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) <u>Abiotic approach</u>
   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) <u>Floristic approach</u> (main approach for ***terrestrial*** habitat types but also used in some ***marine*** and ***inland surface water*** types)
c) <u>Faunistic approach (mainly benthic invertebrates and fish) added for ***inland surface water*** types and in marine habitats</u>

(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 >100km^2 surface area, permanent ponds and pools (P1N) with <2ha surface area and very large rivers (P2S) with a catchment size >10 000km^2 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 $p \leq 0.001$ (***) and $p \leq 0.01$ (**). 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 (

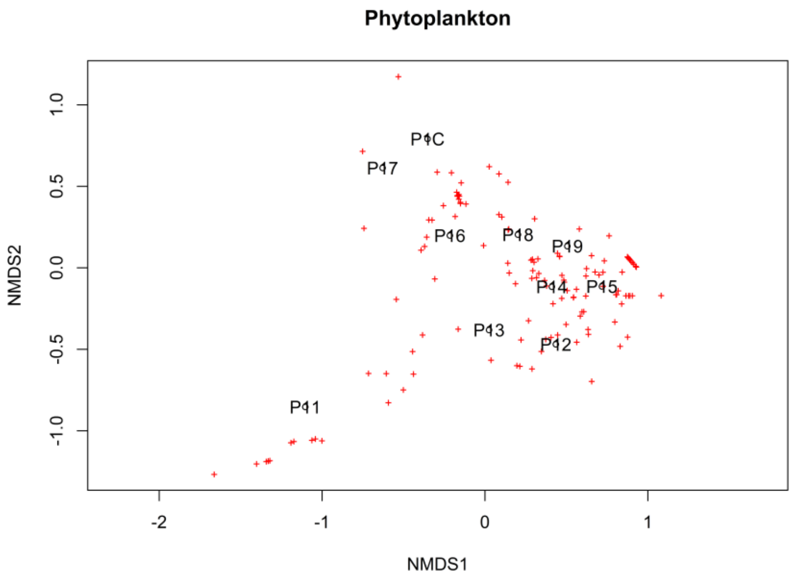
Figure 4-1b,

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.

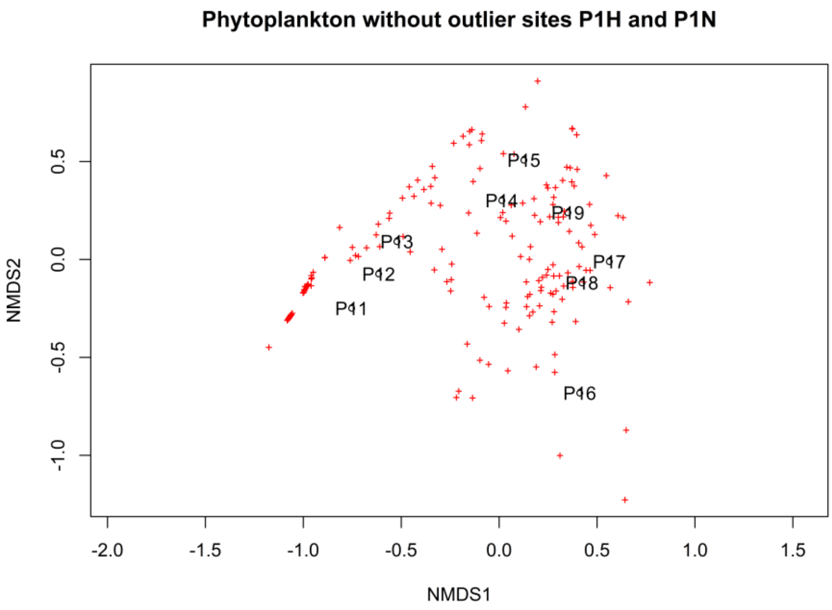
Figure 4-1 Multivariate analysis of differences between selected EUNIS level 3 habitat types for reference and impacted lakes based on their phytoplankton communities. (a, b) NMDS plots, (c, d) cluster analysis.

a) NMDS plot of reference lakes



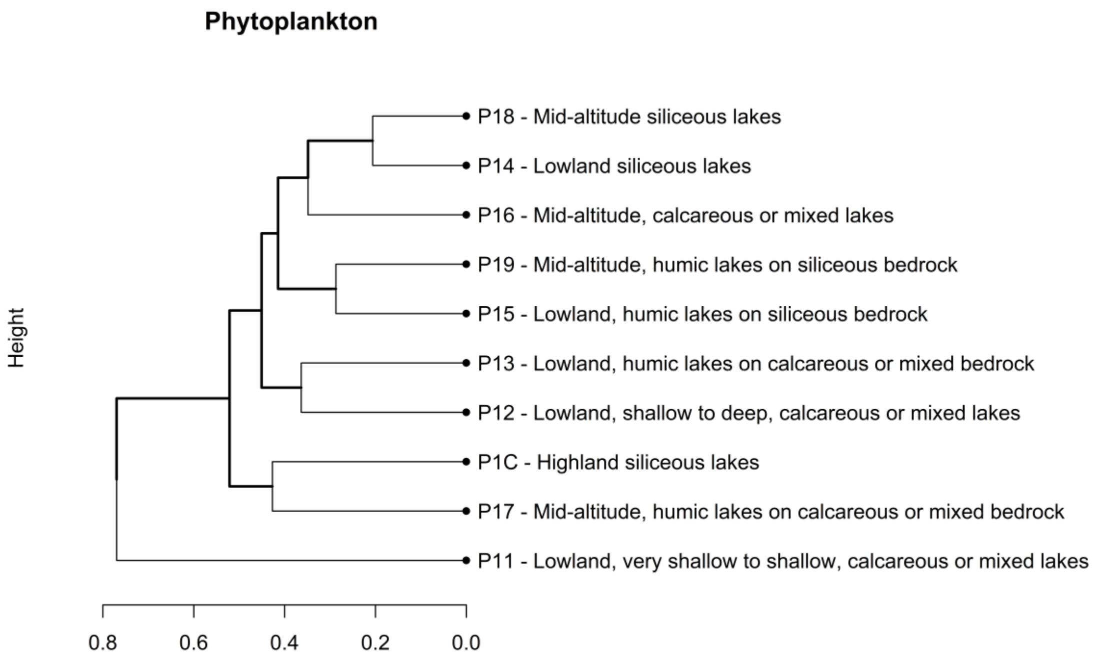
b) NMDS plot of impacted lakes: P1H and P1N were removed from the NMDS plot to better capture the differences in phytoplankton communities for the other habitats. Those habitats are included in the cluster analysis (

c) Figure 4-1d)

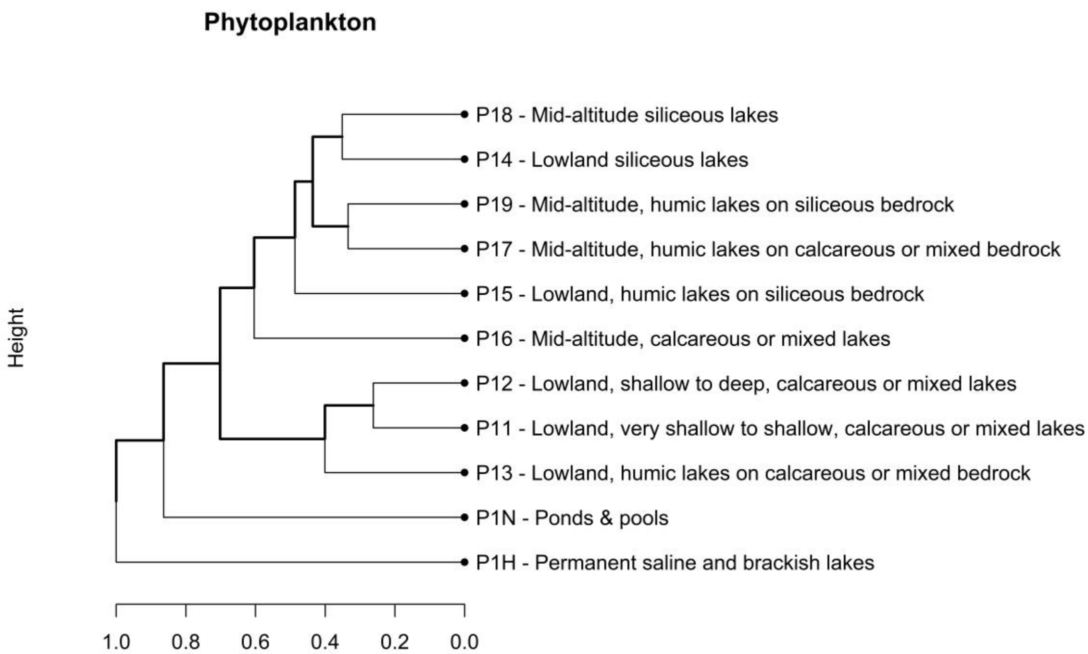


Phytoplankton without outlier sites P1H and P1N
NMDS1
NMDS2
P15
P14
P19
P13
P12
P11
P17
P18
P16
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
0.5
0.0
-0.5
-1.0

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.

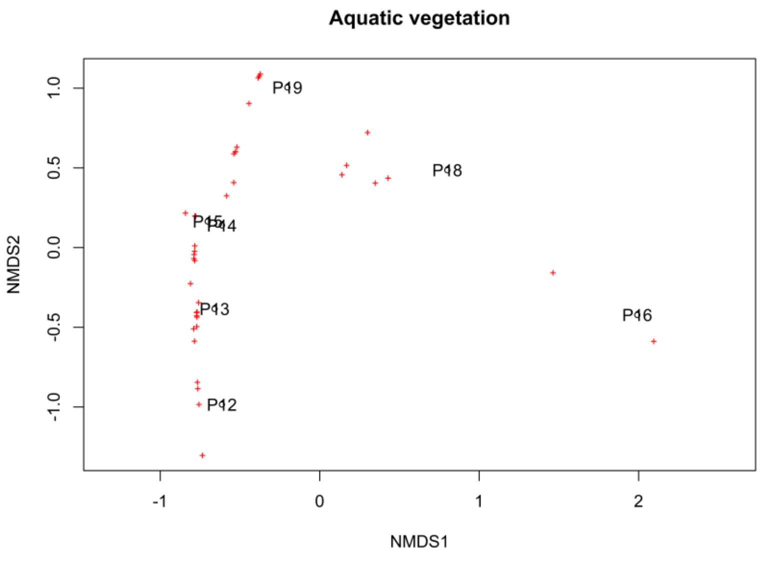
4.1.2 Aquatic vegetation

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.

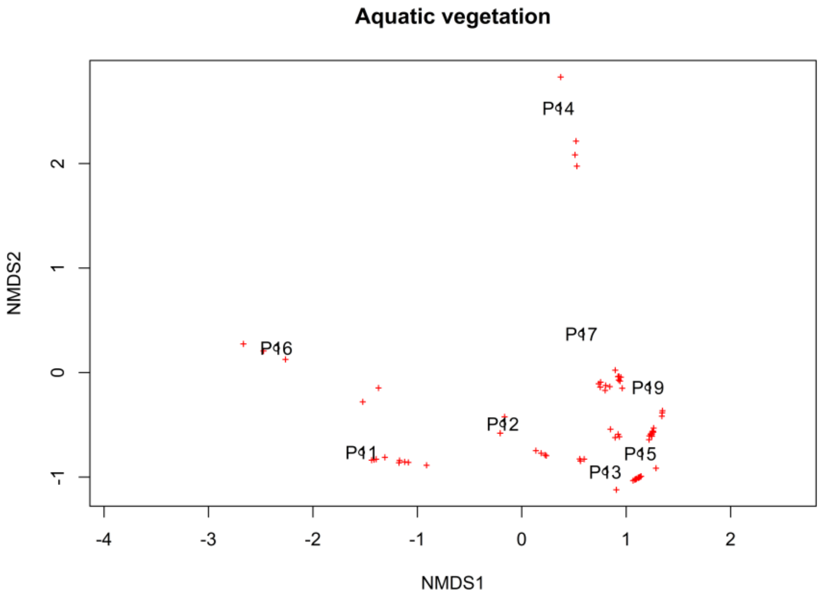
For impacted lakes, the humic lake types (P13, P15, P17 and P19) are quite similar, regardless of altitude and alkalinity. This indicates that the light-climate, which is quite poor due to the humic substances and gets even worse with eutrophication, is the most important factor influencing the species 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.

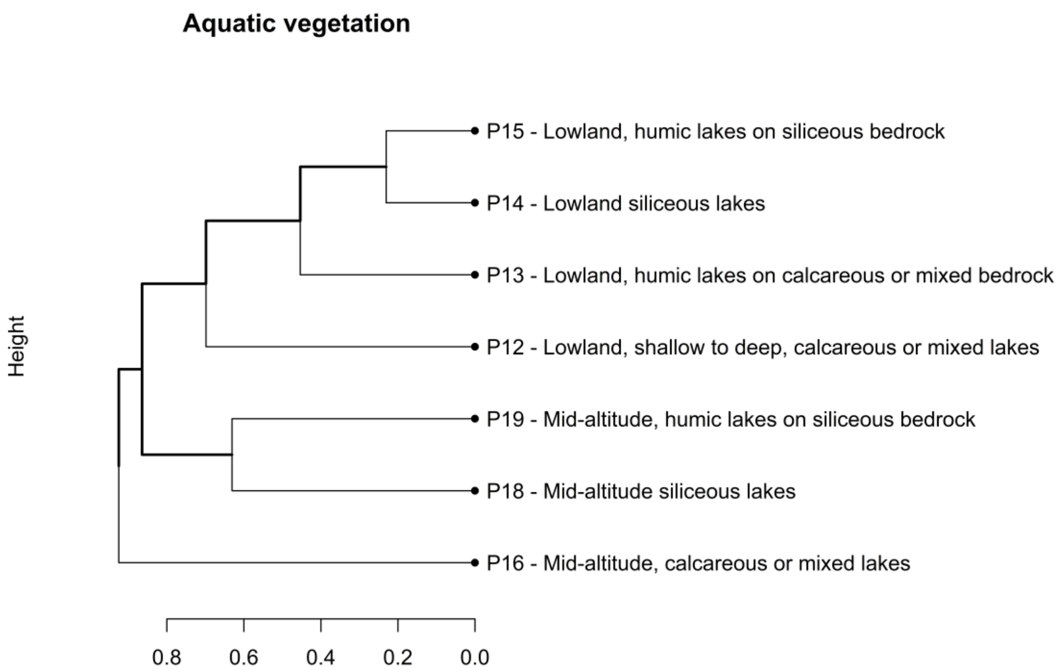
a) NMDS plot of reference lakes



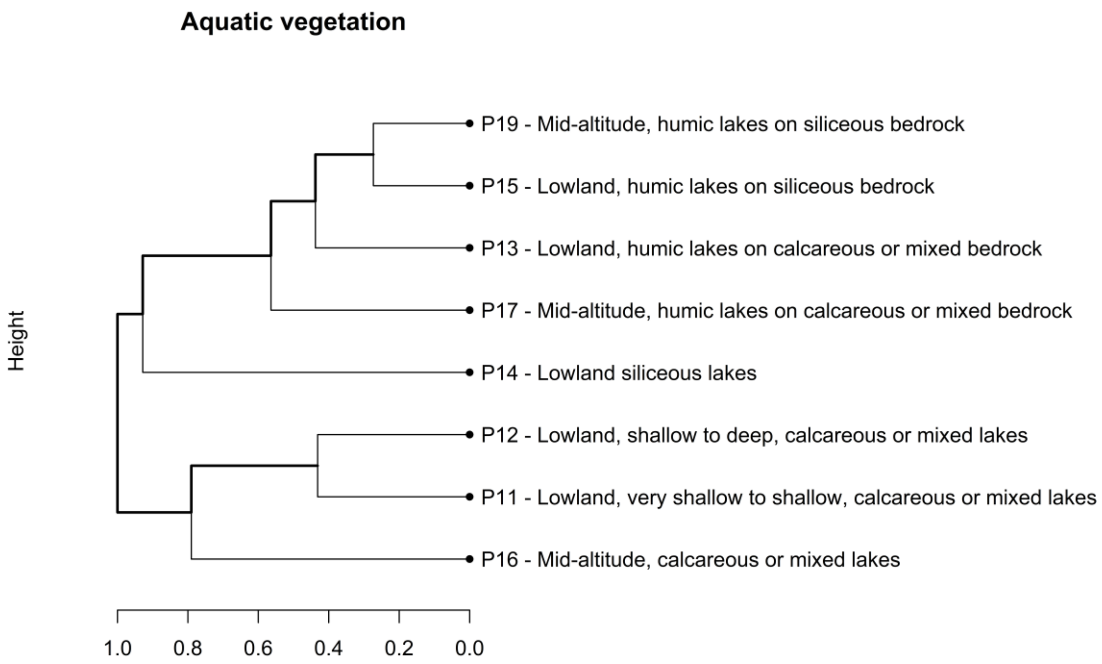
b) NMDS plot of impacted lakes



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.

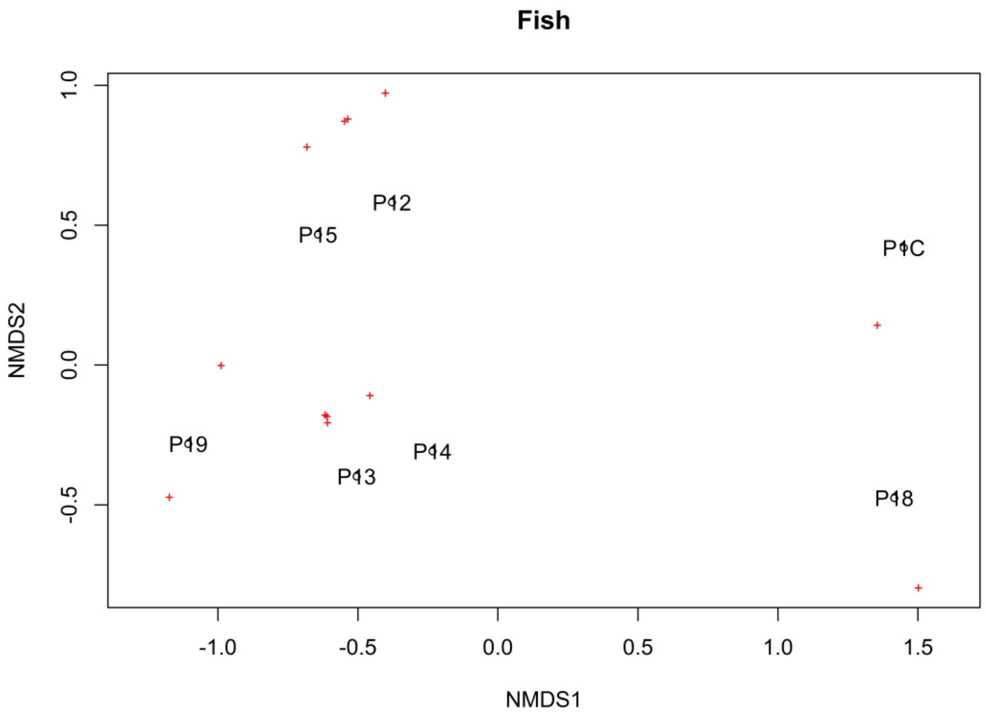
In impacted lakes (

Figure 4-3b and

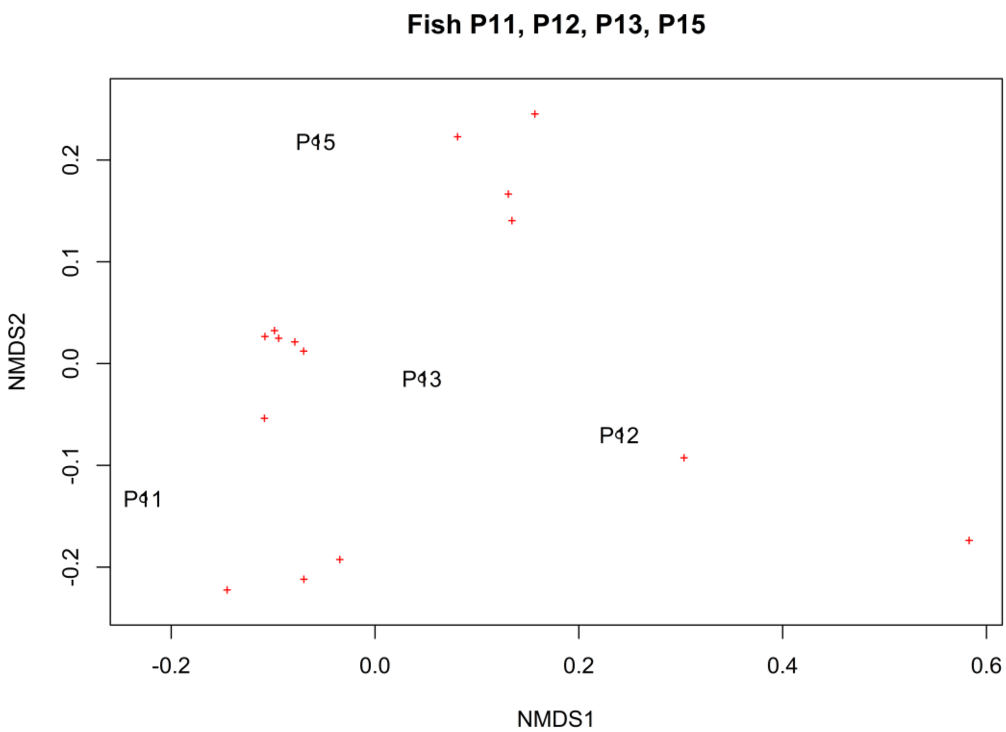
Figure 4-3d), fish communities are quite similar in lowland calcareous lakes (P11, P12, P13) but differ from those in lowland siliceous lakes (e.g. P14). This may indicate that alkalinity is important for fish when lakes become impacted (e.g. by acidification). The mid-altitude humic lakes (P17 and P19) 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.

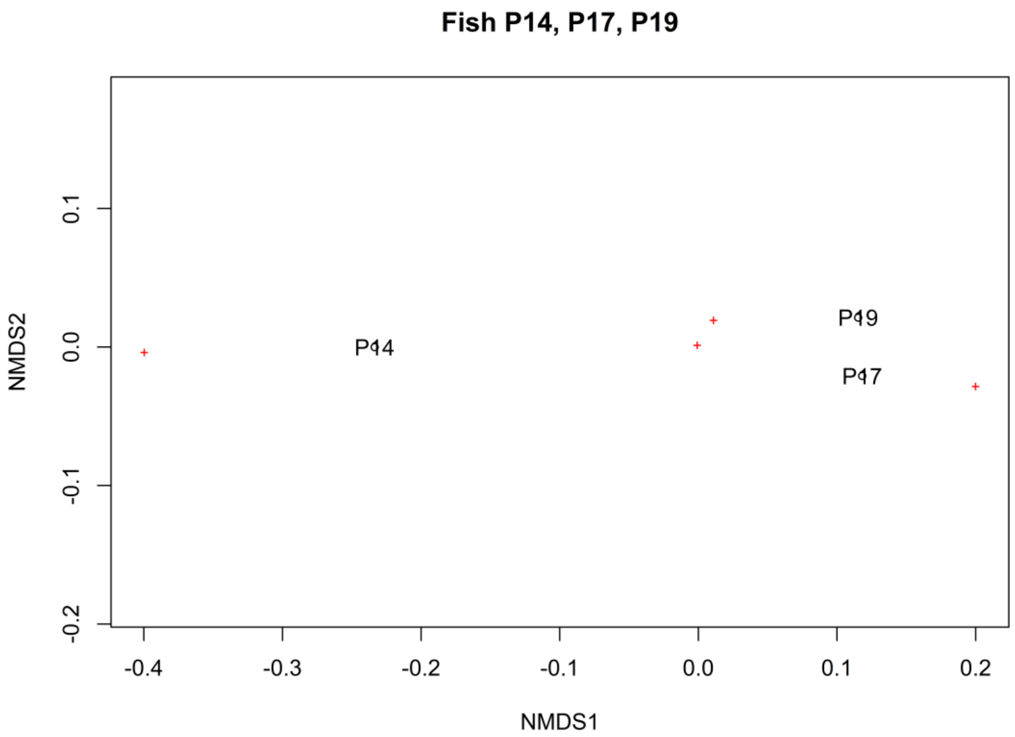
Figure 4-3 Multivariate analysis of differences between selected EUNIS level 3 habitat types for reference and impacted lakes based on their fish communities. (a, b) NMDS plots, (c, d) cluster analysis.

a) NMDS plot of reference lakes

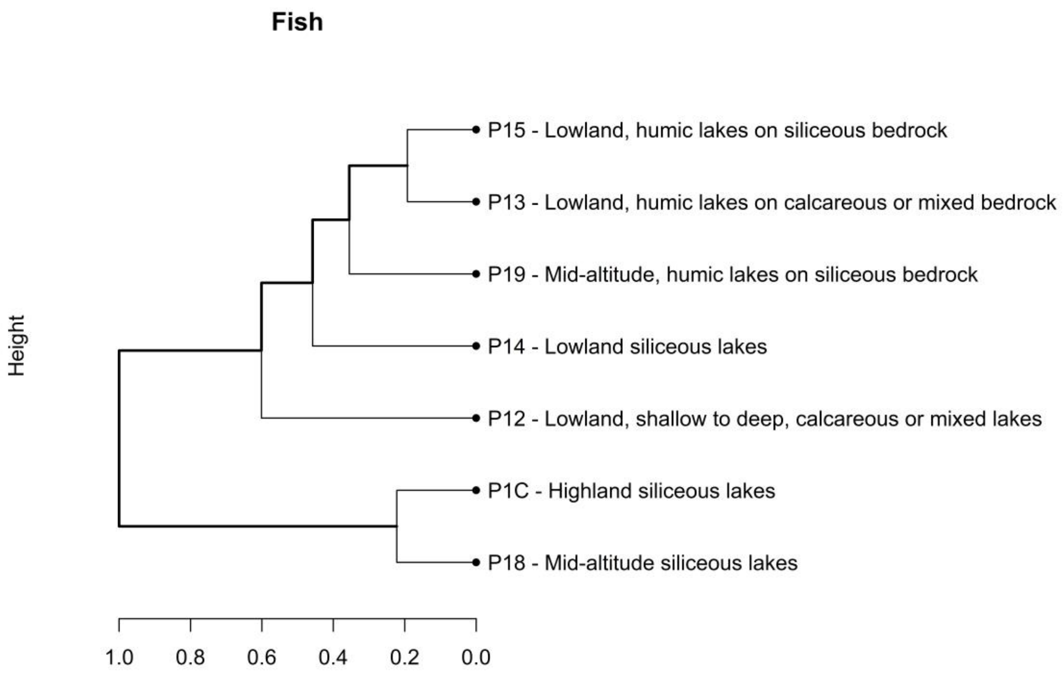


b) NMDS plot of impacted lakes: Initial clustering showed two major groups of habitats. Therefore below, we show the NMDS plots for the two groups separately.

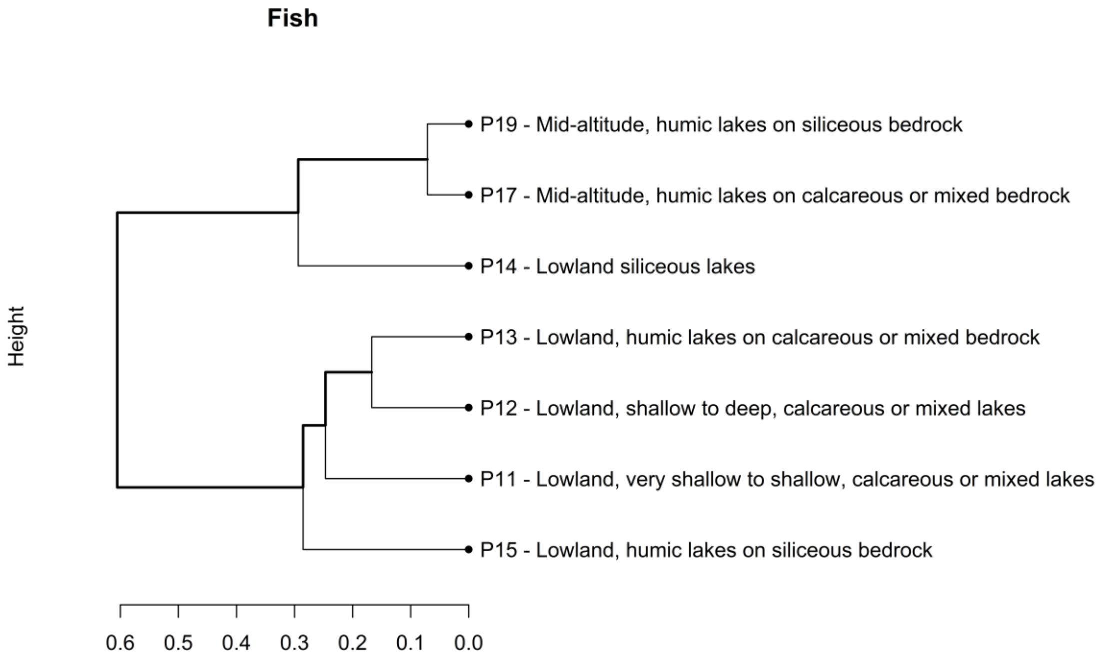




c) Cluster analysis of reference lakes



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

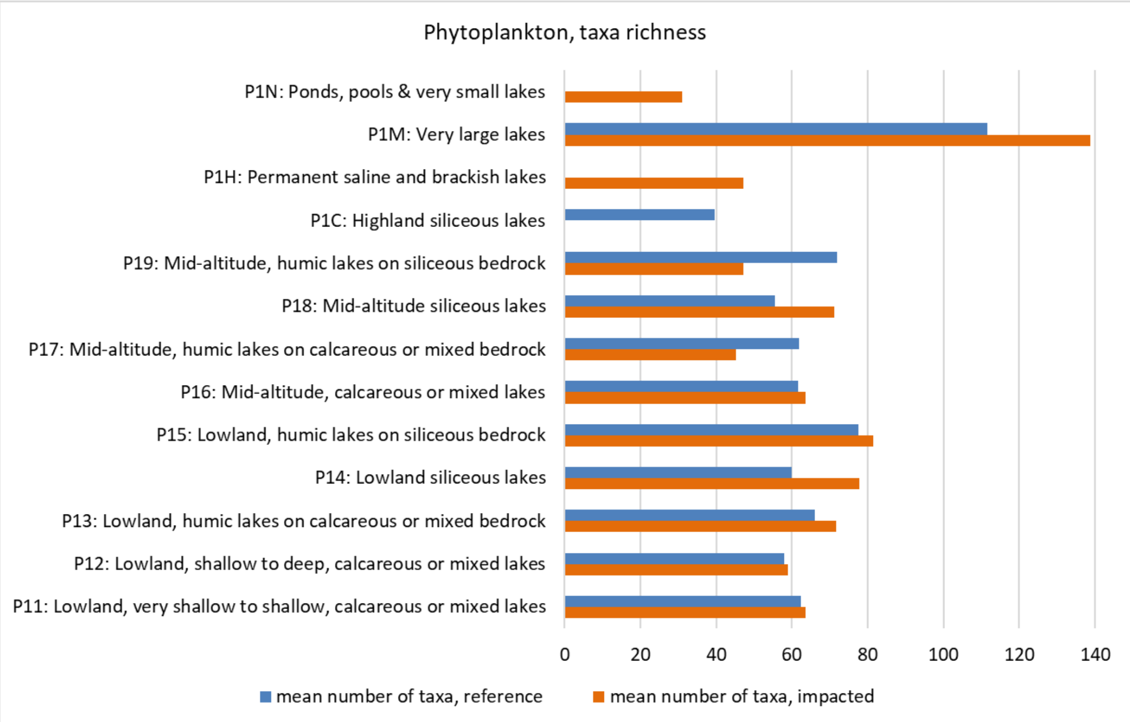
BQE	EUNIS L3 code	EUNIS L3 name	Status	Species richness, mean	Species richness, stdev	Number of lakes
	P17	Mid-altitude, humic lakes on calcareous or mixed bedrock	Reference	62	28	5
			Impacted	45	23	18
	P18	Mid-altitude siliceous lakes	Reference	56	26	72
			Impacted	71	37	14
	P19	Mid-altitude, humic 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

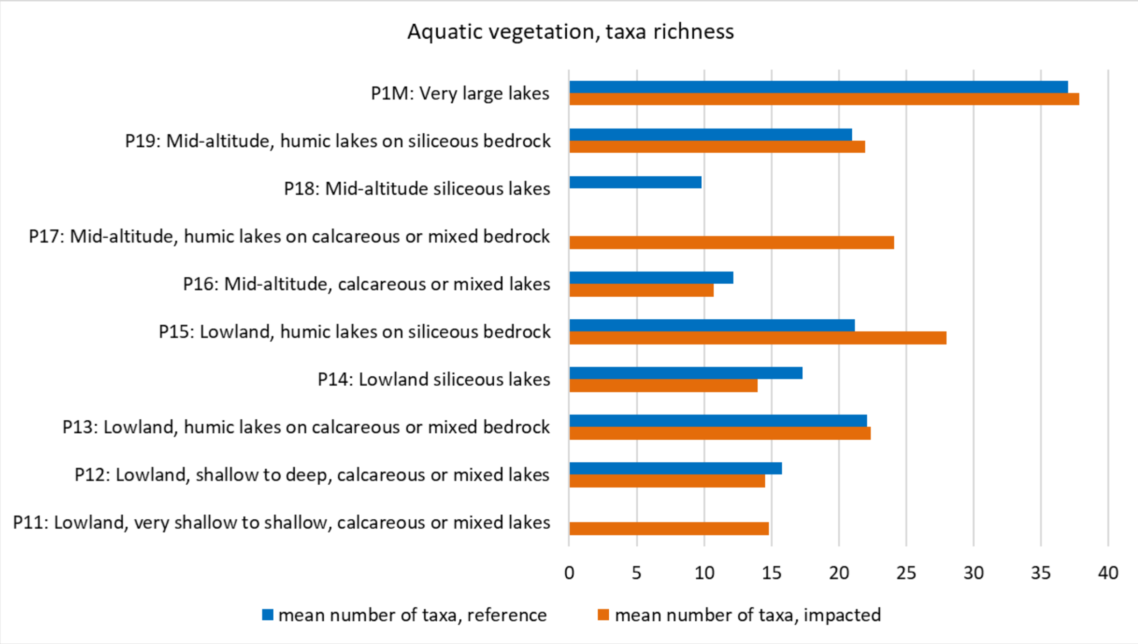
BQE	EUNIS L3 code	EUNIS L3 name	Status	Species richness, mean	Species richness, stdev	Number of lakes
Fish	P11	Lowland, very shallow to shallow, calcareous or mixed lakes	Impacted	7	3	13
	P12	Lowland, shallow to deep, calcareous or mixed lakes	Reference	9	2	10
			Impacted	9	3	54
	P13	Lowland, humic lakes 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).

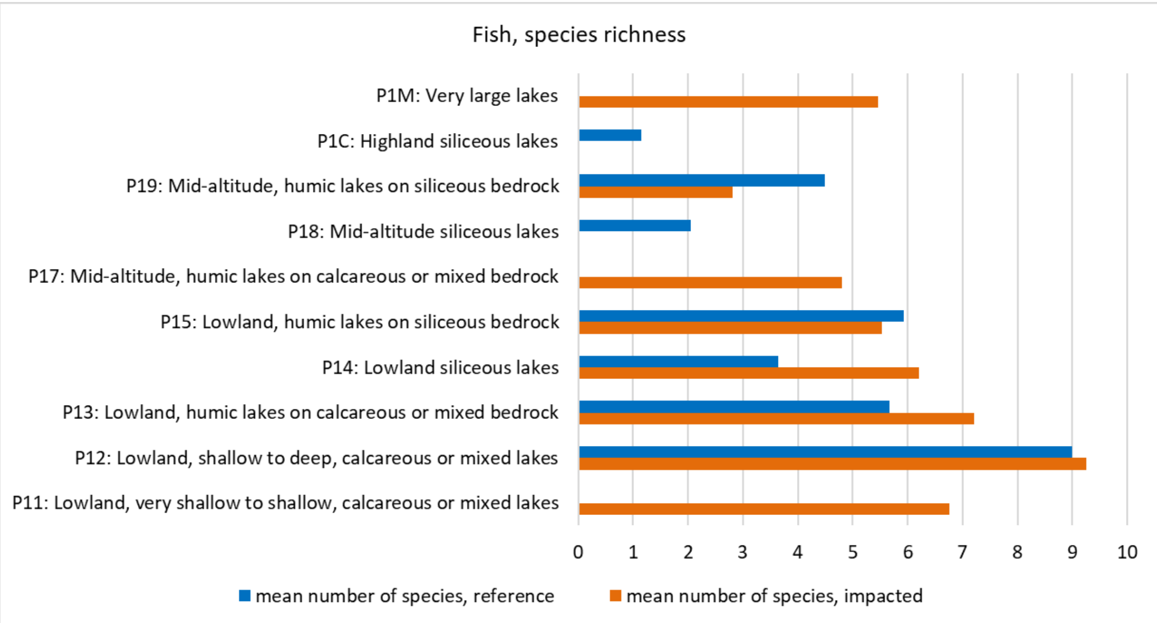
a) Phytoplankton



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

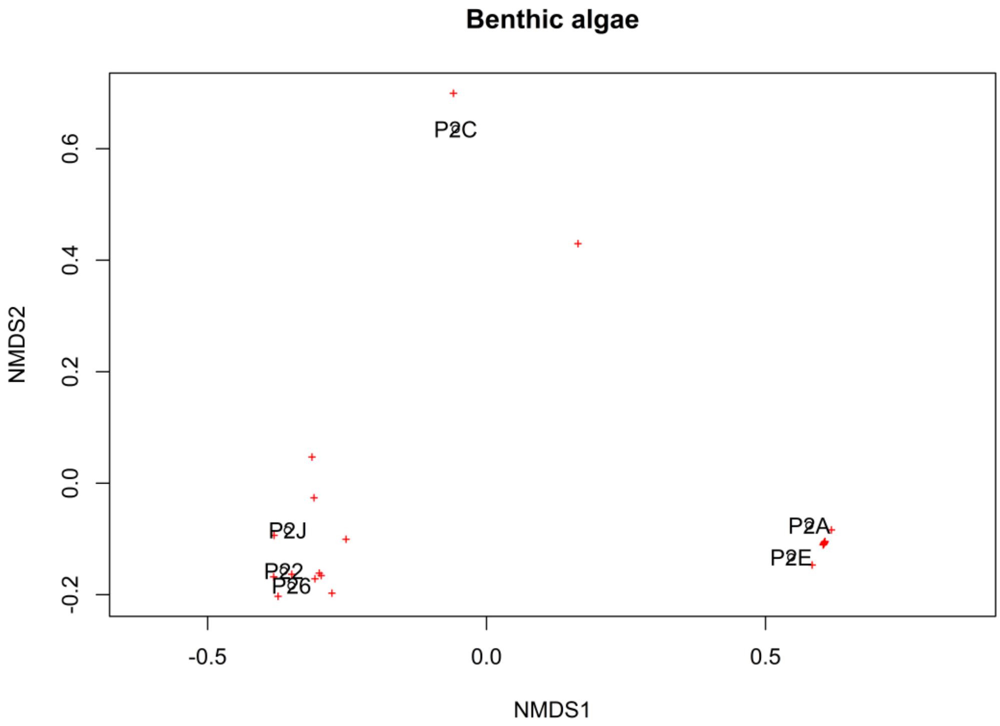
Figure 5-1a and show a very high similarity in **Error! Reference source not found.**b.

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.

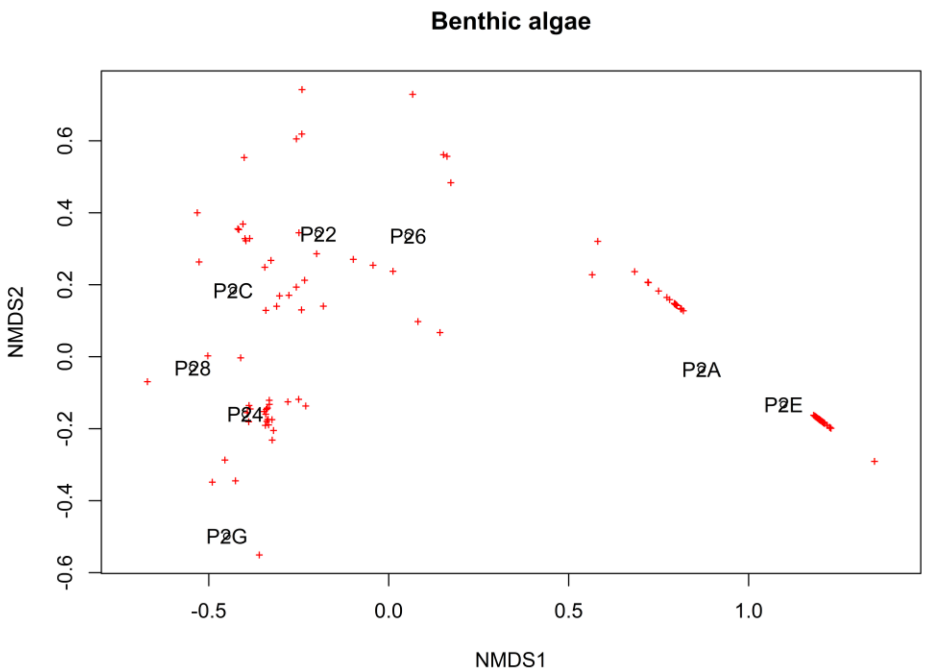
The effect of humic substances could not be tested due to the small amount of data available.

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.

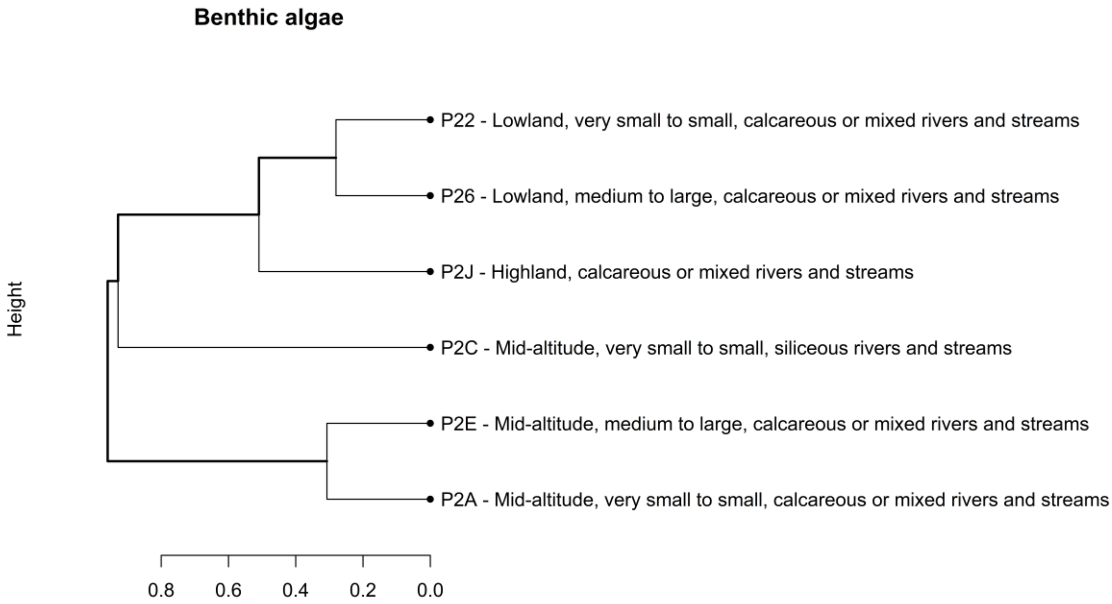
a) NMDS plot of reference rivers



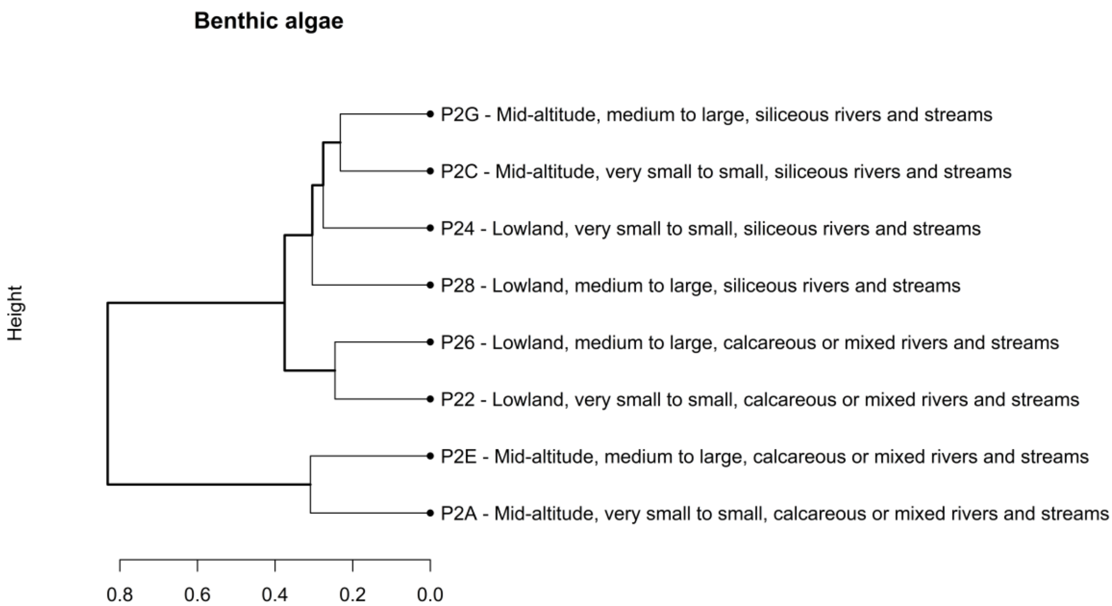
b) NMDS plot of impacted rivers



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.

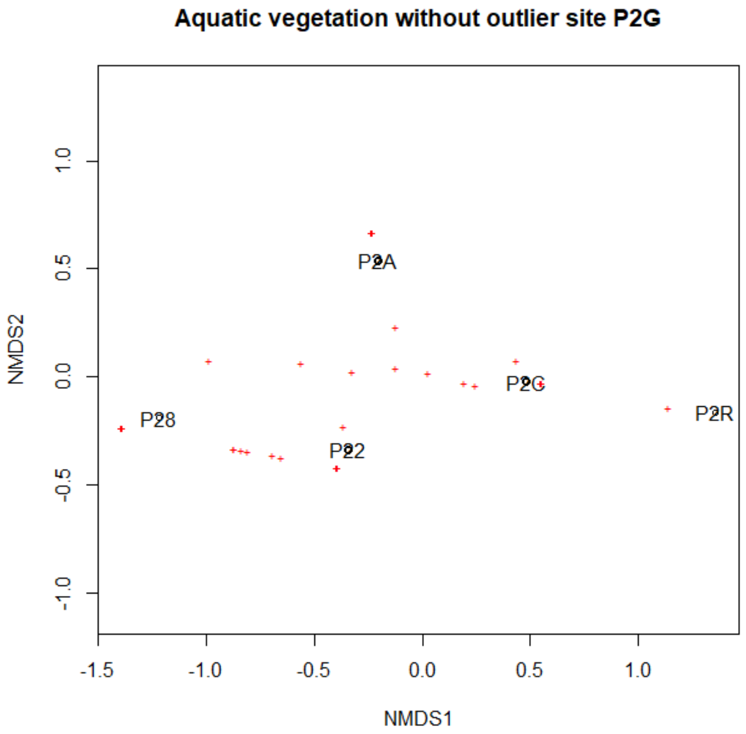
The effect of humic substances could not be tested due to the low amount of data available.

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]:



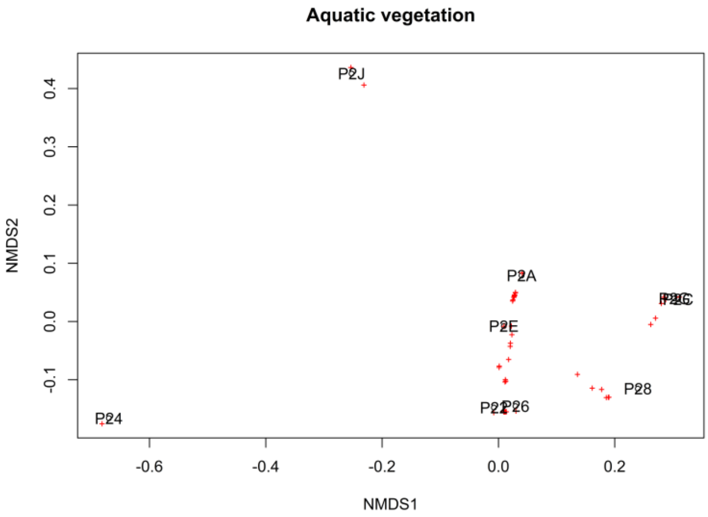
b) NMDS plot of impacted rivers[2]:

[1] The cluster analysis (

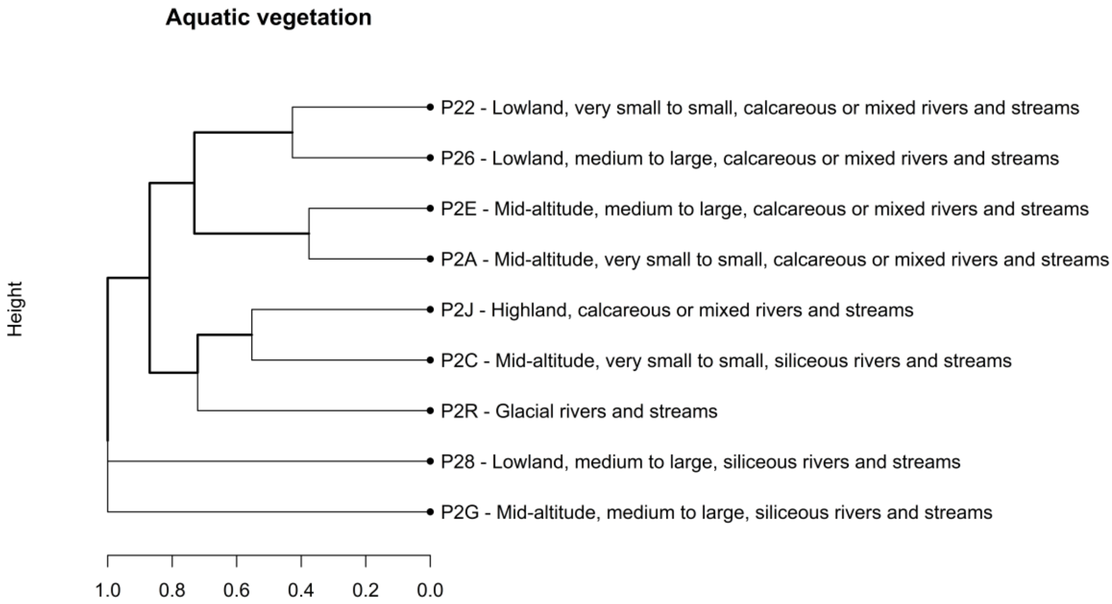
Figure 5-2c) shows several clusters that lead to an overplotted NMDS. Only excluding the outlier P2G gave more of an illustrative NMDS, but note that EUNIS habitat types, visualized in this NMDS plot, actually represents the whole clusters.

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

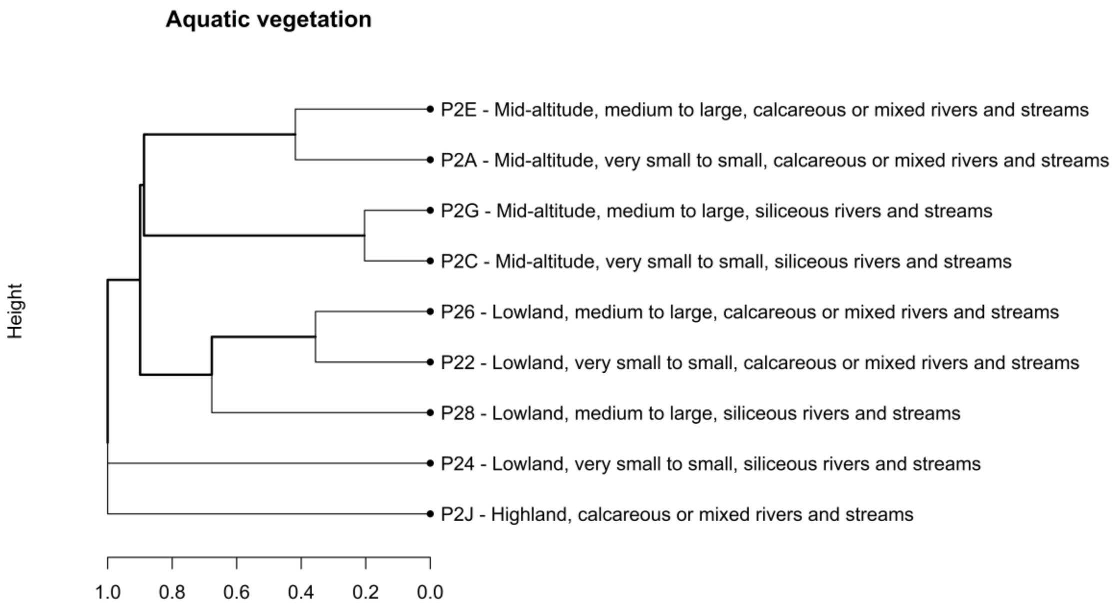
Figure 5-2d) for a better illustration


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

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.

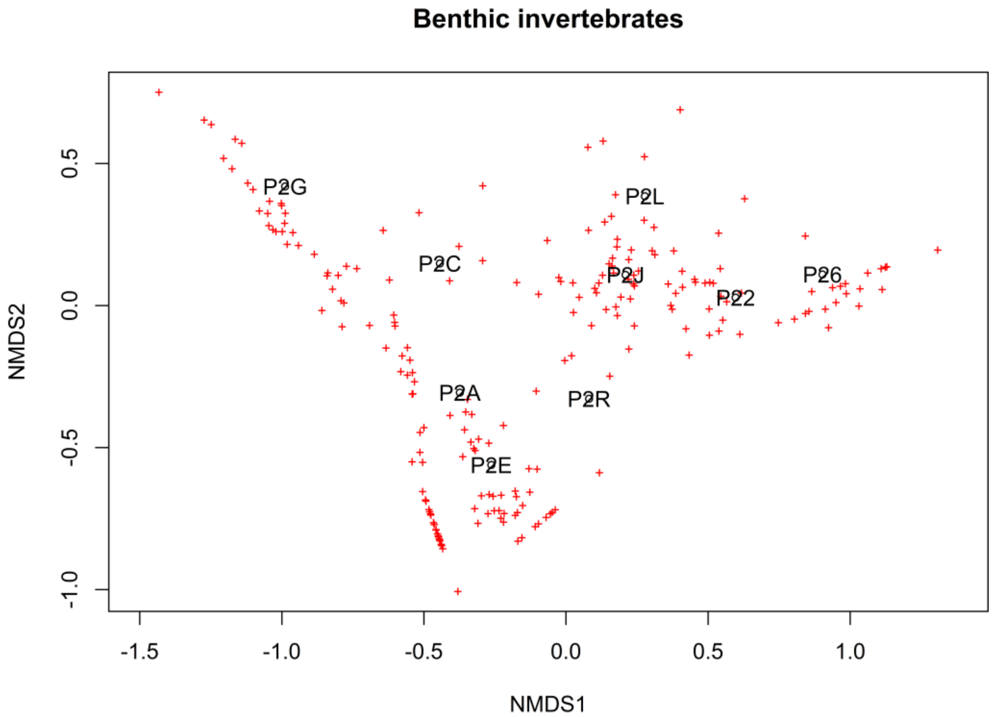
The effect of humic substances could not be tested due to the small amount of data available.

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

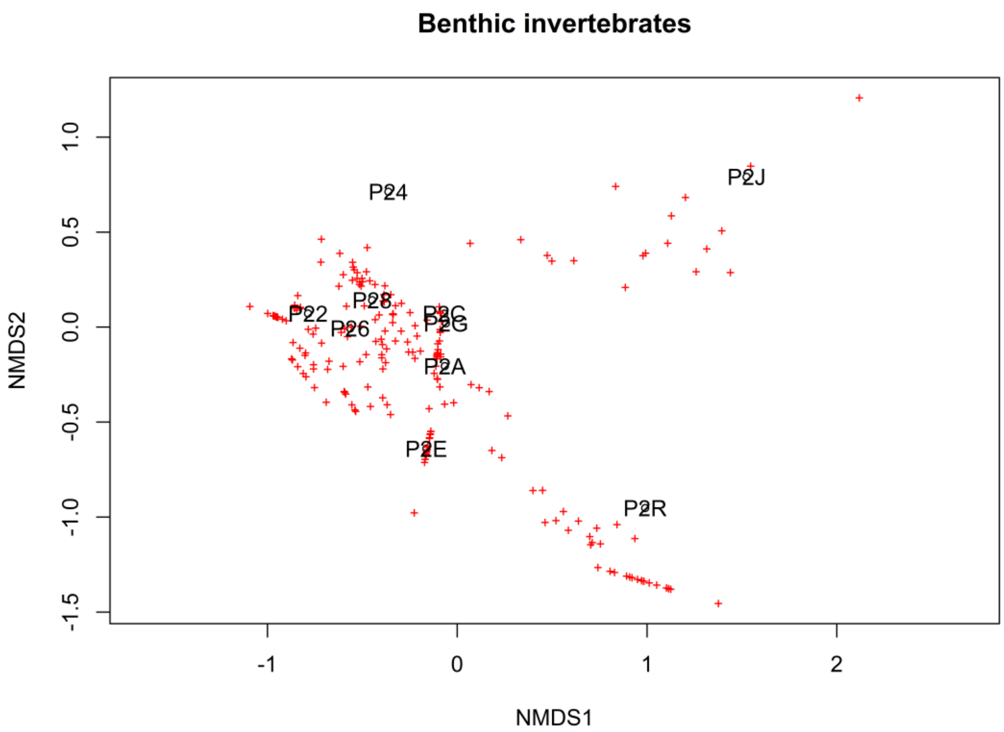
Figure 5-3). There is a higher similarity in impacted rivers than in reference rivers for many of the habitat types, e.g. for P2C and P2G, and for P2A and P2E, which may indicate that human impact favours the same species in these habitats. For several other habitat types, e.g. P22 and P26 (lowland, 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.

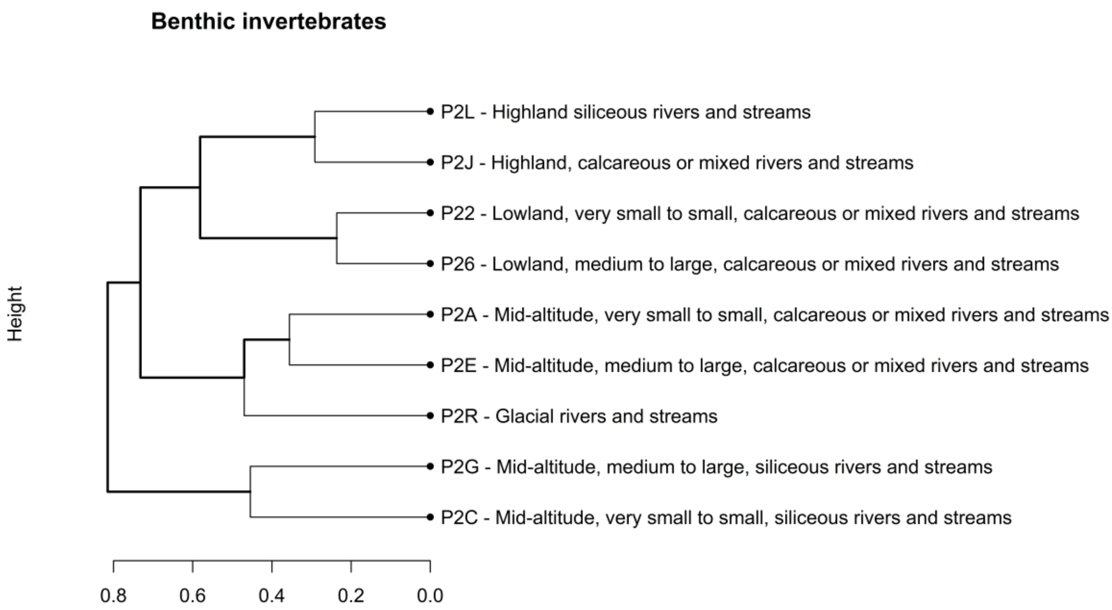
a) NMDS plot of reference rivers



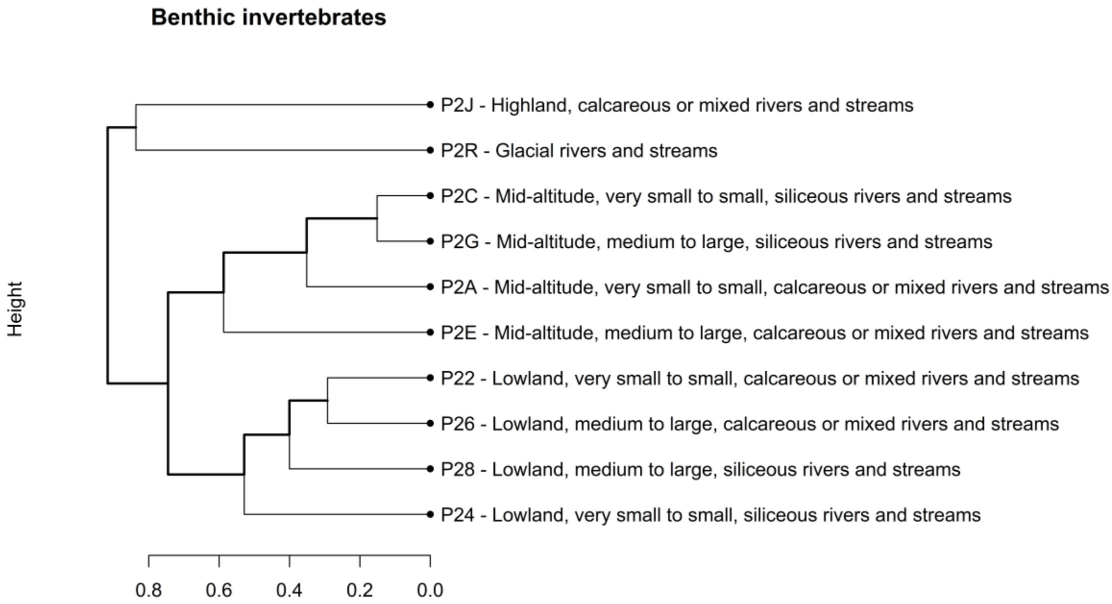
b) NMDS plot of impacted rivers



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).

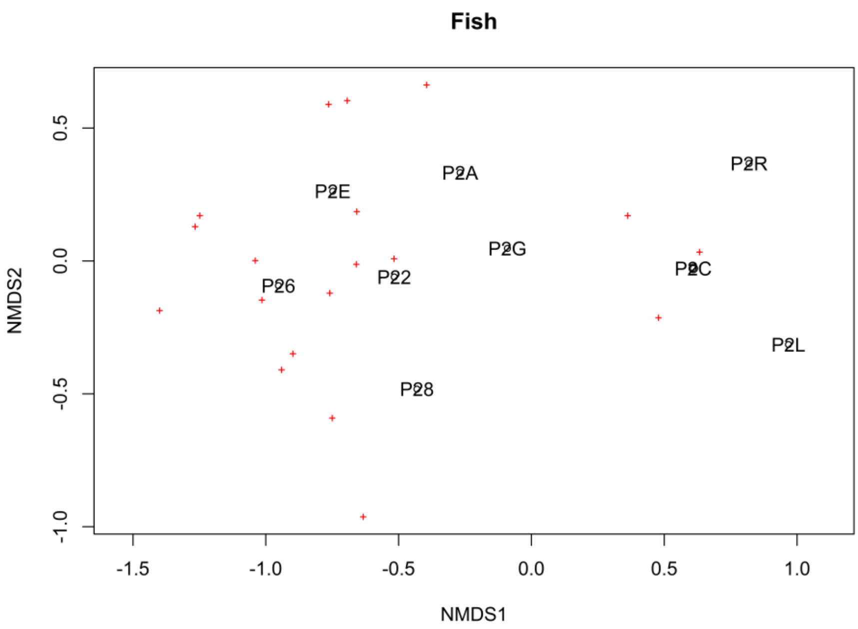
In impacted rivers, fish communities show a higher similarity than in reference rivers for all the lowland types with data for both impacted and reference rivers (

Figure 5-4c and

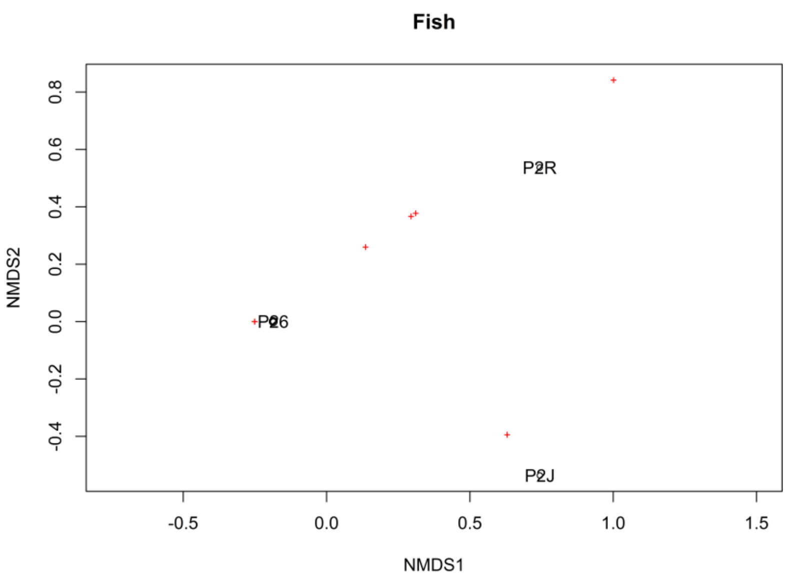
Figure 5-4d). This may indicate that human impact (e.g. organic pollution and/or barriers) favours the same fish species regardless of the geology.

Figure 5-4 Multivariate analysis of the differences between selected EUNIS level 3 habitat types for reference and impacted rivers based on fish communities. (a, b) NMDS plot, (c, d) cluster analysis.

a) NDMS plot of reference rivers



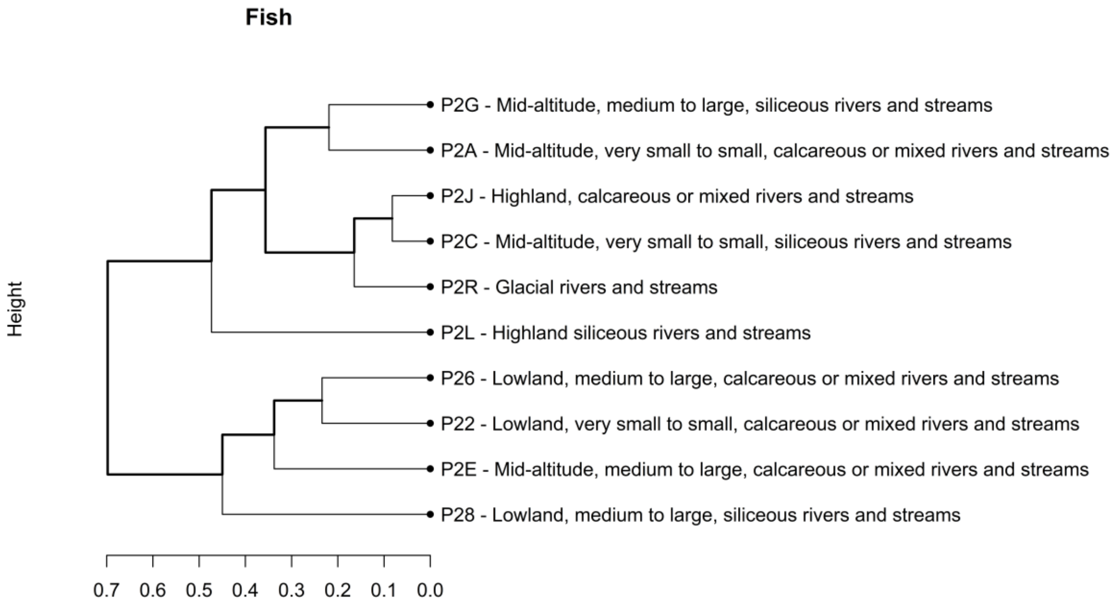
b) NMDS plot of impacted rivers[3]:



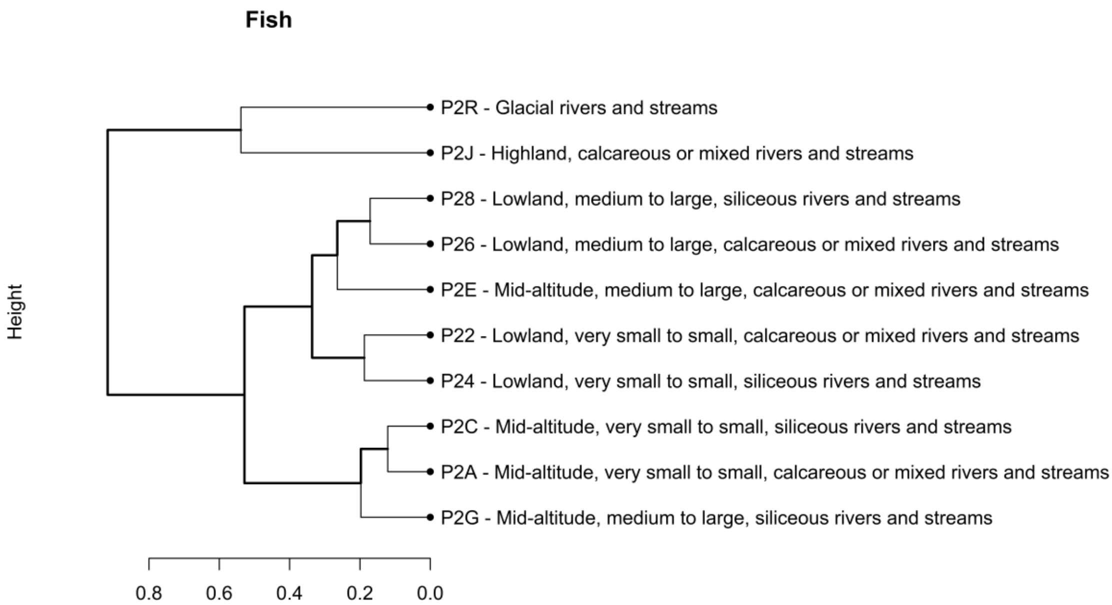
[3] The cluster analysis (

Figure 5-4d) shows three clusters that lead to an overplotted NMDS. In this case, there are no single outliers to be excluded to get an NMDS that would be more illustrative of the differences between the EUNIS habitat types.

c) Cluster analysis of reference rivers



d) Cluster analysis of impacted rivers



5.2 Species richness in rivers per habitat type for benthic algae, benthic invertebrates, aquatic vegetation and fish

The species richness in reference rivers is highest for benthic invertebrates, varying from 46 to 88 species per type, intermediate for benthic algae, varying from 5-48 species per type, lower for aquatic vegetation, varying from 5 to 19 species per type and lowest for fish, varying from 2-12 species per type (

Table 5-1,

Figure 5-5 There is no clear relationship between the mean species richness and the number of reference rivers per type, although there is a positive relationship for some habitats, which is further explained below.

A comparison of species richness in all the habitats show the following patterns:

For benthic algae, the highest species richness was found in mid-altitude, calcareous or mixed rivers and streams, with 48 species in the medium-large rivers (P2E) and 40 species in the very small-small rivers (P2A). These two types also had the highest number of river water bodies, which could partly explain their high species richness. In contrast, the habitats with the lowest species richness of benthic algae are small lowland rivers with either a calcareous (P22) or siliceous geology (P24), in which only 5 species were found in each type. These habitats had quite a low number of water bodies, which could be part of the explanation for the low number of species present.

For aquatic vegetation, the highest species richness was found in lowland, medium-large, siliceous rivers (P28) with 19 species, while the lowest richness was observed in the glacial rivers (P2R). The low richness in the glacial rivers is most likely due to high current velocity and high turbidity that cause very harsh environments for aquatic vegetation. This pattern is not well correlated with the number of river water bodies.

For benthic invertebrates, the highest species richness was found in mid-altitude, medium-large, calcareous or mixed rivers (P2E) with as much as 88 species in 45 river water bodies. The lowest richness was found in the comparable river type with a siliceous geology (P2G) with 46 species found in 33 river water bodies. This difference can be due to the higher alkalinity and higher natural productivity of the calcareous rivers. However, the pattern of species richness for benthic invertebrates is quite diverse with subtle differences that are not clearly related to the number of river water bodies nor to any of the major type descriptors. The results are mainly representative of the Central/Alpine region with most water bodies situated in Austria, France and Germany. Other type descriptors, such as flow (runs, riffles and pools) could play a role here, although most samples are traditionally taken in runs and riffles where the substrate is more suitable for sensitive benthic invertebrates belonging to the so-called EPT-taxa (Ephemeroptera, Plecoptera and Trichoptera).

For fish, most species were found in P26 Lowland, medium-large, calcareous or mixed rivers with a total of 10 species, while the lowest number of species were found in P2J Highland, calcareous or mixed rivers and streams with only 2 species found in 13 river water bodies. This pattern is also hard to explain, as there is no obvious relationship between species richness and any of the major type descriptors, nor with the number of river water bodies in each habitat type.

Table 5-1 Species richness (mean number of species and standard deviation (stdev)) in reference and impacted rivers in EUNIS level 3 habitat types with sufficient data in the WISER database. In this analysis, very large lakes (P1M), ponds and pools (P1N) 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 rivers
Benthic algae	P21[a]	Lowland rivers and streams draining clay rich catchments	Reference	13	15	23
			Impacted	17	10	204
	P22	Lowland, very small to small, calcareous or mixed rivers and streams	Reference	6	5	14
			Impacted	22	16	75
	P24	Lowland, very small to small, siliceous rivers and streams	Impacted	23	8	12
	P26	Lowland, medium to large, calcareous or mixed rivers	Reference	12	21	22
			Impacted	26	19	123
	P28	Lowland, medium to large, siliceous rivers	Impacted	23	10	12
	P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams	Reference	31	25	29
			Impacted	32	23	76
	P2C	Mid-altitude, very small to small, siliceous rivers and streams	Reference	12	5	16
			Impacted	21	9	57
	P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Reference	36	29	25
			Impacted	36	28	80
	P2G	Mid-altitude, medium to large, siliceous rivers	Impacted	26	15	33
	P2J	Highland, calcareous or mixed rivers and streams	Reference	10	14	11
	P2R	Glacial rivers and streams	Reference	20	20	5
	P2S	Very large rivers	Impacted	23	12	13

Note: [a] There were no data in the WISER database for clay rivers (P21). The data comes from 2008-2024 and were obtained from the Norwegian national database only.

BQE	EUNIS L3 code	EUNIS L3 name	Status	Species richness, mean	Species richness, stdev	Number of rivers
Aquatic vegetation	P22	Lowland, very small to small, calcareous or mixed rivers and streams	Reference	13	6	26
			Impacted	15	11	119
	P24	Lowland, very small to small, siliceous rivers and streams	Impacted	12	8	9
	P26	Lowland, medium to large, calcareous or mixed rivers	Reference	16	7	35
			Impacted	13	8	152
	P28	Lowland, medium to large, siliceous rivers	Reference	23	5	4
			Impacted	14	11	15
	P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams	Reference	9	5	42
			Impacted	8	4	68

BQE	EUNIS L3 code	EUNIS L3 name	Status	Species richness, mean	Species richness, stdev	Number of rivers
	P2C	Mid-altitude, very small to small, siliceous rivers and streams	Reference	8	4	11
			Impacted	6	2	25
	P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Reference	11	5	34
			Impacted	11	7	97
	P2G	Mid-altitude, medium to large, siliceous rivers	Reference	7	3	8
			Impacted	7	3	18
	P2J	Highland, calcareous or mixed rivers and streams	Reference	10	5	15
			Impacted	10	4	5
	P2R	Glacial rivers and streams	Reference	5	1	8
	P2S	Very large rivers	Impacted	15	12	9

BQE	EUNIS L3 code	EUNIS L3 name	Status	Species richness, mean	Species richness, stdev	Number of rivers
Benthic invertebrates	P21 [a]	Lowland rivers and streams draining clay rich catchments	Reference	40	26	29
			Impacted	46	20	224
	P22	Lowland, very small to small, calcareous or mixed rivers and streams	Reference	53	19	27
			Impacted	52	48	209
	P24	Lowland, very small to small, siliceous rivers and streams	Impacted	38	26	32
	P26	Lowland, medium to large, calcareous or mixed rivers	Reference	55	20	35
			Impacted	49	34	240
	P28	Lowland, medium to large, siliceous rivers	Impacted	36	21	45
	P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams	Reference	63	25	74
			Impacted	50	34	135
	P2C	Mid-altitude, very small to small, siliceous rivers and streams	Reference	51	19	53
			Impacted	36	22	151
	P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Reference	75	48	47
			Impacted	72	48	166
	P2G	Mid-altitude, medium to large, siliceous rivers	Reference	42	15	20
			Impacted	40	21	83
	P2J	Highland, calcareous or mixed rivers and streams	Reference	58	38	23
			Impacted	51	41	7
	P2L	Highland siliceous rivers and streams	Reference	55	11	4
	P2R	Glacial rivers and streams	Reference	79	43	12
			Impacted	74	18	13
	P2S	Very large rivers	Impacted	52	57	36

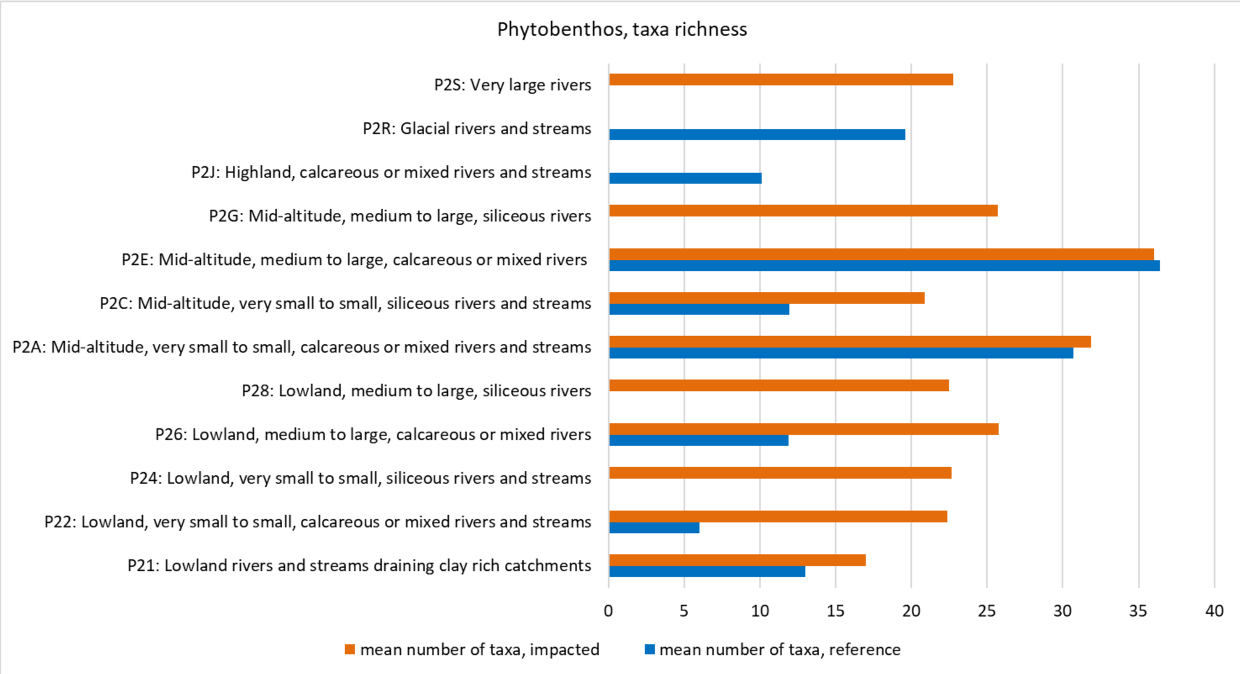
Note: [a] There were no data in the WISER database for clay rivers (P21). The data comes from 2008-2024 and were obtained from the Norwegian national database only.

BQE	EUNIS L3 code	EUNIS L3 name	Status	Species richness, mean	Species richness, stdev	Number of rivers
Fish	P21 [a]	Lowland rivers and streams draining clay rich catchments	Reference	1	1	14
			Impacted	2	1	34
	P22	Lowland, very small to small, calcareous or mixed rivers and streams	Reference	6	3	27
			Impacted	7	4	88
	P24	Lowland, very small to small, siliceous rivers and streams	Impacted	7	4	48
	P26	Lowland, medium to large, calcareous or mixed rivers	Reference	9	5	37
			Impacted	10	6	201
	P28	Lowland, medium to large, siliceous rivers	Reference	6	3	4
			Impacted	9	4	115
	P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams	Reference	4	2	71
			Impacted	5	4	106
	P2C	Mid-altitude, very small to small, siliceous rivers and streams	Reference	4	3	33
			Impacted	5	3	139
	P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Reference	7	4	43
			Impacted	10	6	146
	P2G	Mid-altitude, medium to large, siliceous rivers	Reference	5	4	14
			Impacted	6	3	82
	P2J	Highland, calcareous or mixed rivers and streams	Reference	2	2	22
			Impacted	2	1	8
	P2L	Highland siliceous rivers and streams	Reference	3	3	4
	P2R	Glacial rivers and streams	Reference	3	2	10
			Impacted	4	2	12
	P2S	Very large rivers	Impacted	14	11	26

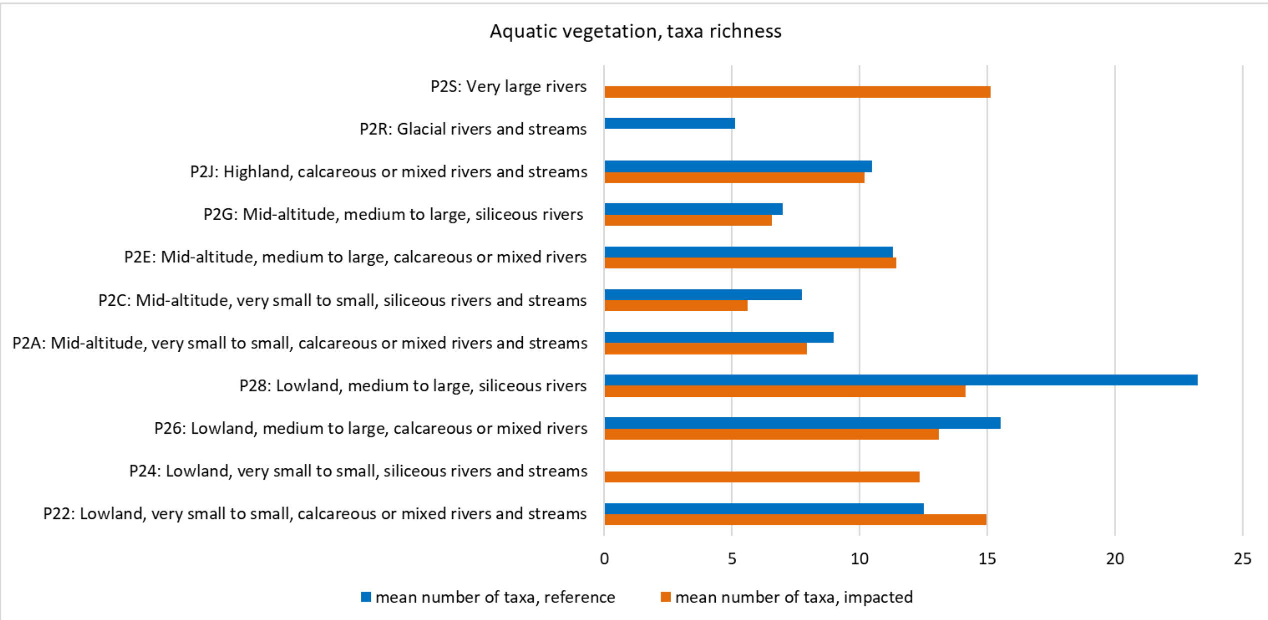
Note: [a] There were no data in the WISER database for clay rivers (P21). The data comes from 2008-2024 and were obtained from the Norwegian national database only.

Figure 5-5 Species richness in rivers for different L3 habitat types, for each of the major biological groups benthic algae (a), aquatic vegetation (b), benthic invertebrates (c), fish (d).

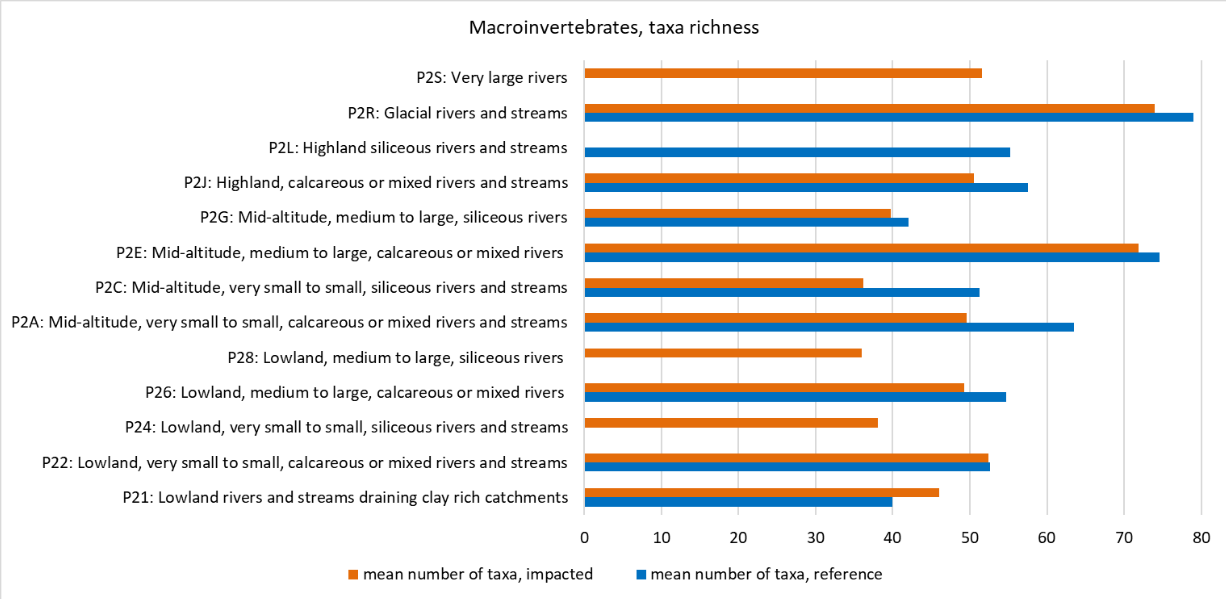
a) Benthic algae (= phytobenthos)



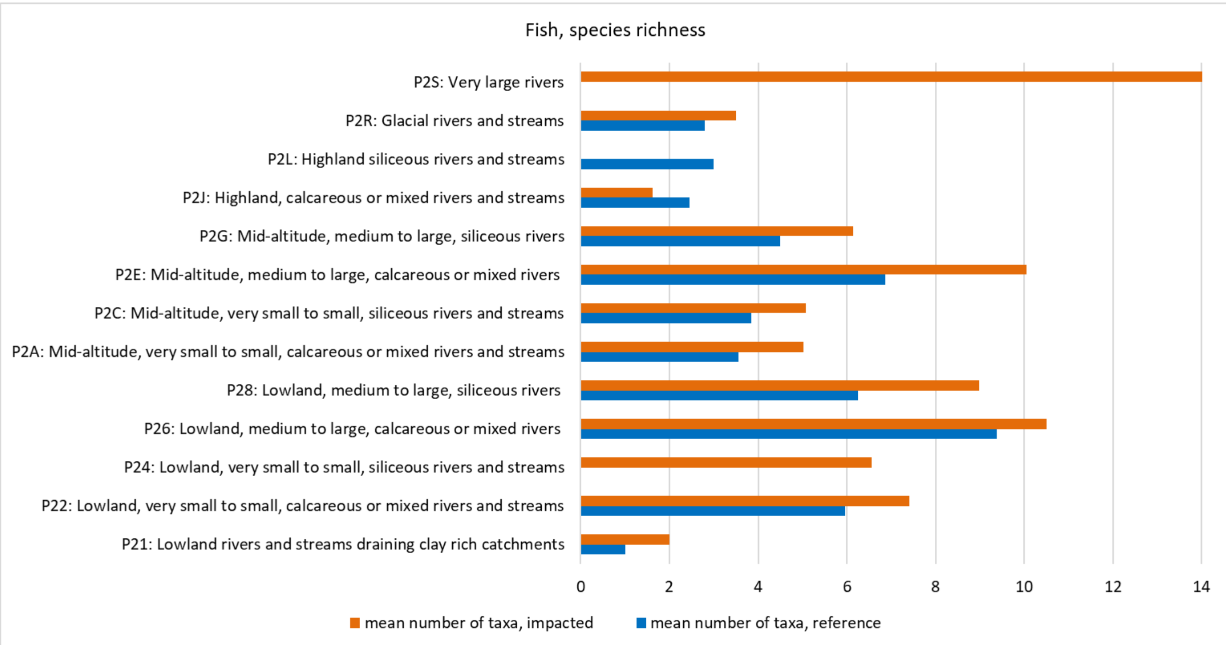
b) Aquatic vegetation



c) Benthic invertebrates



d) Fish



In Table 5-2 we have summarized the results given in

Table 5-1 to try to distinguish the effects of altitude, alkalinity and catchment size on the species richness for each of the four biota groups in reference rivers compared to impacted rivers.

For altitude, the species richness is highest in the mid-altitude region for benthic algae and benthic invertebrates. The pattern can be due to a better quality of substrates (gravel and stony substrates) in the mid-altitude region than in the lowland region and a very cold climate in the highlands. These two biological groups also show a higher species richness in the more naturally productive calcareous types than in the low productivity siliceous types.

Aquatic vegetation show more species present in the lowlands than in other altitude categories, which could be due to slow current velocity in rivers flowing over flat terrain, thereby providing soft sediments suitable for rooted aquatic plants. For fish, the higher diversity in lowland areas can be due to natural migration barriers (e.g. waterfalls) upstream of the lowlands.

Table 5-2 Effects of type-descriptors on species richness in reference (ref.) and impacted (imp.) lakes across all lake habitats with sufficient data. The calculation excluded clay rivers (P21) and glacial rivers (P2R). Highland rivers are excluded from catchment size analysis. The very large rivers (P2S) are only included under catchment size.

Type-descriptor	Benthic algae		Aquatic vegetation		Benthic invertebrates		Fish	
	mean # of taxa		mean # of taxa		mean # of taxa		mean # of taxa	
	ref.	imp.	ref.	imp.	ref.	imp.	ref.	imp.
Altitude								
Lowland	9	23	17	14	54	44	7	8
Mid-altitude	26	29	9	8	58	50	5	7
Highland	10	-	10	10	57	51	3	2
Alkalinity								
Calcareous	19	29	12	11	61	55	6	7
Siliceous	12	23	13	10	49	38	5	7
Catchment size								
Very small to small	16	24	10	10	56	44	5	6
Medium to large	24	28	14	11	57	49	7	10
Very large	-	23	-	15	-	52	-	14

There is no clear response to the geology/alkalinity of the rivers for aquatic vegetation and fish. The reasons are not clear, but many so-called siliceous rivers in Central Europe, which is dominating this dataset (Table 3-1b), may have sufficient alkalinity for bicarbonate taxa, and sufficient calcium concentration to sustain the requirements for most fish species. Another reason may be that CO_2-species are lost in calcareous rivers, so that balances out the increase in bicarbonate-species.

All four species groups show a higher species richness in rivers with larger catchments than in rivers with smaller ones, which is a general pattern seen for biodiversity (Stomp et al., 2011).

The human impact on species richness varies between the different groups of organisms. For benthic algae the impact is consistently giving a higher species richness in almost all the habitats where data from both reference and impacted rivers are available in the WISER database. The reason is most likely that reference rivers are more oligotrophic than impacted rivers, thus not allowing as many benthic algae species to co-exist as in more nutrient-rich rivers. In contrast, for aquatic vegetation, human impact has either no or a negative impact on species richness in most of the habitats, which can be due to a higher turbidity in impacted rivers, causing stronger light-limitation for some aquatic vegetation species. For benthic invertebrates, human impact has a negative effect on species richness in most of the habitat types, which may be related to organic pollution reducing the oxygen-concentration mainly in slow-flowing rivers. This will be further discussed in section 5.3 below. For fish, the species richness is higher in impacted rivers than in reference rivers for most of the habitat types, except for highland rivers. This is difficult to explain but can be an artefact due to the biogeographic differences in the distribution of fish species and in the different levels of human impact in the various biogeographical regions.

5.3 Characteristic (diagnostic), common (constant) and dominant taxa for running water habitats in reference (or good status) and impacted conditions

This sub-chapter presents the species that have been identified as characteristic, common and/or dominant according to the criteria presented in section 3.6. There are also many other species included in the dataset that do not fulfil any of those criteria, such as rare species found only in a few water bodies in several habitat types. Those species are still included in the chapter on species richness above.

5.3.1 Benthic algae communities

Table 5-3 provides the list of characteristics, common and dominant taxa of benthic algae communities in reference rivers and in impacted rivers in 9 of the EUNIS level 3 habitat types. The data are from only three countries: Austria, Germany and France, so are not representative for Europe as a whole. These countries use primarily diatoms to assess ecological status in their rivers. Therefore, the taxa shown in Table 5-3 are dominated by diatom taxa. However, there are also some taxa from other algal classes. The following text summarizes the main results shown in Table 5-3 concerning the effect of the different abiotic habitat type descriptors.

Differences between calcareous versus siliceous running water bodies

Calcareous rivers in the lowland and mid-altitude regions are characterized largely by a variety of diatoms and a few green algae and cyanobacteria species. In siliceous rivers in the same altitude regions, there are fewer diatoms and more red algae in addition to a few cyanobacteria and only one green algae: *Oedogonium sp*. which is highly characteristic for mid-altitude, medium-large siliceous rivers (P2G). In the highland rivers, red algae are only common in siliceous rivers (P2L).

Differences between low-, mid-altitude and highland running water bodies

Mid-altitude calcareous reference rivers have a much higher number of commonly occurring diatoms and more characteristic diatom species than calcareous reference rivers in the lowland and highland areas. However, this could be due to many more river water bodies included in the WISER dataset from the mid-altitude region (51 water bodies) than in the lowland (21 water bodies) and highland regions (6 water bodies) Table 3-1b This pattern is not seen in the siliceous river types, which have a more balanced number of water bodies across the altitude regions.

An interesting finding is the absence of characteristic and common diatoms in the highland calcareous river type. The common species in highland calcareous rivers are from various other algal classes.

Differences between small versus larger running water bodies

There are no clear differences in the species composition of benthic algae between the medium-large rivers and the smaller ones.

Differences between reference rivers versus impacted rivers

The characteristic and common benthic algae taxa are quite different in impacted rivers compared to reference rivers across all the habitats with sufficient data in the WISER database (Table 5-3). There are only a few characteristic and common taxa that are found both in reference rivers and in impacted rivers. Impacted rivers have many more characteristic taxa in the mid-altitude habitats than in the lowland habitats, while the number of common taxa is less different between habitat types in the lowlands compared to those in the mid-altitude area.

This shows that human impact has a huge effect on the species composition. The results are most representative of diatoms, which is the algal class dominating the WISER dataset.

Table 5-3 Benthic algae in reference and impacted rivers: Characteristic (diagnostic) and common (constant) taxa. Characteristic taxa were identified by the phi-index with the highest significance level p≤0.001 marked * or with intermediate significance level p≤0.01 marked **. Common taxa were identified if the frequency of occurrence is ≥0.5 (50%). Dominant taxa could not be identified as data were presence/absence.**

EUNIS L3 code	EUNIS L3 name	Major taxonomic group	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P22	Lowland, very small to small, calcareous or mixed rivers and streams	Bacillariophyceae	*Achnanthes saccula*			0.336 **	
		Bacillariophyceae	*Achnanthidium minutissimum*				0.59
		Bacillariophyceae	*Achnanthidium pusillum*			0.354 **	
		Bacillariophyceae	*Amphora pediculus*				0.62
		Bacillariophyceae	*Catacombas obtusa*			0.316 **	
		Bacillariophyceae	*Melosira* sp.		0.50		
		Bacillariophyceae	*Navicula applicita*			0.316 **	
		Bacillariophyceae	*Navicula gregarioides*				0.66
		Bacillariophyceae	*Navicula lapsa*				0.58
		Bacillariophyceae	*Navicula solutepunctata*			0.405 ***	
		Bacillariophyceae	*Planothidium granum*				0.59
		Bacillariophyceae	*Psammothidium marginulatum*			0.354 **	
		Bacillariophyceae	*Rhoicosphenia linearis*				0.50
		Bacillariophyceae	*Sellaphora pupula* var. *elliptica*			0.316 ***	
		Rhodophyceae	*Hildenbrandia* sp.		0.64		
		Rhodophyceae	*Lemanea* sp.		0.50		
P24	Lowland, very small to small, siliceous rivers and streams	Bacillariophyceae	*Achnanthidium minutissimum*				0.83
		Bacillariophyceae	*Amphora copulata*			0.475 ***	
		Bacillariophyceae	*Amphora pediculus*				0.67
		Bacillariophyceae	*Cocconeis pediculus* f. teratogene				0.67
		Bacillariophyceae	*Encyonema silesiacum* var. *distigmata*				0.50
		Bacillariophyceae	*Fragilaria cassubica*				0.50

EUNIS L3 code	EUNIS L3 name	Major taxonomic group	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P24 (cont.)	Lowland, very small to small, siliceous rivers and streams (cont.)	Bacillariophyceae	*Meridion circulare* f. teratogene				0.67
		Bacillariophyceae	*Navicula cari* var. *linearis*			0.378 **	
		Bacillariophyceae	*Navicula cryptotenelloides* f. teratogene				0.58
		Bacillariophyceae	*Navicula gregarioides*				0.92
		Bacillariophyceae	*Navicula lapsa*				0.67
		Bacillariophyceae	*Navicula tripunctata* var. *schizomenoides*				0.50
		Bacillariophyceae	*Planothidium granum*				0.67
		Bacillariophyceae	*Planothidium lanceolatum* var. *genuinum*				0.67
		Bacillariophyceae	*Reimeria* sp.				0.50
		Bacillariophyceae	*Rhoicosphenia linearis*				0.50
P26	Lowland, medium to large, calcareous or mixed rivers	Bacillariophyceae	*Achnanthidium minutissimum*				0.59
		Bacillariophyceae	*Amphora pediculus*				0.69
		Bacillariophyceae	*Diatoma moniliformis* ssp. *ovalis*			0.309 **	
		Bacillariophyceae	*Fragilaria capucina* var. *septentrionalis*			0.343 **	
		Bacillariophyceae	*Melosira* sp.		0.50		
		Bacillariophyceae	*Navicula gregarioides*				0.57
		Bacillariophyceae	*Navicula tripunctata* var. *schizomenoides*				0.51
		Bacillariophyceae	*Nitzschia distans* var. *tumescens*			0.309 **	
		Bacillariophyceae	*Rhoicosphenia linearis*				0.55
		Chlorophyta	*Rhizoclonium* sp.	0.488 ***			

EUNIS L3 code	EUNIS L3 name	Major taxonomic group	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P28	Lowland, medium to large, siliceous rivers	Bacillariophyceae	*Achnanthidium minutissimum*				0.92
		Bacillariophyceae	*Amphora pediculus*				1.00
		Bacillariophyceae	*Cocconeis pediculus* f. teratogene				0.50
		Bacillariophyceae	*Eolimna neocaledonica*				0.50
		Bacillariophyceae	*Eolimna tantula*				0.50
		Bacillariophyceae	*Navicula cryptotenelloides* f. teratogene				0.67
		Bacillariophyceae	*Navicula gregarioides*				0.75
		Bacillariophyceae	*Navicula lapsa*				0.67
		Bacillariophyceae	*Navicula tripunctata* var. *schizomenoides*				0.58
		Bacillariophyceae	*Nitzschia inducta*				0.50
		Bacillariophyceae	*Nitzschia simplex*			0.475 ***	
		Bacillariophyceae	*Planothidium granum*				0.67
		Bacillariophyceae	*Planothidium lanceolatum* var. *genuinum*				0.67
		Bacillariophyceae	*Reimeria* sp.				0.58
		Bacillariophyceae	*Rhoicosphenia linearis*				0.67
P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams	Bacillariophyceae	*Achnanthes minutissima forma eutrop*		0.52		
		Bacillariophyceae	*Amphora pediculus*		0.59		0.75
		Bacillariophyceae	*Cocconeis placentula* var. *placentula*		0.55		
		Bacillariophyceae	*Navicula tripunctata* var. *schizomenoides*				0.64
		Rhodophyceae	*Audouinella hermannii*	0.51 ***			

EUNIS L3 code	EUNIS L3 name	Major taxonomic group	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P2C	Mid-altitude, very small to small, siliceous rivers and streams	Bacillariophyceae	*Achnanthidium minutissimum*	0.845 ***	0.75		0.89
		Bacillariophyceae	*Amphora pediculus*				0.77
		Bacillariophyceae	*Encyonema riotecense*			0.375 **	
		Bacillariophyceae	*Encyonema silesiacum* var. *distigmata*	0.466 ***			
		Bacillariophyceae	*Eolimna neocaledonica*				0.51
		Bacillariophyceae	*Fragilaria heidenii*			0.435 ***	
		Bacillariophyceae	*Fragilaria spinarum*			0.33 **	
		Bacillariophyceae	*Gomphonema olivaceum* var. *pusilla*			0.33 **	
		Bacillariophyceae	*Navicula gregarioides*	0.674 ***	0.50		0.72
		Bacillariophyceae	*Navicula lapsa*	0.466 ***			0.77
		Bacillariophyceae	*Navicula tripunctata* var. *schizomenoides*				0.51
		Bacillariophyceae	*Nitzschia inducta*				0.60
		Bacillariophyceae	*Planothidium granum*				0.54
		Bacillariophyceae	*Planothidium lanceolatum* var. *genuinum*	0.627 ***			0.61
		Bacillariophyceae	*Reimeria* sp.	0.627 ***			0.65
		Bacillariophyceae	*Rhoicosphenia linearis*	0.466 ***			0.61
P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Bacillariophyceae	*Achnanthes minutissima forma eutrop*		0.56		
		Bacillariophyceae	*Amphora inariensis*			0.333 **	
		Bacillariophyceae	*Amphora pediculus*		0.52		0.63
		Bacillariophyceae	*Caloneis bacillum* var. *densestriata*	0.598 ***			
		Bacillariophyceae	*Cocconeis placentula* var. *placentula*		0.56		
		Bacillariophyceae	*Cymbella affinis* var. *procera*	0.565 ***		0.475 ***	

EUNIS L3 code	EUNIS L3 name	Major taxonomic group	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P2E (cont.)	Mid-altitude, medium to large, calcareous or mixed rivers (cont.)	Bacillariophyceae	*Cymbella minuta*		0.52		
		Bacillariophyceae	*Cymbella silesiaca*			0.408 **	
		Bacillariophyceae	*Cymbella sinuata* var. *capitata*			0.49 ***	
		Bacillariophyceae	*Denticula tenuis* var. *crassula*	0.565 ***		0.437 ***	
		Bacillariophyceae	*Diatoma ehrenbergii*	0.495 ***		0.366 **	
		Bacillariophyceae	*Diatoma mesodon*			0.41 ***	
		Bacillariophyceae	*Diatoma vulgaris*	0.598 ***			
		Bacillariophyceae	*Diatoma vulgaris capitulata*	0.531 **			
		Bacillariophyceae	*Diatoma vulgaris capitulata*			0.381 **	
		Bacillariophyceae	*Fragilaria capucina capitellata* group			0.366 **	
		Bacillariophyceae	*Fragilaria capucina* var. *gracilis*	0.495 **			
		Bacillariophyceae	*Fragilaria capucina* var. *rumpens*	0.565 ***			
		Bacillariophyceae	*Fragilaria pinnata* f. teratogene	0.531 ***		0.316 **	
		Bacillariophyceae	*Fragilaria ulna species*			0.333 **	
		Bacillariophyceae	*Gomphonema minutum* f. teratogene		0.52		
		Bacillariophyceae	*Gomphonema pumilum* var. *rigidum*	0.598 ***			
		Bacillariophyceae	*Navicula cryptocephala*			0.35 **	
		Bacillariophyceae	*Navicula cryptotenella*		0.52		
		Bacillariophyceae	*Navicula tripunctata* var. *schizomenoides*		0.52		0.59
		Bacillariophyceae	*Navicula veneta*			0.333 **	
		Bacillariophyceae	*Navicula viridula* var. *viridula*			0.298 **	
		Bacillariophyceae	*Nitzschia acicularis*			0.333 **	
		Bacillariophyceae	*Nitzschia constricta*			0.298 **	
		Bacillariophyceae	*Nitzschia dissipata* f. *maewensis*		0.52		

EUNIS L3 code	EUNIS L3 name	Major taxonomic group	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P2E (cont.)	Mid-altitude, medium to large, calcareous or mixed rivers (cont.)	Bacillariophyceae	*Nitzschia heufleriana* f. teratogene	0.531 **			
		Bacillariophyceae	*Nitzschia linearis* var. *subtilis*	0.565 ***			
		Bacillariophyceae	*Nitzschia sigmoidea*			0.333 **	
		Bacillariophyceae	*Nitzschia sublinearis*	0.565 ***		0.463 ***	
		Bacillariophyceae	*Surirella brebissonii* var. *kuetzingii*	0.565 ***			
		Charophyta	*Closterium* sp.			0.316 **	
		Charophyta	*Spirogyra* sp.			0.381 ***	
		Chlorophyta	*Oedogonium* sp.	0.495 ***			
		Chlorophyta	*Stigeoclonium* sp.			0.333 **	
		Chrysophyceae	*Hydrurus foetidus*	0.531 ***			
		Chrysophyceae	*Phaeodermatium rivulare*	0.495 ***			
		Cyanophyta	*Chamaesiphon incrustans*			0.424 **	
		Cyanophyta	*Chamaesiphon polonicus*	0.565 ***		0.424 ***	
		Cyanophyta	*Chamaesiphon polymorphus*	0.531 ***		0.417 **	
		Cyanophyta	*Homoeothrix crustacea*	0.565 ***			
		Cyanophyta	*Homoeothrix varians*	0.598 ***			
		Rhodophyceae	*Audouinella hermannii*			0.366 **	
		Rhodophyceae	*Hildenbrandia* sp.			0.316 **	
P2G	Mid-altitude, medium to large, siliceous rivers	Bacillariophyceae	*Achnanthidium minutissimum*				0.79
		Bacillariophyceae	*Amphora pediculus*				0.70
		Bacillariophyceae	*Diatoma vulgaris* f. *lineare*				0.52
		Bacillariophyceae	*Eolimna neocaledonica*				0.73
		Bacillariophyceae	*Eolimna tantula*				0.52
		Bacillariophyceae	*Navicula gregarioides*				0.79
		Bacillariophyceae	*Navicula lapsa*				0.79

EUNIS L3 code	EUNIS L3 name	Major taxonomic group	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P2G (cont.)	Mid-altitude, medium to large, siliceous rivers (cont.)	Bacillariophyceae	*Nitzschia forfica*				0.52
		Bacillariophyceae	*Nitzschia inducta*				0.67
		Bacillariophyceae	*Nitzschia palea* var. *debilis*				0.61
		Bacillariophyceae	*Planothidium granum*				0.64
		Bacillariophyceae	*Planothidium lanceolatum* var. *genuinum*				0.52
		Bacillariophyceae	*Reimeria* sp.				0.64
		Bacillariophyceae	*Rhoicosphenia linearis*				0.67
P2J	Highland, calcareous or mixed rivers and streams	Charophyta	*Spirogyra* sp.	0.64 ***			
		Chrysophyceae	*Hydrurus* sp.	0.488 ***			
		Cyanophyta	*Nostoc* sp.	0.568 ***			
		Cyanophyta	*Oscillatoria* sp.		0.73		
		Rhodophyceae	*Lemanea* sp.		0.55		

5.3.2 Aquatic vegetation communities

Table 5-4 provides the list of characteristic and common taxa of aquatic vegetation communities, in reference rivers in 6 of the 11 EUNIS running water habitats with data in the WISER database. For the other habitat types, there were no taxa that could be identified as significantly characteristic or as commonly occurring in >50% of the river water bodies within each type. Most of the characteristic or common species are likely to occur mainly in slow-flowing rivers, except the bryophyte, *Fontinalis*, which can occur in fast-flowing rivers.

Growth forms are used instead of higher taxonomic information (e.g. class, family), because they provide a better understanding of the aquatic vegetation groups.

The major differences between the characteristic and/or common species in different reference river habitats are that fewer species are found to be characteristic in the calcareous habitats than in the siliceous habitats. Most of the characteristic species are elodeids, especially in the lowland, medium-large siliceous rivers (P28). Several lemnids and a couple of nymphaeids are also characteristic for that habitat type. All the characteristic species in this habitat type are also found to be common species. It is not clear whether all these species are CO_2-species. These results are therefore difficult to explain and raise some doubts about the identification of these rivers as truly siliceous reference rivers.

Altitude also affects the species' composition primarily by decreasing the number of characteristic and common species, especially in the siliceous river habitats. In the lowland region, there are many characteristic and common species (elodeids, lemnids and nymphaeids), while in the mid-altitude siliceous rivers, there are only two characteristic species, the bryophyte *Fontinalis squamosa* in the small rivers (P2C) and charophyte *Nitella capillaris* in the larger rivers (P2G).

Catchment size has no clear effect on the characteristic or common species.

The characteristic and common aquatic vegetation taxa are fundamentally different in impacted rivers compared to reference rivers across all the habitats with sufficient data in the WISER database (Table 5-4). There are no characteristic and common taxa that are found both in reference rivers and in impacted rivers. Moreover, there are only two characteristics and one common taxa in the impacted rivers, while the reference rivers have a much higher number of characteristics and common taxa. This shows that human impact has a huge negative effect on the species composition of aquatic vegetation in rivers.

Table 5-4 Aquatic vegetation in reference and impacted rivers: 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 ≥0.50 (50%). Dominant taxa not identified as data are only presence/absence. Helophytes, mosses (Bryophyta) and terrestrial plants identified within aquatic vegetation surveys are not included in the table, except for *Fontinalis* (genus of aquatic moss).**

EUNIS L3 code	EUNIS L3 name	Growth form	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P22	Lowland, very small to small, calcareous or mixed rivers and streams	Bryophyta	*Fontinalis antipyretica*		0.73		
		Elodeid	*Ranunculus penicillatus*	0.566 **			
P26	Lowland, medium to large, calcareous or mixed rivers	Bryophyta	*Fontinalis antipyretica*		0.74		
		Elodeid	*Callitriche obtusangula*	0.615 **			
		Nymphaeid	*Nymphaea alba x candida*			0.429 **	
P28	Lowland, medium to large, siliceous rivers	Elodeid	*Elodea canadensis*	0.705 ***	0.75		
		Elodeid	*Potamogeton obtusifolius*	0.686 ***	0.50		
		Elodeid	*Potamogeton pectinatus*	0.686 **	0.50		
		Elodeid	*Potamogeton trichoides*	0.686 **	0.50		
		Lemnid	*Lemna minor*		0.75		
		Lemnid	*Lemna trisulca*	0.686 **	0.50		
		Lemnid	*Spirodela polyrhiza*	0.686 ***	0.50		
		Nymphaeid	*Nuphar lutea*	0.686 ***	0.50		
		Nymphaeid	*Sparganium emersum*	0.686 ***	0.50		
P2C	Mid-altitude, very small to small, siliceous rivers and streams	Bryophyta	*Fontinalis squamosa*	0.5 **			
P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Elodeid	*Potamogeton pusillus*	0.516 **			
P2G	Mid-altitude, medium to large, siliceous rivers	Bryophyta	*Fontinalis* sp.				0.5
		Charophyte	*Nitella capillaris*	0.736 ***	0.50		
		Elodeid	*Callitriche lusitanica*			0.736 ***	

5.3.3 Benthic invertebrate communities

Table 5-5 provides a long list of characteristic and common taxa of benthic invertebrate communities in all the 11 EUNIS river habitats with data from reference rivers in the WISER database. This group has a lot more characteristic and common taxa than the other major biological groups included in this report, reflecting the very long monitoring tradition of this group within Europe.

The major differences between the species composition are:

Differences in characteristic and common benthic invertebrates taxa between calcareous and siliceous running water reference habitats

The key distinctions among taxa across various habitats are the higher number of characteristic benthic invertebrate taxa in calcareous environments (46 taxa), than in siliceous habitats (32 taxa). Moreover, calcareous habitats also had more common taxa (123 taxa) than siliceous habitats (87 taxa).

Calcareous rivers include a wide variety of benthic invertebrates, such as several Ephemeroptera (Baetidae, *Baetis* sp., Ephemeridae), Plecoptera (Leuctridae, Nemouridae, Perlodidae), Trichoptera (Hydropsychidae, Hydroptilidae), Chironomidae, Gammaridae (*Gammarus*), Gastropoda (the Planorbidae *Ancylus,* the Bithynidae *Bithynia*, the Neritidae *Theodoxus*), Oligochaeta (Oligochaeta Gen. sp.), Sphaeridae (*Pisidium*), Ceratopogonidae, Simuliidae and Coleoptera (Elmidae).

Siliceous rivers, on the other hand, have more families of Plecoptera (Chloroperlidae, Leuctridae, Nemouridae, Perlodidae, Perlidae), Ephemeroptera (Baetidae, Heptagenidae), Trichoptera (Limnephiliidae, Brachycentridae, Glossostomatidae, Hydrophychidae, Odontoceridae, Polycentropodidae, Ryacophilidae, Sericostomatidae, Uenoidae), Corixidae, Diptera (Blephariceridae, Ceratopogonidae, Simuliidae), flatworms like Dugesiidae, and specific Coleoptera (e.g. Dytiscidae, Elmidae, Scirtidae, *Hydraena*). No gastropods and no amphipod crustaceans (Gammaridae) were found in the WISER dataset for siliceous rivers.

Differences in characteristic and common benthic invertebrates taxa between running water reference habitats in different altitude categories

In glacial and highland rivers and streams, 31 taxa were found to be characteristic, and 45 were common, contrasting with lowland and mid-altitude regions, where 70 were characteristic, and 177 were common.

More stonefly (Plecoptera) taxa were found in highland habitats than in mid-altitude and lowland habitats.

Glacial rivers and streams (P2R) differed from other habitats, showcasing several more characteristic/common dipterans, including many Chironomidae *Eukiefferiella fittkaui*, *E*. *minor*, and *E*. *tirolensis*, along with *Diamesa starmachi* and *Stilocladius montanus*. The red chironomids in the *Diamesa*-genus usually dominate upper glacial streams, with Ephemeroptera (*Baetis alpinus* and *Rhithrogena* spp.), Plecoptera, and Trichoptera becoming more common in lower sections in glacial rivers in reference or good status conditions (Bundi, 2010). The ephemeropteran *Baetis rhodani* was commonly found at mid-altitude. This shows that altitudinal gradients also play a role in benthic invertebrate distributions.

Differences in characteristic and common benthic invertebrates taxa between reference and impacted running water habitats

In impacted rivers in lowland and mid-altitude areas, there are very few characteristic and common taxa compared to what was found in reference rivers. Stoneflies (*Plecoptera*) taxa were only found to be characteristic or common in impacted highland habitats but not in lowland or mid-altitude habitats (Table 5-5). The few characteristic and common taxa found in impacted rivers include mainly chironomids (non-biting midges) and *Tubificidae* (sludge worms) known to tolerate low oxygen concentrations, which is common in rivers with a poor water quality due to organic pollution from wastewater. However, also Leeches (*Erpobdella octoculata*), the amphipod *Gammarus pulex*, a few mayflies (*Baetidae*) and caddisflies (*Hydropsychidae*) were found to be characteristic and/or common in the impacted rivers. Those taxa were mainly found in the mid-altitude habitat types, indicating that most of those rivers have better oxygen conditions compared to impacted lowland rivers. This could be related to higher flow and lower temperature in mid-altitude rivers than in lowland rivers.

In impacted highland, calcareous rivers (P2J), many characteristic taxa were found including several genera within the so-called EPT-taxa (*Ephemeroptera, Plecoptera* and *Trichoptera*), which are known to indicate quite good water quality. Most of these were also common in that habitat type. This indicates that the level of impact in highland rivers is less than in the lowland and mid-altitude rivers and/or that highland rivers are mainly fast flowing and have a lower temperature and thereby a higher oxygen concentration. These conditions increase the tolerance of many benthic invertebrates to moderate organic pollution compared to rivers at lower altitudes or of a slower current velocity.

Due to a lack of data, we found no characteristic nor common species in impacted highland siliceous rivers (P2L) (Table 3-1).

For glacial rivers (P2R), we found many characteristic and common taxa in both reference rivers and impacted rivers, especially chironomids, which could be related to the siltation impact in glacial rivers due to the heavy particle load from the glacial particles, causing a quite compact (dense) sediment and poor light conditions, thereby restricting primary production and thereby the food supply to the benthic invertebrates and also decreasing oxygen concentrations in the sediment. However, there were more characteristic chironomid species in the impacted glacial rivers than in the reference glacial rivers. As chironomids are quite tolerant to reduced oxygen concentrations, this could be a reaction to some organic pollution in the impacted glacial rivers.

Table 5-5 Benthic invertebrates in reference and impacted rivers: 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 ≥0.7 (70%). Dominant taxa not identified as data were only presence/absence.**

EUNIS L3 code	EUNIS L3 name	Family (if not given otherwise)	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P22	Lowland, very small to small, calcareous or mixed rivers and streams	Baetidae	*Baetis* sp.		1		
		Ceratopogonidae	Ceratopogonidae Gen. sp.		0.74		
		Chironomidae	Chironomidae Gen. sp.		0.96		
		Chironomidae	*Chironomus* sp.			0.074 **	
		Chironomidae	*Conchapelopia melanops*			0.074 **	
		Dendrocoelidae	*Dendrocoelum* sp.	0.079 **			
		Elmidae	*Elmis* sp.		0.93		
		Elmidae	*Limnius* sp.		0.85		
		Elmidae	*Oulimnius* sp.		0.78		
		Ephemerellidae	*Ephemerella* sp.		0.78		
		Ephemeridae	*Ephemera* sp.		0.81		
		Erpobdellidae	*Erpobdella octoculata*				0.73
		Gammaridae	Gammaridae Gen. sp.	0.099 **			
		Gammaridae	*Gammarus pulex*				0.73
		Gammaridae	*Gammarus* sp.		0.81		
		Gerridae	*Gerris* sp.	0.089 ***			
		Hydrachnidia	Hydrachnidia Gen. sp.		0.78		
		Hydropsychidae	*Hydropsyche* sp.		0.89		
		Hydroptilidae	*Ithytrichia* sp.	0.099 **			
		Leptoceridae	*Mystacides* sp.	0.065 **			
		Leptoceridae	*Oecetis* sp.	0.079 **			
		Leptophlebiidae	*Paraleptophlebia* sp.	0.089 ***			
		Leuctridae	*Leuctra* sp.		0.7		
		Oligochaeta (subclass)	Oligochaeta Gen. sp.		0.89		
		Planorbidae	*Ancylus* sp.		0.78		

EUNIS L3 code	EUNIS L3 name	Family (if not given otherwise)	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
		Psychomyiidae	*Lype* sp.	0.079 **			
		Rhyacophilidae	*Rhyacophila* sp.		0.85		
		Sericostomatidae	*Sericostoma* sp.		0.78		
		Simuliidae	Simuliidae Gen. sp.		0.78		
P26	Lowland, medium to large, calcareous or mixed rivers	Aphelocheiridae	*Aphelocheirus* sp.	0.105 ***			
		Baetidae	*Baetis* sp.		0.89		
		Bithyniidae	*Bithynia* sp.	0.117 ***			
		Chironomidae	Chironomidae Gen. sp.		0.76		
		Ephemerellidae	*Ephemerella* sp.		0.74		
		Gomphidae	*Onychogomphus* sp.	0.09 ***			
		Hydrachnidia (suborder)	Hydrachnidia Gen. sp.		0.79		
		Hydropsychidae	*Cheumatopsyche* sp.	0.105 ***			
		Hydropsychidae	*Hydropsyche* sp.		0.84		
		Hydroptilidae	*Hydroptila* sp.	0.083 **			
		Neritidae	*Theodoxus* sp.	0.092 **			
		Oligochaeta (subclass)	Oligochaeta Gen. sp.		0.82		
		Psychomyiidae	*Psychomyia* sp.	0.086 ***			
		Rhyacophilidae	*Rhyacophila* sp.		0.71		
		Simuliidae	Simuliidae Gen. sp.		0.82		
		Sphaeriidae	*Pisidium* sp.		0.71		
P28	Lowland, medium to large, siliceous rivers	Chironomidae	Chironomidae Gen. sp.				0.71
		Tubificidae	*Limnodrilus* sp.			0.09 **	
P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams	Ceratopogonidae	*Bezzia* sp.	0.065 **			
		Elmidae	*Elmis maugetii*	0.067 **			
		Elmidae	*Esolus* sp.	0.071 **			
		Heptageniidae	*Ecdyonurus* sp.		0.72		
		Hydraenidae	*Hydraena gracilis*	0.075 **			
		Hydropsychidae	*Hydropsyche saxonica*	0.063 **			

EUNIS L3 code	EUNIS L3 name	Family (if not given otherwise)	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
		Hydropsychidae	*Hydropsyche* sp.		0.86		
		Simuliidae	*Prosimulium hirtipes*	0.069 **			
P2C	Mid-altitude, very small to small, siliceous rivers and streams	Baetidae	*Baetis rhodani*		0.75		0.84
		Baetidae	*Baetis scambus*	0.078 **			
		Blephariceridae	*Liponeura* sp.	0.061 **			
		Brachycentridae	*Micrasema longulum*	0.061 **			
		Dugesiidae	*Dugesia gonocephala*	0.08 ***			
		Leuctridae	*Leuctra nigra*	0.071 **			
		Leuctridae	*Leuctra* sp.		0.75		
		Limnephilidae	*Drusus annulatus*	0.065 **			
		Lymnaeidae	*Radix balthica*	0.075 **			
		Perlidae	*Dinocras cephalotes*	0.071 **			
		Perlodidae	*Isoperla* sp.		0.74		
		Polycentropodidae	*Plectrocnemia conspersa conspersa*	0.057 **			
		Sericostomatidae	*Sericostoma* sp.		0.75		
P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Baetidae	*Baetis* sp.		0.94		0.81
		Chironomidae	*Diamesa hamaticornis*	0.058 **			
		Chironomidae	*Orthocladius obumbratus*			0.069 **	
		Chironomidae	*Orthocladius rivicola*	0.071 **			
		Chironomidae	*Polypedilum convictum*	0.066 **			
		Hydrachnidia (suborder)	Hydrachnidia Gen. sp.		0.79		
		Hydropsychidae	*Hydropsyche* sp.		0.96		0.81
		Leuctridae	*Leuctra* sp.		0.81		
P2G	Mid-altitude, medium to large, siliceous rivers	Baetidae	*Baetis niger*	0.073 **			
		Baetidae	*Baetis rhodani*		0.9		0.94
		Chironomidae	Chironomini Gen. sp.	0.087 ***			
		Chironomidae	Tanypodinae Gen. sp.	0.139 ***			

EUNIS L3 code	EUNIS L3 name	Family (if not given otherwise)	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P2G (cont.)	Mid-altitude, medium to large, siliceous rivers (cont.)	Chironomidae	Tanytarsini Gen. sp.	0.099 **			
		Ephemerellidae	*Ephemerella mucronata*	0.107 ***	0.7		
		Heptageniidae	*Epeorus assimilis*	0.074 **			
		Hydropsychidae	*Hydropsyche instabilis*	0.078 **			
		Hydropsychidae	*Hydropsyche siltalai*				0.73
		Lepidostomatidae	*Lepidostoma hirtum*	0.085 **			
		Limnephilidae	*Anomalopterygella chauviniana*	0.119 ***			
		Limnephilidae	*Ecclisopteryx dalecarlica*	0.1 ***			
		Limoniidae	*Eloeophila* sp.	0.09 ***			
		Pediciidae	*Dicranota* sp.	0.091 ***	0.85		
		Perlodidae	*Isoperla* sp.		0.85		
		Polycentropodidae	*Polycentropus flavomaculatus flavomaculatus*	0.088 **			
		Rhyacophilidae	*Rhyacophila nubila*	0.102 ***			
		Sericostomatidae	*Sericostoma* sp.		0.75		
		Tipulidae	*Tipula* sp.	0.084 **			
P2J	Highland, calcareous or mixed rivers and streams	Athericidae	Athericidae Gen. sp.			0.195 ***	
		Baetidae	*Baetis* sp.		0.91	0.11 ***	1
		Chironomidae	Chironomidae Gen. sp.		0.74		0.71
		Elmidae	*Elmis* sp.			0.166 ***	
		Empididae	Empididae Gen. sp.			0.142 ***	0.71
		Heptageniidae	*Ecdyonurus* sp.		0.91	0.151 ***	0.71
		Heptageniidae	*Rhithrogena* sp.		0.87	0.15 **	0.71
		Hydrachnidia (suborder)	Hydrachnidia Gen. sp.		0.74	0.162 ***	1
		Hydropsychidae	*Hydropsyche* sp.			0.102 ***	0.86
		Leuctridae	*Leuctra* sp.		1	0.124 **	0.86
		Limoniidae	Limoniidae Gen. sp.			0.164 ***	0.71

EUNIS L3 code	EUNIS L3 name	Family (if not given otherwise)	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P2J (cont.)	Highland, calcareous or mixed rivers and streams (cont.)	Nemouridae	*Nemoura* sp.			0.139 ***	0.71
		Nemouridae	*Protonemura* sp.		0.87	0.161 ***	0.86
		Oligochaeta (subclass)	Oligochaeta Gen. sp.				0.71
		Perlodidae	*Dictyogenus* sp.	0.086 **			
		Perlodidae	*Isoperla* sp.		0.83	0.126 **	0.71
		Psychodidae	Psychodidae Gen. sp.			0.086 **	
		Rhyacophilidae	*Rhyacophila* sp.		0.78	0.175 ***	0.86
		Simuliidae	Simuliidae Gen. sp.		0.74	0.141 ***	0.71
P2L	Highland siliceous rivers and streams	Athericidae	Athericidae Gen. sp.		1		
		Baetidae	*Baetis* sp.		1		
		Brachycentridae	*Micrasema* sp.		1		
		Ceratopogonidae	Ceratopogonidae Gen. sp.		1		
		Chironomidae	Chironomidae Gen. sp.		1		
		Chloroperlidae	*Chloroperla* sp.		0.75		
		Chloroperlidae	*Siphonoperla* sp.		1		
		Cordulegastridae	*Cordulegaster* sp.	0.096 ***			
		Corixidae	*Micronecta* sp.	0.096 ***			
		Dytiscidae	Colymbetinae Gen. sp.	0.108 ***	0.75		
		Dytiscidae	Hydroporinae Gen. sp.		1		
		Elmidae	*Dupophilus* sp.		0.75		
		Elmidae	*Elmis* sp.		1		
		Elmidae	*Esolus* sp.		1		
		Elmidae	*Limnius* sp.		1		
		Glossosomatidae	*Glossosoma* sp.		0.75		
		Glossosomatidae	Glossosomatidae Gen. sp.	0.079 **			
		Heptageniidae	*Ecdyonurus* sp.		1		
		Heptageniidae	*Epeorus* sp.		1		
		Heptageniidae	*Rhithrogena* sp.		1		

EUNIS L3 code	EUNIS L3 name	Family (if not given otherwise)	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P2L (cont.)	Highland siliceous rivers and streams (cont.)	Hydrachnidia (suborder)	Hydrachnidia Gen. sp.		1		
		Hydraenidae	*Hydraena* sp.		1		
		Hydropsychidae	*Hydropsyche* sp.		1		
		Leuctridae	*Leuctra* sp.		1		
		Limnephilidae	Drusinae Gen. sp.		0.75		
		Limnephilidae	Stenophylacini Gen. sp.	0.096 ***			
		Limoniidae	Limoniidae Gen. sp.		1		
		Nemouridae	*Amphinemura* sp.		0.75		
		Nemouridae	*Nemoura* sp.		0.75		
		Nemouridae	*Protonemura* sp.		0.75		
		Odontoceridae	*Odontocerum* sp.		1		
		Oligochaeta (subclass)	Oligochaeta Gen. sp.		1		
		Perlidae	*Dinocras* sp.		0.75		
		Perlodidae	*Isoperla* sp.		0.75		
		Perlodidae	Perlodidae Gen. sp.		0.75		
		Philopotamidae	*Philopotamus* sp.		0.75		
		Planariidae	Planariidae Gen. sp.		0.75		
		Polycentropodidae	Polycentropodidae Gen. sp.	0.077 **			
		Rhyacophilidae	*Rhyacophila* sp.		0.75		
		Scirtidae	*Elodes* sp.	0.096 ***			
		Scirtidae	*Hydrocyphon* sp.	0.081 **			
		Sericostomatidae	*Sericostoma* sp.		1		
		Simuliidae	Simuliidae Gen. sp.		1		
		Uenoidae	*Thremma* sp.	0.096 ***			
P2R	Glacial rivers and streams	Baetidae	*Acentrella* sp.	0.067 ***			
		Baetidae	*Baetis alpinus*			0.102 **	
		Baetidae	*Baetis rhodani*				0.92
		Baetidae	*Baetis* sp.		0.92		0.85

EUNIS L3 code	EUNIS L3 name	Family (if not given otherwise)	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P2R (cont.)	Glacial rivers and streams (cont.)	Chironomidae	*Corynoneura* sp.	0.077 ***		0.12 ***	0.77
		Chironomidae	*Diamesa* sp.			0.1 ***	
		Chironomidae	*Diamesa starmachi*	0.067 **			
		Chironomidae	*Eukiefferiella fittkaui*	0.067 ***		0.1 ***	
		Chironomidae	*Eukiefferiella fuldensis*			0.1 ***	
		Chironomidae	*Eukiefferiella minor*	0.067 ***		0.1 ***	
		Chironomidae	*Eukiefferiella minor/fittkaui*				0.77
		Chironomidae	*Eukiefferiella* sp.			0.089 **	
		Chironomidae	*Eukiefferiella tirolensis*	0.077 **		0.1 ***	
		Chironomidae	*Heleniella* sp.			0.1 ***	
		Chironomidae	Orthocladiini COP			0.105 **	0.85
		Chironomidae	*Orthocladius frigidus*			0.098 **	
		Chironomidae	*Orthocladius rivicola*			0.083 **	
		Chironomidae	*Orthocladius rivulorum*			0.085 **	
		Chironomidae	*Orthocladius thienemanni*			0.076 **	
		Chironomidae	*Parakiefferiella* sp.	0.067 ***			
		Chironomidae	*Parorthocladius nudipennis*			0.093 **	
		Chironomidae	*Pseudodiamesa branickii*	0.067 **		0.1 ***	
		Chironomidae	*Rheocricotopus effusus*			0.076 **	
		Chironomidae	*Rheocricotopus* sp.			0.093 **	
		Chironomidae	*Rheosmittia spinicornis*	0.067 **			
		Chironomidae	*Stilocladius montanus*	0.067 **		0.1 **	
		Chironomidae	*Thienemanniella* sp.	0.06 **			
		Chironomidae	*Tvetenia bavarica*	0.077 **		0.113 ***	
		Dixidae	Dixidae Gen. sp.	0.067 **			
		Empididae	Empididae Gen. sp.		0.92		0.92
		Enchytraeidae	*Cognettia* sp.	0.067 ***		0.107 ***	
		Heptageniidae	*Ecdyonurus* sp.		0.83		

EUNIS L3 code	EUNIS L3 name	Family (if not given otherwise)	Taxon name	Taxa in reference rivers		Taxa in impacted rivers	
				Characteristic	Common	Characteristic	Common
P2R (cont.)	Glacial rivers and streams (cont.)	Heptageniidae	*Rhithrogena* sp.		0.83		0.92
		Hydrachnidia (suborder)	Hydrachnidia Gen. sp.		0.83		
		Leuctridae	*Leuctra* sp.		1		1
		Limnephilidae	Drusinae Gen. sp.			0.093 **	
		Limoniidae	*Molophilus* sp.	0.067 ***			
		Nemouridae	Nemouridae Gen. sp.			0.093 **	
		Nemouridae	*Protonemura* sp.		0.92		0.77
		Oligochaeta (subclass)	Oligochaeta Gen. sp.		0.75		
		Pediciidae	*Dicranota* sp.				0.92
		Perlidae	*Perla* sp.		0.75		
		Rhagionidae	Rhagionidae Gen. sp.	0.067 ***			
		Rhyacophilidae	*Rhyacophila* sp.		0.83		
		Rhyacophilidae	*Rhyacophila torrentium*	0.067 **			
		Sperchontidae	*Sperchon* sp.			0.093 **	
		Taeniopterygidae	*Rhabdiopteryx alpina*			0.1 ***	
		Taeniopterygidae	*Rhabdiopteryx* sp.			0.093 **	
		Turbellaria (class)	Turbellaria Gen. sp.	0.077 **		0.09 **	

5.3.4 Fish communities

Table 5-6 provides the list of characteristics, common and dominant fish species in reference rivers in most of the EUNIS level 3 habitat types. The dominant species are uncertain due to unclear methods used by different countries for calculating the number of individuals per river water body (raw data indicate different numbers of sites per river, disaggregated or aggregated across sites). The major differences between the species composition are:

Differences in characteristic and common fish taxa:

Between calcareous and siliceous running water reference habitats:

There are more characteristic, common and dominant fish species identified in the calcareous rivers than in the siliceous rivers. The species are from a range of different families, but most of them are cyprinids in the calcareous lowland rivers.

Between running water reference habitats in different altitude categories:

The most obvious effect of altitude is the quite striking preference for lowland rivers by the cyprinids, which are known to be warm-water species: the number of characteristic, common and dominant cyprinid species decreases substantially from 3-9 species in most of the lowland habitat types to 1-2 species in mid-altitude rivers and 0-1 in highland rivers.

Between running water reference habitats in different categories of catchment size:

The number of characteristic, common and dominant fish species is higher in the larger rivers than in the smaller rivers, especially cyprinids. Apart from that, there is no clear pattern.

Between reference and impacted running water habitats:

There are more characteristic fish species in impacted rivers than in reference rivers in most of the habitat types, e.g. in P2E (mid-altitude, medium-large calcareous rivers) where two cyprinid species and burbot (*Lota lota*) are characteristic. There are also many more common and dominant fish species in impacted rivers than in reference rivers in most of the habitat types. Equivalent results were also found for phytoplankton in impacted lakes versus reference lakes (section 4.3.1) and is a general pattern often found in freshwater ecosystems: Species tolerant to human impact become dominant, while less tolerant species decrease in relative abundance.

Many of the fish species that become more dominant in impacted rivers in the lowland and mid-altitude habitat types are cyprinids, which are quite tolerant to low oxygen concentrations. In contrast, two salmonid species (*Oncorhynchus mykiss* and *Salvelinus fontinalis*) were found to be characteristic in impacted glacial rivers. These are non-native species introduced extensively since the late 19th century. Today, both are widely naturalized and economically important, especially in aquaculture and recreational fishing (Stanković et al. 2015). The colder water in glacial rivers provides better oxygen conditions than in other river types, thereby providing acceptable habitat for salmonids despite human impact.

Table 5-6 Fish in reference and impacted rivers: 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 ≥0.50 (50%). Dominant taxa identified with a mean relative abundance ≥0.1 (10% of the total number of individuals).**

EUNIS L3 code	EUNIS L3 name	Family	Taxon name	Taxa in reference rivers			Taxa in impacted rivers		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P22	Lowland, very small to small, calcareous or mixed rivers and streams	Anguillidae	*Anguilla anguilla*					0.55	
		Cobitidae	*Cobitis taenia*						0.11
		Cottidae	*Cottus gobio*		0.81	0.31			0.29
		Cyprinidae	*Gobio gobio*					0.64	0.22
		Cyprinidae	*Phoxinus phoxinus*		0.67	0.35			0.25
		Cyprinidae	*Rutilus rutilus*					0.52	0.11
		Gasterosteidae	*Gasterosteus aculeatus*					0.53	0.33
		Gasterosteidae	*Pungitius pungitius*				0.48 ***		0.17
		Nemacheilidae	*Barbatula barbatula*		0.7	0.17		0.65	0.19
		Salmonidae	*Salmo salar*	0.489 **		0.1			
		Salmonidae	*Salmo trutta fario*		0.81	0.32		0.56	0.28
P24	Lowland, very small to small, siliceous rivers and streams	Cottidae	*Cottus gobio*						0.31
		Cyprinidae	*Carassius gibelio*				0.308 **		
		Cyprinidae	*Gobio gobio*					0.58	0.28
		Cyprinidae	*Phoxinus phoxinus*						0.24
		Cyprinidae	*Rutilus rutilus*					0.52	0.12
		Cyprinidae	*Squalius cephalus*					0.52	
		Gasterosteidae	*Gasterosteus aculeatus*					0.52	0.19
		Nemacheilidae	*Barbatula barbatula*					0.58	0.22
		Petromyzonidae	*Lampetra planeri*						0.17
		Salmonidae	*Salmo trutta fario*					0.50	0.55

EUNIS L3 code	EUNIS L3 name	Family	Taxon name	Taxa in reference rivers			Taxa in impacted rivers		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P26	Lowland, medium to large, calcareous or mixed rivers	Anguillidae	*Anguilla anguilla*			0.13		0.69	
		Centrarchidae	*Lepomis gibbosus*				0.36 **		
		Cottidae	*Cottus gobio*		0.79	0.22			0.17
		Cyprinidae	*Alburnoides bipunctatus*			0.11			
		Cyprinidae	*Alburnus alburnus*	0.525 **					
		Cyprinidae	*Blicca bjoerkna*				0.419 ***		
		Cyprinidae	*Gobio gobio*		0.54			0.73	0.19
		Cyprinidae	*Gobio gobio*						
		Cyprinidae	*Leuciscus leuciscus*					0.51	
		Cyprinidae	*Phoxinus phoxinus*		0.62	0.32			0.17
		Cyprinidae	*Rutilus rutilus*					0.72	0.16
		Cyprinidae	*Squalius cephalus*			0.1		0.65	
		Cyprinidae	*Squalius cephalus*						
		Esocidae	*Esox lucius*					0.51	
		Gasterosteidae	*Gasterosteus aculeatus*						0.12
		Nemacheilidae	*Barbatula barbatula*		0.64			0.59	0.17
		Percidae	*Perca fluviatilis*						0.11
		Petromyzonidae	*Lampetra planeri*		0.51				
		Salmonidae	*Salmo trutta fario*		0.74	0.12			0.26
P28	Lowland, medium to large, siliceous rivers	Anguillidae	*Anguilla anguilla*					0.50	
		Cottidae	*Cottus gobio*		0.5				0.17
		Cyprinidae	*Alburnoides bipunctatus*		0.5	0.22			
		Cyprinidae	*Gobio gobio*		0.75	0.29		0.80	0.24

EUNIS L3 code	EUNIS L3 name	Family	Taxon name	Taxa in reference rivers			Taxa in impacted rivers		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
		Cyprinidae	*Leucaspius delineatus*	0.688 **	0.5				
		Cyprinidae	*Leuciscus leuciscus*					0.66	
		Cyprinidae	*Phoxinus phoxinus*		0.5	0.6			0.20
		Cyprinidae	*Rutilus rutilus*					0.68	0.16
		Cyprinidae	*Squalius cephalus*					0.72	0.13
		Gasterosteidae	*Gasterosteus aculeatus*	0.608 **	0.5				0.12
		Nemacheilidae	*Barbatula barbatula*		0.5			0.73	0.20
		Percidae	*Perca fluviatilis*						0.10
		Salmonidae	*Salmo trutta fario*		0.75	0.15		0.60	0.20
P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams	Cottidae	*Cottus gobio*		0.59	0.29			0.35
		Cottidae	*Cottus gobio*						
		Cottidae	*Cottus poecilopus*			0.39			
		Cyprinidae	*Gobio gobio*						0.20
		Cyprinidae	*Phoxinus phoxinus*			0.45			0.24
		Cyprinidae	*Squalius cephalus*			0.14			0.17
		Cyprinidae	*Squalius cephalus*						
		Gasterosteidae	*Gasterosteus aculeatus*						0.18
		Nemacheilidae	*Barbatula barbatula*						0.19
		Petromyzonidae	*Lampetra planeri*						0.13
		Salmonidae	*Oncorhynchus mykiss*						0.11
		Salmonidae	*Salmo trutta fario*		0.94	0.55		0.90	0.45

EUNIS L3 code	EUNIS L3 name	Family	Taxon name	Taxa in reference rivers			Taxa in impacted rivers		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P2C	Mid-altitude, very small to small, siliceous rivers and streams	Cottidae	*Cottus gobio*		0.7	0.28		0.51	0.31
		Cyprinidae	*Gobio gobio*						0.13
		Cyprinidae	*Phoxinus phoxinus*			0.28			0.23
		Cyprinidae	*Rutilus rutilus*						0.11
		Gasterosteidae	*Gasterosteus aculeatus*						0.20
		Nemacheilidae	*Barbatula barbatula*					0.58	0.26
		Salmonidae	*Salmo trutta fario*		1	0.57		0.96	0.45
P2E	Mid-altitude, medium to large, calcareous or mixed rivers	Cottidae	*Cottus gobio*		0.84	0.18		0.61	0.17
		Cyprinidae	*Alburnoides bipunctatus*			0.18	0.492 ***		0.14
		Cyprinidae	*Gobio gobio*			0.12		0.63	0.14
		Cyprinidae	*Phoxinus phoxinus*			0.34			0.26
		Cyprinidae	*Phoxinus phoxinus*						
		Cyprinidae	*Pseudochondrostoma nasus*				0.472 ***		
		Cyprinidae	*Rutilus rutilus*					0.52	0.10
		Cyprinidae	*Squalius cephalus*					0.70	0.13
		Lotidae	*Lota lota*				0.332 **		
		Nemacheilidae	*Barbatula barbatula*		0.51			0.66	0.14
		Salmonidae	*Oncorhynchus mykiss*			0.16			0.11
		Salmonidae	*Salmo trutta fario*		1	0.37		0.74	0.30
		Thymallidae	*Thymallus thymallus*	0.573 **		0.13			0.10

EUNIS L3 code	EUNIS L3 name	Family	Taxon name	Taxa in reference rivers			Taxa in impacted rivers		
				Characteristic	Common	Dominant	Characteristic	Common	Dominant
P2G	Mid-altitude, medium to large, siliceous rivers	Cottidae	*Cottus gobio*		0.64	0.18		0.51	0.30
		Cyprinidae	*Gobio gobio*					0.56	0.17
		Cyprinidae	*Phoxinus phoxinus*			0.53			0.34
		Cyprinidae	*Rutilus rutilus*			0.1			
		Cyprinidae	*Squalius cephalus*						0.12
		Nemacheilidae	*Barbatula barbatula*			0.12		0.68	0.16
		Salmonidae	*Salmo trutta fario*		0.86	0.56		0.98	0.33
P2J	Highland, calcareous or mixed rivers and streams	Cottidae	*Cottus gobio*			0.32			
		Cyprinidae	*Phoxinus phoxinus*			0.19			
		Salmonidae	*Salmo trutta fario*		1	0.76		1.00	0.98
P2L	Highland siliceous rivers and streams	Cyprinidae	*Phoxinus phoxinus*		0.75				
		Salmonidae	*Salmo trutta fario*		1	0.77			
P2R	Glacial rivers and streams	Cottidae	*Cottus gobio*		0.5	0.26		0.67	0.15
		Cottidae	*Cottus gobio*						
		Salmonidae	*Oncorhynchus mykiss*				0.437 ***	0.75	0.26
		Salmonidae	*Salmo trutta fario*		1	0.68		1.00	0.64
		Salmonidae	*Salvelinus fontinalis*				0.557 ***		
		Thymallidae	*Thymallus thymallus*					0.58	0.14

6 Literature review of other EUNIS level 3 habitat types without data in the WISER database

6.1 Standing waters

6.1.1 Habitats included in the literature review

The L3 habitat types listed in Table 6-1 did not have sufficient data in the WISER database, and they have therefore been described using the available scientific papers.

Table 6-1 Standing water habitats included in the literature review, extract from Table 3-3

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. marl/karst lakes and turloughs,
P1F	Temporary siliceous lakes
P1G	Temporary saline and brackish lakes
P1J	Glacier fed lakes
P1K	Permanent marl/karst lakes
P1L	Volcanic lakes
P1N	Permanent ponds and pools
P1P	Temporary ponds and pools

6.1.2 Biology in P1A Highland, calcareous or mixed lakes

Highland or alpine permanent lakes on calcareous (>50% calcareous geology) or mixed geology catchments with an alkalinity >0.2mmol/l, corresponding to a calcium concentration >4mg /l, and occurring above the timberline with a surface area between 0.02 to 100km^2. The lakes would mostly be stratified during summer, but the stratification can be quite short and weakly developed and decreases in length with increasing altitude and latitude. The water is usually very clear with a high transparency. Vegetation is scarce due to temperature limitations and ice cover from late autumn to spring.

- Phytoplankton (Mischke et al., 2016):
    - Reference lakes of this lake type have phytoplankton species from many classes, e.g. diatoms, chlorophytes, desmids, cyanobacteria, chrysophytes and dinoflagellates. Common species are the diatoms: *Aulacoseira subarctica*, *Cyclotella comensis, Cymatopleura solea, Fragilaria cyclopum, Fragilaria Danica, Stephanocostis chantaica, Stephanodiscus neoastrea, Tabellaria flocculosa*, the clorophyte *Tetrachlorella alternans*, the desmid (Conjugatophyceae) *Staurastrum pingue*, the cyanobacterium *Synechococcus cedrorum,* the chrysophyte *Bitrichia chodati* and the dinoflagellate *Ceratium cornutum*. These taxa mainly occur in quite oligotrophic, slightly mesotrophic conditions.
    - Impacted lakes of this lake type also have many species from different algal classes: the diatoms *Aulacoseira ambigua, Stephanodiscus hantzschii*, the chlorophytes *Characium, Pediastrum tetras, Volvox aureus, Volvox globator*, the chrysophyte *Synura sphagnicola, Synura uvella*, and the cyanobacterium *Rhabdogloea smithii*. These taxa mainly occur in quite eutrophic conditions.
- Aquatic vegetation (Gacia et al., 1994; Stelzer et al., 2005): Vegetation is scarce due to temperature limitations and ice cover but this type can support communities of freshwater-submerged vegetation:
    - Reference lakes of this type have a dominance of stoneworts (charophytes): e.g. *Chara aspera, C. delicatula, C., hispida, C. intermedia, C. polyacantha, C. rudis, C. strigosa, C. tomentosa, Nitella opaca, N. syncarpa;* a number of elodeids are also common: *Potamogeton alpinus, P.*

coloratus, P. filiformis, P. gramineus, P. zizii, Utricularia australis, U. intermedia, U. minor, U. ochroleuca, U. stygia in addition to a few isoëtids: *Littorella uniflora.*
    - Impacted lakes of this type have mainly elodeids: *Ceratophyllum demersum, Elodea canadensis, Elodea nutalli, Groenlandia densa, Hippurus vulgaris, Potamogeton compressus, P. crispus, P. friesii, P. lucens, P. nodosus, P. obtusifolius, P. pectinatus, P. pusillus, Ranunculus sp*. (subgenus *Batrachium*); the nymphaeid: *Sagittaria sagittifolia*, the lemnids: *Lemna minor, L. trisulca, Spirodela polyrhiza*
- Benthic invertebrates found in Alpine reference lakes (Füreder et al., 2006, see Figure 4 therein showing a CCA plot, upper right quadrat, and the species list in the Annex therein): The macroinvertebrates were dominated by many chironomid species, some water beetles (*Agabus solieri*, Dytiscidae, Hydroporinae), as well as the typical cold stenothermic species of Ephemeroptera, Plecoptera and Trichoptera.
- Fish species found in Alpine lakes: Brown trout (*Salmo trutta*), Arctic charr (*Salvelinus alpinus*), European Whitefish (*Coregonus lavaretus*), Perch (*Perca fluviatilis*).

6.1.3 Biology in P1B Highland, humic lakes on calcareous or mixed bedrock

These lakes are quite rare in Europe and little information is available concerning biological communities. They can occur in highland or alpine areas where the catchments are rich in mires and peatland over calcareous or mixed geology bedrock. Such lakes would normally have an alkalinity >0.2mmol/l, corresponding to a calcium concentration >4mg/l, and occur above the timberline with a surface area from 0.02 to 100km^2. These waterbodies are characterised by a high colour (>30mg Pt/l), low nutrient concentration and neutral pH (7). The catchments are usually rich in mires and peatland, while vegetation is scarce due to temperature and light limitations, as well as experiencing ice cover during a large part of the year.

The taxa given below were listed by the AI tool Copilot, as neither Google Scholar nor Web of Science could provide any relevant papers. These were checked/corrected/supplemented using the expert knowledge of the authors:

- Phytoplankton: Mixotrophic Chrysophytes like *Dinobryon, Synura* and *Mallomonas* and dinoflagellates like *Ceratium*, chlorophytes like *Chlamydomonas* and diatoms like *Asterionella* and *Fragilaria*. The chrysophytes are known to dominate in cold lakes, as well as in brown lakes with low nutrient levels.
- Aquatic vegetation: This lake type can support communities freshwater nymphaeid vegetation, including *Nuphar lutea*. Other genera that may occur are elodeids like *Myriophyllum alterniflorum, Callitriche hamulate, Ranunculus aquatilis*.
- Benthic invertebrates (Füreder et al., 2006 [4]): Benthic invertebrates in highland lakes in peat bog catchments with a mixed geology bedrock: Caddisflies (Trichoptera) in the family Limnephilidae, the leech *Erpobdella testacea*, the water beetle *Agabus bipustulatus*, the dipteran *Bezzia* sp. and the chironomid genera *Endochironomus* and *Pseudesmittia* were found to be associated with such lakes. Taxa that may occur are: Chironomids (non-biting midges), *Pisidium* (pea clams) and Hydrachnidia (Water mites). These species are adapted to the specific conditions of highland or Alpine lakes, including the brown coloration from organic matter and the calcareous nature of the water.
- Fish: Brown trout (*Salmo trutta*), Perch (*Perca fluviatilis*), Eurasian minnow (*Phoxinus phoxinus*).

[4] See Figure 4 in Füreder et al. (2006) showing a CCA plot, upper right quadrat, and a species list in the Annex therein. These lakes are not clearly humic, as the DOC is <3mg/l, whereas in most humic lakes the DOC >5mg/L.

6.1.4 Biology in P1D Highland, humic lakes on siliceous bedrock

Highland or alpine humic lakes in siliceous catchments have a low alkalinity (<0.2mmol/l, corresponding to a calcium concentration <4mg/l, and occurring above the timberline with a surface area of between 0.02 to 100km^2. These waterbodies are characterized by a high level of colour (>30mg Pt/l), a low nutrient concentration and a low pH (5-6). The catchments are usually rich in mires and peatland. The vegetation is scarce due to temperature and light limitations and due to ice cover during a large part of the year.
Due to the difficulties in finding scientific papers on Google Scholar or Web of Science, the AI tool Copilot was used to provide this list (but could not provide the sources). The list was checked/corrected/ supplemented by using the expert knowledge of the authors of this report. So, the occurrence of taxa mentioned below is uncertain but seems quite logical from an ecological/limnological perspective. For aquatic macrophytes and benthic invertebrates, there is some relevant information given in the Norwegian WFD guidance on classification of ecological status (Direktoratsgruppen Vanndirektivet, 2018).

- Phytoplankton: Humic mountain lakes, due to their high levels of dissolved organic matter, often have unique phytoplankton communities. Here are some common taxa that might be found in these environments. Many of these are mixotrophic, which is an adaptation to poor light conditions and low nutrient concentrations. Common or dominant taxa with mixotrophic abilities that may occur in this lake type are: Chrysophytes: These are often dominant in humic lakes due to their ability to thrive in low-light conditions. Dinoflagellates: Some species can tolerate the low pH and high organic content of humic lakes. Cryptophytes: These are also common in humic waters, known for their mixotrophic capabilities. In addition, there may also be some diatoms and green algae.
- Aquatic vegetation (Direktoratsgruppen Vanndirektivet, 2018): communities of dystrophic water vegetation in siliceous mountain lakes include nymphaeids, such as *Nuphar lutea, Nymphaea alba* and *Sparganium angustifolium*, as well as the elodeid *Utricularia*, which can feed on insects and is therefore well adapted to humic lakes with poor light conditions. These species are also known to be tolerant to quite acidic conditions and can therefore thrive in siliceous lakes with low alkalinity.
- Benthic invertebrates (Direktoratsgruppen Vanndirektivet, 2018): Here are some common benthic invertebrate families or orders that may be found in humic siliceous mountain lakes: Plecoptera (Stoneflies) families Chloroperlidae, Nemouridae, Leuctridae; Perlodidae; Taeniopterygidae, Trichoptera (Caddisflies) families Hydrophyschidae, Sericostomatidae, Goeridae, Limnephilidae, Philopotamidae, Lepidostomatidae, Polycentropodidae; Diptera families Chironomidae (Non-biting midges), Simuliidae and Tipulidae; Oligochaeta (aquatic worms), Coleoptera (aquatic beetles) like Gyrinidae, Turbellarians like Planariidae. These invertebrates are adapted to the often low-nutrient, relatively acidic conditions of humic, siliceous mountain lakes.
- Fish: The following fish species can be found in humic, siliceous mountain lakes (according to Copilot): *Salmo trutta* (Brown Trout), *Salvelinus fontinalis* (Brook Trout), *Coregonus* spp. (Whitefish), *Phoxinus Phoxinus* (Eurasian Minnow), *Perca fluviatilis* (European Perch). These species are typically well-adapted to the cold, clear, and often acidic waters of humic siliceous mountain lakes.

6.1.5 Biology in P1E Temporary calcareous lakes incl. turloughs

Temporary calcareous lakes are usually small and very shallow, drying out in summer. Most of them are found in Southern/South-Eastern Europe (e.g. Spain, Hungary) but can also occur further north in dry years. In temporary karst lakes and turloughs, occurring primarily in Slovenia and Ireland, water is often absent for parts of the year, especially during dry summers. Inflow and outflow can occur at a particular place in the lake like a swallow hole or fissure (e.g. turloughs) and depends on the underlying groundwater table. Whenever inundated, they support diverse plant, animal, and microbial communities. The biota often includes species that are specially adapted to these environments and may not be found elsewhere (Williams, 2006). This habitat is well suited for phytoplankton and aquatic vegetation taxa requiring bicarbonate for photosynthesis due to the high alkalinity in calcareous lakes. In some of these lakes, including the temporary karst lakes and turloughs, the alkalinity is very high causing a supersaturation of calcium carbonate, which cause calcite precipitation and adsorption of phosphorus. (see description below for P1K permanent marl/karst lakes).

Many of the taxa presented below can also be found in P1P Temporary ponds and pools but the species richness is likely to be higher in each of the P1E than in P1P due to the positive correlation between ecosystem size and species richness (Stomp et al., 2011).

- Phytoplankton (Celewicz & Goldyn, 2021):
  - Common groups include chlorophytes (green algae) like *Oocystis* and *Oedogonium*, *Chlorococcum*, diatoms like *Pinnularia, Navicula, Diatoma*, cyanobacteria (*Dolichospermum, Aphanizomenon flos-aquae, Chrococcus turgidus, Gloecapsa groans, Nostoc commune, Stigonema mamillosum, Stigonema ocelatum*), euglenoids (*Euglena*), xanthophytes (*Tribonema*, *Vaucheria*) and cryptophytes. Each group has species that are particularly well-suited to the fluctuating conditions of temporary lakes.
- Aquatic vegetation (Lukács et al., 2013; Zacharias et al., 2007):
  - Nymphaeids and lemnids can quickly colonize temporary lakes during wet periods. Other truly aquatic plants (hydrophytes) have a very low abundance.
  - Characteristic (diagnostic) species are partly aquatic and partly amphibious (**Common species are given in bold font**): *Alisma lanceolata,* ***Alopecurus aequalis****, Artemisia molinieri,* ***Callitriche brutia****,* ***Echinochloa crus-galli****,* ***Elatine alsinastrum****,* ***Elatine hungarica, Elatine macropoda, Elatine triandra****, Eleocharis acicularis, Glyceria fluitans, Isoëtes hystrix, Isoëtes heldreichii, Isoëtes setacea, Juncus effusus,* ***Juncus bufonius****,* ***Lindernia procumbens****,* ***Lythrum hyssopifolia****, Marsilea bartardae, Oryza sativa,* ***Peplis portula****,* ***Pilularia minuta****,* ***Plantago weldenii****, Ranunculus longpipes, Ranunculus revelieri, Ranunculus sardous,* ***Schoenoplectus supinus****,* ***Tillaea vaillantii***. An additional common species is ***Lythrum hysoppifolia***.
- Benthic inverterbates (Williams, 2006; Perez-Bilbao et al., 2015; Zacharias et al., 2007):
  - Oligochaetes in the Naididae family
  - Leeches in the Erpobdellidae family
  - Moluscs: Snails like *Lymnea* and *Planorbis*, bivalves like *Pisidium*
  - Caddisflies (Trichoptera) like *Limnephilus, Glyphotaelius*
  - Mayflies (Ephemeroptera) like *Cloeon*
  - Plecoptera like *Nemoura cinerea*
  - Chironomids like *Zavrelimyia, Psectrocladius, Allopsectrocladius, Chironomus*
  - Large Branchiopods: *Triops cancriformis* and *Lepidurus apus* are notable examples. These crustaceans can survive in dry conditions by producing drought-resistant eggs, Fairy Shrimp: *Tanymastix stagnalis* is a type of fairy shrimp that thrives in temporary waters[1], tadpole shrimps (Notostraca) and clam shrimps *Cyzicus bucheti, Cyzicus grubei* (Conchostraca, Spinicaudata).
  - Odonates: *Coenagrion/Enallagma, Cordulegaster* and other Dragonflies and damselflies, particularly in the genera *Lestes* and *Sympetrum*, are often found in these habitats.
  - Hemipterans: *Callicorixa/Corixa, Microvelia*, as well as water bugs such as *Gerris, Notonecta, Sigara,* and *Hesperocorixa* are adapted to living in temporary lakes.
  - Aquatic Beetles: *Colymbetes, Dytiscus, Ilybius, Gyrinus, Anacaena limbate, Hydrobius, Limnebius, Haliplus*, as well as *Genera like Agabus, Graptodytes, Berosus, Helophorus,* and *Hydroporus* are commonly found.
  - Cladocerans, e.g. *Ctenodaphnia chevreuxi, Chydorus, Daphnia pulex/obtuse, Simocephalus expinosus/vetulus,*
  - Ostracods like *Cypricercus, Eucypris*
  - Copepods like Diaptomus, Cyclops and Acanthocyclops, Canthocampus
  - Amphipods like Crangonyx pseudogracilis
  - Isopods like Asellus
  - Acari like Hydrachnida
  - Spiders (Aranea) like *Tetragnatha*
  - Collembola like *Isotomurus, Sminthurides*

- Amphibians (Williams, 2006; Zacharias et al., 2007 and refs therein) may occur where fish are absent:
  - Toads: natterjack toad (*Bufo calamita*), spadefoot toads (*Pelobates*), mid-wife toads (*Alytes*), yellow-bellied toad (*Bombina variegata*), as well as *Bufo bufo.*
  - Frogs: the painted frog (*Discoglossus*), the Mediterranean treefrog (*Hyla meridionalis/arborea*), parsley frogs (*Pelodytes punctatus*), as well as *Rana temporaria* and *Rana lessonae.*
  - Salamanders: true salamanders (*Chioglossa*), the brook salamander (*Euproctus*), the spectacled salamanders (*Salamandrina*), cave salamanders (*Speleomantes*), the caucasian salamander (*Merntensiella*), *Salamandra salamandra.*
  - Newts: Sharp-ribbed newts (*Pleurodeles*), the marbled newts (*Triturus*).
- Fish (Dražina et al., 2022; Discover the Diverse World of Freshwater Fish in Europe):
  - European Perch (*Perca fluviatilis*): This species is highly adaptable and can be found in a range of freshwater habitats, including temporary lakes and ponds.
  - Common Carp (*Cyprinus carpio*): Known for its resilience, the common carp can tolerate low oxygen levels and varying water conditions, making it well-suited for temporary water bodies.
  - Tench (*Tinca tinca*): Tench are often found in slow-moving or still waters, including temporary ponds.
  - Sticklebacks (*Gasterosteidae*): Species like the three-spined stickleback (*Gasterosteus aculeatus*) are common in temporary ponds.
  - Roach (*Rutilus rutilus*): Roach are adaptable fish that can be found in both permanent and temporary water bodies.

This lake type can be associated with habitats from other EUNIS groups: X36 Depressions (pody) of the steppe zone (habitat complexes). It is associated with a range of wetland habitats: Q53 Tall-sedge beds, Q52 small-helophyte beds, Q51 tall-helophyte beds, Q43 Tall-sedge base-rich fens, Q44 Calcareous quaking mires, and if water levels periodically drop, it can be associated with Q61 Periodically exposed shore with stable, eutrophic sediments with pioneer or ephemeral vegetation, Q62 Periodically exposed shore with stable, mesotrophic sediments with pioneer or ephemeral vegetation.

6.1.6 Biology in P1F Temporary siliceous lakes (incl. humic lakes)

Freshwater lakes over siliceous bedrock that periodically dry out. These small lakes are often formed in glacial depressions or areas with impermeable siliceous bedrock that prevents water from draining away. They fill with water during periods of rainfall or snowmelt and can dry out during dry seasons. As a result, their surface area and their depth are fluctuating. The water is typically low in nutrients (oligotrophic) and has a low pH (acidic), which influences the types of organisms that can thrive there.

They can support communities of aquatic vegetation, such as *Isoëtes* (quillworts), which are adapted to low-nutrient, acidic conditions. Carnivorous plant species such as *Drosera* (sundews) and *Utricularia* (bladderworts) can also be found in these environments, where they supplement their nutrient intake by capturing insects.

Invertebrates typically found in this habitat are dipterans such as midge larvae (*Chironomus* sp.), cranefly larvae (*Dicranota* sp.), the phantom midge (*Chaoborus*) and mosquito larvae (Culex sp.) (Brönmark and Hansson, 2005). Amphibians can also be found, as fish are often absent.
This lake type can be associated with habitats from other EUNIS groups: ZX Depressions (pody) of the steppe zone (habitat complexes).

6.1.7 Biology in P1G Temporary saline and brackish lakes

Saline or brackish lakes that periodically dry out. Salinity is >1.5‰. The surface area and depth are fluctuating. This habitat type occurs in arid and semi-arid regions in Europe, e.g. Cyprus, Spain, as well as the steppe zone of eastern Europe and in the Pannonian lowlands and constitutes an important habitat for birds. Many salt lakes in Europe are therefore Ramsar sites as well as part of the Natura 2000 network of protected areas (Zadereev et al., 2020, Ioannidou et al., 2021).

- Phytoplankton (Polykarpou et al., 2023):
  - Chlorophytes are often the dominant and most diverse group, followed by cyanobacteria and diatoms. Increasing salinity reduces species richness. The chlorophyte genus *Dunaliella* is highly tolerant to saline conditions and often dominate in these environments. *Oocystis* and *Planktonema* are other common chlorophytes.
  - Diatoms are also prevalent and can adapt to varying salinity levels[1], including *Cylindrotheca closterium.*
  - Cyanobacteria, like Anabaenopsis can form blooms in saline lakes. *Pseudanabaena, Synechococcus and Arthrospira (Spirulina)* are other common taxa.
  - Other commonly found species are the pyramimonadophyte *Pseudoscourfieldia marina* and the harmful haptophyte *Prymnesium parvum occurs,* the latter mainly in brackish lakes.
- Aquatic vegetation (Camacho et al., 2024, Velasco et al., 2006)
  - Common species found in temporary, saline or brackish lakes are:
    - Charophyte *Lamprothamnium papulosum*
    - ***Ruppia maritima* (Widgeon Grass)**: This species is well-adapted to brackish and saline conditions and is often found in shallow waters.
    - ***Potamogeton pectinatus* (Sago Pondweed):** Another common species found in brackish waters, known for its tolerance to varying salinity levels.
    - ***Cladophora glomerata*:** This green alga can be found in both saline and brackish waters, often forming dense mats.
  - In addition, the following species can be common in this habitat type, as they are adapted to the varying salinity and water levels typical for such saline lakes:

    Bolboschoenus maritimus (Sea Club-rush)
    Schoenoplectus tabernaemontani (Soft-stem Bulrush)
    Schoenoplectus triqueter (Triangular Club-rush)
    Juncus maritimus (Sea Rush)
    Juncus subulatus (Awl-leaf Rush)
    Potamogeton crispus (Curly-leaf Pondweed)
    Potamogeton natans (Broad-leaved Pondweed)
    Callitriche stagnalis (Common Water-starwort)
    Ceratophyllum demersum (Hornwort)
    Myriophyllum spicatum (Eurasian Watermilfoil)
    Nymphaea alba (White Water Lily)
  - A specific vegetation type, the class *Crypsietea aculeatae,* is supported by saline habitats in the lowlands of continental Europe and arid Mediterranean regions and occurs also in temporary saline lakes on the saline soil exposed after drying out in summer. This is further described in Q63 Periodically exposed saline shore with pioneer or ephemeral vegetation.
- Zooplankton and benthic invertebrates (Waterkeyn et al., 2008)
  - The following invertebrate taxa has been reported from Mediterranean temporary saline or brackish lakes:
    - Crustacean zooplankton and benthic invertebrates occurring in lakes and ponds with a conductivity >10mS/cm and hydroperiod of max 6 months (extracted from Figure 4 in Waterkeyn et al., 2008):
    - Cladocerans: *Alona rectangular, Ceriodaphnia reticulata, Pleuroxus letourneuxi, Simocephalus expinosus, Daphnia curvirostris, Daphnia magna*.
    - Copepods: Some cyclopoids and calanoids not defined to genus or species level.

    - Benthic invertebrates: Common taxa are brine shrimp (*Artemia* spp.) and brine flies (*Ephedra* spp.), *Gammarus, Enochrus, Helophorus, Rhantus, Agabus, Hydroglyphus, Berosus, Cymatia, Sigara*, Dixidae, Culicidae, Chironomidae, *Clonheon*, Collembola.
- Fish (Prado et al., 2014)
  - Native species of conservation concern: Eastern mosquitofish *Gambusia holbrooki*, Iberian toothcarp *Aphanius iberus*, the common goby *Potamochistus microps*.
  - Commercial fish species: the European eel *Anguilla anguilla*, the mullet *Liza spp*., and the sand smelt *Atherina boyeri*.

This lake type can be associated with habitats from other EUNIS groups: Q54 Inland saline or brackish helophyte beds and Q63 Periodically exposed saline shore with pioneer or ephemeral vegetation (wetlands), Q61 Periodically exposed shore with stable, eutrophic sediments with pioneer or ephemeral vegetation (wetlands) or Q62 Periodically exposed shore with stable, mesotrophic sediments with pioneer or ephemeral vegetation (wetlands), Z7 Estuaries, Z81 Saline coastal lagoons, Z82 Brackish coastal lagoons and XY Salt lake islands (habitat complexes) and J5.1 Highly artificial saline and brackish standing waters (constructed, industrial and other artificial habitats). Where occurring in areas with a karstic geology, it may be associated with Z6 Anchihaline caves (habitat complexes). Slightly brackish waters can be associated with Q52 Small-helophyte beds (wetlands) or Q51 Tall-helophyte beds (wetlands).

6.1.8 Biology in P1H Permanent saline and brackish lakes

Permanent lakes with a salinity >1.5‰, mainly shallow and can range from very small to large lakes. Salinity varies depending on rainfall, evaporation and the character of the substrate affecting the character of the predominantly halophytic vegetation and associated invertebrates which provide food for birds (text modified from the Red List). The water is alkaline and highly buffered by bicarbonate (high alkalinity). Phosphorus and sulphate concentrations can be relatively high (for submerged macrophyte vegetation), which may be related to the high sulphur concentration in the sediment.

The species composition in permanent saline and brackish lakes is shaped by the degree of salinity: higher salinity usually leads to simpler, but more specialized assemblages. The lakes are characterized by salt tolerant phytoplankton taxa in the classes chlorophytes, cyanophytes and diatoms. The aquatic vegetation is diverse including characteristic halophytes, such as *Najas marina*, *N. minor*, *Ruppia maritima*, *Batrachium* (=*Ranunculus*) *baudotii* and *Zannichellia palustris*, *Z. pedunculata*, *Z. obtusifolia*. Besides vascular plants, some stoneworts are characteristic species, like *Tolypella nidifica*, *Chara canescens*, *Ch. baltica*, *Ch. aspera*, *Ch. intermedia* and *Ch. vulgaris*. Typical brackish water fish assemblages include the species European Sea Bass (*Dicentrarchus labrax*), Three-Spined Stickleback (*Gasterosteus aculeatus*) and Mediterranean Killifish (*Aphanius fasciatus*).

Further details on the biology associated with this habitat type:

- Phytoplankton
  - Chlorophytes (Green Algae)
    - *Picochlorum oklahomense*: a common picophytoplankton species found in the saline lakes of the Transylvanian Basin in Romania. (Keresztes et al., 2012).
    - *Chloroparva*: thrives in the soda lakes of Europe (Somogyi et al., 2022).
  - Cyanobacteria (Blue-Green Algae):
    - *Synechococcus*: Both marine and non-marine strains are found in European saline lakes (Keresztes et al., 2012, Somogyi et al., 2022).
    - *Cyanobium*: Common in soda lakes, contributing significantly to the picophytoplankton community (Somogyi et al., 2022).
  - Diatoms (Sui et al., 2016):
    - *Cyclotella meneghiniana*: often dominant in saline-alkaline lakes across Europe.
    - *Melosira* species: *Melosira ambigua* and *Melosira granulata.*

- Aquatic vegetation in addition to those given above (Red List sheet for C1.5: https://www.eea.europa.eu/data-and-maps/data/european-red-list-of-habitats/descriptions-of-habitats/terrestrial-habitat-descriptions.docx/file):
    - Vascular plants: *Lemna spp. (L. gibba, L. minor, L. trisulca), Spirodela polyrhiza* (Greater Duckweed), *Potamogeton spp. (P. crispus, P. natans, P. pectinatus), Callitriche spp. (C. lenisulca, C. stagnalis, C. truncate subsp. fimbriata), Ceratophyllum demersum, Myriophyllum spicatum, Batrachium spp.,* and *Nymphaea alba*, *Althenia filiformis, Althenia orientalis, Ranunculus polyphyllus, Ruppia cirrhosa, Ruppia drepanensis, Zannichellia pedicellatae.*
    - Macro-algae: *Ceramium diaphanum, Ceramium rubrum, Chaetomorpha linum, Chara connivens, Chara galioides, Chara horrida, Chara tomentosa, Cladophora fracta, Enteromorpha intestinalis, Lamprothamnium papulosum, Tolypella hispanica, Tolypella salina, Ulva sp., Vaucheria sp.*
- Benthic invertebrates (Mrozińska et al., 2021): the crustaceans *Gammarus duebeni, Corophium volutator, Cordylophora caspia, Palaemonetes varians, Artemia spp, Neomysis integer, Daphnia magna, Alona elegans, the damselfly Lestes macrostigma, the leech Erpobdella octoculata, the dipteran chironomids Chironomus plumosus, Chironomus f.l. thummi, Procladius sp., Polypedilum nubeculosum, Polypedilum e.g. scalaeum, Psectrocladius barbimanus, Sergentia coracina, Einfeldia e.g. carbonaria, Pelopia sp., the biting midge (Ceratopogonidae) Bezzia nobilis, the snails Bithynia tentaculata, Theodoxus fluviatilis, Potamopyrgus jenkinsi, Hydrobia ulvae.*
- Fish (Litchfield, 2011):
    - European Sea Bass (*Dicentrarchus labrax*): This species is known for its remarkable tolerance to high salinity, even up to twice that of seawater.
    - Three-Spined Stickleback (*Gasterosteus aculeatus*): Found in both freshwater and saline environments, this small fish is highly adaptable and can tolerate varying salinity levels.
    - Mediterranean Killifish (*Aphanius fasciatus*): This species is often found in coastal lagoons and saline lakes around the Mediterranean region.

This lake type can be associated with habitats from other EUNIS groups: Q54 Inland saline or brackish helophyte beds and Q63 Periodically exposed saline shore with pioneer or ephemeral vegetation (wetlands), Z7 Estuaries, Z81 Saline coastal lagoons, Z82 Brackish coastal lagoons and XY Salt lake islands and J5.1 Highly artificial saline and brackish standing waters (constructed, industrial and other artificial habitats). Where occurring in areas with a karstic geology, it may be associated with Z6 Anchihaline caves (habitat complexes). Slightly brackish waters can be associated with Q52 Small-helophyte beds (wetlands) or Q51 Tall-helophyte beds (wetlands).

6.1.9 Biology in P1J Glacier-fed lakes

Glacier-fed lakes are cold, turbid, oligo-mesotrophic standing waters found in or downstream of glaciated environments, supporting highly specialized, low-diversity biological communities. The water is turquoise-bluegreen coloured. They are mainly found in highland areas and are ice-covered during most of the year. During summer the phosphorus concentration can be higher than in non-glacial high altitude reference lakes due to the influx of glacial silt. The light conditions are poor due to the glacial silt, the water is colder than in otherwise comparable lakes, and the water column is only weakly stratified for a short period in late summer. Most plant and animal species present are adapted to the harsh physical regimes and frequent disturbances caused by glacial meltwater influx. The species richness is therefore low.

Limited information has been found on the biology found in glacier-fed lakes. Below is some information from the Norwegian glacier-fed lake Gjende (Lyche Solheim et al., 2021), supplemented with information about bacterial communities from Alpine glacial lakes (Peter and Sommaruga, 2016):

- **Bacteria: Typical taxa in highly turbid glacial lakes are** Sphingobacteria (e.g. *Arcicella*, *Mucilaginibacter*), Betaproteobacteria: (e.g. *Nitrospira, Polaromonas*, *Methylo-tenera*, *Albidiferax* and *Curvibacter*) and Deltaproteobacteria. In glacial lakes with intermediate turbidity, the following taxa are characteristic: Gammaproteobacteria: family Alteromonadales (e.g. *Haliea*), Betaproteobacteria: Neisseriales (e.g. *Deefgea*) and Alphaproteobacteria (e.g. *Sphingopyxis*, *Pseudorhodobacter*).
- **Phytoplankton:** The following species can survive in glacial lakes, which is under ice cover for a large part of the year and have low light conditions in deep water columns circulating during most of the ice-free season. Diatoms like *Asterionella, Cyclotella* and *Tabellaria* are common taxa and can be highly dominant.
- Aquatic vegetation: Aquatic plants in glacial lakes are typically limited due to the harsh conditions with very short growing season, cold and turbid water with poor light conditions due to the glacial silt. Chara-species can be found (observation by Jan Økland, University of Oslo, later confirmed by Benoit Demars, NIVA).
- Invertebrates: No information found about benthic invertebrates in glacier-fed lakes. There are crustacean zooplankton in glacier-fed lakes, including cyclopoid copepods like *Cyclops scutifer* and cladocerans like *Holopedium gibberum*. *Daphnia longispina* also occurs.
- Fish: **Cold-Water Fish Species**, such as Arctic char (*Salvelinus alpinus*) and brown trout (*Salmo trutta*).

This lake type can be associated with the EUNIS Habitat complex ZW: Periglacial and snow patch complex.

6.1.10 Biology in P1K Permanent marl/karst lakes

Permanent marl/karst lakes are characterized by their very high alkalinity and clear waters. This lake type occurs in karstic regions and/or has thick deposits of white calcite due to the supersaturation of calcium carbonate. This habitat-type includes very shallow to deep lakes of any surface area. The sediment content of calcium carbonate is normally >50%. Marl/Karst lakes are more alkaline than many other calcareous lakes. Due to the adsorption and sedimentation of phosphorus with the calcium carbonate, these marl/karst lakes can be quite oligotrophic. They typically support a unique assemblage of each of the major groups of biota adapted to the high concentration of dissolved calcium carbonate. The aquatic vegetation is dominated by stoneworts (charophytes) but this lake type is also associated with communities of freshwater submerged vegetation, freshwater nymphaeid vegetation and oligotrophic water vegetation.

Below is a list of common taxa for each of the major biological groups:

- Phytoplankton species (Wiik et al., 2014, 2015):
  - Diatoms (Bacillariophyceae): These are often dominant in marl lakes due to their silica-based cell walls and ability to thrive in clear, nutrient-poor waters. Common genera include *Fragilaria* and *Achnanthes*.
  - Green Algae (Chlorophyta): Species such as *Chlamydomonas* and *Scenedesmus* are frequently found in marl lakes. These algae can adapt to varying light conditions and nutrient levels.
  - Cyanobacteria (Blue-Green Algae): While typically associated with eutrophic conditions, some cyanobacteria like *Gloeocapsa* can be present in marl lakes, especially during periods of nutrient enrichment.
  - Dinoflagellates (Dinophyceae): These are less common but can be found in some marl lakes. They are known for their motility and ability to thrive in stratified waters.
  - Cryptophytes (Cryptophyta): These small, flagellated algae are also part of the phytoplankton community in marl lakes, contributing to the diversity of the ecosystem.

- Aquatic vegetation (Pentecost, 2009; Wiik et al., 2014, 2015):
    - Charophytes (Stoneworts): These are often the dominant aquatic vegetation in marl lakes. Species such as *Chara vulgaris* and *Chara contraria* are typical. Charophytes play a significant role in maintaining water clarity by stabilizing sediments and competing with phytoplankton for nutrients. However, they disappear with nutrient enrichment.
    - Elodeids: Various species of pondweeds thrive in marl lakes, including *Potamogeton perfoliatus* and *Potamogeton crispus*. These plants can grow to considerable depths due to the high water-transparency. Species like *Myriophyllum spicatum* (Eurasian watermilfoil) and *Elodea canadensis* (Canadian waterweed) can also be present.
    - Water Lilies (Nymphaeaceae): Species like *Nymphaea alba* and *Nuphar lutea* are also found in marl lakes. These floating-leaved plants provide habitat and shelter for aquatic organisms.
    - Isoëtids: These small, grass-like plants, such as *Isoëtes lacustris*, are adapted to the nutrient-poor conditions of marl lakes.
- Invertebrates (Wiik et al., 2015):
    - Molluscs, including bivalves like Sphaeridae, and snails like *Lymnea peregra*, *Bitynia tentaculata, Bitynia leachi*
    - Trichoptera (*Cyrnus flavidus*)
    - Mites (Oribatida)
    - Micro-crustaceans like the cladocerans *Pseudohydrorus globosus, Simocephalus sp., Daphnia sp*.
- Fish (Wiik et al., 2014, 2015; Buj et al, 2022, Mičetić Stanković, V., 2023):
    - **Perch (*Perca fluviatilis*)**: Perch are commonly found in marl lakes and are well-adapted to the clear, alkaline waters.
    - **Pike (*Esox lucius*)**: Northern pike are another species frequently reported in marl lakes. They are top predators and play a crucial role in the aquatic food web.
    - **Roach (*Rutilus rutilus*)**: Roach are often present in marl lakes, contributing to the diversity of the fish community.
    - **Bream (*Abramis brama*)**: Bream are also found in these lakes, particularly in areas with abundant aquatic vegetation growth[2].
    - **Trout (*Salmo trutta*)**: Brown trout can be found in some marl lakes, especially those with cooler temperatures and good oxygen levels[3].
    - endemic fish species, like the genus Telestes and the species *Delminichthys krbavensis* (Zupančič and Bogutskaya, 2002).

The permanent karst lakes can be linked to HD Annex 1, habitat 3140 Hard oligo-mesotrophic waters with benthic vegetation of Chara spp. Permanent marl/karst lakes can be associated with habitats from other EUNIS groups: U11 Cave habitats (inland habitats with little or no soil and mostly sparse vegetation), Q44 Calcareous quaking mires (wetlands), Q53 Tall-sedge beds (wetlands), Q41 Alkaline, calcareous, carbonate-rich small-sedge spring fen (wetlands), ZZ Karst functional complexes and Z34 Anchihaline caves (habitat complexes).

The subtype Gypsum karst lakes can have quite a different species composition compared to marl/karst lakes, as they are dominated by calcium-sulphate ($CaSO_4$), instead of calcium carbonate ($CaCO_3$). Gypsum lakes correspond to HD Annex 1, habitat 3190 Lakes of gypsum karst. More information can be found at https://eunis.eea.europa.eu/habitats/10240.

6.1.11 Biology in P1L Volcanic lakes

Active volcanoes in Europe are found in Iceland, in the Tyrrhenian volcanic belt (Italy) and the Aegean active arc (Greece). Volcanic lakes can represent a wide range of characteristics depending on the presence or absence of an outlet. These lakes do not have any river inflows and rarely have any outflows. This lake type includes mainly deep relatively large lakes filling the crater of volcanoes. They can either be buffered by HSO_4^-/SO_4^{2-} or H_2CO_3/HCO_3^- determining if the pH is below 3 or between 5 and 8, respectively. Lakes that occupy active volcanic craters or craters of recently active volcanoes are very acidic and rich in sulfur.

In Iceland, there is also a subglacial lake in the crater of an active volcano (Vatnajøkull), for which the physical properties are described by Jóhannesson et al. (2007).

Due to extreme conditions such as high temperatures, low pH and very high concentrations of dissolved metals and minerals, the species diversity in volcanic lakes is poor and mainly consists of microorganisms (Rouwet et al. 2015). Shortly after the formation of a volcanic lake (after a major eruption of the volcano), the biology is composed of hydrothermal bacteria and phytoplankton tolerating high sulphur concentrations (mainly in Iceland), high salinity and high temperatures (due to hydrothermal springs), e.g. Cyanobacteria and chlorophytes (Cockell & Lee, 2002).

In dormant volcanoes, hydrothermal springs can also occur, thereby causing high water temperatures. Otherwise, lakes in craters of dormant and older volcanoes have less acidic/more neutral conditions and differ little from other lakes concerning their flora and fauna (Mapelli et al, 2015 and refs therein). The biology in dormant volcanic lakes can therefore be found in lakes belonging to other rather warm lake types in lowland areas (e.g. P12, P14), mainly in southern Europe. Most crater lakes in dormant volcanoes are found in Italy, and their biology is described for phytoplankton by Guilizzoni et al., (2002), for aquatic vegetation by Azella (2014), for invertebrates by Manca et al., (1996); Guilizzoni et al., (2002), Margaritora et al. (2003) and for fish by Volta et al. (2011).

The volcanic lakes can be linked to the EUNIS habitat complex ZJ: Complexes of volcanic geothermal fields.

6.1.12 Biology in P1N Permanent ponds and pools

Permanent ponds and pools are natural, very small standing surface water bodies which never dry out. Their surface area is <2ha ($0.02km^2$) (Collinson et al., 1995)[5]. Most permanent ponds and pools are very shallow although some can be deeper. They never dry out but can be completely frozen in winter at higher altitudes and latitudes. In the other seasons they are often productive systems (mostly meso- to eutrophic) in which the sunlight reaches the sediment surface, which allows for the development of a rich aquatic community with many species groups represented. Although the species richness per pond is lower than in most of the lake types described above (Søndergaard et al., 2005), the heterogeneity and huge number of permanent ponds and pools together can provide a higher biodiversity than larger lakes.
Ponds and pools can host a variety of aquatic plants, such as duckweed (*Lemna* spp.) and water lilies (*Nymphaea alba*, and *Nuphar lutea*). However, the submerged vegetation can be limited by high turbidity due to heavy algal blooms or by grazing from waterfowl.

Their pelagic zone is either absent or very small and shallow. Many ponds can still have significant phytoplankton and zooplankton communities. Common phytoplankton taxa belong to the classes cyanobacteria, diatoms, chlorophytes and euglenophytes. The zooplankton community can be dominated by large daphnids (e.g. *Dahpnia magna*), other large cladocerans and large copepods in fishless ponds and pools.

[5] Any standing water body >2ha, including very small lakes <50ha, are embedded within the other L3 habitat types, based on the rationale that their biology will be strongly related to the same type descriptors as larger lakes (e.g. altitude and geology).

Permanent ponds and pools are also important habitats for many benthic invertebrates, such as dragonfly nymphs, water beetles, leeches, mosquitoe larvae, bivalves and snails.

Many amphibians, such as frogs, toads and salamanders, rely on ponds and pools for breeding. The absence of fish in many ponds and pools makes them ideal for amphibian tadpoles to develop without predation.

Many ponds and pools, especially in Northern Europe can be dystrophic with lower productivity and lower biodiversity due to lower underwater light intensity. Ponds and pools in mountain areas will have species adapted to more oligotrophic conditions (e.g. Oertli et al., 2007).

Thus, this habitat can be divided at lower EUNIS levels into various subtypes depending on their altitude and geology. In addition, the community composition in permanent ponds and pools may vary across biogeographical regions for some biological groups, especially invertebrates (dragonflies) and amphibians. The taxonomic composition of the major biological groups given below is mostly valid for lowland naturally permanent meso-eutrophic ponds and pools:

- Phytoplankton:
  - Chlorophyta (Green Algae): *Chlorella vulgaris, Scenedesmus quadricauda, Pediastrum boryanum*
  - Bacillariophyta (Diatoms): *Navicula spp., Cyclotella meneghiniana, Fragilaria crotonensis*
  - Cyanobacteria (Blue-Green Algae): *Microcystis aeruginosa, Dolichospermum flos-aquae*, *Aphanizomenon flos-aquae*
  - Euglenophyta (Euglenoids): *Euglena gracilis, Phacus spp.*
  - Cryptophyta (Cryptomonads): *Cryptomonas ovata, Plagioselmis minuta*
- Zooplankton: (de Bie et al., 2007; Oertli et al., 2007): Dominant species of cladocerans: *Bosmina longirostris, Daphnia obtusa, Simocephalus vetulus, Chydorus sphaericus, Alona quadrangularis, Diaphanosoma brachyurum, Megafenestra aurita, Moina macrocopa, Pleuroxus trigonellus, Polyphemus pediculus*.
- Aquatic vegetation: These ponds often host a variety of aquatic plants, such as duckweed (*Lemna* spp.) and water lilies (*Nymphaea alba*, and *Nuphar lutea*). However, the submerged vegetation can be limited by high turbidity due to heavy algal blooms or by grazing from waterfowl (Van Onsem & Triest, 2018).
- Invertebrates: Small ponds are home to numerous invertebrates, including dragonfly nymphs, water beetles, leeches, mosquitoe larvae, bivalves and snails.
- Amphibians: Many amphibians, such as frogs, newts, toads and salamanders, rely on these ponds for breeding.
- Fish: Natural ponds and pools are mostly fishless (which is why amphibians can exist there), while many ponds are used for fish production, e.g. carp (*Cyprinus carpio*).

Permanent ponds and pools can be associated with some of the EUNIS wetland habitats: Q42 Extremely rich moss-sedge fen at low or moderate altitudes, Q51 Tall-helophyte beds, Q52 Small-helophyte beds and Q53 Tall-sedge beds for the lowland ponds and pools. They can also be linked to several of the EUNIS Habitat Complexes, e.g. Z83 Freshwater coastal lagoons.

6.1.13 Biology in P1P Temporary ponds and pools

Temporary ponds and pools dry out in summer and/or in other seasons, depending on the local climate. Their surface area never exceeds 2ha (0.02km^2). Their water originates from rainfall and runoff from the surrounding catchment and is lost mostly though evapotranspiration, as they usually have no outflow. Challenging environmental conditions are characteristic, with substantial changes in water temperature, dissolved oxygen, pH and increased salinity towards the end of wet periods, due to the concentration of dissolved ions by evapotranspiration, alternating with the drought phase. Temporary ponds and pools are quite commonly found in the Mediterranean region but can also occur elsewhere (Pinto-Cruz et al., 2011). Many species are highly specialized and adapted and are found in no other type of habitat.

The aquatic vegetation is characterized by pioneer or ephemeral species that can produce seeds during a short time period and survive the dry phase in the seedbank, e.g. starworts (*Callitriche*-species) and emerging (amphibious) species e.g. from the genera *Ranunculus*, *Lythrum*, *Eryngium, Juncus* and *Solenopsis*.

Fish are normally absent, while the diversity of invertebrates (both Crustaceans and Insects) can be high, including many highly specialised and sometimes regionally endemic species with rapid growth, short life cycles and the ability to produce resting eggs that survive dry periods.

Amphibians can also occur.

More details are given below:

- Aquatic vegetation (Zacharias et al., 2007):
  - Common aquatic plants include species of *Potamogeton* (pondweeds) and *Isoëtes* (quillworts), which are adapted to low-nutrient, acidic conditions.
- Sphagnum mosses (Zacharias et al., 2007):
  - Sphagnum mosses are often abundant in and around these ponds, contributing to the acidic conditions and providing habitat for various microorganisms.
- Carnivorous plants (Zacharias et al., 2007):
  - Species such as *Drosera* (sundews) and *Utricularia* (bladderworts) are often found in these environments, where they supplement their nutrient intake by capturing insects.
- Invertebrates (Pérez-Bilbao et al., 2015):
  - Dragonfly larvae and caddisfly larvae are common in these ponds and are well-adapted to the fluctuating water levels and low nutrient conditions.
  - Fairy shrimp and large branchiopods are also typical inhabitants, capable of surviving dry periods by producing drought-resistant eggs.
- Amphibians (Pérez-Bilbao et al., 2015):
  - Species such as the common frog (*Rana temporaria*) and the smooth newt (*Lissotriton vulgaris*) use these ponds for breeding. Their larvae develop quickly to take advantage of the temporary water availability. The absence of fish in vernal pools makes them ideal for amphibian larvae to develop without predation.

A subtype that can be relevant at the lower level under this main type is vernal pools, which are described as “episaturated seasonal wetlands characterized by a unique assemblage of vegetation and soils”. They are essentially small, seasonal pools that have no permanent inlets or outlets, unlike most ponds. These can be linked to the Wetlands group.

This habitat can be linked to the EUNIS 2012 standing water habitat C1.6 Temporary lakes, ponds and pools and to the HD Annex 1 Standing water habitat 3170 * Mediterranean temporary ponds and more rarely also HD Annex 1 Habitat 3140: Hard oligo-mesotrophic waters with benthic vegetation of Chara (stonewort) species and to HD Annex 1 habitat 3180 * Turloughs.

The following EUNIS wetland habitats can also be associated with temporary ponds and pools and occur at low water levels or in the dry phase: Wetlands Q61 Periodically exposed shore with stable, eutrophic sediments with pioneer or ephemeral vegetation or Q62 Periodically exposed shore with stable, mesotrophic sediments with pioneer or ephemeral vegetation, and Habitat Complexes ZE Machair complexes, ZX Depressions (pody) of the Steppe zone, ZZ Polje complex.

6.2 Running waters

6.2.1 Habitats included in the literature review

The L3 habitat types listed in Table 6-2 did not have sufficient data in the WISER database, and they have therefore been described using the available scientific papers and/or other resources:

Table 6-2 Running water habitats included in the literature review, extract from Table 3-3

EUNIS L3 code	EUNIS L3 name
P21	Lowland rivers and streams draining clay rich catchments
P23	Lowland, very small to small, humic rivers 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

6.2.2 Biology in P21 Lowland rivers and streams draining clay rich catchments

Lowland rivers and streams (altitude <200 m) draining clayish soils are highly turbid rivers with dense, but also unstable sediments. The concentration of suspended solids is above 10mg/l (annual median value). This habitat is found in areas with thick marine deposits, mainly in Northern Europe. For centuries, nearly all regions with marine clay deposits in the Northern region have been cultivated and are therefore subject to agricultural run-off of clay particles and nutrients. As a result of these persistent anthropogenic pressures, many clay rivers have suffered degradation, leading to limited availability of pristine clay river ecosystems which may serve as references.

These lowland clay rivers and streams are not suitable for truly aquatic vegetation, due to poor light conditions and unstable substrate. Benthic algae, especially chlorophytes, can be found mostly in the riffle and run parts where more stable substrate allow growth. Fish and benthic invertebrates also inhabit slow-flowing parts but prefer the riffle and run parts of the habitat where the oxygen-concentration is better and the substrate more suitable for feeding and reproduction.

There were very few publications found concerning biology in European clay rivers. Therefore, data from Norway collected in the period 2008-2024 for benthic algae, benthic invertebrates and fish, was obtained from the Norwegian national database (Vannmiljø). The results are presented below (

Table 6-3,

Table 6-4. For benthic invertebrates, some information from Denmark was included.

Most of the data from both Norway and Denmark are from impacted rivers, as reference rivers are hard to find. The results below are therefore most representative of impacted rivers.

Benthic algae in clay rivers:
Most of the samples taken of benthic algae in clay rivers are from any hard substrate that could be found in such rivers, e.g. stones or rocks.

Dataset obtained from the Norwegian national database (extract from Table 3b and Table 12).

Status	Count of WBs	Count of samples	Mean species richness	Standard deviation
Reference	23	40	13	15
Impacted	204	557	17	10

Species richness for benthic algae seems to be slightly higher in impacted rivers than in reference rivers. However, this difference is not significant, as the standard deviation is quite high and the dataset highly imbalanced with an order of magnitude more data from impacted rivers than from reference rivers.

Chlorophytes are more common than genera from other algal classes (

Table 6-3**Error! Reference source not found.**). In impacted rivers, the organic pollution indicator bacterium *Sphaerotilus natans* is common, illustrating that most of these rivers are highly polluted by urban wastewater. This bacterium can build large colonies that can cover the whole river bottom and fill up the whole river from the bottom up to the surface.

Table 6-3 Taxa list of common benthic algae found in the Norwegian clay rivers, identified by a frequency of occurrence ≥0.5 (50%).

Major taxonomic group	Taxon name	Reference rivers	Impacted rivers
Bacteria	*Sphaerotilus natans*		0.59
Charophyta	*Cosmarium* sp.	0.52	
Chlorophyta	*Microspora amoena*		0.59
Chlorophyta	*Oedogonium* c (filament width = 23-28 µm)	0.57	0.62
Chlorophyta	*Vaucheria* sp.		0.68
Rhodophyceae	*Audouinella hermannii*	0.65	0.64

Benthic invertebrates in clay rivers:
Most of the samples taken of benthic invertebrates in clay rivers are from the few pebble or gravel/sandy substrates that could be found in such rivers, so the results are not representative for the benthic communities in the clay substrate. The clay substrate is very difficult to sample with the normal kick-sampling used.

Dataset obtained from the Norwegian national database (extract from Table 3-1b and Table 4-1).

Status	Count of WBs	Count of samples	Mean species richness	Standard deviation
Reference	29	66	40	26
Impacted	224	903	46	20

The taxa that may occur in the clay substrate are most likely those that can tolerate quite low oxygen levels and can quickly colonize a substrate, e.g. chironomids and Oligochaeta. A Danish study confirms that mud cover negatively affected macroinvertebrate diversity and richness of Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa in lowland streams (Pedersen et al., 2004).

Species richness for benthic invertebrates seems to be slightly higher in impacted rivers than in reference rivers. However, this difference is not significant, as the standard deviation is quite high and the dataset highly imbalanced with an order of magnitude more data from impacted rivers than from reference rivers.

Table 6-4 Taxa list of common benthic invertebrates found in the Norwegian clay rivers. Numerical values representing a frequency of occurrence ≥ 0.5 (50%)), combined with the taxa presented in Nguyen et al. (2023), marked "x".

Family (if not given otherwise)	Taxon name	Reference rivers	Impacted rivers
Aphelocheiridae	*Aphelocheirus aestivalis*		x
Asellidae	*Asellus aquaticus*		0.63
Baetidae	*Baetis niger*	0.79	0.67
Baetidae	*Baetis rhodani*	0.97	0.88, x
Baetidae	*Baetis* sp.	0.76	0.8
Baetidae	*Centroptilum luteolum*		0.58
Ceratopogonidae		0.62	0.85
Chiromonidae	Chironomini Gen.sp.		x
Chironomidae	Chironomidae Gen. sp.	1	1, x
Elmidae	*Limnius* sp.		x
Elmidae			0.6
Ephemerellidae	*Serratella ignita*	x	
Ephemeridae	*Ephemera danica*		x
Gammaridae	*Gammarus fossarum*		x
Gammaridae	*Gammarus pulex*		x
Gammaridae	*Gammarus roeselii*		x
Gammaridae	*Gammarus* sp.		x
Heptageniidae	*Heptagenia sulphurea*		x
Hydraenidae	*Hydraena* sp.	0.72	0.71
Leuctridae	*Leuctra* sp.		x
Limnephilidae	*Anomalopterygella chauviniana*		x
Limnephilidae		0.76	0.79
Limoniidae		0.69	0.73
Nemouridae	*Nemoura* sp.	0.69	0.71
Nemouridae	*Protonemura* sp.	x	
Oligochaeta (subclass)		0.97	0.99
Pediciidae	*Dicranota* sp.		0.54
Perlodidae	*Isoperla* sp.	0.69	
Polycentropodidae	*Plectrocnemia conspersa*		0.51
Polycentropodidae	*Polycentropus flavomaculatus*	0.52	
Polycentropodidae			0.51
Psychodidae			0.62, x
Rhyacophilidae	*Rhyacophila fasciata*		0.54
Rhyacophilidae	*Rhyacophila nubila*	0.59	
Rhyacophilidae	*Rhyacophila* sp.		0.51
Sericostomatidae	*Sericostoma personatum*	0.59, x	
Simuliidae	*Simulium* sp.		x
Simuliidae		0.97	0.96
Sphaeriidae	*Pisidium* sp.		0.57
Sphaeriidae			0.51
Taeniopterygidae	*Brachyptera risi*	0.62	0.54

Family (if not given otherwise)	Taxon name	Reference rivers	Impacted rivers
Tipulidae		0.59	0.77

Fish in clay rivers:
Dataset obtained from the Norwegian national database (Vannmiljø).

Number of water bodies (WBs) and samples with fish data in Norwegian clay rivers and species richness for fish (mean and standard deviation) (extract from Table 3-1b and Table 4-1).

Status	Count of WBs	Count of samples	Mean species richness	Standard deviation
Reference	14	31	1.4	0.8
Impacted	34	172	1.5	0.6

The species richness is very low with only 1-2 fish species found in most of the clay rivers. This is much lower than in most of the other lowland types.

The few fish species commonly found in Norwegian clay rivers include brown trout (*Salmo trutta*), and sometimes salmon (*Salmo salar*). The latter has only been found in clay rivers that are tributaries to major salmon rivers in mid-Norway, so is not a common species found in clay rivers in South-Eastern Norway, where most of the clay rivers are located. The salmonids may not be able to spawn in such rivers due to the dense and highly unstable substrate, and even if they do, the roe is likely to have a low survival rate due to low oxygen concentrations in the sediments.

Other species that have occasionally been found are the cyprinids *Gobio gobio* and *Phoxinus phoxinus*, the stickleback *Gasterosteus aculeatus*, as well as the lamprey *Lampetra planeri*.

This running water habitat type can be associated with habitats from other EUNIS groups: Wetlands Q61 Periodically exposed shore with stable, eutrophic sediments with pioneer or ephemeral vegetation (wetlands), Q62 Periodically exposed shore with stable, mesotrophic sediments with pioneer or ephemeral vegetation (wetlands), Q52 Small helophyte beds or Q51 Tall helophyte beds where periodic flooding occurs (wetlands) and Q53 Tall-sedge beds (wetlands) where periodic flooding occurs and Habitat complexes ZH1 Very flat lowland floodplains, ZH2 Flat lowland floodplains, ZH7 Nordic lowland floodplains.

6.2.3 Biology in P23, P25, P27, P29, P2B, P2D, P2F, P2H, P2K, P2M humic rivers and streams of different altitude, catchment size and geology type

Humic rivers are enriched in dissolved organic matter/tannins (from peat, conifer litter, or bogs), making the water brown and acidic, with reduced light availability. Their biological communities described below are based on publications with data from humic running waters:

- Benthic algae: Dominant diatom species (Bacillariophyceae) in impacted lowland humic rivers and streams on siliceous bedrock in Finland, regardless the catchment size (i.e. belonging to the EUNIS type P25 and/or P29), were: *Achnanthes minutissima, Achnanthes oblongella, Cocconeis placentula, Melosira varians, Navicula cryptocephala, Nitzschia levidensis, Nitzschia palea,* and *Surirella brebissonii* (Soininen & Könönen 2004).
- Aquatic vegetation:
  - Common taxa reported from reference lowland humic rivers and streams in Poland, regardless of their catchment size and bedrock type (i.e. belonging to the EUNIS type P23, P25, P27 and/or P29), were reported by Jusik et al. (2015):
    - Elodeids: *Elodea canadensis* and *Potamogeton alpinus*
    - Nymphaeids: *Hydrocharis morsus-ranae*, *Nuphar lutea*, and *Potamogeton natans*
    - Pleustophytes: *Lemna minor, Lemna trisulca*, and *Spirodela polyrhiza*
  - Intercalibration technical report (Ecke et al., 2016) provides the list of sensitive species found in Nordic humic rivers as follows:
    - Charophyte: *Nitella opaca*

        - Elodeids: *Callitriche hamulata*, *Callitriche palustris*, *Juncus bulbosus*, *Myriophyllum alterniflorum*, *Potamogeton perfoliatus, Ranunculus peltatus*, *Utricularia intermedia*, and *Utricularia vulgaris*
        - Isoëtids: *Eleocharis acicularis*, *Isoëtes echinospora*, *Isoëtes lacustris*, *Lobelia dortmanna*, *Ranunculus reptans*, and *Subularia aquatica*
    - Other species occurring in Nordic humic rivers and streams were (Ecke et al., 2016):
        - Elodeids: *Callitriche hermaphroditica, Elodea canadensis*, *Potamogeton gramineus*, *Potamogeton polygonifolius, Ranunculus aquatilis, Utricularia minor* and *Utricularia ochroleuca.*
        - Isoëtids: *Crassula aquatica*, *Elatine hydropiper*, *Limosella aquatica, Littorella uniflora* and *Ranunculus trichophyllus.*
        - Nymphaeid: *Sparganium angustifolium*
        - Only *Elodea canadensis* was reported by both sources (Jusik et al., 2015, Ecke et al., 2016).
- There were several publications including benthic invertebrates in European humic rivers available. The results are summarized in Table 6-5.
- There was no publication on fish communities found to be suitable for this literature review.

Table 6-5 Benthic invertebrates in reference and impacted humic rivers: Common (constant) and dominant taxa as given in the publications. There were no characteristic (diagnostic) taxa identified. In some cases, it was not possible to determine just one EUNIS type because of missing information (e.g. on catchment size), thus more EUNIS types are given. *Common taxa or taxa that are reported but not identified as characteristic, common or dominant taxa.

EUNIS code	EUNIS name	Major taxonomic group	Taxon name	Reference water bodies		Impacted water bodies		Source
				Common taxa*	Dominant taxa	Common taxa*	Dominant taxa	
P23 / P27	Lowland, very small to small and/or medium to large, humic rivers on calcareous or mixed bedrock	Ametropodidae	*Metretopus borealis*	x				Paavola et al., 2000
		Asellidae	*Asellus aquaticus*	x				
		Athericidae	*Atherix ibis*	x				
		Baetidae	*Baetis liebenauae*	x				
		Baetidae	*Baetis muticus*	x				
		Baetidae	*Baetis rhodani*	x				
		Brachycentridae	*Micrasema setiferum*	x				
		Caenidae	*Caenis horaria*	x				
		Elmidae	*Elmis aenea*	x				
		Ephemerellidae	*Ephemerella mucronata*	x				
		Ephemeridae	*Ephemera danica*	x				
		Erpobdellidae	*Erpobdella octoculata*	x				
		Heptageniidae	*Heptagenia foscogrisea*	x				
		Hydraenidae	*Hydraena* spp.	x				
		Hydropsychidae	*Arctopsyche ladogensis*	x				
		Leptoceridae	*Athripsodes* spp.	x				
		Leptophlebiidae	*Leptophlebia marginata*	x				
		Leptophlebiidae	*Leptophlebia vespertina*	x				
		Lymnaeidae	*Lymnea peregra*	x				
		Molannidae	*Molannodes tinctus*	x				
		Nemouridae	*Amphinemura sulcicollis*	x				
		Nemouridae	*Nemoura cinerea*	x				
		Perlodidae	*Diura bicaudata*	x				
		Polycentropodidae	*Neureclipsis bimaculata*	x				
		Polycentropodidae	*Plectrocnemia conspersa*	x				

EUNIS code	EUNIS name	Major taxonomic group	Taxon name	Reference water bodies		Impacted water bodies		Source
				Common taxa*	Dominant taxa	Common taxa*	Dominant taxa	
		Polycentropodidae	*Polycentropus flavomaculatus*	x				
		Rhyacophilidae	*Rhyacophila nubila*	x				
		Rhyacophilidae	*Rhyacophila obliterata*	x				
P25	Lowland, very small to small, humic rivers and streams on siliceous bedrock	Ametropodidae	*Metretopus borealis*	x				Paavola et al., 2000
		Ancylidae	*Ancylus* spp.	x				Sandin et al., 2014
		Asellidae	*Asellus aquaticus*	x		x		Paavola et al., 2000, McKie et al., 2006
		Asellidae	*Asellus* spp.	x				Sandin et al., 2014
		Athericidae	*Atherix ibis*	x				Paavola et al., 2000
		Baetidae	*Baetis liebenauae*	x				Paavola et al., 2000
		Baetidae	*Baetis muticus*	x				Paavola et al., 2000
		Baetidae	*Baetis niger*			x		McKie et al., 2006
		Baetidae	*Baetis rhodani*	x		x		Paavola et al., 2000, McKie et al., 2006
		Baetidae	*Baetis* spp.			x		Soininen & Könönen 2004
		Brachycentridae	*Micrasema setiferum*	x				Paavola et al., 2000
		Caenidae	*Caenis horaria*	x		x		Paavola et al., 2000, Soininen & Könönen 2004
		Calopterygidae	*Agrion virgo*			x		Soininen & Könönen 2004
		Capniidae	*Capnopsis schilleri*			x		McKie et al., 2006
		Ceratopogonidae				x		Soininen & Könönen 2004
		Chironomidae	Chironomidae			x		Soininen & Könönen 2004, McKie et al., 2006
		Chironomidae	Orthocladiinae				x	McKie et al., 2006

EUNIS code	EUNIS name	Major taxonomic group	Taxon name	Reference water bodies		Impacted water bodies		Source
				Common taxa*	Dominant taxa	Common taxa*	Dominant taxa	
P25 (cont.)	Lowland, very small to small, humic rivers and streams on siliceous bedrock (cont.)	Chironomidae	Tanypodinae			x		McKie et al., 2006
		Chloroperlidae	*Chloroperla torrentium*	x				Sandin et al., 2014
		Chloroperlidae	*Chloroperla tripunctata*	x				Sandin et al., 2014
		Dytiscidae				x		Soininen & Könönen 2004
		Elmidae	*Elmis aenea*	x		x		Paavola et al., 2000, Soininen & Könönen 2004, McKie et al., 2006, Sandin et al., 2014
		Elmidae	*Limnius volckmari*	x		x		Soininen & Könönen 2004, Sandin et al., 2014
		Elmidae	*Oulimnius tuberculatus*			x		Soininen & Könönen 2004
		Elmidae	*Oulimnius* spp.	x				Sandin et al., 2014
		Empididae		x				Sandin et al., 2014
		Ephemerellidae	*Ephemerella mucronata*	x				Paavola et al., 2000
		Ephemeridae	*Ephemera danica*	x				Paavola et al., 2000
		Ephemeridae	*Ephemera vulgata*			x		Soininen & Könönen 2004
		Erpobdellidae	*Erpobdella octoculata*	x				Paavola et al., 2000
		Gammaridae	*Gammarus pulex*			x		Soininen & Könönen 2004
		Gyrinidae				x		Soininen & Könönen 2004
		Heptageniidae	*Ecdyonurus* spp.	x				Sandin et al., 2014
		Heptageniidae	*Heptagenia foscogrisea*	x				Paavola et al., 2000
		Heptageniidae	*Heptagenia lateralis*	x				Sandin et al., 2014
		Hydraenidae	*Hydraena gracilis*	x				Sandin et al., 2014
		Hydraenidae	*Hydraena* spp.	x				Paavola et al., 2000

EUNIS code	EUNIS name	Major taxonomic group	Taxon name	Reference water bodies		Impacted water bodies		Source
				Common taxa*	Dominant taxa	Common taxa*	Dominant taxa	
P25 (cont.)	Lowland, very small to small, humic rivers and streams on siliceous bedrock (cont.)	Hydropsychidae	*Arctopsyche ladogensis*	x				Paavola et al., 2000
		Hydropsychidae	*Hydropsyche angustipennis*			x		Soininen & Könönen 2004
		Hydropsychidae	*Hydropsyche pellucidula*			x		Soininen & Könönen 2004
		Hydropsychidae	*Hydropsyche siltalai*	x		x		Soininen & Könönen 2004, Sandin et al., 2014
		Hydroptilidae	*Ithytrichia lamellaris*			x		Soininen & Könönen 2004
		Lepidostomatidae	*Lepidostoma hirtum*	x				Sandin et al., 2014
		Leptoceridae	*Athripsodes* spp.	x				Paavola et al., 2000
		Leptophlebiidae	*Leptophlebia marginata*	x		x		Paavola et al., 2000, McKie et al., 2006
		Leptophlebiidae	*Leptophlebia vespertina*	x				Paavola et al., 2000
		Leuctridae	*Leuctra hippopus*			x		McKie et al., 2006
		Leuctridae	*Leuctra inermis*	x				Sandin et al., 2014
		Limnephilidae	*Chaetopteryx villosa*			*x*		McKie et al., 2006
		Limnephilidae	*Halesus* sp.			*x*		McKie et al., 2006
		Limnephilidae	*Potamophylax cingulatus*				*x*	McKie et al., 2006
		Limnephilidae	*Potamophylax* sp.			*x*		McKie et al., 2006
		Lymnaeidae	*Lymnea peregra*	x				Paavola et al., 2000
		Lymnaeidae	*Radix* spp.	x				Sandin et al., 2014
		Molannidae	*Molannodes tinctus*	x				Paavola et al., 2000
		Nemouridae	*Amphinemura borealis*			x		McKie et al., 2006
		Nemouridae	*Amphinemura standfussi*			x		McKie et al., 2006
		Nemouridae	*Amphinemura sulcicollis*	x		x		Paavola et al., 2000, McKie et al., 2006
		Nemouridae	*Nemoura avicularis*			x		McKie et al., 2006

EUNIS code	EUNIS name	Major taxonomic group	Taxon name	Reference water bodies		Impacted water bodies		Source
				Common taxa*	Dominant taxa	Common taxa*	Dominant taxa	
P25 (cont.)	Lowland, very small to small, humic rivers and streams on siliceous bedrock (cont.)	Nemouridae	*Nemoura cinerea*	x		x		Paavola et al., 2000, McKie et al., 2006
		Nemouridae	*Nemoura flexuosa*			x		McKie et al., 2006
		Nemouridae	*Protonemura meyeri*			x		McKie et al., 2006
		Oligochaeta				x		McKie et al., 2006
		Perlodidae	*Diura bicaudata*	x				Paavola et al., 2000
		Perlodidae	*Isoperla grammatica*	x		x		McKie et al., 2006, Sandin et al., 2014
		Planorbidae	*Ancylus fluviatilis*			x		Soininen & Könönen 2004
		Polycentropodidae	*Neureclipsis bimaculata*	x				Paavola et al., 2000
		Polycentropodidae	*Plectrocnemia conspersa*	x				Paavola et al., 2000
		Polycentropodidae	*Polycentropus flavomaculatus*	x		*x*		Paavola et al., 2000, McKie et al., 2006
		Rhyacophilidae	*Rhyacophila nubila*	x		x		Paavola et al., 2000, Soininen & Könönen 2004, McKie et al., 2006
		Rhyacophilidae	*Rhyacophila obliterata*	x				Paavola et al., 2000
		Simuliidae					x	Soininen & Könönen 2004, McKie et al., 2006
		Sphaeriidae	*Pisidium* spp.			x		Soininen & Könönen 2004
		Sphaeriidae	*Sphaerium* spp.			x		Soininen & Könönen 2004
		Taeniopterygidae	*Brachyptera risi*	x				Sandin et al., 2014
		Taeniopterygidae	*Taeniopteryx nebulosa*			x		Soininen & Könönen 2004, McKie et al., 2006
		Tipulidae		x				Sandin et al., 2014

EUNIS code	EUNIS name	Major taxonomic group	Taxon name	Reference water bodies		Impacted water bodies		Source
				Common taxa*	Dominant taxa	Common taxa*	Dominant taxa	
P29	Lowland, medium to large, humic rivers on siliceous bedrock	Ametropodidae	*Metretopus borealis*	x				Paavola et al., 2000
		Ancylidae	*Ancylus fluviatilis*			x		Soininen & Könönen 2004
		Ancylidae	*Ancylus* spp.	x				Sandin et al., 2014
		Asellidae	*Asellus aquaticus*	x				Paavola et al., 2000
		Asellidae	*Asellus* spp.	x				Sandin et al., 2014
		Athericidae	*Atherix ibis*	x				Paavola et al., 2000
		Baetidae	*Baetis liebenauae*	x				Paavola et al., 2000
		Baetidae	*Baetis muticus*	x				Paavola et al., 2000
		Baetidae	*Baetis niger*		x			Liljaniemi et al., 2002
		Baetidae	*Baetis rhodani*	x				Paavola et al., 2000
		Baetidae	*Baetis* spp.			x		Soininen & Könönen 2004
		Brachycentridae	*Micrasema gelidum*	x			x	Liljaniemi et al., 2002
		Brachycentridae	*Micrasema setiferum*	x				Paavola et al., 2000
		Caenidae	*Caenis horaria*	x		x		Paavola et al., 2000, Soininen & Könönen 2004
		Calopterygidae	*Agrion virgo*			x		Soininen & Könönen 2004
		Ceratopogonidae	Ceratopogonidae			x		Soininen & Könönen 2004
		Chironomidae	*Ablabesmyia longistyla*			x		Liljaniemi et al., 2002
		Chironomidae	*Conchapelopia* spp.		x		x	Liljaniemi et al., 2002
		Chironomidae	*Cricotopus (Isocladius) laricomalis* gr.	x			x	Liljaniemi et al., 2002
		Chironomidae	*Eukiefferiella claripennis* gr.	x				Liljaniemi et al., 2002
		Chironomidae	*Eukiefferiella devonica*				x	Liljaniemi et al., 2002

EUNIS code	EUNIS name	Major taxonomic group	Taxon name	Reference water bodies		Impacted water bodies		Source
				Common taxa*	Dominant taxa	Common taxa*	Dominant taxa	
P29 (cont.)	Lowland, medium to large, humic rivers on siliceous bedrock (cont.)	Chironomidae	*Heterotrissocladius marcidus* gr.	x				Liljaniemi et al., 2002
		Chironomidae	*Micropsectra* spp.		x	x		Liljaniemi et al., 2002
		Chironomidae	*Orthocladius* spp.		x			Liljaniemi et al., 2002
		Chironomidae	*Rheocricotopus fuscipes*	x				Liljaniemi et al., 2002
		Chironomidae	*Rheotanytarsus* spp.			x		Liljaniemi et al., 2002
		Chironomidae	*Tanytarsus chinyensis* gr.		x		x	Liljaniemi et al., 2002
		Chironomidae	*Tvetenia* (species A) sp.	x				Liljaniemi et al., 2002
		Chironomidae	*Tvetenia paucunca*		x		x	Liljaniemi et al., 2002
		Chironomidae	*Zavrelimyia* spp.	x				Liljaniemi et al., 2002
		Chironomidae				x		Soininen & Könönen 2004
		Chloroperlidae	*Chloroperla torrentium*	x				Sandin et al., 2014
		Chloroperlidae	*Chloroperla tripunctata*	x				Sandin et al., 2014
		Dytiscidae				x		Soininen & Könönen 2004
		Elmidae	*Elmis aenea*	x	x	x		Paavola et al., 2000, Liljaniemi et al., 2002, Soininen & Könönen 2004, Sandin et al., 2014
		Elmidae	*Oulimnius tuberculatus*		x		x	Liljaniemi et al., 2002, Soininen & Könönen 2004
		Elmidae	*Oulimnius* spp.	x				Sandin et al., 2014
		Empididae		x				Sandin et al., 2014
		Ephemerellidae	*Ephemerella mucronata*	x				Paavola et al., 2000, Liljaniemi et al., 2002
		Ephemeridae	*Ephemera danica*	x				Paavola et al., 2000

EUNIS code	EUNIS name	Major taxonomic group	Taxon name	Reference water bodies		Impacted water bodies		Source
				Common taxa*	Dominant taxa	Common taxa*	Dominant taxa	
P29 (cont.)	Lowland, medium to large, humic rivers on siliceous bedrock (cont.)	Ephemeridae	*Ephemera vulgata*			x		Soininen & Könönen 2004
		Erpobdellidae	*Erpobdella octoculata*	x				Paavola et al., 2000
		Gammaridae	*Gammarus pulex*			x		Soininen & Könönen 2004
		Gyrinidae	*Limnius volckmari*	x		x		Liljaniemi et al., 2002, Soininen & Könönen 2004, Sandin et al., 2014
		Gyrinidae				x		Soininen & Könönen 2004
		Heptageniidae	*Ecdyonurus* spp.	x				Sandin et al., 2014
		Heptageniidae	*Heptagenia foscogrisea*	x		x		Paavola et al., 2000, Liljaniemi et al., 2002
		Heptageniidae	*Heptagenia lateralis*	x				Sandin et al., 2014
		Hydraenidae	*Hydraena gracilis*	x				Sandin et al., 2014
		Hydraenidae	*Hydraena* spp.	x				Paavola et al., 2000
		Hydropsychidae	*Arctopsyche ladogensis*	x				Paavola et al., 2000
		Hydropsychidae	*Hydropsyche angustipennis*	x		x		Liljaniemi et al., 2002, Soininen & Könönen 2004
		Hydropsychidae	*Hydropsyche pellucidula*		x	x		Liljaniemi et al., 2002, Soininen & Könönen 2004
		Hydropsychidae	*Hydropsyche siltalai*	x	x	x	x	Liljaniemi et al., 2002, Soininen & Könönen 2004, Sandin et al., 2014
		Hydroptilidae	*Ithytrichia lamellaris*			x		Soininen & Könönen 2004
		Lepidostomatidae	*Lepidostoma hirtum*	x			x	Liljaniemi et al., 2002, Sandin et al., 2014

EUNIS code	EUNIS name	Major taxonomic group	Taxon name	Reference water bodies		Impacted water bodies		Source
				Common taxa*	Dominant taxa	Common taxa*	Dominant taxa	
P29 (cont.)	Lowland, medium to large, humic rivers on siliceous bedrock (cont.)	Leptoceridae	*Athripsodes* spp.	x				Paavola et al., 2000
		Leptophlebiidae	*Leptophlebia marginata*	x	x		x	Paavola et al., 2000, Liljaniemi et al., 2002
		Leptophlebiidae	*Leptophlebia vespertina*	x				Paavola et al., 2000
		Leuctridae	*Leuctra digitata*		x		x	Liljaniemi et al., 2002
		Leuctridae	*Leuctra inermis*	x				Sandin et al., 2014
		Limnephilidae				x		Liljaniemi et al., 2002
		Lymnaeidae	*Lymnea peregra*	x				Paavola et al., 2000
		Lymnaeidae	*Radix* spp.	x				Sandin et al., 2014
		Molannidae	*Molannodes tinctus*	x				Paavola et al., 2000
		Nemouridae	*Amphinemura sulcicollis*	x				Paavola et al., 2000
		Nemouridae	*Nemoura avicularis*				x	Liljaniemi et al., 2002
		Nemouridae	*Nemoura cinerea*	x				Paavola et al., 2000, Liljaniemi et al., 2002
		Nemouridae	*Nemoura flexuosa*				x	Liljaniemi et al., 2002
		Nemouridae	*Protonemura meyeri*		x	x		Liljaniemi et al., 2002
		Nemouridae	*Nemurella pictetii*		x			Liljaniemi et al., 2002
		Pediciidae	*Dicranota* spp.		x			Liljaniemi et al., 2002
		Perlodidae	*Diura bicaudata*	x				Paavola et al., 2000
		Perlodidae	*Isoperla grammatica*	x				Sandin et al., 2014
		Perlodidae	*Isoperla obscura*	x				Liljaniemi et al., 2002
		Polycentropodidae	*Neureclipsis bimaculata*	x	x			Paavola et al., 2000, Liljaniemi et al., 2002
		Polycentropodidae	*Plectrocnemia conspersa*	x				Paavola et al., 2000
		Polycentropodidae	*Polycentropus flavomaculatus*	x	x		x	Paavola et al., 2000, Liljaniemi et al., 2002
		Rhyacophilidae	*Rhyacophila nubila*	x		x		Paavola et al., 2000, Soininen & Könönen 2004

EUNIS code	EUNIS name	Major taxonomic group	Taxon name	Reference water bodies		Impacted water bodies		Source
				Common taxa*	Dominant taxa	Common taxa*	Dominant taxa	
P29 (cont.)	Lowland, medium to large, humic rivers on siliceous bedrock (cont.)	Rhyacophilidae	*Rhyacophila obliterata*	x				Paavola et al., 2000
		Simuliidae			x	x		Liljaniemi et al., 2002, Soininen & Könönen 2004
		Sphaeriidae	*Pisidium hibernicum*	x		x		Liljaniemi et al., 2002
		Sphaeriidae	*Pisidium obtusale*		x			Liljaniemi et al., 2002
		Sphaeriidae	*Pisidium* spp.	x		x	x	Liljaniemi et al., 2002, Soininen & Könönen 2004
		Sphaeriidae	*Sphaerium* spp.			x		Soininen & Könönen 2004
		Taeniopterygidae	*Brachyptera risi*	x				Sandin et al., 2014
		Taeniopterygidae	*Taeniopteryx nebulosa*		x	x	x	Liljaniemi et al., 2002, Soininen & Könönen 2004
		Tipulidae		x				Sandin et al., 2014
P2D/ P2H	Mid-altitude, very small to small and/or medium to large, humic rivers and streams on siliceous bedrock	Ancylidae	*Ancylus* spp.	x				Sandin et al., 2014
		Asellidae	*Asellus* spp.	x				
		Chloroperlidae	*Chloroperla torrentium*	x				
		Chloroperlidae	*Chloroperla tripunctata*	x				
		Elmidae	*Elmis aenea*	x				
		Elmidae	*Limnius volckmari*	x				
		Elmidae	*Oulimnius* spp.	x				
		Empididae		x				
		Heptageniidae	*Ecdyonurus* spp.	x				
		Heptageniidae	*Heptagenia lateralis*	x				
		Hydraenidae	*Hydraena gracilis*	x				

EUNIS code	EUNIS name	Major taxonomic group	Taxon name	Reference water bodies		Impacted water bodies		Source
				Common taxa*	Dominant taxa	Common taxa*	Dominant taxa	
		Hydropsychidae	*Hydropsyche siltalai*	x				
		Lepidostomatidae	*Lepidostoma hirtum*	x				
		Leuctridae	*Leuctra inermis*	x				
		Lymnaeidae	*Radix* spp.	x				
		Perlodidae	*Isoperla grammatica*	x				
		Taeniopterygidae	*Brachyptera risi*	x				
		Tipulidae		x				

6.2.4 Biology in P2N Springs

This habitat includes both siliceous and calcareous springs, as well as saline springs, geysers and thermal springs. The speed, volume, temperature and chemistry of the waters are very stable in each spring but very variable in different springs. Springs are characterized by distinctive vegetation and invertebrate communities. The associated flora and fauna are accordingly diverse in different springs. Moss carpets often prevail among the vegetation cover.

Compared to other moist habitats, as well as their surroundings, spring habitats are characterized by a low temperature (except in thermal springs), small annual variation in the water temperature, and often by a high oxygen concentration. These features are very clear in cold springs where the mean temperature is only a few degrees above zero ^{o}C and the annual amplitude is very small. Groundwater springs often have higher concentrations of minerals than other standing waters.

Siliceous springs and spring brooks develop throughout Europe where ground water emerges from siliceous bedrock or superficial deposits and are usually small in size but can occur in extensive complexes. The pH of siliceous springs is typically from slightly acid (pH >5.5 to circumneutral).

Calcareous springs, spring brooks and associated tufa cascades occur across Europe in areas with calcareous bedrock and soil where surface discharge includes hard, calcareous water. Alkalinity is >1mmol/l and calcium concentration >20mg/l. pH is clearly alkaline (pH 7-8.5) and the conductivity is high (text modified from the Red List).

The springs can be divided at the lower EUNIS level into types listed in the EUNIS 2012 C2.11 Soft water spring, C2.12 Hard water springs, C2.13 Geysers, C 2.14 Thermal springs, C.2.15 Saline springs C2.16, renaming and enlarging the concept of C2.16 from "Crenal springs" to "Crenal and other springs".
The diagnostic, constant and dominant taxa of aquatic vegetation of springs are listed in the FloraVeg.EU (https://floraveg.eu/habitat/species/P2N).

Springs can be associated with habitat types from other EUNIS groups, such as Q44 Calcareous quaking mire (wetlands) and the habitat complexes ZE: Machair complexes and ZF: Alpine River complex and ZH: Floodplain complexes. Thermal springs and geysers are component habitats of habitat complex ZJ: Complexes of volcanic geothermal fields.

Further details are given below:

Springs are unique ecological interfaces that connect terrestrial and aquatic ecosystems, as well as groundwater and surface waters. Despite their small dimensions, they can be very numerous in a landscape, and they are formed by a heterogenic mosaic of microhabitats that gives rise to high biodiversity. Their insularity and disjunct distributions, stable environmental conditions, and reduced competition given by shorter food chains and the rarity of top predators, create favourable conditions for rare and endemic species, incl. specialized organisms like crenobionts (inhabiting springs exclusively) and crenophiles (preferably inhabiting springs and other comparable aquatic habitats and/or inhabiting springs during a particular life cycle phase). Moreover, springs are often referred to as biodiversity hotspots and may serve as refugia for wide range of riverine species, incl. relict species and particular stages of life cycles of species inhabiting adjacent river systems. The function of refugia is particularly important in the arid and semiarid areas of the Mediterranean region. A subtype of springs are Karst springs, which occur in karstic areas. These are defined as sites where an underground stream emerges from the karst bedrock and are sometimes the site for a cave entrance.

Species may be classified as stygobionts when they inhabit the underground part of the spring, stygophiles when they mostly inhabit the spring pool, and rheophiles when they use spring downstream water (Fernández-Martínez et al. 2024). For further reading, please see the reviews of Cantonati et al. (2006 and 2012), Fernández-Martínez et al. (2024) and the references therein.

Numerous studies on European spring biota include a mixture of aquatic and non-aquatic taxa, such as those restricted to moss mats or specific microhabitats covered by a minimal layer of flowing water. Regarding spring vegetation, Tomaselli et al. (2011) identified two most common classes to be *Platyhypnidio-Fontinalietea antipyreticae* (dominated by bryophytes, permanently or intermittently submerged) and *Montio-Cardaminetea* (dominated by bryophytes or vascular plants, non-submerged or only occasionally submerged). The latest classification of the *Montio-Cardaminetea* class and the detailed typology of spring vegetation in Europe is to be found in Peterka et al. (2023).

In summary, European spring communities documented by selected papers in the review of Fernández-Martínez et al. (2023, see Table S2 therein for more information and references), regardless of spring types, consist of:

- Benthic algae:
  - Cyanobacteria (blue-green algae)**:** mainly Oscillatoriales, Chroococcales, Leptolyngbyales and Gomontiellales.
  - Bacillariophyceae (diatoms)
  - Chlorophyta (green algae)
  - Charophyta (stoneworts)
- Benthic invertebrates:
  - Acari: incl. Hydrachnidia (water mites)
  - Annelida (segmented worms)
  - Crustacea: such as Amphipoda, Branchiopoda, Cladocera, Copepoda, Isopoda (Asellota) and Ostracoda.
  - Insecta: such as Coleoptera, Diptera (including Chironomidae), Ephemeroptera, Hemiptera, Odonata, Plecoptera, and Trichoptera.
  - Mollusca: Gastropoda
  - Nematoda
  - Platyhelminthes: Turbellaria
  - Rotifera
- Vegetation: Bryophyta (mosses) and Tracheophytes (vascular plants)
- Vertebrates: Amphibia (like *Salamandra salamandra*)

Alpine springs

Common species found in alpine springs are given by Cantonati et al., (2006, see Table 2 therein for more information and references, also for other communities). Crenophiles among there taxa are indicated in bold:

- Benthic algae:
  - Cyanobacteria (blue-green algae): *Chamaesiphon amethystinus*, *Homoeothrix* spp., *Phormidium* spp.
  - Bacillariophyceae (diatoms): *Achnanthes minutissima, Achnanthes krantzii, Cymbella naviculiformis, Denticula elegans,* ***Diatoma mesodon,*** *Eunotia minor, Eunotia tenella, Meridion circulare, Navicula krasskei, Navicula lange-bertalotii, Surirella spiralis.*
  - Chrysophyceae (golden algae): *Hydrurus foetidus*
  - Chlorophyceae (green algae): *Klebsormidium rivulare*
  - Rhodophyceae: *Batrachospermum*
  - Xanthophyceae (yellow-green algae): *Vaucheria* sp., *Tribonema* sp.
- Benthic Invertebrates besides many crenophiles among water mites and crustaceans:
  - Turbellaria: ***Crenobia alpina***
  - Mollusca: almost all representatives of Hydrobioidea and *Bythinella* spp., springsnails
  - Oligochaeta: Enchytraeidae, Lumbriculidae, *Nais alpina*

- Hydrachnidia (water mites): *Atractides adnatus, Atractides walteri, Atractides panniculatus, Feltria minuta, Hydrovolzia placophora, Hygrobates norvegicus, Partnunia steinmanni, Sperchon thienemanii.*
- Crustacea: Amphipoda (*Niphargus* spp.), Copepoda (*Attjeyella wierzejskii*), Ostracoda (*Candona neglecta* and *Cypria ophtalmica, Psychrodromus fontinalis*).
- Ephemeroptera: *Baetis alpinus*, *Ecdyonurus* spp., *Rhithrogena* spp.
- Plecoptera: *Isoperla saccai, Nemurella pictetii, Leuctra armata, Leuctra braueri,* ***Nemurella pictetii***, *Protonemura* sp.
- Trichoptera: *Allogamus uncatus, Chaetopterix gessneri,* ***Crunoecia irrorate*****,** *Drusus discolor, Lithax niger, Micrasema minimum*, ***Parachiona picicornis***, *Rhyacophila producta*.**,** *Rhyacophyla pubescens,*
- Diptera: Chironomidae (*Corynoneura stylata, Heleniella* spp., ***Krenosmittia boreoalpina***, *Krenopelopia* spp*, Macropelopia* spp., *Metriocnemus* spp., *Paraboreochlus minutissimus, Parametriocnemus stylatus*, *Pseudodiamesa branickii,* and *Thienemannia libanica*), Pediciidae (*Dicranota* sp.), Psychodidae (*Pericoma* spp., *Psychoda* spp., *Ulomyia* spp.), Simuliidae (*Simulium carpathicum, Simulium crenobium*), Stratiomyidae (*Oxycera* sp.).
- Coleoptera: *Agabus guttatus, Elmis latreillei, Elodes* sp., *Hydroporus ferrugineus, Hydroporus nivalis.*

The greatest number of well-documented specialists of spring habitats has been identified among water mites (Acari, Hydrachnidia, 50-90% of the species in permanent springs), dipterans, caddisflies (**Trichoptera),** rotifers, crustaceans, and bryophytes (Cantonati et al., 2006, 2012; Fernández-Martínez et al., 2024). In Mediterranean springs, many endemic species are found for example again among springsnails and crustaceans, e.g. non-marine ostracods and the amphipod genus *Echinogammarus* (Fernández-Martínez et al., 2024).

The particular spring community composition is always dependent on spring type and prevalent environmental conditions. For instance, the most frequent ostracods in European spring habitats have been shown to be *Candona neglecta* and *Cypria ophtalmica*, the first one is commonly found in cold waters, whereas the second one is tolerant to a wide range of environmental factors (Rosati et al., 2014).

Hard-water springs

Hard-water springs (calcareous springs) are characterized by high levels of calcium and bicarbonate causing calcite precipitation due to lower CO_2 pressure in the atmosphere compared to the underground, which causes CO_2 gas emission and pH rises. Calcifying cyanobacteria (e.g. *Rivularia* and *Scytonema*), the desmid *Oocardium stratum*, the xanthophyte algae *Vaucheria*, bryophytes (such as *Eucladium verticillatum*, *Palustriella commutata*), and thick diatom biofilms can also contribute to calcite precipitation (Cantonati et al., 2012). Biodiversity of calcareous springs in Poland is decribed in detail in Okón et al. 2020. A subtype of hardwater springs is Tufa forming springs, which is a priority habitat in the Habitats Directive: 7220 Petrifying springs with tufa formation (Cratoneurion).

Soft-water springs (from EUNIS 2012 habitat C2.11)

Soft-water or siliceous springs with cold, acid to neutral, oligotrophic waters, are dominated either by mosses or vascular plants, depending on light conditions and altitude. Species-poor communities, especially in lower altitudes. Alliance *Caricion remotae* including several associations, with characteristic species *Caltha palustris ssp. laeta*, *Cardamine amara ssp. amara*, *Carex remota*, *Chrysosplenium alternifolium*, *Veronica beccabunga*, *Bryum pseudotriquetrum* and *Conocephalum conicum*. A subtype of soft-water springs is Habitats Directive type 7160 Fennoscandian mineral-rich springs and springfens.

Thermal springs

Thermal springs (also called geothermal springs, hot springs) are natural groundwater outlets where water emerges at temperatures significantly above the mean annual air temperature due to deep circulation and heating by geothermal processes. Some unique endemic microbial lineages exist in different hot springs, shaped by temperature, geochemistry, and light. In cooler zones or at the margins, specialized mosses, algae, and some invertebrates may occur; but true hot spring headwaters are nearly always microbiota dominated. Associated to hot springs U3F Inland spray and steam dependent habitats can occur. Thermal springs and geysers can occur in the habitat complex ZJ Complexes of volcanic geothermal fields.

Benthic algae case studies reported from thermal springs in central Europe and Mediterranean (water temperature preferences are given in Delgado et al., 2000):

- Spain and Portugal: The study focused on springs in the north-western Spain and Portugal, with water temperature ranging from between 18.5 to 42.4°C. The most frequent diatom species were *Achnanthidium minutissimum, A. exiguum, A. catenatum, A. subhudsonis, Nitzschia palea, Diadesmis confervacea, Eolimna minima, Gomphonema parvulum* and *G. rhombicum.* While the majority of diatom species exhibited a preference for water temperatures below 25°C, several eurythermal species, such as *Achnanthidium exiguum, A. minutissimum, Diadesmis confervacea* and *Nitzschia palea,* were also found thriving across a range of water temperatures.
- Central Europe vs. Mediterranean region (Lai et al., 2019): The investigation was done in the thermo-mineral springs of Auvergne (French Massif Central) and in Sardinia (Mediterranean). The diatom species found in both Auvergne and Sardinia included several species of the genera *Navicula* (e.g. *N. cincta, N. veneta, N. sanctamargaritae, N. vilaplanii*) and *Nitzschia* (e.g. *N.* aff. *liebethruthii, N. linearis, N. inconspicua and N. microcephala*). Other common species found in both areas were *Crenotia thermalis, Denticula subtilis, Diploneis elliptica, Halamphora normanii, Gomphonema parvulum, Tryblionella debilis* and *T. hungarica*. The Sardinian thermal springs also had many taxa not found in Auvergne, such as: *Crenotia thermalis* for Auvergne and *Lemnicola exigua, Nitzschia amphibia, N. inconspicua* and *Rhopalodia operculata*.
- Sardinia: Effect of isolation and natural and human disturbances (Lai et al., 2023): Due to both natural and anthropogenic disturbances, the diatom communities were heterogeneous and consisted of a high percentage of aquatic-aerial, as well as some aerial and planktonic species, in addition to species that exclusively inhabit aquatic environments.
    - Benthic algae in thermal springs connected to river systems and those experiencing greater disturbances showed higher species richness with a higher presence of planktonic species (such as *Aulacoseira ambigua, A. granulata* and *Stephanodiscus neoastraea*) and habitat generalist species (such as *Grunowia solgensis, Navicula gregaria*, *Planothidium lanceolatum* and *Nitzschia linearis*). In contrast, more isolated springs appeared to support smaller pools of taxa, including crenophilous species (such as *Caloneis fontinalis*) and sentitive species (such as *Encyonema silesiacum* and *Eunotia pectinalis*) or those with more restricted geographical distribution.
    - The most abundant taxa (relative abundance ≥10%) in both spring types were for example *Gogorevia exilis, Navicula veneta, Nitzschia amphibia, N. microcephala, Pinnularia joculata* and *Rhopalodia operculata*. Differences among the types of springs were determined mainly by generalist *Gomphonema exilis,* pollution tolerant *Sellaphora nigri* and on the other hand disturbance sensitive *Encyonema silesiacum*.

Thermal springs in Iceland

Very hot springs in Iceland support microbial mats and are dominated by thermophilic and other specialist bacteria, with temperature being inversely related to the number of taxa and phylogenetic diversity (Cousins et al., 2018; Podar et al. 2020). Often, the colour of microbial mats differs for different temperature ranges. Mosses, higher plants, or zooplankton are generally absent from the hottest springs.

Saline springs
Benthic algae in mineral saline springs in the French Central Massive (Beauger et al., 2023):

- The dominant diatom species (with an abundance ≥1% of the community) were *Crenotia angustior, C. thermalis, Chamaepinnularia salina, Fragilaria famelica, Halamphora coffeaeformis, Navicula sanctamargaritae, Navicula veneta, Nitzschia communis, Nitzschia valdecostata, Pinnularia kuetzingii, Planothidium frequentissimum, Sellaphora labernardierei, Surirella patella*. Other species (with an abundance <1%) were *Achnanthidium minutissimum, Adlafia bryophila, Fallacia pygmaea, Gomphonema lippertii, Halamphora normanii, Mastogloia elliptica, Navicula salinarum, Pseudostaurosira cubonii.*

Benthic Foraminifera are also reported from saline springs. In central Germany (Milker et al., 2023), taxa that commonly inhabit coastal salt marshes were found to be among the dominants of living specimens (*Trochamminita irregularis, Trochamminita salsa, Entzia macrescens, Miliammina fusca, Siphotrochammina lobata, Haplophragmoides manilaensis, and Haplophragmoides wilberti*), together with one new undescribed species *Entzia* sp., and one calcareous species *Gordiospira arctica.*

Other extreme spring habitats
Iron rich springs in Europe (Cantonati et al., 2006 and 2012 and references therein)

- Dominance of bacteria *Crenothrix*, *Leptothrix*, *Gallionella*
- Poorly developed algal communities with low biomass, characterized for example by absence of cyanobacteria, and dominance of the diatom *Navicula cincta.*

Benthic algae in sulphuric springs in Central Europe (Zgonik et al., 2021 and references therein):

- Bacillariophyta (diatoms): *Caloneis tenuis*, *Frustulla vulgaris*, *Gomphonema* spp., *Navicula radiosa*
- Cyanobacteria: *Oscillatoria* spp.
- Chlorophyta: *Tribonema vulgare*

6.2.5 Biology in P2P Temporary rivers and streams
Temporary rivers and streams are ubiquitous, and they are a significant part of the global landscape, especially in semi-arid and arid areas where they can be more widespread than perennial running waters, thus serving as a refuge for a wide range of biota. In Europe, they occur primarily in the Mediterranean region but can also occur in temperate regions e.g. in chalk areas.

The characteristic feature of temporary water bodies is the cyclical nature of the drought and strong fluctuations in water level, which include alternating dry and wet periods of running water related to the level of the underlying water table, the temperature and the amount of precipitation. They may either be intermittent (flowing during certain times of the year, mostly predictably) or ephemeral (flowing briefly during or immediately after rainfall). Shifting between dry and wet periods of running water leads to the creation of standing water pools or terrestrial habitats for the time being. As such, these habitats harbour low aquatic biodiversity (that decrease with increasing flow intermittence) and usually lower abundances during a given phase, but displaying a high biodiversity associated with species turnover in response to hydrological changes. The aquatic communities are usually a subset of those inhabiting more stable water courses in the broader area. Temporary water species are generally tolerant or well adapted to survive desiccation, e.g. by having a small body size, short life cycle, high dispersal ability, undergoing diapause or dormancy, forming resistant cysts, spores or seeds. During dry periods, the still moist riverbed can sustain terrestrial plants and animals otherwise not able to survive in the drier surroundings and support specifically adapted ephemeral communities.

In the Mediterranean region of Europe, temporary rivers and streams dominate over perennial running waters due to dry climate conditions, climate change and land use development. The increasing human activities (e.g. water abstraction for agriculture and drinking water) have worsened the effect of the other factors, extending the dry phase of temporary water courses and even converting many perennial rivers and streams into non-perennial, that are nowadays considered to be "artificially dry" or "artificially intermittent". In addition to summer desiccation, these ecosystems also experience extreme flooding events in autumn and spring. The communities therefore have to be adapted to a highly variable environment. Read more in Skoulikidis et al. (2017) and Lorenz et al. (2023).

More information about distribution, ecology, as well as the management and conservation of temporary running waters is available in Williams et al. (2006), Darty et al. (2014), Acuña et al. (2017), Sauquet et al. (2020). For the Mediterranean region, see Skoulikidis et al. (2017), Munné et al. (2021) and Lorenz et al. (2023).

This running water habitat type can be associated with habitats from other EUNIS groups: Q61 Periodically exposed shore with stable, eutrophic sediments with pioneer or ephemeral vegetation (wetlands), Q62 Periodically exposed shore with stable, mesotrophic sediments with pioneer or ephemeral vegetation (wetlands), U72 Unvegetated or sparsely vegetated shores with mobile sediments in the Mediterranean region and Q53 Tall sedge-beds (wetlands) where periodic flooding occurs. This habitat is also related to the habitat complexes ZG: Mediterranean river complex with tamarisk and oleander, ZH2: Flat lowland floodplains, ZH3: Mid-altitude high run-off floodplains, ZH4: Mid-altitude low run-off floodplains, ZH5: Mid-altitude plateau floodplains.

The flora and fauna found in temporary rivers and streams are described below:

Benthic algae

Benthic algae are common mainly as part of biofilms and algal mats. Biofilms are formed, as in any other ecosystem, by a mixture of archaea, bacteria, protozoans, fungi, cyanobacteria and algae. Among them, diatoms can be represented by *Amphora fogediana*, *Cocconeis placentula* and *Placoneis gastrum*. *Achnanthidium minutissimum* complex is an example of a significant indicator of high status waters, *Amphora pediculus* of good-to-moderate status waters (Magand et al., 2020). The development of algal mats, particularly intertwined remains of filamentous species, can play a vital role for other organisms that may endure dry phases underneath them (Williams, 2006).

Below are some further details from single countries:
Hungary (B-Béres et al., 2022):

- Characteristic and/or indicative diatom species of dry phases: *Diadesmis contenta*, *Meridion circulare*, *Planothidium lanceolatum*, *Reimeria sinuate*, *Reimeria uniseriate*, *Navicula veneta*, *Frustulia vulgaris*, *Luticola ventricosa* and *Nitzschia liebetruthii*
- Characteristic and/or indicative species of wet phases: *Cocconeis species*, *Navicula* and *Nitzschia sensu lato* (such as *Navicula lanceolata*), *Gomphonema angustatum*, *Gomphonema pumilum* and *Halamphora* spp. (such as *H. montana* and H*. normanii*)
- Dominant species of wet phases: pioneer diatoms (e.g. *Achnanthidium minutissimum* and *Amphora pediculus*) and/or low-profile, small and medium sized diatoms (e.g. *Planothidium lanceolatum*, *Reimeria sinuata*, and *Reimeria uniseriata*)

Balearic Islands (Mallorca, Minorca and Ibiza) (Delgado et al., 2012):

- Reference sites, high and good status sites:
  - Abundant and characteristic species: C*ymbella vulgata, Diploneis oblongella, Encyonopsis microcephala*, together with *Achnanthidium minutissimum, Achnanthidium pyrenaicum, Amphora pediculus, Gomphonema rosenstockianum.*
  - Other common speices: *Navicula cryptotenella, Gomphonema pumilum, Cocconeis euglypta* and *Fragilaria capucina* var. *rumpens.*

- Moderate, poor and bad status sites (affected by high levels of organic and/or nutrient enrichments):
  - *Navicula veneta, Nitzschia inconspicua, Nitzschia frustulum* and *Planothidium frequentissimum.*
- Appendix A in Delgado et al., 2012 has the complete list of sensitive and tolerant species found in the study.

Southern Portugal (Novais et al., 2020):

- The most abundant species: *Achnanthidium minutissimum, Planothidium frequentissimum, Nitzschia paleacea, Navicula veneta, Nitzschia inconspicua, Amphora pediculus, Ulnaria biceps.*
- Other abundant taxa: *Epithemia adnata, Pseudostaurosira* sp*., Fragilaria socia, Nitzschia incognita, Fragilaria pectinalis, Platessa stewartii, Encyonopsis* sp*., Fragilaria tenera, Aulacoseira granulata, Staurosirella pinnata, Encyonopsis subminuta, Nitzschia* cf. *inconspicua, Punctastriata* sp*., Gomphonema tergestinum, Pseudostaurosira elliptica, Navicula gregaria, Gomphonema* sp.
- Characteristic taxa of arheic conditions (i.e. no or close to zero surface discharge, some pools still present in the stream bed or collected from dry biofilm):

  Craticula cuspidata, Fallacia pygmaea, Navicula erifuga, Nitzschia intermedia, Nitzschia supralitorea, Planothidium pericavum, Sellaphora pupula and *Surirella angusta, Achnanthidium eutrophilum, Cocconeis placentula, Eolimna minima, Epithemia turgida, Karayevia clevei, Nitzschia amphibia, Nitzschia filiformis* var. *conferta*, *Nitzschia valdestriata, Pseudofallacia tenera, Pseudostaurosira brevistriata, Pseudostaurosiropsis* sp. and *Staurosirella pinnata*
- Characteristic taxa of the eurheic conditions (i.e. adequate water flow to support the existence of all aquatic habitats and optimum hydraulic connectivity between them):

  Denticula subtilis, Encyonema minutiforme, Eunotia implicata, Eunotia minor, Eunotia pectinalis, Fragilaria aff. *capitellata* and *Nitzschia gracilis*, together with two *Fragilaria* species aff. *pectinalis* group, *Gomphonema pumilum* var. *rigidum*, *Gomphonema truncatum*, *Melosira varians*, *Planothidium* cf. *frequentissimum* and *Ulnaria acus*

Aquatic vegetation

Aquatic vegetation is characterized by the occurrence of only a few strictly aquatic species with suitable life strategies. Waterlilies (*Nymphaea*) and pondweeds (*Potamogeton*) can endure only short-term drying, but annual duckweeds (*Lemna*) may spread in mesotrophic to eutrophic slow-moving streams within weeks after waterflow is restored (Magand et al., 2020). A striking seasonal flora of *Batrachion fluitantis* has been observed in the UK 'winterbournes' found in chalk areas (Text modified from the Red List). For vascular plants in temporary rivers, there is an alternation between aquatic and emergent communities with only limited competition. Under such wet-dry cycles, many species are annual. Strictly aquatic species are eliminated when the temporary river dries out, while the emergent species do not resist the reinundation (Sabater et al. 2017 and references therein).

Aquatic vegetation in Mediterranean temporary rivers and streams is not widely studied. The study from Cyprus of Manolaki et al. (2020) reported aquatic plants together with semi-aquatic and terrestrial ones, as well as benthic filamentous algae. The study showed that flow intermittency led to taxonomical and functional responses of plant communities and supported the occurrence of numerous indicator species with wider ecological preferences and traits allowing resilience to drought. The authors divided intermittent streams into two sub-types, that could be characterized by different indicator species (**aquatic and semi-aquatic taxa are shown in bold**): For lowland intermittent narrow streams, they were *Piptatherum milliaceum* and *Arundo donax,* followed by *Geranium purpureum*, *Sellaginella denticulata*, *Melica minuta,* and ***Cyperus laevigatus***. Higher numbers of indicator taxa were identified for lowland intermittent wide channel streams, including ***Chara vulgaris***, ***Scirpus holoschoenus, Veronica anagallis-aquatica***, *Avena barbata*, *Bromus rigidus*, *Sinapis alba*, bryophyte *Didymodon tophaceus*, and benthic alga ***Cladophora* sp.**

Benthic invertebrates

Crustaceans (like Brachiopoda, Ostracoda, Copepoda, Decapoda, Peracarid) and insects are usually the dominants of the global temporary water fauna. Hydracarina (aquatic mites, class Arachnida) were also found to be common (Williams 2006). European communities include arachnids, crustaceans, flatworms (Platyhelminthes), insects, leeches (Hirudinea), molluscs, and worms (like Annelida, Nematoda). Among insects, there are numerous families commonly represented: beetles (Coleoptera), caddisflies (Trichoptera), damselflies (Odonata), dragonflies (Odonata), mayflies (Ephemeroptera), stoneflies (Plecoptera), true bugs (Hemiptera), and true flies (Diptera, such as Chiromidae) (Magand et al., 2020). Besides that, other communities are also present (Williams 2006, Magand et al., 2020). Below are some further details from single countries:

Below are some further details from single countries:

Northeast Spain (Arias-Real et al., 2022), examples of pollution-sensitive species are in bold:

- Partly tolerant (with moderate mean abundances):
  - Odonata: *Boyeria*
  - Ephemeroptera: *Habroleptoides*, *Baetis*
  - Plecoptera: *Leuctra*
  - Hemiptera: *Gerris*
  - Trichoptera: ***Lepidostoma***
  - Diptera: Athericidae, Simuliidae
- Generalists (the majority of individuals over the drying gradient):
  - Annelida: Lumbricidae, Lumbriculidae
  - Mollusca: Ancylidae, Lymnaeidae, Planorbidae
  - Odonata: **Corduliidae**
  - Ephemeroptera: *Caenis*, *Centroptilum*
  - Coleoptera: *Limnius*, Dytiscidae, Scirtidae
  - Diptera: Tipulidae, Ceratopogonidae, Empididae, Limoniidae, Psychodidae, Stratiomyidae, Chironomidae.
- Specialists (with moderate mean abundances):
  - Crustacea: Asellidae
  - Mollusca: Hydrobiidae, Physidae
  - Plecoptera: ***Nemoura***
  - Coleoptera: *Hydrobius*

Czechia (Straka et al., 2019):

- Indicators of intermittent and near-perennial streams with highest indicator value were:
  - Oligochaeta*: Eiseniella tetraedra* and *Marionina* sp.
  - Plecoptera*: Brachyptera risi*
  - Diptera, Chironomidae: *Parametriocnemus stylatus* (not significant though), *Paraphaenocladius* sp.
- Other flow intermittence tolerant taxa with significant indicator value were:
  - Oligochaeta: *Enchytraeus* sp., *Haplotaxis gordioides, Nais elinguis*
  - Mollusca: *Bythinella austriaca* agg.
  - Annelida (leeches), Hirudinea: *Haemopis sanguisuga*
  - Coleoptera: *Agabus guttatus*, *Anacaena globulus*, *Esolus angustatus*, *Platambus maculatus.*
  - Plecoptera: *Capnia bifrons, Isoperla tripartita*
  - Trichoptera: *Beraeodes minutus, Micropterna nycterobia*
  - Diptera, Chironomidae: *Diplocladius cultriger*, *Chironomus* sp., *Macropelopia* sp., *Micropsectra atrofasciata*-Gr., *Natarsia* sp., *Orthocladius rivicola*-Gr., *Rheocricotopus effusus*, *Zavrelimyia* sp.
- Taxa with a frequency of occurrence above 50% in intermittent streams were:
  - Mollusca*: Pisidium* sp., *Bythinella austriaca* agg.

- Oligochaeta: *Eiseniella tetraedra*,*Henlea/Fridericia* sp., Lumbricidae and *Stylodrilus heringianus.*
- Plecoptera: *Nemoura* sp.
- Diptera, Chironomidae: *Micropsectra atrofasciata*-Gr., *Brillia bifida* and *Parametriocnemus stylatus, Diplocladius cultriger*, *Natarsia* sp., *Rheocricotopus effusus*, *Rheocricotopus fuscipes* and *Zavrelimyia* sp.
- Crustacea: *Gammarus fossarum*
- Coleoptera: *Hydraena gracilis*, *Agabus guttatus* and *Elmis maugetii*

- Taxa reaching the highest densities in intermittent streams were for example:
  - Mollusca*: Pisidium*
  - Oligochaeta: *Stylodrilus heringianus* and *Nais elinguis.*
  - Diptera, Chironomidae: *Micropsectra atrofasciata*-Gr. and *Parametriocnemus stylatus.* Simuliidae: *Prosimulium tomosvaryi*
  - Plecoptera: *Nemoura* sp., *Capnia bifrons* and *Brachyptera risi,*

Western Greece (Theodoropoulos et al., 2015)
These temporary rivers were dominated by Gastropoda, Oligochaeta, and Diptera. Species richness of EPT-taxa (Ephemeroptera, Plecoptera, Trichoptera) was lower than in perennial sites.

Balearic Islands (Mallorca, Minorca and Ibiza)
The benthic invertebrate communities have gastropods, dipterans and EPT taxa (García et al., 2014): Three subtypes are described below.

- The reference community of **lowland** temporary streams: dipterans, the gastropod *Ancylus fluviatilis*, several beetles (Coleoptera, such as *Haliplus*, *Laccobius* and *Agabus*) and EPT taxa (such as mayflies (Ephemeroptera) *Cloeon*, stoneflies (Plecoptera) *Tyrrhenoleuctra* and caddisflies (Trichoptera) *Hydroptila*).
- The reference community of **canyon** temporary streams was dominated by dipterans, aquatic mites (Arachnida, Hydrachnidiae) and mayflies (such as *Cloeon* and *Caenis*), other taxa found in the habitat were for example beetles Dytiscidae, dipterans (such as Chironomini and *Dasyhelea*), gastropods (such as *Gyraulus*), bedbugs (such as *Notonecta* belonging to Hemiptera) and caddisflies (e.g. *Hydroptila* and *Mesophylax*).
- The reference community of **mountain** temporary streams: amphipod *Echinogammarus sicilianus-monomerus*, many dipterans of the Chironomidae family, together with beetles, mayflies (such as *Alainites, Baetis, Caenis, Cloeon*), stoneflies (such as *Leuctra*) and caddisflies (such as *Hydroptila, Tinodes, Polycentropus* and *Rhyacophila*), and beetles (such as *Hydraena* and *Oulimnius*).
- Appendix B in García et al. (2014) presents the complete list of sentitive and tolerant taxa found in this study.

Fish

The fish community has lower species richness than in perennial running waters but includes species with wide niches adapted to the large variations in water flow. No fish species in Europe, incl. Mediterranean, are adapted to survive completely dry periods (Magand et al., 2020, according to Kerezsy et al., 2017). Fish can still survive in this habitat by inhabiting isolated pools in the riverbed during dry phases (Magand et al., 2020) or migrate in and out of temporary rivers and streams (Williams, 2006). Hydrological disturbances in Mediterranean temporary rivers and streams have an impact on fish species richness, density, biomass, composition, and size (age) structure. Taxa are usually small-sized and tolerant. Challenging life conditions during dry periods give an advantage to many exotic species, such as mosquitofish *Gambusia*, pumpkinseed sunfish *Lepomis gibbosus* and common carp *Cyprinus carpio* (Skoulikidis et al., 2017 and references therein). Other known examples of fish species found in Mediterranean temporary running waters are the freshwater blenny (Salariopsis fluviatilis), the ruivaco (Achondrostoma oligolepis), the threatened endemic cyprinids *Pelasgus laconicus*, *Squalius aradensis, Squalius keadicus, Squalius torgalensis* and *Iberochondrostoma lusitanicum*, *Tropidophoxinellus spartiaticus*, and the highly invasive non-native eastern mosquitofish *Gambusia holbrooki* (Almaça, 1995, Magand et al., 2020, Ordeix & Casals, 2024).

Amphibians and reptiles are also found in this habitat (Sánchez-Montoya et al, 2017 and references therein; Jandt, pers.comm.): For amphibians, various salamanders, toads and frogs (*Lissotriton helveticus, Alytes obstetricans, Pelobates cultripes, Pelodytes punctatus, Pelophylax ridibundus, Bufo bufo, Bufo calamita, Bufo spinosus, Epidalea calamita, Hyla meridionalis, Rana dalmatina, Rana perezi*) have been reported. For reptiles, both freshwater turtles (*Mauremys leprosa, Emys orbicularis*) and snakes (e.g. the dice snake *Natrix tesselata and Natrix maura)* have been found. For more information, see also Gomes et al. (2005) and Duguet (2022).

6.2.6 Biology in P2Q Tidal rivers and streams

Tidal rivers and streams are dynamic ecosystems with a highly variable physical and chemical environment situated between the upstream river and the downstream estuary. This habitat includes portions of large, mainly Atlantic, rivers subject to tidal push and pull of brackish waters and freshwater, upstream from the oligohaline part of estuaries.

The distinction between the upstream freshwater part of a tidal river versus the downstream brackish part of tidal rivers are likely to be well reflected by biota. The communities experience differences in river flow and tides, that lead to changes in salinity and temperature.

Tidal rivers may be considered either as components of lower sections of rivers or as transitional zones, depending on the classification system of a particular country (bij de Vaate et al. 2006).

This running water habitat type can be associated with habitats from other EUNIS groups: Q54 Inland, saline or brackish helophyte beds, Q63 Periodically exposed saline shore with pioneer or ephemeral vegetation (wetlands), Q53 Tall sedge-beds (wetlands) where periodic flooding occurs, and the habitat complexes Z7 Estuaries sub-type Z72 Upper Estuary; the Z81 Saline coastal lagoons, Z82 Brackish coastal lagoons, Z83 Freshwater coastal lagoons.

The flora and fauna in this habitat are described below.

Aquatic vegetation

Submerged aquatic vegetation can form extensive beds in areas with waters that are shallow at low tide with emergent species on permanently flooded banks dependent on the flooding frequency and length (text modified from the Red List). These rivers and streams can also support communities of brackish-water vegetation and freshwater submerged vegetation.

Benthic algae

Benthic diatom communities in the Ebro Estuary in northeast Spain show clear differences in species composition between the tidal river upstream freshwater part and the downstream brackish part (Rovira et al., 2012a, 2012b), although many diatom taxa were abundant in both parts. Benthic diatoms with higher abundances in the freshwater part of the tidal river (without salt-wedge influence) were: *Cocconeis placentula* var. *euglypta, Cocconeis placentula var. trilineata*, *Navicula antonii*, *Navicula cryptotenella* and *Amphora pediculus,* while species with higher occurrence in the brackish part of the tidal river (with salt-wedge influence) were: *Nitzschia frustulum* and *Nitzschia inconspicua.*

Benthic invertebrates

Benthic invertebrates collected in the tidal freshwater section of the heavily modified Scheldt River in Belgium and the Netherlands (bij de Vaate et al., 2006) are:

- Arachnida: suborder Hydracarina (water mites)
- Annelida: subclass Oligochaeta, Hirudinae (leeches)
- Crustacea
- Mollusca
- Platyhelminthes
- Insecta: order Coleoptera, Trichoptera, Ephemeroptera, Odonata, Plecoptera, Hemiptera, Megaloptera and Diptera (family Chironomidae, groups of *thummi-plumosus* and other groups, and other Diptera families).

Fish

Fish populations in tidal rivers and streams experience a dramatic decline, or even complete elimination, mostly due to human impacts like deteriorated water quality and lower water levels from upstream water abstraction and climate change.

Historically, fish of tidal waters and rivers reported from Europe (Barendregt et al. (2009)) were:

- Residental species in tidal freshwaters: bleak *Alburnus alburnus*, barbel *Barbus barbus*, nose carp *Chondrostoma nasus*, gudgeon *Gobio gobio,* chub *Leuciscus cephalus*, tench *Tinca tinca,* bitterling *Rhodeus amarus,* burbot *Lota lota.*
- Residental species in tidal brackish waters: sole *Solea solea*, Atlantic cod *Gadus morhua*, tub gurnard *Trigla lucerna*, bib *Trisopterus luscus*, sprat *Sprattus sprattus*, Nilsson's pipefish *Syngnathus rostellatus.*
- Residental species in both tidal fresh and tidal brackish waters: lesser sandeel *Ammodytes tobianus*, common goby *Potamoschistus microps*, sand goby *Pomatoschistus minutus,* herring *Clupea harengus,* ide (or orfe) *Leuciscus idus,* dace *Leuciscus leuciscus,* bream *Abramis brama,* bullhead *Cottus gobio,* silverbream *Blicca bjoerkna,* pike *Esox lucius,* ruffe *Gymnocephalus cernuus,* ten-spined stickleback *Pungitius pungitius.*
- Diadromous species: eel *Anguilla anguilla*, flounder *Platichthys flesus*, smelt *Osmerus eperlanus*, houting *Coregonus oxyrinchus*, twaite shad *Alosa fallax*, river lamprey *Lampetra fluviatilis*, sturgeon *Acipenser sturio*, salmon *Salmo salar*, sea trout *Salmo trutta*, allis shad *Alosa alosa*, three-spined stickleback *Gasterosteus aculeatus.*

6.2.7 Biology in P2T Inland saline rivers and streams (mainly Mediterranean)

Inland saline streams occur both in areas with increased evaporation, concentrating salts in the surface and in areas with geological salt deposits brought to the surface by dissolving water, for example in the Pannonian and the Thuringian basin. Mediterranean inland saline streams mainly occur in south-east Spain. Only one third of the saline streams maintain a permanent flow regime, 55% display an intermittent flow which includes a dry phase both spatially and temporary, and the rest are ephemeral streams with a flow only after heavy rains. Therefore, the biota is well adapted to the extreme conditions of high salinity, temperature and flow fluctuation.

Three sub-types occur depending on their salinity (Millán et al. 2011, incl. the study of Arribas et al. 2009):

a) Hyposaline streams: low salinity, 5-30 mS cm^{-1}, mainly found at higher altitudes with lower temperatures. These are characterized by a high species richness consisting of both freshwater species and those that tolerate low-medium salt concentrations, such as the charophyte *Chara vulgaris* and xanthophyte *Vaucheria dichotoma*, as well as the benthic invertebrate Corixidae (*Sigara scripta*).
b) Mesosaline streams: medium-high salinity, >30-130 mS cm^{-1}, characterized by halotolerant species, such as green algae *Cladophora glomerata*, *Cladophora fracta*, *Enteromorpha instestinalis* and benthic

invertebrates like the beetle families Hydrophilidae (e.g. *Enochrus falcarius*) and Dytiscidae (e.g. *Nebrioporus baeticus*) the Heteropteran family Corixidae (e.g. *Sigara selecta*).

c) Hypersaline streams: highly saline, >130 mS cm^{-1}, a low species richness consisting of salt-dependent halophilic species, such as the vascular plant *Ruppia maritima* and some diatoms and cyanobacteria, as well as the halophilic benthic invertebrate beetle *Ochthebius glaber*.

A few saline streams are found also in Central Europe. The example below is from Germany and is in the smallest European Nature reserve Solgraben Artern (1.63ha): The saline stream originates from a Karst spring which brings saline water up to the surface from a depth of about 300m. The water has a constant temperature of 11.5°C (no freezing in winter) and a dissolved salts concentration of 22.5-25g/l. One fish species occurs in the stream (*Gasterosteus aculeatus)*, emergent insects such as dragonfly species (*Coenagrion mercuriale, Coenagrion pulchellum*) and a rich flora of aquatic halophytes including *Ruppia maritima*, *Lemna trisulca*, *Salicornia europaea* s.l., *Suaeda maritima*, *Bupleurum tenuissimum*, *Centaurium pulchellum*, *Juncus gerardii,* and further saltmarsh species *(Aster tripolium, Artemisia maritima, Artemisia rupestris, Glaux maritima, Trifolium fragiferum, Lobularia maritima, Atriplex prostrata).* The pollution indicating alga *Enteromorpha intestinalis* is regularly removed.

This running water habitat type can be associated with habitats from other EUNIS groups: Q63 Periodically exposed saline shore with pioneer or ephemeral vegetation, Q54 Inland saline or brackish helophyte bed, R63 Temperate inland salt marsh and S93 Mediterranean riparian scrub and P2N (saline) Springs.

7 Regional differences in community structure

7.1 Rationale, data overview and analytical approaches

Community structure can vary between different regions in Europe due to biogeographical distribution patterns. Such regional differences in species composition for freshwater biota can explain a larger part of the variance in reference communities than what is explained by the type descriptors at Level 3, at least for rivers (Jupke et al., 2022, 2023 and Parasiewicz et al., 2023). The best solution for describing differences in reference communities is probably to combine the habitats at level 3 with an analysis of regional differences. Such a solution was proposed and supported by experts attending the expert workshop in 2021.

This chapter therefore presents regional differences in community structure for all level 3 habitat types with sufficient data in the WISER database for the same biological groups as given in Chapters 0 and 5. Table 7-1 below shows the habitat types with sufficient data to allow splitting of the datasets into two or three different regions in Europe: Northern, Central and Southern (= Mediterranean). As regional differences may occur in both reference and impacted water bodies, we have included both in the analysis of regional differences in this chapter, however, showing results separately for reference water bodies and impacted water bodies.

The analytical approaches used for the regional L4 analysis are mainly the same type of multivariate analysis we used at L3, namely NMDS and cluster-analysis. For any combination of biological community and either reference water bodies or impacted water bodies, we analysed regional differences only if at least two habitat types had sufficient data to allow regional splitting. For benthic algae in rivers, the NMDS and cluster-analysis methods could not be used as only one habitat had sufficient data for a regional splitting (at least 4 water bodies per region). Therefore, we analysed the regional differences using only the frequency of occurrence.

While, the lakes part of the WISER database had a lot of data from the Nordic and Central-European regions, there were less data from the Mediterranean region, especially for reference lakes where sufficient data was available only for one habitat type (P16 Mid-altitude, shallow to deep, calcareous or mixed lakes) (Table 7-1). Most of the 20 reference water bodies allocated to that type are Spanish reservoirs (heavily modified or artificial water bodies acc. to WFD designation). We included these in the analysis of regional differences for phytoplankton, based on the assumption that the pelagic zone can still be inhabited by natural phytoplankton taxa.

We did not include reservoirs in the analysis of other biological groups, as natural communities of aquatic vegetation or fish are scarce because the littoral zones of reservoirs are normally man-made concrete walls. There was no data in the WISER database from natural lakes for aquatic vegetation nor for fish from the Mediterranean region.

For impacted lake water bodies, data was available from several habitat types in all three regions (Table 7-1), thereby allowing the analysis of regional differences in communities for more habitat types. There were more data for phytoplankton than for aquatic vegetation. For fish no data was available for reference lakes, while for impacted lakes, data was only available from two habitat types (P12 & P13).

Table 7-1 Available data in the WISER database for regional analysis of (a) standing waters and (b) running waters with data from a minimum of 2 regions and 4 water bodies per region per L3 type. NOR = Nordic region, CEN = Central region, MED = Mediterranean region, ref = reference, imp = impacted. Very large water bodies are included among the other EUNIS types.

a) Number of standing water bodies (lakes) in the different regions

Status	EUNIS L3 code	Phytoplankton			Aquatic vegetation			Fish		
		NOR	CEN	MED	NOR	CEN	MED	NOR	CEN	MED
Reference	P12	49	28		5	11				
	P13	12	16		9	4				
	P16	23		20						
Impacted	P11	9	160		8	15				
	P12	65	311	11	24	45		9	48	
	P13	91	103		52	12		35	22	
	P14	50		11						
	P16	14	12	55						
	P17	16	4							
	P18	13		8						

b) Number of running water bodies (rivers) in the different regions

Status	EUNIS L3 code	Aquatic vegetation			Benthic invertebrates			Fish		
		NOR	CEN	MED	NOR	CEN	MED	NOR	CEN	MED
Reference	P26		34	5		36	5		37	5
	P2A		42	4		74	7		71	7
	P2C				4	49		4	29	
	P2G				5	15		4	10	
Impacted	P26				4	241	8			
	P2C				6	145				

In the case of reference rivers, only three habitat types and two regions (Central and Mediterranean or Nordic and Central) had sufficient data to be included in the regional analysis: for the Central and Mediterranean comparison, P26 (Lowland, medium to large, calcareous or mixed rivers and streams) and P2A (Mid-altitude, very small to small, calcareous or mixed rivers and streams) were analysed, while for the Nordic and Central region, only P2C (Mid-altitude, very small to small, siliceous rivers and streams) could be analysed. For impacted rivers more habitat types had sufficient data to allow a regional analysis (Table 7-1). However, the river dataset was dominated by Central-European rivers both for reference and for impacted rivers. Therefore, the results are highly uncertain. Most data were available for benthic invertebrates, allowing regional analysis of three habitats for reference communities and three habitats for impacted communities (Table 7-1. Data for fish was also available for some habitat types. Little data was available for aquatic vegetation in rivers, and data was not sufficient for any habitat to allowing regional analysis for benthic algae.

The analytical approaches used for the regional difference analysis are the multivariate methods (NMDS and clustering), as described in Chapter 3.7. In addition, we also did an analysis of characteristic, common and dominant taxa for phytoplankton in the standing water habitat P16 (Mid-altitude, shallow to deep, calcareous or mixed lakes) in the Mediterranean region compared to the rest of Europe.

7.2 Analysis of regional differences for standing waters

7.2.1 Phytoplankton in reference and impacted lakes in different regions

Clear regional differences in phytoplankton communities were found, particularly in the Mediterranean region, which was quite different from the phytoplankton communities in the other two regions. This difference was seen for reference lakes in P16 and for impacted lakes in P12, P14, P16 and P18 (Figure 7-1). This is most likely an effect of major differences in climatic conditions but can also partly be due to differences between natural lakes in the Northern and Central European regions versus the artificial reservoirs in the Mediterranean. Unfortunately, we had no data on phytoplankton from natural lakes in the Mediterranean region.

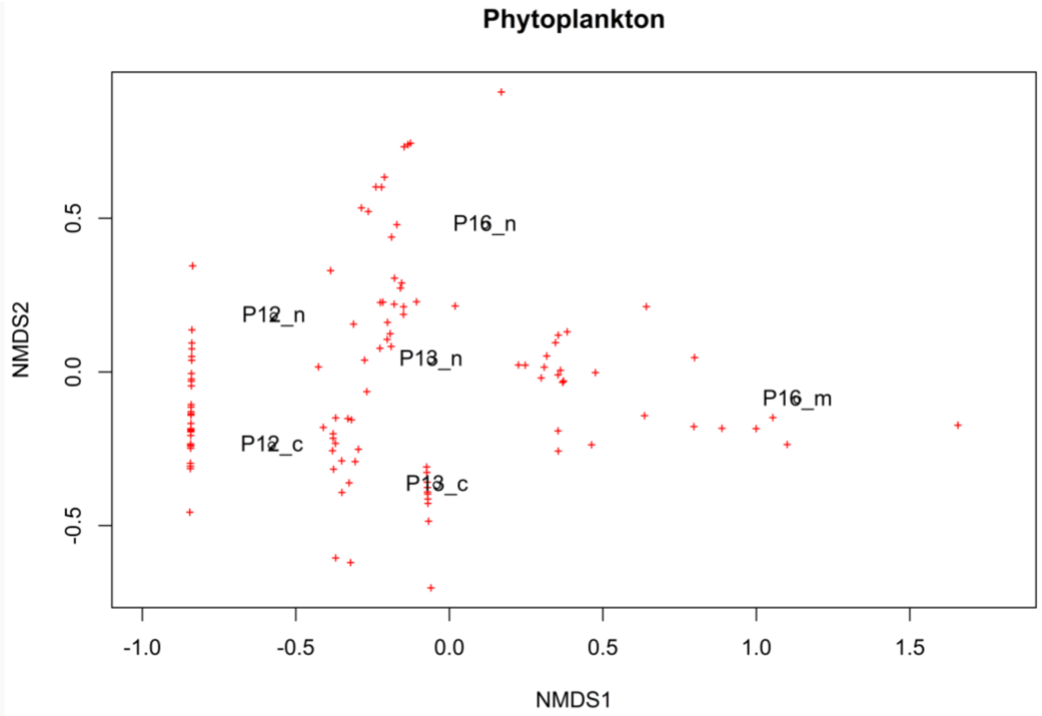
We also revealed some differences in the phytoplankton communities between the Northern and Central European regions, particularly for reference lakes in the lowland calcareous, stratified lake types P12 and P13. These differences were much smaller in the impacted lakes, except for the lowland very shallow, unstratified calcareous lakes in P11 which were still quite different in the Northern region versus the Central European region.

Differences in characteristic, common and dominant taxa between mid-altitude calcareous Mediterranean reservoirs (P16 Med) and the same type in the rest of Europe (P16)

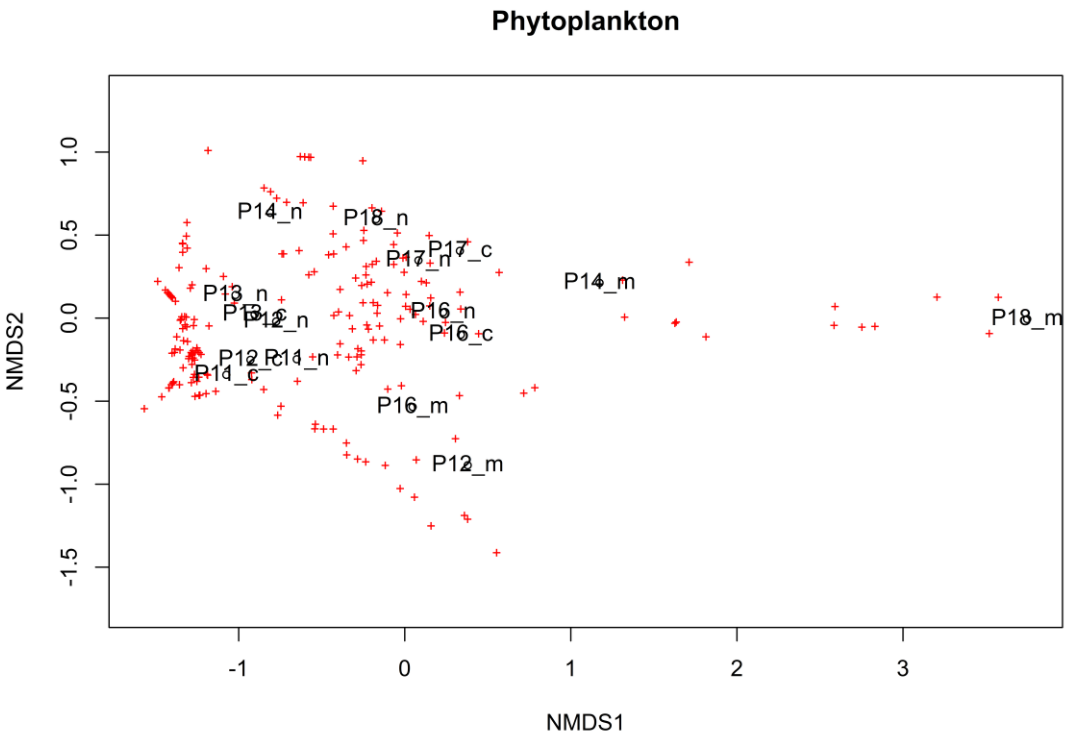
The major differences between the phytoplankton communities in the Mediterranean reservoirs in reference or good condition and the phytoplankton communities in the rest of Europe for the same type are that the Mediterranean reservoirs have fewer common species, but more dominant species. The most conspicuous differences in species composition in the Mediterranean reservoirs compared to lakes in the rest of Europe are that species belonging to the class Ulvophyceae (Planktonema lauterbornii) was only common in the Mediterranean reservoirs, in contrast to a diatom (Fragilaria), as well as a chlorophyte (Monoraphidium), several cryptomonads, a range of chrysophytes and the prymnesiophyte Chrysochromulina parva, which were only common in the Northern and Central European regions (P16 in Table 7-2). The large dinoflagellate Ceratium hirundinella was only common and dominant in the Mediterranean reservoirs but not listed as common (nor dominant) in the other regions. However, this species would have been identified as common (but still not as dominant) if the same threshold for identification of common species (frequency of occurrence) had been used in all regions.

Figure 7-1 Multivariate analysis of regional differences in phytoplankton communities for reference and impacted lakes in all EUNIS habitat types with sufficient data to allow for a region-specific analysis. (a, b) NMDS plots, (c, d) cluster analysis. NOR/n = Nordic region, CEN/c = Central European region, MED/m = Mediterranean region.

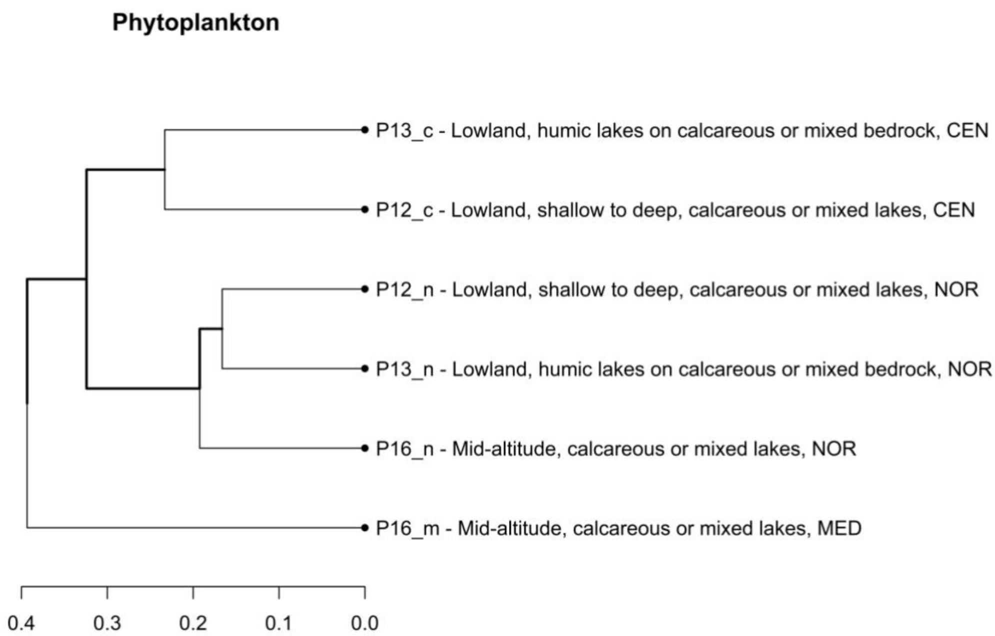
a) NMDS plot for reference lakes



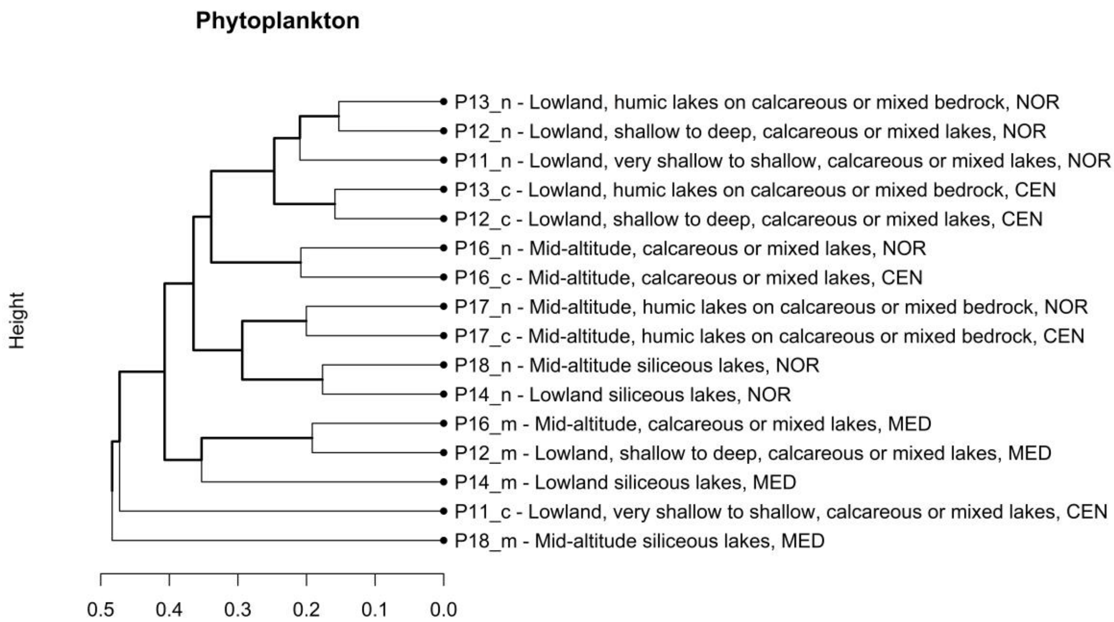
b) NMDS plot for impacted lakes



c) Cluster analysis for reference lakes



d) Cluster analysis for impacted lakes



These differences can be caused by the warmer climate in the Mediterranean reservoirs, especially concerning the absence of common chrysophytes, which are mostly cold-adapted species. However, the absence of several other taxa can be caused by the larger water level fluctuations found in the Mediterranean reservoirs or by capacity problems of species identification.

7.2.2 Aquatic vegetation in reference and impacted lakes in different regions

Clear regional differences in aquatic vegetation communities were found between the Nordic and Central-European regions for the lowland calcareous habitat types (L12, L13) for both reference lakes and impacted lakes (Figure 7-2). This is most likely an effect of differences in climatic conditions related to winter frost. Interestingly, for impacted lakes in P11 (Lowland very shallow, calcareous lakes), there were only small differences in aquatic vegetation communities between the Nordic and Central-European regions. The underwater light climate in these unstratified very shallow lakes is quite poor for aquatic vegetation due to natural wind-driven resuspension of sediments and impacts like nutrient pollution causing phytoplankton blooms. The light limitation may be why these aquatic vegetation communities are so similar in the two regions.

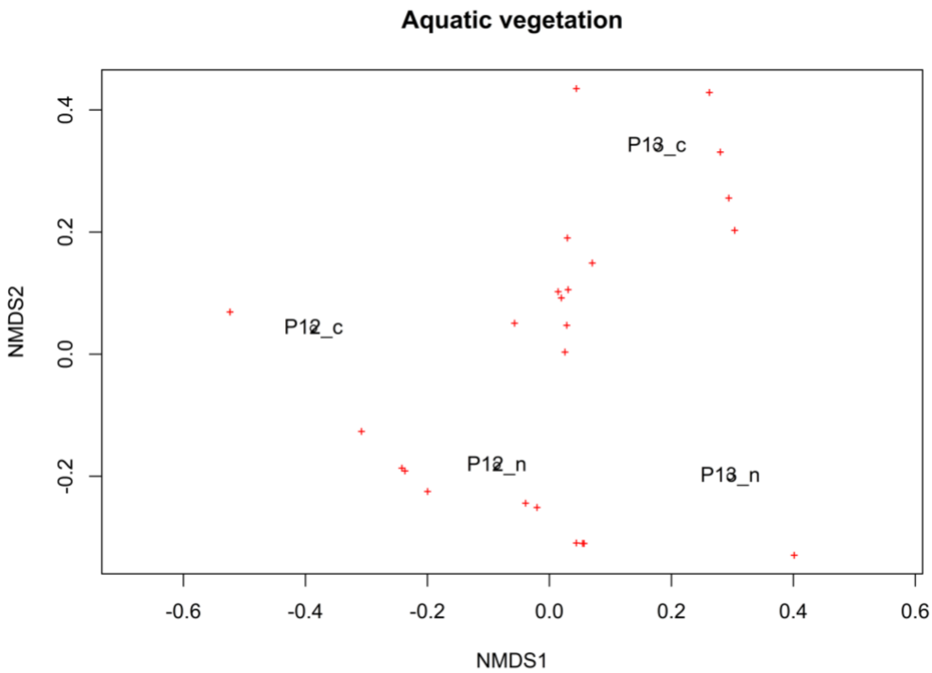
No data was available for the Mediterranean region due to the data being limited to reservoirs with artificial littoral areas. These reservoirs are not suitable habitat for aquatic vegetation due to the often huge water level fluctuations and concrete shorelines. Unfortunately, we had no data on aquatic vegetation from natural lakes in the Mediterranean region. However, in frost free areas further species occur, including genera also found in the north, as well as in lowland Southern Portugal and Southern Spain, e.g. *Callitriche, Typha, Alisma, Ranunculus, Utricularia*. Cross-European commonalities in aquatic vegetation are also illustrated by a phytosociological study from Greece (Sarika-Hatzinikolaou et al., 2003), in which aquatic and emergent species and communities are nearly identical to Germany, with very few exceptions.

Table 7-2 Comparison of phytoplankton communities in reference lakes (reservoirs) between the Mediterranean region (P16 Med) and the rest of Europe (P16) for the only habitat type with sufficient data: Characteristic (diagnostic), common (constant) and dominant taxa.

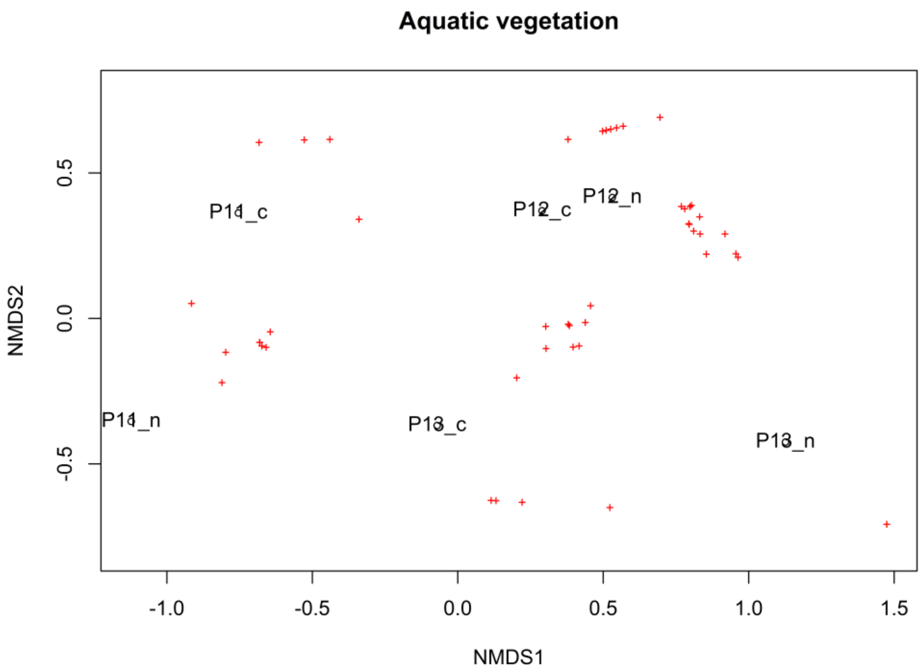
EUNIS L3 code	EUNIS L3 name	Class (if not given otherwise)	Taxon name	Characteristic taxa: phi-index & p-value		Common taxa: freq. of occur.	Dominant taxa: mean rel. abund
P16	Mid-altitude, shallow to deep (stratified) calcareous or mixed lakes	Bacillariophyceae	*Cyclotella radiosa*				0.12
		Bacillariophyceae	*Fragilaria*			0.79	
		Chlorophyceae	*Monoraphidium dybowskii*			0.75	
		Chrysophyceae	*Bitrichia chodatii*			0.71	
		Chrysophyceae	*Kephyrion littorale*	0.520	***		
		Chrysophyceae	*Mallomonas*			0.79	
		Chrysophyceae	*Ochromonas*			0.79	
		Cryptophyceae	*Chroomonas*			0.71	
		Cryptophyceae	*Cryptomonas*			0.92	
		Cryptophyceae	*Katablepharis ovalis*			0.96	
		Cryptophyceae	*Plagioselmis lacustris*			0.83	
		Dinophyceae	*Gymnodinium lacustre*			0.79	
		Dinophyceae	*Peridinium inconspicuum*			0.75	
		Prymnesiophyceae	*Chrysochromulina parva*			0.75	
P16 Med (reservoirs)	Mid-altitude, shallow to deep (stratified) calcareous or mixed lakes	Bacillariophyceae	*Cyclotella meneghiniana*				0.19
		Bacillariophyceae	*Fragilaria crotonensis*				0.21
		Chlorophyceae	*Oocystis marssonii*				0.21
		Chrysophyceae	*Dinobryon divergens*			0.50	
		Cryptophyceae	*Cryptomonas erosa*			0.80	0.10
		Cryptophyceae	*Cryptomonas marssonii*			0.65	
		Dinophyceae	*Ceratium hirundinella*			0.60	0.35
		Dinophyceae	*Peridinium cinctum*				0.23
		Ulvophyceae	*Planctonema lauterbornii*				0.22

Figure 7-2 Multivariate analysis of regional differences in aquatic vegetation communities for reference and impacted lakes in all EUNIS habitat types with sufficient data to allow for a region-specific analysis. (a, b) NMDS plots, (c, d) cluster analysis. NOR/n = Nordic region, CEN/c = Central European region.

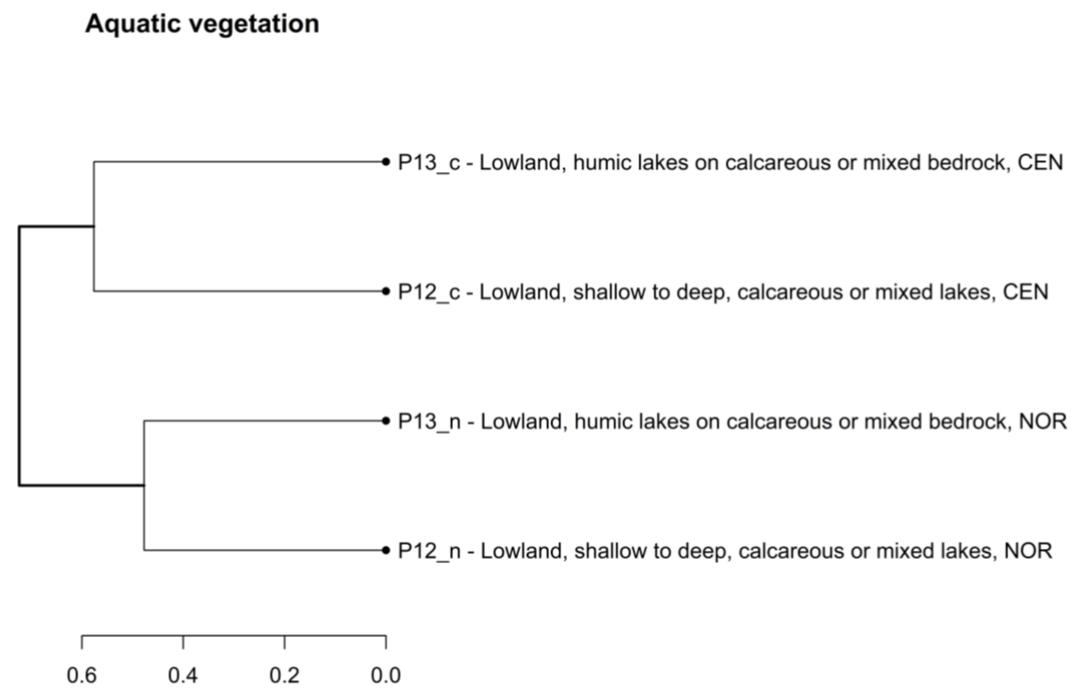
a) NMDS plot for reference lakes



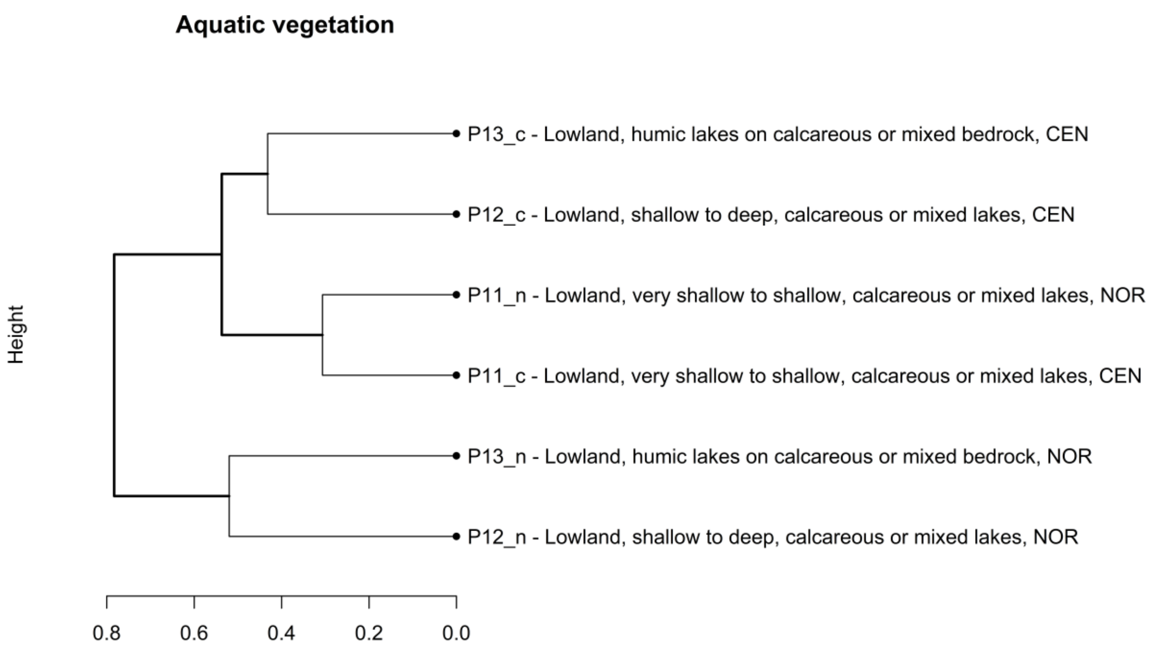
b) NMDS plot for impacted lakes



c) Cluster analysis for reference lakes



d) Cluster analysis for impacted lakes



7.2.3 Fish in impacted lakes

Regional differences in fish communities could only be analysed for impacted lakes, because there was no sufficient data available from reference lakes to allow for regional splitting.

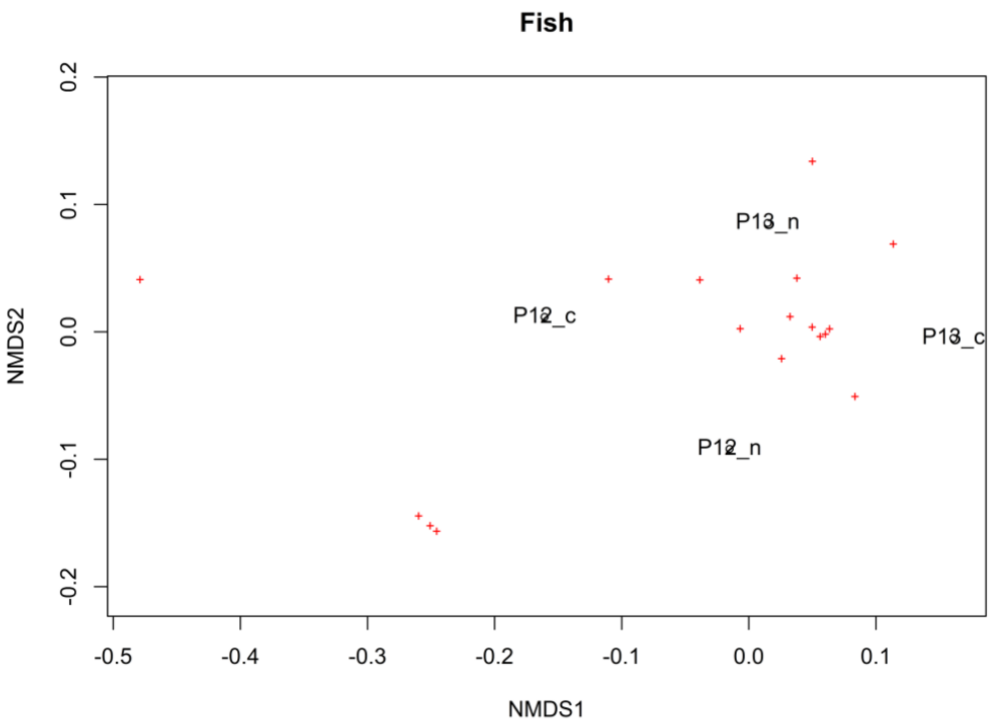
The fish communities show some differences between the Nordic and Central-European regions for impacted lowland, calcareous lakes (P12 and P13) (

Figure 7-3). However, the regional differences were quite small for both habitats, as the dissimilarity was ≤ 0.3 (

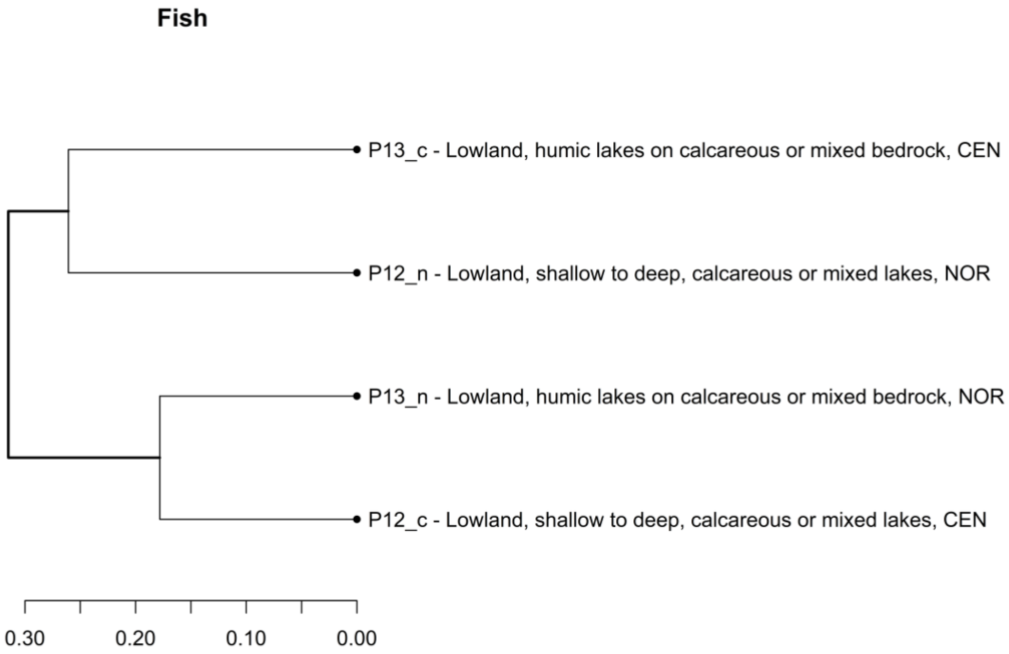
Figure 7-3b). Most of the fish species occur in both regions and both habitats. Moreover, the most common fish species have a high frequency of occurrence in both regions for both P12 and P13, such as brown trout, perch and roach. Some species have a higher frequency of occurrence in the Central region than in the Nordic region, such as the littoral three-spined sticklebacks (*Gasterosteus aculeatus*) in P12; the cyprinid tench (*Tinca tinca*) and the bottom-dwelling percid ruffe (*Gymnocephalus cernuus*) in both P12 and P13. Two pelagic species have a higher frequency of occurrence in the Nordic region than in the Central region, such as the large predatory percid pikeperch (*Sander lucioperca*) and the small zooplanktivorous ray-finned smelt (*Osmerus eperlanus*) in P13, which are calcareous humic lakes. Those two species may have higher oxygen requirements than many of the bottom-dwelling fish species and may therefore not thrive so well in humic lowland lakes (P13), which has less oxygen than lowland clearwater lakes (P12) due to the humic substances. As the Central region has warmer water than the Nordic region, the oxygen-concentration is even lower in the Central region than in the Nordic region.

Figure 7-3 Multivariate analysis of regional differences in fish communities for impacted lakes in all EUNIS habitat types with sufficient data to allow for a region-specific analysis. (a) b) NMDS plot, (b) cluster analysis. NOR/n = Nordic region, CEN/c = Central European region.

a) NMDS plot for impacted lakes



b) Cluster analysis for impacted lakes



7.3 Analysis of regional differences in running waters

7.3.1 Benthic algae in reference rivers and in impacted rivers

There is only one habitat, the Lowland calcareous medium-large rivers (P26), that had sufficient data for benthic algae to allow for splitting into different regions. We could therefore not do any multivariate analysis (NMDS or cluster analysis) but have looked at the differences in the frequency of occurrence between the benthic algae in Central Europe (P26 C) versus those found in the Mediterranean region (P26 Med). As the diatoms were not properly reported from the Mediterranean region, except two genera (*Diatoma* and *Melosira*), we can only compare the occurrence of the other major benthic algae phyla (the non-diatoms) in the two regions. There are also much more river water bodies with benthic algae data in the Central-European region (31 reference rivers and 155 impacted rivers) than in the Mediterranean region (5 reference rivers and 8 impacted rivers), which could bring some bias into the results.

For reference rivers, the major differences for the benthic algae between the two regions are that the Mediterranean rivers have a higher frequency of occurrence than the Central-European rivers for the following genera: the charophyte *Spirogyra*, the chlorophytes (green algae) *Cladophora, Enteromorpha, Microspora, Oedogonium* and *Ulotrhix*, the cyanobacteria *Nostoc* and *Schizothrix*, the diatoms *Diatoma* and *Melosira* and the Rhodophyte *Lemanea*. The only genus with a higher frequency in the Central-European region is the xanthophyte *Vaucheria*. However, there are 11 genera occurring only in the Central-European region and only 4 genera occurring only in the Mediterranean region.

For impacted rivers, the major differences for the benthic algae between the two regions are that the Mediterranean rivers clearly have a higher frequency of occurrence than the Central-European rivers for the following genera: the charophyte *Spirogyra*, the chlorophytes (green algae) *Cladophora* and *Oedogonium*, the cyanobacteria *Oscillatoria* and the diatoms *Diatoma* and *Melosira*. There are no genera with a higher frequency in the Central-European region than in the Mediterranean region. However, there are 11 genera occurring only in the Central-European region and only 3 genera occurring only in the Mediterranean region.

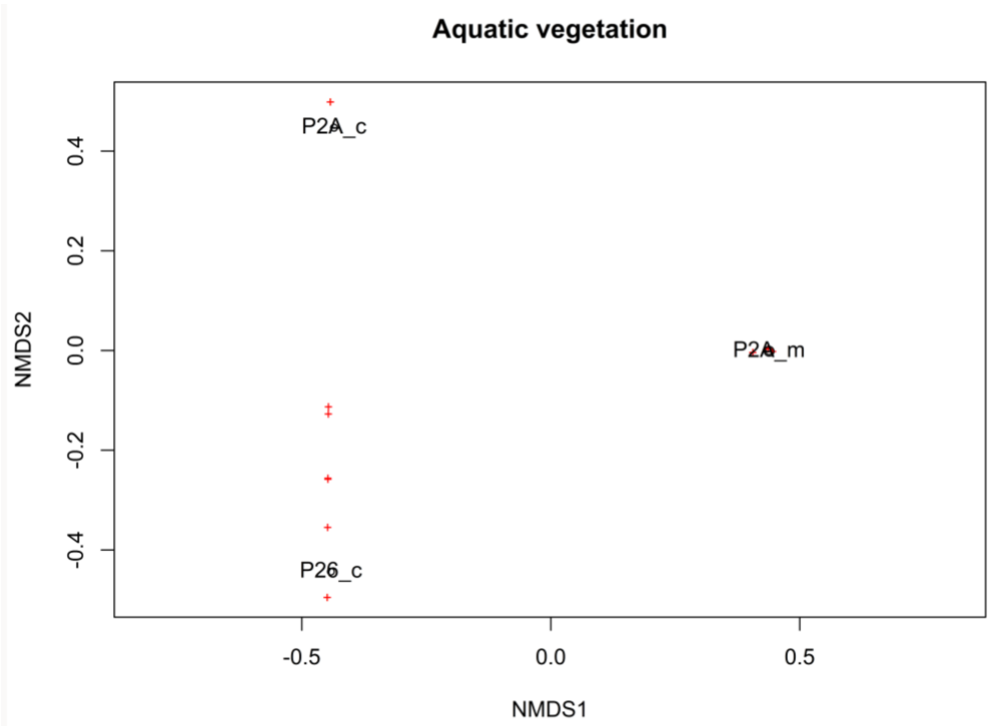
7.3.2 Aquatic vegetation in reference rivers

Only reference rivers could be split into regional datasets, so there are no results for impacted rivers.

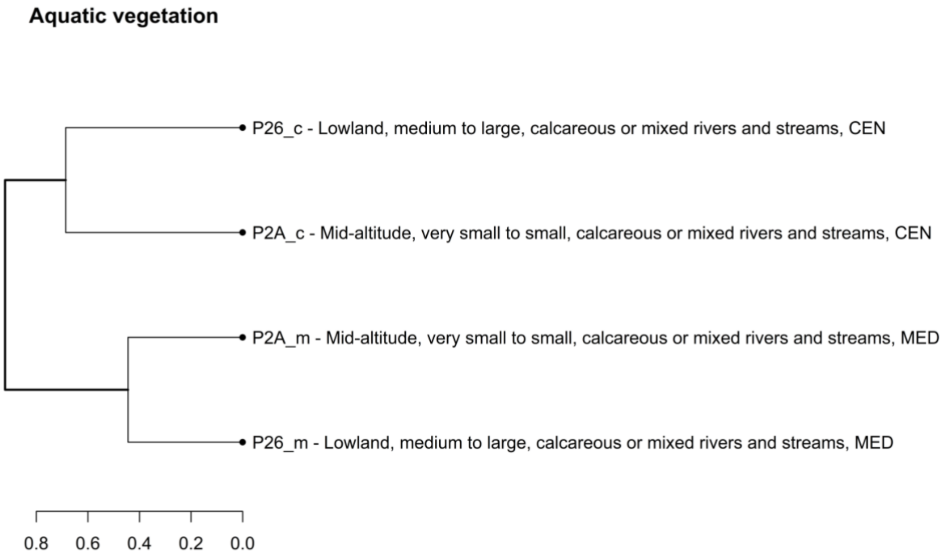
The aquatic vegetation communities in reference calcareous reference rivers are very different in the Central-European region versus those in the Mediterranean region for both lowland, medium-large rivers (P26) and mid-altitude small rivers (P2A) (Figure 7-4). The similarity is high between P2A and P26 within each region, and especially within the Mediterranean region. This shows that region is more important for the species composition of aquatic vegetation communities in reference rivers than altitude differences between lowland and mid-altitude areas, as well as being more important than catchment size. The underlying reason for this pattern could be that the warm Mediterranean climate compared to the temperate Central-European climate is the overriding factor deciding which species are common in each of the two regions.

Figure 7-4 Multivariate analysis of regional differences in aquatic vegetation communities for reference rivers in all EUNIS habitat types with sufficient data to allow for a region-specific analysis. Data from impacted rivers were not sufficient to allow for a regional splitting. (a) NMDS plot, (b) cluster analysis. CEN/c = Central European region, MED/m = Mediterranean region.

a) NMDS plot for reference rivers: P26_m is not visible on the NMDS figure due to the habitat code being hidden behind P2A_m (see cluster diagram below (**Error! Reference source not found.**b) for more info on the similarity between P26_c and P26_m).



b) Cluster analysis for reference rivers



7.3.3 Benthic invertebrates in reference and impacted rivers

The differences in species composition of benthic invertebrates in reference rivers seem to be quite small for the lowland, medium-large, calcareous rivers (P26) between the Central and Mediterranean regions (

Figure 7-5a and

Figure 7-5c). However, larger differences were found between these two regions for benthic invertebrates in mid-altitude, small, calcareous rivers (P2A). This contrasting pattern for large versus small rivers between the Central and Mediterranean regions in otherwise similar river types is likely to be related to climatic differences: small rivers in the warm Mediterranean region could be less suitable than the cooler Central-European region for several benthic invertebrates, e.g. the highly oxygen-demanding stoneflies. Larger rivers have less temperature differences than small rivers between these two regions.

For the mid-altitude siliceous rivers (P2C and P2G), the differences in species composition are considerable between the Central-European and Nordic regions (

Figure 7-5a and

Figure 7-5c). This can be due to differences in alkalinity within the alkalinity range defined for siliceous rivers (<0.2mmol/l), where the Nordic rivers are more acidic having a lower alkalinity and a lower calcium-concentration than the Central-European rivers. Several benthic invertebrates cannot tolerate very low alkalinity, e.g. mayflies like *Baetis rhodani*, amphipods like *Gammarus* and several snails and mussels.

In impacted rivers (

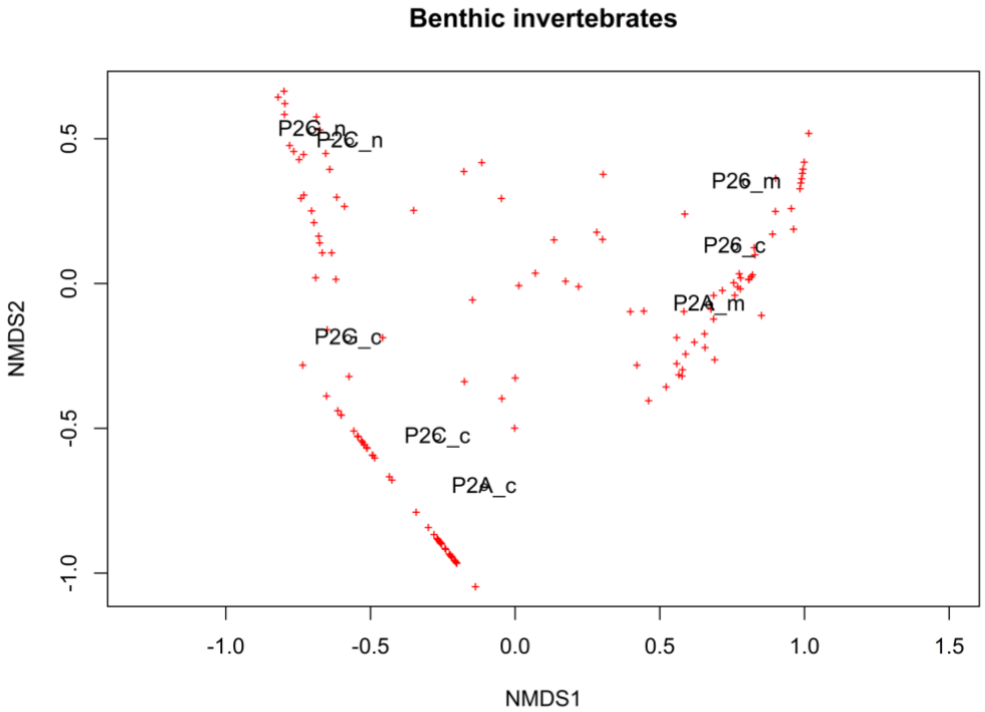
Figure 7-5b and

Figure 7-5d), the regional differences are even higher than in reference rivers, as well as higher than the within-region differences between the two types with sufficient data to assess regional differences: P26 Lowland, medium to large calcareous rivers and P2C Mid-altitude, small, siliceous rivers. This indicates that human impact may be more important for the composition of benthic invertebrate communities than the natural abiotic type descriptors. Moreover, the human impact is likely to differ between the regions both quantitatively (small, moderate, large impact) and qualitatively (organic pollution, acidification, siltation, warming, toxic substances).

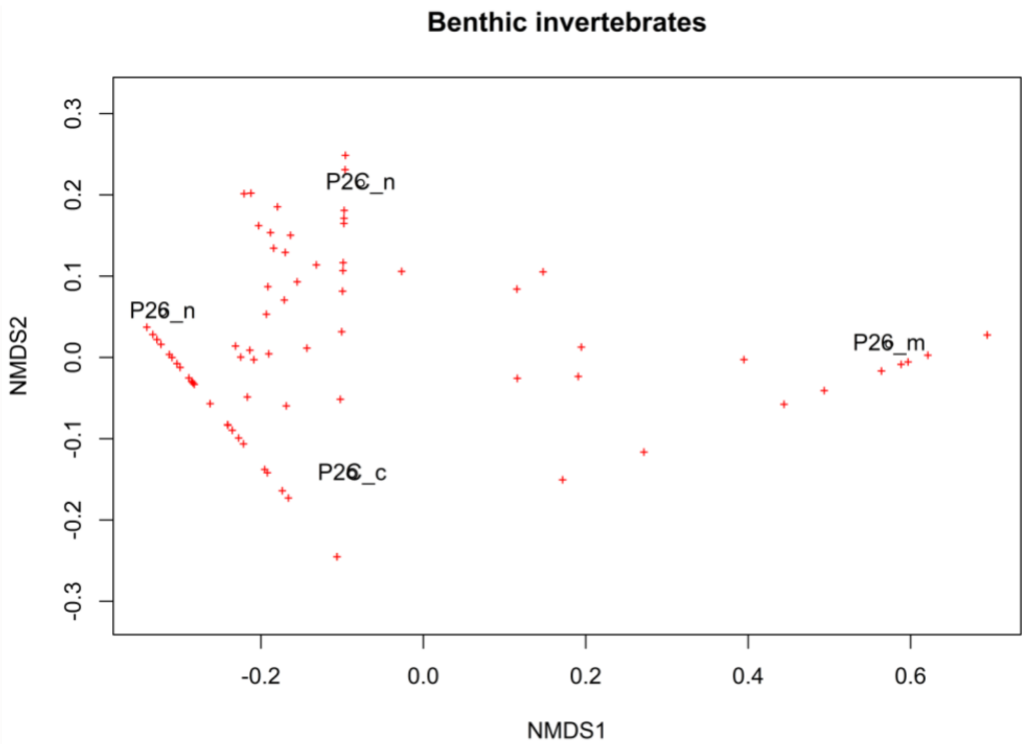
The results for impacted rivers are also likely to be quite uncertain due to few water bodies with data from the Nordic and Mediterranean regions and a high number of water bodies in the Central region (Table 7-1).

Figure 7-5 Multivariate analysis of regional differences in benthic invertebrate communities for reference and impacted rivers in all EUNIS habitat types with sufficient data to allow for a region-specific analysis. (a, b) NMDS plots, (c, d) cluster analysis for reference rivers. NOR/n = Nordic region, CEN/c = Central European region, MED/m = Mediterranean region.

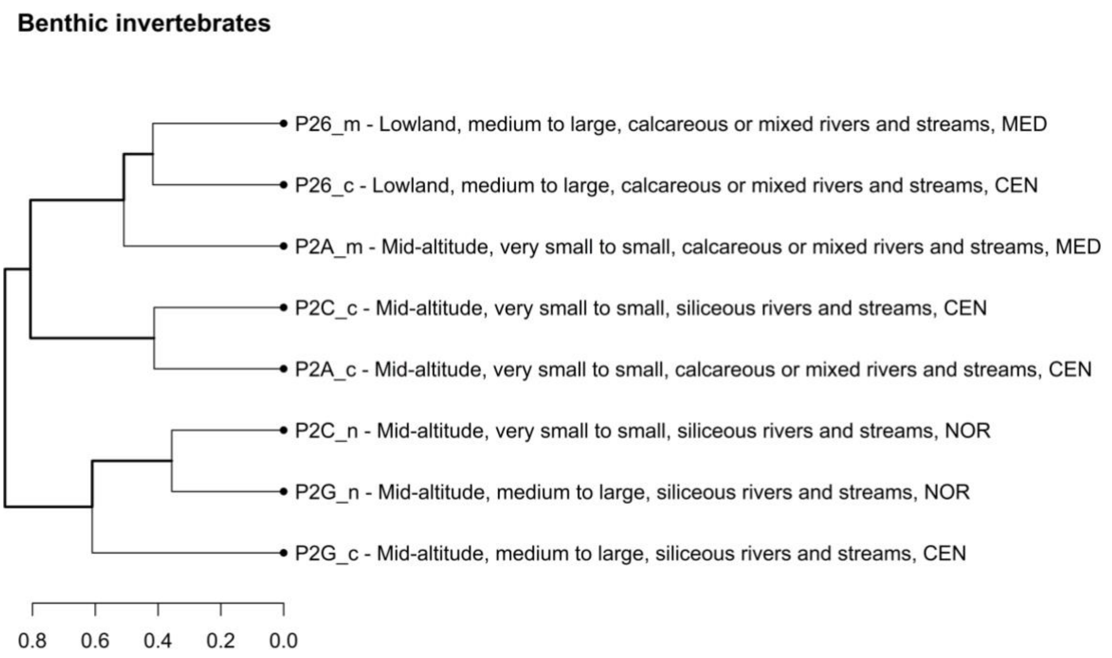
a) NMDS plot for reference rivers



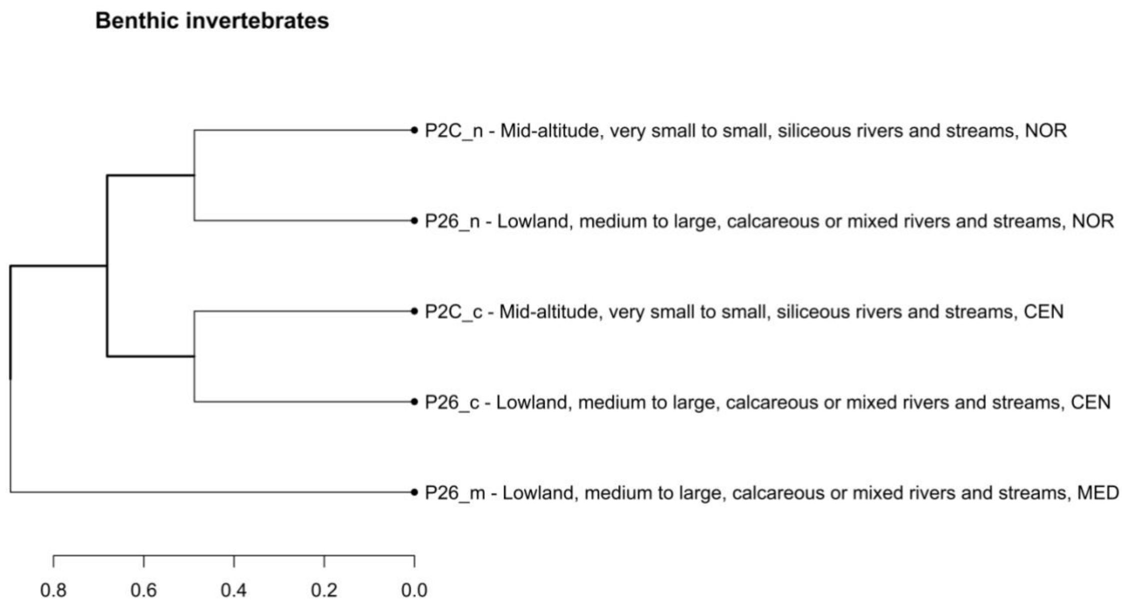
b) NMDS plot for impacted rivers


Benthic invertebrates
NMDS2
NMDS1
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.2
0.0
0.2
0.4
0.6
P26_n
P26_n
P26_m
P26_c

c) Cluster analysis for reference rivers



d) Cluster analysis for impacted rivers



7.3.4 Fish in reference rivers

The regional differences for fish in reference rivers are quite small for both habitat types with sufficient data to allow for a regional splitting between the Nordic and Central regions: the mid-altitude small siliceous rivers (P2C) and the mid-altitude, medium-large siliceous rivers (P2G) (

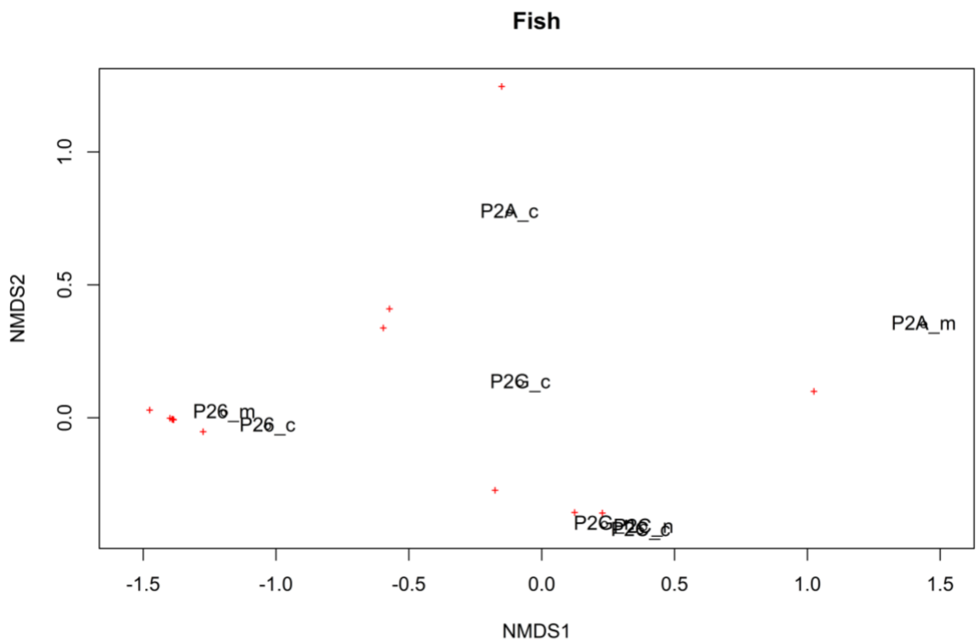
Figure 7-6).

For the habitats with sufficient data to allow for a splitting of the Central and Mediterranean regions, the differences were also relatively minor for the lowland, medium-large, calcareous rivers (P26). However, for the mid-altitude, small calcareous rivers (P2A), the differences between the Central and Mediterranean regions were much larger. The only Mediterranean country with data for fish in references rivers in the WISER database is France, having reported only 5 water bodies for P26 and 7 water bodies for P2A, while the number of water bodies from the Central region has an order of magnitude of more water bodies. Thus, the differences found between the Central and Mediterranean regions for fish communities in reference rivers for P26 and P2A are quite uncertain. Similarly, the small differences found between the Nordic and Central regions for P2C and P2G can also be quite uncertain, as the only Nordic country with fish data from reference rivers in these two habitats is Sweden, having reported only 4 water bodies for each of those two habitats in contrast to 29 and 10 water bodies from the Central region countries (mainly Germany).

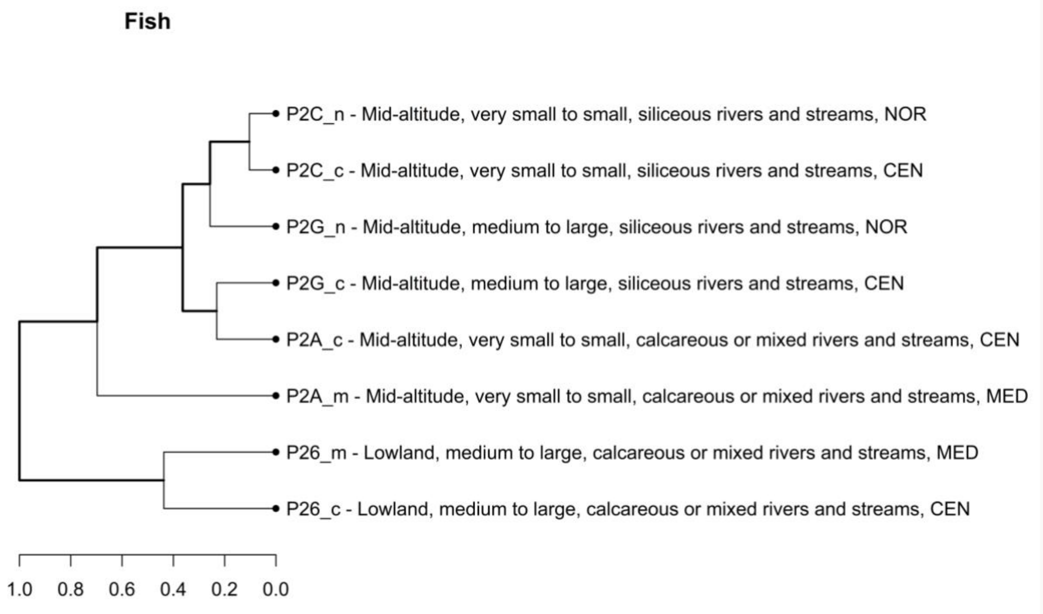
For impacted rivers, there was not enough sufficient data available to allow for a splitting of the regions.

Figure 7-6 Multivariate analysis of regional differences in fish communities for reference rivers in all EUNIS habitat types with sufficient data to allow for a region-specific analysis. (a) NMDS plot, (b) cluster analysis. NOR/n = Nordic region, CEN/c = Central European region, MED/m = Mediterranean region.

a) NMDS plot for reference rivers



b) Cluster analysis for reference rivers



7.4 Synopsis of regional differences

The results reported in this chapter indicate that there are some regional differences in species composition for the various biological communities between the Nordic, Central-European and Mediterranean regions within some of the level 3 habitat types. The regional differences are however uncertain due to unbalanced datasets for the three regions, especially for rivers, where much more data is available from the Central-European region than from the other two regions.

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 overall much warmer climate which favours the species preferring and/or tolerating high temperatures and thereby lower oxygen concentrations (the latter is most important for the benthic invertebrates and fish). Mediterranean aquatic ecosystems also have fluctuating hydrological and physicochemical conditions across seasons requiring a high adaptability of species. In contrast, temperate-climate aquatic ecosystems exhibit comparatively greater stability due to less extreme alternation between wet and dry periods. However, species inhabiting these systems must tolerate lower winter temperatures, including the occurrence of frost and ice.

The differences between the Nordic and Central-European regions are smaller but also quite considerable, especially for phytoplankton and aquatic vegetation in lowland, calcareous, stratified lakes (P12 and P13 both reference lakes and impacted lakes). Regional differences were also found between Northern and Central Europe for benthic invertebrates in mid-altitude, siliceous reference rivers (P2C and P2G) and lowland medium-large calcareous impacted rivers (P26). These differences can be due to a colder climate, as well as to a lower level of human impact than in the Central-European region for impacted lowland, calcareous lakes and rivers. For the benthic invertebrates in mid-altitude, siliceous reference rivers (P2C and P2G), the differences can be due to lower alkalinity and calcium concentrations in the Nordic than in the Central region. Some of the Nordic rivers are naturally acidic.

The importance of regions for the species composition of the biological communities in inland surface waters has been qualitatively considered by visual inspection of the cluster diagrams at level 3 versus at the regional level. The main impression is that the regional differences in phytoplankton and aquatic vegetation communities are smaller than the differences between the same major standing water habitat types at level 3 (which is presented in Chapters 0 and 5). However, for fish in standing water habitats, as well as for aquatic vegetation, benthic invertebrates and fish in running water habitats, the regional differences are larger than the differences between the same major habitat types at level 3, especially for the Mediterranean region. The importance of regions for river biota was also found by Jupke et al. (2022 & 2023).

8 Remaining gaps, EIONET and expert consultation and recommendations for use of the revised L3 habitats

This chapter addresses the gaps left to complete the revision of the L3 habitat types. It also addresses the wider topics related to mapping and access to the wider community.

8.1 Gaps

8.1.1 Gaps in the description of biological communities

Pelagic zooplankton and littoral microcrustaceans found in lakes are missing due to the lack of European-wide datasets. This could be a task for future assessments. However, there are various constraints involved when obtaining reliable data for such assessments. The zooplankton is not included as a biological quality element in the WFD and is therefore less monitored than the other biological quality elements in the WFD. For littoral microcrustaceans, there are very few countries monitoring that group (with Norway as an exception).

Benthic invertebrates in lakes are also missing from this report due to very limited data available in the WISER database. These data were used to develop indices for their response to acidification and to intercalibrate the good ecological status class boundaries for those indices (Sandin et al., 2014). However, a literature review could be possible, if further work is requested.

Concerning riparian/amphibious vegetation and wetland biota (e.g. semi-aquatic plant species), these are described in other EUNIS L1 groups (Z complexes, T forests, R grasslands, or Q wetlands (including helophyte types)), so are not included in the inland surface waters. This was the conclusion after various discussions with the ETC-BD, EIONET and an expert group in 2021-2022. The inland surface water habitats are also in line with what is monitored for the ecological status assessments required by the WFD. A few countries (e.g. FI and PL) include riparian vegetation in their macrophyte method for assessing ecological status, but most other countries use only the truly aquatic vegetation. Many countries use the same methods for monitoring the structure and function component of freshwater habitats under the HD as a basis for their conservation status assessments.

8.1.2 Gaps in Level 4 abiotic descriptors for running waters

In the expert workshop in 2021 it was agreed that river flow is important for the biological communities in rivers and should be addressed at level 4 due to the large temporal and spatial variability of flow in rivers, also within the same river water body. Due to a lack of data on flow in the WISER database, this has not been addressed in this report. However, the more general responses of biology to flow have been briefly described in the Running waters L3 habitats based on expert knowledge, see crosswalk table.

8.1.3 Gaps in the mapping of EUNIS inland water habitats

The mapping is partly done for the L3 habitats that are in line with the WFD broad types (Lyche Solheim et al., 2019, shapefiles are available in the supporting information link here: https://doi.pangaea.de/10.1594/PANGAEA.908578?format=html#download). For the other L3 habitats (e.g. temporary and/or saline waters), further datasets may be needed to generate the required map layer. Work done on EUNIS mapping using machine learning in 2023 (and 2024), which did not include inland water habitats, can also be relevant for inland waters. Furthermore, work done for Remote Sensing supported habitat assessments under the WFD might be relevant here, too, with respect to harmonization to the EUNIS habitats approach (Papathanaopoulou et al. 2019). The latest global approach defining wetlands versus waterbodies, using refined RAMSAR types, might be adapted to align with many EUNIS Inland Water types with some manual matching (Lehner et al., 2025).

Other relevant products are the Copernicus High Resolution Layer Water and Wetness Status, 3 yearly, and other Copernicus products in combination with GBIF data, including Copernicus WATER_BODY: binary presence of water body on a 100m radius.

8.2 Engagement with EIONET and external experts

Throughout the course of the revision, public outreach comprised a public consultation on an early version of level 3 in 2019, an EIONET webinar in 2020 and an expert workshop in 2021. Since the initial 2019 consultation, the level 3 structure has undergone significant change following the outputs from the EIONET webinar and the expert workshop. The most recent EIONET consultation, which lasted until winter/spring 2025, indicated a need for further clarifications on the national use of the revised L3 habitats (see section 8.3), as well as on the definitions of very large rivers, very large lakes, ponds and pools and clay rivers and streams.

Additional work has been done on regional differences within the L3 types (as described in Chapter 6), as well as general considerations of the effect of flow on the biology in running waters. The results of the regional analysis indicate that regions can be important for inland surface water communities, especially for running waters, as suggested by Jupke et al., (2022, and 2023).

These previous engagements with the wider limnological community proved valuable for discussing and deciding the appropriate abiotic factors to set in place at level 3, as well as providing a platform for a much needed and much appreciated debate on the classification on inland water habitats at level 4. The benefits of further consultation with experts, as well as with EIONET is recommended when the L3 (xlsx-crosswalk table and EUNIS manual) and this report have been completed.

8.3 Recommendations for subdivisions of the revised L3 habitats at further levels

The revised Level 3 types P11-P1D for standing waters and P21-P2M for running waters can be subdivided at L4 into regions (at least Northern, Central and Southern) as indicated by the regional analysis shown in Chapter 7. Another option would be to use regions at L3 and the revised inland water habitat types at L4, which would better match the use of biogeographic regions at L3 in the marine EUNIS habitat group.

For the standing water L3 habitats P1E-P1P and for all running water L3 habitats P2N-P2T further potential subtypes at L4 are listed in Chapter 6.

9 Synthesis and Conclusions

The results given in the crosswalk file and in this report are:

- Crosswalks between the revised Level 3 (L3) habitat types for inland waters and other inland water typologies, incl. EUNIS 2012, Habitats Directive Annex I, the WFD, as well as Red List habitats (in the crosswalks-file).
- General descriptions of the abiotic descriptors and the biological communities in each of the L3 habitats for standing (lakes) and running (rivers) waters, including the effect of flow in rivers on the biology (runs, riffles and pools) (L4) (in the crosswalk xlsx-file).
- Identification of the characteristic (= diagnostic), common (= constant) taxa in biological communities of phytoplankton, aquatic vegetation, and fish, as well as dominant taxa for phytoplankton and fish in **reference** water bodies for each of the revised **L3 habitats for standing waters (lakes)** covered by the WISER database.
- Identification of the characteristic (diagnostic), common (constant) taxa in biological communities of phytoplankton, aquatic vegetation, and fish, as well as dominant taxa for phytoplankton and fish in **impacted** water bodies for each of the revised **L3 habitats for standing waters (lakes)** covered by the WISER database.
- Identification of the characteristic (diagnostic), common (constant) taxa in biological communities of benthic algae, aquatic vegetation, benthic invertebrates and fish, as well as dominant taxa for fish in **reference** water bodies for each of the revised **L3 habitats for running waters (rivers)** covered by the WISER database.
- Identification of the characteristic (diagnostic), common (constant) taxa in biological communities of benthic algae, aquatic vegetation, benthic invertebrates and fish, as well as dominant taxa for fish in **impacted** water bodies for each of the revised **L3 habitats for running waters (rivers)** covered by the WISER database.
- Descriptions of typical species occurring in biological communities of phytoplankton, aquatic vegetation and fish in each of the L3 habitat types for **standing waters** without data in the WISER database, using a **literature review**. Amphibians were also included for some of the most relevant habitats, e.g. ponds.
- Descriptions of typical species occurring in biological communities of benthic algae, aquatic vegetation, benthic invertebrates and fish in each of the L3 habitat types for **running waters** without data in the WISER database, using a **literature review**.
- There are regional differences within most of the L3 habitat types allowing to extend the EUNIS hierarchy by adding more specific units at subordinate levels for Nordic, Central and Mediterranean regions.

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 in the WISER database, a joint visual inspection of the cluster diagrams was done for the different biological communities presented in Chapter 0 for standing waters and Chapter 0 for running waters. This inspection revealed that all the level 3 habitat types with data in the WISER database showed a >30% dissimilarity compared to other habitat types for at least one BQE for either reference water bodies and/or impacted water bodies. This means that >30% of the characteristic and common taxa in each habitat are different from those found in the other L3 habitats for at least one of the major biological groups in either reference waters and/or impacted waters. The only potential exception was for lowland, calcareous rivers where the dissimilarity was <30% between the very small-small rivers and streams (P22) versus the medium-large rivers (P26) for all the BQEs with available data, except the aquatic vegetation, which had a slightly higher dissimilarity (ca. 45% in reference rivers and ca. 35% in impacted rivers). The merging of those two habitats is therefore open to discussion.

Based on this visual inspection, **the main conclusion concerning the validity of the L3 habitat types is 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 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 considerable 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 several biological communities in some running water habitat types. This 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 are uncertain due to unbalanced datasets with Central Europe dominating the data for running waters. The revised L3 habitats can still be useful within each region.

The habitat types P11-P1D for standing waters and P21-P2M for running waters can be subdivided at L4 into Northern, Central and Southern regions as shown in Chapter 7.
The standing water L3 habitats P1E-P1P and running water L3 habitats P2N-P2T can be further subdivided at L4 as presented in Chapter 6.

10 List of abbreviations

Abbreviation	Name	Reference
BQE	Biological quality element: • Phytoplankton • Phytobenthos (benthic algae) • Macrophytes (aquatic vegetation) • Macroinvertebrates (benthic invertebrates) • Fish	WFD, Annex V
BT	Broad Types, an aggregation of the most common surface water body types in Europe	As described in Lyche Solheim et al. (2019)
L1, L2, L3, L4	EUNIS habitat types Level 1, 2, 3 or 4	
EEA	European Environment Agency	https://www.eea.europa.eu/en
EUNIS	European Nature Information System	https://eunis.eea.europa.eu/
EVA	European Vegetation Archive	https://euroveg.org/eva-database/
EVS	European Vegetation Survey	https://euroveg.org/
WFD	Water Framework Directive	https://environment.ec.europa.eu/topics/water/water-framework-directive_en
WISER	Water Bodies in Europe Integrative Systems to Assess Ecological Status and Recovery	http://www.wiser.eu/

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Lakes literature review of rare EUNIS level 3 habitat types

P1A Highland, calcareous or mixed lakes:

Füreder, L., Ettinger, R., Boggero, A. et al. (2006). Macroinvertebrate Diversity in Alpine Lakes: Effects of Altitude and Catchment Properties. *Hydrobiologia* **562**, 123–144 (2006). https://doi.org/10.1007/s10750-005-1808-7.

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P1B Highland, humic lakes on calcareous or mixed bedrock

Füreder, L., Ettinger, R., Boggero, A. et al. (2006). Macroinvertebrate Diversity in Alpine Lakes: Effects of Altitude and Catchment Properties. *Hydrobiologia* **562**, 123–144. https://doi.org/10.1007/s10750-005-1808-7.

P1D Highland, humic lakes on siliceous bedrock

Direktoratsgruppen vanndirektivet, 2018. Veileder 2:2018 Klassifisering, Vedlegg.

P1E Temporary calcareous and P1F Temporary siliceous lakes:

Brönmark, C., Hansson, L.A., 2005. The Biology of Lakes and Ponds. 2nd Edition. Oxford University Press, ISBN 0–19–851612–6.

Celewicz, S., Goldyn, B. (2021). Phytoplankton communities in temporary ponds under different climate scenarios. Nature Scientific reports 11:17969. https://doi.org/10.1038/s41598-021-97516-9

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Zacharias, I., Dimitriou, E., Dekker, A., Dorsman, E., 2007. Overview of temporary ponds in the Mediterranean región: Threats, management and conservation issues. J. Env. Biol. 28: p. 1-9.

P1G Temporary and P1H Permanent saline and brackish lakes:

Camacho, A., Morant, D., Rochera, C., et al. (2024). Ecological status and type of alteration determine the C-balance and climate change mitigation capacity of Mediterranean inland brackish and saline shallow lakes, 11 March 2024, PREPRINT (Version 1) available at Research Square. https://doi.org/10.21203/rs.3.rs-4015836/v1

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Annex 1 EUNIS level 3 inland waters

Final level 3 standing waters, including descriptions, list of species and crosslinks

Table A1-1 The complete list of proposed EUNIS standing water habitat types

Level	Proposed new code	EUNIS name
1	*P*	*Inland surface waters*
2	*P1*	*Standing surface waters*
3	P11	Lowland, very shallow to shallow, calcareous or mixed lakes
3	P12	Lowland, shallow to deep, calcareous or mixed lakes
3	P13	Lowland, humic lakes on calcareous or mixed bedrock
3	P14	Lowland siliceous lakes
3	P15	Lowland, humic lakes on siliceous bedrock
3	P16	Mid-altitude, calcareous or mixed lakes
3	P17	Mid-altitude, humic lakes on calcareous or mixed bedrock
3	P18	Mid-altitude siliceous lakes
3	P19	Mid-altitude, humic lakes on siliceous bedrock
3	P1A	Highland, calcareous or mixed lakes
3	P1B	Highland, humic lakes on calcareous or mixed bedrock
3	P1C	Highland siliceous lakes
3	P1D	Highland, humic lakes on siliceous bedrock
3	P1E	Temporary calcareous lakes and marl/karst lakes, incl. turloughs
3	P1F	Temporary siliceous lakes, including humic lakes
3	P1G	Temporary saline and brackish lakes
3	P1H	Permanent saline and brackish lakes
3	P1J	Glacier fed lakes
3	P1K	Permanent marl/karst lakes
3	P1L	Volcanic lakes
3	P1M [a]	Very large lakes
3	P1N [b]	Permanent ponds and pools
3	P1P[b]	Temporary ponds and pools

Notes:

[a] For the description of the biological communities, P1M Very large lakes (surface area >100km^2) were distributed among the other EUNIS types. The only analysis that considered P1M Very large lakes as a separate EUNIS type, was the analysis of species richness.

[b] P1N Ponds and pools are defined as water bodies with a surface area of <2ha

Final level 3 running waters, including descriptions, list of species and crosslinks

Table A1-2 The complete list of proposed EUNIS running water habitat types

Level	Proposed new code	EUNIS name
1	*P*	*Inland surface waters*
2	*P2*	*Running surface waters*
3	P21	Lowland rivers and streams draining clay rich catchments
3	P22	Lowland, very small to small, calcareous or mixed rivers and streams
3	P23	Lowland, very small to small, humic rivers and streams on calcareous or mixed bedrock
3	P24	Lowland, very small to small, siliceous rivers and streams
3	P25	Lowland, very small to small, humic rivers and streams on siliceous bedrock
3	P26	Lowland, medium to large, calcareous or mixed rivers
3	P27	Lowland, medium to large, humic rivers on calcareous or mixed bedrock
3	P28	Lowland, medium to large, siliceous rivers
3	P29	Lowland, medium to large, humic rivers on siliceous bedrock
3	P2A	Mid-altitude, very small to small, calcareous or mixed rivers and streams
3	P2B	Mid-altitude, very small to small, humic rivers and streams on calcareous or mixed bedrock
3	P2C	Mid-altitude, very small to small, siliceous rivers and streams
3	P2D	Mid-altitude, very small to small, humic rivers and streams on siliceous bedrock
3	P2E	Mid-altitude, medium to large, calcareous or mixed rivers
3	P2F	Mid-altitude, medium to large, humic rivers on calcareous or mixed bedrock
3	P2G	Mid-altitude, medium to large, siliceous rivers
3	P2H	Mid-altitude, medium to large, humic rivers on siliceous bedrock
3	P2J	Highland, calcareous or mixed rivers and streams
3	P2K	Highland, humic rivers and streams on calcareous or mixed bedrock
3	P2L	Highland siliceous rivers and streams
3	P2M	Highland humic rivers and streams on siliceous bedrock
3	P2N	Springs
3	P2P	Temporary rivers and streams
3	P2Q	Tidal rivers and streams
3	P2R	Glacial rivers and streams
3	P2S [a]	Very large rivers
3	P2T	Inland saline rivers and streams

Notes: [a] for the description of the biological communities, P2S Very large rivers (catchment area >10 000km^2) were distributed among the other EUNIS types. There were not enough very large rivers in the WISER database (n=3), so it was not possible to do any separate analysis of species richness.

Annex 2 Nutrient thresholds used to selected good status lakes from WISER database

Table A2-1 Nutrient criteria used for selecting additional reference and good status lakes for describing species richness and composition of phytoplankton, aquatic vegetation and fish communities. The criteria are based on Cardoso et al. (2007) adjusted and supplemented by expert judgement by the main author of this report.

Altitude	Depth & stratification	Geology	Total phosphorus (mean)
Lowland	Very shallow, unstratified	Clear, calcareous or mixed	<40 µg/l
Lowland	Shallow to deep, stratified	Clear, calcareous or mixed	<20 µg/l
Lowland	Any depth, mainly stratified	Humic, calcareous or mixed	<50 µg/l (phytoplankton); <40 µg/l (macrophytes & fish)
Lowland	Any depth, mainly stratified	Clear, siliceous	<13 µg/l
Lowland	Any depth, mainly stratified	Humic, siliceous	<27 µg/l
Mid-altitude	Any depth, mainly stratified	Clear, siliceous	<10 µg/l
Mid-altitude	Any depth, mainly stratified	Clear, calcareous or mixed	<20µg/l
Mid-altitude	Any depth, mainly stratified	Humic, calcareous or mixed	<50 µg/l (phytoplankton); <40 µg/l (macrophytes & fish)
Mid-altitude	Any depth, mainly stratified	Humic, siliceous	<20 µg/l
Highland	Any depth, mainly stratified	Clear, siliceous	<10 µg/l

Annex 3 WISER data owners

The data owners listed below have either accepted or not rejected use of their data:

Austria: Bundesministerium Land- und Forstwirtschaft, Regionen und Wasserwirtschaft & Universität für Bodenkultur Wien (BOKU)

Belgium: INBO Research Institute for Nature and Forest

Cyprus: Water Development Department

Czech Republic: Ministry of the Environment of the Czech Republic

Denmark: Danish Environmental Protection Agency & University of Aarhus- DCE - Danish Centre for Environment and Energy

Estonia: Estonian Environment Agency & Estonian University of Life Sciences

Finland: Finnish Environment Institute (SYKE) & Helsinki University

France: l'Office Français de la Biodiversité & France's National Research Institute for Agriculture, Food and Environment (INRAE)

Germany: University of Duisburg-Essen & the federal state administrations:

- Bayerisches Landesamt für Umwelt
- BB, Landesamt für Umwelt, Gesundheit und Verbraucherschutz Brandenburg (LUGV; 127),
- MV, Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz Mecklenburg-Vorpommern (MLUV, Seenprogramm, 65),
- LANUV NRW, FB 55: Ökologie der Oberflächengewässer& Landesamt für Natur, Umwelt und Verbraucherschutz NRW
- SA, Landesbetrieb für Hochwasserschutz und Wasserwirtschaft Sachsen-Anhalt (LHW, 5),
- Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie,
- SH, Landesamt für Landwirtschaft, Umwelt und ländliche Räume Schleswig–Holstein (LLUR, 13),
- BE, Senatsverwaltung für Gesundheit, Soziales und Verbraucherschutz Berlin (SenGUV, 12),
- NL, Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (NLWKN, Sulingen, 1)

Hungary: National Directorate General for Water Management & Vituki Consult

Ireland: Environment Protection Agency & Trinity College Dublin

Italy: CNR-IRSA (Water Research institute)

Latvia: Latvian Environment, Geology and Meteorology Centre

Lithuania: Environmental Protection Agency

Netherlands: Rijkswaterstaat Water, Traffic and Living Environment & Wageningen University and Research

Norway: National Environment Agency & Norwegian Institute for Water Research (NIVA) and Norwegian Institute for Nature Research (NINA)

Poland: Chief Inspectorate of Environmental Protection & The Institute of Environmental Protection – National Research Institute

Portugal: Portuguese Environment Agency (APA), Sistema Nacional de Informacao de Recursos hídricos INAG (Instituto da Agua) & University of Lisbon

Romania: National Administration Romanian Waters

Slovakia: Ministry of the Environment of the Slovak Republic & the Water Research Institute

Spain: Ministry for the Ecological Transition and the Demographic Challenge (MITECO)

Sweden: Havs- och Vattenmyndigheten & Swedish Agricultural University (SLU)

United Kingdom: Environment Agency for England and Wales, Environment Agency for Scotland & UK Centre for Ecology and Hydrology (CEH)

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