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# A typology for fish-based assessment of the ecological status of lowland lakes with description of the reference fish communities

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ABSTRACT

We compared the potential of different lake typologies to discriminate fish communities in least disturbed sites. The typologies tested were based on morphometric and geographical descriptors. The best discrimination was achieved by distinguishing three lake types according to depth and mixes regime: polymictic lakes, stratified lakes with less than 30 m of maximum depth and deep, stratified lakes with maximum depths above 30 m. We conclude that the proposed typology is appropriate for a system to assess the ecological status of German lakes with the fish fauna according to the Water Framework Directive and might well be transferable to other European assessment systems. The fish communities in all lake types were similar and dominated by few fish species. Perch and roach were the most abundant ones, followed by ruffe, bream, rudd and pike. The fish communities in least disturbed sites might be used as reference conditions in future fish-based assessment systems.



## Introduction

The Water Framework Directive (WFD, 2000) has implemented an ambitious goal: all European water bodies should achieve a good ecological status until 2015. As a prerequisite for estimating the need for improvement of a water body, its current ecological status has to be assessed. According to the directive, this is to be done with systems using so called biological quality elements: phytoplankton, macrophytes, macroinvertebrates and fish.

The surface water bodies listed in the WFD are rivers, lakes, transitional and coastal waters. In addition to this classification, the WFD stipulates the use of a typology for each of the water bodies. The subdivision into types has two important advantages for the element-based assessment of the ecological status. First, using type-specific traits of the biological elements allows a more customized indication of the ecological status. Second, a type-specific numerical evaluation of similar traits can be used to counterbalance natural differences of value ranges between the types. A typology in the context of the WFD is a pragmatic tool to achieve reliable assessment results. It is not a comprehensive description of abiotic preconditions, ecological networks or biological community structures in nature.

In the context of the WFD, 'ecological status' exclusively refers to anthropogenic impacts ('pressures'). Therefore, a typology used as basis for biological assessment systems is inherently limited to descriptors that are not potential pressures and it is not allowed to include any trait of the biological elements themselves. WFD-compliant typologies are based on abiotic descriptors, which are unlikely to be altered by human impacts. Annex II of the WFD and various European guidelines give suggestions on possible descriptors and typologies (CIS, 2003; Poikane, 2009).

The present paper elucidates the development of a typology as basis for the assessment of German lakes with the biological element fish. It is well known that morphometric, chemical, and structural descriptors modify the fish community composition in lakes. The descriptors with strongest effects so far are lake area, depth and nutrient concentrations (Browne, 1981; Brucet et al., 2013; Jeppesen et al., 2000; Persson et al., 1991; Sondergaard et al., 2005). Area and depth are independent on human activities. Nutrient concentrations are influenced both by natural conditions and human pressures and should therefore not be used for a typology.

For the German part of the ecoregion central plains, distinct lake fish communities had been related to depth. A cyprinids lake type with mean depths from 6 to 8 m was contrasted to deeper vendace/perch lake types (Mehner et al., 2005). Comparable results were obtained by Diekmann et al. (2005) and Garcia et al. (2006), but they used a maximum depth of 11 m as main separating descriptor.

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Thus, a typology based on abiotic lake descriptors may foster the development of assessment systems because fish communities may differ fundamentally between lakes of different types. The aim of our study is to compare potential abiotic descriptors and find the most appropriate typology. For this purposes we first pre-classified the lakes into types. Then we tested the suitability of the pre-classifications to discriminate fish communities which are undisturbed by anthropogenic pressures. In a final step we describe the type-specific fish communities and reveal some challenges for subsequent fish-based status assessment.

## Materials and methods

### *Selection of least disturbed sites*

The lake typology is developed as basis for a fish-based assessment of the ecological effects of human pressures. For this purpose, human pressures themselves should not influence the result of the typology. Therefore, we based the typology on selected lakes with low levels of human pressures, abbreviated LDC for 'least disturbed conditions' (CIS, 2011). For the selection of LDC lakes we considered shoreline degradation, human lake use and eutrophication as anthropogenic pressures.

The impacts of shoreline degradation and human lake use on the fish community were estimated by experts dealing with investigations of fish communities and limnology, who had scientific training and good knowledge of the lakes. The pressure 'shoreline degradation' included the estimation of relative abundance of artificial beaches, footbridges/marinas, woody erosion control, rip rap revetment and sheet pile walls. 'Human lake use' included the amount of people swimming, boats without motors, surfing/sailing, motorboats and commercial shipping (but did not refer to the extent of fisheries). The impacts of the pressures were estimated on a qualitative four-step scale: no – natural or almost natural shoreline, no or few swimmers/low: small amount of degraded shoreline with artificial structures, some boats present/intermediate: significant degradation of shoreline, recreational use of the lake with sailing boats and motorboats/strong-very strong: shoreline prevailingly unnatural, intense recreational use with boating, surfing, water skiing, commercial shipping. Both shoreline degradation and lake use or boating can potentially impact the fish community in the littoral zones (Arlinghaus et al., 2002; Belpaire et al., 2000; Lewin et al., 2013). Therefore, only lakes rated to have no or low anthropogenic impacts in both shoreline degradation and lake use were assigned to the set of LDC sites.

To estimate the intensity of eutrophication, we used a German Trophic Index (TI). The TI can be modeled for undisturbed conditions (reference index $TI_{ref}$) and for the present situation (actual index $TI_{act}$). $TI_{ref}$ is modeled using morphometric properties of the lake: volume, area, depth, length and width. $TI_{act}$ is calculated by four weighted descriptors (total phosphorus concentration in spring, total phosphorus concentration in summer, chlorophyll-a concentration and secchi depth). The linear difference between both indices ($\Delta TI$) was used as a measure for anthropogenic eutrophication: $\Delta TI = TI_{act} - TI_{ref}$. The values of $\Delta TI$ ranged from −0.9 (the trophic index actually is lower than in reference condition) to 2.7 (equals a hypertrophic lake, which would be oligotrophic in reference conditions). Lakes with a $\Delta TI < 1.0$ were included in the LDC dataset. This value equals the transition from oligo- to mesotrophic or from meso- to eutrophic conditions. The calculations of $TI_{ref}$ and $TI_{act}$ follow guidelines of the German Working Group on Water Issues (LAWA, 1998).

The impacts of other pressures were assessed by literature survey, queries and on site during the fishing campaigns. Acidification, chemical pollution and water level fluctuation were absent or of low intensity and we supposed that these potential pressures had no impacts on the fish community in the LDC lakes. The same holds true for the effects of fisheries, stocking or presence of alien species; the catches showed no signs of unnatural species inventory or composition. However, these pressures were not quantified for the selection of LDC sites. The final dataset of LDC lakes included 38 natural surface water bodies (no anthropogenic lakes like reservoirs).

### *Typology*

We used different approaches for the pre-classification of the lakes. River catchment and the German federal states were used as geographical descriptors. For the assignment of thresholds for quantitative morphometric descriptors we tested proposals provided by the WFD, the German Working Group on Water Issues – LAWA (LAWA, 2003, 2005; Mathes et al., 2002) and preceding results of related investigations (Mehner et al., 2004, 2005). Table 1 provides an overview of the groups chosen.

While most descriptors are self-explaining, 'depth gradient' and 'LAWA-typology' need description. The depth gradient is the maximum depth divided by a theoretical depth of the epilimnetic layer, which is calculated by length and width of the lake (LAWA, 1998). Lakes with depth gradients above 1.5 usually are steadily stratified in summer. However, the LAWA criterion 'stratification' is a morphometric proxy for the real stratification and does not take into account duration or extension of the stratification. The LAWA-typology was developed to implement the requirements of the WFD. For the German area of the Central Lowlands, five LAWA lake-types exist:

- type 10: stratified, catchment area is large when compared to lake volume;
- type 11: polymictic, catchment area is large when compared to lake volume;
- type 12: polymictic, catchment area is large when compared to lake volume, water residence time between 3 and 30 days;
- type 13: stratified, catchment area is small when compared to lake volume;
- type 14: polymictic, catchment area is small when compared to lake volume.

The catchment area is denoted as large, if the ratio of catchment area to lake volume is above $1.5\,m^2/m^3$. The LAWA lake types 10 and 11 describe sites with a bigger risk of eutrophication because they are exposed to a large catchment area and thus to an increased number of potential sources of nutrient pollution. In the LDC dataset, type 11 was represented by one lake only. Type 12 describes lakes with short residence time of the water. Within the original dataset, only lakes where larger rivers flow through belong to this type. They are characterized by eutrophication, intense lake use and shoreline modification and no such lake was included in the LDC dataset.

It became evident during the analyses that stratification is a very important descriptor for a potential fish-specific typology. However, the stratification criterion of the LAWA-typology did not always reflect the real or dominant situation in the lakes. This was caused by assigning the stratification descriptor indirectly, based on the depth gradient or by distinct morphometric features, e.g. the presence of stratification in limited areas of a lake. However, the fish community structure depends on the dominating lake properties, not on features of smaller lake parts. Therefore, we introduce the concept of a 'functional stratification'. Each lake was carefully checked using literature (e.g. lake profiles provided by federal environmental agencies) and asking experts who knew the location. A lake usually is rated to be stratified, if the thermic stratification