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EVALUATION OF THE ECOLOGICAL STATUS OF NATURAL LAKES IN SPAIN: OVERVIEW OF THE WORKS PERFORMED BY THE CEDEX FOR THE IMPLEMENTATION OF THE WATER FRAMEWORK DIRECTIVE

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Abstract

This paper presents an overview of the work that has been done by the CEDEX for the implementation in Spain of the Water Framework Directive on water bodies belonging to the lake category. Firstly, the current national lake typology was developed according to the system B of Water Framework Directive: 30 types of natural lakes were defined according to 9 factors. Next, a selection of reference sites was done based on 9 criteria. After the contrast with River Basin Administrations, up to 70 lakes were selected as possible reference stations. Afterwards, an ecological assessment system has been developed for natural lakes, which includes a selection of metrics for biological, physical and chemical, and hydromorphological quality elements, and sampling and determination protocols. For all these metrics, reference conditions and ecological status class boundaries for each type of lake have been defined, based on the available data of the monitoring networks, scientific data, and expert judgment.

Keywords: natural lakes typology, selection of reference sites, ecological status assessment system, quality elements, pressures, sampling protocols

1. Introduction

The Water Framework Directive (WFD) establishes as mandatory to identify the location and boundaries of lake water bodies including all those which are larger in size than 50 ha. According to this Directive, next step is the characterisation of the lake water bodies in types and the assignment of each one to any of these types. The main goal in the definition of these types is to simplify the natural variability in order to ensure type-specific reference conditions can be more easily established. To define these types, WFD establishes two possibilities: system A or system B. The first one is a closed system based on the separation of different ecorregions of the European Union and the use of some mandatory descriptors. System B allows the use of optional descriptors in order to consider the specific characteristics of natural lakes located in each country.

Once the lake typology has been established, next main task is to establish an ecological status assessment system according to biological, hydromorphological and physical-chemical quality elements. Assessment through Biological Quality Elements is a priority, whereas the assessment based on the other two kinds of quality elements has to support the biological assessment. For the Biological Quality Elements an important point is to define type-specific biological

reference conditions. Up to four options can be followed to do this task (CIS Working Group 2.3, 2005): (i) spatially based definition by using data from monitoring sites, (ii) establishment of reference conditions based on predictive modelling or hindcasting methods, using historical data or paleoreconstruction, (iii) expert judgement and (iv) a combination of all options. The priority, and easiest option, is the first one, but this requires a previous selection of reference sites of each lake type.

At the beginning of the implementation of the WFD in Spain, very few lakes were declared as water bodies in the lake category, identifying only those which satisfied the mandatory criterion on surface area larger than 50 ha. As a consequence of this criterion, most of our important richness in natural lakes could not be fully protected under the most recent legislation related to conservation and protection of water ecosystems. For this reason, the competent Spanish Authorities decided to establish a wider criteria and additional lakes and wetlands were also declared as lake water bodies which shall fit all the requirements of WFD in order to achieve at least the final objective of this Directive, "the good ecological status".

Under the collaboration agreement with the Spanish Ministry of the Environment and Marine and Rural Affairs (MARM), the Department of Aquatic Environment of the Centre for Hydrographic Studies of the CEDEX, with the collaboration of the University of Valencia coordinating a group of recognized experts in lake ecology, have achieved three of the main WFD requirements for the implementation of the Directive for lake water bodies: establishment of a national typology, selection of reference sites and design of a assessment system of the ecological status on natural lakes. These tasks have been carried out by adapting the methodological criteria of WFD to the reality of the Spanish natural lakes. Typology has been made following the system B (CEDEX, 2008), which lets to consider some essential descriptors for the Spanish lakes, like the salinity and the temporary water residence (Bécares *et al.*, 2004). Selection of reference sites has been made taking into account the main difficulty to accomplish this task: most types do not have lakes in true reference conditions since at least one of the criteria is not totally fulfilled (CEDEX, 2009a). Finally, the ecological status assessment system was made according to two options: data from monitoring networks combined with expert judgement. (CEDEX 2009b, 2009c, 2009d and 2009e). Some specific characteristics of Spanish lakes had to be considered in this assessment system, like the temporal variability of some indicators and the relatively higher importance of hydromorphological pressures in the Mediterranean region compared to other European lakes.

2. Materials and methods

2.1. Establishment of a nationwide lake typology

a) Background

The Spanish natural lake typology was designed to include all natural lakes that have been declared as waterbodies by the competent Water Administrations. According to the Spanish Water Management Instruction (BOE, 2008), wider criteria than those of the lake size, such as being included in Ramsar sites or their ecological values, are suitable to be used to declare lakes,

and the associated wetlands, as waterbodies according to the definition of the WFD.

b) Descriptors of the lake typology

This natural lake typology considers 9 descriptors which reflect the main abiotics factors to characterize the Spanish lakes and wetlands. They can be classified in the following kinds of descriptors: climatic, morphological, hydrological, chemical and others like the origin. Table 1 shows these descriptors classified in the mentioned groups, as well as those lake types which are distinguished by each descriptor.

Table 1: Spanish natural lakes typology descriptors (CEDEX, 2008)

Descriptors groups	Descriptors	Distinguished types
Climatic	Humidity index[1]	Distinguishes mountain lake types from the other lake types
	Altitude	Separates among high mountain lake types, medium mountain lake types, inland and karstic lake types and coastal lake types
Morphology	Max depth	Distinguishes deep high mountain lake types from shallower high mountain lake types
	Size	Distinguishes the large karstic evaporate lake type from small karstic evaporite type
Hydrology	Inflow regime	Separates karstic lake types whose water inflows are ground waters from karstic lake types whose water inflows are both ground and surface waters
	Temporality	Distinguishes permanent inland lake types from temporal inland lake types
Chemical	Conductivity	Separates inland lake types according to their salt content when the water level is the highest
	Alkalinity	Distinguishes low-akalinity mountain lake types from alkaline mountain lake types
Others	Origin	Specifically, it distinguishes the following origins: glacial, karstic, humid dune slacks, and fluvial.

[1] Ratio between Mean Annual Precipitation and Potential Evapotranspiration according to Pennan – Monteith method

2.2. Selection of sites in reference conditions for the lake category.

a) Background

According to the Guidance on establishing reference conditions and ecological status class boundaries for inland surface water (CIS Working Group 2.3. –REFCOND, 2005), the selection of reference sites have to be made preferably according to pressure criteria of the water bodies and environmental criteria have to support and validate this selection.

Yet, a detailed study about anthropogenic pressures and impacts on the water bodies belonging to the lake category has not been carried out in Spain. Furthermore, according to the established criteria by the Spanish Hydrological Planning Instruction (BOE, 2008), many inland and coastal lakes and wetlands identified as water bodies which are located in areas surrounded by agricultural lands, could not be considered as true reference sites for their lake types. This lack of information about pressures and impacts and the difficulty to find reference sites in some types have hampered up to now the task of selection of reference sites.

b) Criteria for reference sites of the lake category

The selection of reference sites included in lakes category has been made following 10 criteria: 9 pressure criteria and 1 ecological criterion, the trophic status. Not all criteria have been proposed for the selection in all lake types and for some of these criteria, different thresholds of selection have been proposed according to specific lakes types. For the establishment of these thresholds, especially those referred to land uses, criteria considered by previous works, like the criteria established by the different Lake Goegraphical Intercalibration Groups (JRC, 2009) and those established by some Spanish River Basin Authoroties (ACA, 2003 and 2004, and CHE, 2008), have been taken into account. Table 2 reflects the criteria and their thresholds used for the selection of possible reference sites.

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Table 2. Criteria used for the selection of reference lakes

Criteria	Type and thresholds
Land uses (% of the surface catchment use)	< 10 % agricultural use (mountain lakes types) < 30 % agricultural use (karstic lakes types) < 50 % agricultural use (inland and coastal lakes and wetlands types)
	0 % Irrigation agricultural use (mountain lake types) < 10 % Irrigation agricultural use (karstic lakes types) < 15 % Irrigation agricultural use (inland and coastal lakes and wetlands types)
	0 % urban use (mountain lakes types) 1 % urban use (karstic lakes types) 2 % urban use (inland and coastal lakes and wetlands types)
Morphological pressures	No morphological pressures which could cause any meaningful alteration in biological communities do exist.
Hydrological pressures	No hydrological pressures which could cause any meaningful alteration in biological communities do exist.
Exotic species introduction	No introduction of invading species causing any meaningful alteration in the biological communities does exist
Existence of wastewater spills	No direct wastewater spills do exist (mountain lakes types) No meaningful direct wastewater spills do exist (karstic lakes types and inland and coastal lakes and wetlands types)
Recreational use	No intensive recreational use does exist.
Connection with the ground water bodies	No meaningful alteration in the connection with the associated water body does exists
Status of the associated groundwater bodies	No risk to accomplish the environmental goals of groundwater bodies according to WFD does exist.
Status of associated surface water bodies	No risk to do not accomplish the environmental goals according to WFD does exist.
Trophic status[1]	Low levels of eutrophication (different levels have been considered for the different natural lakes types according to expert criterion)

[1] This ecological criterion has been used to validate the selection according to the pressure criteria, but in inland and coastal lake types it has also been used to select lakes as a benchmark of the best ecological status among those included in these types

c) Process of selection of reference lake sites.

Firstly, a preliminary proposal was made by the Center for Hydrographic Studies of CEDEX to the MARM according to the described criteria (Table 2). This selection differentiated between lakes which fit all criteria and those lakes which did not fit one or some of them. Most among the later are water bodies included in inland and coastal lakes types which were selected as indicators of best ecological status among the lake type according to criterion of trophic status. The main sources of information which were considered are the following:

- Data base of wetlands from Peninsular Spain (MIMAM, 2000)
- Biological Data Base (MARM, 2009a)
- Official Information Sheets on Ramsar Wetlands (Ramsar, 2008)
- Regional lakes inventories
- Monitoring networks from Spanish River Basin Districts
- GIS Shape of land use (CORINE, 2000)

This previous selection was distributed to all Spanish River Basin Authorities in order to contrast and adjust it according to the available information on this subject and their technical criteria. As result of this revision, a final proposal was made.

2.3. Establishment of a system for the assessment of ecological status of water bodies belonging to the lake category

a) Background

According to the Guidance on establishing reference conditions and ecological status class boundaries for inland surface water (CIS Working Group 2.3. –REFCOND, 2005), the assessment system of biological quality elements: phytoplankton, other aquatic flora, benthic invertebrate fauna and fish fauna is a priority, whereas the assessment according the hydromorphological and physical-chemical elements is important in the sense that these elements support the biological elements and it is only deciding for the assessment of the certain ecological classes. For the biological quality elements, the first step in this system is to define reference conditions according the following options: (i) spatially based definition by using data from monitoring sites, (ii) establishment of reference conditions based on predictive modelling or hindcasting methods, using historical data or paleoreconstruction, (iii) expert judgement and, (iv) a combination of all options. Once reference conditions have been defined, the next step is to establish the ecological status class boundaries, both metric units and EQR (Ecological Quality Ratio).

In Spain, the monitoring networks of lakes in all the River Basin Districts started to work few years ago, but no official protocols and metrics were available to be applied in these networks. As a consequence, the usefulness of the information from these monitoring networks, considering both quantity and quality, was not as good as desirable. Some of the Spanish River Basin Administrations have now developed assessment systems of ecological status of water bodies belonging to the lake category which have been taken into account in the proposal reflected in this paper. These systems are the following:

- ACA (2003, 2004)
- Departamento de Ordenación del Territorio y Medio Ambiente del Gobierno Vasco (2004)

- CHE (2008)
- CHG (2009)
- Nature Directorate of the MARM (Camacho *et al.*, 2009)

b) Criteria for the selection of metrics for the assessment of quality elements

In the selection of metrics for the assessment of ecological status according to the different quality elements, metrics which have been used in Spain previously by the River Basin Administrations have been evaluated. Other metrics considered in other European countries (Solimini *et al.*, 2007) have also been taken into account.

The selection of metrics for the assessment according to the biological elements (phytoplankton and other aquatic flora) is based on the following criteria:

- Simplicity of their application.
- Need of information for their application.
- Possibilities to extend the application of the metrics to all lake types.
- Correlation with the pressure indicators.
- Reliability and uncertainty
- Fulfilment of the requirements of the WFD

The selected metrics for phytoplankton try to assess the eutrophication pressure, since this Biological Quality Element is the best indicator for describing the intensity of this pressure (Willen, 2000, Wetzel, 2001), whereas metrics selected for other aquatic flora are focused to assess the hydromorphological pressures because macrophytes' development is a very good indicator of this kind of pressures (Hellsten, 2009). Furthermore, according to this Biological Quality Element some simple metrics have proposed to assess other two pressures: introduction of exotic macrophyte species and eutrophication. In shallow lakes the abundance of certain macrophytes related to eutrophication is a good indicator of the trophic status, (Scheffer, 1998; Mitsch y Gosselink, 2007). Moreover, microphytobenthos is as well a good indicator of eutrophication for certain lake types (Carvalho *et al.*, 2006).

Regarding the other two biological quality elements, benthic invertebrate fauna and fish fauna, the assessment system for the first one is being developed by other experts contracted by the MARM. Concerning fish fauna, for the time being, no proposal is going to be done since most natural lakes are fishless in natural conditions and there is a strong lack of knowledge about the lacustrine fish fauna in Spain.

Finally, in the selection of metrics for the assessment of hydromorphological and physical-chemical elements, the main task has been evaluating their influence on the status of biological quality elements. Furthermore, other specifics questions have been considered such as the use of mandatory physical-chemical parameters for lake monitoring according to the draft protocol for phytoplankton (MARM, 2009a), and the selection of simple metrics for the hydromorphological elements based on the identification of meaningful alterations of these kind of indicators.

c) Criteria for the definition of reference conditions and the establishment of ecological status class boundaries

The definition of reference conditions and the establishment of the boundaries between status classes for the quality elements phytoplankton and other aquatic flora have been made according to different criteria: using data from monitoring of reference sites as well as expert judgment. For the first option, the considered percentiles for the definition of Good/Moderate boundary are nor very strict considering that selection criteria of reference sites have applied in an flexible way and for some lakes types, not truly reference sites has been selected (just as indicative). For the second option, all the available data from the monitoring of lakes have used (EPA, 2000) in order to support this criterion for the definition of reference conditions in lakes types located in agriculture areas, like most of our lakes and wetlands belonging to inland and coastal lake types. Another used tool has been the grouping of the lakes belonging to closets' similar lakes types, and the application of ecological concepts (Wetzel, 2001), once the statistical results of these groups of lakes types were obtained

The data used from the establishment of reference conditions come mainly from the Biological Data Base of the Water Directorate of the Spanish Ministry of Environment and Marine and Rural Affairs (MARM, 2009a) as well as from the monitoring networks of River Basin Administrations. Furthermore, data from scientific publications have been considered in order to have more data to support our proposal.

Nevertheless, only phytoplankton data which satisfied the requirements of the draft protocol of phytoplankton sampling in lakes and reservoirs (MARM, 2009b) have been considered. In case of macrophtyes, not any official sampling protocol was applied and thus the usefulness of these available data has been limited.

All the values established following these criteria have been reviewed according to expert judgement. Remarkably, in the proposed metrics for macrophytes, the expert judgment has played a major role because of the lack of reliable information from monitoring networks.

Other options like predictive modelling, historical data or paleoreconstruction, have not been used to make this proposal, but for a future revision they could be taken into account, specially, for those lakes types which no or very few lakes in real reference conditions appear.

Table 3 shows the finally adopted criteria to establish reference conditions and ecological class boundaries respect to the using of data from lake monitoring

Table 3. Criteria for the definition of reference conditions and the establishment of class boundaries of ecological status based on data from lake monitoring (CEDEX, 2009a)

Situation of lakes types	Reference conditions	Good/Moderate	Other boundaries
Data from monitoring of reference sites (conclusive)[1]	Median of the data distribution on reference sites	Percentile 75th or 25th[2] of data distribution on reference sites	The other boundaries are proportionally distributed[3]
Data from monitoring of all water bodies belong to each lake types (indicative, but not conclusive)[5]	Percentile 25th/10th or 75th/90th[4]	Statistical distribution has been considered, but fixed percentiles have not been defined	The other boundaries are proportionally distributed[3]
Data from water bodies belonging to similar lakes types (indicative, but not conclusive)[5]	Median of the data distribution on reference sites	Percentile 75th or 25th[2] of data distribution on reference sites	The other boundaries are proportionally distributed[3]

[1]According to Guidance on establishing reference conditions and ecological status class boundaries for inland surface water (CIS Working Group 2.3. –REFCOND, 2005), in some lakes types, those which have some meaningful alteration affecting only one of the Biological Quality Elements have been considered as reference sites for the other Biological Quality Elements (It is the case of mountain lakes which have hydromorphological modifications by hydropower use which affects the status of the macrophtyes but not so phytoplankton)

[2] If the metric has a positive correlation with the pressure, the 75th percentile for data on reference sites is used to establish the boundary between good and moderate status, whereas if the metric has a negative correlation with the pressure, 25th percentile is used

[3] if the metric has positive correlation with the pressure indicator, values of the proposed metrics above the 95th percentile have been considered as outliers and have consequently been eliminated, but when metric has a negative correlation with the pressure indicator, values below 5th percentile have been also considered as outliers and eliminated

[4] For metrics with positive correlation, 25th percentile has been considered as informative for the establishment of reference conditions, and 10th percentile in the case of lake types with higher levels of pressure, whereas if the metric has a negative correlation with the pressure indicator, 75th percentile has been considered, or 90th in case of lakes types with higher levels of pressure

[5] These two options have been used only as indicative, in order to support the judgment criteria trying to use all the scarce available data from lakes monitoring

Concerning the proposed metrics for the assessment of physical-chemical elements, the same criteria have been used to establish the mandatory class boundaries: High-Good and Good-Moderate, whereas for the proposed metrics for the assessment of hydromorphological elements, the main criterion used to establish the only mandatory class boundary, High-Good is the presence or absence of modifications of any metrics selected for this kind of elements which means a meaningful alteration in any of the Biological Quality Elements.

d) Description of the process for the establishment of a system for the assessment of ecological status

Firstly, a selection of metrics for the assessment of biological quality elements was made according to the adopted criteria and considering the previously used metrics in Spain. The main objective was to propose simple and reliable metrics which could be adopted in the imminent River Basin Management Plans (2009-2015) and according to the current state of lack of information.

The selection was made in two different reports: one for phytoplankton (CEDEX, 2009b)

and another one for "Other aquatic flora" (CEDEX, 2009c) following the adopted criteria. Furthermore, sampling protocols for these Biological Quality Elements were proposed. Draft reports were produced by CEDEX in collaboration with the University of Valencia, and subsequently they were reviewed by Spanish recognized experts.

Once this selection was made, an additional draft report was produced (CEDEX, 2009d) establishing reference conditions and ecological status class boundaries for the selected metrics for the two Biological Quality Elements. Furthermore, rules for the combination of different metrics related to the same biological quality element were proposed following the criteria given by MARM (2009c). Similarly, this report was written by CEDEX and the University of Valencia and reviewed by experts.

Regarding the hydromorphological and physical-chemical elements, the process was similar. Firstly, a selection was made according to the described criteria and secondly a proposal of the mandatory class boundaries was made. In this case, both tasks were reflected in the same report (CEDEX, 2009e).

All reports were sent for reviewing to each River Basin Authorities. Once their reviews were received, final versions of these reports were made and a final system for the assessment of the ecological status of the water bodies belonging to lakes category was established for the River Basin Management Plans (2009-2015).

3. Results

3.1. Lake typology

The final version of the Spanish natural lakes typology (CEDEX, 2008) has 30 types, including 9 mountain lake types, 6 karstic lake types, 12 inland lake types and 3 coastal lake types. Table 4 shows the natural lake types grouped in these four main classes. These types have been characterized according to 9 descriptors, some of them being determinant to distinguish certain types from others (Table 5)

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Table 4. Types of natural lakes according to the Spanish typology for lake waterbodies (CEDEX, 2008)

Mountain lakes		Inland lakes	
Number	Denomination	Number	Denomination
1	High mountain, northern, deep, acid waters	16	Inland lakes, low mineralization, permanent
2	High mountain, northern, deep, alkaline waters	17	Inland lakes, low mineralization, temporal
3	High mountain, northern, little deep, acid waters	18	Inland lakes, middle mineralization, permanent
4	High mountain, northern, little deep, alkaline waters	19	Inland lakes, middle mineralization, temporal
5	High mountain, temporal, acid waters	20	Inland lakes, high or very high mineralization, permanent
6	Middle mountain, deep, acid waters	21	Inland lakes, high or very high mineralization, temporal

7	Middle mountain, deep, alkaline waters	22	Inland lakes, hypersaline, permanent
8	Middle mountain, little deep, alkaline waters	23	Inland lakes, hypersaline, temporal
9	High mountain, southern	24	Inland lakes, fluvial origin, flood plain, low or middle mineralization
Karstic lakes		25	Inland lakes, fluvial origin, flood plain, high or very high mineralization
Number	Denomination	26	Inland ox-bow lakes, fluvial origin, abandoner meander
10	Karstic, calcareous, fed by groundwaters	27	Inland lakes, associated to alkaline peat moss
11	Karstic, calcareous, permanent, spring	**Coastal lakes**	
12	Karstic, calcareous, permanent, travertine-dam	Number	Denomination
13	Karstic, calcareous, temporal	28	Coastal lakes without marine influence
14	Karstic, evaporite, fed by groundwaters or mixed feeding, large	29	Humid dune slacks, permanent
15	Karstic, evaporite, fed by groundwaters or mixed feeding, small	30	Humid dune slacks, temporal

Table 5 shows the range of values of descriptors which define the lake typology differentiating with blue colour those which are determinant to distinguish specific lakes types.

Table 5. Range of values or qualities of the descriptors which define Spanish lakes typology (see CEDEX, 2008, for further detail)

Nº	Humidity index	Altitude (m)	Origin	Inflow regime	Temporality	Size (ha)	Max depth (m)	Conductivity (µS/cm)	Alkalinity (meq/l)
1	≥2	≥1500	Glacial	Surface Waters	Permanent	<50	≥10	<500	<0,2
2	≥2	≥1500	Glacial or glacio-karst	Mixed	Permanent	<50	≥10	<500	≥0,2
3	≥2	≥1500	Glacial	Surface Waters	Permanent	<50	<10	<500	<0,2
4	≥2	≥1500	Glacial or glacio-karst	Mixed	Permanent	<50	<10	<500	≥0,2
5	≥2	≥1500	Glacial	Surface Waters	Temporal	<50	<3	<500	< 0,2
6	≥2	900-1500	Glacial	Surface Waters	Permanent	≥50	≥10	<500	<0,2
7	≥2	1000-1500	Glacial or glacio-karst	Mixed	Permanent	<50	≥10	<500	≥0,2
8	≥2	1000-1500	Glacial or glacio-karst	Mixed	Permanent	<50	<10	<500	≥0,2
9	<2	≥2000	Glacial	Surface Waters	Permanent	<50	≥3	<500	<1
10	<2	15-1500	Karstic-calcareous	Groundwater	Permanent	<50	≥3	<3000	≥1
11	<2	5-1500	Karstic-calcareous spring	Groundwater	Permanent	<50	<3	500-3000	≥1

Nº	Humidity index	Altitude (m)	Origin	Inflow regime	Temporality	Size (ha)	Max depth (m)	Conductivity (µS/cm)	Alkalinity (meq/l)
12	<2	15-1500	Karstic-calcareous Travertine-dam	Mixed	Permanent	——	≥3	<3000	≥1
13	<2	15-1500	Karstic-calcareous	Underground Waters	Temporal	<50	≥3	<3000	≥1
14	<2	15-1500	Karstic-evaporite	Underground Waters or Mixed	Permanent	≥50	≥3	500-3000	≥1
15	<2	15-1500	Karstic-evaporite	Underground waters or Mixed	Permanent	<50	≥3	500-50000	≥1
16	<2	15-1500	Others	Mixed	Permanent	——	<5	<500	——
17	<2	15-1500	Others	Mixed	Temporal	——	<3	<500	——
18	<2	15-1500	Others	Mixed	Permanent	——	<3	500-3000	≥1
19	<2	15-1500	Others	Mixed	Temporal	——	<3	500-3000	≥1
20	<2	15-1500	Others	Mixed	Permanent	——	<3	3000-50000	≥1
21	<2	15-1500	Others	Mixed	Temporal	——	<3	3000-50000	≥1
22	<2	15-1500	Others	Mixed	Permanent	——	<6	>50000	≥1
23	<2	15-1500	Others	Mixed	Temporal	——	<3	>50000	≥1
24	<2	5-1500	Fluvial. Flood plain	Mixed	———	——	<3	<3000	≥1
25	<2	5-1500	Fluvial. Flood plain	Mixed	———	——	<3	3000-50000	≥1
26	<2	5-1500	Fluvial. Ox-bow lake	Mixed	———	——	<10	500-3000	≥1
27	<2	15-1500	Associated to alkaline peat moss	Groundwater	Permanent	<50	<3	3000-50000	≥1
28	<2	<15	Coastal lakes without marine influence	Mixed	Permanent	——	<3	500-50000	≥1
29	<2	<70	Humid dune slacks	Mixed	Permanent	——	<3	<3000	≥1
30	<2	<70	Humid dune slacks	Mixed	Temporal	<50	<3	<3000	≥1

3.2. Selection of sites in reference conditions for the lake category.

The final version of reference sites for the lake category, including the revision made by the Spanish River Basin Administrations, contains 70 sites. These must be considered as possible sites and subsequently studies of the impacts and pressures on these water bodies and information derived from ongoing monitoring networks, will let to redefine this selection and to establish a new list. For some lakes types, mostly inland and coastal lake types, these sites should be considered as a benchmark for the best ecological status of those lakes belonging to these types.

Map in Figure 1 shows the previous selection differentiating between lakes which fit all the selection criteria and those which do not fit at least one of the criteria but are those in best status among the lake type waterbodies.

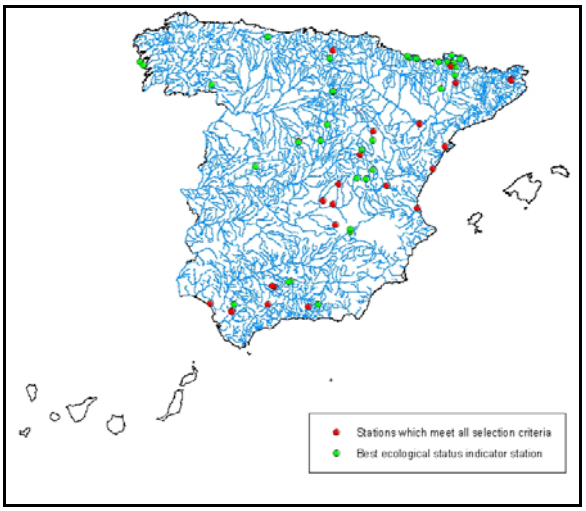

Figure 1. Previous selection of reference sites in the lake category (CEDEX, 2009a)

Next map in the figure 2 shows the location of the lakes proposed as possible reference sites for the lake category.

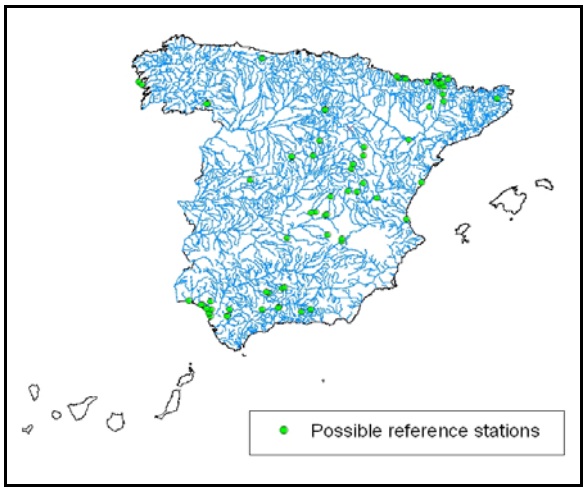

Figure 2. Location of possible reference sites belong to lakes category (CEDEX, 2009a)

3.3. Assessment system of ecological status of water bodies belonging to the lake category

a) Selection of metrics for the assessment of ecological status according to the quality elements

The selection of the metrics for the assessment of ecological status according to the biological quality elements has been made following the criteria described in the section 2 of this paper and trying to fulfil with the requirements of the Water Framework Directive (DOCE, 2000), but conditioned by the current state of information on this subject. Table 6 shows the selected metrics for the Biological Quality Elements: Phytoplankton and "Other aquatic flora", specifying the lake types for which they apply and the assessed pressures

Table 6.- Metrics selected for the assessment of Biological Quality Elements (BQE) in Spanish lake waterbodies (CEDEX, 2009b, 2009c)

BQE	Metrics	Applies on types	Assessed pressures
Phytoplankton	Chlorophyll *a* concentration	All types	Eutrophication
	Total Phytoplankton Biovolume	Types 1 to 15	Eutrophication
	InDia (Diatom index)[1]	Types 1 to 4	Eutrophication

BQE	Metrics	Applies on types	Assessed pressures
Other aquatic flora	Presence/absence of hydrophytes[2]	Types 1 to 8	Hydromorphological pressures
	Species Richness of macrophytes[3]	Types 10 to 12, 14 to 20, 24 to29	Hydromorphological pressures
	Total coverage of hydrophytes[3]	Types 10 to 12, 14 to 16,18, 20 to 29	Hydromorphological pressures
	Total coverage of helophytes[3]	Types 10 to 12, 14 to 16,18, 20 to 29	Hydromorphological pressures
	Total coverage of macrophytes (hydrophytes + helophytes)[3]	Types 17, 19 and 30	Hydromorphological pressures
	Total coverage of eutrophication indicator macrophytes species[3]	All types	Eutrophication
	Total coverage of exotic macrophyte species[3]	All types	Introduction of exotic macrophyte species

[1] InDia is a metric developed for the assessment of eutrophication of mountain lakes of the Pyrenees (ACA, 2004) based on the indicator value of diatoms species.
[2]This metric is applied only for those mountain lakes which have macrophytes under natural conditions, in Spain lakes below 2300 msm (Gacia *et al.*, 1994 and ACA, 2004)
[3] Only typical macrophytes of each lake types are considered for these metrics. In order to estimate the total coverage only those zones in the lakes where growth of macrophytes communities is possible are considered:

Similarly, the selection of metrics for the assessment of hydromorphological and physical-chemical elements has been made according to the criteria mentioned in the section 2 of this paper. Table 7 shows this selection specifying the lake types for which the application of these metrics is proposed, and which specific quality elements which are assessed by them.

Table 7.- Metrics selected for the assessment of physical-chemical and hydromorphological elements in Spanish lake waterbodies (CEDEX, 2009e)

Quality element	Metrics	Applied types	Assessed quality element
Physical-chemical elements	Secchi Disk	Types 1 to 15	Transparency
	Conductivity	All types	Salinity
	pH	All types	Acidification status
	Alkalinity	All types	Acidification status
	Total Phosphorus	All types	Nutrients conditions
Hydromorphological elements	Alteration of stratification regime	Types 1 to 15	Thermal conditions
	Alteration of temporality and fluctuation regime	All types	Quantity and dynamics of water flow
	Alteration of sedimentation regime	All types	Lake depth variation
	Alteration in the state and structure of lake bed	All types	Quantity, structure and substrate of the lake bed
	Alteration in the state and structure of lake shore	All types	Structure of the lake shore

b) Reference conditions and ecological status class boundaries

Reference conditions and ecological status class boundaries for the biological quality

elements have been established according to the criteria and the process described in section 2 of this paper.

In case of phytoplankton, reference conditions and ecological class boundaries have been established for chlorophyll *a* concentration for all lakes types. With respect to Total Phytoplankton Biovolume, reference conditions and ecological class boundaries have been established only for mountain and karstic lakes types because of the lack data, both quantity and quality, for the inland and coastal lakes types

Some exceptions have been considered for the application of the proposed ecological class boundaries of phytoplankton metrics like the overpopulation of birds in some lakes and wetlands included in the lakes types (15-30), which suppose an increase in the trophic state not directly related to anthropogenic pressures.

This system does not fully meet the criteria established by WFD for the assessment of ecological status according to this Biological Quality Element, because composition and phytoplankton blooms are not assessed. On this subject, a caution criterion of not proposing any metrics without a previous test and validation, and the consideration of the lack of knowledge and expertise in the application of this kind of metrics in most of Spanish lakes types, has been a priority, thus avoiding making an uncertain proposal for this step of WFD implementation.

With respect to the reference conditions and ecological class boundaries for the BQE "Other Aquatic flora", the proposed system is an asymmetric system. So, according to the lakes types, some specific metrics and not all, have been proposed for their assessment in any lake type. Most proposed metrics are based on macrophytes and most of them assess hydromorphological pressures. In the case of pressures by eutrophication and exotic species introduction, simple metrics based on the coverage of macrophytes species which are indicators of these kinds of pressures have been proposed. Only one metric which assess phytobenthos has been proposed, as the use, for the high mountain, northern, lakes types (types 1-4), of the metric called InDia (ACA, 2003) based on the indicator value of diatom species for the assessment of eutrophication pressure.

The values of the reference conditions and ecological class boundaries have been established according to the criteria and the process described in the section 2 of this paper, mainly based on the expert judgment criterion for the proposed values for macrophyte-based metrics. Some exceptions have been established for their application considering the specific characteristic of the Spanish lakes. The most important are the following:

- Altitude of the high mountain lakes (mountain lakes above 2300 msnm do not have macrophytes under reference conditions (Gacia *et al.*, 1994)
- Natural turbidity which avoid the development of macrophytes.
- > 80 % total surface of shallow inundated area and non inundated shore of lakes occupied by substrate unable for colonisation by macrophytes.

An important point for the application of the proposed classification system for macrophytes has been the development of the list of macrophytes species: typical of each lakes types,

as well as indicator species for of eutrophication pressures and exotic macrophyte species.

All the information about the proposed values for reference conditions and ecological class boundaries for these two Biological Quality Elements are reflected in the mentioned report (CEDEX, 2009c).

An important point, which this ecological classification system has not been deeply considered because of the lack of information, it is the temporary variability of the Spanish natural lakes. The seasonal variability has been corrected considering different period of year depending of the specific lakes types for the application of the proposed ecological class boundaries and this has been reflected in the mandatory sampling periods established in the protocols. Nevertheless, the interannual variability, very typical of most of Spanish lakes, has been considered in the calculation way of the ecological status based on interannual data, although this question has to be addressed with more detail for a future revision of this assessment system,

In the case of hydromorphological and physical-chemical quality elements, only values for the mandatory boundaries have been established (High/Good and Good/Moderate for physical-chemical quality elements and High/Good for hydromorphological quality elements). The proposed values try to support the assessment according to the Biological Quality Elements. Special care has been taken for the establishment of the Good /Moderate boundary for the physical-chemical element in order to do not to compromise the quality of the assessment of ecological status. For hydromorphological elements, the established boundaries (High/Good) are based on the presence of meaningful alteration having possible influence in any of the Biological Quality Elements. Not all metrics assess all the lakes types, and some exceptions are considered taking into account the different characteristics of Spanish lakes types.

Further information on the proposed values for the ecological class boundaries of the proposed metrics for the assessment of hydromorphological and phycico-chemical elements can be found in CEDEX (2009e).

c) Proposal of metrics combination rules

The proposal of metric combination rules follow those which are reflected in the report by MARM (2009c) and the Guidance on the establishment of reference conditions and ecological status class boundaries for inland surface waters (CIS Working Group 2.3.– REFCOND, 2005).

The main rules, for metrics which assess the same Biological Quality Elements are the following:

- Mean value is calculated for metrics which assess the same kind of pressure
- The principle "one out all out" is applied in case of metrics assessing different kinds of pressures, which means the worst value of any metric is always selected as a result of the assessment of ecological status.

For metrics which assess hydromorphological and physico-chemical elements always the worst value of any metrics which assess the same element is selected as a result of the assessment of ecological status

The final result of the assessment of ecological status through the combination of all Quality Elements follow the criterion of "one out, all out", which means that the worst value obtained for any Quality Elements is selected as a result of assessment of ecological status. This is so that hydromorphological elements are only determinant for the high and good classes, whereas physical-chemical elements only have influence for the determination of the: high, good and moderate ecological classes.

For any of the different quality elements, the proposed rules for the combination are reflected in the proposed ecological classification system (CEDEX, 2009d, CEDEX, 2009e) as follows:

For the BQE "phytoplankton", in which two different metrics assess the eutrophication pressure, weighted averaging is proposed (more weigh for chlorophyll a concentration because of values established as boundaries for this metric are more reliable than those established for total phytoplankton biovolume)

For the BQE "Other aquatic flora", whose metrics assess different kinds of pressures, the following criteria are applied:

- Average values for metrics assessing hydromorphological pressures
- Average values for metrics assessing eutrophication pressures
- Application of the principle "one out all out" for the metrics which assess different kinds of pressures, namely pressures on hydromorphological features, eutrophication, and introduction of exotic macrophyte species.

On the other hand, for the combination of metrics which assess the same physical-chemical and hydromorphological quality elements, and for the combination of all quality elements the proposed rules follow those previously mentioned in this section.

d) Sampling and determination protocols for the monitoring of quality elements

Common nationwide protocols for the monitoring of quality elements have been designed in order to facilitate the application of the ecological classification system. In case of phytoplankton, there is a draft protocol for the sampling in lakes and reservoirs (MARM, 2009a), and the instructions reflected in this protocol have to be followed in the monitoring networks of River Basin Administrations. In case of macrophytes some specific rules have also been established (CEDEX, 2009c), according to CEN protocols (AENOR, 2008), but considering the special characteristics of Spanish lakes. For physical-chemical elements, the rules which have to be applied for their monitoring are those reflected in the draft protocol for phytoplankton sampling since the proposed metrics proposed are considered as a mandatory complementary variables of this protocol, whereas in case of hydromorphological monitoring, the proposed system requires only the identification of meaningful alteration caused by any modification of the selected metrics for the assessment of these kind of elements. Nevertheless some recommendations have been done to do a proper assessment of these metrics.

Apart from the facilitation of the application of the defined ecological assessment system, these sampling rules are very important

for the harmonization of the sampling which is going to be carried out in the River Basin Administration monitoring networks and it will let to have comparable data for the revision of this assessment system.

4. Conclusions

The works which have been made by the Center of Hydrographic Studies of CEDEX related to the implementation of Water Framework Directive (WFD) in Spanish water bodies belonging to lakes category try to accomplish with all the criteria established by this Directive. As a result, a coherent and completed system has been made: typology, selection of reference sites, definition of metrics, sampling protocols and methods for the assessment of ecological status, which has to be applied in the next River Basin Management Plans (2009-2015), representing the best reliable proposal according to the current state of information. Nevertheless, some improvements have to be made, especially in the system for the assessment of ecological status, which will come into force for the next River Basin Management Plans (2015-2021).

Regarding the typology, the different descriptors try to reflect all the diversity of Spanish lakes and wetlands which have been declared as water bodies until now. However, this typology has not yet totally been correlated with biological communities and as consequence of studies for the establishment of reference conditions it could be possible to divide or to join some of the defined types. Furthermore, new lakes could be declared as water bodies of the lakes category in the future which could perhaps not fit with any of the types. For this reason a revision according to the new information coming from the official monitoring networks might be performed for the following River Basin plans (2015-2021).

With regard to the selection of reference sites, a complete list of stations has been proposed according to specific criteria. This proposal has been adopted by consensus with the River Basin Administrations and the lakes and wetlands selected have to be considered as possible candidates for reference sites, although further monitoring in these lakes should confirm their designation as reference sites. The main problem for the selection was the lack of proper information about pressures and impacts on these water bodies. Once this information will be obtained by the Spanish River Basin Administrations, a redefinition of this network will be made.

A complete system for the assessment of ecological status of water bodies belonging to the lake category has been developed. This system assesses the Biological Quality Elements "Phytoplankton" and "Other aquatic flora", as well as the physical-chemical and hydromorphological elements. The evaluation system tries to be adapted to the different characteristics of Spanish lakes, both their ecological behaviour and their human pressures. Regarding the other two Biological Quality Elements which are required for the assessment of the water bodies belong to the lake category according to the Water Framework Directive, in the case of "Benthic fauna" metrics based on the indicator value of invertebrate species is going to be developed by experts contracted by MARM. For "fish fauna", no assessment system for lakes is going to be considered for the River Basin Plans (2009-2015), considering that some of the Spanish lake types do not have fish in natural conditions and most of

the fish species presented in our lakes are exotic or from riverine origin, so further studies are needed to develop a reliable evaluation system based on this BQE.

Regard to Biological Quality Elements and the physical-chemical and hydromorphological elements a revision of the selected metrics seem necessary for the future according to proper studies of correlation between pressure indicator and the selected metrics. This revision will have to cover the ecological class boundaries proposed for the current metrics and the developed of new metrics, for instance to include composition metrics for phytoplankton. It will have to take into account the results of hypothetical intercalibration exercise for natural lakes in the Mediterranean Lake – Geographical Intercalibration Group, and their relation with the natural hydrological regime of specific years in order to consider the interannual hydrological variability of the Spanish lakes and wetlands. Furthermore, other options like predictive modelling or paleoreconstruction could be considered for the confirmation or improvement of reference conditions, especially in those lake types with no or insufficient water bodies under reference conditions. The new assessment system should be applied in the next River Basin Plans (2015-2021).

For the application of the proposed assessment system, it is necessary that River Basin Administration follow the sampling protocols which have been developed for the Biological Quality Elements in their monitoring networks and to include the monitoring data in a proper Data Base. Also, it is very important to collect information about pressures and impacts of the water bodies belong to lakes category. These two questions will provide comparable data for the revision of the whole ecological assessment system and also facilitate the redefinition of the Spanish lakes typology and the proposal of reference sites belonging to the lakes category.

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