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A new broad typology for rivers and lakes in Europe: Development and application for large-scale environmental assessments

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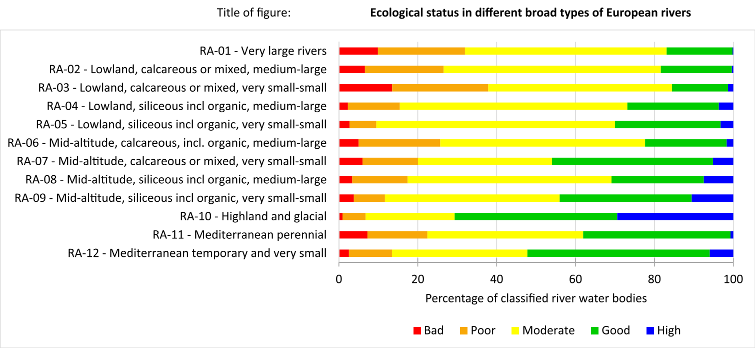
HIGHLIGHTS

- A large number of national types prevent cross country comparison of rivers and lakes.
- Data on type descriptors was compiled to allow similarity analysis of national types.
- Clusters of similar national types provided 20 broad river types and 15 broad lake types.
- The ecological status is best in highland types and worst in lowland calcareous types.
- Broad types facilitate nutrient targets comparison and revision of EUNIS freshwater habitats.

GRAPHICAL ABSTRACT



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ABSTRACT

European countries have defined >1000 national river types and >400 national lake types to implement the EU Water Framework Directive (WFD). In addition, common river and lake types have been defined within regions of Europe for intercalibrating the national classification systems for ecological status of water bodies. However, only a low proportion of national types correspond to these common intercalibration types. This causes uncertainty concerning whether the classification of ecological status is consistent across countries. Therefore, through an extensive dialogue with and data provision from all EU countries, we have developed a generic typology for European rivers and lakes. This new broad typology reflects the natural variability in the most commonly used environmental type descriptors: altitude, size and geology, as well as mean depth for lakes. These broad types capture 60–70% of all national WFD types including almost 80% of all European river and lake water bodies in almost all EU countries and can also be linked to all the common intercalibration types. The typology provides a new framework for large-scale assessments across country borders, as demonstrated with an assessment of ecological status and pressures based on European data from the 2nd set of river basin management plans. The typology can also be used for a variety of other large-scale assessments, such as reviewing and linking the water body types to habitat types under the Habitats Directive and the European Nature Information System (EUNIS), as well as comparing type-specific limit values for nutrients and other supporting quality elements

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across countries. Thus, the broad typology can build the basis for all scientific outputs of managerial relevance related to water body types.

1. Introduction

The typology of lakes and rivers emerged as a highly relevant concept in limnology/freshwater ecology many decades ago (Thienemann, 1925; Naumann, 1932; Strahler, 1952). Despite rivers being open and continuous systems with high temporal and spatial variability, river ecologists early on postulated the concept of isolated sections predictably distributed along the longitudinal dimension of a river. Illies and Botosaneanu (1963) distinguished between river typologies addressing whole watercourses (i.e. similar to lake typologies), individual river sections or (meso-)habitat types, hence already anticipating the hierarchical notion of river systems in modern fluvio-morphological accounts (e.g. Thorp et al., 2006; Gurnell et al., 2016). With the aim of enhancing system understanding and river management, abiotic and biotic section typologies became common sense in the middle of last century (e.g. Huet, 1954; Harrison and Agnew, 1962), while recognising the challenge of scale in defining distinct section borders in continuous systems (Hawkes, 1975). Main confluences were regarded as nodal points, accounting for sudden transitions in the continuously changing environmental factors (Illies and Botosaneanu, 1963).

A water body type can be defined as a group of lakes or rivers having common natural ecological conditions in terms of geo-morphological, hydrological, physico-chemical, and biological characteristics. A type can therefore be considered as a homogenous entity with limited natural environmental variability, allowing the definition of a baseline, from which human-induced impact can be detected (Thorp et al., 2006).

This is why the current legislation for water management in Europe, the Water Framework Directive (WFD) (European Commission, 2000), requires EU Member States to develop typologies for lakes and rivers based on a set of environmental variables or type descriptors with either predefined or more freely defined ranges for each descriptor (WFD Annex II, System A or B respectively). The type descriptors should be permanent characteristics and not respond to human activities. They should represent the fixed abiotic conditions, e.g. altitude, size, basin geology, which are most important to explain the natural variability of the biological components (BQEs = Biological Quality Elements), and supporting abiotic components, e.g. nutrients, transparency, oxygen, flow, structure of the riparian zone. National water body types can be, for example: small lowland calcareous rivers; large mid-altitude siliceous rivers; large and deep mid-altitude siliceous lakes; small and shallow lowland humic lakes. When the national types have been identified, they are used to describe the type-specific natural biological communities for each BQE (phytoplankton, phytobenthos, benthic fauna and fish), as well as natural ranges of physico-chemical and hydromorphological parameters. These natural conditions are termed reference conditions, defined as displaying no or only very minor anthropogenic alterations from totally or nearly totally undisturbed conditions (WFD Annex V).

Human impact on the ecological status of rivers and lakes is assessed as deviations from the type-specific reference conditions for each individual water body (defined as a lake or a river reach with homogenous conditions in terms of type, status and human pressures). The level of deviations is quantified by setting limit values for the different biological and supporting quality elements, representing high, good, moderate, poor or bad ecological status. To harmonize the national classification systems for ecological status, these national limit values (i.e. class boundaries sensu WFD, Annex V) have been compared and adjusted through the intercalibration process, in which countries in different regions of Europe (Alpine, Central-Baltic, Eastern Continental, Mediterranean and Northern) collaborated to identify common types that should represent one or more of their national types (Birk et al., 2013; Poikane et al., 2014). These common intercalibration (IC) types, their corresponding national types and the intercalibrated class boundaries for the different metrics used to classify ecological status for each BQE are given in European Commission (2018) with details in the Intercalibration Technical Reports (e.g. Lyche Solheim et al., 2014; Phillips et al., 2014; Poikane et al., 2015) (all reports available at https://circabc.europa.eu/w/browse/a4c946c8-4c34-4ab0-ae76-8e0f274e7da9).

Although these achievements of the WFD provide a good basis for assessing ecological status of individual rivers and lakes in Europe, there are still several shortcomings. One problem is that many of the >1000 national river types and >400 national lake types that have been defined (e.g. Buraschi et al., 2005; Cheshmedjiev et al., 2010; Dodkins et al., 2005; Drakare, 2014; Free et al., 2006; Kolada et al., 2005; Mathes et al., 2005; Munné and Prat, 2004; Nykänen et al., 2005) do not correspond directly to any IC type (Lyche Solheim et al., 2012 and 2015): 70% of the national types for both rivers and lakes were not linked to any IC type in the first river basin management planning (RBMP) cycle (2010–2015). The situation improved in the 2nd RBMPs reported in 2016 and 2017 to WISE (Water Information System for Europe: https://water.europa.eu/) (WISE-WFD database, https://www.eea.europa.eu/data-and-maps/data/wise-wfd-2, schema: *SWB_surfacewaterbody*), but still 42% of national river types and 56% of national lake types did not correspond to any IC type. Another problem is that many national types overlap with several IC types (European Commission, 2019).

The translation of results from the intercalibration exercise from IC types to the national types is therefore not straightforward. These issues raised questions at EU level as to whether the ecological status can be compared across countries, even within the same region of Europe, as well as how differences in ecological status should be interpreted (EEA, 2018; European Commission, 2019; Reyjol et al., 2014). Thus, a need to identify a new typology emerged, aiming at linking national water body types with high similarity to a few broad European types, which can be used to aggregate and compare information on ecological status and pressures across countries. Moreover, the broad types should also be identified in a way that allows a link to the European freshwater habitat types given in the Habitats Directive (European Council, 1992) and provide a basis for the revision of the inland water habitats of the European Nature Information System (EUNIS, https://eunis.eea.europa.eu/about) (e.g. Evans et al., 2016), thereby contributing to a better basis for further European environmental policy development and assessment.

Large-scale assessments based on international datasets covering long gradients in environmental variables and ecological response indicators are often needed to reveal response patterns and identify potential thresholds or tipping points that can be used to improve water management. European water and nature directives and policies also require large-scale assessments of status and pressures based on data and information reported by EU Member States (e.g. EEA, 2018). Broad types can be useful for such large-scale assessments, as well as for ecological research on impacts of multiple pressures on rivers and lakes, because broad types offer a way to aggregate data that are more comparable across countries.

However, creating a functional typology on a broad scale is indeed challenging, due to the high natural variability of river flow, substrate and shape of the river channel, which affect river biota and river functions (Gurnell et al., 2016). Therefore, other abiotic factors with less variability, such as altitude, catchment size and geology (geochemistry), which are also important to explain the natural variability of rivers and lakes, could be more suitable for the development of a broad typology for European freshwater ecosystems.

The objective of this paper is to describe the development of this broad typology, how the broad types can be linked to the IC types and to give examples on how they can be applied in European assessments of ecological status and pressures and other large-scale spatial assessments.

2. Methods

2.1. General procedure

The process applied to devise the broad types was based on communication with different actors at European and national level following a step-wise procedure. The process started with a request from the European Parliament in 2012 to explore whether broader types of water bodies could be developed and used to facilitate comparison of the status and pressure information reported by the EU Member States with their 1st RBMPs. The objective of that investigation was to assess similarities between national types across countries based on the type descriptors and ranges of the different descriptors used by countries in their national typologies. Due to incomplete results from this first analysis (Lyche Solheim et al., 2012), the work was continued by the European Environment Agency (EEA) and its topic center for inland, coastal and marine water (ETC-ICM) in dialogue with the working group ECOSTAT under the WFD Common Implementation Strategy (CIS) during the years 2013–2014 (Lyche Solheim et al., 2015).

To devise the broad types, we first applied statistical analysis of the national typology descriptors using similarity analysis (Supplementary Material, Figs. S1 and S2), and then adjusted the outputs based on ecological considerations and feedback from the EU countries. A fine-tuning was finally done based on the number of countries, water bodies and national types included in each of the broad types to reduce the number of broad types in order to be more applicable for European-level assessments of status and pressures. The steps to develop the broad types, linking them to the IC types and applying them in European assessments are further detailed below.

2.2. Development of the broad typology

Step 1 was to request national typology data from the EU Member States (and Norway), including all type descriptors (typology descriptors) and numeric ranges of each descriptor for each national type of rivers and lakes.

Step 2 was to compile the replies, providing a dataset with typology data from all the EU Member States and Norway (29 countries), including >100,000 water bodies (Table 1). The overview of the national types for rivers and lakes showed a large variation between countries in terms of the number of national types and typology descriptors used to define them (European Commission, 2019). The variation ranged from 1 to 367 river types with a median of 25 types per country, and from 2 to 75 lake types with a median of 13 types per country. The number of typology descriptors was updated and completed with information provided in bilateral communication with each country in 2013 and 2014. The number of type descriptors ranged from 2 to 16 for river types with a median of 6, and from 2 to 22 for lake types with a median of 7.

Step 3 was to identify the type descriptors used by most countries as a basis for further similarity analysis. These were altitude, size and geology for both river types and lake types, and mean depth for lakes (Supplementary Material, Tables S1 and S2). Size was defined as catchment area for rivers and surface area for lakes. For most of Europe, the most commonly used typology descriptors were used to define the broad types. The ranges for each type descriptor mainly follow the WFD Annex II, System A, but is also reflecting most of the common types used for intercalibration. Since geology is described only qualitatively (as geochemical categories: siliceous, calcareous or organic), including both bedrock and soil, we added more quantitative descriptors of water chemistry reflecting the geology, such as alkalinity (alternatively, concentration of calcium) and colour (concentration of humic substances). The Mediterranean region was separated from the rest of Europe to account for the much warmer climate in that region. River flow was only used for Mediterranean rivers, as they often dry out during summer. The type descriptors and ranges used to define the broad types are given in Table 2.

Step 4 was to perform a cluster analysis to assess the similarity of national types. For this analysis, we used all national types with numerical values for the most commonly used type descriptors, as defined in Step 3. All analyses were performed in the programming software R (version 2.15.1; R Core Development Team, 2012) calculating the pairwise Euclidian distances between each combination of national types. The dendrograms are given in the Supplementary Material (Figs. S1 and S2). The clusters provided the first set of broad types.

Step 5 was to present and discuss the first set of broad types with the countries in an iterative process during 2013 and 2014, adjusting/

Table 1
National types metadata overview including number of types, water bodies and type descriptors. Country abbreviations follow the ISO-codes: https://www.iso.org/obp/ui/. 'n.a.' means not available. Data source: number of types and number of water bodies: WISE (Water Information System for Europe) 2018 database, July 2018: https://www.eea.europa.eu/data-and-maps/data/wise-wfd-2 . For type descriptors, see Step 2 in main text.

Country	# River types	# River water bodies	# Type descriptors for river types	# Lake types	# Lake water bodies	# Type descriptors for lake types
AT	49	8065	8	14	62	22
BE[a]	58	527	3	8	18	5
BG	14	873	10	10	37	9
CY	4	174	2	3	8	2
CZ	34	1044	6	1	77	n.a.
DE	40	8998	3	16	730	9
DK	6	7776	3	12	856	4
EE	7	645	2	8	89	6
EL[b]	24	1158	4	11	52	9
ES	48	4390	9	36	326	8
FI	19	1913	5	15	4617	8
FR	145	10,706	8	34	435	15
HR	28	1484	n.a.	15	37	n.a.
HU	19	963	6	8	115	4
IE[b]	14	4566	3	14	238	4
IT	367	7493	8	29	347	7
LT[b]	5	832	5	3	345	5
LU[a]	7	110	16	–	–	–
LV	6	203	2	10	259	4
MT	1	3	n.a.	1	2	n.a.
NL	12	246	7	18	451	8
NO[c]	29	–	7	30	–	8
PL	25	4586	7	13	1044	4
PT	21	1899	9	4	23	13
RO	54	2891	11	22	130	5
SE	52	15,092	6	77	7422	7
SI	53	137	3	10	12	6
SK[a]	38	1510	5	–	–	–
UK	68	7506	4	41	1068	5
Total	1247	95,790	23	463	18,800	21
Mean[d]	25	3421	6	13	723	7
Sub-total[e]	1175	89,234	23	405	18,165	21

[a] Belgium (BE): Rivers only from Wallonia, lakes only from Flanders; Luxembourg (LU) and Slovakia (SK) have no lakes.

[b] Countries with no available data for the 2nd RBMPs in WISE by July 2018. Data shown are from replies to the ECOSTAT questionnaire 2013 on type descriptors.

[c] Source: Norwegian classification guidance 2018 (no WISE data available by July 2018).

[d] Mean for number of water bodies and type descriptors, median for number of types.

[e] Sub-total excluding countries with no data available in WISE for the 2nd RBMPs by July 2018: Greece (EL), Ireland (IE), Lithuania (LT), Norway (NO).

Table 2
Typology descriptors, categories and codes.

Both Rivers and Lakes

Type descriptor	Categories	Range (m.a.s.l.)
Altitude	lowland	< 200
	mid-altitude	200-800
	highland	> 800

Both Rivers and Lakes

Type descriptor	Categories
Region	Mediterranean rest of Europe

Both Rivers and Lakes

Type descriptor	Categories	Alkalinity	Calcium	Colour	Bedrock or deposits
Geology	siliceous	< 1 mEq/L	< 20 mg/L	< 30 mg Pt/L	crystalline, granite, gneiss
	calcareous	> 1 mEq/L	> 20 mg/L	< 30 mg Pt/L	sedimentary, calcite, carbonaceous
	organic /humic	any	any	> 30 mg Pt/L	peat (inflow of allochtonous organic matter)
	mixed	any	any	any	any mix of siliceous and calcareous

Rivers only

Type descriptor	Categories	Range
Catchment size	very small-small	< 100 km^2
	medium-large	100-10 000 km^2
	very large	>10000 km^2

Rivers only

Type descriptor	Categories
Flow	perennial temporary/intermittent

Lakes only

Type descriptor	Categories	Range
Surface area	very small	< 0,5 km^2
	small-large	0,5-100 km^2
	very large	>100 km^2

Lakes only

Type descriptor	Categories	Range	Stratification	Mixing
Mean depth	very shallow	< 3 m	non-stratified	polymictic
	shallow and deep	> 3 m	stratified	dimictic

correcting and expanding the broad types to obtain a better match to the national types in each country based on the following agreements:

a) Mediterranean types were separated from the rest of Europe due to a warmer and drier climate. For this region, the major type descriptors used by most countries were altitude, size and flow (perennial or temporary/intermittent) for rivers and size and geology for lakes. Ideally, the Mediterranean region could have been distinguished based on flow data from all rivers, but the dataset used did not include quantitative river flow data. Therefore, the distinction was based on categorical information on the basic flow character (perennial or temporary/intermittent), which was provided by the countries for their national types. Mediterranean highland rivers and lakes were merged with other highland river types from the rest of Europe, using a higher altitude limit than in the rest of Europe to distinguish the mid-altitude from the highland altitude types (e.g. 1500 m.a.s.l. rather than 800 m.a.s.l.).
b) Heavily modified and artificial water bodies were usually not distinguished as separate types but are integrated with natural water bodies having comparable type descriptors and ranges for each descriptor. Reservoirs reported as rivers due to their origin were assigned to the equivalent lake types, because their flora and fauna are generally more comparable to lakes than to rivers and are mainly classified using lake biological indicators.
c) In some cases, the numeric intervals given by a country for a type descriptor used to describe their national types deviated from the WFD Annex 2, System A intervals. In such cases, a national type was nevertheless linked to a broad type if the intervals for the major type descriptors were predominantly within the intervals given for the same typology descriptors in Table 2. On the contrary, national types were excluded from further analysis if the interval for one or more type descriptors was overlapping several of the intervals given for those descriptors in Table 2, e.g. if the altitude was spanning 0–2500 m.a.s.l.
d) A final set of broad types with links to the national types was agreed with all of the countries in late autumn 2014 (see Annexes 2 and 3 in Lyche Solheim et al., 2015). Denmark, Spain and Malta had no national river types that could be linked to the broad types, because their national typologies were missing one or more of the major type descriptors used to describe the broad types. The same was true for national lake types from Spain and Malta.

Step 6: The links between the national types and the broad types were updated in autumn 2018 due to changes in national types reported by many countries with the 2nd RBMPs. Greece, Ireland, Lithuania and Norway were not included in the analysis because their data were not available in WISE.

Step 7: To illustrate the geographical distribution of the broad types on a map, we used the location of water bodies reported by the countries to the WISE-WFD database, showing those that belong to a national type that has been linked to one of the broad types. This is called **the bottom-up approach**.

Step 8: We attempted to align the broad types with the IC types to evaluate whether the broad types can cover most of the intercalibration types and whether some broad types are not linked to any intercalibration type, or vice versa. Such cases could indicate gaps in either of the two sets of European types and/or comparability problems in the classification systems for ecological status classification.

The type descriptors used for the IC types were based on the abiotic characteristics of the water bodies and their environment (e.g. Bennett et al., 2011; European Commission, 2018) and were in many cases the same as those used to develop the broad types, i.e. altitude, size and geology.

2.3. Adjustment of the broad typology for specific assessments

To facilitate communication of European type-specific assessment of ecological status and pressures, some of the broad types were further aggregated as described in Steps 9–11.

Step 9: The aggregation of broad types was primarily done by merging individual broad types covering very few water bodies, national types and/or countries with another broad type covering many water bodies, national types and countries if at least two of the type descriptors were the same. All highland types were merged within each water category (rivers or lakes), because altitude was considered more important than size and geology to explain the natural variability of flora and fauna in rivers and lakes in mountain areas. Furthermore, rivers and lakes in the highland areas of Europe are exposed to less human pressures than those in the more densely populated and intensively cultivated lowland areas, which could suggest aggregation of highland types for pragmatic assessments of status and pressures. For Mediterranean rivers, we assume that perennial or temporary/intermittent flow is a more important descriptor to explain variability in reference communities than altitude, suggesting a potential to merge lowland and mid-altitude rivers in this region. The broad humic river types were split according to size and each sub-type was merged with other broad types having the same size range, altitude and basic geology (calcareous or siliceous), based on the assumption that humic substances are less important than the other major type descriptors in rivers.

Step 10: We applied the aggregated broad types from Step 9 to aggregate data on ecological status and main pressures in approximately 65,000 river water bodies and 14,000 lake water bodies that could be linked to the aggregated broad types. The data source used for this application of the broad types was the WISE (Water Information System for Europe) database 2018, which contains all the data on WFD ecological status and pressures reported by the countries with the 2nd RBMPs before July 2018 (which did not hold any data from Norway, Ireland, Lithuania and Greece).

Step 11: We also applied the aggregated broad types from Step 9 to show their geographical distribution in all of Europe by combining available GIS data on altitude, size and geology with the MARS geodatabase (Globevnik et al., 2017) at a scale of functional elementary catchments (FECs), with a mean spatial extent of 62 km^2. This is called the **top-down approach** and allowed us to include rivers and lakes from countries that had not reported their data to WISE, e.g. EFTA countries (see Supplementary Material for more details).

Table 3

Broad river typology descriptors and intervals, number of countries, national types and number and % of water bodies (WBs) linked to each broad type, based on data reported to WISE with the 2nd RBMPs (https://www.eea.europa.eu/data-and-maps/data/wise-wfd-2).

Broad type code	Broad type name	Altitude (m.a.s.l.)	Catchment area (km^2)	Geology	# Countries	# National types	# WBs	% WBs[a]
R-01	Very large rivers	Any	>10,000	Any (usually mixed)	15	48	487	0,6%
R-02	Lowland, siliceous, medium-large	<200	100–10,000	Siliceous	6	16	1149	1,3%
R-03	Lowland, siliceous, very small-small	<200	<100	Siliceous	8	19	5147	6,0%
R-04	Lowland, calcareous or mixed, medium-large	<200	100–10,000	Calcareous/mixed	19	90	3432	4,0%
R-05	Lowland, calcareous or mixed, very small-small	<200	<100	Calcareous/mixed	17	41	11,126	13,0%
R-06a	Lowland, organic and siliceous, very small-small	<200	<100	Organic and siliceous	4	9	4211	4,9%
R-06b	Lowland, organic and siliceous, medium-large	<200	100–10,000	Organic and Siliceous	3	7	2034	2,4%
R-07	Lowland, organic and calcareous/mixed	<200	<10,000	Organic and calcareous/mixed	1	8	354	0,4%
R-08	Mid-altitude, siliceous, medium-large	200–800	100–10,000	Siliceous	11	30	2945	3,4%
R-09	Mid-altitude, siliceous, very small-small	200–800	<100	Siliceous	11	25	8383	9,8%
R-10	Mid-altitude, calcareous or mixed, medium-large	200–800	100–10,000	Calcareous/mixed	13	81	2707	3,2%
R-11	Mid-altitude, calcareous or mixed, very small-small	200–800	<100	Calcareous/mixed	14	72	7568	8,9%
R-12a	Mid-altitude, organic and siliceous, very small-small	200–800	<100	Organic and siliceous	3	4	2371	2,8%
R-12b	Mid-altitude, organic and siliceous, medium-large	200–800	100–10,000	Organic and siliceous	2	3	752	0,9%
R-13	Mid-altitude, organic and calcareous/mixed	200–800	<10,000	Organic and calcareous/mixed	3	6	154	0,2%
R-14	Highland (all Europe), siliceous, incl. organic (humic)	>800	<10,000	Siliceous	7	10	1730	2,0%
R-15	Highland (all Europe), calcareous/mixed	>800	<10,000	Calcareous/mixed	9	18	2223	2,6%
R-16	Glacial rivers (all Europe)	> 200	<10,000	Any	3	16	3692	4,3%
R-17	Mediterranean, lowland, medium-Large, perennial	<200	100–10,000	Any	5	13	502	0,6%
R-18	Mediterranean, mid altitude, medium-large, perennial	200–800	100–10,000	Any	3	8	240	0,3%
R-19	Mediterranean, very small-small, perennial	< 800	<100	Any	4	19	1886	2,2%
R-20	Mediterranean, temporary/intermittent streams	any	<1000	Any	5	29	2747	3,2%
R-00	Not assigned[b]				18	280	19,660	23,0%
Total[c]					25	852	85,500	100%
Total assigned to a broad type[d]					22	572	65,840	77%

[a] "% of WBs" is % of WBs in all member states included in the analysis of national WFD types. No information available from Greece (EL), Ireland (IE), Lithuania (LT), Norway (NO) in time for analysis.

[b] "Not assigned" is the number of countries, national types and water bodies that could not be assigned to any broad type (but most of those countries also had one or more national types and water bodies that could be assigned to the broad types).

[c] "Total" is the total number of countries, national types and water bodies that have been included in the analyses.

[d] "Total assigned to a broad type" is the number of countries which have one or more national types (and water bodies) that could be assigned to the broad types. The difference of three countries between the "Total" and "Total assigned to a broad type" are the countries with '0' in the Supplementary Material Tables S3 and S4, see columns "Total # WBs assigned to a broad type" and "Proportion of WBs assigned to a broad type" in those tables.

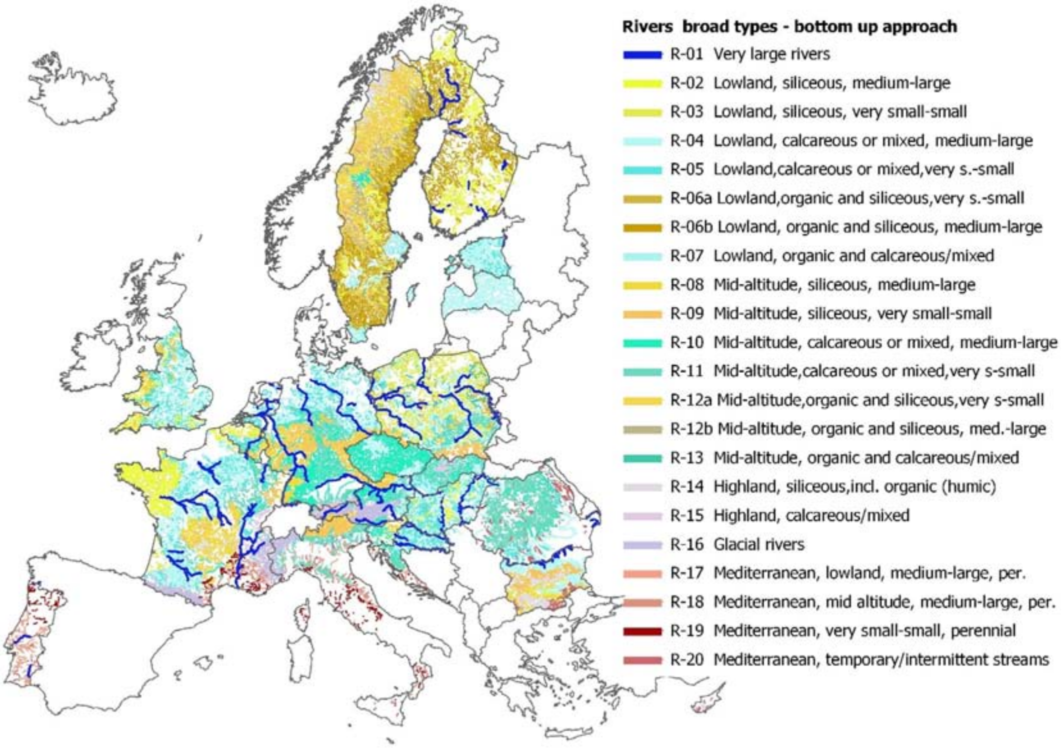

Fig. 1. Geographical distribution of river segments (=water bodies) assigned to different broad river types ("bottom-up approach") (see Table 3 for further description of the broad types).

Table 4
Broad lake typology descriptors and ranges, number of countries, national types and number and % of water bodies (WBs), based on data reported to WISE with the 2nd RBMPs: https://www.eea.europa.eu/data-and-maps/data/wise-wfd-2.

Broad type code	Broad type name	Altitude (m.a.s.l.)	Lake area (km^2)	Geology	Mean depth (m)	Stratification	# Countries	# National types	# WBs[a]	% WBs
L-01	Very large lakes, shallow or deep and stratified (all Europe)[b]	Any	>100	Any	>3	Stratified	6	8	144	0,8%
L-02	Lowland, siliceous	<200	<100	Siliceous	>3	Stratified	7	27	2126	11,6%
L-03	Lowland, calcareous/mixed, stratified	<200	<100	Calcareous/mixed	>3	Stratified	12	38	1677	9,1%
L-04	Lowland, calcareous/mixed, very shallow/unstratified	<200	<100	Calcareous/mixed	≤3	Unstratified	14	36	1621	8,8%
L-05	Lowland organic (humic) and siliceous	<200	<100	Organic and siliceous	> 3	Stratified	5	22	2992	16,3%
L-06	Lowland organic (humic) and calcareous/mixed	<200	<100	Organic and calcareous/mixed	>3	Stratified	6	10	97	0,5%
L-07	Mid-altitude, siliceous	200–800	<100	Siliceous	>3	Stratified	8	18	2705	14,8%
L-08	Mid-altitude, calcareous/mixed	200–800	<100	Calcareous/mixed	>3	Stratified	12	30	383	2,1%
L-09	Mid-altitude, organic (humic) and siliceous	200–800	<100	Organic and siliceous	>3	Stratified	2	7	1389	7,6%
L-10	Mid-altitude, organic (humic) and calcareous/mixed	200–800	<100	Organic and calcareous/mixed	>3	Stratified	1	3	23	0,1%
L-11	Highland, siliceous (all Europe), incl. organic (humic)	>800	<100	Siliceous	>3	Stratified	6	13	742	4,0%
L-12	Highland, calcareous/mixed (all Europe), incl. organic (humic)	>800	<100	Calcareous/mixed	>3	Stratified	3	7	45	0,2%
L-13	Mediterranean, small-large, siliceous	<800	0.5–100	Siliceous	Any	Any	2	4	151	0,8%
L-14	Mediterranean, small-large, calcareous/mixed	<800	0.5–100	Calcareous/mixed	Any	Any	3	9	141	0,8%
L-15	Mediterranean, very small	<800	<0.5	Any	<15	Any	0	0	0	0,0%
L-00	Not assigned[c]						20	153	4101	22,4%
Total[d]							23	385	18,337	100%
Total assigned to a broad type[e]							20	232	14,236	78%

[a] "% of WBs" is % of WBs in all Member States included in the analysis of national WFD types. No information available from Greece (EL), Ireland (IE), Lithuania (LT), Norway (NO) in time for analysis.

[b] Many large lakes are reported as multiple smaller water bodies, and thus do not appear as large lakes in this overview.

[c] "Not assigned" is the number of countries, national types and water bodies that could not be assigned to any broad type (but most of those countries also had one or more national types and water bodies that could be assigned to the broad types).

[d] "Total" is the total number of countries, national types and water bodies that have been included in the analyses.

[e] "Total assigned to a broad type" is the number of countries which have one or more national types (and water bodies) that could be assigned to the broad types. The difference of three countries between the "Total" and "Total assigned to a broad type" are the countries with '0' in the Supplementary Material Tables S3 and S4, see columns "Total # WBs assigned to a broad type" and "Proportion of WBs assigned to a broad type" in those tables.

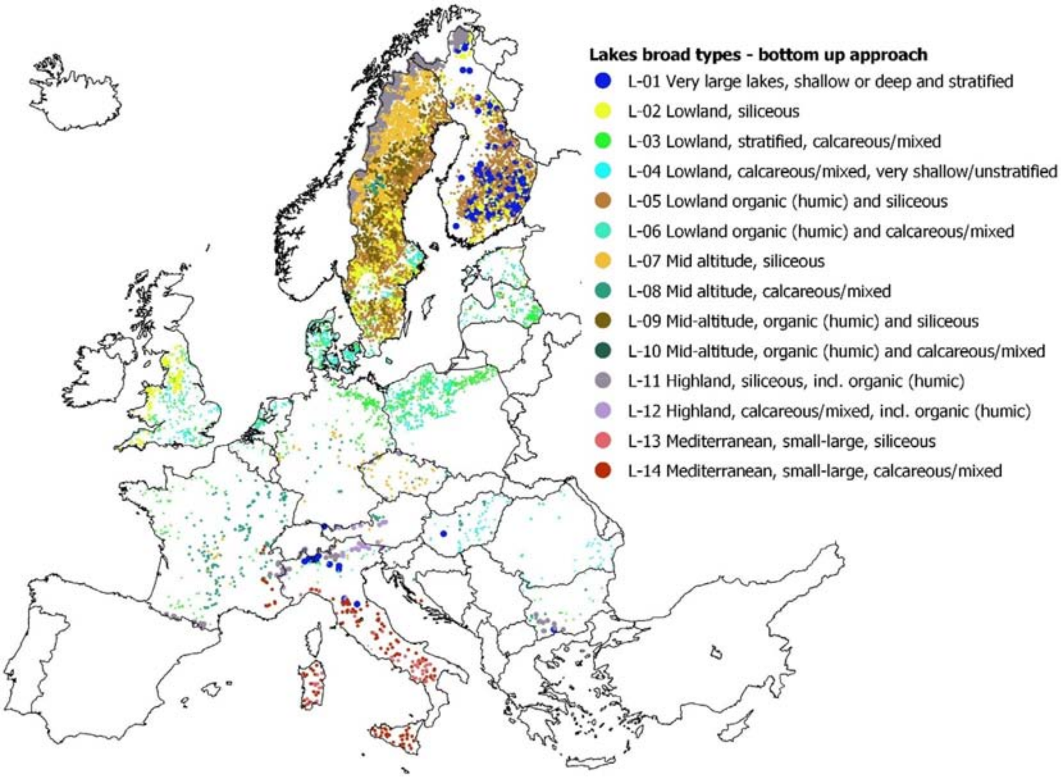

Fig. 2. Geographical distribution of lakes (=water bodies) assigned to different broad types ("bottom-up approach") (see Table 4 for further description of the broad types.)

3. Results

3.1. Broad river types and links to national WFD river types

Steps 1–5 of the typology development resulted in 20 broad river types (R-XX) two of which being divided into sub-types based on size (R-06a and 06b, and R-12a and 12b) (Table 3). Altogether 572 national river types from 22 countries could be linked to one of the 20 broad types, comprising 67% of all national types and 77% of all river water bodies in the countries that could be included in the analysis.

The three broad types having the most water bodies were the lowland, calcareous or mixed, very small-to-small rivers (R-05), the mid-altitude siliceous, very small-to-small rivers (R-09) and the mid-altitude, calcareous or mixed, very small-to-small rivers (R-11).

The overview of river water bodies assigned to the broad river types for each country (Supplementary Material, Table S3) illustrates that most of the broad types comprised water bodies from many countries and/or had a high total number of water bodies, e.g. R-01, 03, 04, 05, 06, 08, 09, 10, 11, while some broad types comprised few countries and/or few water bodies, e.g. the river types with organic and calcareous geology, e.g. R-07 and R-13, and larger, perennial Mediterranean rivers, e.g. R-17 and R-18 (see also Annexes 2a and 3a in Lyche Solheim et al., 2015, including notes with special issues for some countries in Annex 3a). The countries with the highest number of water bodies linked to broad types were Austria, Germany, France, Italy, Poland, Sweden and the UK.

The geographic distribution of the 20 broad river types is shown in Fig. 1. The map clearly shows the location of the large rivers, as well as the different geological (geochemical) types within the lowland and mid-altitude areas of most of Europe, where siliceous and organic (humic) rivers dominate in Sweden and Finland, while calcareous rivers are found over large parts of Central Europe and in the Baltic countries. The highland types are in the mountain areas of Europe (Alps, Pyrenees, North-Western Sweden, but also Slovakia), while the Mediterranean river types are of course mainly found in the Mediterranean countries, but also in parts of Romania and Bulgaria.

3.2. Broad lake types and links to national WFD lake types

The broad lake typology emerging from the Steps 1–5 described above resulted in 15 broad lake types (L-XX) (Table 4). Altogether 232 national lake types from 22 countries could be linked to one of the 15 broad types, comprising 60% of all national lake types and 78% of all lake water bodies in the countries that could be included in the analysis (including also 256 reservoirs reported as rivers). The total number of national lake types given in Table 4 is lower than that given in Table 1 above due to excluding countries with national lake types missing one or more of the core typology descriptors (altitude, size, geology, mean depth) (Spain and Malta), as well as countries with no available data reported to WISE with the 2nd RBMPs by July 2018 (Greece, Ireland, Lithuania and Norway). The three broad lake types having most water bodies were the lowland, siliceous lakes (L-02), the mid-altitude siliceous lakes (L-07) and the lowland organic and siliceous lakes (L-05).

The overview of lake water bodies assigned to the broad lake types for each country (Supplementary Material, Table S4) illustrates that most of the broad lake types comprised water bodies from many countries and/or had a high total number of water bodies, e.g. L-02, 03, 04, 05, 07, 09, while some broad types comprised few countries and/or few water bodies, e.g. the lake types with organic and calcareous geology (L-06,10 and 12) and very small Mediterranean lakes (L-15) with no water bodies reported. The latter was probably due to the WFD reporting requirements only for lakes with >0.5 km^2 surface area. The countries with the highest number of water bodies linked to broad types were Germany, Denmark, Finland, Poland, Sweden and UK, although the proportion of lakes linked to the broad types was quite low in Finland (47%). At the other end of the scale were Cyprus, Spain and Malta having no lake water bodies linked to the broad types, due to their national types missing one or more of the typology descriptors used to describe the broad types.

The geographic distribution of the broad lake types is shown in Fig. 2. The type L-15 (Mediterranean very small lakes) does not appear on the map because there were no national types and therefore no water bodies assigned to this type (Table 4). This does not mean that such lakes do not exist, but rather that they are too small to be reported by the countries to WISE.

3.3. Aligning broad types with common intercalibration types

The broad types could be aligned with the IC types, and there was a good match between the two sets of European types for most of the broad types and most of the IC types for both rivers and lakes (Tables 5 and 6). There were no IC types that could not be matched with at least one broad type. There was often not a one-to-one relationship between the broad types and the IC types, as some of the broad types could be aligned to several IC types, illustrating that many IC types were quite similar, e.g. many of the Eastern Continental and Central-Baltic river types. Some IC types overlapped with several broad types, e.g. R-E1a and R-E1b, due to overlapping size categories with two different broad types. For some broad types there was no matching IC types, e.g. most of the organic broad river types, as well as glacial rivers, highland lake types and very small Mediterranean lakes. The latter illustrates gaps in the IC types. The Mediterranean broad lake types were also well matched across the IC types, although the IC types were only defined for large deep reservoirs.

3.4. Application of broad types for large-scale assessments

3.4.1. Further aggregation of broad types for use in assessment

Following Step 9 in the methods section, the broad types were further grouped from 20 to 12 aggregated broad river types and from 15 to 8 aggregated broad lake types (Supplementary Material, Tables S5 and S6).

Each of the aggregated broad river types (coded RA-XX) comprised at least 2500 river water bodies from at least five countries, except the Mediterranean perennial rivers, which comprised merely 742 river water bodies and the very large rivers with 487 water bodies. The three aggregated broad river types with the highest number of water bodies were lowland, calcareous or mixed, very small-to-small rivers (RA-03), lowland, siliceous (including organic), very small-to-small

Table 5
Conversion table for aligning broad river types and common intercalibration types.

Broad river types	Common intercalibration types[a]
R-01. Very large rivers (all Europe)	**R-L1.** Very large, low alkalinity rivers **R-L2.** Very large, medium to high alkalinity rivers
R-02. Lowland, siliceous, medium-large	**R-N4**. Medium, lowland, siliceous, moderate alkalinity
R-03. Lowland, siliceous, very small-small	**R-C1.** Small lowland, siliceous sand **R-C2.** Small lowland, siliceous rock **R-N1.** Small, lowland, siliceous, moderate alkalinity
R-04. Lowland, calcareous or mixed, medium-Large	**R-E3**. Plains: large, lowland (mixed) **R-EX8.** Balkan: small to medium sized, calcareous karst spring **R-C5.** Large, lowland, mixed **R-C4.** Medium, lowland, mixed **R-E2.** Plains: medium-sized, lowland (mixed)
R-05. Lowland, calcareous or mixed, very small-small	**R-C6.** Small, lowland, calcareous **R-EX5**. Plains: small lowland (mixed) **R-EX8**. Balkan: small to medium sized, calcareous karst spring
R-06. Lowland, organic and siliceous	**R-N3.** Small/medium, lowland, organic, low alkalinity
R-07. Lowland, organic and calcareous/mixed	
R-08. Mid altitude, siliceous, medium-large	
R-09. Mid altitude, Siliceous, very small-Small	**R-C3.** Small, mid-altitude, siliceous **R-N5.** Small, mid-altitude, siliceous, low alkalinity
R-10. Mid altitude, calcareous or mixed, medium-large	**R-E4**. Plains: medium-sized, mid-altitude (mixed) **R-E1a**. Carpathians: small to medium, mid-altitude (mixed) **R-E1b**. Carpathians: small to medium, mid-altitude (mixed) **R-EX4**. Large, mid-altitude (mixed)
R-11. Mid altitude, calcareous or mixed, very small-small	**R-EX7.** Balkan: small, calcareous, mid-altitude **R-E1a**. Carpathians: small to medium, mid-altitude (mixed) **R-E1b**. Carpathians: small to medium, mid-altitude (mixed) **R-EX6**. Plains: small, mid-altitude (mixed)
R-12. Mid-altitude, organic and siliceous	**R-N9:** Small/medium mid-altitude siliceous low alkalinity organic (humic)
R-13. Mid-altitude, organic and calcareous/mixed	
R-14. Highland (all Europe), siliceous	**R-A2.** Small to medium, high altitude, siliceous
R-15. Highland (all Europe), calcareous/mixed	**R-A1.** Pre-alpine, small to medium, high altitude, calcareous **R-M4**. Mediterranean mountain streams (non-silicious)
R-16. Glacial rivers (all Europe)	
R-17. Mediterranean, lowland, medium-large, perennial **R-18.** Mediterranean, mid altitude, medium-large, perennial	**R-M2**. Medium Mediterranean streams (mixed, except silicious)
R-19. Mediterranean, very small-small, perennial	**R-M1**. Small Mediterranean streams (mixed, except silicious)
R-20. Mediterranean, temporary/intermittent streams	**R-M5**. Temporary streams

[a] R: Rivers, L: Very large, cross-GIG, A: Alpine, C: Central/Baltic, E: Eastern continental, EX: Extra types added for the eastern continental IC types, M: Mediterranean, N: Northern. The common intercalibration types are described in the Official IC Decision 2018 (European Commission, 2018).

Table 6
Conversion table for aligning broad lake types and common intercalibration types.

Broad Lake types	Common intercalibration types[a]
L-01. Very large and deep (stratified) (all Europe)	
L-02. Lowland, siliceous	**L-N2b**. Lowland, deep, low alkalinity, clear **L-N2a**. Lowland, shallow, low alkalinity, clear
L-03. Lowland, calcareous/mixed, stratified	**L-N1**. Lowland, shallow, moderate alkalinity, clear **L-AL3**. Lowland or mid-altitude, deep, moderate to high alkalinity (alpine influence), large **L-CB1**. Lowland, shallow, calcareous
L-04. Lowland, calcareous/mixed, very shallow/unstratified	**L-CB2**. Lowland, very shallow, calcareous **L-EC1**. Lowland, very shallow, hardwater
L-05. Lowland organic (humic) and siliceous	**L-N3a**. Lowland, shallow, low alkalinity, meso-humic
L-06. Lowland organic (humic) and calcareous/mixed	**L-N8a**. Lowland, shallow, moderate alkalinity, meso-humic
L-07. Mid altitude, siliceous	**L-N5.** Mid-altitude, shallow, low alkalinity, clear
L-08. Mid altitude, calcareous/mixed	**L-AL4.** Mid-altitude, shallow, moderate to high alkalinity (alpine influence), large **L-AL3**. Lowland or mid-altitude, deep, moderate to high alkalinity (alpine influence), large
L-09. Mid-altitude, organic (humic) and siliceous	**L-N6a.** Mid-altitude, shallow, low alkalinity, meso-humic
L-10. Mid-altitude, organic (humic) and calcareous/mixed	
L-11. Highland, siliceous (all Europe)	
L-12. Highland, calcareous/mixed (all Europe)	
L-13. Mediterranean, small-large, siliceous (incl. reservoirs)	**L-M5/7**. Reservoirs, deep, large, siliceous, "wet areas"
L-14. Mediterranean, small-large, calcareous/mixed (incl. reservoirs)	**L-M8**. Reservoirs, deep, large, calcareous
L-15. Mediterranean, very small	

[a] L =Lakes, A: Alpine, C: Central/Baltic, E: Eastern continental, M: Mediterranean, N: Northern. The intercalibration common types are described in the IC Official Decision 2018.

rivers (RA-05) and mid-altitude, siliceous (including organic), very small-to-small rivers (RA-09).

Most of the aggregated broad lake types (coded LA-XX) had >1500 lake water bodies from at least five countries, except very large lakes (LA-01) and Mediterranean lakes (LA-08), which had <300 lake water bodies in each aggregated type. The three aggregated broad lake types with the highest number of water bodies were lowland-mid-altitude, humic and siliceous lakes (LA-04), mid-altitude, siliceous lakes (LA-06) and lowland-mid-altitude, calcareous (including humic), shallow, stratified lakes (LA-03).

3.4.2. Top-down mapping of aggregated broad river types

A geological map using both bedrock and soil types to distinguish the four main geology categories of the broad types (Fig. 3) was produced based on Step 11 in the methods chapter above with details given in the Supplementary Material (Part e). An independent alkalinity dataset was found to be consistent with the areas assigned to predominantly siliceous and calcareous geology.

The geographical distribution of the assigned aggregated broad river types (Fig. 4) shows the major patterns of river types across all of Europe with siliceous and organic rivers dominating Northern Europe, including Scotland, Iceland and the Czech Republic, while calcareous rivers (blue colours) dominate in large parts of Central and Eastern Europe and in the Baltic countries.

The geographical distribution of the assigned aggregated broad lake types (Fig. 5) shows the major patterns of lake types across all of Europe with siliceous and organic lakes dominating Northern Europe, including Scotland, Iceland and the Czech Republic, while calcareous lakes (blue colours) dominate in large parts of Central and Eastern Europe and in the Baltic countries.

3.4.3. Type-specific assessment of ecological status and pressures

The ecological status and pressures in rivers and lakes reported by countries within their 2nd RBMPs for the WFD was assessed using the aggregated broad types.

3.4.3.1. Rivers. The distribution of ecological status classes and pressures differed considerably between the different aggregated broad types (Fig. 6). Lowland, calcareous, small rivers (RA-03) had the worst status with >80% of the water bodies failing the WFD objective of good status and almost 40% being in poor or bad status. Also, the very large rivers (RA-01) and the medium-to-large lowland and mid-altitude rivers with calcareous or mixed geology (RA-02) had close to 80% failing the WFD good status objective and a quite high proportion (approximately one third) being in poor or bad ecological status. These types of rivers were also affected by various pressures, including hydro-morphological pressures (60–70% of classified water bodies), diffuse pollution (30–50% of classified water bodies) and point pollution (30–40% of classified water bodies).

Also, for the lowland siliceous rivers (RA-04 and 05), as well as mid-altitude calcareous medium-to-large rivers (RA-06) 70% or more of their water bodies were in less than good status, which is probably explained mainly by hydro-morphological pressures (40–60%) and/or atmospheric deposition (70%) for RA-04 and point pollution for RA-06 (30%), the latter corresponding to the 30% in poor or bad status.

At the other end of the scale were the highland rivers (RA-10) of which 70% of the water bodies were in good or better status with as much as one third in high status. Also, very small-to-small rivers in mid-altitude areas (RA-07 and 09) had relatively good status with approximately half of the water bodies in good or better status. Many of these were probably headwater streams with little pollution pressure, although they had hydro-morphological pressures affecting 40% of their water bodies.

For the Mediterranean temporary and very small rivers (RA-12) half of the water bodies were in good or better status, and almost the same proportion was affected by diffuse pollution, but otherwise merely 20% were affected by point source pollution or by hydro-morphological pressures. For the Mediterranean perennial rivers (RA-11) >60% were in moderate or worse status and almost the same proportion was affected by diffuse pollution, as well as roughly half of the water bodies by hydro-morphological pressures and one third by point source pollution.

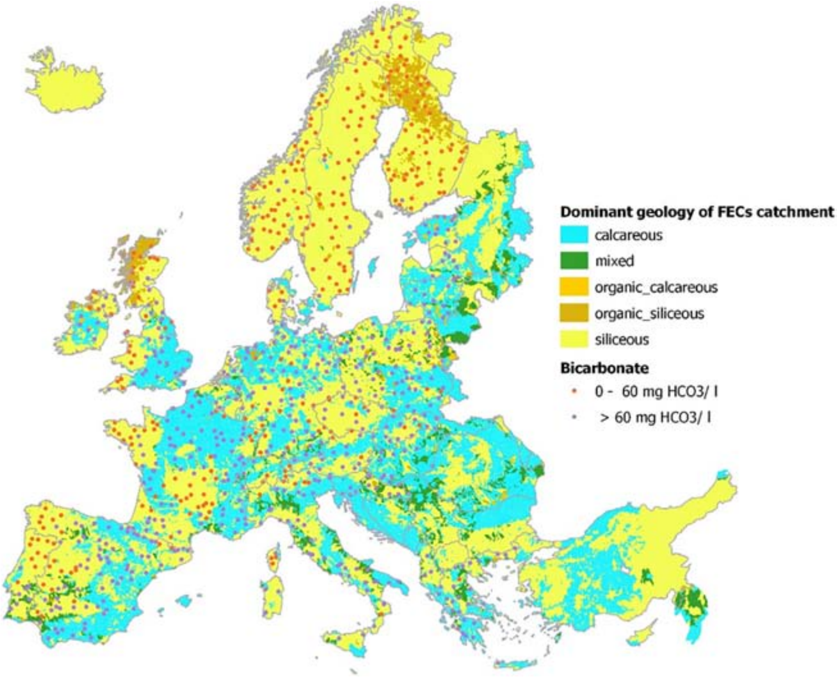

Fig. 3. Geographical distribution of the main geochemical categories used for the aggregated broad types, see text for further explanation. The dots are monitoring sites with data on bicarbonate concentration <60 mg HCO_3/L (orange dots) or >60 mg HCO_3/L (violet dots).

The mid-altitude, siliceous, medium-to-large rivers (RA-08) were a special case having an apparent mismatch between status and pressures, with quite poor status (70% less than good), but very little diffuse and point pollution pressures. However, these had quite considerable hydro-morphological pressures (50%).

In general, the ecological status was positively related to altitude and negatively related to size and alkalinity (calcium concentration). The results also showed a good match between ecological status and pressures for each of the types, with worse status found for types with a high proportion of water bodies with pressure.

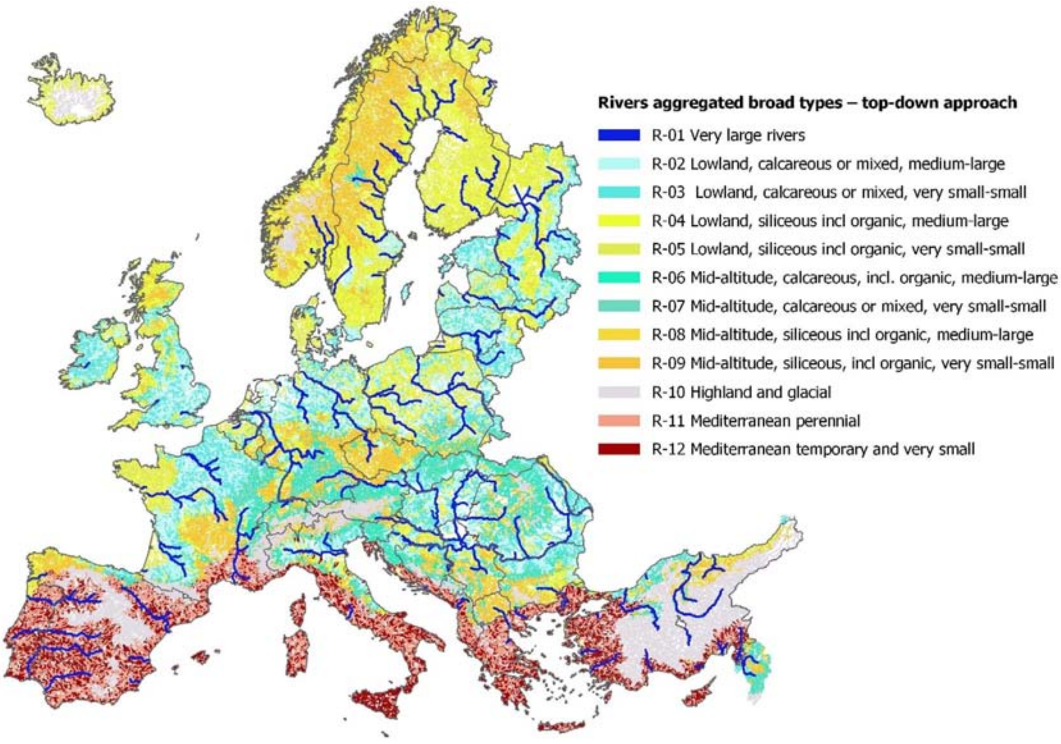

Fig. 4. Distribution of the 12 aggregated broad river types across Europe, using information on altitude, size and geology ("Top-down approach"). Data source: MARS geodatabase (http://mars-project.eu/index.php/databases.html) and GIS-data available on altitude, catchment size and geochemistry (see Fig. 3 and Supplementary material (part e, for more explanation).

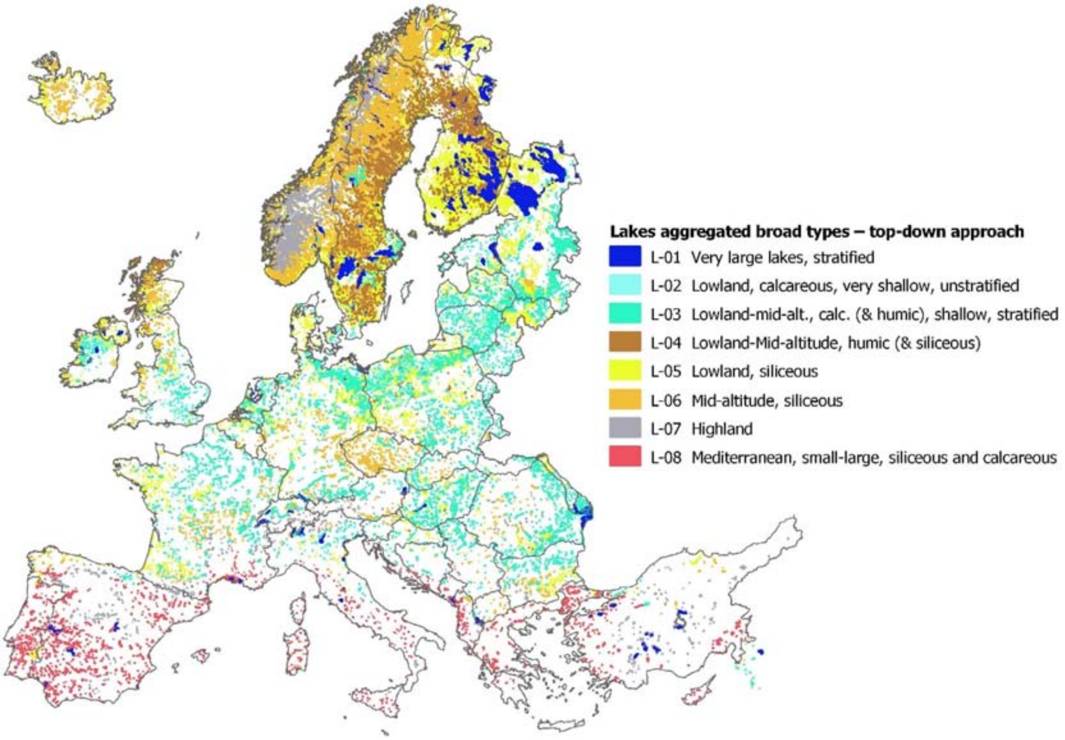

Fig. 5. Distribution of the 8 aggregated broad lake types across Europe, using information on altitude, size, geology and mean depth ("Top-down approach"). Data source: MARS geodatabase (http://mars-project.eu/index.php/databases.html) and GIS-data available on altitude, surface area, mean depth and geochemistry (see Fig. 3 and Supplementary material, part e, for more explanation).

Diffuse source and hydro-morphological pressures were the most important pressures reported. Diffuse pollution affected 40% or more of the lowland, calcareous rivers, as well as Mediterranean rivers, while hydro-morphological pressures affected as much as 60% of lowland rivers and >70% of very large rivers.

Point source pressure was most important in the lowland, calcareous rivers and in perennial Mediterranean rivers affecting 30–40% of the classified river water bodies but was negligible in highland rivers and in siliceous and organic rivers, the latter mostly found in Finland and Sweden.

These results were consistent with our expectations, due to the more intensive agriculture and higher population density in lowland areas of Europe (see also Lyche Solheim et al., 2012b and EEA, 2012). Rivers with calcareous or mixed geology are often located in agricultural areas.

3.4.3.2. Lakes. The ecological status and pressures differed considerably between the different aggregated broad lake types (Fig. 7). Lowland, calcareous, unstratified lakes (LA-02) had the worst status with >70% of the water bodies failing the WFD good status objective and more than one third being in poor or bad status. Also, for the lowland and mid-altitude stratified lakes with calcareous or mixed geology (LA-03) >70% failed to achieve good status and a quite high proportion (approximately 20%) were in poor or bad ecological status. These lake types were mainly affected by diffuse pollution (40%), while hydro-morphological pressures and point pollution seemed less important, affecting merely 10–20% of the classified water bodies.

For the lowland and mid-altitude siliceous lake types (LA-04, 05 and 06) approximately half of the water bodies were in less than good ecological status and <10% in poor or bad status. These lake types had been reported to have <10% diffuse and/or point pollution, but approximately 30% were affected by hydro-morphological pressures.

At the best end of the scale we found the highland lakes (LA-07) with almost 90% of the water bodies having good or better ecological status and two-thirds being in high ecological status. This was consistent with the pressures reporting, showing that very low proportions were exposed to all the three major pressures (diffuse and point pollution and hydro-morphological pressures). This result indicated that highland lakes were mostly pristine lakes.

The very large, stratified lakes (LA-01) were also mainly in good or better ecological status (75%), a result that was in strong contrast to the very large rivers where 80% of the water bodies failed to achieve good status (Fig. 6). This good status was probably due to the large water volume of these very large lakes, having a high recipient capacity for pollution before becoming degraded, as well as their location in low pressure areas of Europe (Scandinavia and the Alpine region). Their good status was also consistent with the pressures reported for these lakes with a low proportion (<20%) of the classified water bodies being exposed to diffuse and/or point pollution, as well as to hydro-morphological pressures.

Finally, for the Mediterranean lakes (LA-08) almost 60% of the water bodies were in less than good ecological status. This lake type was reported to be exposed to diffuse pollution for almost half of the classified water bodies, while hydro-morphological pressures seemed less important (13%).

The general pattern for lakes was the same as for rivers for most of the aggregated broad types showing a positive relationship between ecological status and altitude and a negative relationship between ecological status and calcium concentration. For the very large lakes, both the status and pressures were opposite compared to the very large rivers, due to fundamental ecological and geographical differences between very large lakes and very large rivers (see above).

Diffuse pollution was the pressure affecting the largest percentage of the lake water bodies for the aggregated broad types with worst ecological status, while point pollution also contributed. Hydro-morphological pressures were most important for the siliceous lakes that were mostly found in Scandinavia, while point pollution was most important for Mediterranean lakes/reservoirs.

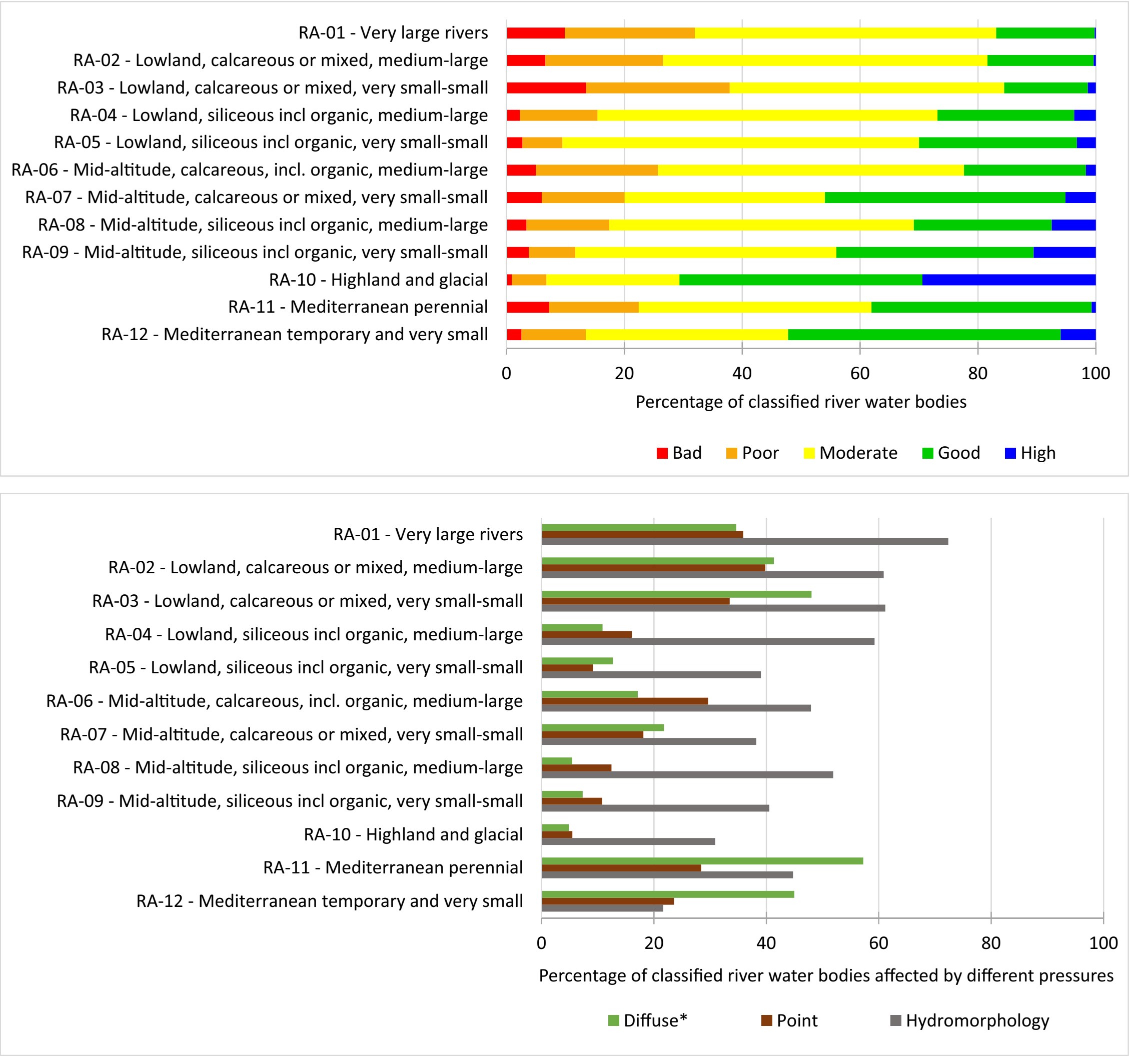

Fig. 6. Ecological status and pressures of 64,751 river water bodies grouped by aggregated broad river types (codes RA-XX). The data include all water bodies where both status and pressures were reported and that could be linked to any of the broad types. Source: WISE-WFD database, 2018: https://www.eea.europa.eu/data-and-maps/data/wise-wfd-2. Upper graph shows ecological status and lower graph shows main pressures. *The diffuse pressures category does not include water bodies with only atmospheric deposition pressure.

4. Discussion

4.1. Major achievements

For the first time since the introduction of the WFD in Europe, we have developed a generic typology for European rivers and lakes, reflecting the natural variability in the most commonly used environmental type descriptors (altitude, size and geology). These broad types capture 60–70% of all national WFD types including almost 80% of all European river and lake water bodies in almost 90% of the EU countries (Tables 3 and 4). They can also be linked to all the IC types (Tables 5 and 6). They provide a framework for large-scale assessments across country borders, as demonstrated here with the assessment of ecological status and pressures (Figs. 6 and 7) and can also be used for a variety of other large-scale assessments (see below). In general, the broad types can provide the basis for all type-related scientific outputs of relevance to management.

4.2. Geographic distribution of the broad types

The uneven distribution of the broad types across Europe (Figs. 1, 2, 4, 5) reflects major differences in natural conditions, such as the geology categories siliceous and/or organic, which are mainly found in Northern Europe. Nevertheless, most of Europe's lakes and almost half of the Europe's rivers could be assigned to broad types with these geology characteristics, illustrating the water-rich Northern region. In contrast, the Mediterranean broad types comprised <10% of the rivers and only 2% of the lakes, reflecting the arid Southern parts of Europe. Even if the number of water bodies assigned to a broad type in that region could be increased by a better match between the Spanish national types and the broad types, the number of water bodies assigned to broad types in Mediterranean regions would still be much lower than for Northern Europe.

4.3. Uncertainties and limitations

The number of very large lakes is underestimated in the WFD reporting because many countries have delineated their very large lakes as multiple smaller water bodies, due to lake-internal variability of types or status or pressures. This is the reason why the very large Swedish lakes, such as lake Vänern and Vättern, are not associated with the very large lakes broad type (Fig. 2).

The very small rivers and lakes are also under-represented in the broad types, because most countries have not reported water bodies smaller than the lower size limits in the requirements for WFD reporting (i.e. rivers with catchments <10 km^2 and lakes with surface

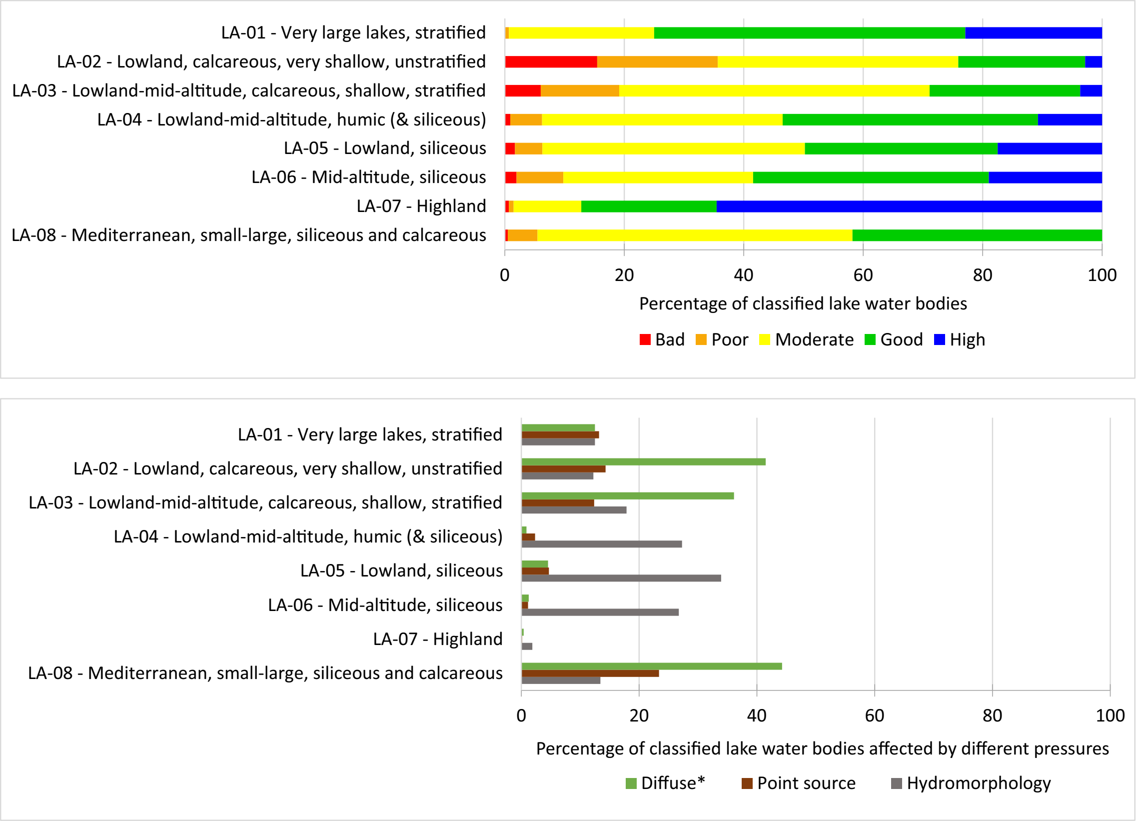

Fig. 7. Ecological status and pressures in 13,927 lake water bodies grouped by aggregated broad lake types (type codes LA-XX). The data include all water bodies where both status and pressures were reported and that could be linked to any of the broad types. Source: WISE-WFD database 2018: https://www.eea.europa.eu/data-and-maps/data/wise-wfd-2. Upper graph shows ecological status and lower graph shows main pressures. *The diffuse pressures category does not include water bodies with only atmospheric deposition pressure.

area <0.5 km^2). This means that the broad types cannot adequately reflect the number of very small water bodies in Europe, including their status and pressures.

The typology descriptors used to develop the broad types are also those most commonly used by most countries in Europe. However, there are also other important type descriptors that are currently not reflected, especially for rivers (e.g. slope, flow and substrate). These aspects of national river typologies are at least partly captured by the different altitude categories of the broad types, assuming that lowland rivers are mainly slow-flowing, while mid-altitude and highland rivers are mainly fast-flowing. Nevertheless, for certain types of assessment, there may be a need to define sub-types for at least some of the broad river types to differentiate between slow-flowing rivers with mainly fine substrates and fast-flowing rivers with mainly gravel or hard substrates. Relevant characteristics to consider in this regard are bed material, valley confinement and channel planform (straight/sinuous/braiding). Such additional descriptors are important to consider if we want to account for effects of hydro-morphological alterations (Gurnell et al., 2016).

For more precise assessments of very large rivers, the broad type could be divided into regional sub-types, capturing more of the natural climatic and biogeographic variability in Europe, as suggested by Borgwardt et al. (2019).

Climatic aspects may also need further attention to capture differences caused by wet oceanic regions (Western Europe) and dry continental regions (Eastern Europe). Several studies have shown, for instance, that shallow lakes in the Pannonian ecoregion (Hungary and Romania) differ significantly in their characteristics comparing to their more northern counterparts (Borics et al., 2013, 2014; Stenger-Kovács et al., 2014). The existing biogeographic regions of Europe should therefore also be considered (EEA, 2019), in particular when using the broad types for biodiversity assessments. However, there will always be trade-offs between the best approximation to natural variability and the total number of broad types, which should be kept at a reasonably low number to be useful for cross-cutting European assessments.

4.4. Outlook on other possible applications for the broad types

The broad types can be applied for a whole range of large-scale assessments across Europe both for further research and for water management purposes. Several examples are given in the following:

1. Comparison of limit values for nutrients (Phillips and Pitt, 2015, see also Poikane et al., 2019.) and other physico-chemical quality elements (e.g. oxygen, Secchi depth, biochemical oxygen demand) reported for different national types by European countries to WISE with the 2nd RBMPs. This is now on the action list of the WFD-CIS-ECOSTAT work program 2019–2021.
2. Comparison with other European typology systems for rivers and lakes given by the Habitats Directive freshwater habitat types (Lyche Solheim et al., 2015) and the European Nature Information System (EUNIS) inland water types for running and standing waters (https://eunis.eea.europa.eu/), which are used for monitoring and assessment of freshwater biodiversity. The EUNIS inland water types are currently being revised by the EEA and the ETC-Biodiversity to better match the broad types.
3. Scenarios for impacts of climate and land use change on future ecological status and pressures (example shown in https://mars-project-sat.shinyapps.io/mars-sat/).

4. Hierarchical modelling of ecological indicators (e.g. phytoplankton community indices) and their response to pressures at large geographic scales, considering variation among individual water bodies as well as among the broad water body types (Aroviita et al., 2017).
5. Extend the current assessment of ecological status and pressures (as shown in Figs. 6 and 7) to all European countries, using the geographical distribution of the aggregated broad types shown in Figs. 4 and 5. Such an application would allow filling the current gaps for several countries, whose national types could not be linked to the broad types.
6. Scenarios of land-use change related to the bioeconomic green shift (Sillanpää and Ncibi, 2017; Jakobsen and Storsletten, 2019) in combination with climate change and the combined impact on water quality, quantity and ecosystem services could also apply the broad types and rivers and lakes to assess specific type-specific responses. Such an application is already being discussed and tested by a Nordic center of excellence (BIOWATER, https://biowater.info/).

Author contributions

Anne Lyche Solheim: Conceptualisation, Data curation; funding acquisition, Investigation; Methodology; Project administration, Writing - original draft; Writing - review & editing.

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Supplementary data

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