

Conservation status assessment of aquatic habitats within the Rhine floodplain using an index based on macrophytes

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The programme LIFE Nature "Conservation and restoration of habitats of the Rhine fringe" (2002-2005) focussed on the assessment of the conservation status of terrestrial and aquatic habitats. Along the Rhine fringe, the degree of connection between waterbodies and the river main channel determined the water flow (surface or phreatic waters, flow velocity) and induced flood disturbances (hydromorphological quality, scouring effect). A new typology based on metrics characterizing the conservation status, was proposed for the upper Rhine floodplain. Seven physical and biological metrics were selected: specific richness, presence or absence of rare, polluto-tolerant and exotic species, species abundance, degree of connection, and trophy level defined by the macrophyte community. Aquatic macrophytes surveys were conducted at 315 sites along the Rhine French fringe. Multiple correspondence analysis and discriminant analysis were used to define metrics scores in a preliminary network of 129 macrophytes surveys stands. Metrics were combined to give a measure of the conservation status of the 315 sites. Five classes of the conservation status have been defined from degraded to excellent status. The mapping of the conservation status was realized to answer the question addressed by the program "Life Nature". We discuss on the choice of the metrics and their justification in the definition of the conservation status. The method was tested in the fluvial hydrosystem of Ill river, the main tributary of the Rhine river in the Alsace floodplain, and compared to the French trophic index based on macrophytes, IBMR.

Keywords: biological index, conservation status, macrophytes, running waters, Rhine floodplain

Introduction

In aquatic systems, both running and standing waters, high physical (current velocity, substrate, light...) and chemical (organic matter and nutrient content) fluctuations were commonly observed (Dodkins et al. 2005). Although they show high ecological plasticity, species and plant communities cope with these fluctuations (Barrett et al. 1993, Garbey et al. 2003). Thus their use as bioindicators can be discussed due to their high adaptability in changing environment. Bioindication is based on the tolerance of certain species to high levels of mineral nutrients or organic pollution and conversely to a high sensitivity to pollution or adaptation to low level of nutrient of others. Affected waters will tend to support an increased abundance of more nutrient-tolerant species associated with an overall loss of species diversity.

Nowadays, macrophytes are commonly used as indicators of the nutrient status and their use lead to the proposal of numerous European typologies (Grasmück 1995,

Robach et al. 1996) or indices (MTR Mean Trophic Rank of Holmes 1995, RPM Relative Pflanzen Menge of Kohler & Janauer 1995, TIM Trophic Index of Macrophytes of Schneider & Melzer 2003, IBMR Indice Biologique Macrophytes en Rivière in France 2003, Haury et al. 2006).

Aquatic systems are more and more considerably altered by organic pollution and then become eutrophic, and sometimes hypertrophic depending on the phosphorus content (SRP) and nitrogen, as a consequence of degradation of organic matter. A 'damage rate' based on macrophytes community relative to an undisturbed reference was proposed by Haslam (1982). Recently, the Water Framework Directive (WFD 2000, transposed in France 2004) required the good ecological status of surface waters to be reached, and the reduction in the release of dangerous and toxic substances. Application of WFD needs (1) to find indicators to estimate ecological quality (e.g. structure and function of habitats) based on physical, chemical and biological quality of water bodies and (2) to establish a reference system. In another hand, the Habitats (Natura 2000) Directive focussed on the definition of conservation status of habitats and species. In the Alsace

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Rhine floodplain (Eastern France), the program LIFE Nature "conservation and restoration of habitats" (2003-2005), aimed (1) the definition of a reference for a good conservation status of habitats (terrestrial and aquatic habitats according to the Natura 2000 definition) and (2) mapping of this status in order to identify sites or stretches to preserve, restore or rehabilitate.

A bioindication scale of eutrophication based on macrophyte communities was established in the phreatic streams of the Alsace floodplain, a scale which covered the whole gradient of trophic level, from oligotrophic to eutrophic (Carbiener et al. 1990, Robach et al. 1996) as that formerly proposed by Kohler (1975). At each trophic level, corresponded a plant community (defined by the phytosociological method according to Braun-Blanquet 1964). However, this method was not validated neither for standing waters (lakes, ponds) nor for marshes habitats; it defined more precisely a trophic level than a conservation status.

To assess the conservation status of water bodies of the Rhine fringe (as defined in the programme LIFE), both running (streams, connected lateral arms) as standing waters (cut-off channels, ponds, marshes), we proposed a new tool based on macrophytes. This tool was set-up in the former lateral arms of the Rhine, in order to identify sectors exhibiting good and bad conservation status and specify the ones that could be restored.

Methodology

Three steps were used 1) vegetation sampling and identification of the plant community, 2) definition of the conservation status through a notation based on 7 metrics, and 3) mapping of the conservation status of aquatic habitats of the Rhine fringe.

Study sites

The upper Rhine floodplain was drastically managed until the 19th century, by straightening and canalisation. As a consequence, many water bodies were cut-off from the river Rhine. Both hydrological connection and exchange between river and water bodies and exchange with the groundwater were highly modified by the hydraulic management of the river. However, some indirect hydrological relationships, *i.e.* seepage from the river to the groundwater were preserved and thus influenced the water quality of disconnected former lateral arms which were still supplied by groundwater. The water nutrient content of water bodies along the river fringe, depends on the type and degree of connection with the river main channel (Trémolières et

al.1993, Eglin et al.1997, Bornette et al.1998). The water bodies which are supplied by surface water (Rhine waters) are eutrophic, whereas the disconnected ones are most of the time mesotrophic. Where water is supplied by a mixture of ground- and surface-water, water-bodies can be mesotrophic to eutrophic, depending on the surface water quality.

In the Alsace floodplain (Eastern France), along the Rhine fringe, we selected aquatic sites or stretches belonging to the five aquatic habitat types according to Natura 2000 classification (Table 1, Bensettiti et al. 2002). Study sites were composed of water bodies, 50 to 100 m length in running waters and 10 m² minimal surface in standing waters.

Table 1. Definition of the five aquatic natural habitat types whose conservation requires designation of Natura 2000 sites present in the Rhine fringe

Natura 2000 Codes	Characteristics, phytosociological name
3130	Oligotrophic to mesotrophic standing waters with vegetation of the <i>Littorelletea uniflorae</i> and/or of the <i>Isoëto-Nanojuncetea</i>
3140	Hard oligo-mesotrophic waters with benthic vegetation of <i>Chara</i> spp.
3150	Natural eutrophic lakes with <i>Magnopotamion</i> or <i>Hydrocharition</i> – type vegetation
3260	Water courses of plain to montane levels with the <i>Ranunculion fluitantis</i> and <i>Callitricho-Batrachion</i> vegetation
3270	Rivers with muddy banks with <i>Chenopodium rubri</i> p.p. and <i>Bidention</i> p.p. vegetation

Vegetation sampling

Macrophyte surveys (N = 315) were carried out between mid-June and mid-September, according to the phytosociological method of Braun-Blanquet (1964). Vascular plants and bryophytes were identified to the species level, whereas algae were identified to the genus level. According to this macrophyte survey, we designated a community according to Oberdorfer (1992) and the trophic scale proposed for the Rhine floodplain by Robach et al. (1996). This latest scale identified six communities named A to F, corresponding to a gradient of trophic, from oligotrophic to eutrophic level.

Each survey was characterized by a phytosociological community and a 'trophic' community coded in the Table 2.

Table 2. Correspondence between phytosociological community, trophic community and Natura 2000 habitat code, and number of surveys per community used in the statistical analyses with the proposed conservation status. N= total number of surveys; *according to Oberdorfer (1992), **according to Robach et al. (1996)

N	Conservation status	Code	Phytosociological community or alliance*	Community in the trophic scale**	Habitat code (Natura 2000)
56		calo	<i>Callitrichetum obtusangulae</i>	C	3260, 3150
26		cerd	<i>Ceratophylletum demersi</i>	E	3260, 3150
13	good	char	<i>Charion</i>	C	3140
59		elod	<i>Elodeetum</i>	E	3260, 3150
15	moderate	lemt	<i>Lemnetum trisulcae</i>	C	3260, 3150
20		lmsp	<i>Lemno minoris-Spirodeletum polyrrhizae</i>	E	3150
1	high	myri	<i>Myriophyllo-Nupharetum</i>	C	3150
25		potl	<i>Potamogetonum lucentis</i>	D	3150
63	poor	potp	<i>Potamogetonum pectinati</i>	E	3260, 3150
37	bad	ranf	<i>Ranunculetum fluitantis</i>	F	3260

Definition of the metrics

Seven metrics were defined for the 315 surveys. Five simple ecological metrics were proposed to assess the conservation status:

- (1) specific richness with four modalities : 1= 0- 4, 2=5 - 7, 3=7 - 10, 4=11 – 23.
- (2) presence of rare species. They were the species of the regional red list such as *Sparganium minimum*, *Potamogeton trichoïdes*, *P. Friesii*, and two less frequent species *Nymphaea alba* and *Najas marina*.
- (3) presence of polluto-tolerant species. Species considered as polluto-tolerant which grow in the Alsace floodplain were *Potamogeton pectinatus*, *Ranunculus fluitans*, *Potamogeton nodosus*, and *Lemna gibba*.
- (4) presence of exotic species (*Elodea* sp.).
- (5) vegetation cover percentage with 4 modalities : 1=0 - 30%, 2=30 - 60%, 3=60 - 80%, 4=80 - 100%.

The classes of specific richness and cover were defined as medians and quartiles of these variables.

Two additional physical and chemical metrics were used:

- (1) connection, that involves fluxes of material (nutrient and sediments) and living organisms, occurs both between cut-off channels and main channel, and between channels and groundwater. Three modalities were considered for the degree of connection: 1 = very

high (permanent connections), 2 = intermediate (depending on frequency and magnitude of floods) and 3 = very low (infrequent connections).

- (2) trophic level with 3 modalities: mesotrophic, eutrophic, hypertrophic. This metric was obtained from the plant community survey according to the bioindication scale (Robach et al. 1996), independently from the degree of connection.

We selected 129 surveys, representing the 5 phytosociological communities which status was known according to experts opinion (ranging from good to bad) in order to calibrate the measure of conservation status (Table 2). Then, the index of the conservation status was calculated for the remaining 186 surveys representing five other phytosociological communities. Conservation status of these sites were not defined *a priori*. The index of conservation defined for a set of 619 surveys (including the 315 surveys) located along the Rhine fringe was mapped with a GIS (Geographical Information System- geoconcept software).

Statistical analyses

The data used in this analysis was obtained from surveys of 315 aquatic sites, along the upper Rhine left bank. This set was analysed by using the SAS software (Version 9.1, 2002-2004, SAS Institute Inc., Cary, NC, USA).

Physical and biological data were coded into classes. We obtained a numerical representation of each site by projection on the first two principal axes through a multiple correspondence analysis (MCA) used in case of qualitative data (Greenacre 1984). This step allows us to transform mixed data (qualitative and quantitative) in normalized numerical data. The first two principal axes explain 30.47% of inertia which can be estimated to be sufficient to classify sites into classes of conservation status.

A canonical discriminant analysis (CDA) was then applied on transformed data (Hand 1981). By this way a linear function of the two principal components was built in order to classify the 129 calibration surveys into communities of known conservation status. A single linear function is sufficient in the case of two components. This linear function gives a score for each modality of coded data. So we are able to classify a site by using the coding of the first step. This procedure was used to classify the 186 supplementary test surveys and to validate the first classification.

Results

Floristic composition of habitats

At first we observe an unequal distribution of Natura 2000 habitats in the Rhine fringe: habitats 3130 and 3270 are present in less than 1% of waterbodies, habitat 3140 in less than 7% and habitats 3150 and 3260 are the most common habitats with approximatively 45% of the whole studied stations. Habitats 3130 and 3270 are colonised by helophytic vegetation with preference for the bank and the zone of tidal range. Habitat 3140 with Characean occurs in recently opened habitats with clear waters.

Ten phytosociological communities of hydrophytes (named according to Oberdorfer 1992) are found in the three aquatic habitats of running waters (3260), standing waters (3150) and Characean habitat (3140). Fourteen phytosociological communities are found in total in the Rhine fringe whether we include marsh habitats (3170 and 3230). All these communities correspond to the mesotrophic and eutrophic levels: C, D and E in the scale of bioindication (Robach et al. 1996) (table 2). In the connected sectors, four phytosociological communities were found: *Ranunculetum fluitantis* and *Potamogetonum pectinati* in running waters, and *Ceratophylletum demersi*, *Potamogetonum lucentis* and again *Potamogetonum pectinati* in standing waters. These four communities are the richest with up to around 30 species and correspond to eutrophic D and E communities in the bioindication scale. In the discon-

nected sectors, the growing vegetation is dominated by *Callitriche obtusangula*, *Berula erecta* and *Lemna trisulca*. These species defined two communities: the *Callitrichetum obtusangulae* and the *Lemnetum trisulcae*. These two communities are attributed to the mesotrophic C community in the bioindication scale (Robach et al. 1996). In oligotrophic conditions (rarely found in the Rhine fringe), the *Myriophyllo-Nupharetum* with *Myriophyllum verticillatum* and *Nymphaea alba*, as characteristic species, is growing in standing waters. The new area opened by the reconnection to the river main channel are often colonised in mesotrophic conditions by pioneer Characean or by exotic species such as *Elodea nuttallii* in more eutrophic conditions.

Distribution of communities according to their conservation status

The distribution of macrophyte communities within the Alsace floodplain exhibits a characteristic pattern as shown by the multivariate analysis in Fig. 1: the first axis of the factorial plan (MCA) is strongly associated with the trophic gradient: hypertrophic level and the presence of polluto-tolerant species are associated with negative values, whereas the presence of rare species is associated with positive values on axis 1. Figure 2 showed the distribution of communities, whose conservation status is already known, in the factorial plan F1xF2 of the discriminant analysis. The first axis, representing trophic gradient, can be considered as an ecological gradient, high values of conservation status representing a good status. All the sites with the communities of good conservation status are located towards the positive values of F1 axis and the communities of a less good quality presented negative values. The *Myriophyllo-Nupharetum* (Myri) community, exhibiting the highest value on the first axis, was characterized by the presence of rare species such as *Nymphaea alba*, and the absence of polluto-tolerant species in an oligotrophic water. The *Lemnetum trisulcae* (Lemn) characterized a "moderate" conservation status with mesotrophic water, medium specific richness, around 7 species and the absence of polluto-tolerant and exotic species. On the opposite way, the *Ranunculetum fluitantis* (Ranf) and the *Potamogetonum pectinati* (Popt) communities present both polluto-tolerant and exotic species. So, they are in a poor to bad conservation status with a high trophic level. Figure 3 showed a factorial plan F1xF2 with the 186 supplementary individual surveys. The mesotrophic community *Callitrichetum* (Calo) had positive values on the axis 1 and the eutrophic community *Potamogetonum lucentis* (Potl) negative values, confirming the first axis as a trophic gradient.

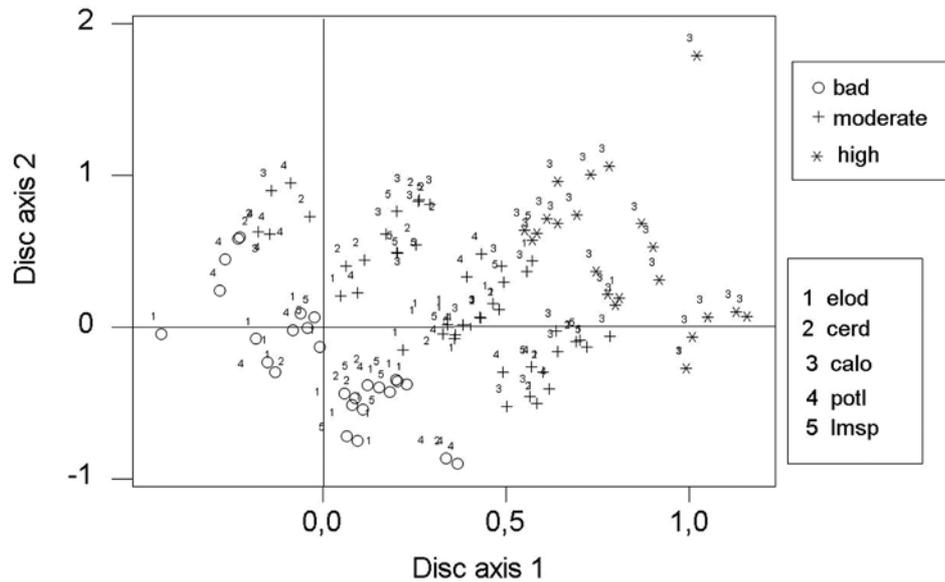


Fig. 3. Distribution of 5 supplementary plant communities (not classified) in the factorial plan F1x2 (CDA Canonical Discriminant Analysis). The code of community is given in the table 2.

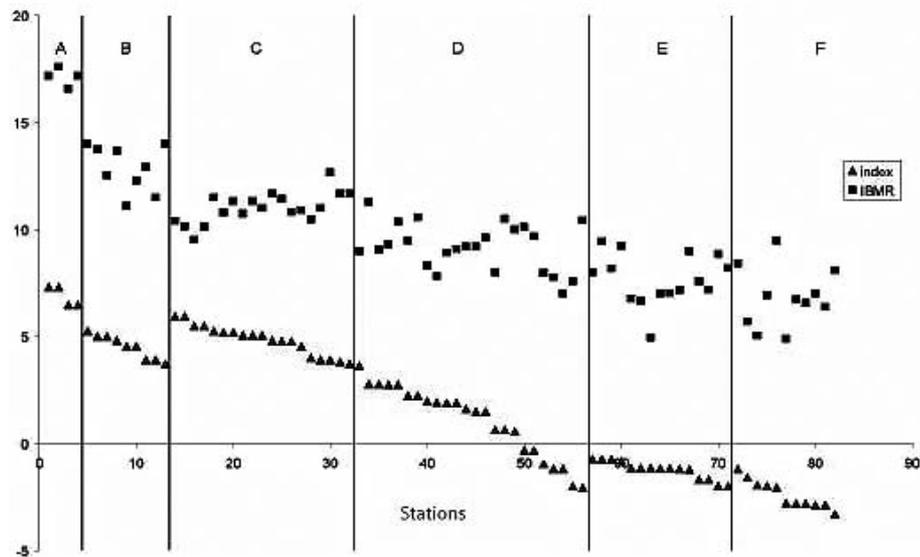


Fig. 4. Correspondence between communities of the trophic scale (named A,B,C,D,E,F from oligotrophic to eutrophic level), IBMR (Biological Macrophyte Index in River, AFNOR 2003) and index of conservation status in the hydrological network of the ILL floodplain (Eastern France).

concerns a flooded forest of the ILL, through which flows a large hydrological network (52 km in a forested surface of 1500 ha). This network encompasses connected, disconnected streams still fed by groundwater, and streams temporarily connected by floods. In this sector, there is no seepage of ILL waters into the

groundwater (Trémolières et al. 1994). So the disconnected streams fed by groundwater are either oligotrophic, characterized by a plant community with *Potamogeton coloratus*, a species characteristic of a very low trophic level, or oligo mesotrophic, with a single species *Berula erecta*.

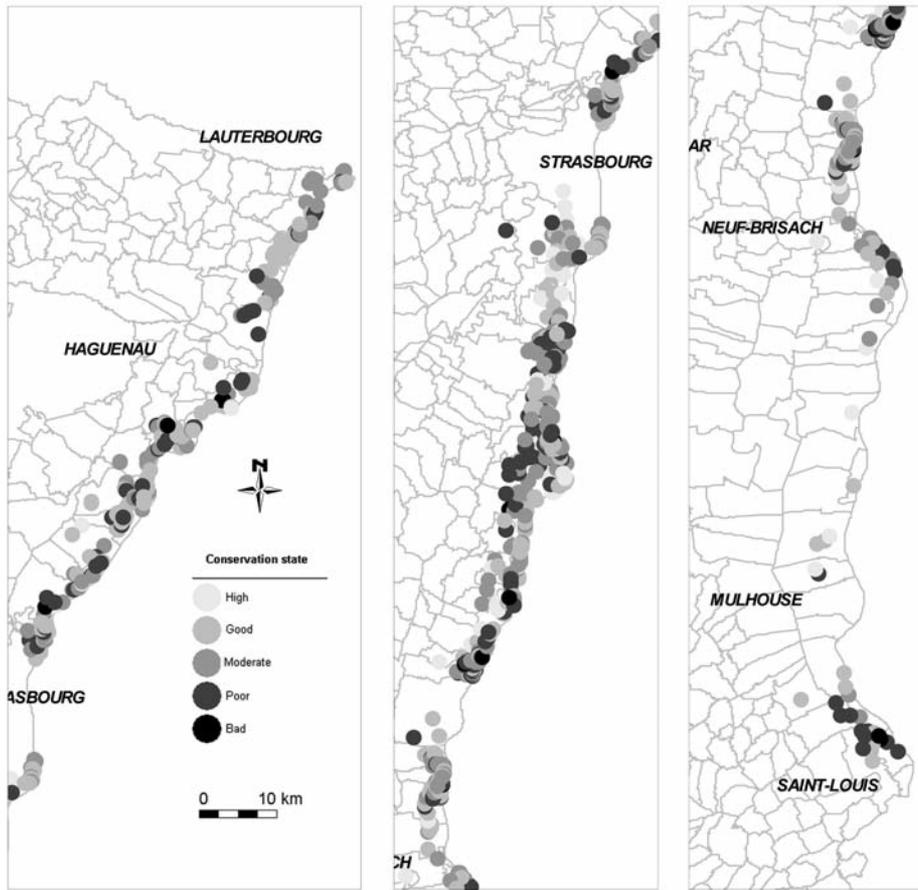


Fig. 5. Mapping of the conservation status of aquatic habitats in the Rhine fringe based on the conservation index.

Table 4. Correspondence between IBMR (Biological Macrophyte Index in River, AFNOR 2003) and conservation status index in the streams of Ill floodplain. In brackets: number of surveys.

Community	A(4)	B(9)	C(19)	D(24)	E(15)	F(11)
IBMR	17.1	12.8	11	9,2	7.7	6.8
std	0.42	1.08	0.7	1.1	1.2	1.7
Index of conservation status	6.9	4.5	4.8	1.05	-1.24	-2.38
Std (index)	0.47	0.55	0.69	1.10	0.43	3.03

The trophic level of 86 stations, are defined according to the bioindication scale and to the IBMR index, the normalized French macrophytes based index (AFNOR 2003, Haury et al. 2006) ; the corresponding conservation status is then calculated at all the stations. The average index per 'trophic' community is given in Table 4. There is a relatively good adequacy between the trophic level founded on the plant communities and

the IBMR. The high correlation between IBMR and conservation index confirms the trophic level as a key factor of the conservation status (Fig. 4). However communities B and C have similar indices, IBMR and conservation status (Table 4). The species composition of these two communities is also very close (Carbiener et al. 1990). Groups D and E have also similar IBMR, but contrasted index of conservation status. In the group D, the conservation status varies strongly from good to poor (+3 to -2, Fig. 4), whereas group E and F present lower variations respectively from -0.7 to -2 and -1.6 to -3.3. The group D has low or high specific richness (3-10 species), but with a high cover. The lowest values of conservation status of this group are mostly related to the presence of polluto-tolerant species, such as *P. pectinatus* or *Ranunculus fluitans*. In the groups E and F, the variations of index seem to be related to the specific richness and cover percentage, all the other metrics being similar.

Discussion

Distribution of communities with regard of environmental factors

Up to nine communities of hydrophytes were found in the Rhine fringe. This relative high number may be due to the high diversity of habitats created by the dynamics of the river (as shown by Bornette et al. 2001) in spite of hydraulic management (straightening and canalisation). The aquatic habitats of the Rhine fringe are characterized by a broad range of vegetation communities: from mesotrophic to eutrophic vegetation (Trémolières et al. 1993, Eglin et al. 1997). In the Rhine cut-off channels conditions, nutrient level was highly related to the connectivity because of the specific hydrological functioning of large rivers as shown in Rhône and Danube (Bornette et al. 1998, Bornette et al. 2001, Janauer & Kum 1996). In river floodplain, the river main channel provides eutrophic waters to the lateral arms during connections (floods) and induces scouring effect due to flow velocity. Such condition may induce highest species richness in waterbodies (Bornette et al. 1998). In the Rhine waterbodies, the nutrient level is actually very low due to an improvement of water quality of the Rhine river (IKSR Rheinatlant 2001). However the growing vegetation remains eutrophic, with species such as *Potamogeton pectinatus*, *P. nodosus*, *Ranunculus fluitans*. The nutrient level of water bodies has to be related to the whole aquatic system (water-plant-sediment) (Carignan & Kalff 1980, Moore et al. 1994). Many authors consider that the nutrient level is not a discriminant parameter in the macrophytes distribution because they consider only the water nutrient content, *i.e.* SRP soluble phosphorus (Demars & Harper 2005). In fact macrophytes growth can depend on the bioavailability of both phosphorus as SRP and interstitial P (Carpenter & Adams 1977, Carignan & Kalff 1980). The change in macrophytes colonisation remains lower than change in nutrient content (hysteresis effect) (Kohler et al. 1989, Debold 1997, Trémolières & Szwab in press).

The disconnected sectors exhibited meso-oligotrophic waters and the growing vegetation is dominated by mesotrophic species such as *Callitriche obtusangula*, *Berula erecta* and *Lemna trisulca*. However, because of seepage from the Rhine river to the groundwater, the former lateral arms close to the Rhine river present meso-eutrophic waters, characterized by eutrophic species such as *Ceratophyllum demersum*, *Potamogeton pectinatus* or *P. lucens* and related phytosociological communities. In standing waters the *Myriophyllum-Nupharetum*, a species-poor community, is growing in

oligotrophic conditions, because of an exclusive groundwater supply of good quality: groundwater quality has been improved by feeding with waters which were purified during the transfer through the soil-root system of the alluvial forest (Sanchez et al. 1991, Sanchez & Trémolières 2003).

The new areas opened by a recent reconnection (2002-2004) with the river are colonised by the exotic species *Elodea nuttallii* in eutrophic waters (Weber 2005, Bornet 2005). In fluvial hydrosystems, the connectivity and the related trophic factor appear therefore as discriminant factors in the distribution of communities and species (Bornette et al. 1998, 2001, Demars & Harper 2005). These last authors attribute the major role of connectivity to the exchange and input of propagules into a network of connected rivers rather than to an increase of nutrient level. This contradiction could be attributed to a scale change of the analysis (at river level or channel level).

Metrics analyses

Positive values of the proposed index represent a good quality, negative values characterized a degraded state (Table 3). Two important metrics are the presence of rare species, indicating good status, and the presence of polluto-tolerant species, indicating a degraded status with high values of correlation with discriminant axis.

The specific richness and the cover percentage (or abundance of species) are inversely related, and together provided an idea of the opening of the habitat and the risk of colonisation by exotic species. High specific richness fails to be an indicator for a good conservation status, the best status being given by a medium richness (5-7 species). The conservation status is good where high cover corresponds to a large specific richness, whereas the same cover with a low richness corresponds to a poor to bad status. Moreover a high nutrient content in water ensures a high development of biomass linked to a low or a high specific richness. Amoros & Bornette (2002), Amoros (in press) and Bornette et al. (1998) observed a higher diversity for an intermediate degree of connection, which corresponds to an intermediate level of trophic in the case of established vegetation.

Connection and trophic level (nutrient P and N content), are narrowly linked to the functioning of the Rhine floodplain (Trémolières et al. 1993, Eglin et al. 1997). Connected stretches are eutrophic to hypertrophic depending on the eutrophication of the river. Disconnected stretches fed by groundwater are mesotrophic, due to the seepage of the river waters through the banks or bed into the groundwater. High trophic level

or strong connection to a high trophic level waterbody can relegate a site to a bad status. In our study, a high specific richness as a result of an increase of trophy level leads to a poor status. In fact species which grew in very nutrient-rich waters, are polluto-tolerant *P. pectinatus* and *Ranunculus fluitans* species (Haslam 1978, Janauer & Dokulil 2006). They then become dominant and exclusive, and lead to a degraded status.

However, superficial connection between a water body and river main channel cannot be reduced to the phenomenon of eutrophication. Such contributes to inputs of sediments and propagules (Combroux et al. 2001), which can enhance the specific richness or decrease it by scouring effect of overflow or input of turbid nutrient-rich waters (see also Bornette et al. 1998). By this way, it appears necessary to associate the assessment of conservation status with both connectivity and biological metrics (such as polluto-tolerant species) as a response to complex effects of connectivity.

Conservation status of Rhine habitats

The phytosociological surveys allowed us to establish a classification of the macrophytes based conservation status of watercourses along the Rhine fringe. On this basis we can propose stretches or water courses to preserve, restore or abandon.

The five aquatic natural habitat types whose conservation requires designation of Natura 2000 sites as regards to the Habitat Directive (92/43/EEC) are present in the Rhine fringe. However, the distribution of sites characterized by a majority of UE 3260 (running waters) and UE 3150 habitats (standing waters) is probably linked to the degradation and artificialisation of aquatic zones by hydraulics works of the river Rhine. These works removed the floods and isolated all the lateral arms. The scarcity of marsh habitats UE 3130 and UE 3270 is relative to the removal of floods and as a consequence, lowering of water fluctuations. They are exclusively located in the areas where floods still occur. These habitats persist in the Northern Alsace plain and on the artificial islands of the Rhine which are still flooded, and where the variations of water level can occur.

The aquatic habitats of the Rhine fringe are in a good to poor conservation status (Fig. 5). More than 32% of the habitats exhibit a good status, and 34% a poor status. Habitats in a high to a good conservation status (respectively 2.1% and 21.5% of 619 stations) are in opposition to habitats in a bad conservation status (around 7%). Along the Rhine French fringe, three sectors were distinguished from the south to the north. These sectors correspond to geomorphic zonation and

degradation of many aquatic habitats (Fig. 5).

The Southern sector ranges from Neuf-Brisach to St Louis in the south of Alsace. It presents a lower density of water courses than the northern and central sectors that can be explained by the low groundwater level (around 7 m) and the consequence of the canalisation of the Rhine. The groundwater sources are rare and water courses are often contaminated by village effluents, and thus become largely eutrophic. This sector is considered to be in poor to bad conservation status. One exception is the natural reserve of the "petite Camargue alsacienne", located in the more Southern area which still presents some habitats of "moderate" conservation status.

The central part of the plain (from Strasbourg to Neuf-Brisach) corresponds to the braided and anastomosed sector of the Rhine. It is characterized by a large network of phreatic streams, due to the proximity of the groundwater from the soil surface. This part included disconnected, temporarily connected by floods and connected sites. The trophic level which is linked to the degree of connection in our study case was reflected by the type of vegetation. Hydrological functioning is characterized by a specific distribution of communities. The disconnected mesotrophic sites which are colonized by the community of *Myriophyllo Nupharetum* with the relatively rare species *Nymphaea alba*, are in a moderate to high conservation status. Temporarily connected sectors are dominated by the mesotrophic *Callitriche obtusangulae* community. The sites connected to eutrophic waters are characterized by two communities: an eutrophic community, *Potamogetonum pectinatis* which is in a poor conservation status and the hyper-eutrophic *Ranunculetum fluitantis* community which is in a bad conservation status. This latest community is observed in some disconnected sectors such as the drainage canal flowing along the Rhine river and more and less contaminated by the seepage of Rhine waters (Trémolières et al. 1993). This sector is characterized by a high diversity of habitats related to a diversity of modalities of connection and thus of different conservation status.

The Northern sector from Strasbourg to Lauterbourg, is characterized by waters flowing from the Northern Vosges (Moder, Sauer, Lauter) into the Rhine. It corresponds to a sector of anastomoses and the beginning of a meandering river. These waters are neutral, lowly mineralized and often highly eutrophicated, they are mixed with phreatic waters in the plain. The Rhine habitats of this sector are in good to poor status. The poor status dominates, due to a high level of trophy and a decrease of flow, compared with the previous sector.

Some waterbodies become shallow with muddy substrate. Under these conditions, water temperature which is not buffered by groundwater inputs, varies with the air temperature and is highly increased during summer. High temperature has a degrading effect on aquatic habitats (Welsh et al. 1998).

Comparison with other biological methods

The comparison between two indices in the Ill system shows that the index IBMR related to the trophic level is also linked to the conservation status. However the within-community and between-community variations of IBMR are relatively regular whereas we observe a gap between communities of the conservation index along the trophic gradient. The meso-eutrophic group D has low or high specific richness (3-10 species), but a high cover, which can explain higher variations of the conservation index. The lowest values of conservation status of this group are mostly related to the presence of polluto-tolerant species, such as *P. pectinatus* or *Ranunculus fluitans*. In the more eutrophic groups E and F, the variations of index seem to be related to the specific richness and cover percentage, all the other metrics being similar.

The presence of rare species, such as *Potamogeton coloratus* due to the scarcity of the oligotrophic habitats, is also a determinant metric although they are species from species-poor habitats (Carbiener et al. 1990). In another way, the presence of polluto-tolerant species deteriorates the conservation status. Commonly a high specific richness was recognized as an indicator of good ecosystem functioning. In our study case it seems not to be a good indicator of conservation status as well in the Rhine sector as the ILL system. We show that at highest trophic level, there are high variations of specific diversity often related to a high level of disturbance (high connectivity, see Bornette et al. 1998, Bornette et al. 2001). Amoros et al. (2000) showed that these two phenomena, nutrient tolerance and disturbance, can interfere in some cases. An example is the oligotrophic species *P. coloratus* which is tolerant to physical disturbances, that is why this species could survive in connected sectors but under nutrient - low conditions.

Concluding remarks

The proposed index of the conservation status of aquatic habitats was founded on both physical and biological metrics. The metrics proposed have to be simple for users. Due to the context of numerous cut-off

channels after the canalisation of the river Rhine and the demand of restoration by reconnection to the main course, the connectivity was integrated as a metric of change in hydrological functioning of the fluvial hydrosystems, and indicator of reversibility. The connection contributes to inputs of nutrient-rich waters, fine sediments, and propagules. The trophic level a metric mostly related to connection in this study case, highly influences the conservation status. The biological response to different degrees of connectivity consists in a change in specific richness and occurrence of exotic and rare species. Superficial connectivity modifies specific richness, by changing propagules pool and favouring the propagation of exotic species. High connection if it is related to a high trophic level combined with absence of rare species and presence of exotic species leads to a poor or bad conservation status. In cases where high connection was linked to low nutrient input with oligotrophic rare species, the conservation status is good to high.

The upper Rhine floodplain seems to be a particular case of good adequacy between hydrological functioning (connectivity), trophic level and conservation status. This relationship between connection and trophic explains the relative good correspondence between the trophic index IBMR, and the index of conservation status in the case of the ILL fluvial system. The objective of determination of conservation status concerns potential for restoration, and consequently reversibility depending on succession stage of terrestrialization of aquatic systems. According to this study, the question is whether preservation of hydrological dynamics (by connection to the river) which favour disturbances, but also often inputs of nutrient-rich waters could be a guarantee of maintenance of communities of interest and of their diversity.

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