ETC-BE Report 2026/1

EUNIS inland water habitats revision - description of biological communities

including species richness, characteristic, common and dominant taxa in habitats in reference conditions and in impacted conditions

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Disclaimer

This report is a proposed revision of the inland water section of the EUNIS habitats classification covering all fully aquatic environments in rivers, lakes, and other standing or running waters in Europe. The habitats are described using an analytical framework based on truly aquatic biota and their presence in waterbodies at bankfull water level. The scope of the report is based on the broad habitat types monitored under the EU Water Framework Directive (WFD), with the addition of some important water body types not captured by the WFD broad types: saline rivers and lakes, tidal rivers, springs, ponds and pools, glacial rivers and lakes, temporary rivers and lakes, permanent marl/karst lakes and volcanic lakes.

At level 3 of the classification, the inland water habitats are frequently habitats which vary both spatially and over time, but these should be distinguished from the EUNIS group Z: Habitat complexes, some of which also include surface water habitats. The report does not include riparian habitats, emergent macrophyte vegetation (e.g. helophytes), semi-terrestrial plant and animal communities nor dry-phase communities of temporary waters. These habitats and communities are covered under other sections within the EUNIS classification; however, some are included in the description of the Inland Water habitat types where appropriate. A few inland water habitat type descriptions may be amended after the finalisation of this report to cover closely associated temporary habitats.

Note that artificial water bodies such as constructed reservoirs, are represented in EUNIS group: Y5 Highly artificial man-made waters and associated structures. Where natural water bodies are used as reservoirs, these fall under inland waters.

The EUNIS habitat classification is available from the European Environment Agency at, https://www.eea.europa.eu/.

1 Executive summary

1.1 Rationale and objective

The EUNIS 2012 habitats for inland surface waters have been revised to better match the broad types developed for the Water Framework Directive (WFD). The revision has been done in dialogue with EIONET and external experts. Some of the rare EUNIS 2012 habitat types are kept due to their importance for nature conservation (temporary lakes, temporary rivers, springs, tidal rivers). Other rare types were added (volcanic lakes, permanent marl/karst lakes, glacial lakes, glacial rivers, inland saline rivers and streams). Very large rivers (catchment area >10 000km^2) and very large lakes (surface area >100km^2), as well as very small habitats (ponds and pools <2ha surface area) were also added.

The revised EUNIS inland surface water habitats are characterized by abiotic type descriptors focusing on altitude, geology and size, as well as other abiotic factors for the rare types. The revised list of level 3 habitats includes 23 standing water habitats and 27 running water habitats.

A crosswalk has been done to link the revised EUNIS habitat types for standing and running waters to the old EUNIS 2012 habitats and to various other inland water habitat typologies, including the Habitats Directive Annex I and the Red List habitats. Links are also provided to other EUNIS habitats that are dependent on water, e.g. gravel bars, helophyte beds, mires and fens within the Wetlands group, and floodplains and estuaries within the Habitat complexes.

The main objective is to complete the EUNIS inland surface water revision at level 3 by including biological descriptions for all the major groups of organisms found in each of the revised inland water habitats both in unimpacted (reference) and in impacted water bodies. The descriptions are limited to truly aquatic taxa. Regional differences between Nordic, Central and Mediterranean regions have also been considered for all habitats with sufficient data.

1.2 Policy relevance

The revised EUNIS inland waters classification encompasses the common types used for the implementation of the Water Framework Directive (WFD) and the related habitat types of the Habitats Directive (HD), including their biological communities and species richness. The revised EUNIS inland waters classification therefore has direct policy relevance allowing comparisons of the WFD ecological status and the HD conservation status in related habitat types of running waters (rivers) and standing waters (lakes). Moreover, the report also describes the rarer types of the Habitats Directive (HD), including their species composition. The revised EUNIS classification can be the basis for a future revision of the WFD Annex 2 and the HD Annex 1 and is relevant for the EU Biodiversity Strategy 2030. The Nature Restoration Regulation can also benefit from using the revised EUNIS types to see effects of restoration measures across Europe. See section 2.8 for more details.

The next steps for the use of the revised classification in upcoming policy making, data reporting and monitoring are first to communicate the main outcomes to the WFD CIS-groups, to HD officials responsible for the HD implementation at EU-level and to the countries through EIONET. The second step can be to revise the systems for data reporting of the WFD ecological status for each biological quality element, the WISE-2-SoE and the HD conservation status to include the revised EUNIS types, as those are likely to capture a higher proportion of the national inland waters habitat types than the current WFD common types and HD Annex 1 habitats. That will allow the data to be aggregated to the revised EUNIS types for the future EU-level State-of-Water and State-of-Nature reports. The EUNIS classification crosswalk table available at the EEA EUNIS webpage can be useful to see the links between the revised EUNIS Inland water habitat types and the WFD common types and HD Annex 1 inland water habitats. The third step is to encourage the EIONET-countries NFPs and NRCs to design their monitoring programmes to include monitoring sites in the revised EUNIS inland water habitat types occurring in their country. The biological communities and species richness described in the report can also be valuable for the countries as a starting point when monitoring inland water habitats that can be linked to the EUNIS inland water habitats.

1.3 Data and analytical approaches

The biological communities have been described using data in the EU-level database WISER (WISER – Water bodies in Europe - Integrative Systems to assess Ecological status and Recovery) for most of the level 3 habitats that are well linked to the WFD.

For all habitats with sufficient data in the WISER database, the following biological communities are described in terms of their characteristic (diagnostic) taxa based on the phi index and their common (constant) taxa based on their frequency of occurrence for each habitat type with sufficient data: phytoplankton, aquatic vegetation and fish in standing waters, and benthic algae, aquatic vegetation, benthic invertebrates and fish in running waters. Dominant taxa are also identified for communities with available abundance data: Phytoplankton in standing waters and fish in standing waters and in running waters.

Species richness was also assessed for each biological community (group of organisms) in each habitat type separately in reference water bodies and impacted water bodies.

Differences between the biological communities in different habitats were assessed using multivariate analysis (NMDS and clustering) separately for reference (or good status) water bodies and for impacted (less than good status) water bodies. For clay rivers (defined as rivers and streams with suspended solids >10mg/l) and humic river habitats (defined as rivers and streams with colour >30mg Pt/l), the biology was described using a national Norwegian database, supplemented with literature data.

For most of the rare habitats, as well as for the ponds, a literature survey was done to extract information on typical species occurring in those habitats. Amphibians were also included for some of the most relevant habitats, e.g. ponds and pools, based on the literature survey.

1.4 Importance of typology descriptors for taxonomic composition of major biological groups in standing and running water habitats

The results of the analysis described above are summarized in the tables blow (Table 1-1 for standing waters, and Table 1-2 for running waters).

1.4.1 Standing water habitats

For standing waters in reference or good condition, humic substances (geology) and altitude are important for the species composition in all the three major community groups included (phytoplankton, aquatic vegetation and fish). Alkalinity is most important for phytoplankton and aquatic vegetation. Species richness increases with size (surface area) and decreases with altitude for all three community groups. The major effects of the typology descriptors on the characteristic, common and dominant taxa are:

- Phytoplankton: There are more mixotrophic chrysophytes in siliceous lakes, at higher altitudes and in humic lakes, while there are more autotrophic diatoms, chlorophytes and large dinoflagellates in calcareous lakes, in clear lakes and in lowland lakes.
- Aquatic vegetation: There are more isoëtids in siliceous lakes, more charophytes and elodeids in calcareous lakes, and more nymphaeids in humic lakes.
- Fish: There are more cyprinids in calcareous lowland lakes, more salmonids in siliceous lakes and at higher altitudes.

The human impact on species composition is to increase the similarity between types for all the three community groups. For phytoplankton, the species composition changes towards more dominant taxa and fewer characteristic and common taxa, especially less mixotrophic chrysophytes and more cyanobacteria, chlorophytes, large diatoms and large dinoflagellates. The major change in aquatic vegetation is less isoëtids due to light limitation. For fish, the main impacts are that alkalinity becomes more important in impacted lakes, and that no characteristic species are found. Impacted lakes also have slightly more cyprinids and less salmonids.

1.4.2 Running waters habitats

For running waters in reference or good conditions, geology (alkalinity) is most important for benthic algae, aquatic vegetation and benthic invertebrates. Altitude is also important for the same three groups, while catchment size is not important. In contrast, for fish, both altitude and catchment size are very important, while geology (alkalinity) is less important. Species richness increases with catchment size for all the four biological groups, increases with alkalinity for benthic algae and benthic invertebrates and decreases with altitude for aquatic vegetation and fish. The major effects of the typology descriptors on the characteristic, common and dominant taxa are:

- Benthic algae: Calcareous rivers have more diatoms, chlorophytes and cyanobacteria, while siliceous rivers have more red algae.
- Aquatic vegetation: Lowland rivers have many characteristic and common elodeids, lemnids and nymphaeids, while mid-altitude rivers have bryophytes and charophytes.
- Benthic invertebrates: Calcareous rivers have more taxa with high calcium requirements, e.g. snails, amphipods, mussels, than siliceous rivers. More stonefly (Plecopteran) taxa are found in highland than in lowland rivers.
- Fish: Calcareous lowland rivers have more characteristic, common and dominant cyprinids than siliceous lowland rivers. The number of characteristic, common and dominant cyprinid species increases with catchment size and decreases substantially with increasing altitude.

The human impact on species composition is to increase the similarity between types for all the four community groups. For benthic algae and fish, the species richness increases in impacted rivers, while it decreases for aquatic vegetation and benthic invertebrates (for Plecoptera species). The number of characteristic and common taxa decreases for aquatic vegetation and benthic invertebrates, while there are more dominant taxa for fish.

1.4.3 Conclusions

To assess whether the L3 habitat types are truly different from each other for at least one of the major biological groups with available data, a joint visual inspection of cluster diagrams was done for the different biological communities. The main conclusion concerning the validity of the L3 habitat types is therefore that each of them is truly different from other L3 habitats for at least one of the biological communities, both for standing waters and for running waters for either reference water bodies and/or impacted water bodies. This indicates that the revised list of L3 habitats should be kept**.**

Another conclusion is that there are some regional differences within some of the L3 habitats: For most of the biological groups in both water categories (lakes and rivers), the Mediterranean region is quite different from the other regions, probably due to the much warmer climate and different precipitation pattern with frequent summer droughts. The differences between the Nordic and Central-European regions are smaller but also quite considerable for most of the biological communities, especially in running water habitats. The differences may be related to a colder climate in the Nordic region than in the Central-European region, as well as biogeographical distribution patterns. However, the results for running waters are uncertain due to unbalanced datasets with Central Europe dominating the dataset. Habitats in a particular region can still be classified using the current L3 habitats given for all standing and running water habitats occurring in that region.
Further subdivisions at lower EUNIS levels can be based on these major regions.

Table 1-1. Summary of changes found in taxonomic composition and species richness for phytoplankton, aquatic vegetation and fish between different standing water habitat types in reference or good condition. Human impact on species composition is also summarised.

Topic	Phytoplankton	Aquatic vegetation	Fish
Importance of type descriptors for taxonomic composition	Alkalinity, humic substances, altitude, depth	Alkalinity, humic substances, altitude,	Altitude, humic substances,
Species richness	Increases with size, decreases with altitude	Increases with size, decreases with altitude	Increases with size and alkalinity, decreases with altitude
Characteristic, common, dominant taxa	More mixotrophic chrysophytes in siliceous lakes, at higher altitudes and in humic lakes, more autotrophic diatoms, chlorophytes and large dinoflagellates in calcareous lakes, in clear lakes and in lowland lakes	More isoëtids in siliceous lakes, more charophytes and elodeids in calcareous lakes, more nymphaeids in humic lakes	More cyprinids in calcareous lowland lakes, more salmonids in siliceous lakes and at higher altitudes.
Human impact on species composition	Increases the similarity between types. More dominant taxa, fewer characteristic and common taxa, esp. less chrysophytes. More cyanobacteria, chlorophytes, large pennate diatoms, large dinoflagellates	Increases the similarity between the humic types, less isoëtids (due to light limitation).	Increases the similarity between types. Alkalinity becomes more important in clear lowland impacted lakes, No characteristic species found in impacted lakes of any type. Slightly more cyprinids and slightly fewer salmonids, but patterns are weak.

Table 1-2. Summary of changes found in taxonomic composition and species richness for benthic algae, aquatic vegetation, benthic invertebrates and fish between different running water habitat types in reference or good condition. Human impact on species composition is also summarised.

Topic	Benthic algae	Aquatic vegetation	Benthic invertebrates	Fish
Importance of type descriptors for taxonomic composition	Alkalinity very important Altitude is important Catchment size not important	Alkalinity very important Altitude is important Catchment size not important	Alkalinity very important Altitude is important Catchment size less important	Altitude and catchment size are most important; alkalinity is less important. Region and flow are also important.
Species richness	Increases with catchment size and alkalinity	Increases with catchment size, decreases with altitude	Increases with catchment size and alkalinity	Increases with catchment size, decreases with altitude
Characteristic, common, dominant taxa	Calcareous rivers have more diatoms, chlorophytes and cyanobacteria, while siliceous rivers have more red algae.	Lowland rivers have many characteristic and common elodeids, lemnids and nymphaeids, while mid-altitude rivers have bryophytes and charophytes.	Calcareous rivers have more taxa with high calcium requirements, e.g. snails, amphipods, mussels than siliceous rivers. More stonefly taxa are found in highland than in lowland rivers.	Calcareous lowland rivers have more characteristic, common and dominant cyprinids than siliceous lowland rivers. The number of characteristic, common and dominant cyprinid species increases with catchment size and decreases substantially with increasing altitude
Human impact on species composition	Increases similarity between most types, increases species richness	Increases similarity between a few types, slightly decreases species richness and largely decreases the number of characteristic and common taxa.	Increases similarity between most types, decreases species richness. Decreases the number of characteristic or common stonefly (Plecoptera) taxa, as well as many other taxa.	Increases similarity between most types, slightly increases species richness in most types. There are more dominant taxa in impacted rivers than in reference rivers.

2 Introduction

2.1 EUNIS habitat classification

The EUNIS habitat classification is a comprehensive and extensive pan-European reference system to harmonize and facilitate the description and collection of data across Europe through criteria for habitat identification (Davies and Moss 1999; Davies et al. 2004; Moss 2008, Rodwell et al. 2018). It is a hierarchical structure and covers all habitat types from natural to artificial, terrestrial to freshwater and marine. It aims to accommodate all habitat types, ranging from highly aggregated types at the European level (Levels 1 to 3) to more detailed types identified at regional and further ecological levels (Levels 4 and lower).

Since its establishment, EUNIS has undergone only modest change, but the increasing need to support European policy on nature conservation with harmonised habitat descriptions ideally underpinned by field data led to an initiation in 2012 of an extensive review of the EUNIS habitat classification. Since then, habitat groups have been addressed and revised one by one. Whereby a floristic approach was considered appropriate for terrestrial EUNIS habitats, which are largely defined by their vegetation, it was agreed that a different approach was required for the marine and inland surface water habitats. The approach for these 3 main groups is outlined in Box 1 below.

Box 1: Approaches used to revise EUNIS habitat classification.
The EUNIS classification is revised down to level 3 through three different approaches:

a) Abiotic approach
    a. for ***inland surface water*** types: altitude/catchment size/geology/depth/flow
    b. for marine benthic types: substrate/depth zone-light availability/marine region
b) Floristic approach (main approach for ***terrestrial*** habitat types but also used in some ***marine*** and ***inland surface water*** types)
c) Faunistic approach (mainly benthic invertebrates and fish) added for ***inland surface water*** types and in marine habitats

(Most habitats identified with the abiotic approach can be separated and identified by biological features (characteristic species for habitats at level 3 or 4)

2.2 Description of the revision process for EUNIS inland surface water habitats

The EUNIS habitat revision commenced in 2012 with the aim to support the nature policy and strengthen/ revisit the links of EUNIS habitats with other European typologies. For the inland waters habitat group, this proved particularly challenging due to the complete restructuring of the hierarchy from the EUNIS 2012 system. After reviewing other inland water habitat typologies such as the Annex I list of habitats and the EU Red List of habitats (ETC BD, 2016), as well as a joint workshop in 2018 between the EEA, the ETC/BD and ETC/ICM, it was decided to develop an updated inland surface waters structure along the lines of the Broad Types (Lyche Solheim et al. 2019) derived from the Water Framework Directive (WFD) surface water typology. The rationale and methodology used for development of the broad types and how they can be used for crosswalks between the WFD types and the HD Annex I habitat types, as well as the EUNIS 2012 Inland surface water habitats, are described in more detail in the European Freshwater Ecosystem Assessment (ETC-ICM 2015).

After workshops with EIONET (ETC/BD, 2021a) and external experts (ETC/BD, 2021b), the revised structure for the EUNIS inland surface water habitat group at level 3 and outlook to level 4 was agreed and is presented in ETC/BD & ETC/ICM (2022). The timeline for the process is given below.

2015	ETC/ICM (2015): Freshwater Ecosystem Assessment including crosswalk between the WFD, HD and EUNIS types for inland surface waters.
2016	ETC/BD (2016) Revising the freshwater section of the EUNIS habitats classification - a scoping paper.
2018	**ETC/BD & ETC/ICM joint workshop at the Museum of Natural History in Paris:** ETC/BD (2018) Freshwater habitats in the EUNIS classification. Report from the EUNIS freshwater workshop.
2019	**EIONET consultation** on EUNIS inland surface water habitats revision: ETC/BD (2019) Revised EUNIS classification of inland water habitats - report on comments from public consultation and outlook for future steps.
2020	**EIONET webinar:** ETC/BD (2021a) Outcome of the EIONET webinar on the revision of EUNIS inland water habitats.
2021	**Expert Workshop on Revision of the EUNIS inland water habitat group:** ETC/BD (2021b) Revision of the EUNIS inland water habitat group - outcome of the expert workshop 16th March 2021.
2022	**Report on the EUNIS revised habitats L3 including the abiotic descriptors:** ETC/BD & ETC/ICM (2022) Revision of the EUNIS inland surface water habitat group: finalisation of the level 3 and outlook to level 4 (ETC/BD & ETC/ICM, 2022).
2023	**Identifying biological communities in reference inland water habitats at L3:** ETC-BE Draft report.
2024	**Final Level 3 EUNIS inland water + biological communities, including both reference and impacted biological communities and regional differences at Level 4:** ETC-BE Technical report (this report).

2.3 Challenges met for the revision of structure

The revision presented various challenges throughout the years, some unique to inland waters. Some of these are described below and the solutions found to address them.

The structure of EUNIS inland waters 2012 had several issues to address in the revised version:
A **non-coherent level 3 structure** separated the inland surface water habitats (C1 Standing waters and C2 Running waters) from their littoral zone habitats (C3). This caused a non-hierarchical structure at Level 3, deviating from the hierarchical structure used for the other habitat groups. Moreover, standing waters include both pelagic and littoral zones.

- Therefore, the truly aquatic vegetation in the littoral zone (at bankfull water level) should be integrated within the C1 Standing waters.
- The group C3 also described habitats more appropriately assigned to other groups in the EUNIS system e.g. helophyte and amphibious vegetation, which is better suited to the EUNIS wetland habitat group Q. The C3.8 Inland spray and steam dependent habitats can be linked with the EUNIS category U: sparsely vegetated habitats, to be described in U3F.
- Within the level 3 groups for C2 Running waters, the scale of habitats was either too wide, such as C2.2 permanent, non-tidal, fast running water courses and C2.3 permanent, non-tidal smooth running water courses covering most of Europe's rivers, or too narrow, such as C2.6 films of water flowing over rocky water-course margins. The latter (C2.6) will be described in the revised sparsely vegetated habitat U3G.
- Trophic state was used as a factor to distinguish between standing water bodies at level 3. This is an issue as the trophic state is often influenced by human nutrient pollution from various sources and sectors, e.g. an oligotrophic lake can become mesotrophic or eutrophic depending on the level of human nutrient pollution, thereby changing its flora and fauna. Trophic state is therefore not only reflecting different undisturbed habitats but also human impact on lakes. The same lake can change its habitat type with increasing or decreasing nutrient pollution. Trophic state was therefore regarded unsuitable as a habitat type descriptor for standing water habitats.

The chosen approach is based on:

- Establishing a standardised hierarchical structure based on major abiotic habitat descriptors known to affect the biological communities (altitude, geology, size/depth).
- Using geology as a proxy for natural (undisturbed) trophic status (i.e. calcareous and siliceous), because the natural unimpacted trophic state is related to the alkalinity (geology): Habitats with low alkalinity mostly have siliceous geology and are naturally oligotrophic, while habitats with moderate or high alkalinity have calcareous or mixed geology and are naturally mesotrophic or even slightly eutrophic, depending on mean depth (Cardoso et al., 2007). The exception is marl/karst lakes, which have a very high alkalinity and calcium concentration causing adsorption and sedimentation of phosphate with calcium-carbonate particles, thereby removing phosphorus from the water column and making those lakes quite oligotrophic.
- Providing suitability for mapping of Level 3 habitats, based on map layers for the major abiotic habitat descriptors, as well as on the condition (WFD ecological status) of water bodies within each habitat.
- Adjust classification hierarchy of C3 littoral habitats – moving wetland habitats into the wetland group etc, (details provided in section 2.9)
- Allowing a better match with the EU Water Framework Directive (WFD) types used for characterization of lakes and rivers in Europe (ETC-ICM, 2015).
- Keeping some of the EUNIS 2012 rare/narrow habitats and include additional habitats that are found in particular areas in Europe.

2.4 The principles used for the revision of EUNIS inland surface water habitats

The principles of the EUNIS inland waters revision follow the approach outlined in 2.3 above):

- To broadly align the revised EUNIS inland surface water habitats at level 3 with the Broad Types developed from the abiotic type descriptors mostly used by the EU countries for their national WFD types (ETC-ICM, 2015, Lyche Solheim et al. 2019). These types are required to ensure that type specific biological reference conditions can be “reliably derived” (WFD Annex II).
- To cover other rare/narrow types of inland surface water habitats from EUNIS 2012 that are not captured by the WFD Broad types and adding further special habitats identified in the HD Annex 1.
- To add smaller water bodies (ponds and pools) that have <2ha surface area.
- To use geology (alkalinity) as a proxy for natural trophic state to describe the water bodies’ natural (pristine or unimpacted) state.
- To reflect differences in at least one of the major biological communities, not just vegetation, by including phytoplankton, benthic algae, aquatic vegetation, benthic invertebrates and fish, because such differences may appear due to abiotic habitat differences.
- To describe the biological communities both in reference or good condition in habitats with no or very little human impact, as well as those in more impacted (disturbed) rivers and lakes. This is done because human pressures (threats) change the species composition. The EUNIS inland water system will therefore describe the species composition of the L3 habitats in their reference, non-impacted state, as well as separately in their impacted state.
- Explore the importance of major geographic regions on the species composition of the biological communities.

2.5 Objectives of the report

The objective of this report is to complete the revision of the EUNIS inland surface water habitats, with special regards to the following activities:

- Describe the biological communities in the revised inland water habitats at L3, providing characteristic (diagnostic), common (constant) and dominant taxa for the major taxonomic groups: phytoplankton, benthic algae (i.e. phytobenthos), aquatic vegetation (i.e. macrophytes), benthic invertebrates (i.e. macroinvertebrates) and fish found in reference lakes and reference rivers.
- Describe the species composition of the same taxonomic groups found in impacted lakes and impacted rivers.
- Describe the differences in these communities between different regions for all L3 habitats with sufficient data.

2.6 Scope of the report

The description of biological communities in inland surface waters included in this report was limited to truly aquatic taxa within the following major communities:

- Phytoplankton, aquatic vegetation and fish in standing waters (lakes).
- Benthic algae, aquatic vegetation, benthic invertebrates and fish in rivers and streams (running waters).

These taxa are identified for water bodies in reference (or good) condition and for impacted water bodies in moderate or worse conditions.
For ponds, amphibians are also included.
The following aspects are not included:

- Recommendations for the inclusion of EUNIS revised inland waters in policy areas where not already used or listed as an information source/data stream.
- Zooplankton in lakes was not included due to limited availability of data, as well as time and resource constraints.
- Emergent vegetation like helophytes (e.g. *Phragmites* and *Typha*) and riparian vegetation, e.g. *Salix*) and wetland birds are not included. These biological groups are included in the EUNIS group Q Wetlands and T Forests and other wooded land (however, cross-links to relevant inland water habitats are provided in section 2.9).
  Floodplains and estuaries are not included, as these are described in the EUNIS group Z Habitat Complexes under ZH Floodplain complexes (however, cross-links to relevant inland water habitats are provided in section 2.9).

2.7 The revised EUNIS habitat types at level 3 for standing waters and running waters

The outcome of the long revision process described in Section 2.2, responding to the challenges given in Section 2.3 and the principles presented in Section 2.4 are a list of 23 standing water habitats and 27 running water habitats at level 3. These are given in Annex 1 below.

2.8 Application of EUNIS inland waters classification for various policies

The revised EUNIS inland waters classification can be used to link to the Water Framework Directive typology and can also be used to read-across to some of the Habitats Directive (HD), Annex I types, thereby allowing comparisons of ecological status and conservation status in related habitat types of rivers and lakes, as well as in different biogeographical regions (ETC-ICM, 2015). The WFD broad types could be linked to most of the HD Annex I types for standing waters and to some running water types, but the match was not perfect due to the different resolution of the typologies of the two directives. While the resolution of the HD Annex I types ranges from very broad types, such as Fennoscandian natural rivers (3210), to very narrow types, such as Lakes of gypsum karst (3190), the WFD broad types are more balanced but do not capture several narrow/rare types of the HD Annex I. Therefore, the EUNIS L3 revision (Annex 1 below) also includes additional habitat types, such as Permanent marl/karst lakes (P1K) that can be linked to the HD Annex I type 3140 Hard oligo-mesotrophic waters with benthic vegetation of Chara spp. and to 3190 Lakes of gypsum karst; Temporary calcareous lakes, incl. temporary marl/karst lakes and turloughs (P1E) that can be linked to the HD Annex 1 habitat type 3180 Turloughs; Many turloughs are very small (small waterbodies), thus belong to temporary ponds and pools (P1P). Lowland clay rivers (P21) may be linked to HD Annex I type 3270 Rivers with muddy banks. Some additional types from the EUNIS 2012 classification are also kept in the revision, e.g. permanent inland saline and brackish lakes (C1.5, now P1H), temporary lakes (C1.6, now P1E, F, G depending on the dominant geology or temporary ponds and pools (P1P)), temporary running waters (C2.5, now P2P), tidal rivers (C2.4, now P2Q), springs (C2.1, now P2N).

The revised EUNIS habitat types can also be applied in biodiversity monitoring of freshwater habitats (using the Essential Biodiversity Variables, EBVs, developed by the EuropaBON, H2020 project, Junker et al., 2023). Moreover, the Nature Restoration Regulation, which was agreed in the EU Council 17.06.2024, can also benefit from using the EUNIS types to see effects of restoration measures across Europe for different habitat types that can be linked to the EUNIS types. This regulation refers to the HD Annex I habitats for the freshwater realms. The links can be considered from the crosswalk done by ETC-BE between the HD Annex I and the revised EUNIS inland surface water habitat types at level 3. Finally, the EU ecosystem typology for accounting can also use the revised EUNIS habitat types to improve comparability with the WFD and HD habitat types.

2.9 Links between the revised inland surface water habitats and other water-related EUNIS L1 groups

The EUNIS system is divided into major habitat groups at Level 1, e.g. forests, grasslands, coastal, inland surface waters, with clear rules delineating one habitat group from the other.

When describing habitats within the inland surface water group, it became clear that habitats which are parts of the wider inland water ecosystem e.g. floodplains, gravel bars, riparian zones, could not be strictly described as inland surface water habitats due to the ability to harbour non-aquatic vegetation e.g. on gravel bars or in riparian areas. Moreover, helophytes occurring around many lakes can also occur in wet areas elsewhere, so are not truly aquatic.

Solution: habitats that could not be strictly defined as truly aquatic occurring only in inland surface water habitats were placed in their relevant EUNIS group (e.g. floodplains were placed in the habitat complex group) but were linked back to their relevant inland water level 3 habitat in the description of those groups.

The delineation of other water-dependent EUNIS L1 groups that are closely related to the Inland surface water are given in the list below (extracted from Table 9 in ETC/BD & ETC/ICM, 2022 and supplemented in 2025 based on further agreements with the EEA).

2.9.1 EUNIS group U: Inland habitats with little or no soil and mostly sparse vegetation

- EUNIS group U: Inland habitats with little or no soil and mostly with sparse vegetation can be found within both standing and running waters:
  - The unvegetated or sparsely vegetated gravel bars in montane and alpine regions U71 can be linked to all inland surface water types in highland areas, i.e. standing water types P1A, P1B, P1C, P1D and the running water types P2J, P2K, P2L, P2M (see Annex 1 for habitat names).
  - The unvegetated or sparsely vegetated gravel bars in the Mediterranean region U72 can be linked to all the surface running water habitats in that region (L4).
  - U1 Terrestrial underground caves, cave systems, passages and waterbodies include all natural underground standing and running water habitats. U1.1.1 Troglobiont vertebrate caves or 1.1.3 Troglobiont invertebrate caves can occur in areas with the standing water habitat P1K Permanent marl/karst lakes and P2E temporary calcareous rivers in karst regions.
  - U3 Inland cliffs, rock pavements and outcrops include the previous EUNIS 2012 C2.6 Films of water flowing over watercourse margins as well as C3.8 Inland spray and steam dependent habitats. These are hydrologically marginal and often vegetated by mosses and algae rather than aquatic communities. Therefore, they align better with U-group habitats under U3 Inland cliffs, rock pavements and outcrops. Associated waterfalls and cascades remain to be placed at lower levels in group P2 running surface waters, as well as the geysers in P2N springs.

2.9.2 EUNIS group Q: Wetlands

- Q Wetlands including Q5 helophyte beds in Q51 (tall-helophyte bed), Q52 (small-helophyte bed) and Q53 (tall-sedge bed) can occur in riparian areas of both standing and running waters but cannot be linked to any particular L3-type of inland surface waters.
- Q Wetlands including Q4 mires and fens can occur around surface water habitats:
  - The alkaline, calcareous mires and fens Q41, Q42, Q43, Q44 can be linked to the L3 inland surface water types that are calcareous and humic due to the humic substances coming from mires and fens. These are the standing water habitats P13, P17, as well as equivalent running water habitats P23, P27, P2B, P2F (see Annex 1 for habitat names).
  - The soft-water spring mire Q42 can be linked to the running water habitat P2N Springs, and potentially also to all the siliceous surface water types
  - The Arctic-alpine rich fen Q45 can be linked to the standing water highlands type P1B and the running water highlands type P2K (see Annex 1 for habitat names).
  - The Carpathian travertine fen with halophytes Q46 (salt-tolerant vegetation) can be linked to a saline subtype of P2N Springs.
  - Inland saline or brackish helophyte bed Q54 can be linked to the P1H Permanent saline and brackish lakes, and to the inland saline rivers and streams (P2T).
  - The Periodically exposed shore with stable, eutrophic sediments with pioneer or ephemeral vegetation Q61 and the equivalent type with mesotrophic sediments Q62 can be linked to the standing water temporary habitats P1E and P1F, respectively, as well as to the running water temporary habitat P2P.
  - The Periodically exposed saline shore with pioneer or ephemeral vegetation, Q63 can be linked to the inland saline standing water bodies P1G Temporary saline and brackish lakes and to the inland saline running water bodies in the Mediterranean P2T Inland saline rivers and streams.

2.9.3 EUNIS group Z: Habitat complexes

EUNIS group Z: Habitat complexes, which are under revision, can also be linked to several standing and running water habitats:

- The ZF Alpine River complex overlaps with the revised L3 highland running water habitats P2J, P2K, P2L, P2M, P2N and P2R. The Alpine River complex is broader as it includes the riparian and gravel bank habitats, while the running water habitats only include the river itself.
- The ZH Floodplains are divided into various sub-types (ZH1-7):
    - Very flat lowland floodplains (ZH1) can occur around any of the medium-large running water lowland habitats P26, P27, P28, P29 and P2S very large rivers, in areas where the river valley is wide enough to allow floodplains. P21 Lowland rivers and streams draining clay-rich catchments can also be connected to very flat lowland floodplains.
    - Flat lowland floodplains (ZH2) can occur together with any of the very small-small lowland rivers belonging to P22, P23, P24, P25, P26, P27, P28, P29, as well as P21 Lowland rivers and streams draining clay-rich catchments and P2P Temporary rivers and streams.
    - Nordic lowland floodplains (ZH7) can occur together with any of the lowland running water habitats in the Nordic region of any of the lowland running water habitats P22, P23, P24, P25, P26, P27, P28, P29, as well as P21 Lowland rivers and streams draining clay-rich catchments.
    - Mid-altitude high run-off floodplains (ZH3), mid-altitude low run-off floodplains (ZH4) and mid-altitude plateau floodplains (ZH5) can occur together with the mid-altitude running water habitats P2A, P2B, P2C, P2D, P2E, P2F, P2G, P2H, as well as to P2P Temporary rivers and streams and P2R Glacial rivers and streams.
    - Highland floodplains (ZH6) can occur together with any of the highland running water habitats P2J, P2K, P2L, P2M and the P2R Glacial rivers and streams.
- The Z7 Upper estuaries (Z72) and Z71 Lower estuaries can be linked to running water types P2Q tidal rivers (e.g. the Thames in England) and P2S very large rivers (e.g. Torne river along the border between Sweden and Finland running into the northern end of the Bothnian Bay, where there are almost no tides but still an influence of brackish water in the lowest downstream part).
- Saline coastal lagoons (Z81) and Brackish coastal lagoons (Z82) can be linked to P1G, P1H, (P1N), P2Q
- ZX Depressions (pody) of the steppe zone can be linked to P1F Temporary siliceous lakes.
- ZY Salt lake islands can be linked to P1G and P1H and saline or brackish ponds, which can be a subtype at lower level of the L3 habitat P1N Permanent ponds and pools.
- A new “Karst functional complex” (ZZ) has been defined in habitat complexes (pending confirmation by the EEA). It will include sinkholes and Polje complexes and should be crosslinked to Permanent karst lakes (P1K), Gypsum lakes (subtype of P1K), Karst springs (subtype of P2N Springs), Temporary calcareous, karst lakes and turloughs (P1E) and surface karst rivers (subtype of P2P Temporary rivers and streams).
- ZJ Complexes of volcanic geothermal fields includes geysers and hot water bodies which can be related to subtypes of P2N springs. Regionally specific fumarole and solfatara types which may also include waterbodies are listed as subtypes of U6 Recent volcanic features (U611, U621-U627).

2.9.4 EUNIS group Y: Artificial inland standing and running water systems

Artificial inland standing and running water systems remain inclusively defined within P1/P2 only if hosting seminatural aquatic communities (e.g. reservoirs, canals, fishponds). Inland artificial waterbodies with wholly constructed beds and sterile, impermeable, or heavily contaminated waters are placed in group Y5 Highly artificial man-made waters and associated structures.

- Y51 Highly artificial saline and brackish standing waters.
- Y52 Highly artificial saline and brackish running waters.
- Y53 Highly artificial non-saline standing waters.
    - Y534 Standing waterbodies of extractive industrial sites with extreme chemistry including iron-oxide (FeO) lakes. These usually originate from coal-mining and artificial man-made lakes with a very low pH and almost no higher vegetation on their banks.
- Y54 Highly artificial non-saline running waters.
- Y55 Highly artificial non-saline fountains and cascades.

Canal banks, ditch margins, and impoundment fringes belong to Y5 Highly artificial man-made waters and associated structures when constructed, otherwise also Q6 or U7, depending on vegetation cover (e.g. with helophytes or natural sediments).

3 Data and approach used to describe biological communities in inland surface waters

3.1 Main approach

A well-established system exists for defining EUNIS terrestrial habitats by using species composition in vegetation plots (Chytrý et al., 2020). For inland water habitats, an equivalent approach was used, expanding the descriptions to include not only aquatic vegetation but also other biological groups: phytoplankton and fish in lakes and benthic algae, benthic invertebrates and fish in rivers. These groups are identical to the WFD Annex V Biological Quality Elements (BQEs).
The metrics chosen to describe each of the major biological communities in most of the L3 types of inland surface waters are:

- The phi-index to identify characteristic taxa, which is equivalent to diagnostic taxa used in other major terrestrial EUNIS groups (Chytrý et al, 2002). Characteristic taxa are those that have their main occurrence in one habitat type.
- The frequency of occurrence to identify common taxa, which is equivalent to constant taxa used in other major terrestrial EUNIS groups. Common taxa are occurring in most water bodies in a habitat type.
- The relative abundance to identify dominant taxa, which is the same term used in other major terrestrial EUNIS groups. Dominant taxa are those that have high relative abundance across most water bodies in a habitat type.

The reason why we chose the terms "characteristic" and "common" instead of "diagnostic" and "constant" is simply that "characteristic" and "common" are widely used in freshwater ecology.
The datasets and details of the methodology used to identify biological communities in the revised inland waters EUNIS habitats is described in sections 0 to 3.11 below.

3.2 Challenges

Unlike the terrestrial classification system which assigns vegetation plot communities to habitat types from a well-established expert system (Chytrý et al., 2020 and 2021), EUNIS inland water habitats should be described by the full extent of biological communities depending on the habitat. This is a huge task involving extracting data representing reference conditions of water bodies for the species groups: macroinvertebrates, fish, benthic algae, phytoplankton and aquatic vegetation. Moreover, the same work was needed for impacted water bodies, due to the changes in species composition caused by various types of human impact, which decreases the habitat suitability for naturally occurring species that are found in pristine water bodies and water bodies in good condition and paves the way for other species that can tolerate and even be favoured by human impacts, such as nutrient pollution.
Specific challenges were:

- The initial screening of biological community information for the standing and running water types used the WFD intercalibration reports in pdf format as an information source (e.g. Lyche Solheim et al., 2014, Poikane et al., 2015 and equivalent results: Search results - Publications Office of the EU). This screening required a lot of manual work to create lists for the reference communities.
- There is little information in the WFD intercalibration reports on the impacted communities.
- Insufficient data in the intercalibration reports for biological communities in certain regions, e.g. the Mediterranean region temporary and saline water body types.
- Insufficient data on aquatic vegetation for the Northern region both in the intercalibration reports and in the EVA database (European Vegetation Archive (EVA) – European Vegetation Survey).

3.3 Data sources

The solution to the challenges listed above (Section 3.2) was to extract data from the WISER database (Moe et al., 2013) for all revised EUNIS L3 habitats that can be linked to one of the WFD broad types (Lyche Solheim et al., 2019). The WISER database was compiled 15 years ago during the WISER EU FP7 research project. It is quite comprehensive, including biological data at species or genus level for all the major biological communities in lakes and rivers (phytoplankton, aquatic vegetation (i.e. macrophytes) and fish in lakes, and benthic algae (i.e. phytobenthos), aquatic vegetation (i.e. macrophytes), benthic invertebrates (i.e. macroinvertebrates) and fish in rivers) in more than 2000 lake water bodies and more than 1300 river water bodies. Moreover, this database also has abiotic data for the same water bodies, including numeric data for the major type descriptors, e.g. altitude, alkalinity, colour (proxy for humic substances), surface area and mean depth, as well as phosphorus concentration for lakes and altitude and catchment area for rivers. Categorical data was also given for WFD common types (analogue to the broad types published by Lyche Solheim et al., 2019), geology, region and ecological status class.

The data owners for this database are acknowledged and listed in Annex 3.

The WISER database was used to describe the biological communities in 13 out of 23 level 3 (L3) habitat types for lakes (Table 3-1a) and 11 of the 27 L3 habitat types for rivers (Table 3-1b). The habitats described by using this database comprise most of the revised L3 habitats that match the WFD broad types (Lyche Solheim et al., 2019). Additionally, the very large lakes (P1M), which are defined as lakes with a surface area >100km^2, and very larger rivers (P2S), which are defined as rivers with a catchment area >10 000km^2, were also described with this database concerning species richness.
For the L3 habitats with insufficient or no data in the WISER database we used other data or information sources to describe the biological communities:

- Data in the National Norwegian database, Vannmiljø, was used for describing:
  - Fish in very large lakes were found in the data collected in the national Norwegian monitoring programme ØKOSTOR (e.g. Lyche Solheim et al., 2021).
  - All the biological communities in the clay rivers (P21).
  - All the biological communities in all the humic running water habitat types in the lowlands (P23, P25, P27, P29), in the mid-altitude areas (P2B, P2D, P2F, P2H) and in the highland areas (P2K, P2M), due to the lack of colour data (proxy for the level of humic substances) in the rivers part of the WISER database. This limits the representativity of the results for these types. However, humic rivers are quite common in the Nordic (boreal) region and less common in the other regions, so the data can still be fairly representative for the Nordic region.
- A literature survey was used for 8 standing water habitats: the temporary lakes (P1E, P1F, P1G), the permanent saline lakes (P1H), the glacial lakes (P1J), the permanent marl/karst lakes (P1K), the volcanic lakes (P1L) and the ponds and pools (P1N, P1P).
- A literature survey was also used for 4 running water habitats: springs (P2N), temporary rivers (P2P), tidal rivers (P2Q) and inland saline rivers and streams (P2T).

3.4 Dividing the data into reference and impacted water bodies

3.4.1 General approach for both standing and running waters

The reference lakes and reference rivers (= non-impacted) that have been assessed, correspond to high ecological status lakes and rivers having their naturally occurring flora and fauna. However, to obtain sufficient data for as many habitat types as possible, we also included lakes and rivers in good status for most of the biological communities, as these are only slightly deviating from reference conditions.

There was also a need to describe biological communities representing impacted conditions to see how the biological communities change with human pressure. This is important, as ca. 60% of rivers and lakes in the EU are degraded by pollution or hydro-morphological changes (EEA, 2018 State-of Water report and EEA, 2024 State-of-Water report). In impacted lakes and rivers, there will be different species that are more tolerant to such pressures (Lyche Solheim et al., 2013, Friberg, 2010, Jacks et al., 2021, Schneider & Lindstrøm, 2011). The impacted lakes and rivers are in a moderate, poor or bad ecological status.

3.4.2 Standing waters

Reference lakes (= lakes in high status acc. to the WFD) supplemented with some lakes in good status were extracted from the WISER database to analyse the natural (non-impacted) flora and fauna (= species decreasing with human pressures). To increase this dataset, we included some lakes with unknown status class if they had total phosphorus concentration lower than the type-specific median for reference lakes of different WFD types, as reported by Cardoso et al., 2007 (details in Annex 2 Nutrient thresholds used to selected good status lakes from WISER database).

Impacted lakes (= lakes in moderate, poor or bad ecological status acc. to the WFD) were also extracted from the WISER database to analyse the impacted flora and fauna (= species increasing with human pressures). In addition, lakes in unknown status were also included if they had moderate to high average total phosphorus concentration clearly exceeding the type-specific median for reference lakes of different WFD types, as reported by Cardoso et al., 2007.

For aquatic vegetation and fish in reference lakes and in impacted lakes, the artificial and highly modified lakes were excluded from the final dataset. Artificial and highly modified lakes were kept only for phytoplankton based on the assumption that their pelagic zones can still be relatively unaffected by the artificial littoral zones.

3.4.3 Running waters

There was no indication of status class nor nutrient concentration for rivers in the WISER database. To allow the selection of reference water bodies for rivers, the WISER data were combined with the WFD data for status class for each of the different biological quality elements for the same river water bodies, using corresponding geographical coordinates in both databases (done by the ETC-BE partner TC Vode). The strict selection of rivers in high ecological status acc. to the WFD resulted in a very limited dataset of only 28 water bodies. Therefore, it was decided to extend the dataset with rivers that have good ecological status for all biological communities, resulting in a dataset of 381 reference river water bodies.

The remaining data on river biology in the WISER database were used to describe the impacted communities.

Table 3-1 Overview of data used for analysis of biological communities for EUNIS level 3 habitat types (= EUNIS L3) for (a) standing waters (lakes) and (b) running waters (rivers) included in the WISER database, with the number of reference and impacted water bodies and samples, as well as with the number of countries where these water bodies are located. In this table, very large lakes (P1M) with >100km² surface area, permanent ponds and pools (P1N) with <2ha surface area and very large rivers (P2S) with a catchment size >10 000km² are listed separately from the other types. EUNIS level 3 habitat types were analysed if they were represented by at least 4 water bodies with samples of any particular biological community (= biological quality element, BQE). Samples included are those with at least 3 taxa (except from fish communities that have no such criterium). EUNIS level 3 habitat types that are missing in this table did not have sufficient data for the analysis of particular biological quality elements (BQEs).

a) Standing waters (lakes)

BQE	EUNIS L3 code	EUNIS L3 name	Status	# of water bodies	# of samples	# of countries	Countries (country codes **in bold** have most data)
Phytoplankton	P11	Lowland, very shallow to shallow, calcareous or mixed lakes	Reference	**10**	53	6	**DE,** EE, LT, LV, SE, UK
			Impacted	**169**	1188	13	BE, **DE**, EE, FI, HU, IE, LT, LV, **NL**, NO, PL, SE, UK
	P12	Lowland, shallow to deep, calcareous or mixed lakes	Reference	**73**	534	9	DE, DK, FI, IE, LT, LV, **NO**, PL, SE
			Impacted	**369**	3307	15	BE, **DE**, DK, EE, FI, FR, HU, IE, LT, LV, NL, NO, PL, SE, UK
	P13	Lowland, humic lakes on calcareous or mixed bedrock	Reference	**25**	144	6	**EE**, FI, FR, NO, SE, UK
			Impacted	**177**	1699	10	**EE**, **FI**, FR, HU, IE, LV, **NO**, PL, SE, **UK**
	P14	Lowland siliceous lakes	Reference	**144**	1066	6	EE, FI, IE, **NO**, SE, UK
			Impacted	**50**	450	5	EE, FI, IE, **NO**, **UK**
	P15	Lowland, humic lakes on siliceous bedrock	Reference	**61**	604	4	**FI, NO**, SE, UK
			Impacted	**101**	697	5	**FI**, IE, **NO**, **SE**, UK
	P16	Mid-altitude, shallow to deep, calcareous or mixed lakes	Reference	**23**	154	5	FI, IT, **NO**, SE, UK
			Impacted	**26**	344	5	FI, IT, **NO**, RO, UK
	P17	Mid-altitude, humic lakes on calcareous or mixed bedrock	Reference	**5**	40	2	NO, SE
			Impacted	**18**	50	5	EE, FI, **NO**, SE, UK
	P18	Mid-altitude siliceous lakes	Reference	**72**	819	4	FI, **NO**, SE, UK
			Impacted	**14**	125	3	IT, **NO**, UK
	P19	Mid-altitude, humic lakes on siliceous bedrock	Reference	**47**	444	4	FI, **NO, SE,** UK
			Impacted	**44**	159	4	FI, **NO**, SE, UK
	P1C	Highland siliceous lakes	Reference	**6**	58	2	NO, SE

BQE	EUNIS L3 code	EUNIS L3 name	Status	# of water bodies	# of samples	# of countries	Countries (country codes **in bold** have most data)
	P1H	Permanent saline and brackish lakes	Impacted	**5**	29	1	HU[a]
	P1M	Very large lakes	Reference	**35**	580	3	**FI**, IT, NO
			Impacted	**39**	1494	7	DE, **FI**, HU, IE, NL, NO, UK
	P1N	Permanent ponds and pools	Impacted	**6**	90	3	BE, EE, NO

Notes: [a] Habitat type comparable to WFD Intercalibration type L-EC2, which have a conductivity >1000µS/cm (Borics et al., 2018).

BQE	EUNIS L3 code	EUNIS L3 name	Status	# of water bodies	# of samples	# of countries	Countries (country codes **in bold** have most data)
Aquatic vegetation	P11	Lowland, very shallow to shallow, calcareous or mixed lakes	Impacted	**23**	32	7	BE, FI, IE, **LV**, NL, NO, UK
	P12	Lowland, shallow to deep, calcareous or mixed lakes	Reference	**15**	17	6	DE, FI, **LT, LV, NO**, PL
			Impacted	**69**	115	12	DE, DK, EE, FI, IE, LT, **LV**, NL, **NO**, PL, SE, UK
	P13	Lowland, humic lakes on calcareous or mixed bedrock	Reference	**12**	19	4	EE, **FI,** NO, SE
			Impacted	**62**	63	6	EE, **FI**, IE, LV, NO, SE
	P14	Lowland siliceous lakes	Reference	**28**	34	4	**FI, NO,** SE, UK
			Impacted	**9**	50	4	EE, FI, **NO**, UK
	P15	Lowland, humic lakes on siliceous bedrock	Reference	**15**	19	4	**FI,** NO, SE, UK
			Impacted	**47**	52	3	**FI**, NO, SE
	P16	Mid-altitude, calcareous or mixed lakes	Reference	**7**	14	4	FI, IT, **NO,** UK
			Impacted	**8**	10	1	NO
	P17	Mid-altitude, humic lakes on calcareous or mixed bedrock	Impacted	**8**	9	1	FI
	P18	Mid-altitude siliceous lakes	Reference	**5**	5	3	FI, NO, SE
	P19	Mid-altitude, humic lakes on siliceous bedrock	Reference	**5**	16	2	FI, SE
			Impacted	**13**	14	3	**FI**, NO, SE
	P1M	Very large lakes	Reference	**10**	18	2	**FI**, NO
			Impacted	**5**	5	1	FI

BQE	EUNIS L3 code	EUNIS L3 name	Status	# of water bodies	# of samples	# of countries	Countries (country codes **in bold** have most data)
Fish	P11	Lowland, very shallow to shallow, calcareous or mixed lakes	Impacted	**13**	121	5	DE, FI, IE, LT, SE
	P12	Lowland, shallow to deep, calcareous or mixed lakes	Reference	**10**	141	5	**DE**, FI, IE, **LT**, LV
			Impacted	**54**	1457	8	**DE**, EE, FI, IE, LT, **LV**, SE, UK
	P13	Lowland, humic lakes on calcareous or mixed bedrock	Reference	**6**	296	3	EE, FI, SE
			Impacted	**51**	649	6	EE, **FI**, IE, LV, NO, SE
	P14	Lowland siliceous lakes	Reference	**17**	762	4	**FI**, **NO**, **SE**, UK
			Impacted	**5**	46	3	FI, IE, UK
	P15	Lowland, humic lakes on siliceous bedrock	Reference	**28**	1748	3	**FI,** NO, **SE**
			Impacted	**40**	914	2	FI, SE
	P17	Mid-altitude, humic lakes on calcareous or mixed bedrock	Impacted	**5**	20	2	**FI**, SE
	P18	Mid-altitude siliceous lakes	Reference	**23**	2244	2	NO, **SE**
	P19	Mid-altitude, humic lakes on siliceous bedrock	Reference	**22**	2918	2	NO, **SE**
			Impacted	**11**	411	2	FI, **SE**
	P1C	Highland siliceous lakes	Reference	**7**	208	2	**NO**, SE
	P1M[a]	Very large lakes	Reference	**5**	see[a]	1	NO
			Impacted	**11**	196	1	IE

Note: [a] There were no data in the WISER database for fish in very large lakes (P1M) in reference conditions. Data shown here are based on a series of reports from the Norwegian national monitoring programme for large lakes (ØKOSTOR) from 2017-2020, following WFD – Annex V requirements (e.g. Lyche Solheim et al., 2021). The fish data is collected from trawling in the pelagic zone of each lake and using standardised gill netting with various mesh sizes in the littoral zone.

b) Running waters (rivers)

BQE	EUNIS L3 code	EUNIS L3 name	Status	# of water bodies	# of samples	# of countries	Countries (country codes **in bold** have most data)
Benthic algae	P21[a]	Lowland rivers and streams draining clay rich catchments	Reference	**23**	40	1	NO
			Impacted	**204**	557	1	NO
	P22	Lowland, very small to small, calcareous or mixed rivers and streams	Reference	**14**	14	2	DE, **FR**
			Impacted	**75**	105	4	AT, **DE**, FR, NL
	P24	Lowland, very small to small, siliceous rivers and streams	Impacted	**12**	19	1	DE
	P26	Lowland, medium to large, calcareous or mixed rivers	Reference	**22**	22	2	AT, **FR**
			Impacted	**123**	183	5	AT, **DE**, FR, NL, SE
	P28	Lowland, medium to large, siliceous rivers	Impacted	**12**	16	1	DE
	P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams	Reference	**29**	35	3	**AT**, DE, **FR**
			Impacted	**76**	149	3	**AT**, **DE**, FR
	P2C	Mid-altitude, very small to small, siliceous rivers and streams	Reference	**16**	16	2	**DE**, FR
			Impacted	**57**	79	1	DE
	P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Reference	**25**	34	2	AT, FR
			Impacted	**80**	128	3	AT, DE. FR
	P2G	Mid-altitude, medium to large, siliceous rivers	Impacted	**33**	51	2	**DE**, AT
	P2J	Highland, calcareous or mixed rivers and streams	Reference	**11**	11	2	AT, **FR**
	P2R	Glacial rivers and streams	Reference	**5**	5	2	AT, FR
	P2S	Very large rivers	Impacted	**13**	18	3	**DE**, FR, NL

Note: [a] There were no data in the WISER database for clay rivers (P21). The data were obtained from the Norwegian national database from 2008-2023.

BQE	EUNIS L3 code	EUNIS L3 name	Status	# of water bodies	# of samples	# of countries	**Countries** (country codes **in bold** have most data)
Aquatic vegetation	P22	Lowland, very small to small, calcareous or mixed rivers and streams	Reference	**26**	26	1	FR
			Impacted	**119**	188	6	AT, **DE**, DK, **FR**, **NL**, PL
	P24	Lowland, very small to small, siliceous rivers and streams	Impacted	**9**	9	2	**DE**, PL
	P26	Lowland, medium to large, calcareous or mixed rivers and streams	Reference	**35**	36	6	AT, DE, DK, **FR**, PL, SE
			Impacted	**152**	218	7	AT, **DE**, DK, **FR**, NL, PL, SE
	P28	Lowland, medium to large, siliceous rivers	Reference	**4**	4	1	PL
			Impacted	**15**	19	3	**DE**, FR, PL
	P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams	Reference	**42**	46	4	**AT**, CZ, DE, **FR**
			Impacted	**68**	97	4	**AT**, CZ, **DE**, **FR**
	P2C	Mid-altitude, very small to small, siliceous rivers and streams	Reference	**11**	12	2	DE, FR
			Impacted	**25**	26	1	DE
	P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Reference	**34**	43	3	**AT**, DE, **FR**
			Impacted	**97**	134	3	AT, DE, FR
	P2G	Mid-altitude, medium to large, siliceous rivers	Reference	**8**	8	2	**DE**, SE
			Impacted	**18**	21	2	AT, **DE**
	P2J	Highland, calcareous or mixed rivers and streams	Reference	**15**	15	2	AT, **FR**
			Impacted	**5**	5	1	FR
	P2R	Glacial rivers and streams	Reference	**8**	8	2	AT, FR
	P2S	Very large rivers	Impacted	**9**	24	3	**DE**, FR, **NL**

BQE	EUNIS L3 code	EUNIS L3 name	Status	# of water bodies	# of samples	# of countries	Countries (country codes **in bold** have most data)
Benthic invertebrates	P21[a]	Lowland rivers and streams draining clay rich catchments	Reference	**29**	66	1	NO
			Impacted	**224**	903	1	NO
	P22	Lowland, very small to small, calcareous or mixed rivers and streams	Reference	**27**	46	2	DE, **FR**
			Impacted	**209**	491	5	AT, **DE**, DK, FR, NL
	P24	Lowland, very small to small, siliceous rivers and streams	Impacted	**32**	62	3	**DE**, FR, SE
	P26	Lowland, medium to large, calcareous or mixed rivers	Reference	**35**	55	5	AT, DE, DK, **FR,** SE
			Impacted	**240**	555	6	AT, **DE**, DK, FR, NL, SE
	P28	Lowland, medium to large, siliceous rivers	Impacted	**45**	84	4	**DE**, FR, NL, SE
	P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams	Reference	**74**	115	5	**AT**, CZ, DE, **FR**, **SK**
			Impacted	**135**	298	5	AT, CZ, **DE**, FR, SK
	P2C	Mid-altitude, very small to small, siliceous rivers and streams	Reference	**53**	77	4	AT, **DE**, FR, SE
			Impacted	**151**	238	3	AT, **DE**, SE
	P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Reference	**47**	94	3	**AT**, DE, **FR**
			Impacted	**166**	382	4	**AT, DE**, FR, SE
	P2G	Mid-altitude, medium to large, siliceous rivers	Reference	**20**	23	2	**DE**, SE
			Impacted	**83**	137	3	AT, **DE**, SE
	P2J	Highland, calcareous or mixed rivers and streams	Reference	**23**	40	3	AT, DE, **FR**
			Impacted	**7**	13	2	AT, **FR**
	P2L	Highland siliceous rivers and streams	Reference	**4**	7	1	FR
	P2R	Glacial rivers and streams	Reference	**12**	27	2	AT, FR
			Impacted	**13**	15	2	**AT**, FR
	P2S	Very large rivers	Impacted	**36**	91	5	AT, **DE**, FR, NL, SE

Note: [a] There were no data in the WISER database for clay rivers (P21). The data were obtained from the Norwegian national database from 2008-2023.

BQE	EUNIS L3 code	EUNIS L3 name	Status	# of water bodies	# of samples	# of countries	Countries (country codes **in bold** have most data)
Fish	P21[a]	Lowland rivers and streams draining clay rich catchments	Reference	**14**	31	1	NO
			Impacted	**34**	172	1	NO
	P22	Lowland, very small to small, calcareous or mixed rivers and streams	Reference	**27**	27	2	DE, **FR**
			Impacted	**88**	127	6	AT, **DE**, DK, **FR**, NL, PL
	P24	Lowland, very small to small, siliceous rivers and streams	Impacted	**48**	60	4	**DE**, FR, PL, SE
	P26	Lowland, medium to large, calcareous or mixed rivers	Reference	**37**	45	6	AT, DE, DK, **FR**, PL, SE
			Impacted	**201**	309	7	AT, **DE**, DK, FR, NL, PL, SE
	P28	Lowland, medium to large, siliceous rivers	Reference	**4**	4	1	PL
			Impacted	**115**	143	4	**DE**, FR, PL, SE
	P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams	Reference	**71**	122	5	**AT**, CZ, DE, **FR**, **SK**
			Impacted	**106**	159	5	**AT**, CZ, **DE**, **FR**, SK
	P2C	Mid-altitude, very small to small, siliceous rivers and streams	Reference	**33**	42	4	AT, **DE**, FR, SE
			Impacted	**139**	160	3	AT, **DE**, SE
	P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Reference	**43**	95	3	**AT**, DE, **FR**
			Impacted	**146**	416	4	**AT,** DE, FR, SE
	P2G	Mid-altitude, medium to large, siliceous rivers	Reference	**14**	18	2	**DE**, SE
			Impacted	**82**	99	3	AT, **DE**, SE
	P2J	Highland, calcareous or mixed rivers and streams	Reference	**22**	26	2	AT, **FR**
			Impacted	**8**	12	2	AT, **FR**
	P2L	Highland siliceous rivers and streams	Reference	**4**	4	1	FR
	P2R	Glacial rivers and streams	Reference	**10**	12	2	AT, **FR**
			Impacted	**12**	30	2	**AT**, FR
	P2S	Very large rivers	Impacted	**26**	46	5	AT, **DE**, FR, NL, SE

Note: [a] There were no data in the WISER database for clay rivers (P21). The data were obtained from the Norwegian national database from 2008-2023.

The biological communities (= biological quality elements, BQE) included in this report, the parameters used and the total number of water bodies for standing water habitats and running water habitats are given in Table 3-2.

Table 3-2 Overview of biological communities, parameters used and number of reference and impacted water bodies across all L3 habitats with at least 4 water bodies per habitat[1].

EUNIS level 2 name (WFD water category in WISER)	Biological community	Data type and parameter used for analysis	Number of water bodies across all L3 habitats	
			Reference	Impacted
Standing waters (lakes)	Phytoplankton	Abundance for each species, biovolume in mm^3/l	501	1018
	Aquatic vegetation	Presence/absence	97	244
	Fish	Abundance for each species, total numbers of individuals	113	190
Running waters (rivers)	Benthic algae	Presence/absence	122	481
	Aquatic vegetation	Presence/absence	183	517
	Benthic invertebrates	Presence/absence	295	1117
	Fish	Abundance for each species, total numbers of individuals	265	971

[1] Only data from the WISER database are presented, i.e. data for fish in very large lakes (P1M) in reference conditions and all clay rivers (P21), are excluded from the table, as these are based on other data sources.

3.5 Geographical coverage

Further metadata for the revised level 3 habitat types are given in Table 3-1a and Table 3-1b for each L3 habitat with sufficient data for analysis. The dataset for siliceous and humic lakes, as well as for mid-altitude and highland lakes is dominated by Northern European countries (NO, SE, FI), where most of the pristine lakes in Europe are located. The results are therefore mainly representative for that region. This applies to all three biological communities with sufficient data for analysis (phytoplankton, aquatic vegetation and fish). In contrast, the calcareous and impacted lakes data are dominated by Central-European and Southern regions.

For phytoplankton in Mediterranean reference lakes, the results are only representative for Spain, as 18 out of 20 lakes (reservoirs) with sufficient data are Spanish. There are no data for other biological communities from the Mediterranean countries. There are also no data in the WISER database for natural lakes in the Mediterranean region.

The dataset for both reference rivers and impacted rivers is dominated by several Central/Alpine European countries (AT, FR and DE), but there is also a relatively small number of Swedish reference rivers. The results are therefore mainly representative for the Central/Alpine European region. This applies to all the four investigated biological communities (benthic algae, benthic invertebrates, aquatic vegetation and fish). Note that benthic algae data are from AT
and FR only, but the numbers of water bodies (43 and 72, respectively) seem sufficient for further analysis and generalization.

The Mediterranean reference rivers and impacted rivers in the presented dataset come only from southern France, and thus they are only representative for that country. This applies to all four investigated biological communities (benthic algae, benthic invertebrates, aquatic vegetation and fish).

3.6 Data selection criteria

To decrease uncertainty in the results we applied the following criteria for including habitats, water bodies and species:

- EUNIS level 3 habitat types with at least 10 water bodies for reference lakes or rivers and for impacted lakes or rivers. This is in line with the recommendations given by Schaminée et al., 2019 for the number of vegetation plots required per habitat type.
- In some cases, we deviated from this rule to allow a rough description to be made for habitats with 4-9 water bodies. This was done to close some of the gaps presented in section 3.11. Results based on so few water bodies are more uncertain than habitats with at least 10 water bodies. Table 3-3 shows which habitats and biological communities have so few water bodies.
- Samples with at least 3 species for each of the biological communities were included, except for fish, which can have fewer species in many water bodies due to biogeographical distribution patterns.

This dataset was used to calculate species richness in each EUNIS level 3 habitat type.
Additional criteria were applied to identify the characteristic, common and dominant taxa for each habitat with sufficient data in the WISER database. These are given in the section **Error! Reference source not found.** below.

3.7 Multivariate analysis of biological communities

To gain an initial understanding of the similarities among biological communities, including phytoplankton, benthic algae, benthic invertebrates, aquatic vegetation and fish, across a range of EUNIS habitat types, we conducted hierarchical cluster analysis and non-metric multidimensional scaling (NMDS) ordination. The hierarchical cluster analysis utilized the 'hclust' function in R, employing the 'vegdist' distance model ("bray") from the 'vegan' package (Oksanen et al., 2022). NMDS was performed using the 'vegan' package and 'metaMDS' function, with the "bray" distance model. This analysis aimed to assess the distinctiveness of EUNIS level 3 habitat types in terms of their biological communities. If certain habitat types exhibited notably similar communities, consideration was given to merging them, provided this similarity was consistent across all groups of organisms.

3.8 Calculation of species richness per habitat type

This analysis included all species, i.e. also those that were later excluded from the analysis due to low mean frequency of occurrence and low mean relative abundance (see section 3.6). This is important to allow rare taxa (red list taxa) to be included.

For each group of organisms and each EUNIS level 3 habitat type, we calculated the mean species richness by counting the number of species in each reference water body and averaging across all the water bodies belonging to the same habitat type. We also calculated the standard deviation of the species richness to get an impression of the variation between the water bodies in each habitat type.

3.9 Identification of characteristics (diagnostic), common (constant) and dominant taxa

These taxa are not suitable for the identification of rare species. The dataset is biased in terms of geographical coverage as described in section 3.5 and in terms of less data for aquatic vegetation and fish than for phytoplankton and benthic invertebrates. The results should therefore be interpreted with these limitations and possible biases in mind.

For the rare/narrow habitats without data in the WISER database, the reviewed literature did not allow precise identification of characteristic, common and dominant taxa. The taxa described in the literature for those habitat types are defined as “typical taxa” or “indicator taxa” in some papers and as “common taxa” or “dominant taxa” in others. Most of the papers did not specify “characteristic taxa”. The statistics used in those papers for identification of taxa are not well described, so we cannot directly compare them to the methods described below for habitats with sufficient data in the WISER database.

3.9.1 Characteristics (diagnostic) species

Characteristic (diagnostic) species were identified using the phi-index (Chytrý et al., 2002, Tichý & Chytrý, 2006). In short, the phi index quantifies the association between a species and a group of habitat types, assessing the strength of these relationships. The phi-index is calculated using indicator species analysis (ISA). The index assists in identifying species strongly associated with specific EUNIS level 3 habitat types. High positive phi-index indicates a positive association to a particular habitat type. The phi index was calculated using the R package 'indicspecies' (De Cáceres et al., 2009), its 'multipatt' function and 999 permutations. This Phi value analysis determines a list of species associated with one or a group of EUNIS level 3 habitat types. This report considers only distinct habitat level 3 associations among different species, i.e. not including species associated with several level 3 habitats. These associations are based on significant phi-values at p≤0.001 (***) and p≤0.01 (**). These significance levels can be seen as species having a narrow niche in one particular habitat (***) or a slightly wider niche mainly found in one habitat but can also be found occasionally in a few other habitats (**).

3.9.2 Common (constant) species

Common (constant) species in a habitat were identified using frequency of occurrence. For phytoplankton in reference lakes and benthic invertebrates in reference rivers, we applied a threshold of ≥0.70 (70%). For aquatic vegetation in reference rivers, we applied a threshold for frequency of occurrence of ≥0.50 (50%) of all the water bodies in the habitat. This allowed inclusion of several typical species, e.g. *Lobelia dortmanna, Nuphar lutea, Potamogeton natans*. For benthic algae in reference rivers and for fish in reference lakes and reference rivers, we also applied a threshold of 50%. This differentiation of thresholds was included due to the much higher number of phytoplankton species and benthic invertebrate species than the other biological groups. In case of all biological communities in Mediterranean reservoirs and rivers, the frequency of occurrence was set to ≥ 0.30 (30%) due to a low number of species.

3.9.3 Dominant species

Dominant species in both reference lakes and rivers were identified as species with a mean relative abundance ≥ 10% of the total biomass for phytoplankton in lakes or of the total number of individuals for fish in the water bodies in each habitat. This % refers to the abundance of a single species or taxon divided by the total abundance across all taxa in the habitat, measured as biomass for the phytoplankton community or as the total number of individuals in the fish community in each water body and then calculating the mean relative abundance across all the water bodies within a habitat type.
We first tried a higher threshold (≥30%) but found that no species had such a high percentage of the total biomass in any of the EUNIS level 3 habitat types. After trying with ≥ 20% and ≥15%, we ended up using ≥ 10% to allow for the identification of dominant taxa in as many habitats as possible.

Dominance data for fish are uncertain due to different methods used by different countries (raw data indicate different numbers of depth strata and sites per lake, disaggregated or aggregated across sites). For aquatic vegetation, benthic algae and benthic invertebrates, we had no abundance data, so we could not identify the dominant taxa.

3.10 Approach used for very large lakes and very large rivers

For the biological description of EUNIS types (i.e., the analysis of characteristic, common and dominant taxa), the P1M Very large lakes (surface area >50km^2) were merged with the other EUNIS level 3 habitat types, because their species composition is likely to differ according to altitude, geology and size/depth. However, for the analysis of species richness, the very large lakes were treated as a separate EUNIS type, as they are expected to have higher species richness than smaller lakes (Stomp et al., 2011). In contrast, for the very large rivers (P2S), species richness was only analysed for impacted rivers, and there were not sufficient reference rivers available (minimum 4). This is due to the dominance of Central-European rivers in the WISER database, and almost all the very large rivers impacted by multiple human pressures.

3.11 Data gaps and approaches used to cover them

The minimum number of observation units (vegetation plots or water bodies) per habitat type recommended for assessments of biological communities is 10 units per habitat (Schaminée et al., 2019). However, we included also habitats with 4-9 water bodies for aquatic vegetation and fish to allow some information on those communities to be reported. However, those results are therefore highly uncertain and should be validated with further literature studies.

Some EUNIS level 3 habitats have data from less than 4 water bodies in the WISER database, thus they were excluded from the statistical analysis of biological communities (characteristic, common and dominant taxa) (Table 3-3). For those habitats, the biological communities were described by means of a literature review (Chapter 6).

For fish, we still accepted certain habitats with fewer taxa, as the number of fish species can be <4 due to biogeographic distribution limits (e.g. in Norway, there are several habitats with only one or two species in Western Norway and in highland areas).

Table 3-3. EUNIS level 3 habitat types for reference and/or impacted (a) standing and (b) running water bodies with no or insufficient data (<4 water bodies per L3 habitat type) in the WISER database.

a) Standing waters

EUNIS L3 code	EUNIS L3 name
P1A	Highland, calcareous or mixed lakes
P1B	Highland, humic lakes on calcareous or mixed bedrock
P1D	Highland, humic lakes on siliceous bedrock
P1E	Temporary calcareous lakes, incl. turloughs
P1F	Temporary siliceous lakes
P1G	Temporary saline and brackish lakes
P1J	Glacier fed lakes
P1K	Permanent marl/karst lakes
P1L	Volcanic lakes
P1N reference [a]	Permanent ponds and pools
P1P	Temporary ponds and pools

Note: [a] The size limit for ponds/pools versus lakes was reduced from 50 ha to 2ha, based on stakeholder consultation. This means that very small lakes between 2ha and 50ha are included in the main L3 types. There were sufficient data for analysis of impacted ponds/pools of size <2ha, but not for the reference (unimpacted) ones.

b) Running waters

EUNIS L3 code	EUNIS L3 name
P21	Lowland rivers and streams draining clay rich catchments
P23	Lowland, very small to small, humic rivers and streams on calcareous or mixed bedrock
P25	Lowland, very small to small, humic rivers and streams on siliceous bedrock
P27	Lowland, medium to large, humic rivers on calcareous or mixed bedrock
P29	Lowland, medium to large, humic rivers on siliceous bedrock
P2B	Mid-altitude, very small to small, humic rivers and streams on calcareous or mixed bedrock
P2D	Mid-altitude, very small to small, humic rivers and streams on siliceous bedrock
P2F	Mid-altitude, medium to large, humic rivers on calcareous or mixed bedrock
P2H	Mid-altitude, medium to large, humic rivers on siliceous bedrock
P2K	Highland, humic rivers and streams on calcareous or mixed bedrock
P2M	Highland humic rivers and streams on siliceous bedrock
P2N	Springs
P2P	Temporary rivers and streams
P2Q	Tidal rivers and streams
P2T	Inland saline rivers and streams

For humic rivers, we could not use the WISER database, as there is no information on the level of humic substances in the rivers part of the WISER database. Therefore, a Norwegian dataset was used and combined with a literature study to describe the biology in humic rivers.

For habitats with no or very little data in WISER, for example P1N Permanent ponds and pools (surface area <2ha), saline, temporary, volcanic, karstic etc., a literature study to identify the characteristic, common and dominant taxa have been done. The literature search was done by using Google scholar and supported by the AI tool Co-Pilot, which is NIVA's recommended AI tool. When using Co-Pilot, the outputs are always supported by references to publications, which were thoroughly checked manually. If the publications were not reliable or relevant for the search term (e.g. "aquatic vegetation in temporary saline and brackish lakes in Europe"), Google scholar was used instead, and the most relevant papers were selected as the source of information on common species. For some of these habitats, e.g. glacial lakes, the literature was particularly scarce.

Clay rivers (P21) are defined as rivers and streams with suspended solids >10mg/l (annual median value) were described using data from the Norwegian national database (Vannmiljø) as these could not be identified by using the WISER database. Data on benthic algae, benthic invertebrates and fish in Norwegian clay rivers were available. We used only data from the years after 2007. The results are included in the literature review (section 0). No data for aquatic vegetation were available. Due to the highly turbid waters and quite unstable clay sediments in such rivers, that habitat type can be considered marginally suitable for aquatic vegetation.

3.12 Regional analysis of differences in biological communities between the Nordic, Central and Southern (Mediterranean) Europe.

A separate analysis was done to assess regional differences in biological communities within each L3 habitat with sufficient datasets in the WISER database. Regional differences are likely to occur due to climatic differences between these three regions. In the recent papers by Jupke et al. (2022 & 2023), regional differences were found to explain more of the variance in reference communities than the broad types which have been used as a basis for the L3 habitats revision. Regions were also considered as important for biological communities by several experts attending the expert workshop in 2021, for species composition of fish. Therefore, this additional analysis of regional differences was included. Moreover, regions are also used in most of the other major EUNIS groups in the terrestrial and marine realms.

For lakes, the regions Nordic, Central or Mediterranean were indicated in the WISER database (e.g. Med-GIG) For rivers, the regions are indicated in the WFD-based dataset on ecological status under the field “biogeo_name” (provided by ETC-BE partner TC Vode).
However, the data from the reference lakes and rivers and from impacted lakes and rivers extracted from the WISER dataset was not evenly distributed between the regions, because many countries were greatly under-represented. Therefore, the results are uncertain especially for the Mediterranean region but can still indicate major differences from the other two regions. Table 7-1 in Chapter 7 shows the habitats that had sufficient data to allow regional splitting.

3.13 Level 3 descriptions of the effect of flow and biology in rivers

River flow was the major type of descriptor for running waters in EUNIS 2012: C2.2 Permanent, non-tidal fast, turbulent watercourses and C2.3 Permanent, non-tidal, smooth-flowing watercourses. River flow also affects the substrate and the oxygen conditions in the substrate, with fast-flowing rivers having a substrate with stones, gravel and sand, while smooth-flowing rivers have a substrate with silt, clay or organic detritus.

Flow was therefore agreed as a typology factor at level 4 in the workshop with external experts in 2021. Due to the high variability of flow and substrate in space and time along many rivers (even within single water bodies delineated under the WFD), flow is less suitable to be used at Level 3. The effect of flow (riffles, runs, pools) is however important for the biological communities. These effects have therefore been briefly described within each of the L3 revised habitat types in the EUNIS classification file (xlsx-file incl. cross-links to other policies) based on expert knowledge. No further analysis was possible, as there was no data on flow in the WISER database to allow splitting the river data by flow. This is unfortunate, as flow is known to affect the species composition and is therefore used by many countries in their national WFD typologies (Lyche Solheim et al., 2019).

4 Results for biology in standing waters

This chapter provides the following results:

- 4.1: Similarity of species composition in different L3 habitats, including separate analysis for reference communities and impacted communities.
- 4.2: Species richness per habitat type for phytoplankton, aquatic vegetation and fish.
- 4.3: Characteristic, common and dominant species per L3 habitat type for habitats with sufficient data (acc. To Table 3-1a). Dominant species could only be given for phytoplankton and fish, because abundance data were missing for the other major biological groups (Table 3-2).

4.1 Similarity analysis of species composition in different L3 habitats

The results of the multivariate analysis show quite good separation of the EUNIS level 3 habitat types with sufficient data to enable such analysis (

Figure 4-1,
Figure 4-2,

Figure 4-3 for phytoplankton, aquatic vegetation and fish, respectively).

4.1.1 Phytoplankton

For phytoplankton, the results (

Figure 4-1a) show quite a clear distinction between siliceous (P14, 15, 18, 19) versus calcareous (P11, 12, 13, 16, 17) lakes, as well as between clear versus humic lakes: P12 vs P13; P16 vs P17; and the clear P14 & P18 lakes vs. the humic P15 & P19 lakes, see also

Figure 4-1b showing separate clusters for the clear and the humic siliceous lakes. Altitude also has an effect, especially for the highland siliceous lakes (P1C), as well as for mid-altitude calcareous lakes, where the lakes (P16 & P17) are quite different from lowland lakes (P11, P12 and P13). However, for the siliceous lakes there is little response to altitude in lowland versus mid-altitude, as the highest similarity is found between lowland and mid-altitude siliceous (clear) lakes, as well as between lowland and mid-altitude siliceous humic lakes (

Figure 4-1). This may indicate that the low alkalinity in those lakes is more important than temperature for the phytoplankton community composition.

For phytoplankton in impacted lakes, the results (

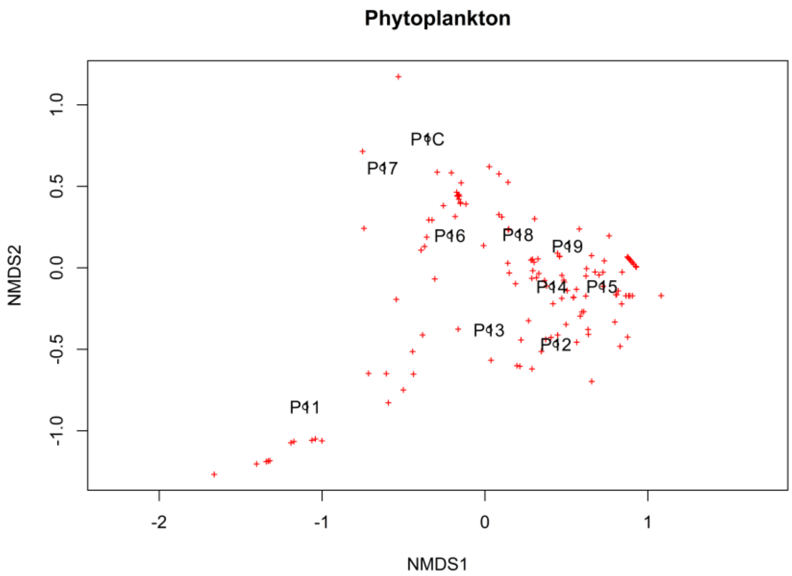
Figure 4-1b,

Figure 4-1d) show some differences from reference lakes: The three types of lowland calcareous lakes get more similar regardless of their depth and thermal stratification, as the very shallow unstratified lakes (P11) appear closer to the shallow, stratified lakes (P12 & P13) than we see for the reference lakes in

Figure 4-1a. This indicates that human impact (mainly nutrient pollution causing eutrophication) favours the same nutrient-requiring species regardless of depth and stratification patterns.

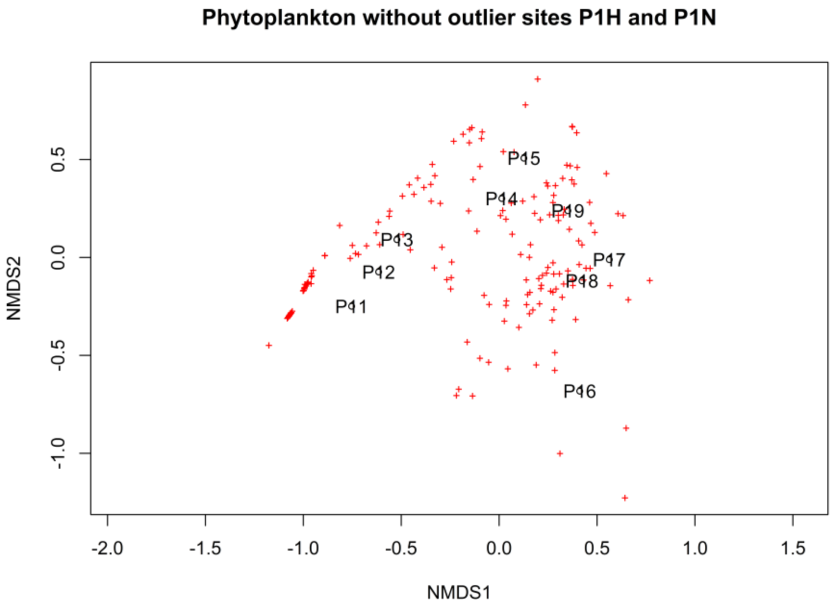
Figure 4-1 Multivariate analysis of differences between selected EUNIS level 3 habitat types for reference and impacted lakes based on their phytoplankton communities. (a, b) NMDS plots, (c, d) cluster analysis.

a) NMDS plot of reference lakes

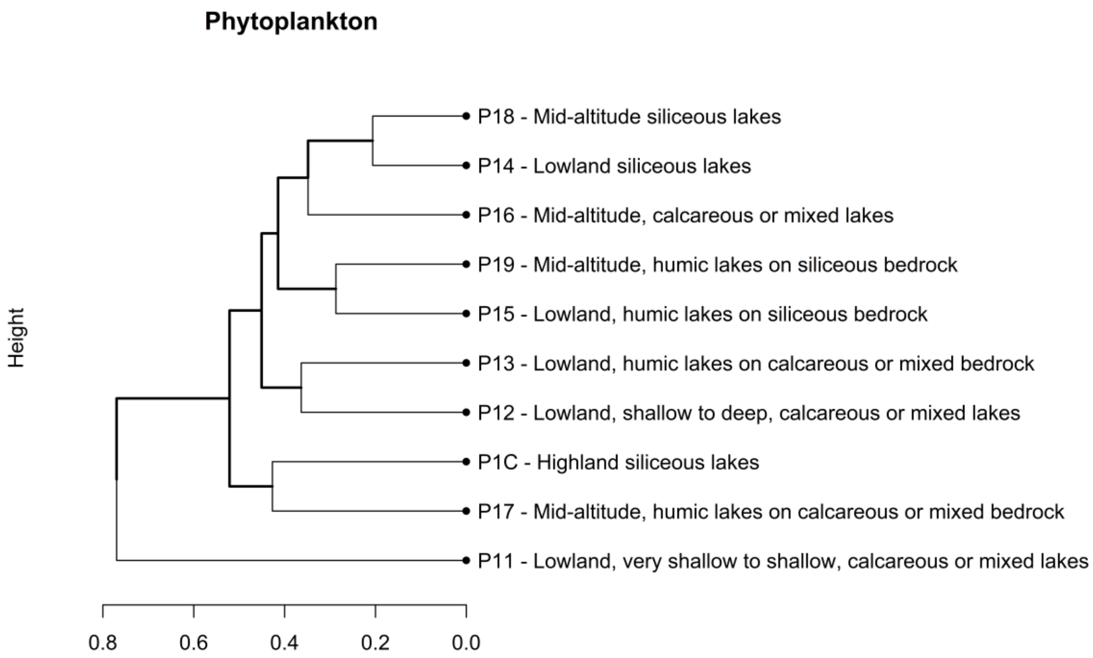


b) NMDS plot of impacted lakes: P1H and P1N were removed from the NMDS plot to better capture the differences in phytoplankton communities for the other habitats. Those habitats are included in the cluster analysis (

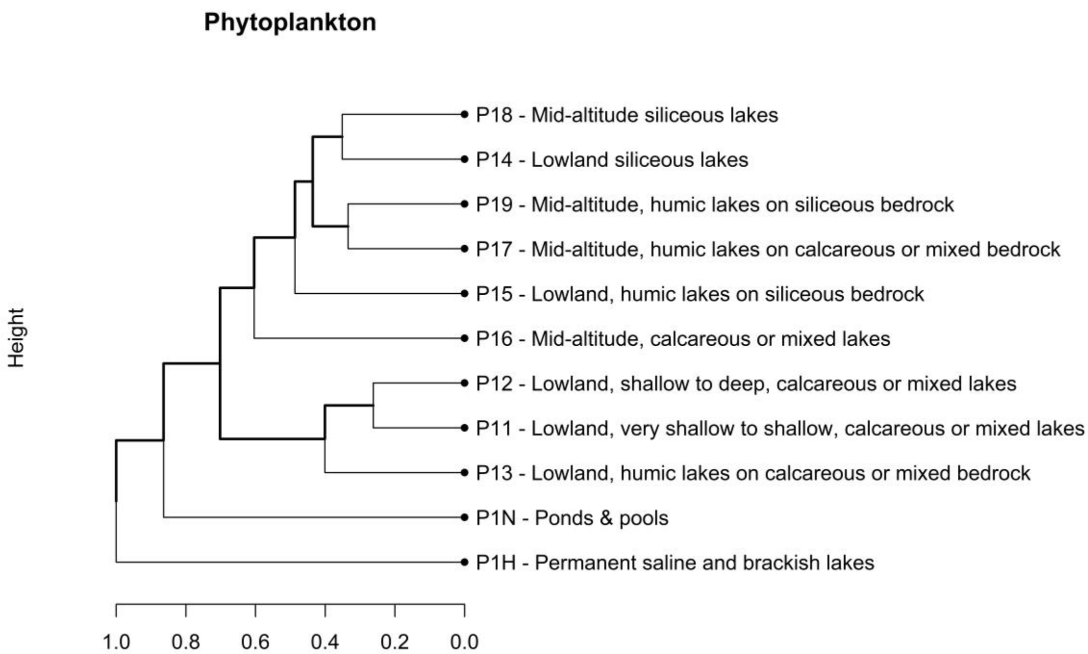
c) Figure 4-1d)


Phytoplankton without outlier sites P1H and P1N
NMDS1
NMDS2
P1
P2
P3
P4
P5
P6
P7
P8
P9
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
0.5
0.0
-0.5
-1.0

d) Cluster analysis of reference lakes



e) Cluster analysis of impacted lakes



Another difference between reference lakes and impacted lakes phytoplankton communities is seen for P17 (Mid-altitude, humic, calcareous lakes), which is quite far away from P19 (Mid-altitude, humic, siliceous lakes) in reference lakes but becomes more similar in impacted lakes. A possible explanation for this can be related to light-limitation in humic lakes, which becomes even worse in eutrophied lakes due to nutrient enrichment increasing the phytoplankton biomass. Thereby, the shade-adapted species can be favoured, regardless of alkalinity.

Noteworthy are also the major differences between the permanent saline and brackish lakes (P1H) and the ponds and pools (P1N) from the other types in impacted lakes seen in the cluster diagrams (

Figure 4-1d). Unfortunately, there are no reference lakes for those types in the WISER database.

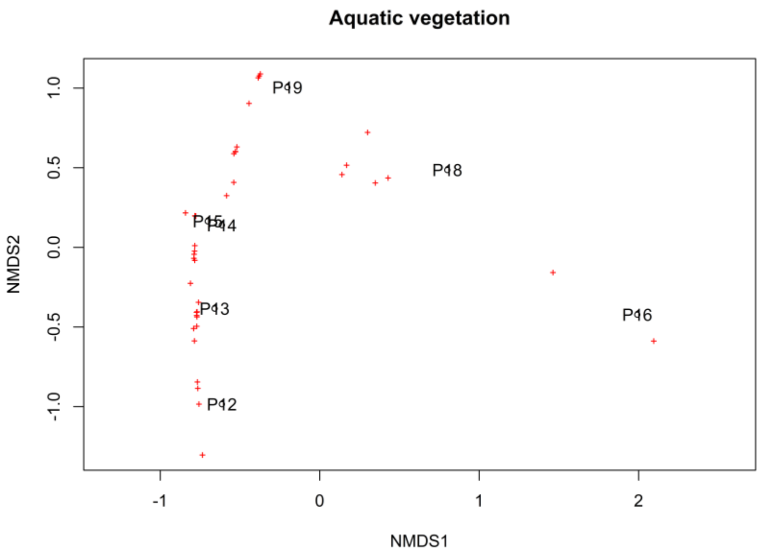
4.1.2 Aquatic vegetation

The results of the multivariate analysis for aquatic vegetation in reference lakes show quite good separation of the EUNIS habitats with sufficient data to enable such analysis (
Figure 4-2). The results show quite clear distinction between lowland siliceous lakes (P14 & P15), which are very similar, compared to the lowland calcareous lakes (P12 & P13). In contrast, for the lowland siliceous lakes P14 (clear) and P15 (humic), the aquatic vegetation is very similar. Another conspicuous result is that the mid-altitude types (P16, P18, P19) are quite different from the lowland types, indicating that temperature and length of growing season is important for aquatic vegetation in reference lakes. Unfortunately, there are no data available for highland lakes.

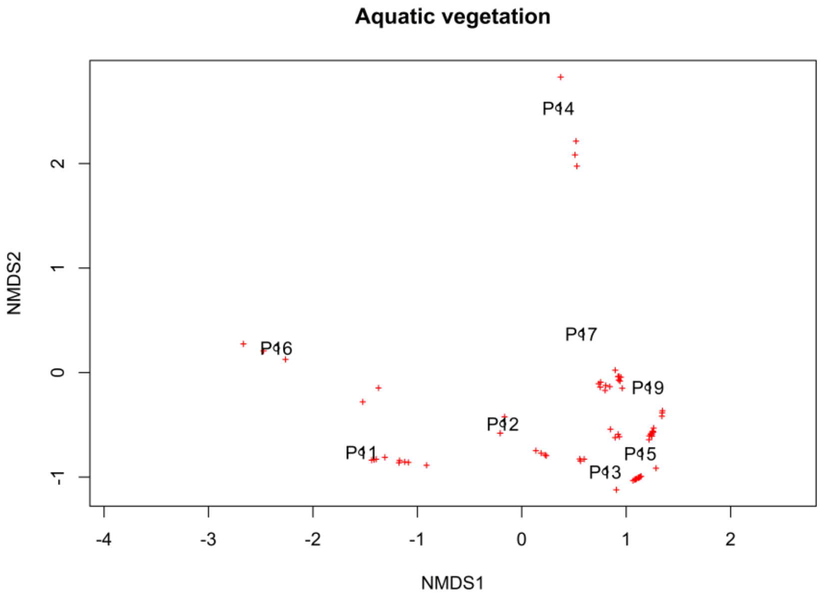
For impacted lakes, the humic lake types (P13, P15, P17 and P19) are quite similar, regardless of altitude and alkalinity. This indicates that the light-climate, which is quite poor due to the humic substances and gets even worse with eutrophication, is the most important factor influencing the species composition of aquatic vegetation in lakes impacted by nutrient pollution. For non-humic lake types, the alkalinity is still very important, as the P14 (lowland siliceous lakes) are very different from the P11, P12 and P16 types, which are all calcareous, clearwater lakes.

Figure 4-2 Multivariate analysis of differences between selected EUNIS level 3 habitat types for reference and impacted lakes based on their aquatic vegetation (macrophytes) communities. (a, b) NMDS plots, (c, d) cluster analysis.

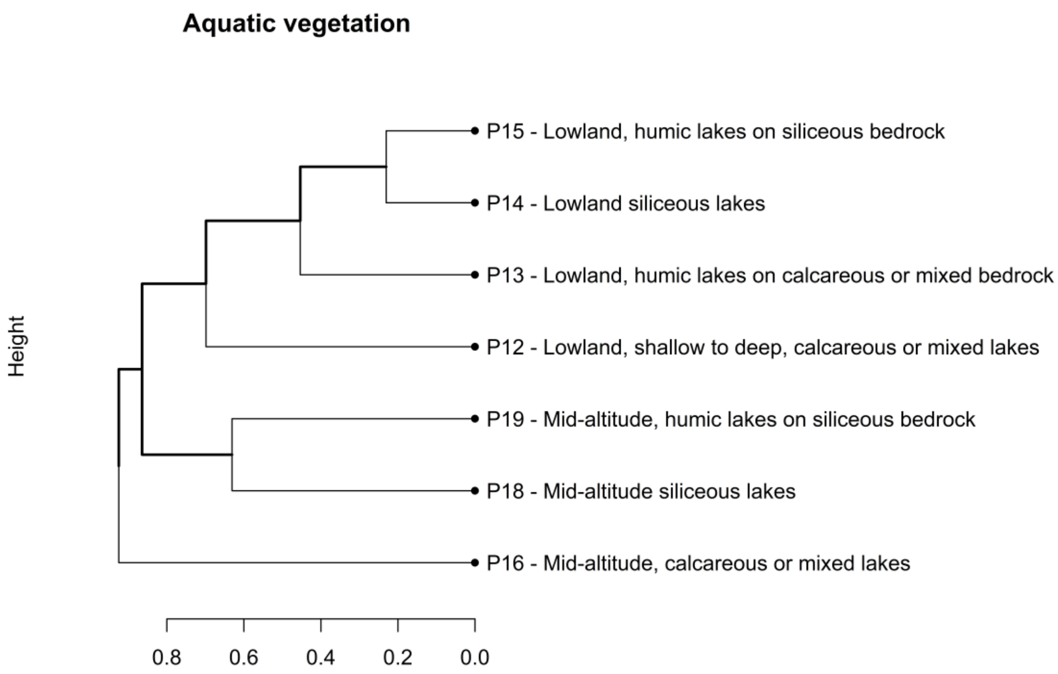
a) NMDS plot of reference lakes



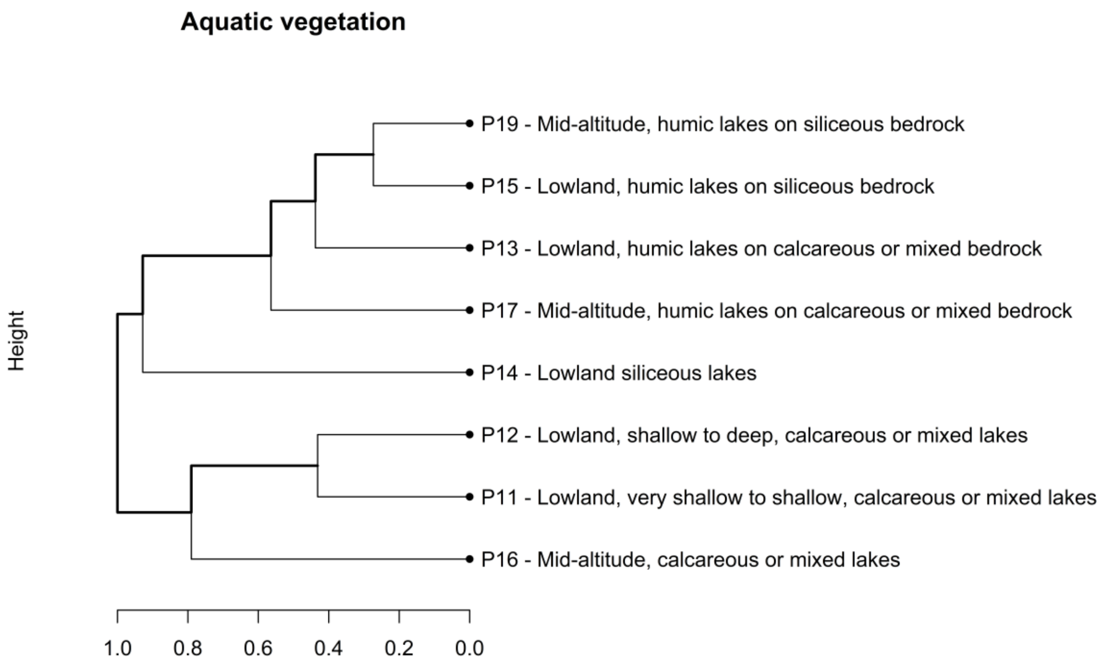
b) NMDS plot of impacted lakes



c) Cluster analysis of reference lakes



d) Cluster analysis of impacted lakes



4.1.3 Fish

The results for fish in reference lakes show quite good separation of the EUNIS level 3 habitat types with sufficient data to enable such analysis (

Figure 4-3a and

Figure 4-3c). The results show a high similarity for fish in the siliceous and clear lakes in mid-altitude (P18) and highland areas (P1C) (

Figure 4-3b and

Figure 4-3c) compared to the other types. The humic lake types P13, P15 and P19 also are quite similar (

Figure 4-3c), but quite different from fish found in non-humic lowland lakes (P12 & P14). This indicates that temperature and light and oxygen conditions (which are less good in humic lakes than in clearwater lakes) are more important for fish than alkalinity in reference lakes.

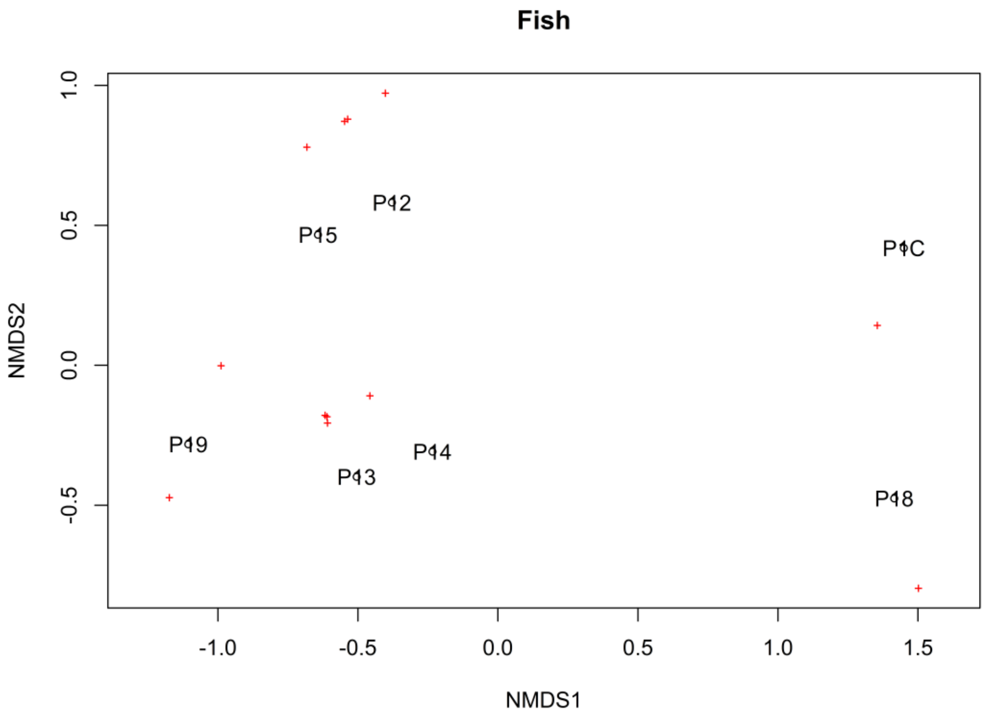
In impacted lakes (

Figure 4-3b and

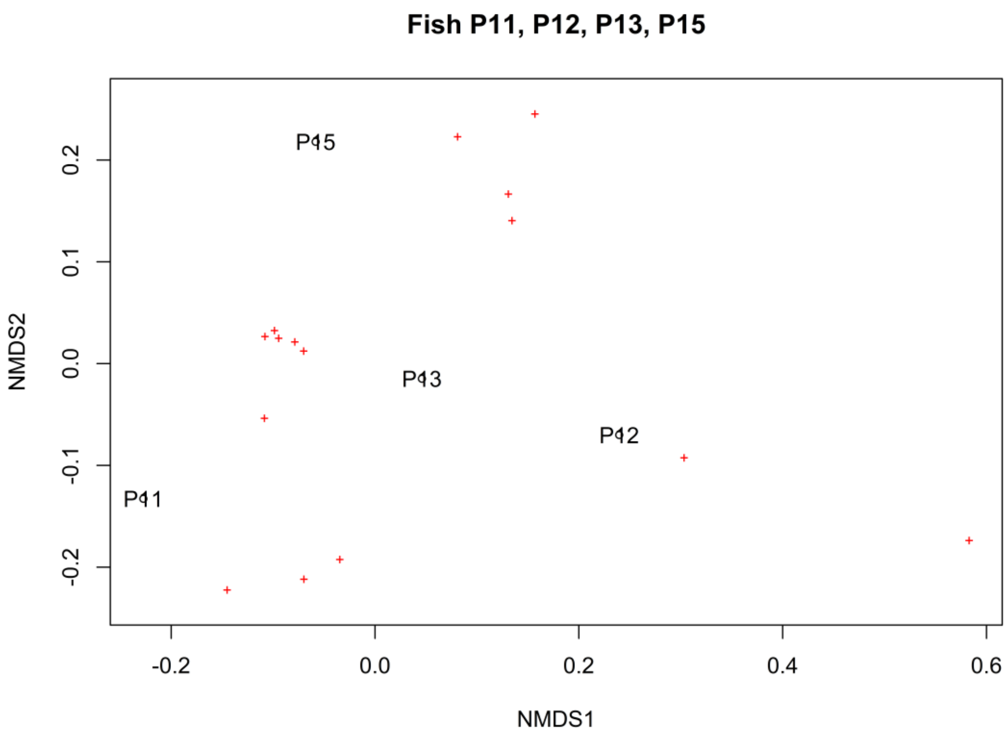
Figure 4-3d), fish communities are quite similar in lowland calcareous lakes (P11, P12, P13) but differ from those in lowland siliceous lakes (e.g. P14). This may indicate that alkalinity is important for fish when lakes become impacted (e.g. by acidification). The mid-altitude humic lakes (P17 and P19) are also quite similar regardless of alkalinity, but are clearly distinguished from the lowland lakes, indicating that temperature and light-climate and/or oxygen conditions are more important than alkalinity for fish in impacted humic lakes.

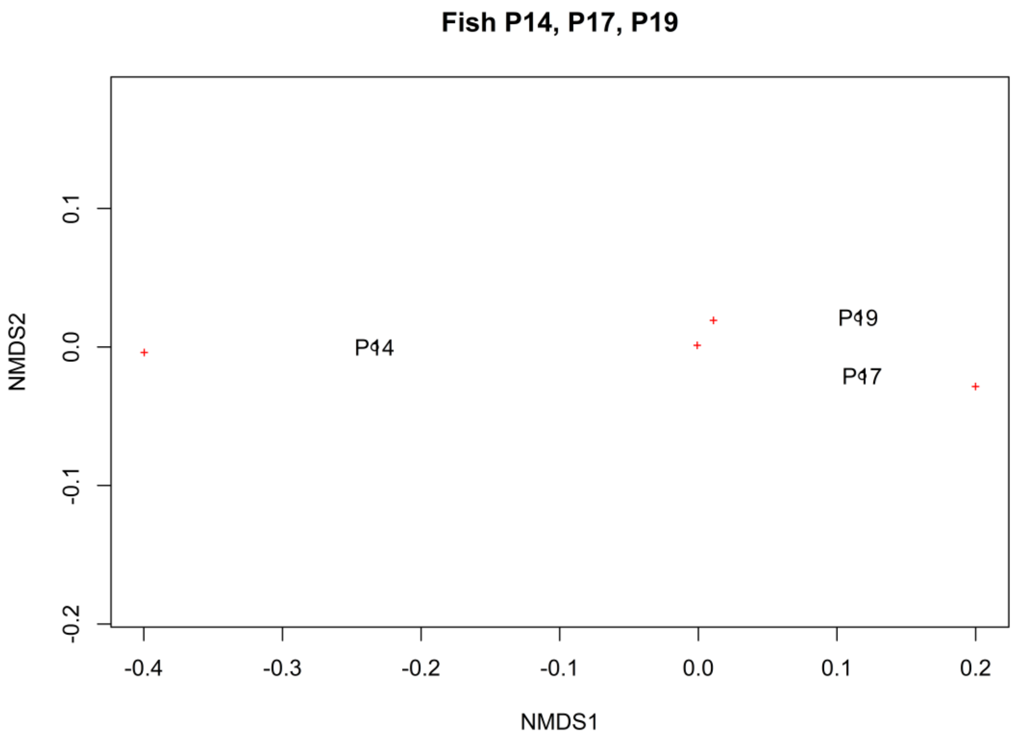
Figure 4-3 Multivariate analysis of differences between selected EUNIS level 3 habitat types for reference and impacted lakes based on their fish communities. (a, b) NMDS plots, (c, d) cluster analysis.

a) NMDS plot of reference lakes

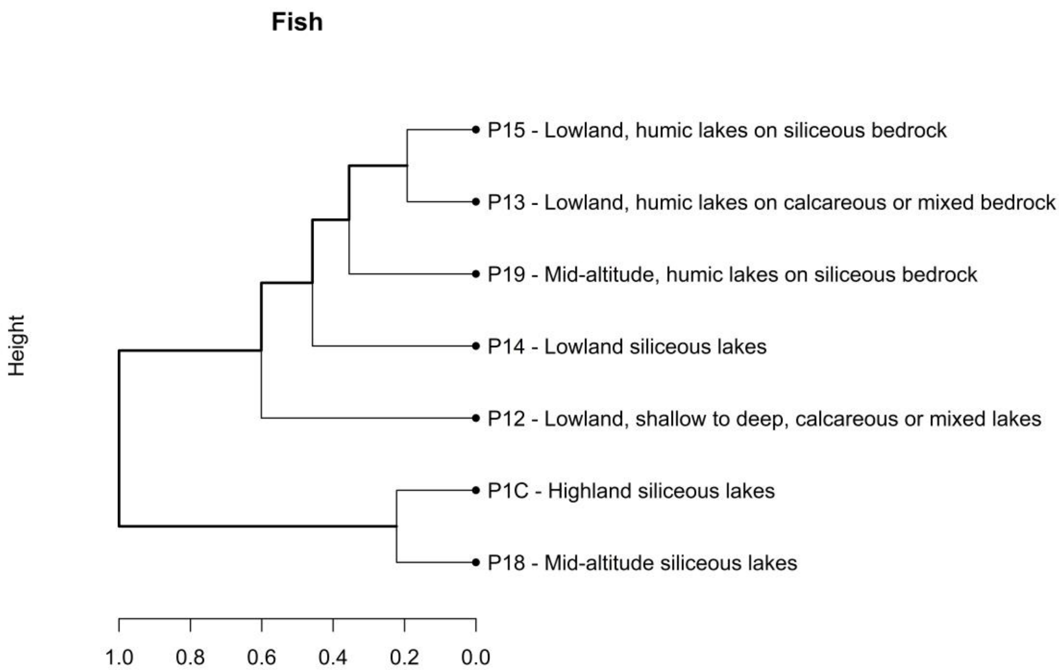


b) NMDS plot of impacted lakes: Initial clustering showed two major groups of habitats. Therefore below, we show the NMDS plots for the two groups separately.

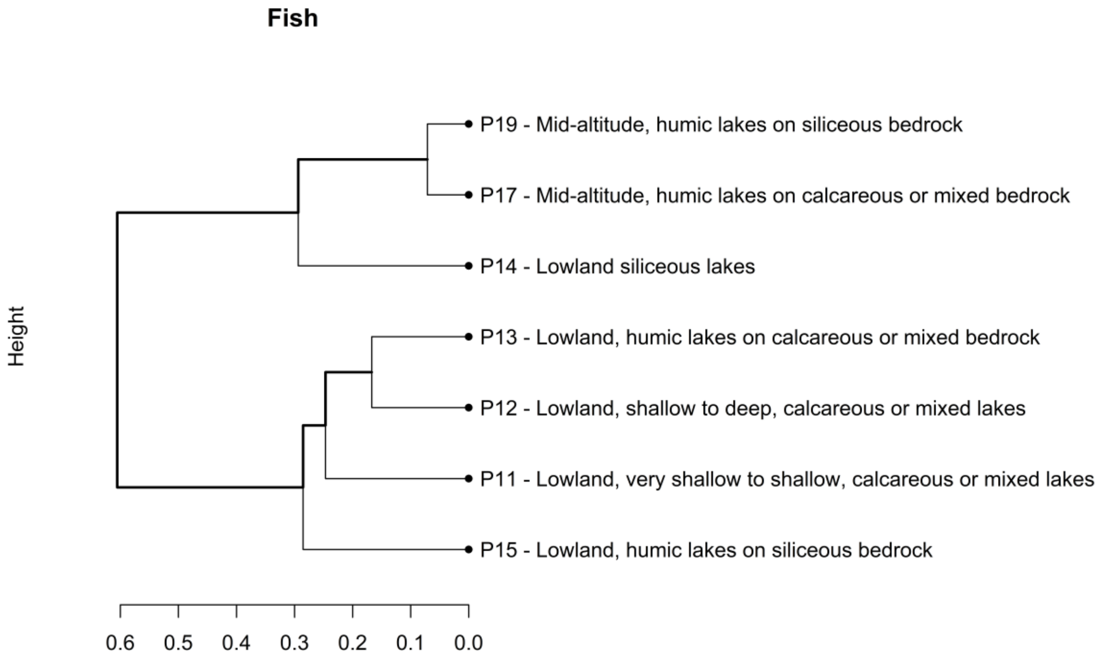




c) Cluster analysis of reference lakes



d) Cluster analysis of impacted lakes



4.2 Species richness per habitat type for phytoplankton, aquatic vegetation and fish

The species richness is highest for phytoplankton, intermediate for aquatic vegetation and lowest for fish in both reference lakes and impacted lakes (Table 4-1, Figure 4-4). There is no clear relationship between the mean species richness and the number of reference lakes or impacted lakes per type for any of the major biological groups (r^2 <0.001 for phytoplankton and aquatic vegetation and <0.17 for fish) (graphs not shown). For phytoplankton and aquatic vegetation, the mean species richness per lake was much higher in very large lakes compared to all the other habitat types for both reference lakes and impacted lakes (Table 4-1,Figure 4-4).

Table 4-1. Species richness (mean number of species and standard deviation (stdev)) in reference and impacted lakes in EUNIS level 3 habitat types with sufficient data in the WISER database. In this analysis, very large lakes (P1M) and very large rivers (P2S) are taken separately from the other types.

BQE	EUNIS L3 code	EUNIS L3 name	Status	Species richness, mean	Species richness, stdev	Number of lakes
Phytoplankton	P11	Lowland, very shallow to shallow, calcareous or mixed lakes	Reference	62	32	10
			Impacted	64	32	169
	P12	Lowland, shallow to deep, calcareous or mixed lakes	Reference	58	29	73
			Impacted	59	31	369
	P13	Lowland, humic lakes on calcareous or mixed bedrock	Reference	66	31	25
			Impacted	72	59	177
	P14	Lowland siliceous lakes	Reference	60	28	144
			Impacted	78	39	50
	P15	Lowland, humic lakes on siliceous bedrock	Reference	78	34	61
			Impacted	81	31	101
	P16	Mid-altitude, calcareous or mixed lakes	Reference	62	22	23
			Impacted	64	38	26

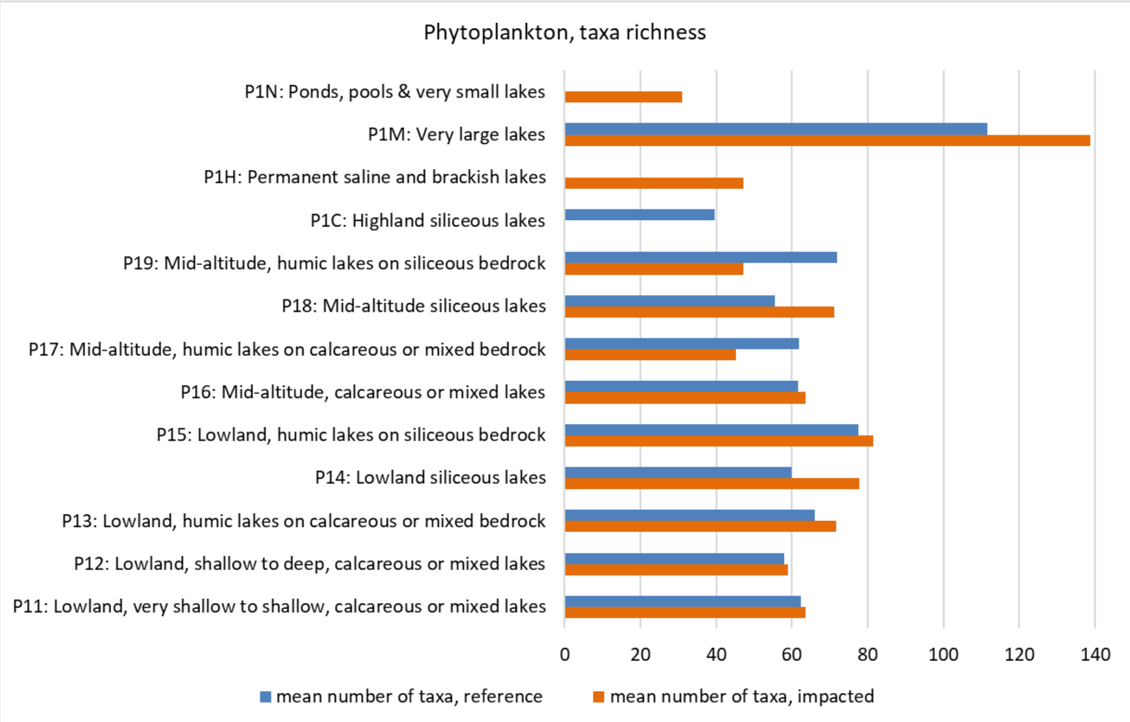
BQE	EUNIS L3 code	EUNIS L3 name	Status	Species richness, mean	Species richness, stdev	Number of lakes
	P17	Mid-altitude, humic lakes on calcareous or mixed bedrock	Reference	62	28	5
			Impacted	45	23	18
	P18	Mid-altitude siliceous lakes	Reference	56	26	72
			Impacted	71	37	14
	P19	Mid-altitude, humic lakes on siliceous bedrock	Reference	72	28	47
			Impacted	47	29	44
	P1C	Highland siliceous lakes	Reference	40	9	6
	P1H	Permanent saline and brackish lakes	Impacted	47	41	5
	P1M	Very large lakes	Reference	112	59	35
			Impacted	139	74	39
	P1N	Permanent ponds and pools	Impacted	31	26	6

BQE	EUNIS L3 code	EUNIS L3 name	Status	Species richness, mean	Species richness, stdev	Number of lakes
Aquatic vegetation	P11	Lowland, very shallow to shallow, calcareous or mixed lakes	Impacted	15	12	23
	P12	Lowland, shallow to deep, calcareous or mixed lakes	Reference	16	7	15
			Impacted	15	11	69
	P13	Lowland, humic lakes on calcareous or mixed bedrock	Reference	22	11	12
			Impacted	22	14	62
	P14	Lowland siliceous lakes	Reference	17	11	28
			Impacted	14	6	9
	P15	Lowland, humic lakes on siliceous bedrock	Reference	21	8	15
			Impacted	28	9	47
	P16	Mid-altitude, calcareous or mixed lakes	Reference	12	6	7
			Impacted	11	8	8
	P17	Mid-altitude, humic lakes on calcareous or mixed bedrock	Impacted	24	9	8
	P18	Mid-altitude siliceous lakes	Reference	10	3	5
	P19	Mid-altitude, humic lakes on siliceous bedrock	Reference	21	11	5
			Impacted	22	9	13
	P1M	Very large lakes	Reference	37	13	10
			Impacted	38	9	5

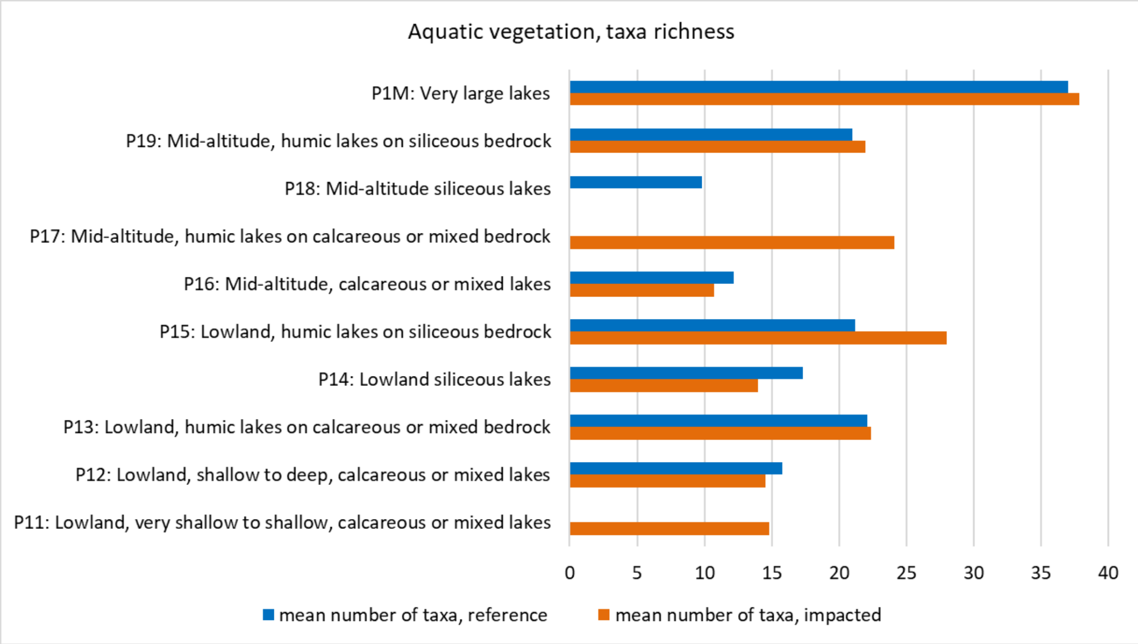
BQE	EUNIS L3 code	EUNIS L3 name	Status	Species richness, mean	Species richness, stdev	Number of lakes
Fish	P11	Lowland, very shallow to shallow, calcareous or mixed lakes	Impacted	7	3	13
	P12	Lowland, shallow to deep, calcareous or mixed lakes	Reference	9	2	10
			Impacted	9	3	54
	P13	Lowland, humic lakes on calcareous or mixed bedrock	Reference	6	2	6
			Impacted	7	3	51
	P14	Lowland siliceous lakes	Reference	4	3	17
			Impacted	6	5	5
	P15	Lowland, humic lakes on siliceous bedrock	Reference	6	2	28
			Impacted	6	3	40
	P17	Mid-altitude, humic lakes on calcareous or mixed bedrock	Impacted	5	3	5
	P18	Mid-altitude siliceous lakes	Reference	2	2	23
	P19	Mid-altitude, humic lakes on siliceous bedrock	Reference	5	2	22
			Impacted	3	1	11
	P1C	Highland siliceous lakes	Reference	1	0	7
	P1M	Very large lakes	Impacted	5	2	11

Figure 4-4. Species richness in lakes for different L3 habitat types, for each of the major biological groups: phytoplankton (a), aquatic vegetation (b), and fish (c).

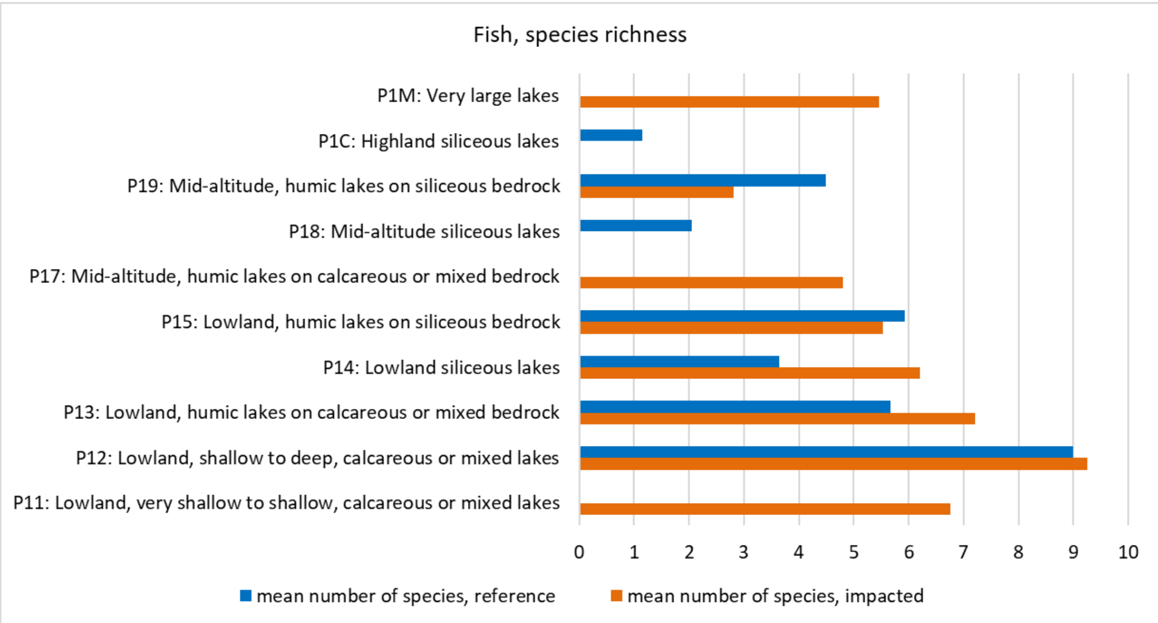
a) Phytoplankton



b) Aquatic vegetation



c) Fish



The results show that very large lakes clearly have the highest species richness for both phytoplankton and aquatic vegetation, while highland or mid-altitude, siliceous lakes clearly have the lowest species richness. These results reflect the higher within-lake habitat diversity within very large lakes compared to smaller lakes, as well as the lack of bicarbonate taxa in siliceous lakes. For fish, the species richness is also lowest in siliceous lakes in the mid-altitude and highland areas, indicating that such lakes may be challenging habitats for many species.

Ponds also appear to have low species richness for phytoplankton, but the data are quite uncertain due to the low number of water bodies (6 water bodies, Table 4-1). Moreover, data are missing for aquatic vegetation and fish in ponds, so a literature review has been done (Chapter 6.1.12).

The impacted lakes have more species than the reference lakes for most of the habitat types (Table 4-1,Figure 4-4), which probably reflect that higher nutrient concentrations allow more species to co-exist. However, for most of the habitat types, the differences between reference lakes and impacted lakes are quite small for most of them. As the standard deviation of these mean values is quite high (**Error! Reference source not found.**), these differences are not significant. Several habitat types only have data for either reference lakes or impacted lakes.

The separate importance of each of the main type descriptors: altitude, geology (alkalinity), humic substances and surface area on the species richness for each of the three biota groups is given in Table 4-2.

Table 4-2. Effects of type-descriptors on species richness in reference (ref.) and impacted (imp.) lakes across all lake habitats with sufficient data. The calculation excluded permanent saline and brackish lakes (P1H). Highland lakes are excluded from surface area analysis. The very large lakes (P1M) and ponds and pools (P1N) are only included under surface area.

Type-descriptors	**Phytoplankton**		**Aquatic vegetation**		**Fish**	
	mean # of taxa		mean # of taxa		mean # of taxa	
	ref.	imp.	ref.	imp.	ref.	imp.
Altitude						
Lowland	65	71	19	19	6	7
Mid-altitude	63	57	14	19	3	4
Highland	40	-	-	-	1	-
Alkalinity						
Calcareous	62	61	17	17	7	7
Siliceous	61	69	17	21	3	5
Humic type						
Clear	56	67	14	14	4	7
Humic	69	61	21	24	5	5
Surface area						
Very large	112	139	37	38	-	5
Small-large	61	65	17	19	5	6
Very small (ponds and pools)	-	31	-	-	-	-

Altitude seems to have a clearly negative effect on species richness for all the three groups, as the number of species is highest in the lowlands and lower in mid-altitude and lowest in highland lakes which are only available for phytoplankton and fish in reference lakes. This pattern for altitude is seen in both reference lakes and impacted lakes for phytoplankton and fish and is consistent with the general effect of temperature on species richness (Stomp et al., 2011).

For alkalinity, there are slightly more taxa in calcareous than in siliceous lakes for fish in both reference and impacted lakes, possibly indicating vulnerability to acidification for fish in many siliceous lakes. However, alkalinity (geology) has no effect on species richness for phytoplankton and aquatic vegetation in reference lakes, while in impacted lakes more species are found in siliceous than in calcareous lakes for those biological groups. The response to alkalinity for phytoplankton and aquatic vegetation is counter-intuitive, as bicarbonate-demanding phytoplankton and aquatic vegetation species would not be expected to thrive in siliceous lakes. This could indicate that most of the siliceous lakes still have sufficient alkalinity to allow bicarbonate species to exist. There are however not many bicarbonate taxa seen in the siliceous lakes (Table 4-3). A possible explanation is that CO_2-species are not competitive in calcareous lakes, so that may balance the increase of bicarbonate taxa (e.g. cyanobacteria) in those lakes compared to the siliceous ones, which are dominated by CO_2-species, e.g. chrysophytes. Another option is that the taxonomic resolution is better among Scandinavian phytoplankton taxonomists than in other regions of Europe. Siliceous lakes are the most common lakes type in Scandinavia, while calcareous lakes are most common in the rest of Europe.

For humic substances, the effects are positive for both phytoplankton and aquatic vegetation, in reference lakes but no effect was found on the number of fish species. In impacted lakes, there are more phytoplankton species and more fish species in clear than in humic lakes (67 versus 61 species for phytoplankton and 7 versus 5 fish species). For aquatic vegetation in impacted lakes, we found more species in humic lakes than in clearwater lakes, which is the same pattern as we found in reference lakes (Table 4-2). The positive effect of humic substances on species richness for both phytoplankton and aquatic vegetation is also a surprise, as those substances reduce the underwater light needed for primary production. For phytoplankton, humic substances will provide a competitive advantage for mixotrophic species, e.g. chrysophytes, cryptophytes and dinoflagellates, but should be a disadvantage for autotrophic species, e.g. chlorophytes, diatoms and cyanobacteria. For aquatic vegetation, this is even more surprising, as the isoëtids are likely to suffer from low light in humic lakes. On the other hand, the nymphaeids would be quite competitive in humic lakes. Humic lakes could also be expected to not be good habitats for fish, due to lower oxygen concentration, but the species richness does not differ among clear and humic lakes for fish in this dataset. Again, this pattern may indicate that most of the humic reference lakes are only slightly humic (mesohumic), allowing both taxa with different functional traits (e.g. littoral and pelagic) and growth forms to co-exist.

Surface area has a clear positive effect on species richness, with most species per lake found in very large lakes and the lowest number of species per lake found in very small lakes, i.e. ponds and pools. This is in line with the general knowledge that large ecosystems have more species than smaller ones (Stomp et al., 2011). However, for ponds and pools, the WISER data are limited to phytoplankton. For aquatic vegetation and fish, the species diversity is also lower in ponds than in lakes (section 6.1.12). This does not mean that ponds and pools are less important for biodiversity, as the number of ponds and pools are several orders of magnitude larger than the number of very large lakes. Moreover, ponds and pools are often fishless and therefore well-suited habitats for amphibians, such as salamanders (section 6.1.12).

The effect of human impacts on species richness is less clear. For most of the habitats (small-large lakes in Table 4-2), the effect is positive, which may seem surprising. The explanation can be that reference lakes are mostly quite oligotrophic with low nutrient concentrations preventing the co-existence of a high number of species. The general relationship between nutrient enrichment and species richness for phytoplankton, zooplankton and aquatic vegetation seems to be unimodal with the highest species richness found in meso-eutrophic lakes (Dodson et al., 2000).

4.3 Characteristic, common and dominant taxa for standing water habitats in reference (or good status) and impacted conditions

4.3.1 Phytoplankton communities

Table 4-3 provides the list of characteristics, common and dominant taxa of phytoplankton in reference lakes and in impacted lakes in most of the EUNIS level 3 habitat types. The total number of phytoplankton species which is given in **Error! Reference source not found.** above is however much higher than the number of characteristic, common and/or dominant taxa because many taxa are rare and/or do not satisfy the criteria used to identify characteristic, common and/or dominant taxa.

Differences between reference and impacted standing water habitats

In general, there are more dominant taxa in impacted lakes than in reference lakes and the level of dominance is also higher in impacted lakes for single species that are dominant in both reference and impacted lakes (e.g. the harmful algae *Gonyostomum semen* in P19 Mid-altitude humic lakes on siliceous bedrock) (Table 4-3). In contrast, there are twice as many common species in reference lakes than in impacted lakes. Some species are common in both reference and impacted lakes, but most of the common species are common in either reference lakes or impacted lakes. Those that are dominant or common in impacted lakes are mainly species that are well-known to prefer high nutrient concentrations, e.g. many chlorophytes, large dinoflagellates (e.g. *Ceratium hirundinella*), large pennate diatoms (e.g. *Asterionella formosa*, *Fragilaria crotonensis and Stephanodiscus sp)* and some cyanophytes (cyanobacteria such as *Aphanizonmenon flos-aquae* and *Planktothrix agardhii,* which can produce cyanotoxins). In addition, there are also several common species occurring in both reference lakes and impacted lakes, as these are found in most lakes regardless of the nutrient concentrations, e.g. cryptophytes like *Cryptomonas* and *Plagioselmis* (previously called *Rhodomonas)*.

The characteristic species are quite different in reference lakes compared to impacted lakes, and there are many more characteristic species in reference lakes than in impacted lakes. Some of the characteristic species in reference lakes are well-known to thrive in lakes with low nutrient concentrations, belonging to mixotrophic algal classes, such as chrysophytes and dinoflagellates. However, many of the species that are found to be characteristic in lowland, calcareous reference lakes (P11 & P12) are also known to prefer quite high nutrient levels. This illustrates that these lake types have high natural productivity.

Differences between calcareous versus siliceous standing water habitats in reference or good condition

Calcareous shallow or deep stratified lowland lakes (P12) are characterized by autotrophic diatoms and green algae with higher nutrient requirements than those commonly found in siliceous lowland lakes (P14). The chrysophytes are common only in the siliceous lakes, in which the natural productivity is normally lower than in calcareous lakes. The diatoms in the calcareous lakes are those that have relatively high nutrient requirements (e.g. *Diatoma*, *Stephanodiscus*) compared to those commonly found in the siliceous lowland lakes (e.g. *Tabellaria*).

In mid-altitude lakes (P16 vs P18), the major phytoplankton classes are the same in the calcareous and the siliceous lakes, but there are some differences at species level. One example is the diatom *Fragilaria*, which has quite high nutrient requirements and is only common in the calcareous lakes.

Differences between low-, mid-altitude and highland standing water habitats in reference or good conditions

- Highland siliceous lakes (P1C) are characterized by mixotrophic chrysophytes that can thrive in cold lakes. Such taxa are also found in the spring in mid-altitude lakes, when the water is cold and not yet stratified. Small dinoflagellates are also common in highland siliceous lakes. These lakes are normally oligotrophic, but the characteristic and common taxa can survive there due to their mixotrophy, which enables them to combine photosynthesis with feeding on bacteria that are quite rich in phosphorus. The results are quite uncertain due to the low number of highland lakes with species data in the WISER database (6 reference lakes only, Table 3-1). The species composition is still in line with expert knowledge, so may be quite representative for this type of lake. The mean species diversity is quite low (40 taxa, Table 4-1).
- Mid-altitude, siliceous lakes (P18) have many of the same mixotrophic chrysophytes and dinoflagellates as the highland siliceous lakes, but also have other characteristic taxa, including one diatom species (*Hannaea arcus*) and one flagellate (*Gyromitus cordiformis*). There is also a higher number of common species compared to highland lakes, including a green algae *Oocystis submarina*, as well as two cryptomonads, which are also found in many other habitat types. The results are less uncertain than those for highland lakes, as there are 74 lakes of this type included in the dataset. The species diversity (55 taxa, Table 4-1) is higher than that found in highland lakes, but lower than that found in lowland lakes.

- Lowland, siliceous lakes (P14) also have many common taxa of mixotrophic chrysophytes and dinoflagellates in addition to two species of chlorophytes and cryptophytes and a dominant diatom species (*Tabellaria fenestrata*). The results are quite certain due to the high number of lakes of this type in the dataset (151 lakes). The species diversity is higher (62 taxa, Table 4-1) than in the mid-altitude lakes and highland lakes.
- A similar comparison of clear calcareous lowland lakes versus mid-altitude lakes (P12 versus P16 in Table 4-3) shows that the chrysophytes are only common in the mid-altitude lakes, but not in the lowland lakes, where diatoms and chlorophytes, as well as a very large dinoflagellate (*Ceratium hirundinella*) are common and can be dominant. The species diversity is however the same in those two types of calcareous lakes with 61 taxa (Table 4-1). The results are relatively certain for the lowland lakes (73 lakes), but less certain for the mid-altitude lakes (23 lakes, Table 3-1). There is no data from highland calcareous lakes in the dataset.

Differences between clear versus humic standing water habitats in reference or good conditions

There are more characteristic species in the humic lakes compared to siliceous lakes both in lowland lakes and in mid-altitude lakes (Table 4-3).

In lowland lakes, there are more diatoms and green algae that are characteristic in the clearwater lakes than in the humic lakes. However, there are two characteristic and one dominant Cyanobacteria species in the humic lakes, but none in the clear lakes. In the mid-altitude calcareous lakes (P16 and P17), there are more common species in the clear lakes than in the humic lakes, but this result is quite uncertain due to the very low number of mid-altitude calcareous, humic lakes (5 lakes only). These results may still be attributed to the slightly higher nutrient concentrations in humic lakes compared to clearwater lakes, due to the adsorption of phosphorus to the humic substances. Mixotrophic taxa may be able to use those nutrients.

These differences represent mainly clear (oligohumic) versus mesohumic lakes, but may not be representative for polyhumic lakes, due to the very poor underwater light climate in such lakes.

Differences between very shallow (unstratified) and deeper (stratified) calcareous standing water habitats reference or good conditions

The major differences between these two lake types (P11 vs P12) are more nutrient requiring diatoms and green algae, as well as several common & characteristic Cyanobacteria in the very shallow lakes compared to the deeper stratified lakes.

Permanent saline and brackish standing water habitats (P1H)

For this habitat type, the WISER data includes only 5 impacted lakes and no reference lakes. The phytoplankton community in these 5 lakes is characterized and dominated by euglenophytes with *Euglena proxima* as the most dominant species. These species are very tolerant to high conductivity. More information about the biological communities in this habitat type is given in the literature study in Section 6.1.8.

Permanent ponds and pools (P1N)

For this habitat type, the WISER data includes only 6 impacted ponds and no reference (unimpacted) ponds. The phytoplankton community in these 6 ponds is dominated by green algae, cryptophytes and dinoflagellates. The same genera are also common in this habitat type, while only one genus of dinoflagellates is characteristic: *Glenodinium*. The results may not be representative for all ponds, as the data are from Estonia and Belgium only. A literature study has therefore been done to complete these results (Section 6.1.12)

General summary of type-specific differences in phytoplankton communities

The major differences between the habitat types are:

- More characteristic and/or common mixotrophic chrysophytes in:
    - Highland versus mid-altitude lakes
    - Mid-altitude than in lowland lakes
    - Siliceous lakes than in calcareous lakes
- More characteristic and/or common autotrophic taxa (diatoms, green algae) in:
    - Calcareous than in siliceous lakes
    - Lowland than in mid-altitude lakes

In impacted lakes, there are fewer chrysophyte species and more pennate diatoms, green algae and cyanobacteria than in reference lakes of comparable types. In general, there are fewer characteristic species and more dominant species in impacted lakes than in reference lakes.

Most of these differences reflect differences in natural productivity, nutrient enrichment, alkalinity and climatic conditions of different types, and are in line with previous papers, e.g. Phillips et al. (2013), Järvinen et al. (2013).

Table 4-3. Phytoplankton in reference and impacted lakes: Characteristic (diagnostic), common (constant) and dominant taxa. Characteristic taxa were identified by the phi-index with the highest significance level p≤0.001 marked * or p≤0.01 marked **. Common taxa have a frequency of occurrence ≥0.7 (70%). Dominant taxa have a mean relative abundance ≥0.1 (10%) of the total phytoplankton biomass.**

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P11	Lowland, very shallow (unstratified), calcareous or mixed lakes	Bacillariophyceae	*Asterionella formosa*	0.448 ***					
		Bacillariophyceae	*Aulacoseira ambigua*						0.18
		Bacillariophyceae	*Aulacoseira granulata*						0.12
		Bacillariophyceae	*Aulacoseira islandica*						0.13
		Bacillariophyceae	*Cyclotella*			0.11			
		Bacillariophyceae	*Cymbella*				0.354 **		
		Bacillariophyceae	*Fragilaria*	0.585 ***					
		Bacillariophyceae	*Navicula*	0.598 ***					
		Bacillariophyceae	*Nitzschia*	0.619 ***	0.70				
		Bacillariophyceae	*Stephanodiscus*	0.598 ***					0.13
		Bacillariophyceae	*Ulnaria acus*	0.621 ***					
		Chlorophyceae	*Chlamydomonas*	0.743 ***					
		Chlorophyceae	*Micractinium pusillum*				0.33 **		
		Chlorophyceae	*Monoraphidium griffithii*				0.531 ***		
		Chlorophyceae	*Oocystis*	0.564 ***					
		Chlorophyceae	*Pediastrum boryanum*	0.648 ***					
		Chlorophyceae	*Scenedesmus*	0.758 ***					
		Chlorophyceae	*Scenedesmus opoliensis*				0.515 ***		
		Chlorophyceae	*Scenedesmus quadricauda*	0.69 ***					
		Chrysophyceae	*Dinobryon divergens*	0.544 ***					

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P11 (cont.)	Lowland, very shallow (unstratified), calcareous or mixed lakes (cont.)	Conjugatophyceae	*Cosmarium*	0.525 ***	0.90				
		Conjugatophyceae	*Staurastrum*	0.641 ***					
		Cryptophyceae	*Cryptomonas*		1.00	0.12		0.86	
		Cryptophyceae	*Plagioselmis*	0.653 ***	0.80	0.10			
		Cyanophyta (phylum)	*Anabaena*	0.555 ***					
		Cyanophyta (phylum)	*Aphanizomenon flos-aquae*						0.11
		Cyanophyta (phylum)	*Aphanocapsa*	0.612 ***		0.13			
		Cyanophyta (phylum)	*Chroococcus limneticus*	0.713 ***	0.70				
		Cyanophyta (phylum)	*Microcystis aeruginosa*	0.529 ***					
		Cyanophyta (phylum)	*Oscillatoria*						0.10
		Cyanophyta (phylum)	*Planktothrix agardhii*	0.449 **					0.12
		Cyanophyta (phylum)	*Pseudanabaena limnetica*	0.688 ***					
		Dinophyceae	*Ceratium hirundinella*	0.508 ***	1.00	0.15			
		Dinophyceae	*Peridinium*		0.70				
P12	Lowland, shallow to deep (stratified) calcareous or mixed lakes	Bacillariophyceae	*Asterionella formosa*		0.71			0.85	
		Bacillariophyceae	*Aulacoseira granulata*	0.361 **					
		Bacillariophyceae	*Centrales*						0.12
		Bacillariophyceae	*Cyclotella*		0.78				
		Bacillariophyceae	*Cyclotella radiosa*	0.412 **					
		Bacillariophyceae	*Diatoma tenuis*	0.526 **					
		Bacillariophyceae	*Discostella glomerata*	0.499 ***					
		Bacillariophyceae	*Fragilaria crotonensis*	0.548 **				0.70	

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P12 (cont.)	Lowland, shallow to deep (stratified) calcareous or mixed lakes (cont.)	Bacillariophyceae	*Stephanodiscus*						0.11
		Bacillariophyceae	*Stephanodiscus hantzschii*	0.477 **					
		Bacillariophyceae	*Tabellaria flocculosa*	0.487 ***					
		Bacillariophyceae	*Ulnaria ulna*	0.445 **					
		Bacillariophyceae	*Urosolenia longiseta*	0.403 **					
		Chlorophyceae	*Ankyra judayi*				0.505 ***		
		Chlorophyceae	*Chlorococcales*	0.435 ***					
		Chlorophyceae	*Dictyosphaerium subsolitarium*	0.503 ***					
		Chlorophyceae	*Gloeocystis*	0.423 **					
		Chlorophyceae	*Monoraphidium dybowskii*	0.553 ***					
		Chlorophyceae	*Pandorina morum*	0.344 **					
		Chlorophyceae	*Phacotus lenticularis*				0.412 **		
		Chlorophyceae	*Quadrigula pfitzeri*	0.474 **					
		Chlorophyceae	*Volvocales*	0.526 ***					
		Chrysophyceae	*Chromulina*	0.604 ***					
		Chrysophyceae	*Dinobryon*	0.723 ***					
		Chrysophyceae	*Dinobryon bavaricum*	0.614 ***					
		Chrysophyceae	*Dinobryon crenulatum*	0.822 ***					
		Chrysophyceae	*Dinobryon cylindricum* var. *Alpinum*	0.533 ***					
		Chrysophyceae	*Dinobryon sociale*	0.432 **					
		Chrysophyceae	*Dinobryon sociale* var. *Americanum*	0.501 ***					

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P12 (cont.)	Lowland, shallow to deep (stratified) calcareous or mixed lakes (cont.)	Chrysophyceae	*Mallomonas*	0.504 ***					
		Chrysophyceae	*Mallomonas akrokomos* var. *Parvula*	0.496 **					
		Chrysophyceae	*Ochromonas*	0.391 **					
		Chrysophyceae	*Stichogloea doederleinii*	0.407 **					
		Conjugatophyceae	*Closterium acutum* var. *Variabile*	0.377 **					
		Cryptophyceae	*Cryptomonas*		0.84			0.88	
		Cryptophyceae	*Cryptomonas marssonii*	0.501 ***					
		Cryptophyceae	*Katablepharis ovalis*	0.598 ***					
		Cryptophyceae	*Plagioselmis lacustris*	0.487 **	0.75				
		Cyanophyta (phylum)	*Snowella lacustris*	0.385 **					
		Cyanophyta (phylum)	*Woronichinia naegeliana*	0.431 **					
		Dinophyceae	*Ceratium furcoides*						0.12
		Dinophyceae	*Ceratium hirundinella*		0.74	0.18		0.86	0.18
		Dinophyceae	*Gymnodinium helveticum*	0.441 ***					
		Dinophyceae	*Gymnodinium lacustre*	0.594 ***					
		Dinophyceae	*Gymnodinium uberrimum*	0.462 ***					
		Dinophyceae	*Peridinium*					0.70	
		Dinophyceae	*Peridinium inconspicuum*	0.576 ***					

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
		Prymnesiophyceae	*Chrysochromulina parva*	0.602 ***					
P13	Lowland, humic lakes on calcareous or mixed bedrock	Bacillariophyceae	*Asterionella formosa*					0.75	
		Bacillariophyceae	*Aulacoseira ambigua*	0.453 **					
		Bacillariophyceae	*Cyclotella*		0.82				
		Bacillariophyceae	*Pennales*	0.522 **					
		Bacillariophyceae	*Ulnaria delicatissima* var. *angustissima*	0.47 **					
		Chlorophyceae	*Botryococcus*	0.525 ***					
		Chlorophyceae	*Botryococcus braunii*	0.47 **					
		Chrysophyceae	*Dinobryon bavaricum*				0.518 ***		
		Chrysophyceae	*Mallomonas*		0.79				
		Chrysophyceae	*Mallomonas caudata*	0.502 ***					
		Chrysophyceae	*Mallomonas crassisquama*	0.431 **					
		Chrysophyceae	*Synura*	0.402 **					
		Chrysophyceae	*Uroglena*	0.486 ***					
		Conjugatophyceae	*Staurodesmus*				0.344 **		
		Cryptophyceae	*Cryptomonas*		0.96	0.10		0.89	0.12
		Cryptophyceae	*Plagioselmis lacustris*			0.11			
		Cyanophyta (phylum)	*Aphanizomenon flos-aquae*						0.10
		Cyanophyta (phylum)	*Cyanodictyon imperfectum*	0.514 **			0.475 ***		
		Cyanophyta (phylum)	*Radiocystis geminata*	0.514 **					

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
		Cyanophyta (phylum)	*Snowella septentrionalis*	0.48 **					
		Dinophyceae	*Gymnodinium*		0.82				
		Raphidophyceae	*Gonyostomum semen*						0.10
P14	Lowland siliceous lakes	Bacillariophyceae	*Asterionella formosa*					0.78	
		Bacillariophyceae	*Fragilaria*					0.84	
		Bacillariophyceae	*Tabellaria fenestrata*			0.13			
		Bacillariophyceae	*Tabellaria flocculosa*					0.90	
		Bacillariophyceae	*Urosolenia eriensis*				0.608 ***		
		Chlorophyceae	*Ankyra lanceolata*	0.453 **					
		Chlorophyceae	*Crucigenia tetrapedia*	0.448 **					
		Chlorophyceae	*Gloeocystis*				0.426 **		
		Chlorophyceae	*Monoraphidium dybowskii*		0.79			0.73	
		Chlorophyceae	*Monoraphidium griffithii*	0.582 ***					
		Chlorophyceae	*Monoraphidium komarkovae*	0.441 **					
		Chlorophyceae	*Oocystis submarina* var. *variabilis*	0.584 ***					
		Chlorophyceae	*Sphaerocystis schroeteri*	0.469 ***					
		Chrysophyceae	*Chromulina*		0.71				
		Chrysophyceae	*Chrysidiastrum catenatum*				0.559 ***		
		Chrysophyceae	*Chrysococcus*	0.443 **					
		Chrysophyceae	*Chrysolykos skujae*	0.686 ***	0.71				

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P14 (cont.)	Lowland siliceous lakes (cont.)	Chrysophyceae	*Dinobryon*		0.78				
		Chrysophyceae	*Dinobryon crenulatum*		0.93				
		Chrysophyceae	*Mallomonas*		0.72				
		Chrysophyceae	*Monas*	0.447 **					
		Chrysophyceae	*Ochromonadales*	0.723 ***					
		Chrysophyceae	*Ochromonas*		0.74				
		Chrysophyceae	*Uroglena americana*						0.15
		Conjugatophyceae	*Staurastrum cingulum*				0.487 **		
		Cryptophyceae	*Chroomonas*	0.354 **					
		Cryptophyceae	*Cryptomonas*		0.91			0.96	
		Cryptophyceae	*Cryptomonas parapyrenoidifera*				0.404 **		
		Cryptophyceae	*Katablepharis ovalis*		0.80			0.71	
		Cryptophyceae	*Plagioselmis lacustris*		0.77			0.76	
		Cyanophyta (phylum)	*Merismopedia tenuissima*	0.624 ***					
		Cyanophyta (phylum)	*Merismopedia warmingiana*	0.45 **			0.404 **		
		Dictyochophyceae	*Pseudopedinella*					0.75	
		Dinophyceae	*Gymnodinium*		0.87				
		Dinophyceae	*Peridinium inconspicuum*		0.78				
		Klebsormidiophyceae	*Koliella*	0.568 ***					

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P15	Lowland humic lakes on siliceous bedrock	Bacillariophyceae	*Asterionella formosa*					0.83	
		Bacillariophyceae	*Aulacoseira alpigena*	0.444 **					
		Bacillariophyceae	*Aulacoseira distans*	0.454 **					
		Bacillariophyceae	*Aulacoseira islandica*						0.11
		Bacillariophyceae	*Eunotia zasuminensis*				0.422 **		
		Bacillariophyceae	*Tabellaria fenestrata*						0.11
		Bacillariophyceae	*Tabellaria flocculosa*		0.85			0.84	
		Bacillariophyceae	*Urosolenia*	0.483 **			0.515 ***		
		Bacillariophyceae	*Urosolenia longiseta*					0.80	
		Chlorophyceae	*Botryococcus terribilis*	0.552 ***					
		Chlorophyceae	*Chlorococcales*		0.80				
		Chlorophyceae	*Monoraphidium dybowskii*		0.84			0.82	
		Chlorophyceae	*Pediastrum tetras*				0.412 **		
		Chlorophyceae	*Polytoma*	0.527 ***					
		Chrysophyceae	*Chrysidiastrum catenatum*	0.449 ***					
		Chrysophyceae	*Dinobryon crenulatum*		0.92				
		Chrysophyceae	*Dinobryon cylindricum*				0.379 **		
		Chrysophyceae	*Mallomonas*		0.87			0.83	
		Chrysophyceae	*Mallomonas akrokomos*	0.489 **			0.466 ***		
		Chrysophyceae	*Mallomonas allorgei*	0.543 ***					
		Chrysophyceae	*Mallomonas caudata*					0.75	
		Chrysophyceae	*Mallomonas punctifera*	0.544 ***					

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P15 (cont.)	Lowland humic lakes on siliceous bedrock (cont.)	Chrysophyceae	*Monas*				0.524 **		
		Cryptophyceae	*Cryptomonas*		0.99			0.99	
		Cryptophyceae	*Katablepharis ovalis*		0.90			0.88	
		Cryptophyceae	*Plagioselmis lacustris*		0.91			0.84	
		Cryptophyceae	*Plagioselmis nannoplanctica*	0.527 **					
		Cyanophyta (phylum)	*Anabaena lemmermannii*	0.495 **					
		Cyanophyta (phylum)	*Aphanizomenon*	0.553 **					
		Dictyochophyceae	*Pseudopedinella*		0.75			0.83	
		Dinophyceae	*Gymnodinium*		0.94			0.80	
		Dinophyceae	*Peridinium*					0.71	
		Dinophyceae	*Peridinium inconspicuum*		0.80				
		Euglenophyceae	*Trachelomonas*	0.431 **					
		Prymnesiophyceae	*Chrysochromulina*	0.626 ***					
		Raphidophyceae	*Gonyostomum semen*	0.59 ***				0.73	0.26
P16	Mid-altitude, shallow to deep (stratified) calcareous or mixed lakes	Bacillariophyceae	*Asterionella formosa*					0.73	
		Bacillariophyceae	*Cyclotella ocellata*				0.435 **		
		Bacillariophyceae	*Cyclotella radiosa*			0.12			0.14
		Bacillariophyceae	*Cyclotella rossii*				0.501 ***		0.12
		Bacillariophyceae	*Fragilaria*		0.79				
		Chlorophyceae	*Monoraphidium dybowskii*		0.75				
		Chrysophyceae	*Bitrichia chodatii*	0.908 ***	0.71				
		Chrysophyceae	*Kephyrion littorale*	0.52 ***					

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P16 (cont.)	Mid-altitude, shallow to deep (stratified) calcareous or mixed lakes (cont.)	Chrysophyceae	*Mallomonas*		0.79				
		Chrysophyceae	*Ochromonas*		0.79				
		Chrysophyceae	*Uroglena americana*						0.10
		Cryptophyceae	*Chroomonas*		0.71				
		Cryptophyceae	*Cryptomonas*		0.92			0.85	
		Cryptophyceae	*Katablepharis ovalis*		0.96				
		Cryptophyceae	*Plagioselmis lacustris*		0.83				
		Dinophyceae	*Ceratium hirundinella*					0.73	0.19
		Dinophyceae	*Gymnodinium lacustre*		0.79				
		Dinophyceae	*Peridinium inconspicuum*		0.75				
		Klebsormidiophyceae	*Elakatothrix gelatinosa*				0.501 ***		
		Prymnesiophyceae	*Chrysochromulina parva*		0.75				
P17	Mid-altitude, humic lakes on calcareous or mixed bedrock	Bacillariophyceae	*Cyclotella radiosa*		0.80	0.10			
		Chlorophyceae	*Chlorococcales*		1.00				
		Chlorophyceae	*Sphaerocystis schroeteri*		0.80				
		Chrysophyceae	*Bitrichia chodatii*		1.00				
		Chrysophyceae	*Mallomonas*		1.00				
		Cryptophyceae	*Cryptomonas*		1.00			0.95	
		Cryptophyceae	*Katablepharis ovalis*		1.00			0.70	
		Cryptophyceae	*Plagioselmis lacustris*		0.80	0.12		0.70	

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
		Dictyochophyceae	*Pseudopedinella*		0.80				
		Dinophyceae	*Ceratium hirundinella*						0.19
		Dinophyceae	*Gymnodinium*		1.00				
		Euglenophyceae	*Trachelomonas volvocina*						0.11
		Raphidophyceae	*Gonyostomum semen*						0.15
P18	Mid-altitude siliceous lakes	Bacillariophyceae	*Asterionella formosa*					0.71	
		Bacillariophyceae	*Cyclotella rossii*			0.11			
		Bacillariophyceae	*Hannaea arcus*	0.5 **					
		Bacillariophyceae	*Tabellaria flocculosa*					0.79	
		Chlorophyceae	*Monoraphidium dybowskii*					0.71	
		Chlorophyceae	*Oocystis submarina* var. *variabilis*		0.78				
		Chlorophyceae	*Tetraedron minimum*						0.11
		Chlorophyceae	*Thelesphaera alpina*	0.417 **					
		Chrysophyceae	*Chromulina*		0.76			0.93	
		Chrysophyceae	*Chrysolykos skujae*		0.82		0.74 ***		
		Chrysophyceae	*Dinobryon*		0.80				
		Chrysophyceae	*Dinobryon crenulatum*						
		Chrysophyceae	*Dinobryon crenulatum*		0.92			0.71	
		Chrysophyceae	*Mallomonas*		0.73				
		Chrysophyceae	*Ochromonadales*		0.76		0.663 ***		
		Chrysophyceae	*Ochromonas*		0.84				

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P18 (cont.)	Mid-altitude siliceous lakes (cont.)	Cryptophyceae	*Chroomonas*		0.80			0.71	
		Cryptophyceae	*Cryptomonas*		0.93			0.93	
		Cryptophyceae	*Cryptomonas marssonii*					0.71	
		Cryptophyceae	*Katablepharis ovalis*		0.92				
		Cryptophyceae	*Plagioselmis lacustris*		0.84				0.11
		Cyanophyta (phylum)	*Anabaena flos-aquae*						0.14
		Dinophyceae	*Gymnodinium*		0.88				
		Dinophyceae	*Gymnodinium lacustre*		0.78				
		Dinophyceae	*Peridinium inconspicuum*		0.76				
		Klebsormidiophyceae	*Elakatothrix*				0.74 ***		
		Protozoan	*Gyromitus cordiformis*	0.658 ***					
		Protozoan	*Paramastix conifera*				0.516 ***		
P19	Mid-altitude, humic lakes on siliceous bedrock	Bacillariophyceae	*Aulacoseira distans* var. *tenella*	0.464 **					
		Bacillariophyceae	*Cyclotella radiosa*			0.11			
		Bacillariophyceae	*Tabellaria flocculosa*		0.79				
		Bacillariophyceae	*Tabellaria flocculosa* var. *asterionelloides*	0.5 **					
		Chlorophyceae	*Chlamydomonas*		0.85				
		Chlorophyceae	*Chlorococcales*					0.72	
		Chlorophyceae	*Chlorococcales*		0.85				
		Chlorophyceae	*Crucigenia quadrata*	0.369 **					
		Chlorophyceae	*Dictyosphaerium subsolitarium*				0.466 **		

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P19 (cont.)	Mid-altitude, humic lakes on siliceous bedrock (cont.)	Chlorophyceae	*Monoraphidium dybowskii*		0.87				
		Chlorophyceae	*Tetrastrum triangulare*	0.464 **					
		Chrysophyceae	*Chrysococcus cordiformis*	0.486 **			0.453 **		
		Chrysophyceae	*Dinobryon bavaricum* var. *vanhoeffenii*	0.486 **					
		Chrysophyceae	*Mallomonas*		0.81				
		Chrysophyceae	*Mallomonas caudata*		0.72				
		Cryptophyceae	*Cryptomonas*		0.94			0.91	
		Cryptophyceae	*Katablepharis ovalis*		0.89			0.74	
		Cryptophyceae	*Plagioselmis lacustris*		0.87				
		Cryptophyceae	*Telonema subtile*	0.534 **					
		Dictyochophyceae	*Pseudopedinella*		0.81				
		Dinophyceae	*Gymnodinium*		0.94			0.70	
		Dinophyceae	*Peridinium inconspicuum*		0.74				
		Raphidophyceae	*Gonyostomum semen*			0.16			0.47
P1C	Highland siliceous lakes	Chlorophyceae	*Chlorococcales*			0.16			
		Chrysophyceae	*Chrysolykos skujae*		0.83				
		Chrysophyceae	*Dinobryon*		0.83				
		Chrysophyceae	*Dinobryon crenulatum*		1.00				
		Chrysophyceae	*Pseudokephyrion*	0.688 ***					
		Chrysophyceae	*Pseudokephyrion entzii*	0.905 ***	0.83				

EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P1C (cont.)	Highland siliceous lakes (cont.)	Cryptophyceae	*Katablepharis ovalis*		0.83				
		Dinophyceae	*Gymnodinium*		0.83				
		Dinophyceae	*Gymnodinium uberrimum*		1.00				
		Dinophyceae	*Peridinium inconspicuum*		0.83				
		Xanthophyceae	*Isthmochloron trispinatum*	0.688 ***					
P1H	Permanent saline and brackish lakes	Chlorophyceae	*Scenedesmus acuminatus*				0.76 ***		
		Chlorophyceae	*Scenedesmus quadricauda*					0.80	
		Cryptophyceae	*Cryptomonas erosa*						0.17
		Cryptophyceae	*Cryptomonas ovata*				0.556 ***		
		Euglenophyceae	*Euglena*					0.80	0.19
		Euglenophyceae	*Euglena acus*				0.76 ***		
		Euglenophyceae	*Euglena pisciformis*				0.76 ***		0.16
		Euglenophyceae	*Euglena proxima*				0.76 ***		0.37
		Euglenophyceae	*Phacus curvicauda*				0.76 ***		
		Trebouxiophyceae	*Chlorella*				0.694 ***		
P1N	Permanent ponds and pools	Chlorophyceae	*Chlamydomonas*					0.83	0.14
		Chlorophyceae	*Chlorococcales*					1.00	0.17
		Chrysophyceae	*Kephyrion*					0.83	
		Cryptophyceae	*Cryptomonas*					1.00	0.24
		Dinophyceae	*Glenodinium*				0.68 ***		
		Dinophyceae	*Peridinium*						0.13

4.3.2 Zooplankton communities

There were no zooplankton data included in the WISER database; therefore zooplankton has not been analysed. The analysis requires data from other sources (mostly publications and reports). Further work is needed.

4.3.3 Aquatic vegetation communities

Table 4-4 provides the list of characteristic and common species of aquatic vegetation communities in reference and impacted lakes in most of the EUNIS lake habitats. Growth forms (isoëtids, elodeids, nymphaeids, lemnids) are used instead of higher taxonomical units (e.g. class, family, except for charophytes), because they provide a better understanding of the aquatic vegetation groups. The total number of species, which is given in Table 4-1, is however much higher than the number of characteristic and common taxa, because many taxa are rare and/or do not satisfy the criteria used to identify characteristic and common species.

Differences between reference and impacted standing water habitats

The characteristic and common species are quite different in reference lakes compared to impacted lakes belonging to the same habitat type. Some of the characteristic species in siliceous reference lakes are well-known to thrive in clear lakes with low nutrient concentrations, such as isoëtids and a few elodeids, e.g. *Myriophyllum alterniflorum*. When such lakes are impacted, there is a major change in species composition with a loss of most of the isoëtids, probably due to light limitation and competition. The isoëtids remaining in siliceous impacted lakes are *Lobelia dortmanna* and *Elatine hydropiper.* The result for *Lobelia dortmanna* is astonishing, because it is known that this species is sensitive to eutrophication, even if only indirectly (Nielsen et al. 2023). The result is uncertain, as the phi-index had relatively low significance for that species. The elodeid *Juncus bulbosus*, which can develop into mass growth in some lakes, was found to be characteristic as well as common in impacted siliceous lakes.

In impacted calcareous lakes, some of the charophytes disappear, while others become characteristic (as in P16). However, the result that two charophyte-species were found to be characteristic in the impacted P16 lakes is based on only Norwegian lakes, in which the level of impact is often quite small. So, this result cannot be generalized to be valid in other parts of Europe where the level of impact may be much higher. For the other types, the comparison with reference lakes is difficult as most of the calcareous lake types have characteristic and/or common species either for reference lakes (P12) or for impacted lakes (P11, P17). We found no charophytes in the impacted lakes of P11 and P17, while we found several characteristic Chara-species in the reference lakes of P12. The latter result is consistent with the findings of Poikane et al., (2018) for good status lakes comparable to P12, in which a number of charophyte species are described as indicator species (*Chara contraria, C. hispida, C. rudis, C. tomentosa, C. vulgaris, Nitella flexilis, Nitellopsis obtusa*). They also found *Chara aspera* and *C. hispida* as indicator taxa in good status lakes equivalent to P11. Although these systems are somewhat resistant to small nutrient enrichment due to charophyte sediment stabilization, calcium precipitation and phosphorus binding, the charophytes are in fact highly sensitive to even moderate nutrient increases, which promote the growth of nymphaeids and other tall aquatic species, reducing light availability for benthic submerged charophytes (e.g. Wiik et al., 2015).

Differences between calcareous and siliceous standing water habitats in reference or good condition

The aquatic vegetation communities in lowland lakes are quite different in calcareous versus siliceous lakes, probably due to the absence of bicarbonate-requiring species in siliceous lakes. The main differences are:

- Several characteristic species were identified in the lowland calcareous lakes (P12), including a charophyte (*Nitellopsis obtusa*) and many elodeids, e.g. *Elodea canadensis* and two *Potamogeton* species. No characteristic nor common isoëtids were identified.
- In contrast, the lowland siliceous lakes (P14) have no characteristic species and only one common elodeid (*Myriophyllum alterniflorum*). Several common isoëtids, e.g. *Isoëtes lacustris* and *Lobelia dortmanna* were identified.
- The nymphaeids are also different in the calcareous versus in the siliceous lakes.

A similar comparison between the humic and calcareous (P13) versus the humic and siliceous lakes (P15) shows:

- Two characteristic nymphaeids and 9 commonly occurring species, mostly elodeids and nymphaeids in P13.
- In P15, no characteristic species was identified, but 11 common species were found, mostly isoëtids. The latter observation is surprising given the poor light conditions in humic lakes, which would suggest problems for isoëtids with their small size. This may indicate that most of the lakes identified as humic are only slightly humic allowing sufficient light for isoëtids to exist.

Differences between low-, mid-altitude, highland standing water habitats in reference or good condition

We only have reliable results for lowland lakes (see section 4.1.2), so the effect of altitude is uncertain. The only comparable types are clear siliceous lakes in lowland areas (P14) versus at mid-altitude (P18), both having no characteristic species and almost the same common species, except twice as many isoëtid species in the lowland (6 species) than at mid-altitude (3 species). This difference can be related to a warmer climate in the lowlands, but the much lower number of mid-altitude lakes (n=5) compared to lowland lakes (n=28, Table 3-1a) cause high uncertainty in this comparison. The uncertainty is also further underlined by the observations of species composition in the humic and siliceous lowland lakes (P15) versus the humic and siliceous mid-altitude lakes (P19), which had almost the same number of lakes (15 versus 5 lakes, Table 3-1a), and showed almost the same common species. One additional curiosity is the bryophyte *Fontinalis antipyretica* which was found to be characteristic in P19, but not in P15. For highland lakes, there was no data. Thus, other data sources are needed to assess the true effect of altitude on aquatic vegetation in lakes.

Differences between clear versus humic standing water habitats in reference or good condition

The lowland clear calcareous lakes (P12) have four characteristic elodeids, as well as a charophyte, while lowland calcareous humic lakes (P13), show only two characteristic species, which are nymphaeids that are well adapted to brown lakes, as their leaves float on the surface. However, there are more commonly occurring species in P13 (9 species) than in P12 (6 species). *Elodea canadensis* was only found in P12, while two *Sparganium* species were only found in P13.

In lowland siliceous lakes, the differences are between clear (P14) and humic lakes (P15) are less apparent, as the growth forms are the same and neither of these had any characteristic species. The only difference is more commonly occurring species in the humic lakes (11 species in P15) than in the clear lakes (7 species in P14), and the nymphaeid species are different: *Nuphar lutea* and *Potamogeton natans* in the humic lakes, but a *Sparganium* species in the clear lakes.

Finally, the mid-altitude siliceous lakes also show a similar pattern with more commonly occurring species in the humic lakes (13 species in P19) than in the clear ones (6 species in P18).
The general pattern with more commonly occurring species in the humic lakes than in the clear lakes is worth noting, as it was found in all the three pairs of comparable altitude and alkalinity types. The ecological explanation for this unexpected pattern is unclear, as the light conditions are less good in humic lakes than in clear lakes.

General summary of type-specific differences in aquatic vegetation in reference lakes

The major differences between the habitat types are:

- More characteristic species in calcareous than in siliceous lakes, e.g. charophytes and elodeids in calcareous lakes.
- More commonly occurring species in siliceous than in calcareous lakes, e.g. many isoëtids in siliceous lakes.
- More commonly occurring species in humic lakes than in clear lakes, especially nymphaeids which are well adapted to poor light conditions with their floating leaves.

When siliceous lakes are impacted by nutrient enrichment (eutrophication), many isoëtids are no longer common.

Most of these differences reflect differences in natural productivity, nutrient enrichment and light conditions of different types, and are in line with previous papers, e.g. Lesiv et al., 2020 (review paper).

Table 4-4. Aquatic vegetation in reference and impacted lakes: Characteristic (diagnostic) and common (constant) taxa. Characteristic taxa were identified by the phi-index with the highest significance level p≤0.001 marked * or p≤0.01 marked **. Common taxa identified with a frequency of occurrence ≥0.5 (50%). Dominant taxa were not identified as the data were only presence/absence. Helophytes and mosses (Bryophyta) identified within aquatic vegetation surveys are not included in the table, except from *Fontinalis* (genus of aquatic moss).**

EUNIS L3 code	EUNIS L3 name	Growth form	Taxon name	Taxa in reference lakes		Taxa in impacted lakes	
				Characteristic	Common	Characteristic	Common
P11	Lowland, very shallow to shallow, calcareous or mixed lakes	Elodeid	*Potamogeton perfoliatus*				0.70
		Nymphaeid	*Nuphar lutea*				0.70
		Nymphaeid	*Potamogeton natans*				0.70
P12	Lowland, shallow to deep, calcareous or mixed lakes	Charophyte	*Chara contraria*	0.53 **			
		Charophyte	*Chara tomentosa*	0.53 **			
		Charophyte	*Charophyta*	0.53 **			
		Charophyte	*Nitellopsis obtusa*	0.583 **			
		Elodeid	*Ceratophyllum demersum*	0.583 **			
		Elodeid	*Elodea canadensis*		0.69		
		Elodeid	*Myriophyllum spicatum*	0.679 ***	0.50		
		Elodeid	*Potamogeton filiformis*	0.53 **			
		Elodeid	*Potamogeton lucens*	0.679 ***	0.50		
		Elodeid	*Potamogeton perfoliatus*		0.88		
		Nymphaeid	*Nuphar lutea*		0.63		
		Nymphaeid	*Potamogeton natans*		0.69		
P13	Lowland, humic lakes on calcareous or mixed bedrock	Elodeid	*Myriophyllum alterniflorum*		0.54		
		Elodeid	*Potamogeton gramineus*		0.54		
		Elodeid	*Potamogeton perfoliatus*		0.85		
		Lemnid	*Lemna minor*	0.525 **			0.52

EUNIS L3 code	EUNIS L3 name	Growth form	Taxon name	Taxa in reference lakes		Taxa in impacted lakes	
				Characteristic	Common	Characteristic	Common
P13 (cont.)	Lowland, humic lakes on calcareous or mixed bedrock (cont.)	Nymphaeid	*Nuphar lutea*		0.85		
		Nymphaeid	*Nymphaea alba*	0.707 ***	0.54		
		Nymphaeid	*Potamogeton natans*		0.77		
		Nymphaeid	*Sparganium emersum*	0.651 **			
P14	Lowland siliceous lakes	Elodeid	*Juncus bulbosus*			0.765 ***	0.56
		Elodeid	*Myriophyllum alterniflorum*		0.84		
		Isoëtid	*Eleocharis acicularis*		0.52		
		Isoëtid	*Isoëtes echinospora*		0.58		
		Isoëtid	*Isoëtes lacustris*		0.77		
		Isoëtid	*Lobelia dortmanna*		0.65		
		Isoëtid	*Ranunculus reptans*		0.77		
		Isoëtid	*Subularia aquatica*		0.58		
		Nymphaeid	*Sparganium angustifolium*		0.71		
P15	Lowland, humic lakes on siliceous bedrock	Bryophyta	*Fontinalis antipyretica*				0.65
		Elodeid	*Myriophyllum alterniflorum*		0.75		
		Elodeid	*Potamogeton perfoliatus*		0.50		
		Elodeid	*Utricularia vulgaris*				0.55
		Isoëtid	*Elatine hydropiper*			0.49 ***	
		Isoëtid	*Eleocharis acicularis*		0.60		
		Isoëtid	*Isoëtes echinospora*		0.75		
		Isoëtid	*Isoëtes lacustris*		0.85		
		Isoëtid	*Littorella uniflora*		0.55		
		Isoëtid	*Lobelia dortmanna*		0.85	0.431 **	
		Isoëtid	*Ranunculus reptans*		0.75		

EUNIS L3 code	EUNIS L3 name	Growth form	Taxon name	Taxa in reference lakes		Taxa in impacted lakes	
				Characteristic	Common	Characteristic	Common
		Isoëtid	*Subularia aquatica*		0.65		
		Nymphaeid	*Nuphar lutea*		0.65		
		Nymphaeid	*Nymphaea alba* ssp. *candida*	0.518 **			0.53
		Nymphaeid	*Potamogeton natans*		0.60		
		Nymphaeid	*Sagittaria natans*			0.453 **	
		Nymphaeid	*Sparganium emersum*				0.57
		Nymphaeid	*Sparganium gramineum*				0.59
P16	Mid-altitude, calcareous or mixed lakes	Charophyte	*Chara aspera*				0.50
		Charophyte	*Chara rudis*			0.902 ***	0.63
		Charophyte	*Chara tomentosa*			0.798 ***	0.50
		Elodeid	*Myriophyllum alterniflorum*		0.71		
		Elodeid	*Potamogeton alpinus*		0.57		
		Elodeid	*Potamogeton filiformis*			0.724 ***	0.50
		Nymphaeid	*Nuphar lutea*				0.75
		Nymphaeid	*Nymphaea alba*			0.62 ***	0.50
		Nymphaeid	*Potamogeton natans*				0.63
P17	Mid-altitude, humic lakes on calcareous or mixed bedrock	Elodeid	*Myriophyllum alterniflorum*				0.78
		Elodeid	*Potamogeton alpinus*				0.67
		Elodeid	*Potamogeton berchtoldii*				0.56
		Elodeid	*Potamogeton perfoliatus*				1.00
		Elodeid	*Ranunculus peltatus*				0.78
		Isoëtid	*Eleocharis acicularis*				0.56
		Isoëtid	*Isoëtes lacustris*				0.56
		Isoëtid	*Ranunculus reptans*				0.78

EUNIS L3 code	EUNIS L3 name	Growth form	Taxon name	Taxa in reference lakes		Taxa in impacted lakes	
				Characteristic	Common	Characteristic	Common
		Nymphaeid	*Nuphar lutea*				0.89
		Nymphaeid	*Sparganium angustifolium*				0.67
P18	Mid-altitude siliceous lakes	Elodeid	*Myriophyllum alterniflorum*		0.60		
		Elodeid	*Ranunculus peltatus*		0.60		
		Isoëtid	*Isoëtes echinospora*		0.60		
		Isoëtid	*Ranunculus reptans*		0.60		
		Isoëtid	*Subularia aquatica*		0.60		
		Nymphaeid	*Sparganium angustifolium*		0.60		
P19	Mid-altitude, humic lakes on siliceous bedrock	Elodeid	*Myriophyllum alterniflorum*		0.60		
		Isoëtid	*Eleocharis acicularis*		0.60		
		Isoëtid	*Isoëtes echinospora*		0.80		
		Isoëtid	*Isoëtes lacustris*		0.60		
		Isoëtid	*Ranunculus reptans*		0.60		
		Isoëtid	*Subularia aquatica*		0.80		
		Nymphaeid	*Nuphar x spenneriana*				0.54
		Nymphaeid	*Sparganium gramineum*		0.60		

4.3.4 Fish communities

Table 4-5 provides the number of lakes with fish data in the different habitat types. Table 4-6 provides the list of characteristics, common and dominant taxa of fish communities in reference and impacted lakes in most of the EUNIS level 3 habitat types. The total number of species which is given in **Error! Reference source not found.** is however higher than the number of characteristic, common and/or dominant taxa. The dominant taxon in almost all the habitat types is perch, contributing on average to more than 40% of the total number of individuals in the lakes in each type. However, the dominance data are uncertain due to unclear methods used by different countries to calculate the number of individuals per lake and species.

Table 4-5. Number of lakes with fish data in different habitat types, extract from Table 3a.

EUNIS L3 code	EUNIS L3 name	# of lakes	
		Reference	Impacted
P11	Lowland, very shallow to shallow, calcareous or mixed lakes	-	13
P12	Lowland, shallow to deep, calcareous or mixed lakes	10	54
P13	Lowland, humic lakes on calcareous or mixed bedrock	6	51
P14	Lowland siliceous lakes	17	5
P15	Lowland, humic lakes on siliceous bedrock	28	40
P17	Mid-altitude, humic lakes on calcareous or mixed bedrock	-	5
P18	Mid-altitude siliceous lakes	23	-
P19	Mid-altitude, humic lakes on siliceous bedrock	22	11
P1C	Highland siliceous lakes	7	-
P1M	Very large lakes	5	11

Differences in species composition between calcareous and siliceous standing water habitats in reference or good condition

The major difference is that more cyprinid species are characteristic, common and dominant in the calcareous lakes than in the siliceous lakes, where no cyprinids are characteristic and only one cyprinid (*Rutilus rutilus*) is commonly occurring and dominant. The salmonid *Coregonus lavaretus* is only dominant in the siliceous lakes.

Differences in species composition in low-, middle-altitude, highland standing water habitats in reference or good condition

There are slightly more common species in the siliceous lowland lakes (P14 & P15) than in the siliceous mid-altitude lakes (P18 & P19) (Table 4-6) which could be due to the general pattern of fewer species present in colder habitats, as seen in Table 4-2. The only common species found in highland siliceous reference lakes (P1C) is brown trout (*Salmo trutta*).

Differences in species composition in clear versus humic standing water habitats in reference or good condition

For calcareous lakes, there are more common fish species in the clear lakes (P12) than in the humic lakes (P13). For the siliceous lakes, the results are opposite with more commonly occurring species in humic lakes (P15 & P19), e.g. pike (*Esox lucius*) and smelt (*Osmerus eperlanus*) than in clearwater lakes (P14 & P18). The underlying reasons for these different effects of humic substances in calcareous versus siliceous lakes are unclear.

Differences between reference and impacted standing water habitats

There are more common and dominant cyprinids in impacted lakes than in reference lakes. In contrast, there are fewer characteristic and common salmonids in impacted lakes than in reference lakes.

Table 4-6 Fish in (a) reference and (b) impacted lakes: Characteristic (diagnostic), common (constant) and dominant taxa. Characteristic taxa were identified by the phi-index with the highest significance level p≤0.001 marked * or p≤0.01 marked **. Common taxa identified with a frequency of occurrence ≥0.5 (50%). Dominant taxa identified with a mean relative abundance ≥0.1 (10% of the total numbers of individuals). Note that there were no characteristic taxa identified for impacted lakes at the given significance level.**

EUNIS L3 code	EUNIS L3 name	Family	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P11	Lowland, very shallow to shallow, calcareous or mixed lakes	Cyprinidae	*Abramis brama*					0.57	
		Cyprinidae	*Blicca bjoerkna*						0.2
		Cyprinidae	*Rutilus rutilus*					0.86	0.36
		Cyprinidae	*Scardinius erythrophthalmus*					0.64	0.23
		Esocidae	*Esox lucius*					0.86	
		Percidae	*Gymnocephalus cernuus*					0.57	
		Percidae	*Perca fluviatilis*					0.93	0.42
P12	Lowland, shallow to deep, calcareous or mixed lakes	Cyprinidae	*Abramis brama*	0.88 ***	0.8	0.16		0.84	
		Cyprinidae	*Alburnus alburnus*		0.6			0.61	0.1
		Cyprinidae	*Blicca bjoerkna*	0.75 ***	0.6			0.6	0.1
		Cyprinidae	*Rutilus rutilus*		0.9	0.42		0.89	0.32
		Cyprinidae	*Scardinius erythrophthalmus*	0.816 ***	0.7			0.61	
		Cyprinidae	*Tinca tinca*	0.679 ***	0.5				
		Esocidae	*Esox lucius*		0.7	0.13		0.74	
		Gasterosteidae	*Gasterosteus aculeatus*						0.13
		Osmeridae	*Osmerus eperlanus*						0.26
		Percidae	*Gymnocephalus cernuus*		0.8			0.79	0.19
		Percidae	*Perca fluviatilis*		1	0.44		0.95	0.48
		Percidae	*Sander lucioperca*						0.1

EUNIS L3 code	EUNIS L3 name	Family	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
		Salmonidae	*Coregonus albula*		0.9	0.36			0.47
		Salmonidae	*Salmo trutta fario*						0.48
P13	Lowland, humic lakes on calcareous or mixed bedrock	Cyprinidae	*Abramis brama*					0.74	0.1
		Cyprinidae	*Blicca bjoerkna*					0.42	0.14
		Cyprinidae	*Hybrids cyprinid*						0.11
		Cyprinidae	*Rutilus rutilus*		1	0.39		0.91	0.39
		Cyprinidae	*Scardinius erythrophthalmus*		0.5				
		Esocidae	*Esox lucius*		0.67			0.79	
		Percidae	*Gymnocephalus cernuus*		0.83	0.15		0.61	0.11
		Percidae	*Perca fluviatilis*		1	0.4		0.89	0.37
		Salmonidae	*Salmo trutta fario*						0.59
P14	Lowland siliceous lakes	Cyprinidae	*Rutilus rutilus*			0.34			
		Esocidae	*Esox lucius*					0.6	
		Percidae	*Gymnocephalus cernuus*			0.29		0.6	0.53
		Percidae	*Perca fluviatilis*		0.76	0.67		0.8	0.79
		Salmonidae	*Salmo trutta*			0.85			
P15	Lowland, humic lakes on siliceous bedrock	Cyprinidae	*Abramis brama*					0.51	
		Cyprinidae	*Alburnus alburnus*			0.13			
		Cyprinidae	*Rutilus rutilus*		0.89	0.35		0.83	0.36
		Esocidae	*Esox lucius*		0.86			0.8	
		Osmeridae	*Osmerus eperlanus*	0.505 **		0.3			
		Osmeridae	*Osmerus eperlanus*						0.14
		Percidae	*Gymnocephalus cernuus*		0.75	0.16		0.56	

EUNIS L3 code	EUNIS L3 name	Family	Taxon name	Taxa in reference lakes			Taxa in impacted lakes		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
		Percidae	*Perca fluviatilis*		1	0.58		0.98	0.59
		Salmonidae	*Coregonus albula*			0.23			
P17	Mid-altitude, humic lakes on calcareous or mixed bedrock	Cyprinidae	*Rutilus rutilus*					0.6	0.44
		Esocidae	*Esox lucius*					0.8	
		Percidae	*Perca fluviatilis*					1	0.68
P18	Mid-altitude siliceous lakes	Salmonidae	*Salmo trutta*		0.65	0.84			
		Salmonidae	*Salvelinus umbla*	0.583 **		0.88			
P19	Mid-altitude, humic lakes on siliceous bedrock	Cyprinidae	*Rutilus rutilus*		0.64	0.28			0.38
		Esocidae	*Esox lucius*		0.59			1	0.13
		Lotidae	*Lota lota*	0.642 ***		0.32			
		Percidae	*Perca fluviatilis*		0.95	0.7		1	0.85
		Salmonidae	*Coregonus lavaretus*			0.44			
P1C	Highland siliceous lakes	Salmonidae	*Salmo trutta*		0.86	0.99			

5 Results for biology in running waters

This chapter provides the following results for benthic algae, aquatic vegetation, benthic invertebrates and fish:

- 5.1: Similarity analysis of species composition in different L3 habitats, including separate analysis for reference communities and impacted communities.
- 5.2: Species richness per habitat type.
- 5.3: Characteristic, common and dominant species per L3 habitat type for habitats with sufficient data (acc. to Table 3-1). Dominant species could only be given for fish, because abundance data were missing for the other major biological groups (Table 3-2).

5.1 Similarity analysis of species composition in different L13 habitats

The results of the multivariate analysis show quite a good separation of the EUNIS level 3 habitat types with sufficient data to enable such an analysis (

Figure 5-1

Figure 5-2,

Figure 5-3,

Figure 5-4 for benthic algae, aquatic vegetation, benthic invertebrates and fish, respectively).

5.1.1 Benthic algae

The results (

Figure 5-1) show quite a clear distinction between siliceous (P24, P28, P2C, P2G, P2L) versus calcareous (P22, P26, P2A, P2E, P2J) rivers, (see also

Figure 5-1b showing separate clusters for the siliceous and calcareous river types). Altitude also has an effect, showing separate clusters for lowland, mid-altitude and highland rivers for each of the two geology types (siliceous or calcareous). The glacial rivers (P2R) are obviously very different from all the other habitats, indicating a very different species composition there. However, there is little response to catchment size, especially for lowland siliceous rivers and for mid-altitude calcareous rivers, which partly cover each other in

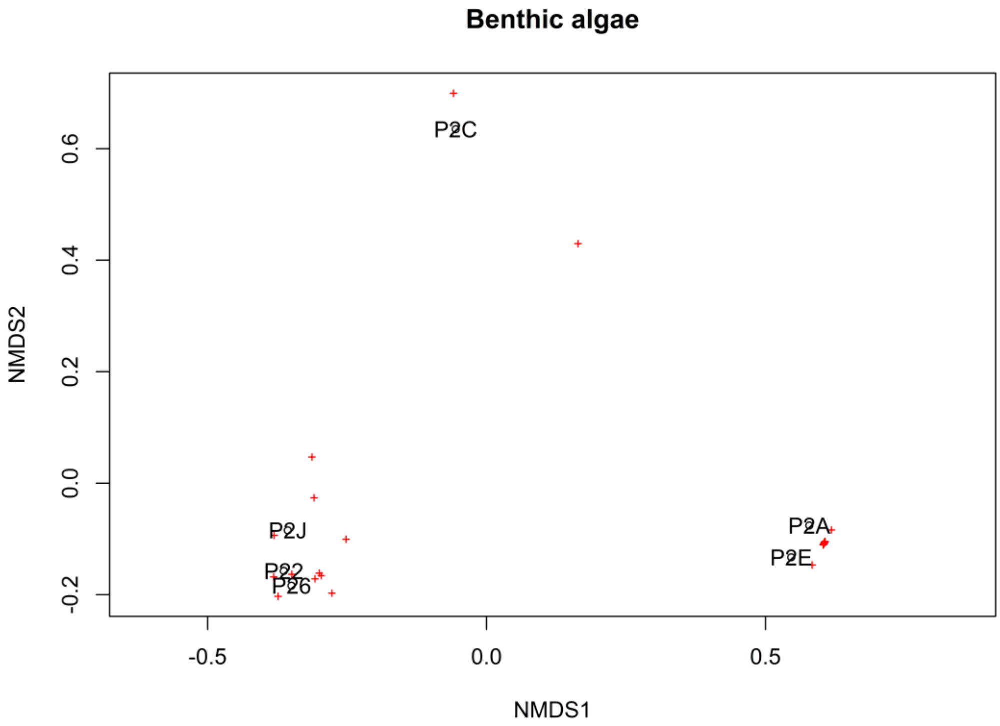
Figure 5-1a and show a very high similarity in **Error! Reference source not found.**b.

This indicates that geology (alkalinity) is the most important type-descriptor for the occurrence of benthic algae species. Climatic conditions in the different altitude categories are also important for the composition of the benthic algae community in reference rivers.

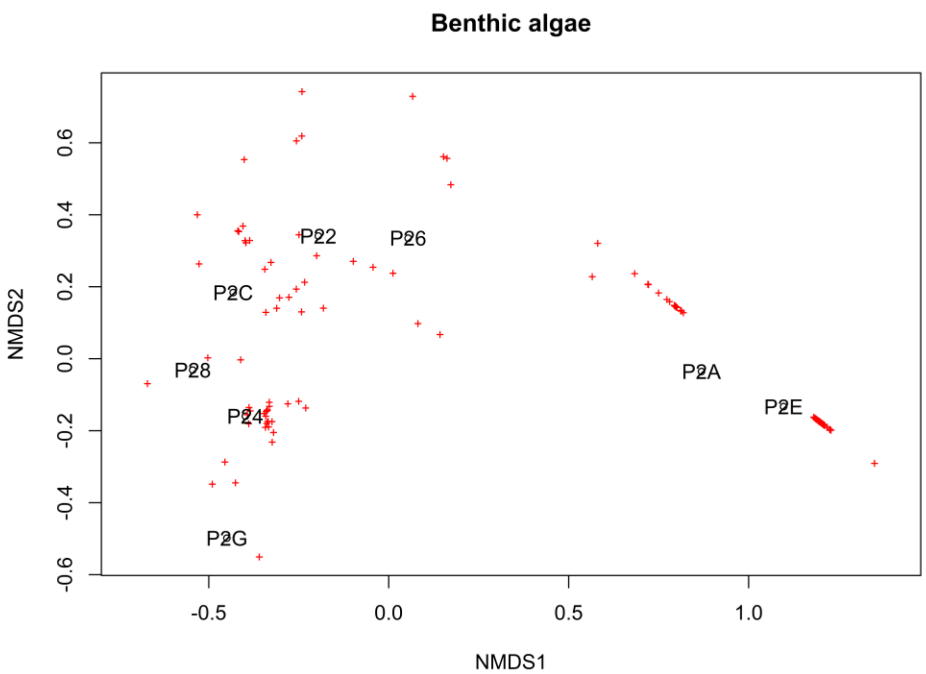
The effect of humic substances could not be tested due to the small amount of data available.

Figure 5-1 Multivariate analysis of the differences between selected EUNIS level 3 habitat types for reference and impacted rivers based on their benthic algae communities. (a, b) NMDS plots, (c, d) cluster analysis.

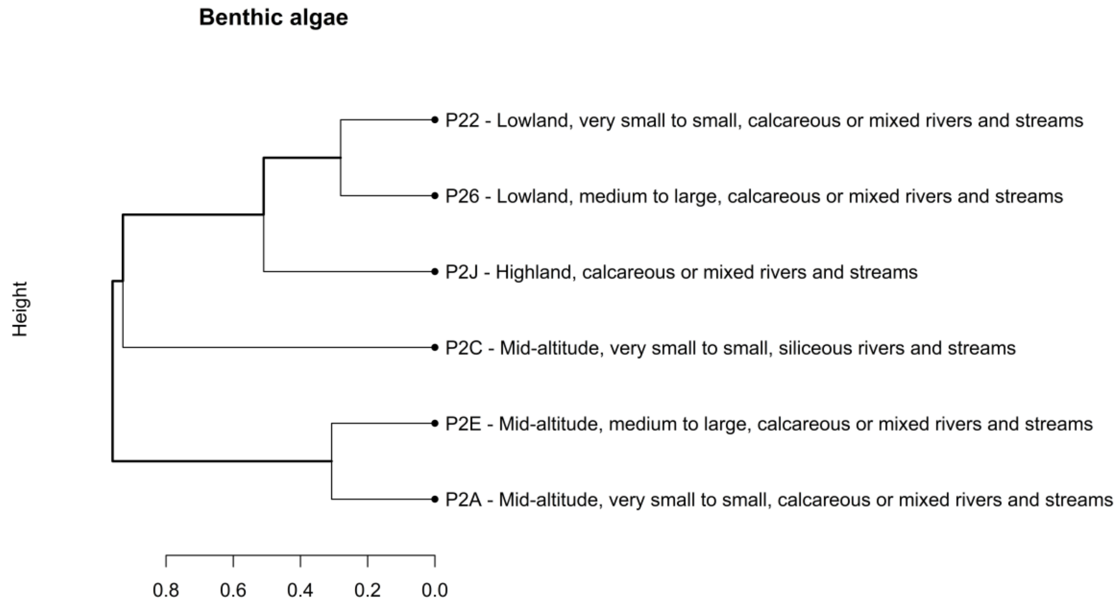
a) NMDS plot of reference rivers



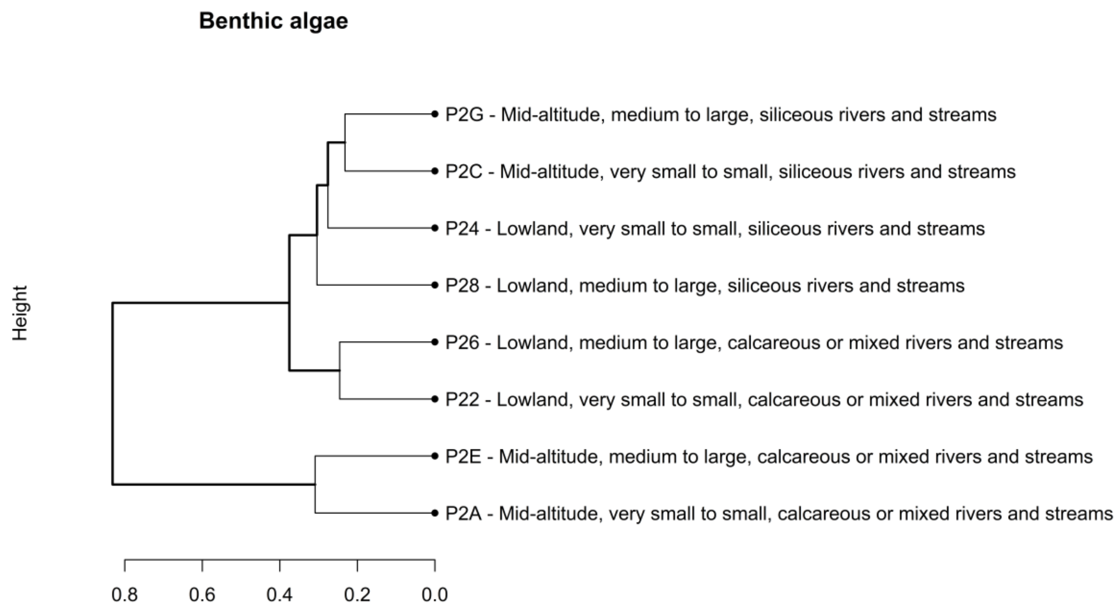
b) NMDS plot of impacted rivers



c) Cluster analysis of reference rivers



d) Cluster analysis of impacted rivers



The differences between benthic algae communities in reference rivers and impacted rivers are unclear for several habitat types as data are only available either for reference rivers (highland calcareous rivers, P2J) or for impacted rivers (P2G, P24, P28). However, the mid-altitude small siliceous rivers (P2C) get more similar to other small lowland calcareous rivers (P22, P26) than we see for reference rivers in

Figure 5-1a and

Figure 5-1c where the benthic algae in P2C are quite different from P22 and P26. This indicates that human impact (mainly nutrient pollution causing eutrophication) favours the same nutrient-requiring species regardless of geology and altitude patterns. In contrast, the mid-altitude calcareous rivers (P2A, P2E) are very different from the other habitat types in both reference rivers and impacted rivers.

5.1.2 Aquatic vegetation

The results

Figure 5-2 show quite a clear distinction between siliceous (P24, P28, P2C, P2G, P2L) versus calcareous (P22, P26, P2A, P2E, P2J) rivers (see also

Figure 5-2b showing separate clusters for the siliceous and calcareous river types). Altitude also has an effect, showing separate clusters for lowland, mid-altitude and highland rivers for each of the two geology types (siliceous or calcareous). The glacial rivers (P2R) are rather similar to highland, calcareous rivers (P2J), which is most likely due to the data for these two habitats that are from the same Alpine countries (AT & FR, Table 3-1b). These two habitats are obviously very different from all the other habitats, indicating a very different species composition there. However, there is little response to catchment size, especially for siliceous rivers (P24 & P26), which partly cover each other in

Figure 5-2a and show a very high similarity in

Figure 5-2b. For lowland calcareous rivers (P22 & P26) the similarity is also relatively high.

This indicates that geology (alkalinity) is the most important factor for the occurrence of aquatic vegetation species, and that climatic conditions found in the different altitude categories are also important for the composition of the aquatic vegetation community in reference rivers.

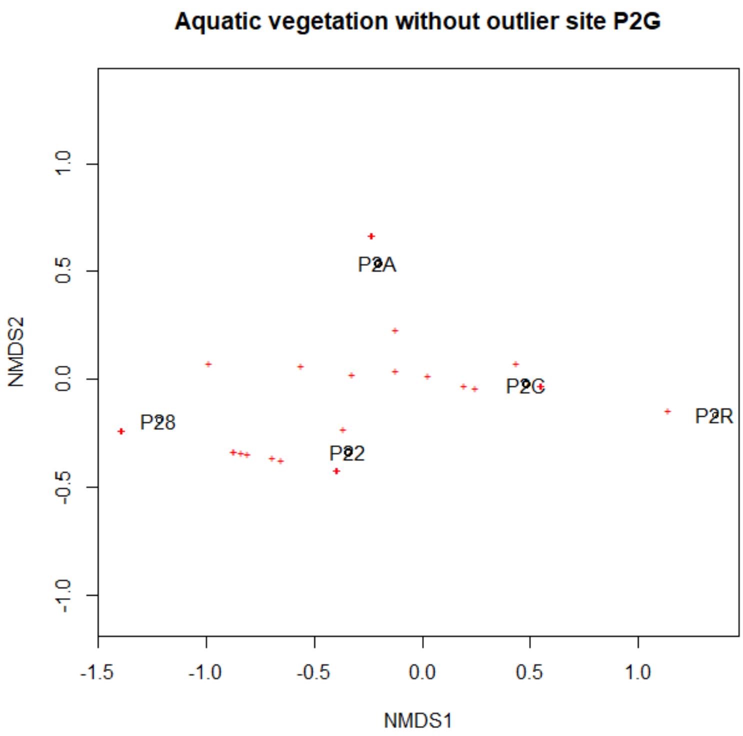
The effect of humic substances could not be tested due to the low amount of data available.

The effect of human impact on the aquatic vegetation in rivers is highly variable for different habitat types. In impacted mid-altitude, siliceous rivers (the small P2C and the larger P2G rivers) the aquatic vegetation is more similar compared to reference rivers of the same types, in which the vegetation is quite different (

Figure 5-2). This indicates that nutrient pollution mostly favours the species that thrive in eutrophied siliceous rivers regardless of their catchment size. In contrast, there is no clear difference between the aquatic vegetation in reference rivers compared to impacted rivers for the habitat types P2A and P2E, which are mid-altitude calcareous small or large rivers respectively. The same can be said about the equivalent lowland calcareous small or large rivers (P22 and P26), which have highly similar aquatic vegetation in both reference and impacted rivers. This may indicate that calcareous rivers are less sensitive to nutrient enrichment than siliceous rivers.

Figure 5-2 Multivariate analysis of the differences between selected EUNIS level 3 habitat types for reference and impacted rivers based on their aquatic vegetation (macrophytes) communities. (a, b) NMDS plots, (c, d) cluster analysis.

a) NMDS plot of reference rivers[1]:



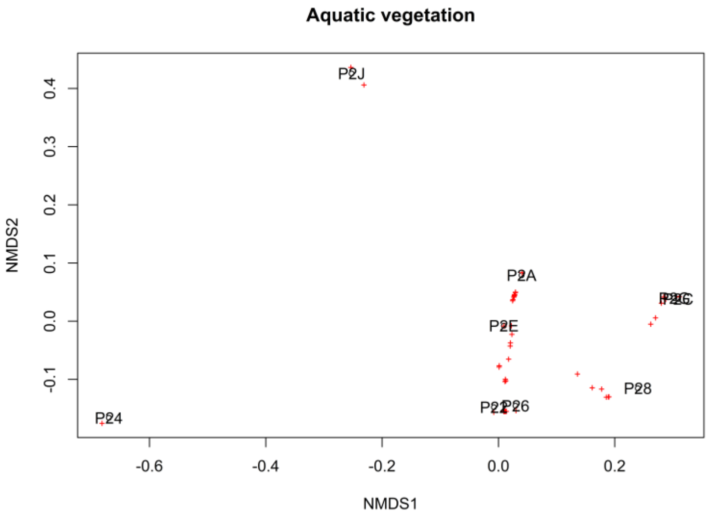
b) NMDS plot of impacted rivers[2]:

[1] The cluster analysis (

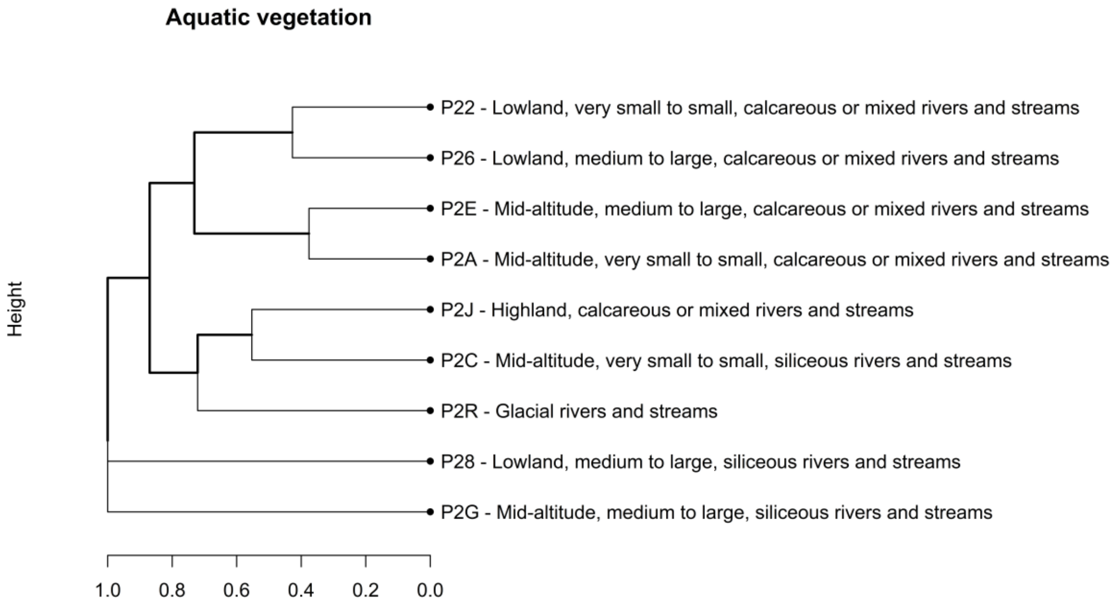
Figure 5-2c) shows several clusters that lead to an overplotted NMDS. Only excluding the outlier P2G gave more of an illustrative NMDS, but note that EUNIS habitat types, visualized in this NMDS plot, actually represents the whole clusters.

[2] The figure is overplotted. See the cluster analysis (

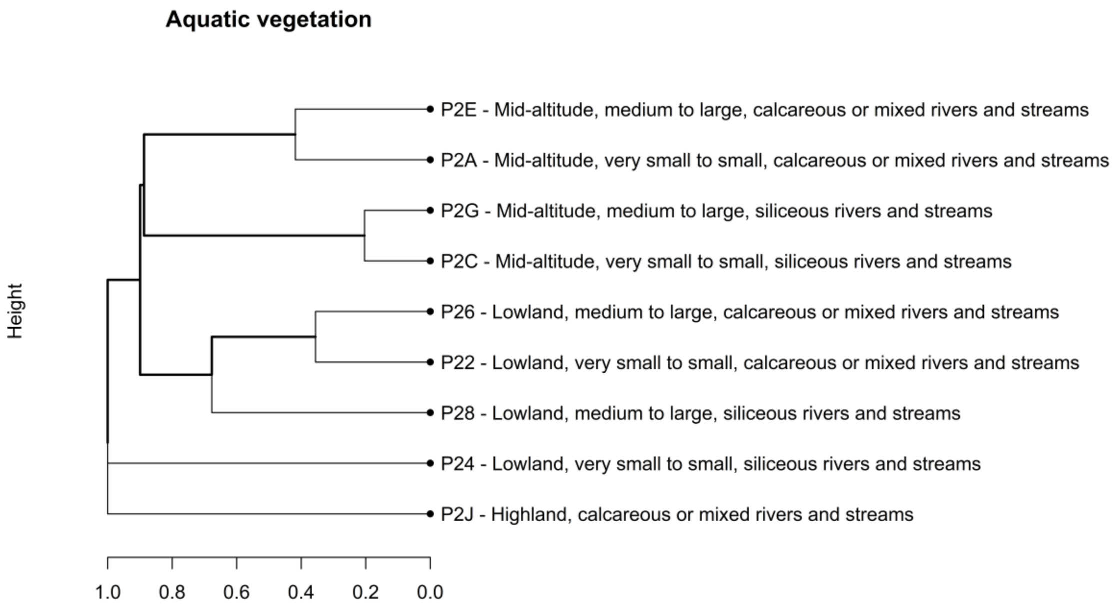
Figure 5-2d) for a better illustration


Aquatic vegetation
P2J
P2A
P2E
P26
P28
P24
NMDS1
NMDS2
-0.6
-0.4
-0.2
0.0
0.2
-0.1
0.0
0.1
0.2
0.3
0.4

c) Cluster analysis of reference rivers



d) Cluster analysis of impacted rivers



5.1.3 Benthic invertebrates

The results

Figure 5-3 show quite a clear distinction between siliceous (P24, P28, P2C, P2G, P2L) versus calcareous (P22, P26, P2A, P2E, P2J) rivers (see also

Figure 5-3b showing separate clusters for the siliceous and calcareous river types). Altitude also has an effect, showing separate clusters for lowland, mid-altitude and highland rivers for each of the two geology types (siliceous or calcareous). The glacial rivers (P2R) are rather similar to highland, calcareous rivers (P2J), probably because the data for these two habitats are mainly from the same Alpine countries (AT & FR,

Error! Reference source not found.b). As for the benthic algae and aquatic vegetation, there is little response to catchment size, especially for lowland siliceous rivers and for both pairs of small and larger lowland and mid-altitude calcareous rivers. Worth noting is the very high similarity between the two size classes of lowland calcareous rivers (P22 and P26) in both

Figure 5-3a and

Figure 5-3b.
This indicates that geology (alkalinity) is most important for the occurrence of benthic invertebrate species and that climatic conditions found in the different altitude categories are also important for the composition of the benthic invertebrate community in reference rivers.

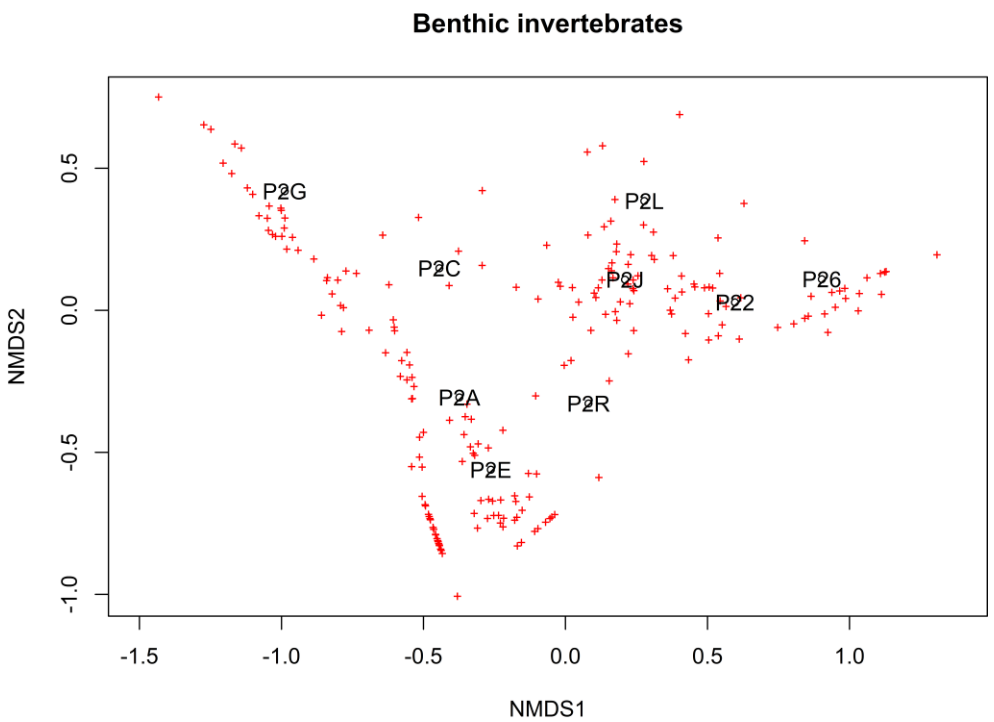
The effect of humic substances could not be tested due to the small amount of data available.

The benthic invertebrate communities differ between the reference rivers and impacted rivers (

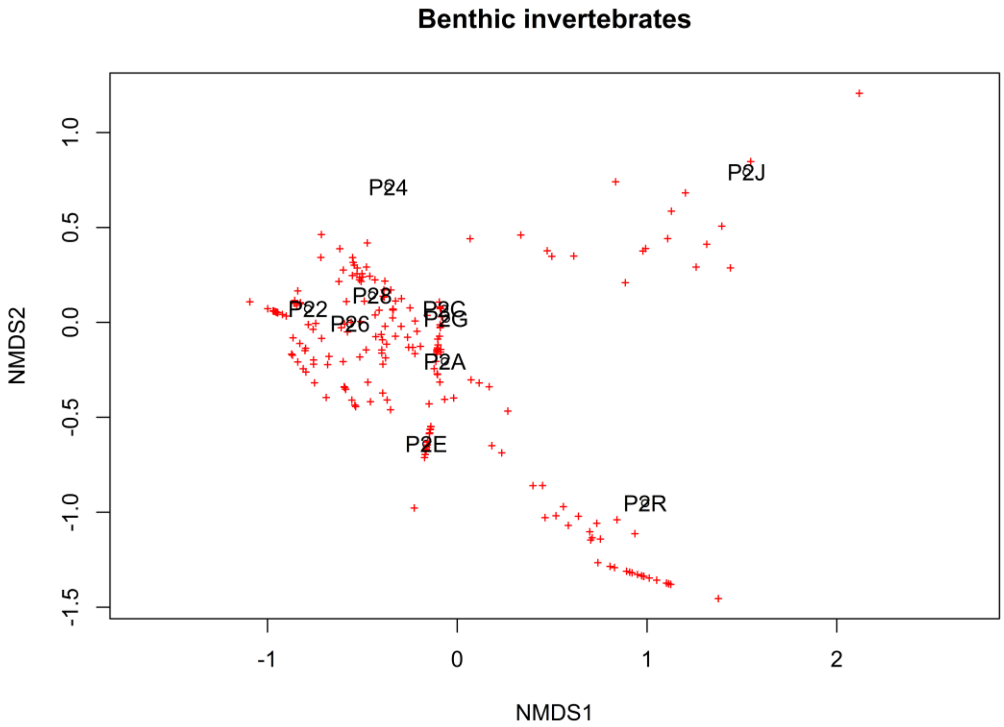
Figure 5-3). There is a higher similarity in impacted rivers than in reference rivers for many of the habitat types, e.g. for P2C and P2G, and for P2A and P2E, which may indicate that human impact favours the same species in these habitats. For several other habitat types, e.g. P22 and P26 (lowland, calcareous rivers), the similarity is roughly the same in reference rivers as it is in impacted rivers, indicating that catchment size is not important for the species composition of benthic invertebrates.

Figure 5-3 Multivariate analysis of the differences between selected EUNIS level 3 habitat types for reference and impacted rivers based on their benthic invertebrate communities. (a, b) NMDS plots, (c, d) cluster analysis.

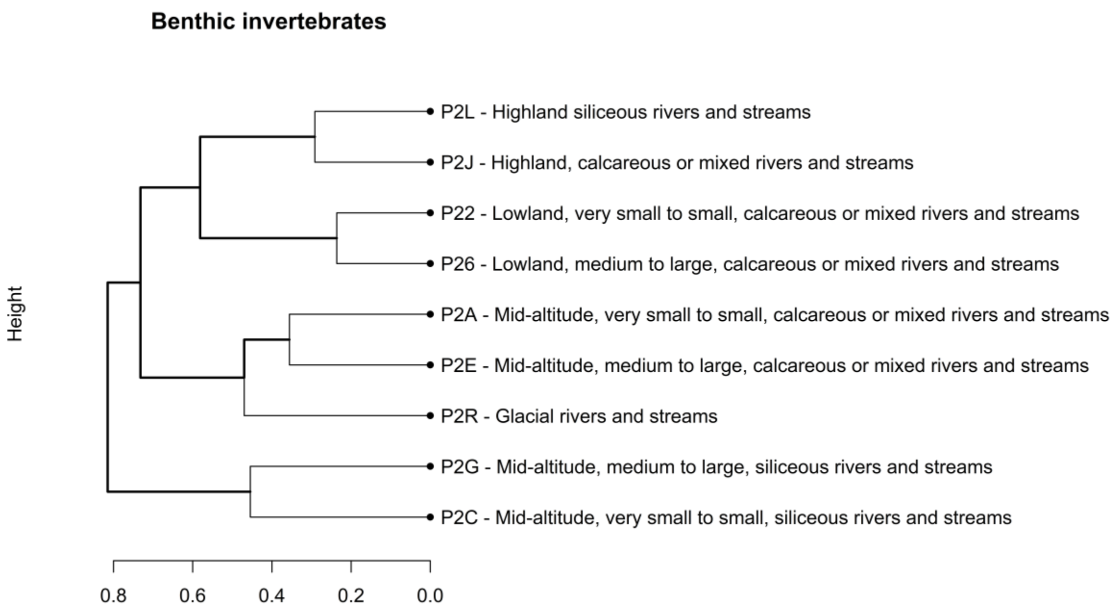
a) NMDS plot of reference rivers



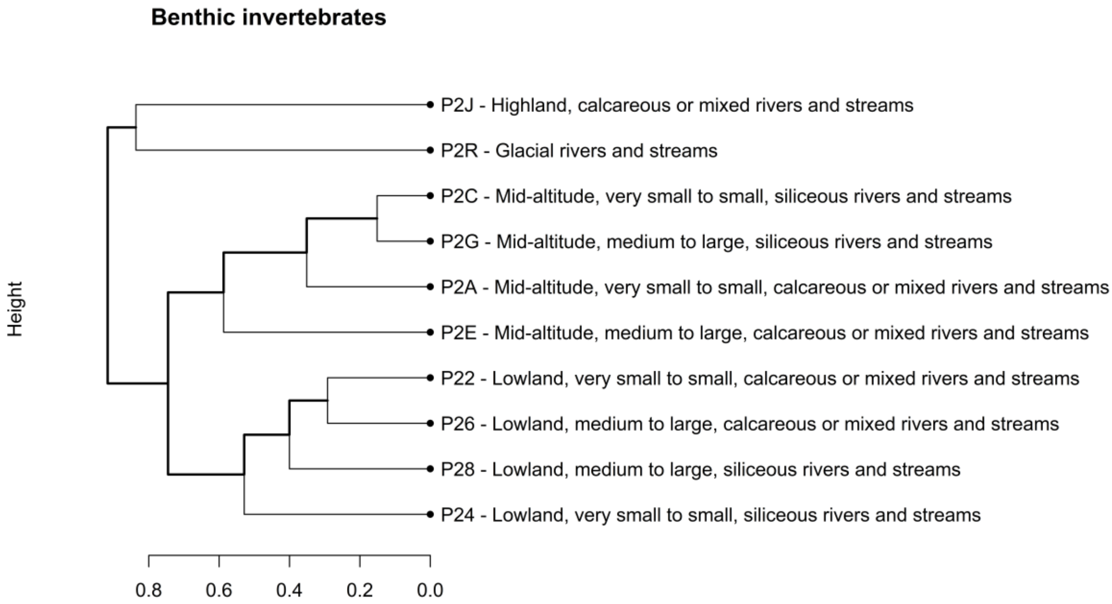
b) NMDS plot of impacted rivers



c) Cluster analysis of reference rivers



d) Cluster analysis of impacted rivers



5.1.4 Fish

The results (

Figure 5-4) show a less clear distinction between siliceous (P24, P28, P2C, P2G, P2L) versus calcareous (P22, P26, P2A, P2E, P2J) rivers, than what is found for the other biological groups in rivers. Although, the small and larger lowland siliceous rivers (P24 & P28) have a high similarity, the other pairs of habitats with a high similarity have the same altitude type and the same catchment size category, but not the same geology: P2C & P2A. Moreover, altitude is the only common factor for the cluster glacial and highland rivers (P2R, P2J & P2L). Finally, there are two habitats with a high similarity, but not having many of the major habitat type-descriptors in common, as they have a different altitude, different catchment size and different geology: P2G & P22 (the upper pair of habitats in the cluster diagram). The data underlying the P2G and P22 fish communities are both dominated by French and partly German rivers, which may suggest a regional factor, e.g. that these rivers are in the same major catchment, such as the Rhine. A closer look at the actual fish species present in P2G and P22 shows that all the species in P2G are also present in P22 (section 5.3.4 for more details).

This indicates that altitude (climatic conditions) and catchment size are most important for the structure of reference fish communities, and that geology is less important for the occurrence of fish than for the other biological groups in rivers. Moreover, additional factors, such as bioregion and/or slope may also play a role for structuring the composition of fish communities in reference rivers (and in impacted rivers). The latter is in line with results from the AMBER project, in which habitat types suitable to distinguish different fish communities are identified to include bioclimatic regions and slope (flow) in addition to the same type-descriptors as those used for the revised EUNIS L3 river types (Parasiewicz et al., 2023). Those additional factors could be relevant to include at level 4. In chapter 6 the effect of region is considered, while the effect of flow is considered at the general level in the L3 habitat descriptions given in the crosswalk file (column C).

In impacted rivers, fish communities show a higher similarity than in reference rivers for all the lowland types with data for both impacted and reference rivers (

Figure 5-4c and