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From expert judgement to supervised classification: A new approach to assess ecological status in lowland streams

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HIGHLIGHTS

► We find that a paradigm exists among experts that can guide the development of WFD assessment systems for aquatic plants.
► The expert interpretation of ecological status can be transferred into a supervised classification model.
► The model can be used to classify plant assemblages from new stream sites into ecological status classes.
► This approach may be particularly useful in water body types where a reference network cannot be established.

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ABSTRACT

The EC Water Framework Directive (WFD) clearly states that undisturbed reference states of aquatic ecosystems should be used to set standards for restoration. Across Europe defining biological reference status and setting boundaries for ecological status classes continues to represent a major challenge. In the present study we investigate if a paradigm exists among experts that can guide the development of assessment systems based on the normative definitions of ecological status classes of the WFD. Our main questions were: 1) Will experts from species abundance data and typology descriptors independently arrive at similar assessments of ecological status, and 2) Can the expert interpretation of ecological status be transferred into a statistical model allowing for a standardization of assessments from plant assemblages in lowland streams? We used a large dataset covering 1244 randomly distributed stream sites in Denmark and asked a group of experts to independently classify the sites using the WFD's normative definitions of ecological status. According to the combined expert group, no Danish stream sites belonged to the undisturbed reference state. For the remaining ecological status classes we found good concordance in the classification made by the five experts. From this we infer that a common paradigm does exist, which may guide the development of assessment methods for aquatic plants in lowland streams. We also found that the common view of the experts could be transferred into a supervised classification model that can serve as a classification tool for aquatic plant assemblages in lowland streams. We conclude that the combined use of experts and advanced multivariate statistics can provide a useful approach in the development of systems for assessment of ecological status in water types, where a reference network cannot be established.

1. Introduction

The EC Water Framework Directive (WFD; European Commission, 2000) is an ambitious instrument in the Europe-wide legislation that aims to set harmonized environmental objectives for surface water and groundwater. Unlike almost all previous legislation, objectives are set relative to the ecological quality rather than physico-chemical thresholds (Logan and Furse, 2002). This change in focus from the use of ecological measurements as proxies for chemical water quality, to the development of monitoring tools that envelop the structure and functioning of a whole ecosystem as described in the Directive is a fundamental change in the assessment of European waters.

The definition of reference condition is crucial for the classification of surface waters from high to bad, including intermediate steps of good, moderate and poor. Ideally, the definition should be clear and unambiguous, based on analyses of empirical data from a network of references sites. Moreover, the definition should embrace spatial and temporal variability within the biological communities to adequately fulfil the intentions of the Directive. Across Europe, however, there are only few sites in an undisturbed state, and these are unevenly distributed and do not cover all types of habitats. This was clearly demonstrated for lowland rivers, where the use of a variety of reference screening criteria based on the REFCOND guidance document (Wallin et al., 2003) for physico-chemical, hydro-morphological

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and pressure criteria failed to identify reference sites (Nijboer et al., 2004; Chaves et al., 2006; Baattrup-Pedersen et al., 2009).

Despite 10 years of intensive efforts, establishing values for biological reference conditions, considering both structural and functional properties of the ecosystem, and setting boundaries for ecological status classes remain a challenge in the implementation of the Directive (Stoddard et al., 2006; Solheim et al., 2008; Nõges et al., 2009; Yates and Bailey, 2010). As today, most WFD-compliant assessment systems build on reference values for specific stressors relying on ecological preferences of single species (Hering et al., 2010; Demars et al., 2012), as opposed to a more comprehensive definition that encompass whole communities. The ecological preferences are often derived from data showing correlations between presence and abundance of species and the specific pressures (Birk and Wilby, 2010; Demars et al., 2012). Yet, these correlations rarely reflect causal relationships, since they are based on observations in the field where environmental variables are inter-dependent. For example, stream water alkalinity, which significantly influences aquatic plant assemblages, is often linked to eutrophication, and these variables therefore co-vary in nature (Hutchinson, 1975; Demars and Thiebaut, 2008; Demars and Tremolieres, 2009). For the same reasons, the current use of reference values has been questioned (*e.g.* Moss, 2008; Demars and Edwards, 2009; Demars et al., 2012), as they may not capture the structural and functional characteristics of the ecosystems.

In the present study we pursue the challenge of defining ecological status classes in lowland streams. We explore if a paradigm exists that can be used to guide the development of an assessment system to classify lowland streams from aquatic plant assemblages, building on the normative definitions of high, good, moderate, poor and bad ecological status (2000/60/EC; Wallin et al., 2003). We use the term 'paradigm' in the sense suggested by Kuhn (1962) that scientists can agree in the identification of a paradigm without necessarily implying that any full set of rules shall or can be defined and, therefore, we did not attempt to formulate specific criteria for the different ecological status classes. We used a large dataset covering 1244 randomly distributed stream sites in Denmark and asked a group of aquatic botanists with profound knowledge on the ecology of aquatic plants to independently classify the sites into ecological status classes. Specifically, we addressed the following two questions: 1) Will experts independently arrive at similar assessments based on normative definitions of ecological status from species abundance data and typology descriptors?, and 2) Can the view of the experts be transferred into a statistical model that can be applied in monitoring and assessments of ecological status from plant assemblages in lowland streams?

2. Materials and methods

2.1. Study sites

Denmark is a small and flat country situated in the deciduous woodland biome in Northern Europe between approx. 54°–58° N and 8°–5° E. The landscape is intensively cultivated (60% agriculture) and with a dense network of ditches and natural streams, of which more than 90% has been regulated to increase agricultural productivity. The streams are generally small and shallow (>95% of the stream reaches are less than 10 m wide and 1 m deep), have low slopes (<0.005 m m^{-1}), low water velocities (<0.8 m s^{-1}) and sediments dominated by clay, silt and sand. We used an extensive dataset including 1244 stream sites covering natural size and alkalinity gradients in Danish streams (Table 1). The data originated from different sources. A large majority of the data were collected as part of former and current national monitoring programmes (968 sites; Skriver et al., 1999; Pedersen et al., 2007) of which a subset were the least anthropogenically disturbed stream sites in Denmark (a total of 130 sites). In addition, we integrated published data from previous research projects, including also some of the least impacted sites in Denmark, to be sure that these were adequately covered in the dataset (276 sites; Baattrup-Pedersen and Riis, 1999; Riis, 2001; Baattrup-Pedersen et al., 2002, 2003; Baattrup-Pedersen and Riis, 2004; Pedersen et al., 2006).

Table 1
Characteristics of the 1244 Danish stream reaches included in the present study.

	Median	Minimum	Maximum	25%	75%
Stream characteristics					
Width (m)	3.4	0.3	47.0	1.9	6.6
Depth (cm)	34.1	0.1	125.5	18.0	59.2
Alkalinity (mEq L^{-1})	2.6	0.1	8.4	1.3	4.3
Plant characteristics					
Coverage (%)	56.1	2.3	103.3	30.5	77.8
Species richness	10	1	45	7	15
Shannon diversity	1.56	0	3.23	1.14	1.91
Evenness	0.68	0	0.99	0.58	0.77

All data were collected using the technical guidance document for stream monitoring in Denmark (Pedersen et al., 2007). In summary, a 100 m long stream reach was delimited. Plant recordings were made in plots (25×25 cm) placed side by side in 10–15 cross-sectional transects reaching from the edge of the water at one side of the stream channel to the edge of the water at the other side. In each plot a cover score was allocated to all species that were present using the following scale: 1 = 1–5%, 2 = 6–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100%. Relative species abundance was calculated as the sum of all cover scores assigned to that particular species divided by the maximum score sum (*i.e.* the number of plots multiplied by the maximal score of five). Table 1 summarizes plant coverage and diversity data from the stream sites.

2.2. Analytical approach

2.2.1. A priori classification

Five experienced aquatic botanists (Anne Gro Thomsen, Annette Sode, Bjarne Moeslund, Tina Pedersen and Tenna Riis), that during their professional career have gathered significant knowledge on aquatic plant communities, were asked to participate in the project. Anne Gro Thomsen, Annette Sode and Tina Pedersen have for several years (>10 years) been working with aquatic plant monitoring in streams regionally; they have participated in working groups and attended national conferences on aquatic plants and, therefore, they have an extensive knowledge on the distribution of aquatic plants in streams. Bjarne Moeslund has been working in a consultancy firm for >30 years. He has been involved in several projects studying effects of changed management practice, including restoration, on the aquatic plant communities and has contributed to the taxonomic literature. Tenna Riis has been studying aquatic plant assemblages for >15 years. During her Ph.D. she has been investigating both the contemporary stream vegetation and former vegetation based on literature studies of old Danish reports and articles from around 1900.

The experts received a list of species abundance data from all stream sites together with information on stream width, depth and alkalinity according to the type-specific requirements of the WFD. The experts were then asked to assign each of the 1244 stream sites to an ecological status class (high, good, moderate, poor and bad), 'poor' and 'bad' being states with major (poor) or greater (bad) deviation according to the REFCOND guidance document (Wallin et al., 2003). Two of the experts did the ecological class assessments twice, and the intra-expert uncertainty in the classifications could therefore be assessed.

Eq. (1) was developed as a measure of concordance in the ecological status class assessments by and among the experts and gives more weight to status classes close to each other than to status classes far for from each other. A range of pairwise comparisons were made using Eq. (1):

$$I = \frac{N_0 + 0.5 \times N_1 + 0.25 \times N_2 + 0.125 \times N_3 + 0.06 \times N_4}{N} \quad (1)$$