TDI does not necessarily lead to deterioration in the quality of the information supplied by such indices for the purposes of reporting ecological status boundaries. Several of the simplifications suggested above involve merging taxa that are recognised as being difficult to identify (e.g. Kahlert *et al*. 2008). Simplification will also reduce the time required to train analysts to the standard required for ecological monitoring.

It is proposed that the reduced taxon list given the Appendix is used as the basis for all routine surveillance monitoring using the TDI. This list includes all taxa fulfilling the requirement of having a maximum relative abundance >2%, along with the taxon merges proposed in Table 3.2, plus additional instances (e.g. *Brachysira, Rossithidium*) where all representatives of a genus already have the same sensitivity values. The 548 taxa of the current taxon list are reduced to 342 taxa, if only those taxa found at ≥ 2% maximum relative abundance are included, and to 265 once the taxa merges described here are included (less than half the number on the current list). This is close to the spirit of the original TDI (Kelly and Whitton 1995), although the taxa lists do differ in a number of respects. There are, however, instances where fine-scale taxonomy is still recommended:

(a) The TDI measures changes along a nutrient gradient, and acid-sensitive genera which are generally infrequent in nutrient-rich water (*Eunotia, Fragilariforma, Pinnularia*) are included in complexes in the revised TDI. Where diatoms are being used to evaluate acidification effects then it may be necessary to revert to species-level identification of these taxa. A rule in the counting protocols could be applied.

(b) For specific case studies there may be benefits in retaining the full fine-level taxonomy. While the streamlined TDI sets the national benchmark for diatom analysis, analysts should also be encouraged to continue developing more in-depth taxonomic skills, which will further inform the interpretations and advice given to colleagues and stakeholders.

4.3 Overall recommendations

1. Reduce the taxon list to only those taxa recorded with a maximum relative abundance ≥2% in the database and implement the taxonomic merges outlined in Table 3.1.

2. Use the streamlined Trophic Diatom Index for routine surveillance monitoring, but retain an option for an expanded TDI for case studies associated with investigative monitoring where fine-level taxonomy can be of benefit, and noting local differences in floras may yield further insights. However, where the goal is nationwide assessment of status, then the benefits of fine-level taxonomy are outweighed by the problems of precision described above.

3. Apply a ‘rule’ to trigger special protocols for acid-sensitive sites (e.g. >5% acid-sensitive taxa requires *Eunotia* and *Pinnularia* to be identified to species).

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Appendix: Final revised taxon list

Taxon	**Authority**	**TDI4**
Achnanthes clevei	Grun. in Cleve & Grun.	5
Achnanthes exigua	Grun. in Cleve & Grun.	3
Achnanthes oblongella	Ostr.	1
Achnanthes sp.	Bory	3
Achnanthidium eutrophilum	(Lange-Bert.) Lange-Bert. 1999	2
Achnanthidium microcephalum	Kütz.	1
Achnanthidium pyrenaicum	(Hust.) Kobayasi 1997	2
Achnanthidium sp.	Kütz.	2
Achnanthidium subatomus		2
Adlafia minuscula	(Grunow) Lange-Bert. 1999	3
Adlafia minuscula var. *muralis*	(Grunow) Lange-Bert. 1999	5
Amphipleura pellucida	(Kutz.) Kutz.	3
Amphora libyca	Ehr.	4
Amphora montana	Krasske	5
Amphora ovalis	(Kutz.) Kutz.	5
Amphora pediculus agg.	(Kutz.) Grun.	5
Amphora sp.	Ehrenb.	4
Amphora veneta	Kutz.	5
Bacillaria paradoxa	Gmelin in Linnaeus	5
Brachysira brebissonii	R. Ross in Hartley	1
Brachysira vitrea	(Grun.) R. Ross in Hartley	1
Caloneis bacillum	(Grun.) Cleve	4
Caloneis hyalina	Hust.	5
Caloneis silicula	(Ehrenb.) Cleve	4
Caloneis sp.	Cleve	3
Cavinula cocconeiformis	(Greg. ex Greville) Mann & Stickle	2
Cavinula variostriata	(Krasske) Mann	3
Cocconeis diminuta	Pant.	5
Cocconeis pediculus	Ehrenb.	4
Cocconeis placentula	Ehrenb.	3.1
Cocconeis scutellum	Ehrenb.	3
Cocconeis sp.	Ehrenb.	3
Craticula accomoda	(Hust.) Mann	4
Craticula halophila	(Grun. ex Heurck) Mann	4
Craticula molestiformis	(Hust.) Lange-Bert. 2000	5
Ctenophora pulchella	(Ralfs ex Kutz.) Williams & Round	2
Cymatopleura solea	(Breb. & Godey) W. Sm.	5
Cymbella affinis	Kutz.	2
Cymbella cistula	(Ehrenb. in Hempr. & Ehrenb.) Kirchner	2
Cymbella helvetica	Kutz.	2
Cymbella lanceolata	(Ag.) Ag.	4
Cymbella sp.	Ag.	3
Cymbellonitzschia diluviana	Hust.	4
Delicata delicatula	Krammer 2003	1
Denticula tenuis	Kutz.	2
Diadesmis contenta	(Grun. ex Van Heurck) Mann	5
Diadesmis contenta fo. *biceps*	(Grunow) P.B. Hamilton 1992	3
Diadesmis gallica	W. Sm.	3
Diatoma ehrenbergii	Kutz.	1
Diatoma mesodon	(Ehrenber) Kutzing	1
Diatoma moniliformis	Kutz	1

Taxon	**Authority**	**TDI4**
Diatoma problematica		2
Diatoma sp.	Bory	2
Diatoma tenue	Ag.	1
Diatoma vulgare	Bory	5
Didymosphenia geminata	(Lyngb.) M. Schmidt in A. Schmidt	1
Diploneis elliptica	(Kutz.) Cleve	5
Diploneis marginestriata	Hust.	5
Diploneis oblongella	(Naegeli ex Kutz.) R. Ross	5
Ellerbeckia arenaria	(Moore) Crawford	4
Encyonema 'ventricosum' agg.		2.6
Encyonema caespitosum	Kutz.	4
Encyonema gracile	Ehrenberg	1
Encyonema hebridicum	Grun. ex Cleve	1
Encyonema prostratum	(Berkeley) Kutz.	5
Encyonema sp.	Kutz.	4
Encyonopsis cesatii		2
Encyonopsis falaisensis	(Grunow) Krammer 1997	1
Encyonopsis microcephala		2
Eolimna minima	(Grounow) Lange-Bert. 1998	3
Eolimna subminuscula	(Manguin) G. Moser Lange-Bertalot & D. Metzeltin	4
Eolimna submuralis	(Hustedt) Lange-Bertalot & Kulikovskiy	5
Epithemia adnata	(Kutz.) Rabenh.	5
Epithemia sorex	Kutz.	3
Epithemia sp.	Bréb.	2
Epithemia turgida	(Ehrenb.) Kutz.	1
Eucocconeis flexella	Kutz.	1
Eucocconeis laevis	(Ostr.) Lange-Bert.	1
Eunotia sp.	Ehrenb.	1.4
Fallacia helensis	(Schulz) Mann	5
Fallacia indifferens		2
Fallacia lenzii	(Hust.) Lange-Bert.	5
Fallacia pygmaea	(Kutz.) Stickle & Mann	5
Fallacia subhamulata	(Grun. in Van Heurck) Mann	5
Fistulifera/Mayamaea spp.		3.9
Fragilaria bidens	Heib.	3
Fragilaria capucina	Desm.	1.2
Fragilaria fasciculata	(Agardh) Lange-Bertalot *sensu lato*	4
Fragilaria nitzschioides	Grun. in Van Heurck	3
Fragilaria sp.	Lyngbye	2
Fragilaria vaucheriae	(Kutz.) J.B. Petersen	2
Fragilariforma sp.	D.M. Williams & F.E. Round	2.5
Frustulia krammeri	Lange-Bertalot & Metzeltin 2000	1
Frustulia sp.	Ag.	5
Frustulia vulgaris	(Thwaites) De Toni	2
Geissleria acceptata	(Hust.) Lange-Bert. & D. Metzeltin	4
Geissleria ignota	(Krasske) Lange-Bert. & D. Metzeltin	4
Geissleria schoenfeldii	(Hust.) Lange-Bert. & D. Metzeltin	3
Gomphonema 'intricatum' type		3.6
Gomphonema acuminatum	Ehrenb.	2
Gomphonema angustatum	(Kutz.) Rabenh.	3
Gomphonema anoenum	Lange-Bertalot	4
Gomphonema clavatum	Ehr.	2
Gomphonema clevei	Fricke in A. Schmidt	1
Gomphonema constrictum var. *capitatum*	(Ehrenb.) Grun. in Van Heurck	2
Gomphonema gracile	Ehrenb.	1

Taxon	**Authority**	**TDI4**
Gomphonema insigne	Greg.	5
Gomphonema olivaceoides	Hust.	2
Gomphonema olivaceum	(Hornemann) Breb.	3
Gomphonema parvulum	(Kutz.) Kutz.	3
Gomphonema pseudoaugur	Lange-Bertalot	5
Gomphonema sp.	Ehrenb.	3
Gomphonema tergestinum	(Grun. in Van Heurck) Fricke in A. Schmidt	4
Gomphonema truncatum	Ehrenb.	3
Gomphonema ventricosum	Greg.	1
Gomphosphenia grovei	(M. Schmidt) Lange-Bert. 1995	4
Gyrosigma acuminatum	(Kutz.) Rabenh.	5
Gyrosigma attenuatum	(Kutz.) Rabenh.	5
Gyrosigma nodiferum	(Grunov) Reimer	4
Gyrosigma scalproides	(Rabenh.) Cleve	5
Hannaea arcus	(Ehrenb.) Patr. in Patr. & Reimer	1
Hantzschia abundans		5
Hantzschia amphioxys	(Ehrenb.) Grun.	4
Karayevia laterostrata		3
Kolbesia ploenensis		5
Lemnicola hungarica		5
Luticola goeppertiana	(Bleisch in Rabenhorst) Mann	5
Luticola mutica	(Kutz.) Mann	3
Luticola sp.	D.G. Mann in F.E. Round *et al.*	4
Luticola ventricosa	(Kutz.) Mann	3
Melosira varians	Ag.	4
Meridion circulare	(Grev.) Ag.	2
Meridion circulare var. *constrictum*	(Ralfs) Van Heurck	1
Navicula [small species]		4
Navicula angusta	Grun.	1
Navicula capitata	Ehrenb.	4
Navicula capitatoradiata	Germain	4
Navicula cari	Ehrenb.	4
Navicula carteri	Van Land.	3
Navicula cincta	(Ehrenb.) Ralfs in Pritch.	4
Navicula claytonii	Carter	3
Navicula cryptocephala	Kutz.	3
Navicula cryptotenella	Lange-Bertalot	4
Navicula digitoradiata	(Greg.) Ralfs in Pritch.	4
Navicula gregaria	Donk.	4
Navicula hungarica	Grun.	5
Navicula integra	(W. Sm.) Ralfs in Pritch.	4
Navicula lanceolata	(Ag.) Ehrenb.	4
Navicula menisculus	Schum.	4
Navicula modica	Hust.	5
Navicula oblonga	(Kutz.) Kutz.	4
Navicula radiosa	Kutz.	3
Navicula recens	(Lange-Bertalot) LB	5
Navicula reichardtiana	Lange-Bertalot	4
Navicula reinhardtii	Grun. in Van Heurck	4
Navicula rhynchocephala	Kutz.	2
Navicula schroeterii	Meister	5
Navicula slesvicensis	Grun. in Van Heurck	3
Navicula sp.	Bory	4
Navicula subrhynchocephala	Hustedt	4
Navicula subrotundata	Hust.	5

Taxon	**Authority**	**TDI4**
Navicula tenelloides	Hust.	4
Navicula tripunctata	(O.F. Mull.) Bory	5
Navicula trivialis	Lange-Bertalot	4
Navicula veneta	Kutz.	4
Navicula viridula	(Kutz.) Ehrenb.	4
Nitzschia acicularioides	Archibald	5
Nitzschia acicularis	(Kutz.) W. Sm.	3
Nitzschia amphibia	Grun.	5
Nitzschia archibaldii	Lange-Bertalot	2
Nitzschia brevissima	Grun. in Van Heurck	2
Nitzschia capitellata	Hust.	4
Nitzschia clausii	Hantzsch	4
Nitzschia communis	Rabh.	5
Nitzschia disputata	J.R. Carter	2
Nitzschia dissipata	(Kutz.) Grun.	3
Nitzschia dissipata subsp. *media*		3
Nitzschia filiformis	(W. Sm.) Van Heurck	5
Nitzschia flexa	Schum.	3
Nitzschia fonticola	Grun. in Van Heurck	4
Nitzschia fossilis	(Grun.) Grun. in Van Heurck	5
Nitzschia frustulum	(Kutz.) Grun. in Cleve & Grun.	3
Nitzschia gracilis	Hantzsch	3
Nitzschia hantzschiana	Rabenh.	2
Nitzschia heufleriana	Grun.	4
Nitzschia inconspicua	Grun.	4
Nitzschia lacuum	Lange-Bertalot	2
Nitzschia liebetruthii	Rabenhorst	1
Nitzschia linearis	W. Sm.	4
Nitzschia littoralis	Grun. in Cleve & Grun.	4
Nitzschia microcephala	Grun. in Cleve & Grun.	3
Nitzschia palea	(Kutz.) W. Sm.	4
Nitzschia paleacea	(Grun. in Cleve & Grun.) Grun. in Van Heurck	3
Nitzschia paleaeformis	Hust.	3
Nitzschia perminuta	(Grun. in Van Heurck) M. Perag.	3
Nitzschia perspicua	Cholnoky	3
Nitzschia pusilla	Grun.	4
Nitzschia recta	Hantzsch ex Rabenh.	4
Nitzschia sigma	(Kutz.) W. Sm.	4
Nitzschia sigmoidea	(Nitzsch) W. Sm.	3
Nitzschia sociabilis	Hust.	4
Nitzschia sp.	Hassall	3
Nitzschia subacicularis	Hust.	4
Nitzschia sublinearis	Hust.	4
Nitzschia supralitorea	Lange-Bertalot	5
Nitzschia tubicola	Grun. in Cleve & Grun.	4
Nitzschia vermicularis	(Kutz.) Hantzsch in Rabenh.	4
Parlibellus protracta	(Grunow) Witkowski	4
Peronia fibula	(Breb. ex Kutz.) R. Ross	1
Pinnularia sp.	Ehrenb.	2.2
Placoneis clementis		4
Placoneis elginensis		5
Planothidium bioretti		2
Planothidium delicatulum		5
Planothidium dubium		3
Planothidium ellipticum		3

Taxon	**Authority**	**TDI4**
Planothidium frequentissimum		3
Planothidium granum		5
Planothidium lanceolatum		4
Planothidium rostratum		5
Planothidium sp.		4
Platessa conspicua		5
Psammothidium chlidanos		2
Psammothidium grishunun fo. *daonensis*		2
Psammothidium helveticum		2
Psammothidium lauenburgianum		5
Psammothidium levanderi		3
Psammothidium marginulatum		2
Psammothidium scoticum		2
Psammothidium sp.	L. Bukhtiyarova & F.E. Round	2
Psammothidium subatomoides		2
Pseudostaurosira/Staurosira agg.		3.7
Reimeria sp.	(Greg.) Kociolek & Stoermer	3
Rhoicosphenia abbreviata	(Ag.) Lange-Bertalot	4
Rossithidium sp.	F.E. Round & L. Bukhtiyarova	1
Sellaphora joubaudii	(H. Germain) M. Aboal 2003	4
Sellaphora pupula	(Kutz.) Mereschkowsky	4
Sellaphora seminulum	(Grun.) Mann	4
Simonsenia delognei	(Grun. in Van Heurck) Lange-Bertalot	5
Stauroneis anceps	Ehrenb.	2
Stauroneis kriegeri	Patr.	2
Stauroneis sp.	Ehrenb.	3
Stauroneis thermicola	(J.B. Petersen) J.W.G. Lund	3
Staurosirella leptostauron	(Ehrenb.) Williams & Round	4
Staurosirella pinnata	(Ehrenb.) Williams & Round	4
Surirella angusta	Kutz.	3
Surirella brebissonii	Krammer & Lange-Bertalot	3
Surirella crumena	Breb. ex Kutz.	3
Surirella islandica	Ostr.	3
Surirella linearis	W. Sm.	1
Surirella minuta	Breb. ex Kutz.	4
Surirella ovalis	Breb.	5
Surirella roba	Leclercq	2
Surirella sp.	Turpin	2
Surirella terricola		4
Synedella parasticia	(W. Sm.) Round & N.I. Maidana 2001	5
Synedra acus	Kutz.	3
Synedra famelica	Kutz.	2
Synedra tenera	W. Sm.	1
Synedra ulna	(Nitzsch) Ehrenb.	2
Tabellaria sp.	Ehrenb.	1
Tryblionella acuminata	W. Sm.	5
Tryblionella apiculata	Greg.	5
Tryblionella debilis	Arnott in O’Meara	4
Tryblionella hungarica	(Grun) Mann	4
Tryblionella sp.	W. Sm.	4

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