Chapter 3

Ecological aspects of the Water Framework Directive

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Summary

The Water Framework Directive (2000/60/EC) includes the concept of ecological status as a measure of the level of health of aquatic systems. This is largely evaluated by analysing the structure of biological communities, including habitat, physicochemical elements and the functionality of ecosystems. Measuring ecological status makes it possible to evaluate the effect of human activity on water ecosystems, and it will be an essential tool for the sustainable management of water resources. The basic objective of the Water Framework Directive is the achievement of good ecological status by the end of 2015, except water bodies declared to be strongly modified and artificial ones. This must be achieved through programmes of measures and management criteria appropriate for the environmental objectives fixed for each ecosystem. The River Basin District Management Plan (that must be approved by the end of 2009) will be the document that must be used to conserve and/or recover our aquatic ecosystems.

Measurement of ecological status is a tool now being developed, and it is in a process of inter-calibration in which work is going on according to the European Directives. The assessment of the ecological status establishes the analysis of the structure of biological communities of macroinvertebrates, fish and algae (phytoplankton or phytobenthos, depending on the environment). The status of the riparian woodland, the morphometry and morphodynamics of the systems and the variety of habitats present have to be measured, and physiochemical variables (general and specific parameters) that affect the good quality of the system have to be used. At the same time, the measurement of ecological status has to be adapted to each particular feature and functional characteristic of the categories of ecosystem where the measurement is being taken (lakes, rivers, reservoirs), which will be divided into types according to the characteristics that unite or differentiate them. For each type, reference conditions must be established with which the characteristics of the water bodies we have marked out must be compared.

Generally, the knowledge we have in Catalonia makes it possible to diagnose more or less accurately the current level of alteration suffered by its aquatic systems and to define the ecological status. Nowadays, the first versions of measurements of the ecological status of Catalan rivers provide us with a rather negative view, particularly in the middle and lower stretches of rivers, because of the moderate and low quality of their waters, but above all because of the degradation of the riparian woodland, the strong alteration and reduction of the flow system and, generally, the modification and loss of habitats making it possible to keep the ecosystem working well. We find good and very good ecological status in rivers and ecosystems at their heads and on stretches little affected by human beings – areas that must be preserved because of their high ecological value and as reference elements for the diagnosis and management of water environments.

It becomes necessary to suggest a resource management model compatible with the protection and regeneration of the environment that enables the achievement and maintenance of the good ecological and chemical status of aquatic systems. This is one of the basic principles on which the Water Framework Directive is based when it proposes measuring ecological status as a basic tool in integrated water management.

Introduction: The ecological status of water bodies

The structure and composition of the communities present in an aquatic ecosystem is the consequence both of the characteristics of the environment and of a series of biotic interactions (predation, competition, etc.), which can vary over time and space. Meanwhile, the various effects resulting from human activities considerably modify, to a greater or lesser degree, the abiotic and biotic characteristics of rivers. The study of aquatic ecosystems in Catalonia (rivers, lakes, dams, wetlands, etc.) has developed in such a way over the last few years that we now have good knowledge of the structure of the communities living in them and we can better understand their operation and the effects of human activity.

In general, the best knowledge we have of Catalan aquatic systems should make it possible to diagnose the level of alteration suffered by these systems more accurately and to suggest more appropriate management and protection models. This is one of the basic principles on which the Water Framework Directive is based when it proposes measurement of the ecological status as a basic tool in integrated water management. Water, as a resource, must be managed taking into account the fact that it forms an indispensable part of the environment which must be preserved as a guarantee of the resource and of quality of life within a framework policy of responsible management of water resources. The use made of water and its associated space (fundamental parts of aquatic ecosystems) must be made compatible with the good state of health of aquatic systems, making possible a good structure and sustainable operation of ecosystems over time. Under this principle, the diagnosis of the state of health of aquatic systems takes on great importance, with the introduction of the concept of ecological status, which is based on the combination of biological, hydromorphological and physico-chemical indicators (including priority substances) which are capable of providing the necessary information and which, at the same time, fit the structural and functional context of these ecosystems. Once the ecological status of the different water bodies have been analysed and the pressures conditioning the impacts measured, the programmes of measures to make human activity compatible with the good ecological and chemical status of water bodies will have to be drawn up.

Thanks precisely to the considerable research effort made in the study of aquatic ecosystems, driven by the pioneering work of Prof. Ramon Margalef more than 50 years ago, in Catalonia we now have the knowledge we need to be able to develop appropriate management instruments concerning the obligations imposed on us by the Directive. It is for this reason that we particularly dedicate this chapter to Prof. Margalef, a year after he passed on.

1. The Water Framework Directive: from physico-chemical quality to ecological status

At the end of 2000, the so-called Water Framework Directive (2000/60/EC) (DOCE, 2000; hereafter, WFD) was published by the Commission and the European Parliament. As its name indicates, this European regulation attempts to provide a framework for common water management action for all European Union member states. Water ceases to be seen exclusively as a resource and is considered as a basic element of aquatic ecosystems and a fundamental part of the achievement of a good state of health, defined by the Directive as *ecological status*. In these regulations, biological and hydromorphological aspects become important in the integral diagnosis of quality, together with the already traditionally used physico-chemical elements and priority substances or persistent harmful pollutants (some newly included). The Water Framework Directive proposed regulation of the use of water and associated spaces based on the capacity they have to receive the different types of impact they can support. So, an attempt is made to promote responsible, rational and sustainable use of the environment so the maintenance of the structure and operation of the community belonging to the system, or the most similar one possible within an acceptable margin, can be guaranteed over time; the ecological status is very good or good. The difference between very good ecological status (an almost natural state) and good status (a slightly altered state but one that ensures sustainable structure and functioning acceptable for the ecosystem) is the margin of effects tolerated by the Directive in terms of the repercussion of human activity and use of resources on aquatic systems.

This community regulation stems from the will to organise and manage the water available in its natural cycle in an integrated way, accounting for its functionality in the environment and its use as a resource and getting away from a sectorial and over-utilitarian view. To a degree, it is a result of the general dissatisfaction in Europe caused by the implementation and coming into force of various sectorial regulations which, in many cases, have not obtained the desired results in improving aquatic systems. Although they limit discharges and aggression towards the environment and improve the physico-chemical quality through the application of different directives, in many cases aquatic ecosystems have not recovered their state of health (their functionality). The idea of this Directive was to change the trend of previous Directives to limit discharges above certain parameters (91/271/EEC, 76/464/EEC), or to determine the quality of the environment depending on its uses (75/440/EEC, 76/160/EEC, 78/659/EEC and 79/923/EEC), and introduces the following basic principles:

- **Principle of non-deterioration and achievement of a good integrated condition of surface water and groundwater bodies**. The need to limit uses, discharges or activities directly or indirectly affecting the water environment, depending on the receiving environment and its capacity to stand these impacts, taking into account the structure and operation of the associated aquatic ecosystems at all times. So, aquatic systems will have to be characterised and typified in order for the monitoring and diagnosis programme and the management model for the system to be better adapted.
- **Principle of combined approach to pollution and integrated management of the resource**. The Directive includes the objectives and purpos-

es of previous directives and incorporates them into an integrated view of the systems to be analysed – in our case, aquatic systems – with a combined approach and from an ecosystem point of view. Limitations on the use of water, discharges or activities that could have an impact on aquatic ecosystems are imposed based on an integrated analysis of the environment which, as well as considering appropriate physico-chemical elements for the maintenance of good quality, establish use by the main natural elements making them up (biological communities) and the quality of the structure that supports them (the habitat). The unit (part of the system) for which integrated management, the monitoring programme and the programme of measures for the achievement or maintenance of good ecological status are drawn up, is called a *water body*.

- **Principle of full recovery of costs of services related to water and the use of aquatic spaces**. The new directive introduces the concept of full recovery and internalisation of costs, as well as environmental costs and the costs of the resource (opportunity cost) deriving from the services related to the use of water, and of the sustainable maintenance of the good state of health of the associated ecosystems. The cost of the use of water and river space in a sustainable way must be passed on to the beneficiary or owner of the activity that generates it.
- **Principle of public participation and transparency in water policy**. The management of resources and programmes of measures and monitoring have to be integrated into the new Management Plan (new Water Plan) to achieve the good ecological status of river systems, which has to be drawn up through participation and social consensus, based on mechanisms of public participation and under complete public transparency.

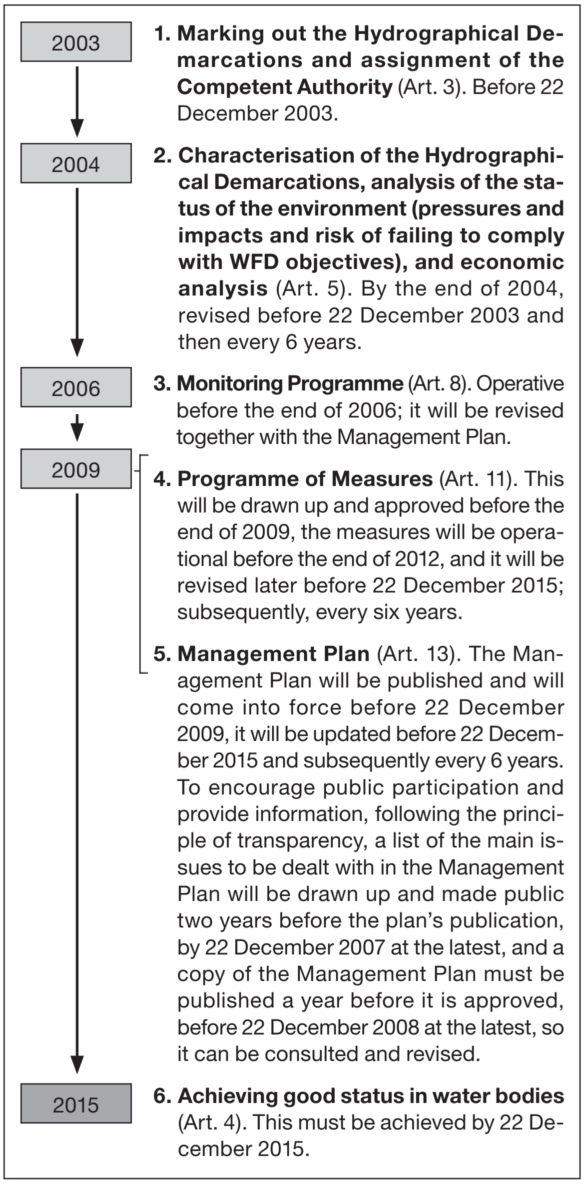

Figure 3.1. Schematic summary of the schedule of the main actions to be implemented under the Water Framework Directive: (2000/60/EC).

As we have said, the main purpose of the WFD is the achievement and maintenance of the good ecological and chemical status of surface water, the good ecological and chemical potential of bodies declared to be strongly modified and the good chemical and quantitative status of groundwater through a series of commitments and work that must be carried out before the end of 2015 (figure 3.1.). It is worth saying that the Directive itself includes mechanisms to postpone objectives and the reduction in requirements based on the declaration of various water bodies as strongly modified because of their high degree of hydromorphological alteration and condition of irreversibility for economic, social or environmental reasons in the achievement of good ecological status (reservoirs, heavily canalised stretches of river, etc.), or for the justified impossibility of achieving the objectives of the WFD under the established terms (two extensions of six years or exemption).

The concept of ecological status is introduced by the regulatory text of the Water Framework Directive and appears as a key measurement element for the analysis of the quality of the aquatic systems and their management, including the vision of their state of health (an expression of the structure and operation of ecosystems). This concept appears in Catalan legislation (Act 6/1999, and the reformed text of the legislation concerning water in Catalonia, Legislative Decree 3/2003, 4 November), and has been transposed into Spanish regulations (Act 46/1999, the reformed text of the Water Act 1/2001, 20 July, amended by Financial and Administrative Measures and Social Order Act 62/2003, 30 December). In all cases, the procedures and protocols for measuring the ecological status are under full development and discussion (Prat *et al.*, 2000; Prat, 2002; European Commission, 2003), where there are still uncertainties to be cleared up, such as the establishment of the measurement of the hydromorphological quality of aquatic systems (rivers, lakes, etc.), although there are some approximations for Catalan rivers (Munné *et al.*, 1998; 2003; Gutiérrez *et al.*, 2001), lakes (Ventura and Catalán, 2003), and wetlands (Quintana *et al.*, 2004), or the specific way the different elements of analysis to measure the ecological condition will be established and combined, depending on the operation of each type and system to be investigated.

The types of aquatic systems must first be defined. It is understood that ecological status cannot be measured in the same way nor can the same quality objectives be demanded, for example, for mountain river waters as for lower river flows, or for karstic lakes as for alpine ones, or for coastal salty wetlands as for temporary fresh water ones, or ponds, etc., and the elements of the system that must be used and the way in which they must be used to measure ecological status must be decided for and adapted to each case or type. The elements to be taken into account are indicated in the Directive in its Appendix V (table 3.1) and, gradually, initiatives and studies oriented towards combining the different elements and parameters for analysing the ecological status of rivers are coming out (Prat *et al.*, 2000a; Jáimez-Cuéllar *et al.*, 2002; European Commission, 2003; Catalan Water Agency, 2005), lakes (Burton *et al.*, 1999; Sutcliffe, 2001; Ventura and Catalan, 2003), wetlands (Burton *et al.*, 1999; Simon *et al.*, 2000; Lillie *et al.*, 2002; Quintana *et al.*, 2004), and reservoirs (Armengol *et al.*, 2003; Ferreira *et al.*, 2004).

Biological parameters	Aquatic flora Benthic invertebrates Fish fauna
Hydromorphological parameters	Water system *Flow quantity and dynamic* *Connection with groundwater* Continuity of the river Morphological conditions *Depth and width (ecohydraulic)* *Substrate* *Bank structure*
Physico-chemical parameters	General *Temperature* *Dissolved oxygen* *Salts (conductivity)* *Acidification (pH, alkalinity)* *Nutrients* Specific *Priority substances (toxic and hazardous)* *Substances discharged in significant quantities*

Table 3.1. Elements to be considered in defining the ecological status of the different water bodies (for example, rivers) defined in the European Framework Directive (Appendix V).

2. Types of water systems and reference conditions

According to the criteria established in Appendix II of the WFD, the first step that must be taken is to characterise the water bodies in each hydrographical demarcation and group them, depending on whether they are rivers, lakes (including wetlands), transition waters, coastal waters, highly modified waters or artificial waters. Once included in a category, the different water bodies are subdivided into types according to the natural characteristics that might condition the structure and operation of the ecosystem and, therefore, the management model and diagnosis protocol. A hierarchical approach must therefore be taken, firstly establishing the categories of water bodies (rivers, lakes, etc.), and then classifying them into types (typification). Finally, the water bodies (belonging to a type within a category) are defined as the functional and management unit, taking into account: (i) the geographical and hydromorphological characteristics; (ii) human pressures; (iii) their ecological status; or (iv) the fact that they have a particular protection status.

The ultimate objective of this process is to mark out the appropriate management units (water bodies) to achieve the environment objectives of good status (or potential). For each type of water body, the Directive requires the establishment of specific reference conditions that must correspond with the hydromorphological, physico-chemical and biological status of an undisturbed water body (or one little affected by humans) in order to adapt the diagnosis as an element of reference for the management of resources. For the establishment of the reference condition and thresholds between classes of ecological status there are the guidelines of the European Commission working group on reference conditions (Wallin *et al.*, 2003), and subsequent proposals for the inter-calibration of procedures to determine quality classes (Pollard, 2005), in the Common Strategy for the Implementation of the Water Framework Directive of the European Commission.

In the case of **river systems**, the Catalan Water Agency, together with the Department of Ecology of the UB, has carried out the work necessary for determining the types of rivers we can find in the internal basins of Catalonia (Munné and Prat, 2002; Munné and Prat, 2004), in accordance with the criteria established by the WFD. Concerning the Catalan river basins of the Ebre, the river typology had already been defined by studies carried out through an agreement between the Ebre Hydrographical Confederation and the Department of Ecology at the UB (Munné and Prat, 2000), which have subsequently been revised and adapted by the Environment Ministry (CEDEX). River types are necessary in order to establish quality objectives and adapt the programme of corrective measures most appropriate for each system. For the classification, neither human activity nor the modified descriptive factors deriving from it must be taken into account, as the purpose of this typification is centred on classifying groups of rivers with homogeneous natural environmental conditions and, therefore, with the structures and operation of similar ecosystems in unaltered conditions. This will allow us, based on the analysis of the references in each river type, to classify disturbances of human origin more accurately (Bailey *et al.* 1998), and to specify the programmes of measures for recovering these environments and achieving and preserving at least a good ecological status.

The environmental heterogeneity of Catalonia and the availability of reliable data representing this condition make it possible to adapt the level of discrimination while, at the same time, maintaining coherent spatial interpretation and justification. So, using multivariant analysis methodologies to classify and organise the different stretches of river, through the analysis of environmental variables unaltered by human activity or restored to their natural state (where and when pos-

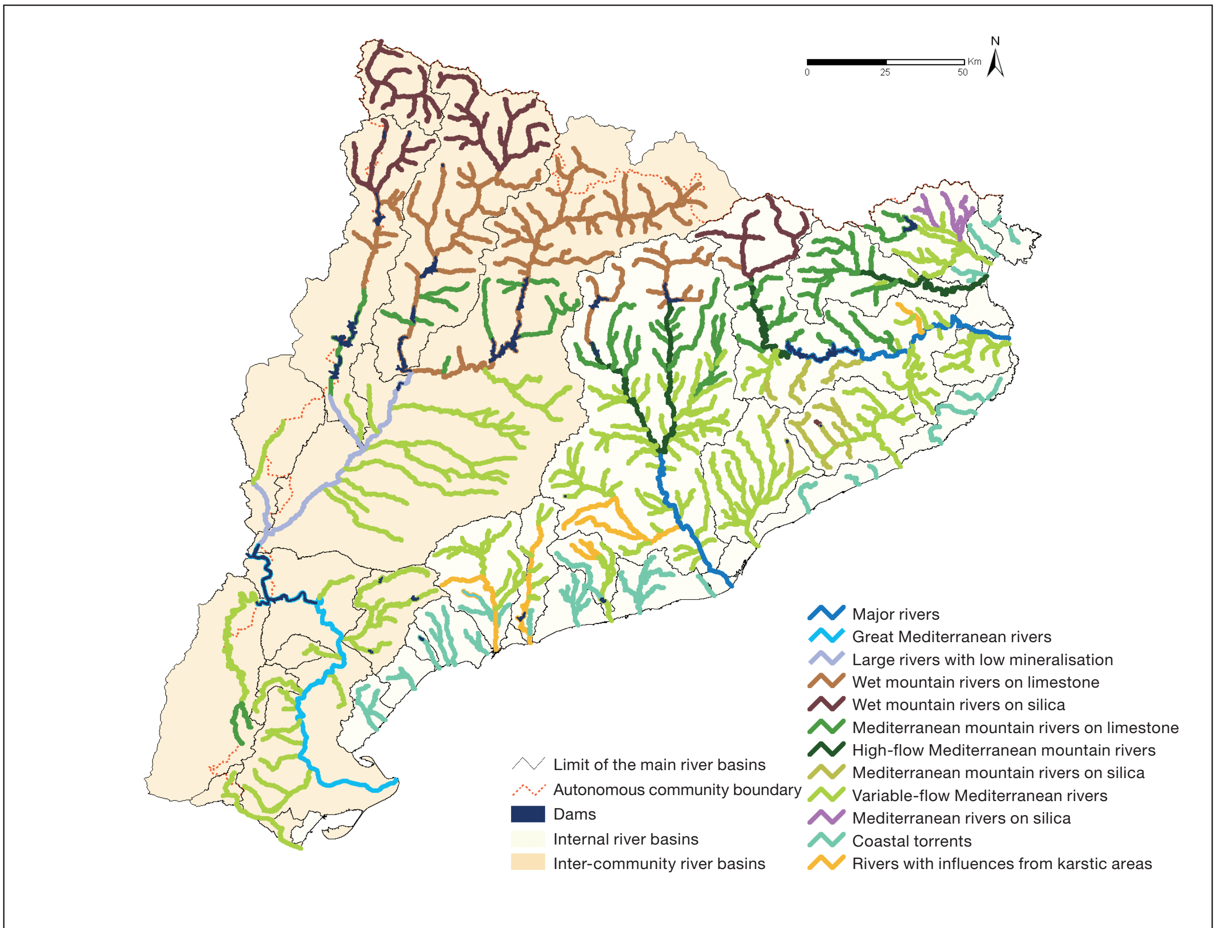

Figure 3.2. Fluvial types in the Inland River Basins of Catalonia (Munné i Prat, 2002; Munné i Prat, 2004), and in the Catalan Basins of the Ebre and Garona rivers (Munné i Prat, 2000).

Fluvial types
1a. Wet mountain rivers on silica
1b. Wet mountain rivers on limestone
2a. Mediterranean mountain rivers on silica
2b. Mediterranean mountain rivers on limestone
2c. High-flow Mediterranean mountain rivers
3a. Lowland Mediterranean rivers
3b. Mediterranean lowland rivers on silica
3c. Rivers with karstic influence
4a. Major rivers
5a. Coastal torrents
6a. Large rivers with low mineralisation
7a. Great Mediterranean rivers (lower stretch of the Ebre)

Table 3.2. Fluvial types in the Internal River Basins of Catalonia (Munné i Prat, 2002; Munné i Prat, 2004), and in the Catalan Basins of the Ebre and Garona rivers (Munné i Prat, 2000).

sible), hydrological, morphometric, geological and climatic variables, 12 “river types” have been defined in Catalonia within a European contextual framework useful in the sphere of river basin management and operating at the level of river basin body (the Catalan Water Agency) (table 3.2 and figure 3.1).

The reference water bodies for each *river type* must be defined and the reference conditions assigned through the analysis of the biological, morphometric and physico-chemical quality. For this task, stretches of river must be sought out within each river type, which are very well preserved and natural, and almost no alteration by human activity (reference stretches of river) (Bonada *et al.*, 2002). Through the analysis of the natural conditions of the selected reference stretches, the quality objectives will be set for each river type which, in some cases and for some of the elements analysed, may be the same for two or more types. In the case of the internal river basins of Catalonia, the search for reference stretches of river is quite complex, above all in the case of some river types with strong human presence on their banks or in their drainage basins. This is the case of the major rivers (lower stretches greatly affected by human action) or the high-flow Mediterranean mountain rivers (with many industrial activities on their banks).

The typification of rivers and analysis of their reference conditions are the basis making it possible to adapt the sectorial plans and action programmes to the specific characteristics of the river areas of the internal river basins of Catalonia, such as the Sanitation Plan and its future revisions, Restoration and Hydromorphological Recovery and Riparian Woodland Plans or Zonal Plans for the implementation of environmental flows.

Concerning **lakes and wetlands**, prior to the typification and characterisation of the systems, the criteria making it possible to select them as water bodies must be defined. The WFD, in Appendix II, establishes the criteria of 50ha when it comes to selecting lake systems to be considered as water bodies, but this criterion is shown to be totally insufficient when it comes to taking into account more singular and representative systems of various surrounding areas and aquatic environments, above all in the Mediterranean area. In the Catalan river basins, the Catalan Water Agency has proposed as water bodies all lakes and ponds measuring more than 8ha, and lake systems smaller than 8ha, but which come under some protection system (PEIN, SAC, SPA, Partial and Total Nature Reserves, Wildlife Reserves), conservation plans for threatened species such as the otter, the Spanish toothcarp or the grey heron (wetlands of interest for the conservation of fauna and flora), systems that ca be considered reference ones (with *very good* or *good* ecological status) and those with singular characteristics within Catalan aquatic ecosystems defined according to the many studies carried out up to now in Catalonia.

With this consideration, 9 different types of lakes (more than 0.5ha in area and more than 6m deep) have been differentiated in Catalonia (Ventura and Catalan, 2003) (table 3.3), according to their origin (alpine or karstic), their alkalinity (acid or alkaline water), the size of the lake or the influence of the river basin on the water body (small lakes with a great deal of influence from the drainage basin or large ones with little influence and contributions of organic matter). As an example, the following lakes are classified into the different corresponding categories (the acronym for the different categories found in table 3.3. is in brackets): Banyoles (CGG), Montcortés and Basturs (CPP), Baiau superior (AAA), Romedo de dalt (AAM), Senó (AAG), Garrabeia and Gerber (ACG), Gran d’Amitges and Gran de la Pera (ACA), Llong, Nere and Ratera (ACB), Llebreta (ALK).

For the typification of **wetlands**, understood as ecosystems with (seasonal or permanent) shallow (less than 6m) standing water, in comparison with lakes, in the Catalan river basins, the Catalan Water Agency has based itself on the *Inventari de zones humides de Catalunya (Inventory of wetlands of Catalonia)* (202 wetlands) (Balaguer and Muñoz, 2001), and studies already carried out on the Iberian peninsula (Alonso, 1998; Trobajo *et al.*, 2002). Alonso (1998) defines as lagoons wetlands with a defined perimeter,

Types of lakes		Characteristics
(CGG)	Large karstic lakes	Karstic origin and larger than 50ha in area
(CPP)	Small karstic lakes	Karstic origin and smaller than 50ha in area
(AAA)	Alpine lakes with very acid water	Alpine origin (> 1,500m altitude) and less than 0μeq./l alkalinity
(AAM)	Alpine lakes with acid water	Alpine origin (> 1,500m in altitude), between 0 and 20 μeq./l alkalinity, with metamorphic rock
(AAG)	Alpine lakes with very diluted waters	Alpine origin (> 1,500m altitude), between 0 and 20 μeq./l alkalinity, with metamorphic rock
(ACG)	Large alpine lakes	Alpine origin (> 1,500m altitude), between 20 and 200 μeq./l alkalinity, more than 10ha in area
(ACA)	Typical alpine lakes	Alpine origin (> 2,300m altitude), between 20 and 200 μeq./l alkalinity, more than 10ha in area
(ACB)	Low-lying alpine lakes	Alpine origin (between 1,500m and 2,300 in altitude), between 20 and 200μeq./l alkalinity, more than 10ha in area
(ALK)	Alkaline alpine lakes	Alpine origin (> 1,500m altitude) and less than 200μeq./l alkalinity

Table 3.3. Types of lakes (> 0.5ha in area) defined in the Catalan River Basins (Ventura i Catalan, 2003).

but whose maximum depth does not allow the establishment of a stable thermocline and where the bottom is or can be covered with macrophytes. A typification of these ecosystems has been drawn up (Quintana *et al.*, 2004) based on the exhaustive analysis of the communities and dynamics in 27 wetlands. It has subsequently been adjusted and verified through the seasonal analysis of 40 more systems. The result is the definition of 4 types of wetlands in Catalonia, depending on the salinity of the water (average conductivity), its origin (marine or continental) and the permanence of the water (the seasonality of the system) (table 3.4). The fact that there are differences in the composition of the fauna and abundance and diversity of taxons in the different (undisturbed) wetland typologies means the quality of these groups must be assessed separately.

Types of wetlands		Characteristics
(HTA)	Athalassohaline	> 5mS/cm, of continental origin
(HTA)	Thalassohaline	> 5mS/cm of marine origin
(HDP)	Permanent and semi-permanent, fresh water	< 5mS/cm and flooded > 6 months of the year
(HDT)	Seasonal, fresh water	< 5 mS/cm and flooded < 6 months of the year

Table 3.4. Types of wetlands defined in the Catalan River Basins (Quintana *et al.*, 2004).

Forming part of lenitic epicontinental systems (lakes), in Catalonia we find **reservoirs –** manmade systems for regulating river flows and making use of their water. Within the category of highly modified water bodies, reservoirs are considered as highly modified stretches of river, similar to lenitic ecosystems (lakes). The analysis of some of the biggest reservoirs in Catalan river basins has been being carried out for some time in order to improve their management, as is the case with Sau or Boadella, but there is still much to be discovered in other reservoirs. Because of this, at the Catalan Water Agency, through an agreement with the University of Barcelona (Drs. Armengol and Navarro) and the University of Girona (Dr. Garcia-Bertou and collaborators), seasonal sampling of the whole annual cycle in Catalan reservoirs has been carried out in order to characterise them and to put forward the appropriate protocols for analysing and monitoring them (Armengol *et al.*, 2003). In total, 21 reservoirs have been analysed, seasonally sampling their main physico-chemical characteristics and their water column profiles, the main phyto-plankton pigments and the fish populations (in 14 reservoirs). As a result, Catalan reservoirs have been classified into 6 different types (table 3.5), according to altitude criteria (over or under 815m), size of the reservoir or volume (over or under 20hm³), distance from the coast (over or under 25km), concentration of chlorides from the drainage of the river basin (over or under 40mg/l) and size of entry flow or surface of the drainage basin (over or under 10,000km^2).

Types of reservoir	Characteristics
I. Large reservoirs at altitude	Altitude above 815m and capacity of more than 20hm^3
II. Small reservoirs at altitude	Altitude above 815m and capacity of less than 20hm^3
III. Coastal reservoirs at low altitude	Altitude below 815m and less than 25km from the coast
IV. Reservoirs at low altitude whose water contains few minerals	Altitude below 815m, less than 25km from the coast and with chlorine concentrations of less than 40mg/l
V. Small reservoirs with mineralised water	Altitude below 815m, less than 25km from the coast, with chlorine concentrations greater than 40mg/l and with a drainage area of less than 100km^2
VI. Large reservoirs with mineralised water	Altitude below 815m, more than 25km from the coast, with chlorine concentrations greater than 40mg/l and with a drainage area of more than 100km^2

Table 3.5. Types of reservoir defined in the Catalan River Basins (Armengol *et al.*, 2003).

3. The concept of bioindicator and ecological status: experiences in Catalonia

In the last few years, various studies of Catalan river systems have been carried out aimed at environmental diagnosis using biological elements, such as the community of benthic algae (Cambra *et al.*, 1991; Muñoz and Prat, 1994; Merino *et al.*, 1994; Sabater *et al.*, 1996), macroinvertebrates (Muñoz *et al.* 1998; Munné and Prat, 1999; Prat *et al.*, 1999), or the fish community (Aparicio *et al.*, 2000). In addition, the competent administration for the river basin's of Catalonia (the Catalan Water Agency) has established quality monitoring networks using indices based on macroinvertebrates, such as the (Benito i Puig, 1999), deriving from the Iberian IBMWP (Alba-Tercedor and Sánchez-Ortega, 1988; Alba-Tercedor *et al.*, 2002), and the use of indicators to measure the quality of riverbank woodland is being introduced, such as the QBR (Munné *et al.*, 1998; Munné *et al.*, 2003), and the IVF (river vegetation index) (Gutiérrez *et al.*, 2001), the analysis of the fish community with using the IBICAT index (Sostoa *et al.*, 2003), the analysis of the phytobenthic community using of diatom algae (IPS, IBD and CEE indices) (Sabater *et al.*, 2003; Cambra *et al.*, 2003), or the use of benthic macroalgae (Cambra *et al.*, 2003), and the analysis of the river habitat (IHF index) (Pardo *et al.*, 2002). Work is continuing on the response of these indices to river typology, specifying the reference conditions for each one of them, so that the value of the diagnosis can be adjusted to make it comparable between stretches of river.

In order to ensure that it is possible to compare different monitoring systems, the results must be expressed in the form of the ecological quality relativised index (EQR). This indicator is the quotient between the values of a biological parameter measured in a water body and the value of the same parameter under reference conditions within the same type. The EQR must expressed as a numerical value between zero and one, where very good ecological status is represented by values close to one and poor ecological status by values close to zero. A procedure for calculating the EQR needs to be developed for each of the indicators used for elements of biological quality.

Using the different biological water quality indicators and combining them in accordance with the protocols established in the working groups for the interpretation of the Water Framework Directive and its Appendix V (Wallin *et al.*, 2002; European Commission, 2003), together with the analysis of the hydromorphological and physico-chemical quality, it is possible to design a procedure for analysing ecological statuses. This is currently at the phase of detailed adjustment before being definitively adopted as a protocol for analysing ecological status in Catalonia (figure 3.3). This analysis protocol for ecological status, adjusted to the river types existing in Catalonia, must become the tool on which the future programme of measures for achieving the objectives of the Water Framework Directive is based.

Using the combination of measurements shown in figure 3.3, an analysis is made of the ecological status of the rivers and internal river basins of Catalonia (figure 3.4). The results show that, despite the im-

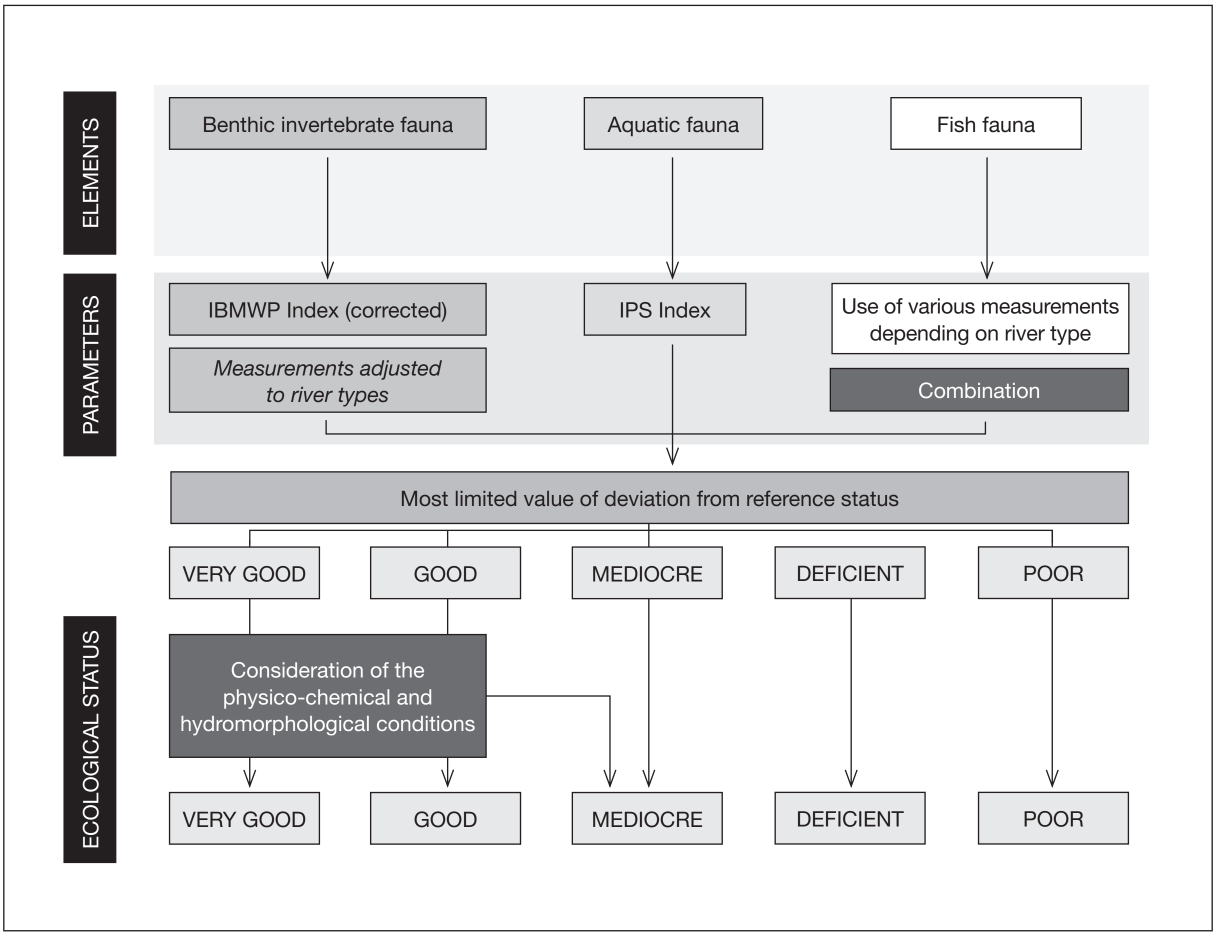

Figure 3.3. Combination of quality measurements and indicators of fluvial systems for establishing the ecological status of Catalan rivers.

provement in quality of the last few years, above all since the implementation of the sanitation plan in Catalonia, there are still approximately 40% of river stretches whose status is below acceptable according to the Water Framework Directive (good or very good status). Along these stretches, programmes of measures will have to be applied to improve the health of the environment. In some cases this will not only come through cleaner water but also through ensuring a minimum circulation flow, improving habitat diversity or restoring riparian woodland. The stations with biological water quality similar to a natural, undisturbed state (very good status) are at the heads of rivers and in areas with little human activity, while the majority of river stretches show moderate or deficient status, with euthrophised water – above all stretches with discharges from treatment plants and low natural flow to dilute these, or river stretches with insufficient clean-up systems – are in the lower reaches, near the large urban concentrations. In the lower stretches of rivers we find the most degraded quality states, above all in the most urbanised stretches – the Besòs and the Llobregat beside Barcelona and the lower stretches of the Francolí and the Anoia. On these stretches the possibility and real viability of improvement to good status will have to be analysed and, if this is not possible, the best possible quality will have to be defined and adopted for each location – what the WFD calls *ecological potential*.

The **fish community** is probably the one that has suffered the sharpest and most progressive deterioration in the last few years. Certain species, such as the chub *(Squalius cephalus),* and three-spined stickleback *(Gasterosteus gymnurus),* have suffered a significant recession in their distribution areas, above all in the last 50 years (Sostoa *et al.,* 2003), and invading species such as the carp *(Cyprinus carpio),* the pumpkinseed fish *(Lepomis gibbosus),* the roach *(Rutilus rutilus)*, the bleak *(Albustus alburnus)* and the American perch *(Micropterus salmoides),* among many others, have proliferated, altering the trophic network and the balance of the ecosystem. Nowadays in Catalonia there is a continental fish fauna of about 47 species, of which 21

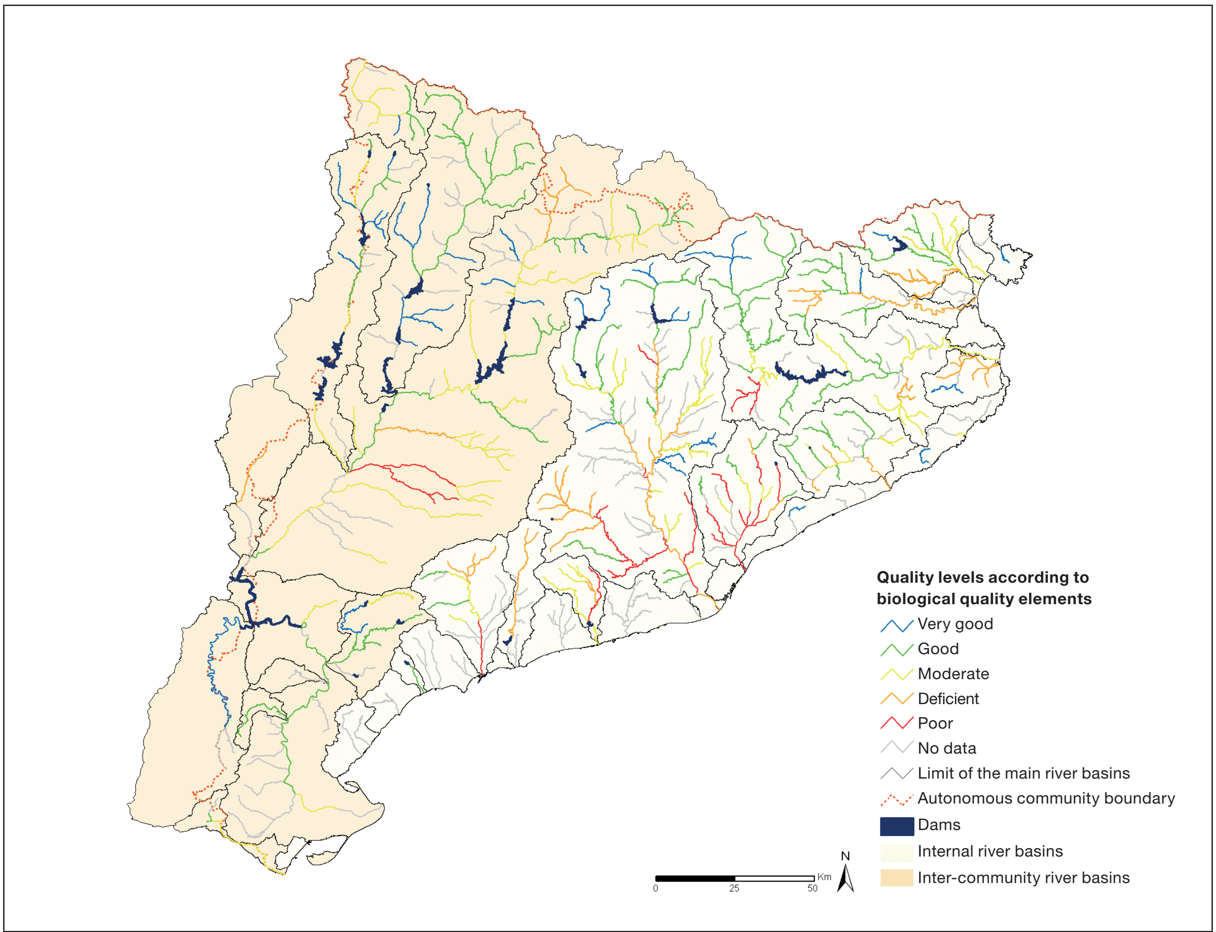

Figure 3.4. Analysis of integral biological quality (using benthic macroinvertebrates, diatom algae and fish) in the internal river basins of Catalonia. Data from the Catalan Water Agency (IMPRESS document, 2005).

(45%) are considered to have been introduced (most recent unpublished data indicate that the percentage is now over 50%). This situation has occurred not only because of the lack of physico-chemical quality suffered in many stretches of river which, as they have slowly recovered, have encouraged the invasion of rapidly colonising introduced species, but also because of the constant destruction of river habitats, the lack of adequate circulating flows (above all because of the regulation of rivers by dams and the action of mini-power stations), the absence of periodic flooding, water pollution (Poff *et al.*, 1997), and the lack of quality of riparian woodland. However, as well as the favourable conditions for the proliferation of invading species, it must also be emphasised that someone introduces them or encourages this practice. Fish density in the majority of Catalan rivers is nowadays under 1,000 individuals per hectare and only some well-preserved heads or stretches of rivers show densities above 10,000 ind./ha. (Sostoa *et al.*, 2003). In the first approach to analysing river quality in Catalonia using a fish index (IBICAT index), out of a sample of 317 stations analysed, 193 (61%) were considered affected and the rest – 124 stations basically situated at the heads of the Fluvià, Ter and Tordera and in the higher basins of the Nogueras and the Segre (39%) showed a status of acceptable quality, that is, with fish communities showing good structure and taxonomic composition.

Concerning the quality of the riverbank areas – riparian woodland – this has also suffered severe degradation in the last few years (figure 3.5). At the Department of Ecology at the UB, and with the support of the Environmental Service of the Barcelona Provincial Council, the quality of riparian woodland on the major rivers of the province of Barcelona has been monitored since 1998, using the QBR index. At the same time, at the Catalan Water Agency, the information available on the use of the QBR index at various places in Catalonia studies by different organisations and local or supramunicipal bodies has been collected and samples have been taken at some stations (figure 3.4, table 3.6). The results show us that almost 70% of the stations studied show unacceptable status and this situation appears to indicate a growing trend over the last few years, probably because of various urban development actions, occupation of the land closest to the major rivers, canalisations and channels carried out to gain land for development or the passage of line services and infrastructures or forestry exploitations on the riverbank and extraction of aggregates in a way that does not respect the environment. Only 10% of the stations analysed are in excellent or almost natural state (table 3.6). The analysis of the results indicates the great effort that will be necessary to improve this situation and to be able to achieve good ecological status, if we want to comply with the European directives (WFD).

Quality Status	Stations analysed	%
Very good	57	12
Good	99	19
Mediocre	125	24
Deficient	127	25
Poor	104	20
Total	**512**	**100**

Table 3.6. Quality of riparian woodland using the QBR index in internal river basins in Catalonia. The number of stations at each quality level is indicated, as well as the respective percentages. Data compiled from various sources.

Concerning **lakes or ponds**, there are various studies and works bringing us closer to discovering the dynamics and operation of Catalan lenitic ecosystems, as is the case with karstic lakes (Miracle and Gonzalvo, 1979), and specifically Banyoles (Planas, 1973; Abellà, 1986; Bolós, 1986; Rieradevall and Prat, 1991; Garcia-Bertou and Moreno-Amich, 2002) and Montcortés (Margalef, 1950; Camps *et al.*, 1986; Modamio *et al.*, 1988), or the Pyrenean lakes (Ballesteros and Garcia, 1988; Catalan *et al.*, 1993; Ventura *et al.*, 2000). Both the alpine and karstic lakes and ponds of Catalonia are generally oligotrophic systems, which greatly limits the abundance and composition of the phytoplankton that can be found

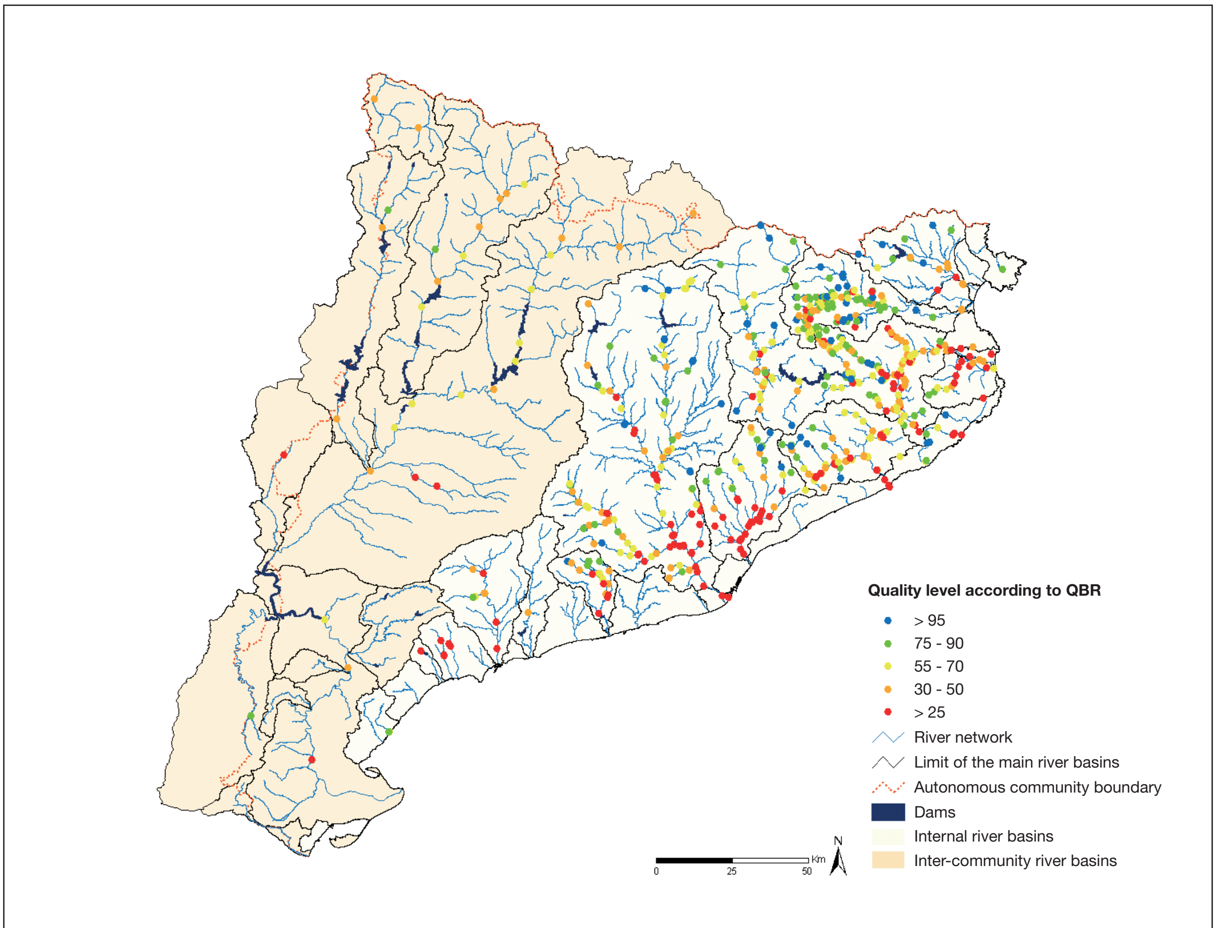

Figure 3.5. Quality of riparian woodland using the QBR index in internal river basins in Catalonia. The stations analysed are shown with the colour identifying each quality level. Data compiled based on various sources (Catalan Water Agency, 2005).

Analysis elements	Indicators or measurements used
Biological elements	
Phytoplankton (composition and abundance)	Concentration of chlorophyll a, index of algae groups (IGA)
Phytobenthic (Diatoms)	Diatom index
Macrophytes	Richness of macrophytes, percentage of helophytic vegetation on the coast
Invertebrates	Macroinvertebrate index
Fish	Richness of species, introduced species
Hydromorphological elements	
Depth fluctuations	Relative measurement of the change in level (in cm) compared to a fixed shore point. In lakes, use the terrestrial vegetation threshold
Physico-chemical elements	
Transparency	Secchi disc and turbidity
Thermal, oxygenation and salinity conditions	Temperature, Oxygen, TOC and Conductivity
State of acidification	pH and Alkalinity
State of nutrients	TP, SRP, TN, N-NO_3, N-NO_2, N-NH_4

Table 3.7. Analysis elements and indicators used for calculating the ecological status of lakes in Catalonia (Ventura and Catalan, 2003).

there (Ventura and Catalan, 2003). This means that, rather than defining the species that should be there, which can vary greatly from one place to another and throughout the year in the same place, it is necessary to define well the communities that should not be found there, using the right indicators. The singularities of each lake must not be taken into account separately and individually, something that is very clear in the case of karstic lakes, where the phytoplankton in each one is often singular (e.g. *Ceratium cornutum* in Basturs pond). Instead it is a question of establishing an overall value for their state of health. For this reason, it is important to define an indicator for an appropriate quantity, which will normally be the concentration of chlorophyll, accompanied by a general quality indicator that makes clear any deviation from the reference conditions (table 3.7).

Benthic algae are more seasonal than phytoplankton, which means the result does not depend so much on sampling at a particular time of year; against it, there is the fact that there is high spatial heterogeneity, which makes it more difficult to take representative samples. Macrophytes form another important element of aquatic fauna. In oligotrophic lakes, where there is considerable light penetration, they are common and constitute an element denoting quality; however, in alpine lakes their presence is limited at altitude, especially above 2,300m. Finally, the presence of a belt of helophytic vegetation around these lakes is a characteristic feature of them. This aspect, in alpine lakes, depends on many factors and it is very difficult to take into account with the general typology that has been established. However, it is a fundamental feature of karstic lakes.

As for fish, in alpine lakes these are usually introduced (Miró and Ventura, 2003). Although from a conservation point of view this is a very negative aspect, from the point of view of ecological status, in relation to water quality, the effect is less serious, as in many cases it is difficult to show the consequences of this alteration in the ecosystem (Ventura and Catalan, 2003). The case of karstic lakes is very different: each one can be a world of its own. The most studied has been the one at Banyoles, where the introduction of species has been a constant and now these dominate the population (Garcia-Bertou and Moreno-Amich, 2002), causing serious alterations to the environment.

In general, it can be stated that the ecological status of lakes in Catalonia is good (figure 3.6). The majority of alpine lakes are show very good status even though the majority have several introduced or translocated fish species (*Salmo trutta* and *Phoxinus phoxinus*), except for those used for hydro-electric generation (deficient or poor status). As for the karstic lakes of Basturs, Montcortés and Banyoles, these show good status and their protection is essential, given their singularity.

As for **wetlands**, there is relatively little information about the application of biological indices to marshes and lagoons (Burton *et al.* 1999, Veraart 1999, Simon *et al.* 2000, Lillie *et al.* 2002, Pennings *et al.*

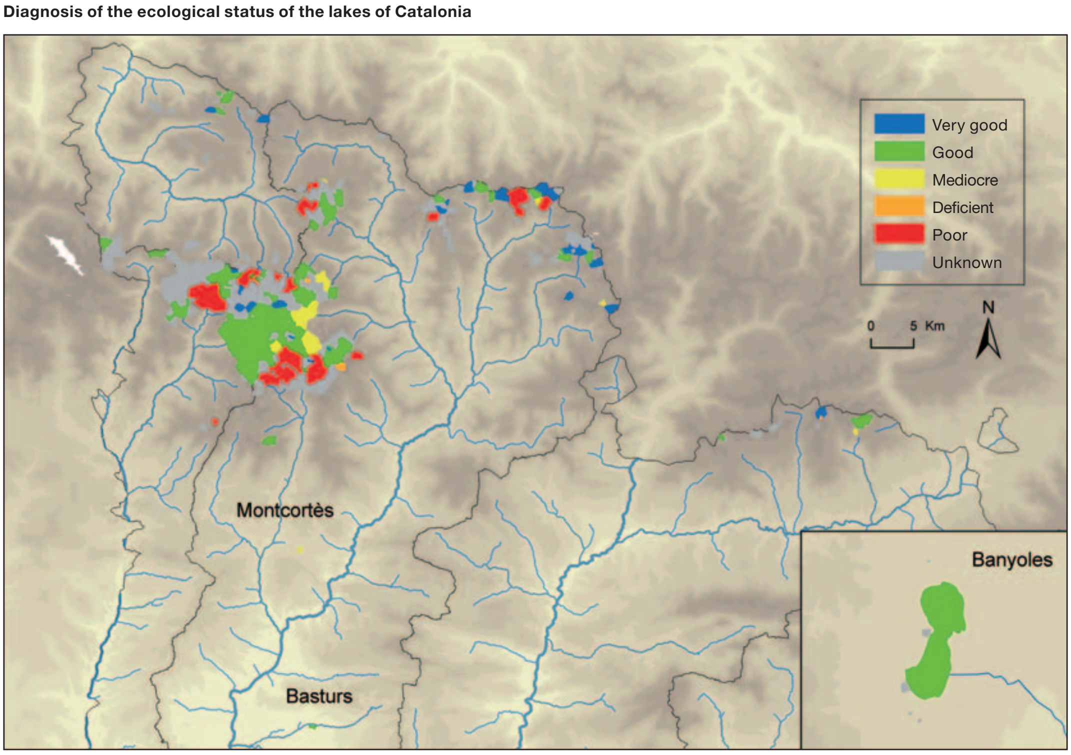

Figure 3.6. Ecological status of the alpine and karstic lakes (> 0.5ha) of Catalonia (data from 2002) (Ventura and Catalan, 2003).

2002; Fano *et al.*, 2003). All this is very recent and often limited to geographical areas that have little to do with Mediterranean climatology. On the Iberian peninsula, Cirujano *et al.* (1992) suggested the use of vegetation for assessing marsh systems, which has been a reference up to now, together with other Spanish (Bayo *et al.*, 2001) or international studies (Adamus *et al.*, 2001). Through the European ECOFRAME project (Moss *et al.*, 2003), methods for analysing the qualitative status of wetland areas have also been suggested. In Catalonia there are few studies aimed at assessing water quality in marshes (e.g. Bach *et al.* 1998), and still fewer suggesting a system for monitoring water quality based on aquatic organisms (Moreno-Amich *et al.* 1999).

The Catalan Water Agency, by agreement with the University of Girona, has developed two indices for establishing the ecological status of wetlands: the *QAELS* index (Water Quality of Shallow Lenitic Ecosystems), which assesses water quality based on the composition, richness and abundance of invertebrates, and the *ECELS* index (State of Conservation of Shallow Lenitic Ecosystems), which assesses the conditions of the whole ecosystem, (Quintana *et al.*, 2004). Each index provides additional information about the ecological status.

The *QAELS* index is obtained based on the combination of two preliminary indices: one based on the abundance of indicator taxons of cladocerans, copepods and ostracods (*ACCO* index), and another based on the richness of taxons of crustaceans and insects present (*RIC* index). The *ACCO* is calculated based on the relative abundance of the quality indicator (sensitive) taxons, which are different for each of the three types of aquatic system. To obtain the *ACCO* index, a criterion has been identified for each of the groups resulting from the typification. The *RIC* index takes into account another fraction of the community (macroinvertebrates) as well as microcrustaceans and provides additional information for assessing the water quality. Taxonomic resolutions at family level and above are not suitable for calculating the *ACCO* index, because in the same family (in some cases even in the same genus) there can be species corresponding to very different water quality situations.

QAELS values vary over time, in accordance with the intrinsic variability in shallow lenitic Mediterranean ecosystems. To discover the variation in *QAELS* values throughout the year in a water body, it is necessary to take a sample every month. However, an approximate *QAELS* value for a water body can be obtained with four seasonal samples. If the purpose is to assess the water quality in the wetlands of an area, two samples can be taken: one at the beginning of the spring and one at the end.

In the 91 wetlands studied in Catalonia (Quintana *et al.*, 2004) a different pattern in the relationship between the biological quality of the water and the state of conservation or hydromorphological quality has been made clear, depending on the typology (table 3.8). So, in thalassohaline water, most water bodies show biological water quality between moderate and very poor (categories from III to V), with very good or good hydromorphological status (categories I and II). In this same typology, a single water body has shown “acceptable” biological quality and “deficient” hydromorphological status. By contrast, in permanent and semi-permanent salt or fresh water, a considerable number of water bodies have shown “acceptable” biological quality and “deficient” hydromorphological status, while there are few cases of the opposite type. Most temporary salt or fresh water shows both good water quality and good hydromorphological status. A closer relationship between water quality and hydromorphological status has been observed in this group, as in more than 70% of cases both aspects have been either “acceptable” or “unacceptable”. It must be mentioned that in the four types of wetlands, environments with *very good* ecological status have been found.

Variations throughout the year in *QAELS* index values may be very great, especially for thalassohaline water bodies, where there are three water bodies varying throughout the year between categories I and V (Fra Ramon, Bassa del Pi, Reguerons) or nine water bodies (35%) that include categories between I and IV or between II and V throughout the year (table 3.8). The values corresponding to the best quality occur during autumn and winter, periods when water usually circulates in the marsh. In the summer, by contrast, lower quality values appear, coinciding with periods of confinement, during which most of the nutrients that have entered these water bodies become concentrated. In permanent or semi-permanent salt-fresh water bodies, the category variations are not so great, although one water body that takes values between category I and V (Rec Madral at the middle bridge) is observed, together with three water bodies (9%) with categories between I and IV or between II and V. It is difficult to analyse the variability of the ponds in group III because many of them are temporary and there is only a single sample. Despite this, the variability in this group seems relatively low, as indicated by the degree of change in water bodies shown in more than one sample.

Faced with this variability, which is the result of seasonal changes in the concentration of nutrients in wetlands and in the biological cycles of organisms, it must be taken into account that a single value of *QAELS*, measured during the year may not correctly reflect the water quality. In this sense, the collection of samples at times of year when there are very rapid changes must be avoided, such as during days following a flood episode or on days immediately before temporary marshes dry out. The *QAELS* index must be determined differently if the objective sought is to study the water quality of a particular pond or if the index is being used as one of the descriptive factors for the environmental assessment of an area. So, in order to assign a single *QAELS* value to a body of water, it is proposed that the *QAELS* value should be calculated once a month throughout the annual cycle and the average of the *QAELS* values obtained should be assigned to each

	Thalassohaline waters (28 cases)	Salt/fresh perm./semi-p. waters (39 cases)	Salt/fresh temporary waters (24 cases)
QAELSe I / II & ECELS I / II	7 (25%)	9 (23%)	12 (50%)
QAELSe I / II & ECELS III / V	1 (4%)	14 (36%)	2 (8%)
QAELSe III / V & ECELS I /II	14 (50%)	4 (10%)	5 (21%)
QAELSe III / V & ECELS III / V	6 (21%)	12 (31%)	5 (21%)

Table 3.8. Relationship between water quality and the state of conservation of the water bodies studied. Categories I and II are considered as “acceptable” and categories III, IV and V as “deficient”.

water body. If, because of sampling difficulties, there is a need to reduce the number of samples over time, a minimum of one sample per season must be ensured. If, however, the idea is to assess the water quality in all the ponds and lagoons in an area (e.g. EIN, municipality, county or all Catalonia) it is suggested that two samples a year should be taken, one at the beginning of spring and the other at the end of spring (always avoiding times of maximum flooding and times of near drought) and the average *QAELS* value calculated. The end of spring is also the right time for calculating the *ECELS* index.

Concerning reservoirs, the Catalan Water Agency, through an agreement with the University of Barcelona and University of Girona, has analysed 21 of them (Armengol *et al.*, 2003) in order to establish the mechanisms and protocols for the integrated analysis of ecological potential and to diagnose their state of health. From the studies, it is concluded that the analysis of the chlorophyll together with the presence and abundance or density of carp *(Cyprinus carpio)* are the key biological elements for determining the quality of the system, together with the measurement of the turbidity of the water, the concentration of oxygen in the hypolimnion and the total concentration of phosphorus in the reservoir (table 3.9). The presence of exotic introduced species in reservoirs increasingly conditions the quality of the system as they alter the trophic chain, destructuring the balance between predators and prey, zooplankton and phytoplankton and causing algae blooms, some cases of cyanobacteria and the generation of toxic substances (e.g. microcystins, etc.) (Armengol, com. pers.).

The quality or ecological potential of Catalan reservoirs shows great spatial variability and also, in some cases, temporal variability (figure 3.7). Generally, the Ebre reservoirs show good status, together with those of Noguera Ribagorçana, while in the internal basins (Llobregat, Ter and Muga) and Noguera Pallaresa, the situation is more pessimistic. The Oliana (receiving water from Andorra) and St. Llorenç

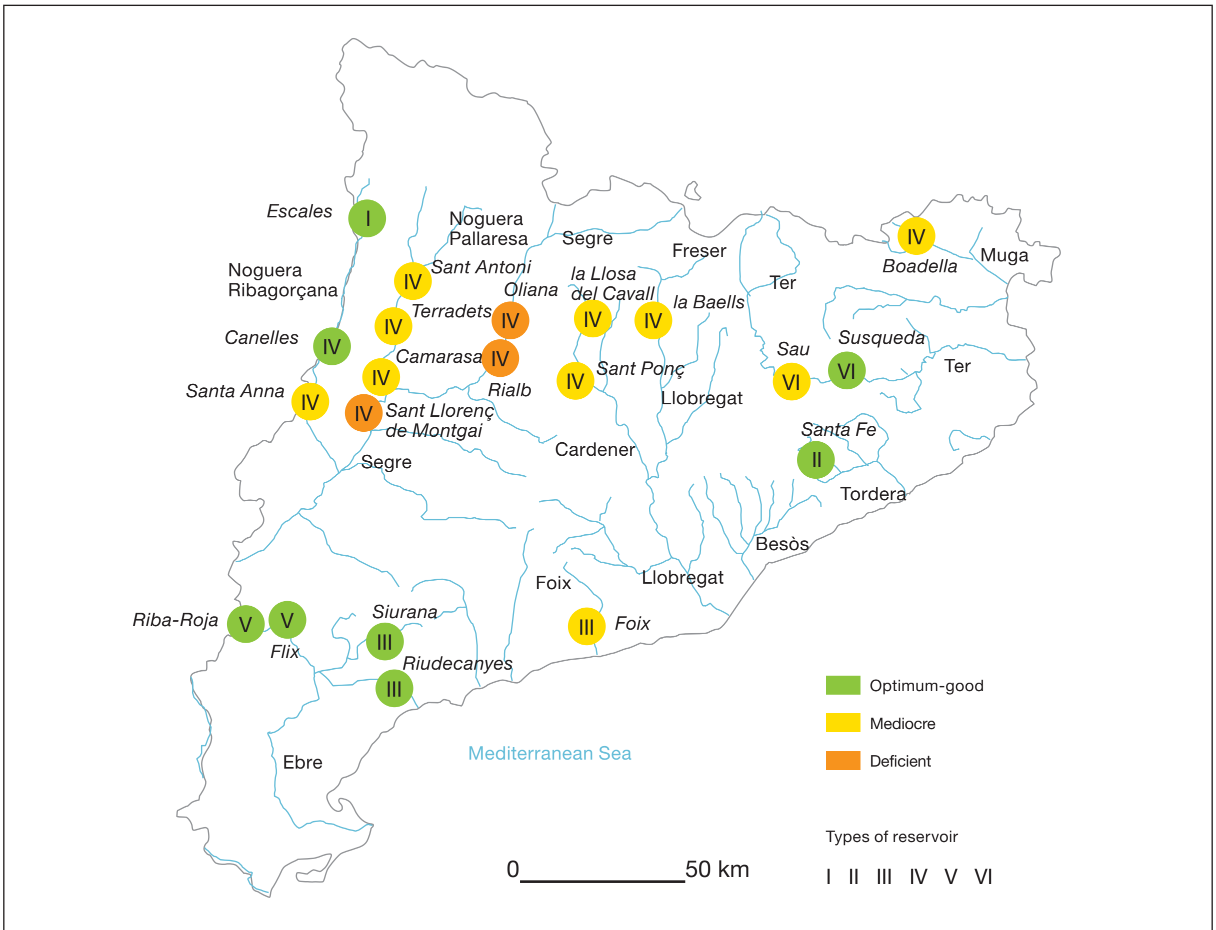

Figure 3.7. Ecological potential of the reservoirs analysed (data from 2002-2003) in Catalonia (Armengol *et al.*, 2003). The types of reservoir correspond to those described in table 3.5.

Analysis elements	Indicators or measurements used
Biological elements	
Phytoplankton	Concentration of chlorophyll a Concentration of chlorophyll from cyanophytes
Fish	Percentage of species with anomalies CPUE for shore carp CPUE limnetic carp
Physico-chemical elements	
Transparency	Depth of Secchi's disc
Oxygenation conditions	% saturation of hypolimnetic oxygen
Concentration of nutrients	Total phosphorus

Table 3.9. Analysis elements and indicators used to calculate ecological potential in the reservoirs of Catalonia (Armengol *et al.*, 2003).

de Montgai reservoirs show deficient status, as does the Rialb reservoir (although the latter shows this status because it has recently been flooded and is at a maturing phase). In the internal river basins of Catalonia, the Foix reservoir shows worst status in terms of quality, on the threshold between mediocre and deficient, while Sau reservoir has undergone a notable improvement in recent years.

4. Risk of failing to meet the Water Framework Directive objectives. Challenges and problems in the immediate future

In order to find out the problems suffered by our river ecosystems and improve the design and creation of the appropriate corrective measures allowing us to achieve the objectives of the Water Framework Directive and good ecological and chemical status before the end of 2015, the WFD, in its Art. 5, establishes that for each hydrographical demarcation an analysis of the pressures and impacts on water bodies and an assessment of the risk of not achieving the objectives set by the WFD should be drawn up.

The analysis of pressures and impacts on internal river basins in Catalonia has been carried out following the recommendations of Guidance Document No. 3 (CIS, 2003) and is shown in the WFD IMPRESS document (Catalan Water Agency, 2005). In this way, the risk faced by certain river stretches, based on the pressures assessed as significant, taking account of the magnitude of the pressure and the susceptibility or vulnerability of the receiving environment (the river type and its capacity to withstand pressure) has been evaluated, and through an analysis of the impacts measured in the environment (using biological, hydromorphological and physiochemical indicators), the effect of the pressures on the ecosystem can be specified. Based on both analyses, the risk of not achieving the objectives set by the Water Framework Directive can be specified and assessed as being high, medium, low or nil (figure 3.8).

The stretches of river (water bodies) coloured yellow (low risk) and orange (medium risk) indicate that programmes of measures must be drawn up to make human activity compatible with the good status of the water bodies. The water bodies coloured red (high risk) indicate that greater effort and an analysis of the viability of the corrective measures is required. Some of the red stretches (high risk) are candidates to be declared highly modified water bodies in which the quality levels required will be lower and adjusted to their ecological potential (as established by the Water Framework Directive).

Some of the water bodies identified as low or medium risk (coloured yellow or orange) can show good or very good status (figure 3.8), which means good management of the pressures on these river stretches, at least in a wet year (data from 2003). In these water bodies, the risk must be managed and monitored and particular situations analysed.

40% of river water bodies show high risk of failure to comply according to the analysis of pressures, while this percentage is 9% according to the analysis of impacts (figure 3.9). However, the lack of data for the analysis of impacts has made it impossible to assess the risk of non-compliance in 36% of water bodies.

The main effects detected in Catalan river basins that could involve a significant risk of not achieving the objectives set by the Water Framework Directive and therefore require future action with appropriate Programmes of Measures, can be summarised in the following points:

- High density of dams and weirs, diversions for mini-hydroelectric power stations and altered flow systems. Zonal plans for implementing environmental flows, compatibility of uses and sustainable hydroelectric production, resource manage-

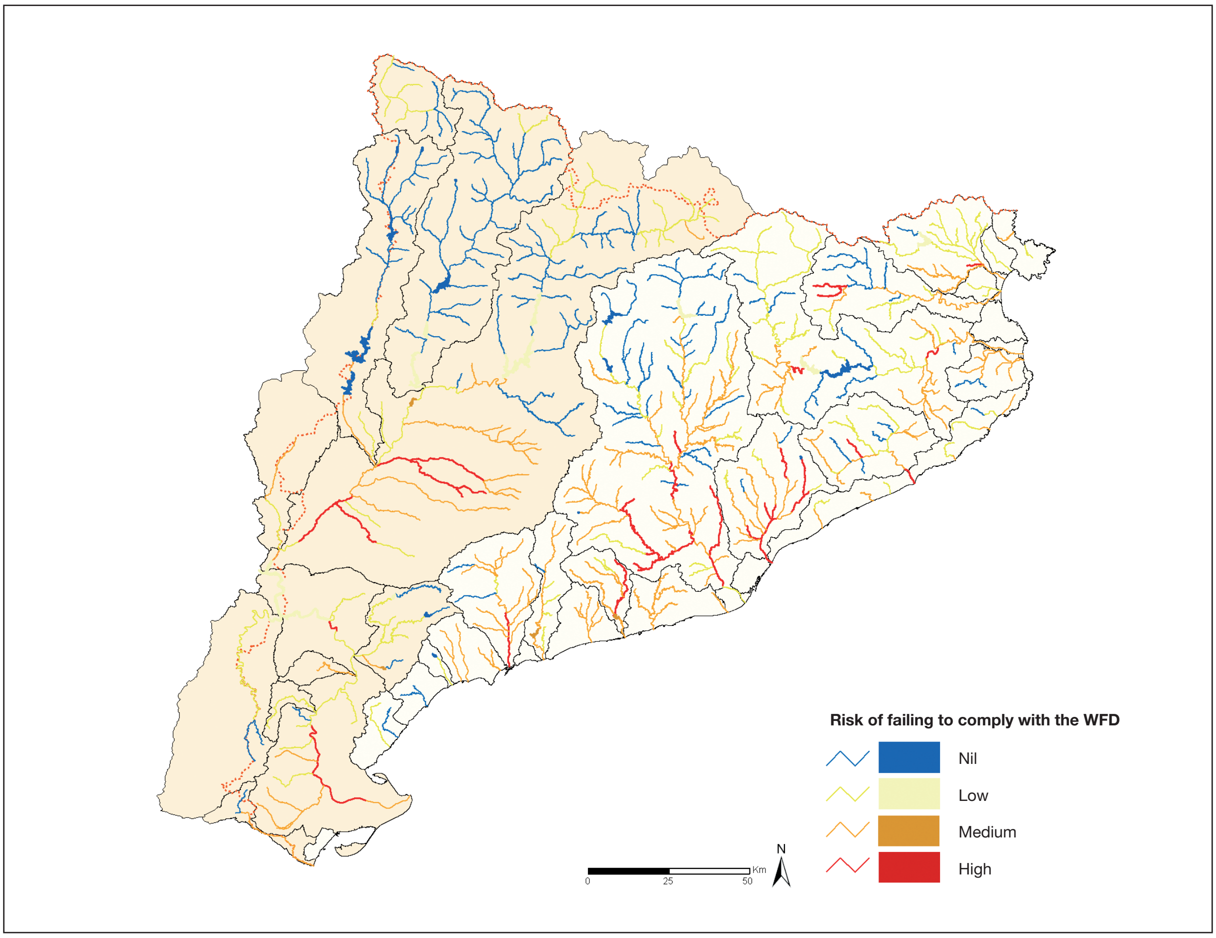

Figure 3.8. River stretches (water bodies) with risk of failing to comply with the WFD objectives based on an analysis of pressures and impacts on river water bodies in Catalan river basins. (Catalan Water Agency, 2005).

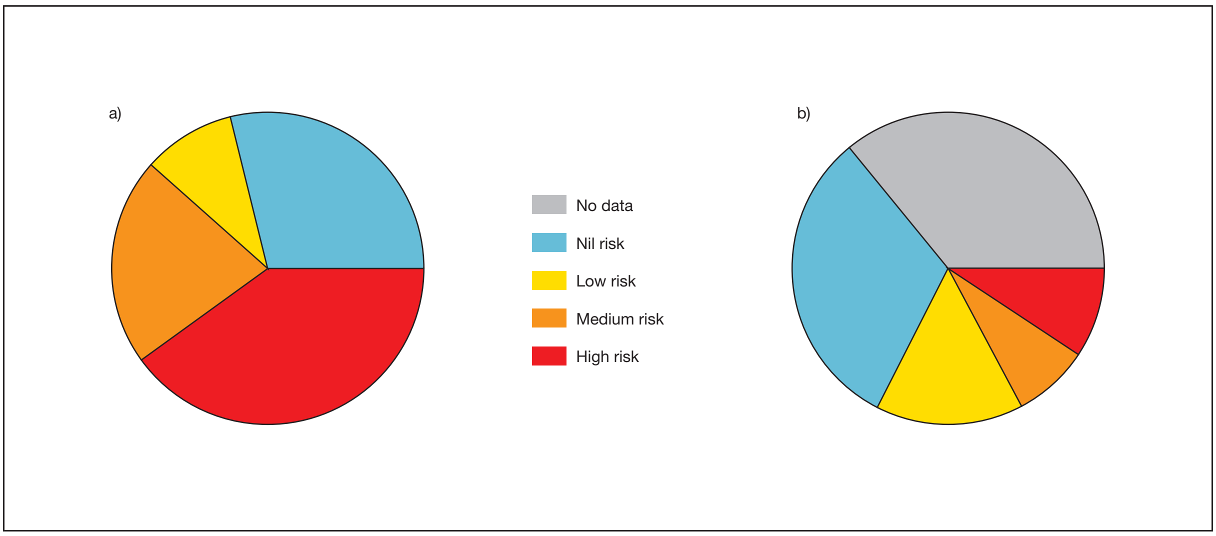

Figure 3.9. Risk of failure to comply according to analysis of pressures (a) and analysis of impacts (b).

ment plans, demand management and reservoir exploitation rules are required.
- Hydromorphological degradation, disappearance of riparian woodland and morphodynamic alteration. Loss of river habitats and occupation of areas subject to flooding. Hydromorphological restoration and riverbank protection plans or programmes must be implemented together with planning of river spaces and areas subject to flooding (PEF) (effect on regional planning).
- Isolated biodegradable and industrial discharges into sensitive stretches of river. (Review of the sanitation plan for Catalonia. Implementation of more efficient tertiary treatments and corrective measures at origin).
- Dispersed pollution, excess nitrogen of livestock-rearing origin and herbicides (organic pollutants) of agricultural origin. (Control of the application of nitrogen and herbicides on farms. Control of dumping from livestock farms).
- Very low fish population quality. Heavy introduction of invasive, foreign species and loss of river habitats. (Programme of monitoring and eradication of invasive species and recovery of river habitats).
- Low biological quality of the middle and lower stretches of the major rivers. (Programme to reuse regenerated water. Improvement of effluents, programme to treat discharges from unitary systems, programme to monitor priority substances).
- High sensitivity to drought given the concentration of capture of surface water in particular stretches of river (Supply Plan for Catalonia).

5. Conclusions

The Water Framework Directive has the virtue of integrating into the same management sphere (the River Basin District or Hydrographic Demarcation) surface water, groundwater, coastal water and seawater affected by continental water from the district. The proper implementation of the concepts and provisions established by the WFD become a complex organisational diagram of actions in order to achieve the required tools and appropriate criteria for new water management based on concepts of sustainability both from the environmental, economic points of view including water resource maintenance, full transparency and public participation in future plans and management programmes.

The ecological status of the aquatic systems is a new tool for measuring the human effect on natural systems that is provided to us by the new Water Framework Directive (2000/60/EC) and which has already been included in the Water Organisation, Management and Charging Act (Act 6/1999) in Catalonia. The ecological status measures for us, in an integrated way, the operation and health of the ecosystem and provides us with a reference for its management and recovery. The programmes of measures that must be included in the new Management Plan (Hydrological Plan) to achieve the objectives of the Water Framework Directive (Plan that must be drawn up before 2009) must make it possible to achieve good ecological status by the end of 2015 at the latest, and the analysis and sensitivity of the receiving environment therefore becomes a key element conditioning the measures to be implemented.

It must be taken into account, as the Water Framework Directive says, that a cost/efficiency analysis in order to define the most appropriate measures. This means some of the “end of the pipe” measures planned could be replaced by preventive measures and action at source. Concentrating treatment at the end of the process may turn out to be too costly and not very efficient if we compare it with the results obtained by improving and recovering the environment.

In the context of integrated water planning, the National Plan for the Sustainable Management of Water (announced by the Minister of the Environment and Housing of the Government of Catalonia), future Programmes of Measures for achieving the objectives set by the Water Framework Directive must be analysed and assessed, which must mean an important change in strategy and in the use of resources and spaces associated with aquatic ecosystems, making the good health of the environment compatible with the use of water as a resource. The studies carried out to date by the ACA (summarised in the IMPRESS document) form a very important document for drawing up a future Management Plan following the WFD guidelines (these studies can be found on the ACA website: http://www.gencat.net/aca).

6. References

ABELLÀ, C. (1986) “L’estany de Banyoles com a unitat ecològica. Perills de contaminació”. *Primeres Jornades sobre l’estany de Banyoles, ponències i comunicacions:* 27-32.

ADAMUS, P., DANIELSON, T.J. and GONYAW, A. (2001). Indicators for monitoring biological integrity of inland, freshwater wetlands. A survey of North American technical literature (1990-2000). USA Environmental Protection Agency, Office of Water Office of Wetland, Oceans, and Watersheds, Washington, DC 20460.

Catalan Water Agency. (2005). Caracterització de les masses d'aigua i anàlisi del risc d'incompliment dels objectius de la Directiva Marc de l'Aigua (2000/60/CE) a les Conques Internes de Catalunya. *Technical document (February 2005)*. 623 pp.

ALBA-TERCEDOR, J., JÁIMEZ-CUÉLLAR, P., ÁLVAREZ, M., AVILÉS, J., BONADA, N., CASAS, J., MELLADO, A., ORTEGA, M., PARDO, I., PRAT, N., RIERADEVALL, M., ROBLES, S., SÁINZ-CANTERO, C.E., SÁNCHEZ-ORTEGA, A., SUÁREZ, M.L., TORO, M., VIDAL-ALBARCA, M.R., VIVAS, S. and ZAMORA-MUÑOZ, C. (2002). Caracterización del estado ecológico de los ríos mediterráneos ibéricos mediante el índice IBMWP (antes BMWP'). *Limnetica.* 21 (3-4): 175-185.

ALBA-TERCEDOR, J. and SÁNCHEZ-ORTEGA, A. (1988). Un método rápido y simple para evaluar la calidad biológica de las aguas corrientes basado en el de Hellawell (1978). *Limnetica*, 4: 51-56.

APARICIO, E., VARGAS, M.J., OLMO, J.M., SOSTOA, A. (2000). Decline of native freshwater fishes in a Mediterranean watershed on the Iberian Peninsula: a quantitative assessment. *Environm. Biology of Fishes*, 59: 11-19.

ARMENGOL, J., NAVARRO, E., GARCIA-BERTHOU, E., MORENO-AMICH, R. (2003). Caracterització i propostes d'estudi dels embassaments catalans segons la Directiva 2000/60/CE del Parlament Europeu. *Technical Catalan Water Agency documents*. 212 pp.

BACH, J., GARCÍA, J., MARQUÈS, E., MORENO-AMICH, R., MUJERIEGO, R., QUINTANA, X.D. and SALVADÓ, V. (1998). *Seguiment de la qualitat de les aigües a la zona del Parc Natural dels Aiguamolls de l'Alt Empordà.* Girona: Costa Brava Consortium. (Cd-Rom).

BAILEY, R.C., KENNEDY, M.G., DERVISH, M.Z. and TAYLOR, R.M. (1998). Biological assessment of freshwater ecosystems using a reference condition approach: Comparing predicted and actual benthic invertebrate communities in Yukon streams. *Freshwater Biology* 39 (4): 765-774.

BALAGUER, LL. and MUÑOZ, A. (2001) *Inventari de les zones humides de Catalunya*. Directorate General of Natural Heritage and the Physical Environment. CDROM.

BALLESTEROS, E. and GACIA, E. (1988) Los macrófitos acuáticos de los lagos del parque nacional de Aigüestortes i Estany de Sant Maurici. First research conference. 144-165.

BAYO, M., ORTEGA, M., LANGTON, P. and CASAS, J.J. (2001). Evaluación ecológica de humedales y la directiva marco europea sobre el agua: sobre el valor indicador de las comunidades de dípteros quironómidos en los humedales litorales de la provincia de Almería. *Actas V simposio sobre el agua en Andalucía*: 375-384.

BENITO, G., PUIG, M.A. (1999). BMWPC, un índice biológico para la calidad de las aguas adaptado a las características de los ríos catalanes. *Tecnología del Agua*, 191: 43-56.

BOLÒS, O. de. (1986) "Comentaris sobre l'estany de Banyoles i la seva vegetació". *Primeres Jornades sobre l'estany de Banyoles, ponències i comunicacions:* 133-137.

BONADA, N., PRAT, N., MUNNÉ, A., RIERADEVALL, M., ALBA-TERCEDOR, J., ÁLVAREZ, M., AVILÉS, J., CASAS, J., JÁIMEZ-CUÉLLAR, P., MELLADO, A., MOYÀ, G., PARDO, I., ROBLES, S., RAMÓN, G., SUÁREZ, M.L., TORO, M., VIDAL-ALBARCA, M.R., VIVAS, D. i ZAMORA-MUÑOZ, C. (2002). Criterios para la selección de condiciones de referencia en los ríos mediterráneos. Resultados del proyecto GUADALMED. *Limnetica.* 21 (3-4): 99-114.

BURTON, T.M., UZARSKI, D.G., GATHMAN, J.P., GENET, J.A., KEAS, B.E. and STRICKER, C.A. (1999). Development of a preliminary invertebrate index of biotic integrity for great lakes coastal wetlands of Lake Huron. *Wetlands* 19 (4): 869-882.

CAMBRA, J., GOMÀ, J. and ORTIZ, R. (2003). Anàlisi de viabilitat i proposta d'indicadors fitobentònics de la qualitat de l'aigua per als cursos fluvials de Catalunya (Tordera, Besòs, Llobregat, Foix, Gaià, Francolí i Riudecanyes). *Technical Catalan Water Agency documents*. 113 pp.

CAMBRA, J., SABATER, S. and TOMÀS, X. (1991). Diatom check-list from Catalonian countries (eastern Spain). *Butlletí de la Institució Catalana d'Història Natural*, 59: 41-55.

CAMPS, J., GONZALVO, I., GÜELL, J., LÓPEZ, P., TEJERO, A., TOLDRÀ, X., VALLESPINOS, F. i VI-

CENS, M. (1976) “El lago de Montcortés: descripción de un ciclo anual”. *Oecologia aquatica*, 2: 99-110.

CATALAN, J., BALLESTEROS, E., CAMARERO, L., FELIP, M. and GACIA, E. (1993) Limnology in the Pyrenean lakes. *Limnetica* 8: 27-38.

CIRUJANO, S., VELAYOS, M., CASTILLA, F. and GIL, M. (1992). *Criterios botánicos para la valoración de las lagunas y humedales españoles (Península Ibérica e Islas Baleares)*. ICONA-CSIC Madrid. 456 p.

Common Implementation Strategy (2003). *Guidance document n. 3. Analysis of Pressures and Impacts*.

DOCE. (2003). Directive 2000/60/EC of the European Parliament and the Council, 23 October 2000, establishing a Community framework for action in the sphere of water policy. *Official Newspaper of the European Community*. L 327, 22 December 2000: 72 pp.

European Comission. (2003). Overall approach to the Classification of the Ecological Status and Ecological Potential. *Water Framework Directive. Common Implementation Strategy. Working Group 2A. Ecological Status (ECOSTAT)*. 27 November 2003: 47 pp.

FANO, E.A., MISTRI, M. and ROSSI, R. (2003). The ecofunctional quality index (EQI): a new tool for assessing lagoonal ecosystem impairment. *Estuarine, Coastal and Shelf Science*, 56: 709-716.

FERREIRA, M.T., GODINHO, F., ALBURQUERQUE, A., RIVAES, E.R., CORTÉS, M.V. and MORAIS, M. (2004). Qualidade ecológica es gestao integrada de albufeiras. *Contract 2003/067/INAG*. October, 2004. Lisboa. 43 pp.

GARCIA-BERTHOU, E. and MORENO-AMICH, R. (2002). Fish ecology and conservation in Lake Banyoles (Spain): the neglected problem of exotic species. Cowx, I. G. Management and Ecology of Lake and Reservoir Fisheries, 223-231. Oxford, Blackwell Science Ltd.

GUTIÉRREZ, C., SALVAT, A. and SABATER, F. (2001). IVF. Índex per a l’avaluació de la qualitat del medi fluvial a partir de la vegetació de ribera. *Technical Catalan Water Agency documents*. 49 pp.

JÁIMEZ-CUÉLLAR, P., VIVAS, S., BONADA, N., ROBLES, S., MELLADO, A., ÁLVAREZ, M., AVILÉS, J., CASAS, J., ORTEGA, M., PARDO, I., PRAT, N., RIERADEVALL, M., SÁINZ-CANTERO, C.E., SÁNCHEZ-ORTEGA, A., SUÁREZ, M.L., TORO, M., VIDAL-ALBARCA, M.R., ZAMORA-MUÑOZ, C. and ALBA-TERCEDOR, J. (2002). Protocolo GUADALMED (PRECE). *Limnetica.* 21 (3-4): 187-204.

LILLIE, R.A., GARRISON, P., DODSON, S.I., BAUTZ, R.A. and LALIBERTE, G. (2002). *Refinement and expansion of wetland biological indices for Wisconsin*. USEPA Report.

MARGALEF, R. (1950) “Datos para la hidrobiología del estanque de Montcortés (provincia de Lérida)”. *Newsletter of the Real Sociedad Española de Historia Natural,* 48: 209-218.

MERINO, V., GARCÍA, J. and HERNÁNDEZ-MARINÉ, M. (1994). Use of diatoms for pollution monitoring in the Valira Basin (Andorra). *Proceedings of the 13th International Diatom Symposium.* 107-119.

MIRACLE, M.R. and GONZALVO, I. (1979) “Els llacs càrstics”, in MARGALEF, R. (ed.), *La Limnologia. Els llacs, els embassaments i els rius catalans com a ecosistemes*, p.37-50. Quaderns d’Ecologia Aplicada. Barcelona Provincial Council.

MIRÓ, A. and M. VENTURA (2004) “Història de la truita comuna i altres espècies de peixos als estanys del parc Nacional d’Aigüestortes i estany de Sant Maurici: Orígens, aprofitament i distribució. La investigació al Parc Nacional d’Aigüestortes i estany de Sant Maurici”. VI Research Conference. October 2003.

MODAMIO, X., PÉREZ, V. and SAMARRA, F. (1988) “Limnología del lago de Montcortès (ciclo 1978-79) (Pallars Jussà, Lleida)”. *Oecologia aquatica*, 9: 9-17.

MORENO-AMICH, R., QUINTANA, X.D., SUÑER, L., TROBAJO, R. and GASCÓN, S. (1999). “Dinámica del heleoplancton en relación a las fluctuaciones hidrológicas en “Aiguamolls de l’Empordà” (NE de la Península Ibérica). Propuesta de un método sencillo de monitorización basado en la abundancia de grupos taxonómicos”. *Limnetica*, 16: 17-31.

MOSS, B., STEPHEN, D., ÁLVAREZ, C., BÉCARES, E., VAN DE BUND, W., COLLINGS, S.E., VAN DONK, E., DE EYTO, E., FELDMANN, T., FERNÁNDEZ-ALÁEZ, C., FERNÁNDEZ-ALÁEZ, M., FRANKEN, R.J.M., GARCÍA-CRIADO, F., GROSS, E.M., GYLLSTRÖM, M., HANSSON, L.-A., IRVINE, K., JÄRVALT, A., JENSEN, J.-P., JEPPESEN, E., KAIRESALO, T., KORNIJÓW, R., KRAUSE, T., KÜNNAP, H.,

LAAS, A., LILL, E., LORENS, B., LUUP, H., MIRACLE, M.R., NÕGES, P., NÕGES, T., NYKÄNEN, M., OTT, I., PECZULA, W., PEETERS, E.T.H.M., PHILLIPS, G., ROMO, S., RUSSELL, V., SALUJÕE, J., SCHEFFER, M., SIEWERTSEN, K., SMAL, H., TESCH, C., TIMM, H., TUVIKENE, L., TONNO, I., VIRRO, T., VICENTE, E. and WILSON, D. (2003). The determination of ecological status in shallow lakes – a tested system (ECOFRAME) for implementation of the European Water Framework Directive. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 13: 507-549.

MUNNÉ, A. and PRAT, N. (2004). Defining river types in a Mediterranean area. A methodology for the implementation of the EU Water Framework Directive. *Environmental Management*, 34 (5): 711-729.

MUNNÉ, A., PRAT. N., SOLÀ, C., BONADA, N. and RIERADEVALL, M. (2003). A simple field method for assessing the ecological quality of riparian habitat in rivers and streams: QBR index. *Aquatic Conserv: Mar. Freshw. Ecosyst*. 13: 147-163.

MUNNÉ, A. and PRAT, N. (2002). Regionalització del sistema fluvial a les Conques Internes de Catalunya. Aplicació de la Directiva Marc en Política d'Aigües de la Unió Europea. *Technical Catalan Water Agency documents*. 92 pp.

MUNNÉ, A. and PRAT, N. (2000). Delimitación de regiones ecológicas para el establecimiento de tipos de referencia y umbrales de calidad biológica: Propuesta de aplicación de la Nueva Directiva Marco del agua en la cuenca del Ebro. II Congreso de la Fundación Nueva Culura del Agua. Oporto, 2000. 19 pp.

MUNNÉ, A. and PRAT, N. (1999). Cabals i qualitat biològica del riu Anoia. Diagnosi de l'estat del riu i dels trams finals dels afluents principals. *Estudis de la qualitat ecològica dels rius*. 5. 76 pages Barcelona: Diputació de Barcelona, Àrea de Medi Ambient.

MUNNÉ, A., SOLÀ, C. and PRAT. N. (1998). QBR: Un índice rápido para la evaluación de la calidad de los ecosistemas de ribera. *Tecnología del Agua*, 175: 20-37.

MUÑOZ, I., PICÓN, A., SABATER, S. and ARMENGOL, J. (1998). La calidad del agua del río Ter a partir del uso de índices biológicos. *Tecnología del Agua,* 175: 60-67.

MUÑOZ, I. and PRAT, N. (1994). A comparación between different biological water quality indexes in the Llobregat Basin (NE Spain). *Ver. Internal. Verein. Limnol.,* 25: 1945-1949.

PARDO, I., ÁLVAREZ, M., CASAS, J., MORENO, J.L., VIVAS, S., BONADA, N., ALBA-TERCEDOR, J., JÁIMEZ-CUÉLLAR, P., MOYÀ, G., PRAT, N., ROBLES, S., SUÁREZ, M. L., TORO, M. and VIDAL-ALBARCA, M.R. (2002). El hábitat de los ríos mediterráneos. Diseño de un índice de diversidad de hábitat. *Limnetica.* 21 (3-4): 115-133.

PENNINGS S.C., DAN WALL, V., MOORE, D.J., PATTANAYEK, M., BUCK, T.L. and ALBERTS, J.J. (2002). Assessing salt marsh health: a test of the utility of five potential indicators. *Wetlands*, 22 (2): 405-414.

PLANAS, M.D. (1973). "Composición, ciclo y productividad del fitoplancton del lago de Banyoles". *Oecologia aquatica*, 1: 3-106.

POFF, N.L., ALLAN, J.D., BAIN, M.B., KARR, J.R., PRESTEGAARD, K.L., RICHTER, B.D., SPEARKS, R.E. and STROMBERG, J.C. (1997). The natural flow regime, A paradigm for river conservation and restortion. *BioScience* 47 (11): 769-784.

POLLARD, P. (2005). Template for the development of a boundary setting protocol for the purposes of the intercalibration exercise. *Common Implementation Strategy (CIS) – Working Group A ECOSTAT.* Report (CEN/TC 230/WG 2/TG 1 N99). 18 pp.

PRAT, N. (2002). El proyecto GUADALMED. *Limnetica.* 21 (3-4): 1-3.

PRAT, N., MUNNÉ, A., RIERADEVALL, M. and BONADA, N. (2000). La determinación del estado ecológico de los ecosistemas acuáticos en España. A FABRA, A., and BARREIRA, A. (eds.): *La aplicación de la Directiva Marco del Agua en España. Retos y oportunidades.* Madrid: IIDMA. 48-81.

PRAT, N., MUNNÉ, A., RIERADEVALL, M., SOLÀ, C. and BONADA, N. (2000a). ECOSTRIMED. Protocol per determinar l'estat ecològic dels rius mediterranis. *Estudis de la qualitat ecològica dels rius*. 8. 94 pp. Department of the Environment, Barcelona Provincial Council.

PRAT, N., MUNNÉ, A., RIERADEVALL, M., SOLÀ, C. and BONADA, N. (1999). La qualitat ecològica del Llobregat, el Besòs, el Foix i la Tordera. Report 1997. *Estudis de la qualitat ecològica dels rius*. 7. 154 pp. Department of the Environment, Barcelona Provincial Council.

QUINTANA, X., BOIX, D., GASCÓN, S., GIFRÉ, J., MARTINOY, M., SALA, J. and MORENO-AMICH, R. (2004). Caracterització, regionalització i elaboració d'eines d'establiment de l'estat ecològic de les zones humides de Catalunya. *Technical Catalan Water Agency documents*. 85 pp.

RIERADEVALL, M. and PRAT, N. (1991). "Benthic fauna of Banyoles lake (NE Spain)". *Internationale Vereinigung für theoretische und Angewandte Limnologie (Verh. Internat. Verein. Limnol.),* 24: 1020-1023.

SABATER, S., TORNÉS, E., LEIRA, M., TROBAJO, R. (2003). Anàlisi de viabilitat i proposta d'indicadors fitobentònics de la qualitat de l'aigua per als cursos fluvials de Catalunya (Muga, Fluvià, Ter i Daró). *Technical Catalan Water Agency documents*. 113 pp.

SABATER, S., GUASCH, H., PICON, A., ROMANÍ, A. and MUÑOZ, I. (1996). Using diatom communities to monitor water quality in a river after the impllle-mentation of a sanitation plan (river Ter, Spain). Whiton, BA, Rott, E (eds): *Use of algae for monitoring rives II*: 97-103.

SABATER, S., SABATER, F. and ARMENGOL, J. (1993). Ecología de los ríos mediterráneos. *Investigación y Ciencia* August 1993: 72-79.

SIMON, T.P., JANKOWSKI, R. and MORRIS, C. (2000). Modification of an index of biotic integrity for assessing vernal ponds and small palustrine wetlands using fish, crayfish, and amphibian assemblages along southern Lake Michigan. *Aquatic Ecosystem Health and Management*: 3 (3): 407-418.

SOSTOA, A., CASALS, F., CAIOLA, N.M., VINYOLES, D., SÁNCHEZ, S. and FRANCH, C. (2003). Desenvolupament d'un índex d'integritat biòtica (IBICAT) basat en l'ús dels peixos com a indicadors de la qualitat ambiental dels rius a Catalunya. *Technical Catalan Water Agency documents*. 203 pp.

SUTCLIFFE, D. (2001). Lake assessment and the EC Water Framework Directive. *Freshwater Forum*. 16. Freshwater Biological Association.

TROBAJO, R., QUINTANA, X.D. and MORENO-AMICH, R. (2002). Model of alternative predominance of phytoplankton-periphyton-macrophytes in relation to nutrient level in lentic systems in Mediterranean coastal wetlands. *Archiv für Hydrobiologie*, 154 (1): 19-40.

VENTURA, M., CATALÁN, J. (2003). Desenvolupament d'un índex integral de qualitat ecològica i regionalització ambiental dels sistemes lacustres de Catalunya. *Technical Catalan Water Agency documents*. 177 pp.

VENTURA, M., CAMARERO, L., BUCHACA, T., BARTUMEUS, F., LIVINGSTONE, D.M., and CATALAN, J. (2000). The main features of seasonal variability in the external forcing and dynamics of a deep mountain lake (Redó, Pyrenees). *Journal of Limnology* 59 (Suppl.): 97-108.

VERAART, J.A. (1999). *Selection of bio-indicators to monitor water quality regulation and biodiversity conservation in S'Albufera Natural Park, Mallorca*. Afstudeerverslag, Leerstoelgroep Milieusysteemanalyse, Leerstoelgroep Aquatische Ecologie in Waterkwaliteitsbeheer, Wageningen Universiteit.

WALLIN, M., WIEDERHOLM, T., JOHNSON, R. (2003). Guidance on establishing reference conditions and ecological status class boundaries for inland surface waters. Common Implementation Strategy Working Group 2.3 – REFCOND guidance. Final version 7.0. 93 pp.

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