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# Assessment of the ecological status of eight lakes from northern Germany according to the Water Framework Directive (WFD) using benthic diatoms: problems and achievements of the newest German WFD guideline

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## INTRODUCTION

According to the European Water Framework Directive (EU-WFD 2000) identifying the ecological status of lakes larger than 50 ha is necessary for monitoring purposes and thus, for recognising possible lake management mitigation targets. The ecological status of each lake needs to be defined using fish assemblages, macro-invertebrates, phytoplankton and the littoral flora as bioindicators (EU-WFD 2000). Over the past few years, Schaumburg and colleagues have developed a guideline for the identification of the ecological status of the littoral flora in lakes based on macrophytes and benthic diatoms for Germany (e.g. Schaumburg et al. 2004a, b, 2005, 2006, 2007).

In this study, the guideline was applied to eight carbonate-rich lowland lakes from northern Germany to identify the ecological status based solely on benthic diatoms. Potential problems of the guidelines (Schaumburg et al. 2006, 2007) for benthic diatoms are discussed.

## MATERIAL & METHODS

The ecological status of eight carbonate-rich lowland lakes from Schleswig-Holstein, northern Germany (Table 1), was identified according to Schaumburg et al. (2006). Depending on lake size, two to ten samples from stones, sand and mud were taken from the littoral of each lake in late August 2006 (Table 1). The ecological status of each lake was identified based on a minimum of 400 benthic diatoms (according to the guideline, valves and frustules were counted as one object and are referred to as valves in this study) using the index **$DI_{Lakes}$**, which was calculated using the average of the modules Trophic Index (**$TI_{North}$**) and Reference Taxa Ratio (**RTR**) (Schaumburg et al. 2006):

- The **RTR** is based on presence/absence data (i.e. taxonomic composition only, the relative abundance is not incorporated) and uses taxa with relatively narrow ecological niches as indicators of a good versus a poor ecological status.
- If the **RTR** was based on an insufficient number of taxa (8 or 12 depending on lake type), the $DI_{Lakes}$ was solely based on $TI_{North}$ and was labelled as 'not reliable' according to Schaumburg et al. (2006, 2007).
- The **$TI_{North}$** is based on relative abundance data multiplied by the trophic state value for a taxon. A trophic state value is not available for all taxa as some taxa have wide ecological niches or were insufficiently represented in the calibration set.
- Diatom identification was based on the **taxonomy** of Krammer & Lange-Bertalot (1986, 1988, 1991a, b), Krammer (2000), Lange-Bertalot (1993, 2001), Lange-Bertalot & Moser (1994) and Lange-Bertalot & Metzeltin (1996). However, the revised taxonomy of the genus *Cymbella* (Krammer 1997a, b, 2002 & 2003) is not yet incorporated in this guideline.
- **Reliability**: Samples with > 5 % of ambiguously identifiable valves (i.e. taxa with sp., spp., cf. or aff.) were not used for the assessment of the ecological status. For the remaining samples, only unmistakably identified taxa were used for calculating each module ($DI_{Lakes}$, $TI_{North}$ and RTR).

## RESULTS & DISCUSSION

The benthic diatom assemblages suggest a good ecological status for Lake Ahrensee and a moderate ecological status for Lake Blankensee (Fig. 1, Table 1). However, the inferred ecological status of these lakes was not reliable according to Schaumburg et al. (2006) (Table 1). The remaining lakes had an overall inferred good ecological status (class 2, lakes Großensee & Westensee) and moderate ecological status (class 3, lakes Bordesholmer See, Bothkamper See, Selenter See & Wardersee; Table 1) according to Schaumburg et al. (2006). The substrate seemed to strongly influence the composition of the diatom assemblages (Fig. 2).

**Table 1**: Calculation of the Ecological Status Classes (ESC) using the Diatom-Index Lakes ($DI_{Lakes}$), which is based on the modules (M) of the trophic index ($TI_{North}$) and the Reference Taxa Ratio (RTR) according to Schaumburg et al. (2006), for eight lakes from Schleswig-Holstein, northern Germany, in 2006. D-type = diatom lake type, cf/aff/sp = only ambiguously identifiable taxa [%]; grey colour & bold = results classified as "unreliable" according to Schaumburg et al. (2006, 2007), because the samples contained > 5 % of ambiguously identifiable valves or an insufficient number of taxa with a RAQ value. light blue colour = samples in which $TI_{North}$ is based on < 60 % of the valves. green colour = ESC 2, yellow colour = ESC 3, orange colour = ESC 4.

| Lake (official lake #) | sample | D-type | cf/aff/sp [%] | TI North | TI North valves [%] | RTR | RTR taxa [n] | RTR min taxa [n] | M TI | M RTR | DI Lake | ESC diatoms | ESC lake |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ahrensee (0003) | AHS1 | 10.1 | **6.2** | 2.69 | 81 | -0.29 | 14 | 12 | 0.62 | 0.36 | **0.49** | 3 | **2** |
| | AHS2 | 10.1 | 0.6 | 2.34 | 80 | -0.33 | **9** | 12 | 0.76 | | **0.76** | 2 | |
| | AHS3 | 10.1 | **6.8** | 2.91 | 75 | -0.23 | 13 | 12 | 0.53 | 0.38 | **0.46** | 3 | |
| | AHS4 | 10.1 | 4.0 | 2.44 | 82 | 0.50 | **8** | 12 | 0.72 | | **0.72** | 2 | |
| Blankensee (0026) | BLA1 | 11 | **5.3** | 3.36 | 69 | -0.60 | 15 | 8 | 0.45 | 0.20 | **0.33** | 4 | **3** |
| | BLA2 | 11 | 1.2 | 3.15 | 56 | -0.43 | **7** | 8 | 0.53 | | **0.53** | 3 | |
| Bordesholmer See (0033) | BH1 | 11 | 2.9 | 2.84 | 78 | -0.33 | 9 | 8 | 0.66 | 0.33 | 0.50 | 3 | 3 |
| | BH2 | 11 | **12.7** | 3.18 | 41 | 0.00 | 8 | 8 | 0.52 | 0.50 | **0.51** | 3 | |
| Bothkamper See (0040) | BOS1 | 11 | **5.8** | 3.33 | 82 | -0.09 | 11 | 8 | 0.46 | 0.45 | **0.46** | 3 | 3 |
| | BOS2 | 11 | 2.7 | 3.35 | 68 | -0.80 | 10 | 8 | 0.46 | 0.10 | 0.28 | 4 | |
| | BOS3 | 11 | 4.4 | 3.36 | 81 | -0.78 | 9 | 8 | 0.45 | 0.11 | 0.28 | 4 | |
| | BOS4 | 11 | 3.2 | 3.02 | 72 | -0.11 | 9 | 8 | 0.59 | 0.44 | 0.52 | 3 | |
| Großensee (0107) | GR1 | 13.2 | 0.0 | 2.32 | 70 | 0.08 | 13 | 12 | 0.77 | 0.54 | 0.65 | 2 | 2 |
| | GR2 | 13.2 | 3.5 | 2.30 | 84 | -0.33 | 12 | 12 | 0.78 | 0.33 | 0.56 | 2 | |
| | GR3 | 13.2 | **7.9** | 2.32 | 64 | -0.07 | 15 | 12 | 0.77 | 0.47 | **0.62** | 2 | |
| | GR4 | 13.2 | 0.7 | 2.48 | 77 | -0.18 | 17 | 12 | 0.71 | 0.41 | 0.56 | 2 | |
| Selenter See (0383) | SL1 | 13.1 | 0.0 | 2.63 | 84 | -0.57 | 23 | 12 | 0.44 | 0.22 | 0.33 | 4 | 3 |
| | SL2 | 13.1 | 0.0 | 2.46 | 96 | -0.47 | 15 | 12 | 0.51 | 0.27 | 0.39 | 3 | |
| | SL3 | 13.1 | 0.0 | 2.61 | 74 | -0.67 | 18 | 12 | 0.45 | 0.17 | 0.31 | 4 | |
| | SL4 | 13.1 | 0.0 | 2.79 | 59 | -0.79 | 19 | 12 | 0.38 | 0.11 | 0.24 | 4 | |
| | SL5 | 13.1 | 0.7 | 2.62 | 62 | -0.41 | 17 | 12 | 0.45 | 0.29 | 0.37 | 3 | |
| | SL6 | 13.1 | 0.0 | 2.45 | 93 | -0.65 | 17 | 12 | 0.52 | 0.18 | 0.35 | 3 | |
| | SL7 | 13.1 | 0.0 | 2.90 | 67 | -0.44 | 18 | 12 | 0.33 | 0.28 | 0.31 | 4 | |
| | SL8 | 13.1 | 0.0 | 2.52 | 91 | -0.62 | 21 | 12 | 0.49 | 0.19 | 0.34 | 3 | |
| | SL9 | 13.1 | 0.5 | 2.48 | 80 | -0.33 | 18 | 12 | 0.50 | 0.33 | 0.42 | 3 | |
| | SL10 | 13.1 | 0.2 | 2.62 | 95 | -0.52 | 21 | 12 | 0.45 | 0.24 | 0.34 | 3 | |
| Wardersee (0434) | WAD1 | 11 | 1.7 | 2.73 | 77 | -0.25 | 8 | 8 | 0.70 | 0.38 | 0.54 | 3 | 3 |
| | WAD2 | 11 | 3.4 | 2.78 | 78 | 0.14 | **7** | 8 | 0.69 | | **0.69** | 2 | |
| | WAD3 | 11 | **5.3** | 3.43 | 74 | -0.75 | 8 | 8 | 0.43 | 0.13 | **0.28** | 4 | |
| | WAD4 | 11 | 0.6 | 3.09 | 56 | -0.56 | 9 | 8 | 0.56 | 0.22 | 0.39 | 3 | |
| | WAD5 | 11 | 0.5 | 2.90 | 57 | -0.75 | 8 | 8 | 0.64 | 0.13 | 0.38 | 3 | |
| | WAD6 | 11 | 1.4 | 2.71 | 52 | -0.20 | **5** | 8 | 0.71 | | **0.71** | 2 | |
| Westensee (0443) | WS1 | 11 | 1.1 | 3.18 | 81 | 0.25 | 8 | 8 | 0.52 | 0.63 | 0.57 | 2 | 2 |
| | WS2 | 11 | 2.5 | 2.55 | 90 | 0.14 | **7** | 8 | 0.77 | | **0.77** | 2 | |
| | WS3 | 11 | 0.6 | 2.72 | 91 | 0.00 | 8 | 8 | 0.71 | 0.50 | 0.60 | 2 | |
| | WS4 | 11 | 0.0 | 2.64 | 92 | -0.43 | **7** | 8 | 0.74 | | **0.74** | 2 | |
| | WS5 | 11 | 4.0 | 2.88 | 39 | -0.50 | 8 | 8 | 0.65 | 0.25 | 0.45 | 3 | |
| | WS6 | 11 | 3.9 | 2.88 | 75 | 0.14 | **7** | 8 | 0.64 | | **0.64** | 2 | |
| | WS7 | 11 | 0.7 | 2.80 | 80 | 0.25 | 8 | 8 | 0.68 | 0.63 | 0.65 | 2 | |

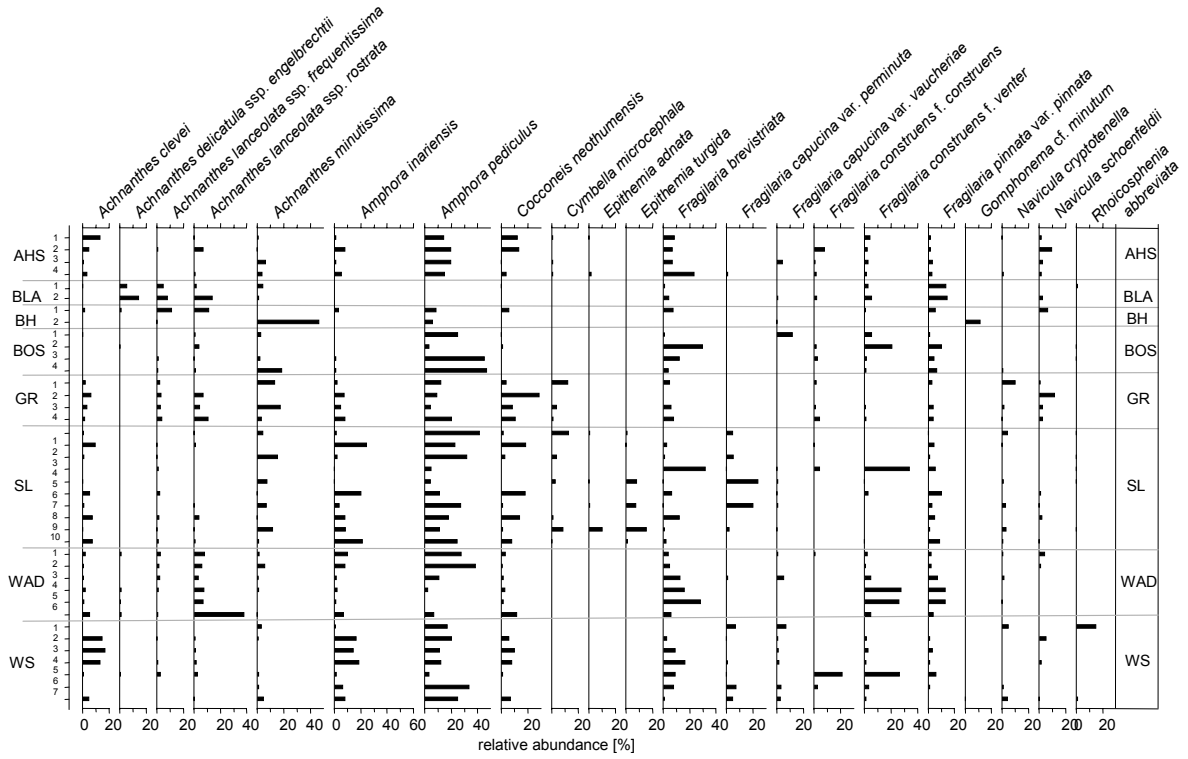


**Fig. 1.** Relative abundance [%] of the most common benthic diatoms (> 10 %) in the littoral of Lake Ahrensee (AHS), Blankensee (BLA), Bordesholmer See (BH), Bothkamper See (BOS), Großensee (GR), Selenter See (SL), Wardersee (WAD) and Westensee (WS) in Schleswig-Holstein, northern Germany, in 2006.

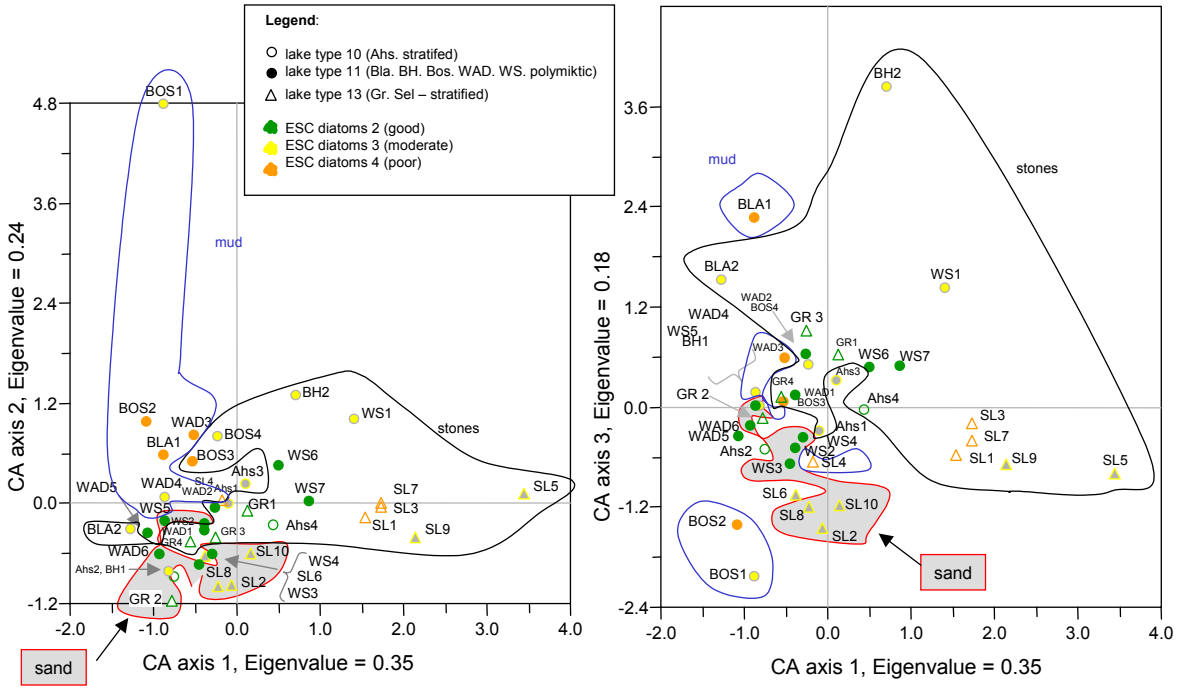


**Fig. 2.** Correspondence Analysis (CA) of all unmistakably identifiable diatoms, which were used in the calculation of the Ecological Status Classes (ESC) (87–100 % of each sample). Samples without a given substrate were taken from sandy mud. The northern German study lakes (Schleswig-Holstein) were sampled in 2006. For lake abbreviations see Table 1.

**Overall performance**

Overall, the inferred ecological status of most of the lowland lakes seems reliable based on benthic diatoms. For example, although the substrate clearly influenced the diatom assemblages, the diatom assemblages of samples which identified a poor ecological status (class 4) (BLA 1, BOS 2, BOS 3 and WAD 3), were very similar to each other independent of the sampled substrate (mud and stones) (Fig. 2). Also, the inferred ecological status based on benthic diatoms was generally supported by the ecological preferences of the identified planktic diatoms.

**Reliability of modules $DI_{Lakes}$, $TI_{North}$ & RTR**

**$DI_{Lakes}$:** Seven of the 39 samples had more than 5 % of ambiguously identifiable taxa (i.e. taxa with sp., spp., cf. or aff.) and could thus not be used in the assessment of the ecological status according to Schaumburg et al. (2006, 2007) (Table 1). However, the $DI_{Lakes}$ of those lakes was often based on more data than the $DI_{Lakes}$ of samples labelled as reliable. For example, sample BOS1 contained 5.8 % of ambiguously identified taxa, and was thus classified as unreliable (Table 1). Still, the trophic index was based on 82 % of the valves and the RTR value was based on 11 taxa. In contrast, sample BOS2 was classified as reliable (only 2.7 % of ambiguously identified taxa). However, the $TI_{North}$ was based on just 68 % of the valves and the RTR value on only ten taxa (Table 1). Consequently, we suggest a re-evaluation of the reliability of $DI_{Lakes}$ for lowland lakes.

**$TI_{North}$**: In some samples the $TI_{North}$ was based on less than 60 % of the valves but the $DI_{Lakes}$ were still classified as reliable according to the guideline, e.g. samples WAD4 and WAD5. Again, we suggest a re-evaluation of the reliability of $DI_{Lakes}$ for lowland lakes.

**RTR**: If RTR is based on an insufficient number of taxa (less than 8 or 12 depending on lake type), the $DI_{Lakes}$ is supposed to be solely based on $TI_{North}$ and is labelled as unreliable (Schaumburg et al. 2006, 2007). Thus, 21 % of all samples (n=39) were labelled as unreliable (Table 1). Therefore, our assessment was based on very few samples per lake and the applicability of the entire method starts to be questionable. Similarly, another study investigated the littoral diatom assemblages of 17 lakes in northern Germany (n=104) and identified 18 % as unreliable due to an insufficient number of taxa with RAQ values (Hofmann 2006). Therefore, we suggest to refine the RAQ module to improve the overall reliability of the inferred ecological status of a lake.

Interestingly, the module RTR seems to generally infer a lower ecological status than the module $TI_{North}$ (Table 1, only exception: sample WS1; Hofmann 2006). For example, the module $TI_{North}$ suggestsa good and the module RTR a poor ecological status in samples WAD4, WAD5 and WS5 (Table 1). As the $DI_{Lakes}$ is an average of the two modules, this discrepancy needs to be investigated.

## CONCLUSION

The guidelines from Schaumburg et al. (2006, 2007) provide a relatively **solid method** to reliably infer the ecological status in German lowland lakes based on benthic diatoms.

The classification of samples with a **reliable $DI_{Lake}$** for lowland lakes should be re-evaluated. We suggest to define the reliability of module $TI_{North}$. We propose that $TI_{North}$ should to be based on at least 60 % (or 70 %?) relative abundance of all taxa. If the $TI_{North}$ represents less than the given percentage, we suggest to declare the overall ecological status identified by $DI_{Lakes}$ as not reliable, independent of the number of taxa used in the RTR module. Alternatively, the same limit as for the trophic state index for lakes from southern Germany ($TI_{South}$) could be applied. Here, the module is defined as unreliable, if $TI_{South}$ is based on less than ten taxa. This cut-off would prevent a $TI_{North}$ that is based on a single taxon that happens to contribute 70 % to the relative abundance. Consequently, the 5 % limit of ambiguously identified taxa becomes unnecessary, assuming that the ecological status is still only assessed with unmistakably identified taxa. Also, the percent of ambiguously identified taxa should still be provided in every assessment.

The **taxonomic conformity** of the studied diatom assemblages and the assemblages on which the trophic state and RTR values are based on, are crucial for a reliable identification of the ecologic status (see above). Thus, we suggest to improve taxonomic conformity by 1) broadening the literature used in the identification, with books, such as Reichardt (1999) and especially by including the revised taxonomy of the genus *Cymbella* C.Agardh (Krammer 1997a, b, 2002, 2003) and 2) by publishing a commented photographic documentation of the taxa that were used to generate the guidelines. This publication would increase the number of unmistakably identifiable taxa, as even usually problematic taxa, such as *Gomphonema* spp., could be included in the assessment of the ecological status and would thus improve the quality of the inferred ecological status, as more taxa and valves could be included in the calculations.

Schaumburg et al. (2006, 2007) suggest to count unidentifiable **girdle views** according to genera and length and to subsequently classify the girdle band views as belonging to the most common identifiable taxon with similar length of the genus in the same sample. We agree that girdle views should be counted with as much taxonomic resolution as possible. However, we would prefer not to include such unidentifiable girdle valves in the calculation of the ecological status as we would always classify such girdle valves as "cf.".

Schaumburg et al. (2006, 2007) emphasize that centric diatoms (except *Melosira varians* C.Agardh) and euplanktic pennates are not to be included in the count of each sample. Yet, trophic state values ($TI_{North}$) are given for some **centric or planktic taxa** such as *Ellerbeckia arenaria* (D.Moore ex Ralfs) R.M.Crawford, *Fragilaria nanana* Lange-Bert., *Fragilaria ulna* var. *acus* (Kütz.) Lange-Bert., and *Fragilaria ulna angustissima*-Sippen sensu Krammer & Lange-Bertalot (1991a). A table clarifying which centric taxa and which planktic pennates are to be included (or excluded) would be helpful.

The **number of valves** that need to be counted per sample is given as 400 valves on p. 18 (Schaumburg et al. 2006) and p. 19 (Schaumburg et al. 2007) and given as 500 valves on p. 19 and 20 (Schaumburg et al. 2006 and 2007, respectively). This discrepancy needs clarification.

**King and colleagues (2006)** have reviewed the methods for sampling littoral diatoms in lakes for ecological status assessments for temperate regions. We suggest to implement their recommendations. For example, the authors suggest that the sample of each site should be a composite sample (King et al. 2006).

Overall, it will probably be less costly to slightly improve the guideline and to publish a commented taxonomic booklet, than to derive sometimes questionable results when using the guideline in its current state.

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