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A Review of Assessment Approaches for Lake Hydro-Morphology Before and After the European Water Framework Directive (WFD)

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Abstract

Europe, as well as the other continents, is characterized by the presence of both natural lakes and reservoirs. The first scientific approach on lakes dealt with the biological and chemical aspects, in order to face the eutrophication problem; at the same time, physical aspects, such as mixing and stratification dynamics, started to be considered. It was only several years later that chemical, physical, biological and hydro-morphological aspects were considered all together, when researchers focused on the whole ecosystem. In fact, methods are aimed at evaluating the hydro-morphological quality through the use of indexes and related to biological quality have been defined only after WFD 2000/60. Before, only some Member States have developed studies and assessment methods based on single morphological or hydrological features. In this study, we will describe the change in the focus of research studies on lakes, considering in particular the development of methods for the evaluation of the hydro-morphological features in the European countries. In addition, we want to contribute to introduce different approaches on the same topic highlighting the strengths, the weaknesses and the shortcomings of each one. A summary of the main hydro-morphological features, typology of survey and feasibility on lakes is also presented. The new knowledge on hydro-morphology aspects and pressure on ecosystem will be useful to develop new studies and research to improve ecosystem and environmental quality.

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Introduction

Most of the European Lakes are located in the northern part of the continent, especially in Norway, Sweden, Finland and the Karelo-Kola part of Russia. About 80% to 90% of lakes have a surface area between 0.01 and 0.1 km^2, where as around 16000

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lakes have a surface area exceeding 1 km^2 and 24 European lakes have a surface area larger than 400 km[21]. Most of natural lakes were formed or reshaped by glacial activity, when the ice covered all of northern Europe; in central and southern Europe it covered only mountain chains. Lakes of glacial origin can be found in Iceland, Ireland, in the northern and western parts of the United Kingdom and in central Europe, in mountain regions. Lakes placed at high altitudes are deep but not as wide as those in northern Europe[1]. In Southern (Portugal, Spain, France) and central Europe (Belgium, southern England, central Germany) where glaciation was limited, only few natural lakes have been formed[1]. In these areas a lot of reservoirs have been built for hydroelectric production, in mountain valleys, but also for agricultural needs or for other human activities such as peat, sand quarrying, or fish ponds in Netherlands, Germany, France, Czech Republic and Slovaki[1].

Natural lakes and reservoirs represent a richness for Europe, so the knowledge of their quality under physical, chemical and biological point of views has been the driving force for starting limnological research since the end of 1800. The first studies concerned deep sub-alpine lakes with focus on biological aspects, invertebrates[2,3], fishes, phytoplankton, zooplankton[4,5,6], in particular in Lake Maggiore and in Lake Léman[7]. During time, biological studies has been evolved around European lakes, in particular: Lake Erken, Sweeden[8], Lake Constance, Switzerland, Germany and Austria[9], Lake Zürich, Switzerland[10].

During the Sixties, the eutrophication problem pushed researchers to deal with the nutrients dynamics in all Europe[11,12,13]. In some cases, serious pollution problems were detected[14], linked with industrial production, and this was an input to standardize chemical samplings, analyses and methodologies. In fact, the specific attention on eutrophication and pollution have contributed to the development of new research lines around Europe. These new studies have contributed to improve the chemical quality and trophic level of lakes[15,16,17,18,19,20,21,22].

From the sixties and seventies onwards, studies on physical aspects such as mixing, stability and warming were also developed, for example for deep lakes[23,24,25] as well as studies based on theoretical description, field observation and modelling, to explain natural phenomena with their driving mechanism with a modern limnological aim[26].

Only in recent years, chemical, physical and biological aspects were considered together, for example physico chemical and biologically based measures (such as nutrient reduction or fish removals), have been done in numerous case studies[27,28,29]. In addition, according to Premazzi and Chiaudani[30], hydrological and physical changes such as water level stabilization and siltation have played an important role in degrading the quality of European lakes in recent decades. Hondzo and Stefan[31] explored the Minnesota Lakes Fisheries Database, which contains lake survey data regarding 22 physical variables and all common fish species for 3002 lakes. The parameters considered and evaluated in this work are above all physical parameters such as water temperature and dissolved oxygen and morphometric features, such as shape, dimension and volume, presented as morphological elements; Hill *et al.* [32], analysed the effects of dams, in particular lake fluctuation, on the shoreline vegetation of lakes and reservoirs. First approaches on hydro-morphological features of lakes considered different hydro-morphological features, such as shape, slope, material of bank and lacustrine basin, variety of habitat, presence of natural or artificial elements around littoral and shore zone, bathymetry, depth, altitude and latitude, hydrological regime of lakes with its natural or artificial fluctuations, and have been studied as single features[33,34,35,36,37]. It is important to highlight that in a fore mentioned studies the morphological aspects, presented by morphometric features, such as bathymetry, lake area, lake volume and mean or maximum depth are considered separately with land use or geology or level fluctuation or habitat. In particular, Håkanson[37] defined a predictive model on eutrophication, using each morphometric feature and chemical data. In addition, Morey[38] and Duane[39] dealt with sediment transport and littoral zone origin, developing in detail, a specific model on bed form generation. The impact on bed form of water motion, direction of flow and lake level fluctuations has been also analysed. The first studies in according to Water Framework Directive[40] Idea and approach are summarized in Baker *et al.*[41]. They developed in the USA a protocol for data collection on water quality, ecological variables and physical structure, including physical and chemical measurements in lake, as well as for shore zone habitat survey. Field sampling and data collection have been transformed, all together, into numerical equivalents of the quality of habitat and morphological modification. In December 2000, the European Water Framework Directive (WFD) became the fundamental basis for any water policy-related action by the European Community. All European water bodies, lakes, rivers, coastal marine, groundwater shall attain, or maintain the existing "good status", defined by a good ecological and chemical status[40]. In according to the Water Framework Directive, in particular to the Annex V,[42] the two elements for evaluating the hydro-morphological quality of lakes are Hydrological regime and Morphological conditions. The Hydrological regime, following the WFD, means "the quantity and dynamics of flow, the water level, the residence time, and the resultant connection to groundwater"[40] Morphological conditions mean "the lake depth variation, the quantity and structure of the substrate, and both the structure and condition of the lake shore zone"[43]. So hydrological and morphological aspects become new entities on which studies, methods and model were developed. The new approach on lake hydro-morphology was born thanks to WFD with the idea that morphological aspects such as substrate, shore zone, habitat, lake depth variation considered together with lake level fluctuation, residence time, connection to groundwater have to be evaluated as important factors for lake quality, not as subordinate to eutrophication problems. These hydro-morphological features have been evaluated in Europe through different approaches; some of them are able to define the degree of deviation from natural conditions, as provided from WFD, but other not completely. In addition, WFD requires the same approach both natural, heavily modified (HMWB) and artificial water bodies (AWB). To regards HMWB and AWB it is not possible to consider the same ecological quality as natural lakes and so it is necessary to speak about ecological potential, evaluating it as maximum quality possible. When defining maximum ecological potential, three groups of quality elements – biological, hydro-morphological, and physical and chemical – have to be considered[43].

In according to WFD request, different method was developed to assess hydro-morphological features around Europe, based on field survey and remote sensing data, contemplated as complementary approaches in the assessment of lake hydro-morphology.

For example, the research project SALMON (SAtellite remote sensing for Lake MONitoring) encouraged cooperation among limnologist and remote sensing specialists to evaluate capacity and potentiality of remote sensing for water quality monitoring in Europe, in order to define guidelines and protocol to develop a useful tool for monitoring and management. However, the objective was only the monitoring of the chlorophyll concentration with its evaluation[44].

Following stages and progression of studies and method developed thanks to WFD, it is arrived that a deep knowledge of the relationship among hydro-morphological parameters, habitat and biological communities, is required, even if the sensitivity of different biological elements to some pressures or impacts is not well known.

As regard the possible relationship between hydro-morphological parameters and nutrients, we can mention that only few parameters are connected with the presence or absence of these elements. Several human activities may impact lake habitat through sediment loading, nutrient loading, contaminant loading, hydrological changes, and direct habitat alteration through the removal of wetlands.

Indeed, during the monitoring actions, even for hydro-morphological aspects, evaluations and data sampling of riparian, shore and littoral habitats are included. In this way, it is possible to gain a vast knowledge of human activities and their consequences on habitat and on water body quality. This knowledge is very important for management plans and restoration actions of water bodies, according to the WFD. A guidance on hydro-morphological parameters according to WFD that takes into account also biological quality elements has been developed not long ago[45,46].

The importance of the definition of methods for the assessment of hydro-morphological parameters was the reason of the organization of two CEN (European Committee for Standardization) standards; the first one regarding the evaluation of hydro-morphological features of lakes[47] and the second one regarding the assessment of the degree of alteration of lake hydro-morphology[48].

In the next section different European methods for the evaluation of hydro-morphological quality will be analysed, with a particular focus on: i) the considered parameters, ii) what kind of indexes or analyses have been developed into each method, iii) strengths and weaknesses for each method, iv) shortcomings and aspects to be developed yet.

Materials and Methods

The aim of this paper is to reorganize studies and outcomes on lakes and in particular on hydro-morphological aspects and to make the point of actual studies on lake hydro-morphology, above all after WFD 2000/60. Furthermore, it is aimed at understanding the European level of knowledge and research on this topic and to analyse the most important methods, their applicability and their possible adaptation out of Europe. Previous review papers examined in depth each single aspect of hydro-morphological features but without summarizing their use and application through particular methods around Europe in the same manuscript. For example, a review of methods for the assessment of the hydro-morphological quality of lakes[44] has been conducted by Sniffer, in 2003. In this work, the Author/Authors highlights that since 1900 a lot of studies regarding the hydro-morphological aspects have been developed, starting from bathymetric surveys. The first morphological parameters were considered above all within sedimentology studies: drainage area, lake surface area, length, mean breadth, mean depth and maximum depth of the lake, to regard each single aspects, considered separately. Hydro-morphological methods and index presented in the aforementioned paper concern mainly UK applications.

Since most hydro-morphology methods and indexes have been developed after WFD, this paper considers Member States methods included in ECOSTAT activities and works, and which contributed to developed the two standard CEN on lake hydro-morphology[46,47]. Considering hydro-morphological method developed before WFD, a program for the assessment of surface water quality, with focus on hydro-morphological features, was developed by Environmental Protection Agency of US[41]. In this work, they presented data of the structure of littoral and riparian physical habitats measured at 10 predetermined stations and a macroscale classification and mapping of riparian and littoral habitat for the whole lake. From this experience and thanks to this assessment, each European Member States has developed methods and methodology on hydro-morphological aspects, to answer WFD requirements.

According to the WFD, hydro-morphological parameters are necessary to evaluate reference conditions and as support to biological quality elements (phytoplankton, diatom, macroinvertebrates, macrophytes and fishes). Hydro-morphological parameters have been divided in: 1) hydrological regime and 2) morphological conditions. As regards the hydrological regime, it is necessary to consider quantity and dynamic of flow, level, residence time and connection with groundwater; for morphological conditions, it is necessary to consider lake depth variation (landfill), quality and quantity of substratum, structure and condition of shoreline, riparian and littoral zone[40,42].

The outcomes from different working groups have allowed us to summarize the methods published under EC support. Thus, in the following paragraphs, we describe the methods for hydro-morphological assessment adopted in different European countries:

United Kingdom

Considering the approach of method River Habitat Survey for hydro-morphological evaluation of rivers[49] and the studies developed by US EPA, during the period 1997-1998, a group of researchers from the Dundee University have studied and developed a method for lake hydro-morphological assessment, complying with the WFD requirements. This method was given the name of Lake Habitat Survey (LHS)[50,51,52,53]. This method is based on a field survey that records shoreline and littoral features, pressures and modification, on 10 equidistant hab-plots around the lake and hydrological regime and others features for the entire lake. Furthermore, a temperature and dissolved oxygen profile is conducted at the deepest point of lake (Index Site). Existing database and remote sensing data (example aerial photographs) are used to improve field based observations[54]. In addition, it has been developed a method for calculating the degree of anthropogenic impact on surface waters in Scotland, DHRAM (The Dundee Hydrological Regime Assessment Method). This method can assess the alteration of water level fluctuations in the lake and can estimate the impact on residence time[44]. In addition, to interpolate hydrological and morphological features a single Abiotic Index using LHS morphological alteration has been defined, HMS index and DHRAM regime alteration [44]. Further work has been developed during time, concerning also a decision support tool related to Lake Habitat Survey, Lake MImAS (Morphological Impact Assessment System). This tool evaluates lake system capacity to absorb pressure and answer to human activities without consequences on its own ecological status. The Data that it needs for Lake MImAS are those collected during the Lake Habitat Survey field work and connected with each observed pressure. Therefore, the percentage limits of response capacity to morphological alteration are defined as MCLs (Morphological Condition Limits) and represent limits beyond which the lake risks to have a deterioration of its ecological and morphological conditions[55]. A recent test on Lake MImAS tool has been realized in Scottish lochs, England and Wales and in Northern Ireland loughs[56]. This work represents an important step to fill a gap between the academic research as geomorphology and ecology, and the needs of practitioners and stakeholders who require decision-support tools for practical environmental management. Lake-MImAS provides an important new framework for understanding the physical condition of lakes an operational scheme linking ecological response to hydro-morphological pressures[56].

Republic of Ireland

LHS method, bathymetric surveys and aerial photography are adopted in this country. A score system is used to describe the quality of habitat (LHQA) within each hab-plots of LHS in order to assess the relationship between physical structure of shore and littoral zones and metrics of the macroinvertebrate community. The comparison between macroinvertebrates community and data sampling with LHS method through different hab-plots has showed that changes in the physical structure of macrophytes have a great influence on macroinvertebrates, more than other physical and hydro-morphological characteristics. In any case it is necessary to carry out detailed studies regarding the relationship between hydro-morphology and ecology[57]. Also in Northern Ireland Lake MImAS has been applied and it field information was collected to test this tool, with the help of Statutory Conservation Agency staff from the Northern Ireland Environment Agency[55,56]. Another study developed using biological and hydro-morphological aspects focused on the importance of shoreline habitat features for littoral macroinvertebrate. This study gathered in six Irish lakes, of similar depth and size but varying along gradients of total phosphorus and alkalinity. Macroinvertebrate communities have been sampled considering mesohabitats and habitat diversity recorded by the Lake Habitat Survey (LHS). The results of this study highlighted the importance of macrophytes extended lake wards, the diversity of littoral features, the presence/absence of complex riparian vegetation and the total number of macrophyte types, for littoral macroinvertebrate communities[58].

Serbia

LHS was applied for the first time in 2005 on three lakes of Montenegro[59]. Later, this method was applied on others 10 Serbian lakes within the Danubio River Basin. During 2008 this method was tested on an ephemeral lake, Slano Kopovo, within the catchment of river Tisa, but it was verified that this method is not appropriate for this kind of habitat[60]. LHS has been also applied to Crnojezero (Black lake) to evaluate, with aquatic macrophytes samplings, the ecological status, water quality and habitat characteristics. LHS protocol was applied, collecting detailed information on riparian, shore and littoral zones and on land cover, riparian vegetation structure, shore zone geomorphology and macrophyte abundance. All anthropogenic modifications and human pressures were also recorded.

It can mention that the use of macrophytes to assess the response of human pressure is being developed, for all Europe Countries, due to the lack of homogenous monitoring methodologies. Although researchers are trying to harmonize the different methodologies using a common CEN standard or a common hydro-morphology assessment method such as Lake Habitat Survey[61].

France

The Agency of Water has applied LHS along with biological samplings on 190 natural lakes and reservoirs. They used also aerial photograph with high resolution (0.5 m) to evaluate the presence of hydro-morphological pressures. Data obtained were inserted in a database by CEMAGREF (CEntre national du Machinisme AGRicole du génie rural, des Eaux et des Forêts) and at the end of 2009 the number of studied lakes was 230, which present more than 50% of lakes evaluated according to WFD(CEN TC 230/WG 2/TG 5). Two simultaneous protocols have been recently adopted (i) ALBER (ALtération des BERges) and CHARLI (Caractérisation des HAbitats des Rives *et du* LIttoral). Alber[62] is a protocol for characterizing the lakes riparian alterations based on photo-interpretation coupled with field observations. Charli[63] is a protocol for characterizing the lakes riparian habitat based also on photo-interpretation coupled with field observations. The preparation of essential maps represents the first stage of this method followed by in situ observations and finally by data integration with GIS. Following this protocol, hydrological (water level fluctuations) and morphological parameters (lakeshore alterations, littoral habitats) should be analysed and crossed with a biological descriptor (fish fauna) in order to evaluate the hydro-morphological alterations of lakes. The application of the Alber & Charli protocol makes it possible to have a hierarchical classification of lakes and to identify actions of their morphological restoration.

Poland

LHS technique has been tested in Poland since 2006 within the project financed by the Ministry of Science and Higher Education. The aim of the study was to analyse at which extent aerial photographs could be used as a supporting tool in Lake Habitat Survey. From this study it comes to light that in many cases the integrated use of LHS boat assessment and RS (aerial imagery or high resolution satellite imagery) data is fundamental to achieve accurate hydro-morphology information[64]. Further more, the use of RS data is essential, where it is not possible to identify the exact land use, change in features, presence of human structures or natural components. However, RS data analysis alone will not be sufficient and it should be used as additional information to improve field work[64].

In Poland LHS was also applied on 25 flat lakes with high alkalinity. These lakes present high ecological condition variability and cover all classes included in reference sites (CEN TC 230/WG 2/TG 5). Recently, the influence of hydro-morphological modifications of the littoral zone on the biodiversity of macrophytes has been evaluated in 5 lakes. The macrophyte survey was conducted in different transects by evaluating the maximum colonization depth of plants, a list of taxa and their estimated ground cover together with hydro-morphology elements recorded using the LHS method (physical habitat, dominant littoral substrate and human activities along the shoreline). Hydro-morphological impacts on Polish lakes result principally from tourism-recreational pressures, construction of piers (including angling piers), harbours for boats, creation of beaches and bathing sites. Hydro-morphological modifications of lakes are so an important ecological factor affecting biodiversity of macrophytes[65].

Italy

The assessment of ecological status in according to WFD has started since 2004 for phytoplankton, macrophytes, macroinvertebrates and fishes, and since 2007 for hydro-morphological parameters, considering: hydrological regime (lake level), morphological condition (lake depth variation, structure and condition of lake shores, structure of substrate, littoral zone). In Italy a method for the evaluation of shore zone functionality, above all in terms of capacity of nutrient removal from diffuse sources, has been developed: the Lake Shore zone Functionality Index (SFI or IFP)[66,67]. This method was born in 2004 and developed between 2004 and 2009 and consider high numbers of parameters divided in:

- General parameters: topographic (a), morphological (b), climatic (c), geological (d), others (e);
- Ecological parameters: vegetation typology (a), size (b), continuity (c), break (d);

- Socio-economic parameters: generic (a), land use (b), infrastructure (c), tourism (d), touristic-recreational infrastructures (e), productive activities.

Together with survey applications it is foreseen the use of orthophotomaps. This method does not consider standard dimensions of the Minimum Detectable Reach (TMR)[67], and the classification tree used in the method gives only probabilistic values, assuming as final judgment the most probable value or a subjective judgment of the field operator. For these reasons, it does not fully respond to the WFD requirements with respect to hydro-morphological parameters. From here comes the idea to adopt LHS in Italy, too. LHS has been tested on some 24 Italian lakes of Alpine and Mediterranean typologies[68], since 2009, but it will be necessary to implement other applications in order to cover most of the 18 Italian lake typologies, above all to explain accurately Lake Habitat Quality Assessment (LHQA) values[69,70]. Moreover, thanks to the Life project INAHBIT (LIFE 08 ENV/IT/000413 INHABIT), it was possible to apply LHS connecting some of the applications with macroinvertebrates sampling to evaluate pressure typology on riparian and littoral zone and to evaluate relationships among hydro-morphological features and biological quality. Using statistical approaches, it was highlighted that macroinvertebrates distribution is influenced by anthropogenic alterations. Indeed, where it has been possible to obtain a good overlapping between biological quality element (macroinvertebrates) and the hab-plot (the observation transect of LHS), results showed clearly how macroinvertebrates are linked with habitat typology and diversity and littoral/riparian modifications[71].

Germany

The HML method (Hydro-Morphology of Lakes), developed in Germany[72], includes both field surveys and aerial photographic analysis. It presents a sort of mapping and hydro-morphological classification of both natural and man-induced shore structures[73,74]. In addition, it uses GIS to enable the assignment of macroinvertebrate sampling sites to specific environmental characteristics of the shore sections of interest. The contribution by Ostendorp & Ostendorp[73] tested the recently developed HML protocol in order to identify anthropogenic changes of the hydro-morphological conditions of lakes in Germany compared to natural reference conditions with regard to the requirements of the WFD. According to HML, the degree of hydro-morphological impacts is evaluated using an impact index in three different littoral subzones: first the epilittoral zone is generally most affected by hydro-morphological alterations, followed by the eulittoral and finally the sublittoral zone. Finally, we can confirm that the HML protocol provides information on hydro-morphological shore alterations that helps decision makers to plan specific restoration measures in order to fulfil the requirements of the WFD.

Slovenia

It was developed a method for assessing those hydro-morphological alterations that cause some kind of response by lakeshore ecosystem, using benthic invertebrates as indicators. This method was applied in two Alpine lakes (Lake Bled and Lake Bohinj). Different levels of physical alterations and lakeshore uses were considered as well as variables for four lakeshore zones (littoral, shoreline and riparian zone and lakeshore region). On the basis of these four variables, a Lakeshore Modification Index (LMI) was developed as a weighted sum of all variables and without using biological data[75].

Among hydro-morphological methods that were developed within the scope of the WFD, the most comprehensive is the LHS that assess and characterizes physical habitats; respect to the two developed indices (LHQA and LHMS), LMI index is a combination of them. The number of categories used for the zonation of sampling plots differs between the two methods (LHS and LMI), three for LHS (littoral, shoreline and riparian zones) four for LMI. Also The LMI and LHS methods are different in terms of extent of the terrestrial lakeshore included in the assessment: the LHS includes a 15m wide band, whereas the LMI includes a 100m wide lakeshore zone. The LHS scoring system is unrelated to the response of the lake ecosystem, whereas the criteria developed for LMI are related to the richness of benthic invertebrates with different assessment weights. In addition, LMI is also useful for spatial planning, for environmental impact assessments of urban development plans and for understanding ecosystem response to human activities. In the future, this method will include biological data collected from lakes from other regions (lowlands and mountains)[75].

Switzerland

The protection of surface water is ruled by the "Federal Act on the Protection of Waters". According to this federal act " Everyone is required to take all the care due in the circumstances to avoid any harmful effects to waters" [76]. In fact, the Swiss cantons have to draw up a strategic plan for the recovery of their water basins by 2018. As a member of the European Environment Agency (EEA), Switzerland is expected to provide the Agency with data on the ecological status of its lakes. These data should respect the requirements of the EU WFD and include biological, chemical and hydro-morphological aspects. In fact, Switzerland must ensure that it has an appropriate methodology for water assessment in order to be able to include its lakes in a European classification in the future[76]. Recently, the federal office of the environment (Office fédéral de l'environnement, OFEV), with the collaboration of experts from Eawag and differents Cantons, published a working model to evaluate the state of Swiss lakes, entitled: System of analysis and appreciation of Swiss lakes (Méthodesd'analyse et d'appréciation des lacs en Suisse). This modular system generates a hierarchal structure based on a main objective of attaining a "natural state" in Swiss lakes[76]. Each module must be able to be applied independently. The physical module was divided in three sub-models:

1) hydrological regime;2) stratification;3) the morphological state of the lakeshores.

The later was developed first and before the other models and sub-model[76]. The others like biological model will follow as needed. The morphological state of the lakeshore Module, with the help of aerial photographs, it is possible to survey: 1) the actual lakeshore morphology and the uses; 2) the installations and control structures in and along the lakeside. The morphological state of the lakeshore is recorded directly in a Geographic Information System (GIS)[77].

Results and discussion

Studies on natural and artificial lakes have been developed since 1800 on different kinds of topics. Studies were related to pollution and eutrophication when chemical point of view was considered. Considering a biological point of view, research was focused on all the trophic elements, bacteria, phytoplankton, zooplankton, macroinvertebrates and fish. At the beginning, studies on the physical, morphological and hydrological aspects were developed considering only some features. Hydro-morphological aspects, as considered by WFD, have been studied only since the Nineties, and many studies have been developed to define methodologies useful to improve ecological quality, management of water resources, to reduce pressures of human activities and to reduce the impacts on biological communities. In fact, WFD have had consequences on environmental management of water resource and aquatic ecosystem promoting discussion and comparison among different European Member States so that it has been possible to harmonize classification and monitor methods across Europe[78]. Furthermore, the biotic communities of waters have become now the primary focus of assessment and legislation, rather than the more limited aspects of chemical quality, supporting data sampling and investigations, also in regions rarely investigated[78]. Thanks to field work and data processing by each Member States it is possible report here, the most frequent stress types on water bodies: i) general degradation (19%), ii) hydro-morphological degradation (10%), iii) habitat destruction (8%), iv) riparian habitat alterations (5%), v) catchment land use (4%), vi) flow modifications (4%) and vii) impact of alien species (4%) [78]. Analysing hydro-morphological pressures and biological elements at the same time has given the opportunity to deepen the link and relationship between biological quality elements and hydro-morphological aspects, developing specific project as WISER EU FP 7 project (www.wiser.eu – Water bodies in Europe: Integrative System to asses Ecological status and Recovery). In fact, it has been possible to define new biological metrics to assess hydro-morphological pressures. Macrophytes and benthic invertebrates reveal the two biological quality elements more sensitive to hydro-morphological pressures, in particular macrophytes are strictly related to level fluctuations and benthic invertebrates to morphological alterations of lake shores and physical habitats[79]. Another important point that appears from different methods is the evaluation of habitats, which are a fundamental element for biological communities. Definition and conservation of habitats are so important that in 1992 the Council Directive 92/43/EEC[80] on the conservation of natural habitats and of wild fauna and flora has been adopted, to promote the maintenance of biodiversity. For this Directive, natural habitats means, “terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural” and presents a list of different habitat typology to be preserved. A summary of lake habitats related to the evaluation of hydro-morphological pressures are reported in table 1. The presence of different habitats and their quality identifies the capability of a lake to support high biodiversity and therefore ecosystem quality and services. Habitats present on riparian, shore and littoral zone are features to assess into hydro-morphological method, to get a more complete view of: i) hydro-morphological features, correlated between human activities; ii) pressure on water body and biotic communities; iii) impact on ecological quality of the water body, to improve the management of Water Basin (WBMP) and to recover lake water bodies in according to WFD.

Table 1: Description of habitats connected with the evaluation of hydro-morphological pressures

Lake shore zone	Habitat
Riparian	Groundcover (trees, shrubs, grass, etc)
	Land use
	Presence of alien species
	Features of the top of the lake shore
Bankface/shore	Height and slope of the lake shores, presence of erosion
	Prevalent material of the lake shores, presence of vegetation
Bankface/beach	Type of material of the beach, slope, presence of vegetation
	Beach modifications, presence of erosion, deposition
Littoral	Prevalent substratum in the littoral zone

As regards the evaluation of habitats, it is important to remind that the United States Environmental Protection Agency (USEPA) has developed a monitoring program with different criteria for the evaluation of natural lakes and reservoirs from a biological point of view. In particular, in 1997 the Field Operations Manual for Lakes (FOLM) was developed[41]. The FOLM presents a handbook for collecting data, samples and information about biotic assemblages, environmental measures, or attributes of indicators of lake ecosystem condition. The procedures were developed based on standard or accepted methods, and the manual describes procedures for collecting chlorophyll, water, sedimentary diatoms, and zooplankton data in conjunction with the development of standard methods to obtain acceptable index samples for macrobenthos, fish assemblage, fish tissue contaminants, riparian birds and physical habitat structure.

Habitats are evaluated using two different kinds of variables

- Classification variables, such as geology, soil, lake morphology and catchment, which are intrinsic of the environment;
- Evaluation variables, which are represented by all the elements that are related to human impacts.

In table 2 the hydro-morphological methods actually present in Europe within different Member States are summarized, to highlight the hydro-morphological features sampled.

Most of methods reported in table 2 are applied through field survey and all of them use aerial imagines or orthophotomaps. All methods assess riparian and shore zone, and evaluate presence of artificial structure and artificial material. Almost all methods consider water level fluctuation bank structure and modifications features of littoral zone and littoral substrate, aquatic vegetation and lake cover.

Table 2: European hydro-morphological methods, application tools and features evaluated. Grey space indicates: "features not evaluated"

	LHS method	LMI index	HML protocol	SFI method	Alber & Charli protocol	Méthodes d'analyse et d'appréciation des lacs en Suisse
Field survey	X	X	X	X	X	
Orthophotomaps or aerial imagines	X	X	X	X	X	X
Water level fluctuation	X	X		X	X	X
Lake volume		X		X		
Feature of riparian zone	X	X	X	X	X	X
Feature of shore zone	X	X	X	X	X	X
Feature of littoral zone	X	X	X		X	X
Feature of lakeshore region		X				
Bank structure and modifications	X	X	X		X	X
Littoral substrate	X	X			X	X
Presence of artificial structure	X	X	X	X	X	X
Presence of artificial material	X	X	X	X	X	X
Natural exchange with groundwater						X
Sediment transport		X				
Aquatic Vegetation	X	X	X		X	X
Benthic invertebrates		X	X			
Fish fauna					X	
Land cover	X	X	X	X		X
Oxygen of water column	X					
Water temperature	X					X

Only two methods consider lake volume, water temperature and benthic invertebrates (table 2). Only one method considers natural exchange with ground water (Swiss method), only one consider oxygen of water column (LHS method), only one consider fish fauna (Alber & Charli protocol) and only one consider feature of lakeshore region (LMI index). All of the methods assess most of hydro-morphological parameters requested by WFD among these methods, but no one takes into account the parameters all together. Differences among methods are linked to lake typology and to pressure and impact problems, in addition to the hydrological, morphological, chemical, physical and biological available data. For example, Swiss method "Méthodesd' analyse et d' appréciation des lacs en Suisse" uses only orthophotomaps, aerial imagines and has a lot of official available data (morphological information, GIS data etc.[77]. LMI index evaluate a wide territory, more than LHS methods and it is more linked to biological communities, in particular to benthic invertebrates, rather than LHS methods[75]. HML protocol focuses on riparian and shore zone using more survey detailed respect to LHS method[74]. Alber & Charli protocol shares riparian, shore and littoral features with LHS methods but expands the application of water level fluctuation, considered a lot of type of reservoir management, introducing also fish fauna to analyse the impacts on them, due to morphological pressures as alteration of littoral habitats[63]. SFI methods mainly focus on riparian and shore zone, evaluating functionality of perilacual zone but without considering the whole lake from riparian to littoral zone and physics feature as water temperature and oxygen of water column[66]. LHS method is the most applied method in Europe[54]. It is possible to apply this method to small and large lakes, even if for large lake it loses a bit of detail. It does not consider natural exchange with groundwater and sediment transport. As all the other methods reported here, it gives a lot of importance to habitat features (table 1). Keeping in mind biological elements assessment into different methods and all studies developed regarding relationships among hydro-morphological feature/pressure and these quality elements, it is possible to summarize interactions between hydro-morphological and biological parameters (table 3).

Table 3: Summary of the impacts on biological indicators due to hydro-morphological pressures, according to the WFD. (X= impact, XX= strong impact)

Physical and hydro-morphological parameters	Phytoplankton	Macrophytes	Macrobenthos	Fish
Coast line		X	X	X
Structure of the littoral area		XX	XX	XX
Quality and quantity of the substratum		XX	XX	XX
Increase of the sediment of the bottom	X	X	X	X
Fluctuation in water level	X	XX	XX	XX
Influence of groundwater				
Residence time	X		X	X
Changes in the thermocline depth, stability, stratification	XX			
Meromixis			X	XX

The interactions reported in table 3 represent the most known direct impact between particular hydro-morphological pressures and those biological elements, more sensitive to them[79]. However, it is possible that other impacts, less important or not known now, are present on different biological elements without clear consequences. Hydro-morphological pressures can have an unknown indirect impact on other biological elements not usually considered, such as for example, the impact of groundwater quality on phytoplankton or fishes. Indeed, the effects of human pressures are rarely isolated, and a single pressure can often create different direct or indirect impacts on biota causing effects on habitat, hydro-morphological, physical and chemical quality. Moreover, pressures within lake catchment cause impacts on hydrology and morphology, related for example to sediment transport[43]. To date, impacts on ecosystem from sum of pressures and from pressures prolonged in time don't know, as well as effects of these pressures on biological quality elements, habitats and hydro-morphological aspects.

Conclusions and Recommendations

Therefore, as regards the relationship between hydro-morphological parameters and biological communities, further detailed studies are necessary. Hydro-morphological methods evaluated in this paper have been defined not using biological data but only abiotic information such as lake level variation, features of shore or littoral zone etc., but their fulfilment considers also biological aspects such as macrophytes, presence of macroinvertebrates, different type of algae. The contemporary collection of abiotic data and biological information has become very important to get defined, structured and statistically verified link and relationships between hydro-morphological features and biological/ ecological lake quality. It knows that for example, macrobenthos or macrophytes are linked with features of habitat and presence of shore zone artificialisation, but it doesn't know how and in what way there are linked. Latest studies[79,71] emphasize the importance of finding a methodology able to assess hydro-morphological features, habitats, pressures of human activities and infrastructures and their impact on biological communities and lake ecosystem. The solution can be a simultaneous sampling of biological quality elements with application of hydro-morphological methods, accurately planned and realized, on different habitats. Statistical analyses can also help to define relationships and links between pressures and impacts. All data have to be collected with focus on the link among hydro-morphological pressures and biological impacts as well as abiotic features and ecosystem[71]. The highlight of these connections is the basis of any future action of requalification, management and lake ecosystem protection, taking into account its uses and its socio-economic importance.

Analysing all the methods used around Europe on lake hydro-morphology, we can conclude that a lot of work has been done on field surveys, the evaluation of features, data analyses, and collection of different kind of data (Ortophotomaps, aerial images, field survey). The WFD is important and fundamental for lake management and ecosystem services protection. Despite this a lot of aspects still remain to be clarified and studied, such as 1) relationship between pressure on abiotic aspect and impact on biological community and ecosystem, in time; 2) consequences of more than one pressure on biological elements; 3) how to consider climate change within WFD request and within pressure and impact analyses. Moreover, the ecological quality of reservoirs is strictly linked with their use and a methodology to define this ecological quality is under study, because of the socio-economic importance of these uses. Further studies and insights at European level are needed, keeping in mind the differences regarding lake typology, climate, water uses and quality.

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