ECOLOGY OF THE LOWER RHÔNE AFTER 200 YEARS OF HUMAN INFLUENCE: A REVIEW

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ABSTRACT

Embarkments of the last century and contemporary channelization and development of urban and industrial areas along the Rhône Valley have greatly changed the river. The impacts of these on three biological descriptors of the hydrosystem (benthic invertebrates, fish communities and aquatic birds) have been studied. A reduction in the morphological diversity of the regulated hydrosystem has caused a reduction in biological diversity. This system has become a slow potamic system as a consequence of the more uniform environmental conditions: the benthic macroinvertebrate fauna has become eurytopic and pollution tolerant, with very localized potamic species; fish communities are dominated by limnophilic cyprinids; and water bird communities are limited by the absence of typical species of fluvial areas, such as terns.

KEYWORDS Regulated river Rhône Benthic macroinvertebrates Fish Water birds

INTRODUCTION

During the last 200 years human activity has markedly changed the Lower Rhône, i.e. the part of the river between Lyon and the Camargue. Levees were built at the beginning of the 19th century to protect riverside residents from floods. Unsubmersible and then submersible dykes were erected to improve navigation. Finally hydroelectric schemes appeared and the river was recently channelized by the Compagnie Nationale du Rhône (CNR). Its water is also used to cool thermal and nuclear power plants. Simultaneously, the spreading of towns such as Lyon, Valence and Avignon, and the presence of large petrochemical plants, especially downstream from Lyon, have altered the chemical properties of the water. We attempt to draw together the biological impact of all these physical and chemical disturbances using three biological descriptors of the hydrosystem: benthic invertebrates, fish communities and aquatic and riverside birds.

STUDY AREA

Location and regulation of the Lower Rhône

The Lower Rhône, part of the river between Lyon and its delta before it flows into the Mediterranean Sea, is approximately 280 km long (Figure 1A and B). In pristine conditions the Lower Rhône was a braided river with a tendency to meander (Michelot, 1983). Its thorough regulation began in the middle of the 19th century by embanking to improve navigation by concentrating the discharge in a single, deep channel (Béthemont, 1972). At first, longitudinal unsubmersible dykes were erected. Later on, submersible dykes, called 'Girardon's embankments', created a system of compartments new characteristic of the fluvial landscapes of the Lower Rhône. These embankments constrained the fluvial dynamics; excavation of the bed of the main channel occurred with silting and drying up of side-arms and former channels (Figure 2). Hydroelectric schemes appeared more than 30 years ago and the river was channelized. Twelve dams were built, together
Figure 1. Regulation of the Lower Rhône. (A) Geographical location of the Lower Rhône. (B) Location and chronology of the regulation. (C) CNR hydropower development scheme. (D) Hydrological regime of an impoundment.
with several nuclear power plants (Figure 1B). The original CNR hydropower development scheme was the construction of a diversion canal parallel to the old channel, which is closed by a diversion dam (Figure 1C). The old channel only receives a very small compensation flow (10 or 20 m$^3$ s$^{-1}$) but this increases during floods when the capacity of the canal is exceeded (Figure 1D).

*Longitudinal profile*

Formerly, numerous rocky outcrops were present in the channel bed of the Lower Rhône. Thus the longitudinal profile was irregular and the overall slope was steep compared with the small distance to the sea (Figure 3). This slope was moderate in the upstream third of the river (the part of the river between Lyon and the confluence with the River Isère), but increased between Tournon and the confluence with the River Ardèche. Some parts had a slope greater than 1 m/km. This last stretch was also called the ‘riffles zone’ (Figure 3). The relatively steep slope was still noticeable at Aramon, but then the slope decreased until Arles at the head of the delta. Flow velocities were high (up to 4 m s$^{-1}$ during high flood in the riffles zone) and played an important part in the transmission of floods (Pardé, 1925).

The thorough regulation of the river by the CNR changed the longitudinal profile of the Lower Rhône into a series of impounded reaches (Figure 3). Reservoirs and diversion canals have very low slopes (some dm/km in the former, less than 20 cm/km in the latter). The flow velocity was greatly reduced to 0.3 m s$^{-1}$ on average during medium flow, but may reach 3 m s$^{-1}$ during high flow (Savey and Deleglise, 1967; Savey et al., 1983). Turbulence has decreased and transit times have increased. However, the opposite occurs during floods; the propagation time is reduced in the regulated stretches when discharge exceeds 1500 m$^3$ s$^{-1}$ (Béthemont, 1972). Carbiener (1988) showed the same trend in the regulated Aisian Rhône. During low flow, the flow velocity is near zero in the by-passed sections, except on some riffles, but it reaches more natural values during floods, when the gauged discharge of the power plants is exceeded.
Figure 3. Longitudinal evolution of the channel profile and of the average discharge of the Lower Rhône. The average discharge of its main tributaries is also plotted.

Hydrology

The hydrological regime of the Lower Rhône is complex, reflecting the position of the Rhône Valley at a climatic crossroad: the hydrological regime between Lyon and Arles passes from a rainy oceanic type to a rainy Mediterranean type with nival supplies (Pardé, 1925). Its mean annual discharge is 1000 m³ s⁻¹ downstream from Lyon and 1700 m³ s⁻¹ upstream from its delta (Figure 3). In general, high waters occur in February and low waters in August–September. Table I gives some characteristic average discharges.

The natural regime, described by Pardé (1925), was affected by the hydroelectric schemes erected on the course of the Rhône and its tributaries. Vivian (1983; 1989) and Agence de Bassin RMC (1988) noted the retention of discharge from the beginning of the spring to the end of the autumn, and an increase in the winter. However, if the summer low flow was of anthropogenic origin (retention by dams in the upper part of the watershed, and pumping for irrigation), Vivian (1989) considered that the reason for the autumn deficit was natural and due to the important rainfall deficit recorded over the past 30 years.

Table I. Some characteristic average discharges of the Lower Rhône

<table>
<thead>
<tr>
<th>Hydrology station</th>
<th>Average discharge (m³ s⁻¹)</th>
<th>Low flow discharge (m³ s⁻¹)</th>
<th>Semi-permanent discharge (m³ s⁻¹)</th>
<th>Discharge 10 days/year (m³ s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyon-Saint-Clairs</td>
<td>600</td>
<td>215</td>
<td>500</td>
<td>1400</td>
</tr>
<tr>
<td>Ternay</td>
<td>1030</td>
<td>300</td>
<td>800</td>
<td>2640</td>
</tr>
<tr>
<td>Valence</td>
<td>1410</td>
<td>480</td>
<td>1200</td>
<td>3290</td>
</tr>
<tr>
<td>Le Teil</td>
<td>1450</td>
<td>490</td>
<td>1340</td>
<td>3540</td>
</tr>
<tr>
<td>Beaucaire</td>
<td>1690</td>
<td>580</td>
<td>1460</td>
<td>4350</td>
</tr>
</tbody>
</table>
Physicochemical quality

The Lower Rhône receives important domestic and industrial inputs, in particular in its upstream third (Figure 4A): in the ‘chemistry corridor’ downstream from Lyon there are ammonia and phosphorus inputs from factories downstream from Vienne to the Péage-de-Roussillon scheme (Fruget, 1989). The river was often ranked in class II of the multi-use quality grid of the Agence de Bassin RMC due to organic pollution and to toxic pollution (Figure 4B and C), that is to say in a class of moderate pollution. However, the situation was more critical for the parameters of toxic pollution, the river being ranked in class II from upstream of the confluence of the River Ain to the delta. The critical standard parameter was ammonia; the critical organic compounds were polychlorinated biphenyls, DDT and solvents, and metallic pollution was due to copper and lead (Agence de Bassin RMC, 1988).

RESULTS

Benthic invertebrates

A synchronic study of six hydroelectric schemes was undertaken to establish a qualitative record of the macroinvertebrate communities of the Lower Rhône (Fruget, 1989; 1991; for the impoundments sampled, see legend Figure 1). The samples were collected by dredges in the channel of the two main lotic functional sets of the regulated Rhône—the diversion canal and the old bed of the river, the ‘by-passed section’. These functional sets are divided into four types of functional units from the most to the least impacted: headraces and tailraces of the canal, embanked and riffled parts of by-passed sections (Figure 1C). Thirty-four samples were collected from 24 stations under stable and comparable hydrological conditions (low flow). This study showed that there was no longitudinal pattern. The macroinvertebrate communities were homogeneous along the continuum, despite some local disturbances. They included lentic potamic species typologically related to this kind of river (metapotamon according to Illies, 1961; typological order B8–B9 according to Vermeaux, 1973), as well as eurytopic and pollution tolerant species, such as oligochaetes, leeches, gammarids and asellid crustaceae, some gastropod molluses and chironomid dipters (Figure 5). Some potamic species (Hydropyche modesta, Baetis fuscatus) were still present, but only locally. It was closed to particular mesological conditions: presence of riffles in by-passed sections, tributary confluence (Fruget, 1991). It is significant for caddisflies in Péage-de-Roussillon and Donzère-Mondragon schemes where they represent 3 and 10% of the relative abundance (three and seven taxa respectively), or for mayflies in Donzère-Mondragon (three taxa, 3-6% of the total number of individuals) (Figure 5). According to its fauna, the Lower Rhône has now become a slow potamic river as a consequence of the change in environmental conditions. Other large mid-European rivers (Meuse, Rhine or Po) have undergone the same changes (Meurisse-Genin et al., 1987; Tittizer et al., 1989; Chiaudani and Marchetti, 1984). The statistical analysis of the data matrix (PCA on the results expressed as presence/absence) showed a clustering between samples, from less impacted (rifflles of the by-passed sections) to more impacted (headraces with concrete banks and bed), according to a gradient of increasing flow velocity, which appears to be the most important structural factor (Fruget, 1991). Thus with high flow velocities and coarse granulometry (typical characteristics of epipotamic zones) the rifflles of the by-passed sections showed the most diversified macrobenthic fauna (Figure 6), especially because of the presence of potamic insect larvae (Caenis lucuola, Baetis fuscatus, Hydropyche modesta, Ceraclea disstatis, Psychomya putilla). The diptera, mainly chironomids, were highly dominant in relative abundance (72%, see Figure 6) related to the development of epilithon on the coarse substrate of the channel bed.

Fish fauna

Maps of fish distribution have been drawn from field investigations from the middle of the 20th century. Despite their inaccuracy, they provide a typology of river species at this period (Kreitmann, 1932; Léger, 1948; Dorier, 1954; 1956). We compared these results with present data obtained by electroshocking to detect the changes in the fish communities of the Lower Rhône. The study focused on two sectors within the upper third of the river (the part of the river between Lyon and the confluence of the Isère): first the ‘biological
Figure 4. Present general quality of the Rhône water (according to Pelosato, 1982 and Agence de Bassin RMC, 1988). (A) Location of the main domestic and industrial inputs. (B) Classification according to the parameters of standard pollution. (C) Classification according to the parameters of toxic pollution.
sector’ between Pierre-Benie, its by-passed section and the Vaugris Reservoir; and secondly the different functional sets of the Péage-de-Roussillon CNR scheme (Table II). These changes were of two types: (1) a structural modification of the community from a qualitative point of view, with the reduction in diversity and the transition from a community of rhyophilic cyprinids (barbel zone) to one dominated by limnophilic cyprinids (particularly in the reservoirs) and from a quantitative point of view, with the increase in biomass due to the domination of some ubiquitous and wide spectrum species (such as chub), with the disappearance or decline of migratory species (shad, sea lamprey, eel) because of the obstacles created by dams (the Rhône is no longer free-flowing), and with the loss of sensitive species (burbot, dace) or southern species (south-west-European nase, asper); (2) the expansion of introduced species in the new biotypes (diversion canals, reservoirs) created by the impoundments (pumpkinseed, black bullhead), the increase of pike-perch and the recent appearance of sheatfish.

Thus the original community described by Léger (1948), with the dominant group of nase/chub/gudgeon/bream and the resident barbel/minnow/bleak/perch/cel/sea-lamprey, has been replaced by a dominant group
of chub/roach/bleak/bream/pumpkinsized. Nase, barbel and gudgeon have become accessory; eel and minnow are now rare; and sea lamprey and shad have disappeared. A similar alteration has also been observed in the French Upper Rhône (Persat, 1988). Figure 7 shows this transition to a community of limnophilic cyprinids in the Péage-de-Roussillon scheme, where five species represent nearly 87% of the community by number of individuals.

One of the more important consequences of the hydroelectric developments of the Lower Rhône concerns the migratory fish, especially shad (Alosa) (Gallos, 1946; 1950; Ramey et al., 1976; Quignard, 1977; Kiener, 1985; Pattee, 1988). Before 1950, shad migrated upstream into the Rhône watershed as far as the River Saône and Lake Bourget. The first hydroelectric scheme, Donzère-Mondragon (see location Figure 1B), was completed in 1952 and immediately cut off the access of migrating fish to 75% of the watershed. Numerous other spawning grounds nevertheless existed between Beaucet-Avignon and the confluence of the River Ardèche. These were excluded by the erection of the Vallabréguès dam in 1970, and later the dams of Avignon and Caderousse in the mid-1970s (see location on Figure 1B). Nowadays the only possible migration route is via the Vallabréguès by-passed section into the River Gard, where the last spawning grounds are found. A weir at the mouth of this by-passed section is equipped with a fish ladder but it does not function correctly (CTGREF, 1975; Larnier et al., 1978; Maurel, 1985). Thus only about 15% of the original route is still accessible for shad in the mainstream (480 km before the erection of the Donzère-Mondragon dam, now nearly 70 km), and less than one-third in the last usable tributary, the River Gard. The changes in physical structure and hydrological pattern of the River Rhône are reflected by shad catches since 1950: 53 tonne of shad were caught in 1927 between Pont-St-Esprit and Arles; 10 tonne in 1950 (Gallos, 1950) and only about 8 tonne at the beginning of the 1970s (Ramey et al., 1976). In the middle of the 1940s, before the completion of the Donzère-Mondragon dam, about 15 tonne of shad were caught downstream from Lyon (Pattee, 1988). Ninety-nine per cent of shad caught were Alosa fallax (Ramey et al., 1976).

The fish typology of the Lower Rhône from Lyon to Donzère has been discussed by CTGREF (1977). They pointed out a change in typological level when compared with the data of Kreitmann (1932) and Léger (1948): from B6-B7 (barbel zone) in the middle of the century, the present typological level has become B8-B9 (bream zone, with a tendency to being atypical). Perrin (1978) defined the Brégnier-Cordon sector on the Upper Rhône as a barbel zone, but also reported the significant presence of fish belonging to the grayling
Table II. Changes in the fish communities of the upper third of the Lower Rhône. Results are expressed in relative abundance and coded: D = dominant (≥ 5%), R = resident (2.5 to ≤ 5%), A = accessory (1 to ≤ 2.5%), r = rare (≤ 1%), a = accidental species (one or two individuals). PB/VS = biological sector Pierre-Benite by-passed section/VAugris reservoir, PR = Péage-de-Roussillon CNR scheme

<table>
<thead>
<tr>
<th>Species</th>
<th>Leger (1948)</th>
<th>PB/VS</th>
<th>PR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salmo trutta fario</td>
<td>r</td>
<td>r</td>
<td>r</td>
</tr>
<tr>
<td>Phoxinus phoxinus</td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cottus gobio</td>
<td>r</td>
<td>r</td>
<td>a</td>
</tr>
<tr>
<td>Nocemichthys barbatulus</td>
<td>r</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Leneictus senia</td>
<td>r</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Chondrostoma nasus</td>
<td>D</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Chondrostoma toxostoma</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zingel asper</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leneictus leuciscus</td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leneictus cephalus</td>
<td>D</td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>Alburnoides bimaculatus</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gobio gobio</td>
<td>D</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Barbus barbus</td>
<td>R</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Gasterosteus aculeatus</td>
<td>r</td>
<td></td>
<td>r</td>
</tr>
<tr>
<td>Rutilus rutilus</td>
<td>r</td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>Esox lucius</td>
<td>r</td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>Alburnus alburnus</td>
<td>R</td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>Perca fluviatilis</td>
<td>R</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Scardinius erythroptalmus</td>
<td>r</td>
<td></td>
<td>r</td>
</tr>
<tr>
<td>Ictalurus melas</td>
<td>r</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Sillago glanis</td>
<td>r</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Bleoche biperina + A. brama</td>
<td>D</td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>Lota lota</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyprinus carpio</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tinca tinca</td>
<td>r</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Leptos gibbosus</td>
<td>r</td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>Anguilla anguilla</td>
<td>r</td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>Micropterus salmoides</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stizostedion lucioperca</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acipenser cernua</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudorasbora parva</td>
<td>r</td>
<td></td>
<td>a</td>
</tr>
<tr>
<td>Alosa alosa</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alosa fallax</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petromyzon marinus</td>
<td>R</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of species: 36
Number of species: 30
Number of species: 25
Number of species: 31

Zone (level B5) in the Miribel Canal, an arm of the Rhône immediately upstream from Lyon. Thus the barbel zone (epipotamic area) has shifted upstream about 210 km during the last 20 or 30 years.

The fish richness of the Middle Rhône River (31 species) can be compared with those of regulated reaches of similar rivers or parts of rivers, e.g. 33 species in the French Upper Rhône, and more than 40 species in all of the basin (Persat, 1988); 29 species in the Alsace Rhine (Dolédec et al., 1991) (61 species in all of the basin. Lelek, 1989), 42 species in the German–Austrian regulated Danube upstream from the confluence of the River Inn (Balon et al., 1986), 37 species in the Yugoslav Danube influenced by Iron Gates I and II dams (Jankovic et al., 1987) and 39 species in the impounded Middle Missouri reach upstream from Fort Randall dam (Hesse et al., 1980). These figures represent fish compositions and structures in man-made environmental contexts such as impoundments and polluting inputs.
Figure 7. Relative abundance of fish species at Pèage-de-Rousillon (1982-90, five stations, 29 sampling campaigns).

**Water birds**

After the complete harnessing of the Lower Rhône, the reduction of the floodplain area, the disappearance of some forested zones and the creation of new water bodies (reservoirs) have been the main factors influencing not only the aquatic birds but also the terrestrial birds of the dykes. Published work shows the previous existence of a specific fluvial bird fauna on the pristine braided Lower Rhône: common tern (*Sterna hirundo*), stone-curlew (*Burhinus oedicnemus*) and little ringed plover (*Charadrius dubius*). This fauna was akin to the one of the Loire, Allier and Durance rivers (Michelot, 1990). It disappeared with the erection of the embankments in the last century, the disappearance of islands and the resulting single and simple channel. The aquatic bird fauna of the middle part of the Rhône valley (from Lyon to Montélimar) is characterized now by its instability and the absence of typical fluvial species (terns) (Pont, 1985). Species diversity and abundance are related to the existence of relict areas (some dead arms, some alluvial forests) and man-made areas (reservoirs, canals). The Anatidae (ducks *sensu lato*) and the Rallidae (coots in particular) were most favoured by the large water bodies of the reservoirs. The example of the Printegarde Reserve, in the reservoir of Baix-Le-Logis-Neuf scheme, is significant. Within 10 years, the abundance of Anatidae shifted from 200 to 1000-1500 individuals, with common pochard (*Aythya ferina*) and mallard (*Anas platyrhynchos*) as the dominant species (Figure 8). Reichhoff (1982) noted the same change on a

Figure 8. Changes in numbers of wintering Anatidae in the hunting reserve of Printegarde (Baix-Le-Logis-Neuf reservoir and confluence of the Drôme river), from winter 1975-6 to winter 1984-5 (according to FRAPNA Drôme, 1985)
hydroelectric reservoir of the Inn river in Germany, and Dister et al. (1990) on the impounded Rhine reservoirs. The Laridae, with anthropophilic species (black-headed gull, *Larus ridibundus* and herring gull, *Larus argentatus*) occurring about beacons near locks were also favoured. This phenomenon is well known on the Alsacian Rhine (Müller, 1981; Andres, 1987). In the same way, the great cormorant, *Phalacrocorax carbo*, appeared on the Rhône during the 1981–2 winter. In 1985 300 individuals occurred, and 90% of them were present at the confluence within the River Drôme (FRAPNA Drôme, 1985). This number increases every year.

New landscapes have appeared in the former floodplain, as a consequence of the contemporary harnessing of the river and the erection of dykes and gravel embankments. These landscapes show some biological potential owing to their position at the land–water ecotone and to the management of their vegetation: in fact, the gravel areas of dykes may be considered as substitutes for islands and natural shores (Michelot, 1990). For several years these areas have allowed the new development of species characteristic of braided rivers, species of the 'terns zone' according to Roché (1989). Michelot (1989) noted the presence, on several artificial embankments of the Rhône Valley, of island and shingle-shore species, that is to say of species characteristic of rivers with intense fluvial dynamics. These species were: little ringed plover (*Charadrius dubius*), pied wagtail (*Motacilla alba*), tawny pipit (*Anthus campestris*), corn bunting (*Emberiza calandra*), red-capped lark (*Calandrella cinera*), crested lark (*Galerida cristata*) and stone-curlew (*Burhinus oedicnemus*). Figure 9 shows the actual biological function of these environments, the number of species increasing with the age of the gravel embankments.

Last of all a lentic water community occurs near some reservoirs colonized by *Phragmites* (confluence of the Drôme river, reservoirs of the Montélimar and Donzère-Mondragon schemes). Black coat (*Fulica atra*), little bittern (*Ixobrychus minutus*), purple heron (*Ardea purpurea*), grebes (*Podiceps cristatus* and *P. ruficollis*) and mute swan (*Cygnus olor*) are the main species.

**CONCLUSIONS**

The three biological descriptors show that biological diversity has decreased with the decrease in morphological diversity and connectivity of the regulated hydrosystem, as a consequence of the succession of human impacts over more than a century. River regulation has decreased the natural spatio-temporal heterogeneity of the hydrosystem and disrupted exchanges between its different parts, thereby reducing their structural and functional integrity. However, areas with specific environmental conditions allowed the
survival (invertebrates, fishes) or the reappearance (birds) of characteristic fluvial species. These include riffles in by-passed sections, dykes and gravel embankments in reservoirs and canals.

The Rhône and the Rhine are very similar in their geological, hydrological and geochemical characteristics (Golterman, 1982), but also in the human pressures to which they are submitted (impoundments, polluting inputs). This similarity also exists in the results of all these changes. In fact, the physicochemistry of the River Rhine shows that a maximum load of pollution occurred in the 1960s, with numerous problems of mortality of some species because of the presence of toxic substances. Some improvements were recorded between 1976 and 1985, especially in the Upper Rhine, and the number of stretches of the river in class II, that is to say fish-mesosaprobic with a moderate pollution, has increased (Friedrich and Müller, 1984; Lelek, 1989).

Simultaneously, the increasing uniformity of the river bed and the increasing waste load have led to a considerable change in the invertebrate fauna of the Rhine, with a disappearance of pollution sensitive and potamic species and a decrease of species diversity, especially insect diversity, over the period from the 1950s to the early 1970s (Friedrich and Müller, 1984; Schiller et al., 1989). During the 1980s, with the decrease in pollution and the improvement in oxygen supply, a gradual recolonization has taken place (by the gastropod molluscs *Theodoxus fluviatilis* in particular). However, the invertebrate fauna of the Rhine is still dominated by eurytopic taxa (Ziese, 1985; Kinzelbach, 1987; Tittizer et al., 1989). The same disappearance of migrating fish (sturgeon, shad) as in the River Rhône has occurred, and the communities are now dominated by phytophilous cyprinids (roach, bleak, bream) (Lelek, 1989; Lelek and Köhler, 1990). An important difference with the Rhône concerns shad: shad has completely disappeared from the Rhine, but is still present in the lower course of the Rhône upstream from the delta, though its total strength is reduced. Last of all, in the impounded Rhine reservoirs, a large number of aquatic birds rest and overwinter, especially diving ducks and coots, and an important decrease in former bird species nesting in gravel banks (little tern, stone-curlew) was noted (Dister et al., 1990). The similarity in response of the Rhône and the Rhine to human works and pollution leads us to expect that these effects are fairly similar for numerous other large rivers in the temperate zone with fish and benthic communities similar to those of these two rivers.

We have only described the effects on the main channel and the lotic parts of the river, but these effects are similar in the lentic parts of the alluvial plain (dead arms, network of connected and isolated ponds, i.e. the old, and now abandoned, channels), when it still exists. However, for some years an effort has been made to improve the Rhône water quality (by the reduction or suppression of some inputs, the building of industrial and domestic purification plants). Some scientific programmes for restoring and enhancing the quality of the river exist (see Comité de Bassin RMC, 1989). Social, political and economic willpower, similar to that which has been used to harness the river, is now required to restore it. A holistic environmental approach to management must be applied, considering the river corridor as a whole, from the aquatic to the semi-aquatic and terrestrial biotopes and biocoenoses that are permanently or intermittently connected with the lotic environment of the main channel (Amoros et al., 1987; Petts et al., 1989). The final aim must be the more or less complete (according to the system) re-establishment of the hydrological functioning of the floodplain (Lelek, 1989).

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