THE USE OF HISTORICAL DATA IN THE ECOLOGICAL ZONATION OF RIVERS : THE CASE OF THE 'TERN ZONE'

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RIVIÈRES
ZONATION ÉCOLOGIQUE
STERNES
PAYSAGES FLUVIAUX
HISTOIRE
MOULINS-BATEAUX

RÉSUMÉ – L'étude de la distribution ancienne et actuelle des colonies de reproduction de la Sterne Pierregarin (*Sterna hirundo*) le long des cours d'eau d'Europe révèle l'existence d'une «zone à Sternes» située dans les cours moyens inférieurs des grands fleuves. Indicatrice d'un style de dynamique fluviale anastomosé, l'espèce est aussi un descripteur de l'instabilité du milieu. Des moulins-bateaux, étudiés par divers auteurs dans le cadre de recherche en archéologie industrielle, ont flotté sur les fleuves entre les X^e et XIX^e siècles; ils sont aussi présentés comme des descripteurs de cette instabilité et montrent une grande analogie de distribution avec les Sternes. Ce sont en outre des «traceurs historiques» qui peuvent témoigner de cette instabilité avant les grands aménagements du XIX^e siècle (endiguement, canalisation...) et par conséquent renseigner sur la distribution probable des Sternes le long des fleuves il y a près d'un millier d'années. L'étude valide ainsi un modèle de zonation ornithologique proposé par ailleurs (Roché et Frochot 1989) et plaide en faveur d'une approche pluridisciplinaire des écosystèmes fluviaux intégrant la dimension historique (la molinologie notamment).

RIVERS
ECOLOGICAL ZONATION
TERNS
ALLUVIAL LANDSCAPE
HISTORICAL DATAS
BOAT-MILLS

ABSTRACT – Distribution of ancient and actual colonies of Common Tern (*Sterna hirundo*) is studied along European watercourses and lead to the concept of a "Tern zone", generally situated in the lower middle reaches of large rivers. *Sterna hirundo* is considered as a good indicator of anastomosed river pattern and chanel instability so as boat-mills, an original type of water mill which was floating on rivers from Xth to XIXth century. Both show similar distribution pattern. Boat-mills are also witnesses of this instability during a period of history without important hydraulic engineering and suggest a picture of the probable distribution of *Sterna hirundo* along european rivers during the last millenary. The present paper is a contribution to a general ornithological zonation described elsewere (Roché & Frochot 1989), and invites to multidisciplinary research upon fluvial ecosystem where history, and particularly molinology, takes a good place.

INTRODUCTION

The animal and plant populations of rivers, and particularly the invertebrates and fish, have frequently been described in terms of ecological zones. This approach, that aims to identify supposedly homogeneous stretches of river within the upstream-downstream gradient, has tended to be abandoned over the last ten years in favour of more subtle theories adapted to the concept of gradient, such as that of the "river continuum concept" (Vannote *et al.* 1980, Minshall *et al.* 1985) or of "nutrient spiralling" (Newbold *et al.* 1981, Elwood *et al.* 1983).

Zonation does however remain an interesting concept in the case of riverine birds. The perception that these semi-aquatic animals have of their environment includes both the water course itself and its surroundings, which makes them particularly good indicators of the interactions between the river and its valley. Nevertheless, this approach has been little explored in the riverine environment. Ornithological studies on habitat subdivision (Blondel 1980), on connections between habitats (Joachim 1987) and of edge effects (Frochot & Lobreau 1987) have gained interest with the development of research on "landscape ecology" (Forman & Godron 1981), but they have usually been situated away from riverine areas;

whereas works carried out on riverine landscapes (Amoros *et al.* 1988; Décamps & Naiman 1989) provide information on their structure and dynamics (Pautou & Decamps 1985), but rarely involve studies of birds (Joachim 1986, Roché 1986, Décamps *et al.* 1987).

In a previous work (Roché & Frochot 1989), a proposal was made to establish a parallel between the four main types of fluvial dynamics (torrents, braided rivers, anastomosing rivers and meanders), Huet's (1949) four fish zones (the *Salmo trutta, Thymallus thymallus, Barbus barbus* and *Abramis brama* zones), and four ornithological zones (the *Cinclus cinclus, Actitis hypoleucos, Sterna* spp. and *Fulica atra* zones). Few references have been made to such analogies. A few works have attempted to find relations between various zonation schemes (e.g. Illies 1961), but most try to define a classification that is as general as possible, using pertinent criteria such as the physical properties of the water course (Illies 1961, Statzner & Higler 1986), the fish populations (Huet 1949), or invertebrates (Vaillant 1967, Verneaux 1973), or else discuss the possibilities of applying existing zonations to various regions of the world (Harrison 1975, Culp & Davies 1982).

These zones are also frequently altered by many types of engineering works (canalisation, bank protection, gravel extraction, etc...), some of them ancient (e.g. mediaeval embankments), which make it difficult to describe their true ecological potential. We are only starting to understand, from a historical perspective, what effect such management has on habitats and riverine communities : on the configuration of water courses in urban environments (Fortuné 1986), on the dynamics of fluvial landscapes (Décamps *et al.* 1988), on aquatic ecosystems and plant succession (Bravard *et al.* 1986), on invertebrate populations (C.T.G.R.E.F. 1976) or on fish (Sedell & Luchesa 1981, Thibault & Rainelli 1986).

The subject of this work will be considered from both the ecological and the historical perspectives. The first aim is to confirm the ornithological zonation scheme on water courses. The existence of a common sandpiper (*Actitis hypoleucos*) zone of French and European rivers has previously been demonstrated (Roché 1989) and its analogy with the grayling (*Thymallus thymallus*) zone and the braided river zone has been discussed. In this work, a test will be made of existence of a "tern zone" by analysing the distribution of the common tern (*Sterna hirundo*) throughout Europe. The second aim will be to show how, on the basis of the ecological requirements of the species, and via fluvial archaeology, it is possible to advance hypotheses on the past distribution and therefore the extent of the tern zone. Thirdly, a wider historical approach to fluvial activities will provide information on the probable changes to the bird communities of this very unusual zone in the altitudinal gradient of rivers, which is particularly threatened at present.

1. FROM THE BIOLOGICAL INDICATOR TO THE FUNCTION DESCRIBER

1.1. The problem

The common tern is a widely distributed species in Europe, but is mainly coastal (Cramp 1985, Géroudet 1972, Glutz & Bauer 1982). It can nest in very varied habitats, including rivers, where it has been recorded as from the 19th century (e.g. Millet 1828, Ternier 1897). Studies on the riverine environment are however recent and concern mainly the abundance of populations and breeding biology. Very few authors have yet envisaged describing the fluvial habitat.

With their altitudinal gradient, rivers lend themselves to the study of ecological niches and the habitat amplitude of species. For this reason, research has been carried out with the aim of defining the distribution of populations of the common tern in natural sites along water courses in Europe, with the view of assessing the indicator value of the species.

1.2. Methods

The only distribution maps currently available for the whole of Europe are those of Voous (1960) and Cramp (1985), which are too diagrammatic for the purposes envisaged here.

The various national atlases are better sources. These exist for France (Spitz 1963, Muselet 1983), Benelux (Rappe 1969), Romania (Papadopol 1966), Central Europe (Glutz & Bauer 1982), Italy (Bogliani 1986), Switzerland (Bruderer & Schmid 1988). As the populations are on the whole well monitored by observers at the present time, questionnaires sent to ornithologists likely to provide information stressed the search for old breeding records, so as to provide as wide a possible impression of the ecological niche of this species on water courses.

1.3. Results

The review of information on the past and present distribution of the common tern (Fig. 1) de-

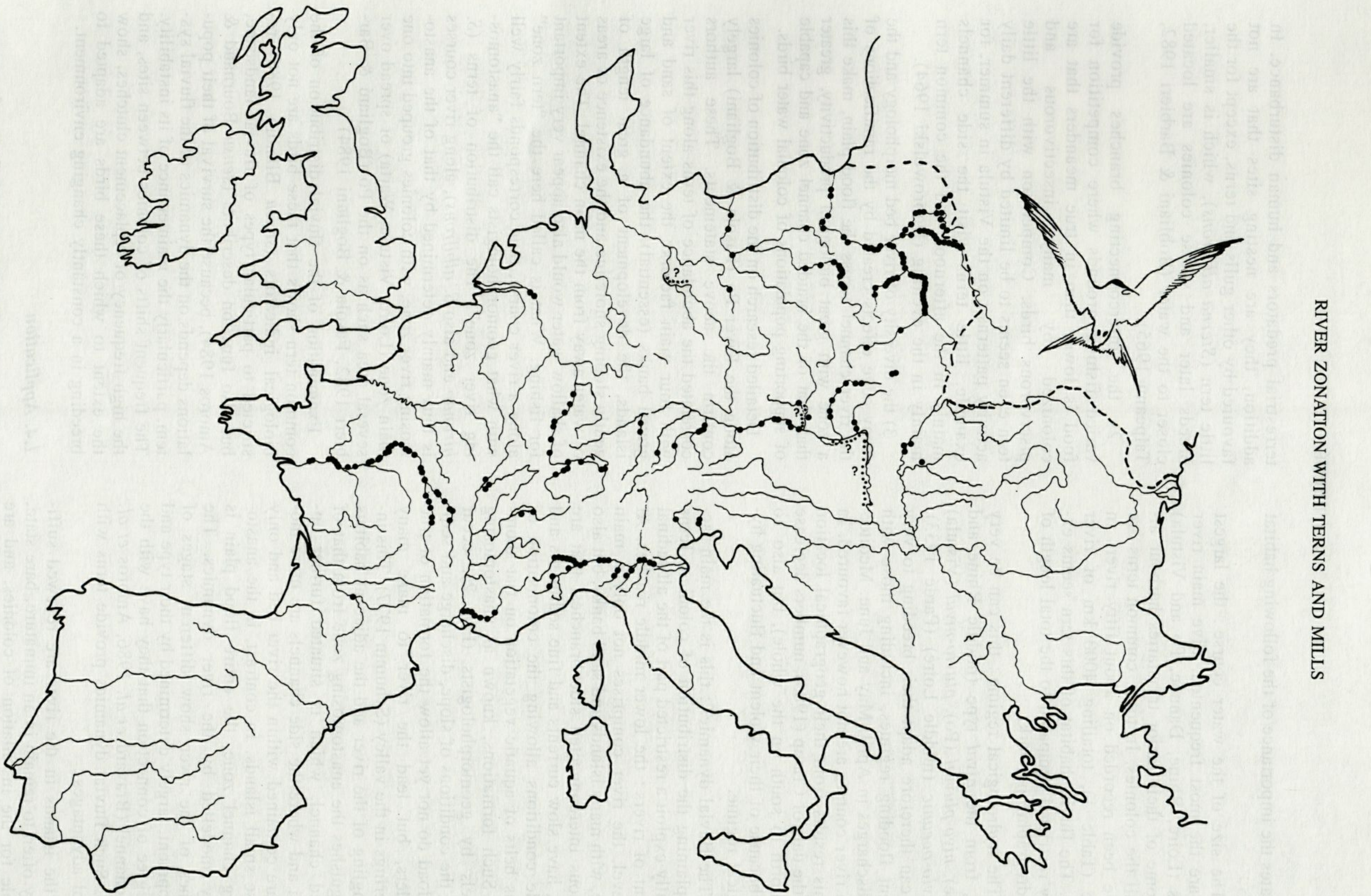

Fig. 1. – Geographical distribution of Common Tern (*Sterna hirundo*) colonies mentioned along European rivers from mid XIXth century to the end of XXth century. • Mention of a precise site. ...?... Mention of a river section (site not precised).

monstrates the importance of the following habitat features :

— The size of the water course : the largest rivers are the most frequented. Five main river courses (Loire, Rhine, Danube, Po and Vistula) with some of their major tributaries harbour almost all the colonies. In total, common terns are or have been recorded on about fifty rivers in Europe (Table 1), totalling 4000 km of river course. The fluvial habitat of this tern seems extremely restricted compared to the total length of the hydrographic network.

— The hydrological regime : this can be very varied, from the *nival* type (middle Rhine and Danube), *nivo-pluvial* (Po), *pluvio-nival* (Vistula) to *pluvio-oceanic* (middle Loire) (Pardé 1933). Terns can therefore adapt their breeding to very different flooding regimes, including those with peak discharges in April, May and June. Mediterranean river courses are not however favoured. In part this results from their geographical location (from the data of Cramp (1985), numbers decrease from north to south on the whole), but also no doubt because of their violent and fluctuating hydrological regime.

— The fluvial dynamics : this is the main factor explaining the distribution of colonies. Terns generally exploit a restricted part of the altitudinal gradient of rivers : the lower middle reaches. At this level, the river comprises not only a main course, with many islands and sand banks, but also numerous interconnected side branches, that are stable, have slow currents and fine sediments and provide conditions allowing the colonisation of various belts of aquatic vegetation on flat shorelines. Such formations, known as anastomosing channels by geomorphologists (Fig. 2), occur where the conditions of slope, discharge and sediment load do not yet allow the formation of true meanders, but lead the river to make many wanderings in the valley (Schumm 1977). This intermingling of the river and the adjacent habitats distinguishes the anastomosing zone from that of braided channel, which is situated further upstream and where the side channels are more mobile, are contained within the river bed and only enclose small islands. In contrast, in the anastomosing channel zone, the entire flood plain is greatly modelled by the river dynamics. The branches of the river show different stages of development, largely determined by their type and the degree of connection that they have with the main channel (Bravard *et al.* 1986, Amoros *et al.* 1988). Such fluvial dynamics provide terns with several advantages :

1) the islands in the river are renewed sufficiently often to remain in an immature, bare state, suitable for the installation of colonies, and are sufficiently numerous to provide room for viable populations. They also provide protection from terrestrial predators and human disturbance. In addition, they are nesting sites that are not favoured by other gulls and terns, except for the little tern (*Sterna albifrons*), which is smaller, breeds later and whose colonies are located closer to the water (Bobliani & Barbieri 1982, Talpeanu 1965).

2) the interconnecting branches provide varied fishing grounds where competition for food is lower than in true meanders that are colonized by many insectivorous and piscivorous birds. Competition with the little tern even seems to be limited by different daily activity patterns : on the Vistula in summer, for example, little terns visit the side channels mainly in the afternoon and the common tern mainly in the evening (Dobrowolski 1964).

3) the diversity of river bed morphology and the many edge effects created by the ramifications of the river channel across the flood plain, make this a zone with great biological productivity, greater than that of the braided channel zone and capable of supporting populations of colonial water birds.

Detailed research on the distribution of colonies along the River Po (Fasola & Bogliani) largely confirm the above statements. These authors correlated the abundance of terns along this river with four main factors : the extent of sand and gravel banks (essential), the abundance of large islands, the development of a great length of gently sloping shoreline and the existence of areas of water away from the main channel. The extent of shallow water would also appear very important for fishing. What is called here the "tern zone" along a river course, thus corresponds fairly well with what geomorphologists call the "anastomosing river zone". The distribution of terns (*S. hirundo* and also *S. albifrons*), along river courses is thus mainly determined by that of the anastomosing river zone, with colonies grouped into one main zone (Loire, Vistula, Warta) or spread over several area such as on the Po (Bogliani & Barbieri 1982, Fasola & Bogliani 1984)

Examination of the fluvial distribution of the common tern shows that these birds are not only biological indicators (*sensu* Blandin 1986) restricted to particular types of fluvial landscape, but also function describers (*sensu* Bournaud & Amoros 1984), because the survival of their populations depends on the dynamics of the fluvial system, particularly the maintenance of its instability. The frequent shifts of colonies between sites, and the high frequency of replacement clutches, show the extent to which these birds are adapted to breeding in a constantly changing environment.

1.4. Application

Monitoring breeding populations of common terns could be a method for assessing the "state

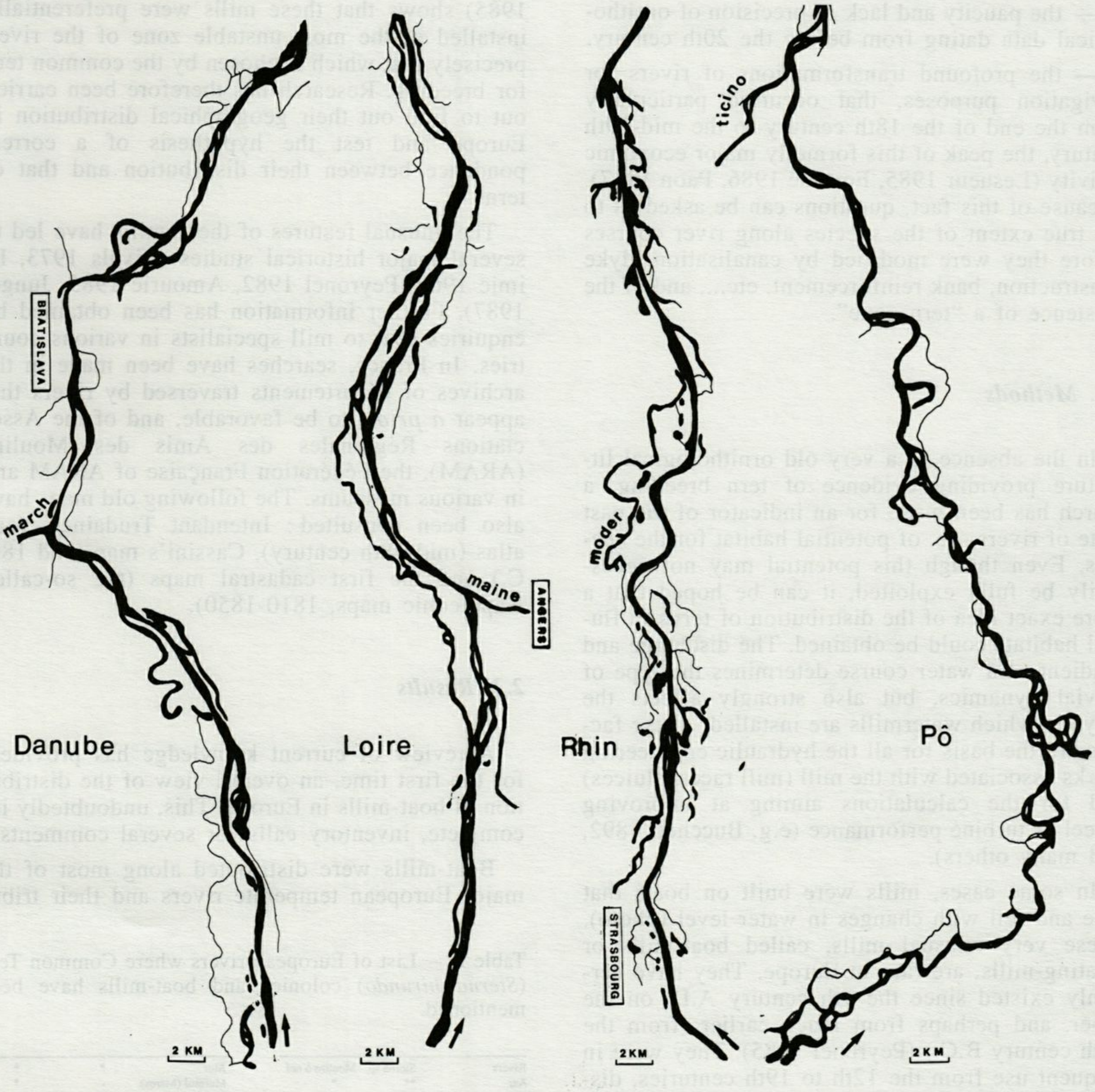

Fig. 2. – Four examples of anastomosed section of large European rivers along which Common Tern (*Sterna hirundo*) is breeding.

of health" of anastomosing river courses. Although many causes, such as mortality on migration or on the wintering grounds, or illegal shooting, could explain fluctuations in fluvial populations, the main causes at present are habitat degradation : canalisation of minor channels, discharge regulation, stabilisation of islands, drainage and siltation of former river channels. Annual censuses of the remaining large fluvial populations (Vistula, Danube, Po and Loire basins) would provide information on the changes in habitat quality and fluvial dynamics, particularly when major engineering projects are envisaged (major dams on the Loire, Allier and Danube, wide berth canals).

2. FROM THE FUNCTION DESCRIBERS TO THE "HISTORICAL TRACER"

2.1. The problem

The description of the distribution of the common tern in riverine habitats meets with two main difficulties :

— the paucity and lack of precision of ornithological data dating from before the 20th century.

— the profound transformations of rivers for navigation purposes, that occurred particularly from the end of the 18th century to the mid-19th century, the peak of this formerly major economic activity (Lesueur 1985, Fortuné 1986, Paon 1987). Because of this fact, questions can be asked as to the true extent of the species along river courses before they were modified by canalisation, dyke construction, bank reinforcement, etc..., and of the existence of a "tern zone".

2.2. Methods

In the absence of a very old ornithological literature providing evidence of tern breeding, a search has been made for an indicator of the past state of rivers, i.e. of potential habitat for the species. Even though this potential may not necessarily be fully exploited, it can be hoped that a more exact idea of the distribution of terns in fluvial habitats could be obtained. The discharge and gradient of a water course determines the type of fluvial dynamics, but also strongly affects the ways in which watermills are installed. These factors are the basis for all the hydraulic engineering works associated with the mill (mill races, sluices) and for the calculations aiming at improving wheel or turbine performance (e.g. Buccheti 1892, and many others).

In some cases, mills were built on boats that rose and fell with changes in water level (photo). These very unusual mills, called boat-mills or floating-mills, are rare in Europe. They have certainly existed since the 7th century A.D. on the Tiber, and perhaps from much earlier (from the 10th century B.C.) (Peyronel 1985). They were in frequent use from the 12th to 19th centuries, disappeared in France at the start of the 20th century (Roché 1985), but survived in a few regions of Europe, notably Yugoslavia, where they have just been rediscovered (Rivals 1990). Research carried out on the lower reaches of the Doubs (Roché 1985) shows that these mills were preferentially installed in the most unstable zone of the river, precisely that which is chosen by the common tern for breeding. Research has therefore been carried out to find out their geographical distribution in Europe and test the hypothesis of a correspondence between their distribution and that of terns.

The unusual features of these mills have led to several major historical studies (Rivals 1973, Irimie 1969, Peyronel 1982, Amouric 1985, Jungel 1987). Further information has been obtained by enquiries sent to mill specialists in various countries. In France, searches have been made in the archives of départements traversed by rivers that appear *a priori* to be favorable, and of the Associations Régionales des Amis des Moulins (ARAM), the Fédération Française of ARAM and in various museums. The following old maps have also been consulted : Intendant Trudaine's road atlas (mid-18th century), Cassini's map (end 18th C.) and the first cadastral maps (the so-called Napoleonic maps, 1810-1850).

2.3. Results

A review of current knowledge has provided, for the first time, an overall view of the distribution of boat-mills in Europe. This, undoubtedly incomplete, inventory calls for several comments.

Boat-mills were distributed along most of the major European temperate rivers and their tribu-

Table I. – List of European rivers where Common Tern (*Sterna hirundo*) colonies and boat-mills have been mentioned.

Rivers	Sterna sp.	Moulins à nef
Aar	**	*
Adige	*	***
Agoût	-	*
Ain	(*)	*
Allier	**	*
Bodrog	-	*
Brenta	-	*
Bug	**	-
Cher	-	*
Danube (Donau)	***	***
Dordogne	-	*
Doubs	*	**
Drava	*	*
Duero	-	*
Durance	**	*
Ebro	*	*
Elbe (Labe)	*	*
Enns	-	*
Enza	*	-
Garonne	*	***
Guadiana	(*)	*
Hron	*	-
Inn	*	*
Isar	*	-
Isère	-	*
Koros	*	*
Lech	*	-
Loire	***	***
Lot	-	*
Malina	*	-
Marne	-	*
Meuse (Maas)	-	*
Morava (CSK)	-	*
Morava (YU)	-	*
Mulde	-	*
Mur	*	*
Muresul (Maros)	-	*
Narew	**	-
Odra (Oder)	*	*
Oltul	*	*
Piave	*	-
Parma	*	-
Pilica	*	-
Pô	***	***
Poprad	*	-
Rhin (Rhein)	***	***
Rhône	*	***
Salzach	-	*
Saône	*	*
Save	*	*
Seine	-	*
Siretul	-	*
Somesul (Szamos)	-	*
Stura	*	-
Tagliamento	*	-
Tanaro	*	**
Tarn	-	*
Taro	**	-
Tevere	-	*
Thaya (Dyje)	*	*
Ticino	*	-
Tisza	**	*
Torysa	*	-
Touvre	-	*
Vah	**	*
Warta	***	-
Weser	-	*
Wisly	***	*

*** Très abondant ** Abondant * Rare
( ) Sterna albifrons

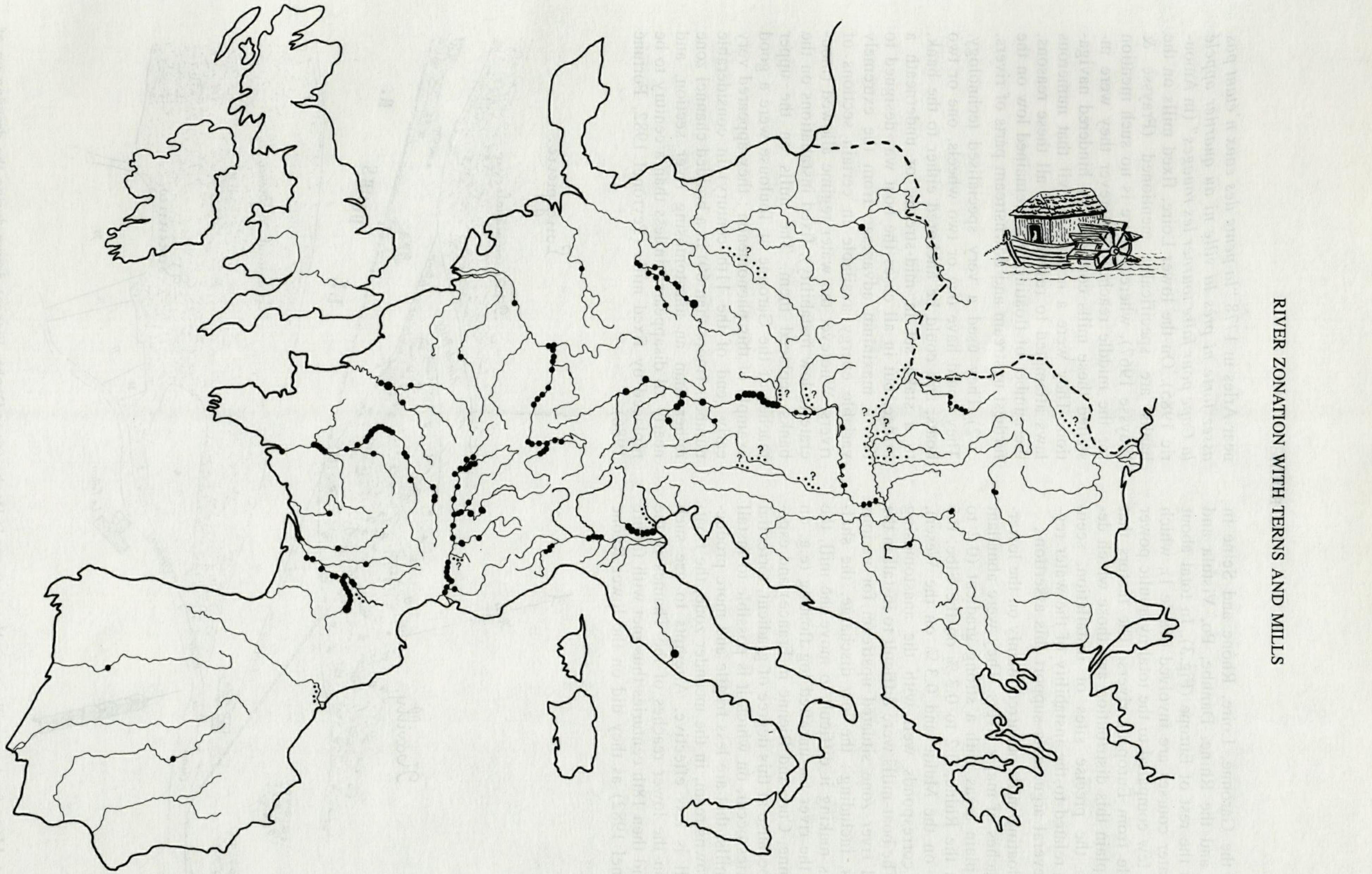

Fig. 3. – Geographical distribution of boat-mills mentioned along European rivers from IXth century to the beginning of XXth century. • Mention of a precise site ...?... Mention of a river section (site not precised).

taries : the Garonne, Loire, Rhône and Seine in France and the Rhine, Danube, Po, Vistula and Elbe in the rest of Europe (Fig.3). In total about fifty water courses are involved (Table I), which is very few compared to the total hydraulic power available from European rivers. The factors that best explain this distribution and those which determine the precise sites of installation, seem closely related to the instability of the water regime. Several arguments support this assertion :

1) Floating mills occurred mainly on the lower-mid reaches of major rivers. They were abundant in the plain areas with a strong gradient (0.2 to 1 % on the Rhine, 0.2 to 0.3 % on the Elbe, 0.5 to 1 % on the Mulde and 0.3 % on the Weser), which corresponds well with the anastomosing zone. The boat-mills were difficult to install in the braided river zone situated upstream for various reasons, including : the low discharge, the shallowness making it difficult to move the mill, the use of the river for unrafted log floating (e.g. on the Yonne, Cure and Bienne in France) and especially because at this degree of gradient, torrential tributaries occur, on which it is possible to install fixed mills, that are less fragile and more productive. Downstream, in the meander zone, the floating-mill is less effective. Attempts to use such mills on the lower reaches of the Thames in the 16th and then 18th centuries thus met with failure (Peyronel 1982) as they did on the lower Rhône near Arles in 1778 "*la pente des eaux n'étant pas assez forte ni près la ville ni au quartier appelé la Cape pour faire tourner les rouages*" (in Amouric 1985). On the lower Loire, fixed mills on the banks are specifically mentioned (Fraysse & Fraysse 1967), whereas there is no such mention for the middle reaches. Wherever they were installed these mills considerably hindered navigation. They were a necessary evil that numerous laws attempted to restrict. For all these reasons, the number of floating mills remained low on the furthest upstream and downstream parts of rivers.

2) They used a very specialised technology. They could have one or two wheels, one or two boats, and could be anchored either to the bank, to a stake set in mid-stream, or underneath a bridge, but in all cases the boat was designed to derive maximum advantage from the extremely variable energy available in certain sections of rivers. Wherever the water regime allowed (moderate to low instability), fixed installations on the banks replaced them. The mills on the upper reaches of the Garonne at Toulouse were a good example of this phenomenon : they appeared very early (end of the 11th century) in considerable numbers (more than 60) in a braided channel zone rather than an anastomosing river section, and nearly all disappeared in less than a century to be replaced by fixed mills (Peyronel 1982, Fortuné 1986).

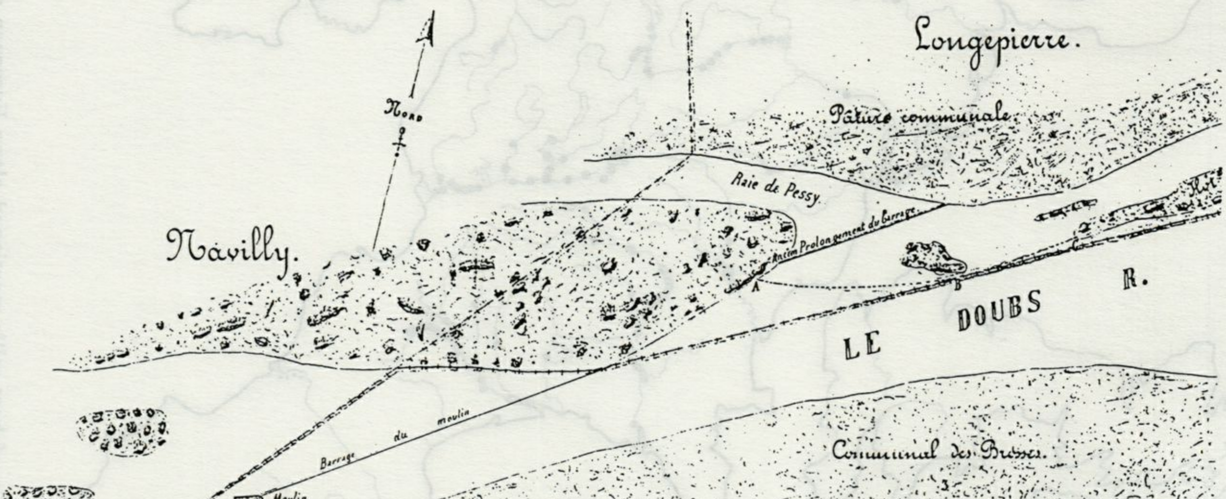

Fig. 4. – Map of a boat-mill site at Varennes-sur-le-Doubs (river Doubs, France) drawn during the drawing up of this mill's statutes in 1847.

3) Natural local factors clearly influenced the choice of installation site. Changes in slope (e.g. on the lower Rhône), areas with strong currents downstream of confluences (Loire-Maine, Garonne-Tarn, Danube-Morava, Rhine-Aar, Po-Adda, etc...) and natural millraces (river branches caused by the presence of islands) were all skilfully used by millers to draw the maximum power from the river – frequently even in contravention of regulations in force – or to make a proposed installation seem more profitable for public authorities. The relatively rich illustrative evidence, in the form of plans appended to water regulations (Fig. 4), sketches, paintings or more rarely photographs, confirms this point of view. The distribution of floating mills is also well correlated with other factors, particularly demographic factors. The great mediaeval riverside cities used these mills, often in great numbers, to meet the flour requirements of a large and increasing population. But this only accounts for their existence at a few sites such as Paris, Cologne, Dresden, Prague, Warsaw and Rome. Cultural factors also undoubtedly played a role in the spread of the technology. The predominance of the horizontal-wheeled watermill in southern France (Rivals 1984) could in part explain the rarity of boat-mills (in which the wheel is vertical) along Mediterranean river courses. As far as possible competition from windmills is concerned, this is unlikely to have been a major factor, since the latter often occurred side by side or even supplemented the power of the watermill, and windmills occur preferentially along the major river valleys in France such as the Seine, Loire and Garonne (Rivals 1984). It seems therefore that the geographical distribution of boat-mills can be largely explained in terms of river hydrodynamics. These not only affected their installation, but also their survival : violent floods, ice-floes, and various calamities very frequently led to the disappearance of the mill (Defarges 1973, Chauney 1979, Amouric 1985). The many, and frequently infringed, regulations usually only gave the *coup de grâce* to a technology that had become obsolete. The historical timing demonstrates this : "all the water courses that had possessed floating mills, other than those that had only seen isolated, unsuccessful attempts, lost them only in the 19th, or more rarely 18th or 20th centuries..." (Peyronel 1982). Although this technology was particularly fragile and challenged over the centuries, this did not prevent it from being remarkably dynamic. The boat-mill seems therefore to be both a good biological indicator (river on the plain, with a strong gradient, large discharge, often with scattered islands and anastomoses) and a good function describer (instability of the water regime). Are there therefore similarities between the distribution of common terns and boat-mills since both these indicators reveal the presence of the anastomosing zone along rivers ? Three results would appear to confirm this similarity :

— 41 % of rivers inventoried share both common terns and boat-mills. If the approximate abundance ("very abundant", "abundant" or "rare") of terns and mills on these rivers is taken into account, the similarity expressed by the Steinhaus index increases to 54 % (Table 1).

— the length of the water courses occupied largely overlap (Figs. 1 and 3), at least on the main river courses.

— the changes in abundance along the same water course are in certain cases remarkably similar (Fig. 5).

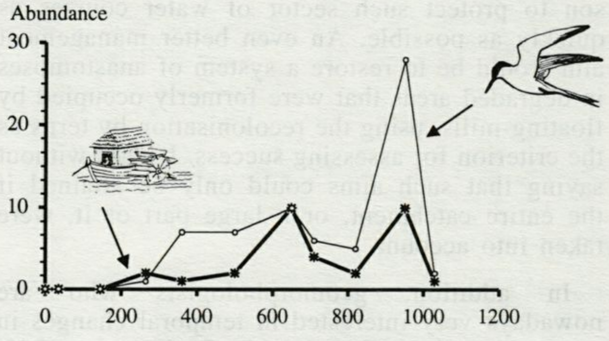

Fig. 5. – Number of Common Tern (*Sterna hirundo*) colonies and boat-mills mentioned along river Loire. Each point takes into account the available datas in each french "département".

On the whole, the "ecological niche" of the boat-mill is somewhat more extensive than that of the common tern. Upstream it can overlap with the grayling/common sandpiper zone (e.g. rivers Somesul and Oltul in Romania, upper Rhine in Switzerland), and downstream with the bream/coot zone (lower Saône, Rhine and Seine). It is possible that these differences can be explained by technological variants of the mills, the least stable systems (mills comprising one boat with a wheel either side) being installed on the calmer sections of rivers (e.g. the meander zones on the Seine and Saône). In addition, some differences in distribution could become similarities if the areas along rivers occupied by little terns are included in the tern zone (lower valley of the Ain, France and the middle reaches of the Guadiana, Spain).

2.4. Application

Despite some exceptions, the analogy between the tern zone, the anastomosing zone and the boat-mill zone retains a value in several fields.

The distribution of boat-mills provides the ornithologist with information on those sections of river that were probably used by terns for several centuries, when river management was still very restricted. It can be estimated that up until the 18th century, the extent of favourable sections in Europe was about 7000 to 8000 km, or twice as great as the length occupied today. This simple estimate shows that the sector of rivers with numerous branches (which are often called "wild rivers") were formerly much less extensive than had previously been believed.

Managers of natural habitats (such as local authorities, and government and non-governmental conservation bodies) will find this another reason to protect such sector of water courses as quickly as possible. An even better management aim would be to restore a system of anastomoses in degraded areas that were formerly occupied by floating-mills, using the recolonisation by terns as the criterion for assessing success. It goes without saying that such aims could only be attained if the entire catchment, or a large part of it, were taken into account.

In addition, geomorphologists who are nowadays very interested in temporal changes in river dynamics (Bravard & Bethemont 1989, Bravard 1989), could find with boat-mills an archival source likely to provide them with information on the past configuration of water courses (illustrations) and fluctuations in their regime (floods, ice-floes, etc...). As an example, Trafas (1975) (in Bravard 1989) considered that braided channels had been replaced by meanders on the upper Vistula over about the last 200 years. A detailed study of "populations" of boat-mills in this sector would probably provide information on this hypothesis. The fact that boat-mills survived for several centuries and were adapted to the aquatic environment makes them a historical tracer adapted to this type of problem and their use in ecology would appear promising.

3. FROM THE HISTORICAL TRACER TO THE HISTORY OF BIRD POPULATIONS

It is difficult, if not impossible, to find information on fluctuations in the abundance of bird populations over past centuries because of the lack of scientific studies or sufficiently precise and old indices of abundance. We will therefore restrict ourselves here to what may have been the ornithological impact of fluvial activities on the populations of breeding birds in the tern zone.

3.1. Navigation

Navigation, undertaken almost exclusively at periods of high water level, probably had little direct effect on birds breeding on sand banks or on the shores (observations carried out recently also confirm that passing boats cause little disturbance). On the other hand, the engineering works that navigation required were more destructive than the activity itself :

— The canalisation of the river channel restricted the wanderings of the river, decreased the number of islands, the connections with the flood plain and the length of shoreline per unit length of course (Fortuné, 1988), all of which, as we have seen, are important for tern populations.

— The stabilisation of the banks by rock protection, which led to the disappearance of steep banks, only affected a few species (those that built tunnels nests in the bank, such as the kingfisher, sand martin or bee-eater) which are in any case not very sensitive to such modifications so long as they do not occur everywhere. The impact is therefore recent (start of 20th century).

— Towing of boats from a tow path required regular vegetation cutting (Défontaines 1932 in Décamps *et al.* 1988) which would have favoured shrubdwelling species such as warblers and thrushes at the expense of tree-nesting species such as woodpeckers, herons and pigeons.

— Canals, that followed along the river valleys, cut off the anastomoses from the main channel, favouring siltation and were in the long term detrimental to most aquatic species that require open water, such as ducks, herons and grebes. These new aquatic habitats of low ecological value are nowadays exploited by the most ubiquitous species such as moorhen and coot. In addition, the densities of breeding riverine species along canals is lower than that recorded on rivers (Marchant & Hyde 1980).

3.2. Boat-mills

Their impact was almost certainly negligible when the river channel was not obstructed. Sometimes a dam of stakes planted in the river bed directed the current towards the wheels (Allier, Loire). If the channel was completely obstructed, a dam and a true waterfall could appear (e.g. a 1 m fall on the Doubs). The many complaints of boatmen demonstrate the impact that these dams could have by recording the appearance, upstream of sand and gravel deposits, dangerous for navigation (Ligeron 1977). The impact of these dams was not always local. On the Doubs, for example, a 1 m high dam would (because of the gradient) cause the river to back up over a length of about

1 km. With 12 mills spread over the 55 km of anastomosing channel in the 18th century, about 12 km or 20 to 25 % of this zone would therefore have been disturbed. Did this contribute to the decline of running water species, such as terns and little ringed plover, and favour those of still water, such as Rallidae and ducks ?

3.3. *Log floating*

This was carried out in two ways. Floating with unrafted logs (the tree trunks floating separately down the river) was used on the upper reaches, and particularly, it would appear, on the river sections where the fluvial dynamics were of the braided channel type. The zone involved by this type of log floating would therefore have been the grayling/common sandpiper zone (Roché 1989). Raft floating (logs formed into guided rafts) was more frequent on the lower reaches (anastomosing and meander zones). As these activities were, like navigation, carried out at seasons of high water levels, they probably had little impact on breeding bird populations.

3.4. *Agriculture and urbanisation*

Agriculture and urbanisation in the Middle Ages, by creating new types of habitat in formely heterogeneous valleys, that were however probably dominated by forest cover, must have greatly contributed to the diversification of the breeding bird populations. This hypothesis is supported by the results of censures carried out using the same methods (*Indice Ponctuel d'Abondance*, I.B.C.C. 1977), in Burgundy (France), which showed that at present the habitat with the most diverse bird fauna is the river bank (Fig. 6). This results from the great diversity of the landscape : the variety of habitats present at any one locality, the many edge effects, the high degree of connection between habitats (compensating for the impoverishing effect caused by partitioning). Agriculture and urbanisation, that previously favoured population diversification, have more recently caused serious disruption because of :

— intensification : the harmful effects of agricultural modernisation on the avifauna have already been highlighted (Broyer 1989),

— the major engineering works, such as dyke construction and flood plain drainage, that they engender. Dyke construction has not only modified the fluvial dynamics, the habitats, and indirectly the bird populations, but has also formed major access routes which contribute directly to the decline of many species by the disturbance that they produce (Talpeanu 1968). This brief review shows that, in ornithological terms, the impact of former fluvial activities were more often caused by associated engineering works, rather than by the activities themselves. This tendency seems to be completely reversed in modern times, when major engineering works, such as dams, only disturb the environment locally, but allow a range of activities such as irrigated agriculture, urbanisation of the valley bottom, and leisure activities, that can transform the landscape and therefore the bird populations in the entire catchment area, usually in a detrimental manner.

CONCLUSION

This work that was initially a study of fluvial ornithology, relies of four approaches of a more general nature :

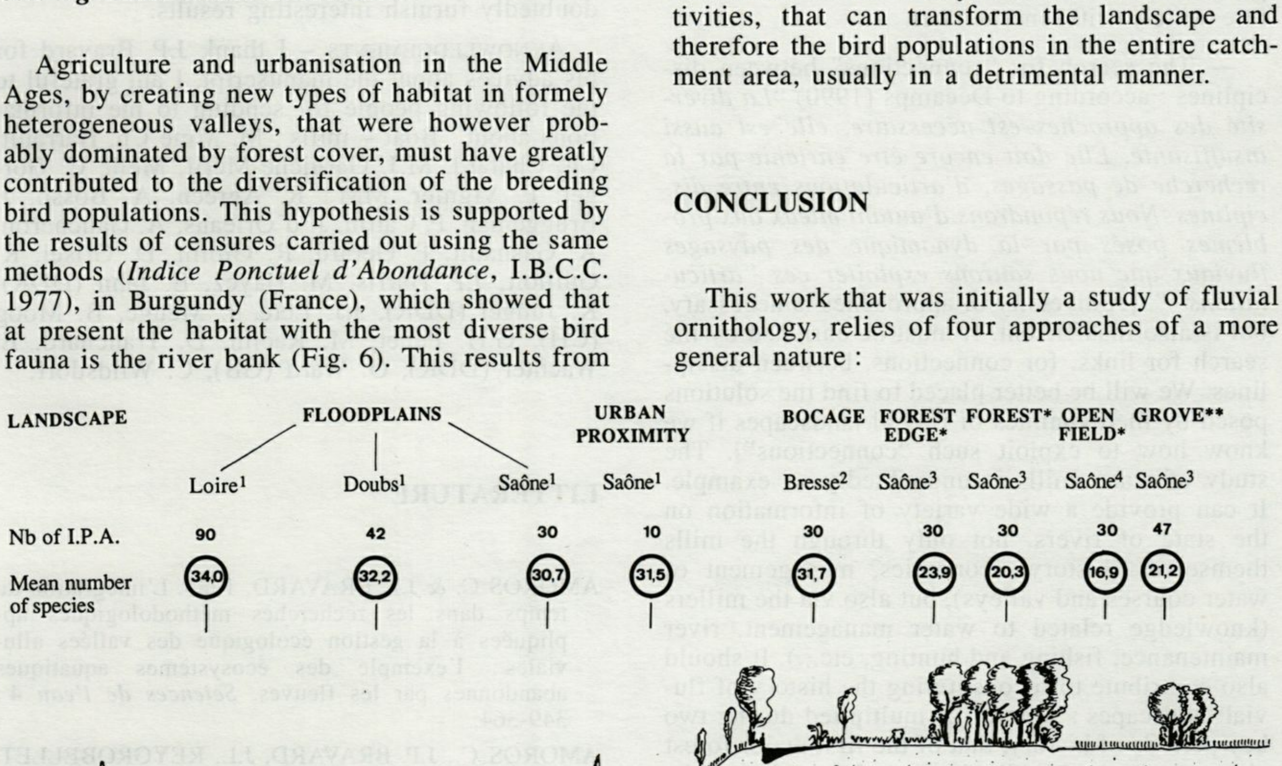

Fig. 6. – Mean number of breeding bird species in different landscapes of Burgundy (France). *from Frochot & Lobreau (1987), **from Hermant (1989) I.P.A. : Indice Ponctuel d'Abondance (for census methodology see I.B.C.C., 1977) 1 : edge of rivers, 2 : edge of ponds, 3 : coppice-with-standards, 4 : cereals.

— the validation of a model : terns are a good indicator of a type of river, to the extent that areal "tern zone" can be identified. This result supports the concept of a general ornithological zonation scheme for running water courses, and also of a more general ecological zonation scheme. It seems, in fact, that whatever approach is taken, there exist four zones along the major European river courses, the most remarkable of which, both because of its very restricted area and because of its landscape complexity, is the anastomosing zone.

— The search for analogies : the comparison between describers of fluvial system functioning, which are correlated with one another, can be rich sources of insight, especially when the describers are derived from distant disciplines. By comparing an aquatic describer (the grayling) and a terrestrial describer (the common sandpiper), problems of ecology, biogeography and speciation have been raised (Roché 1989). By comparing an ecological describer with a "historical tracer" it is possible to raise problems relating to local habitat evolution over the centuries. This search for analogies is propitious for stimulating a multidisciplinary approach and for furthering understanding of systems that are as complex as river valleys, where past and present, natural and human factors interfere widely with one another.

— The search for "connections" between disciplines : according to Décamps (1990) "*La diversité des approches est nécessaire, elle est aussi insuffisante. Elle doit encore être enrichie par la recherche de passages, d'articulations entre disciplines. Nous répondrons d'autant mieux aux problèmes posés par la dynamique des paysages fluviaux que nous saurons exploiter ces "articulations"*". [A diversity of approaches is necessary, but is also insufficient. It must be enriched by the search for links, for connections, between disciplines. We will be better placed to find the solutions posed by the dynamics of fluvial landscapes if we know how to exploit such "connections"]. The study of water mills is undoubtedly an example. It can provide a wide variety of information on the state of rivers, not only through the mills themselves (history, economics, management of water courses and valleys), but also via the millers (knowledge related to water management, river maintenance, fishing and hunting, etc...). It should also contribute to reconstituting the history of fluvial landscapes : watermills multiplied during two key periods of history, that of the first major forest clearance in the Middle Ages, and then during the industrialisation of the 19th century. The study of watermills is also of value in understanding the history of certain animal populations, such as that of the Atlantic salmon, which is related to that of watermills in some regions (Thibault & Vinot 1989). In the urban environment Guillerme (1983, 1990) has shown the formerly important position that mills occupied in the management of water and has attempted to define their environmental impact. In many respects, the history of watermills (particularly boat-mills, that are so closely related to rivers) involves us in the history of the river valley landscape.

— Taking into account the past : historical ornithology has until now developped over time scales of either decades or millenia, each period involving different problems. Very little is known, however, of bird populations in past centuries. At this time scale, how can a start be made to study "mediaeval ornithology" ? Two complementary routes seem possible : the search for historical indicators likely to provide information on the state and functioning of ecological systems in the Middle Ages – this is the route taken here – and the search for a site that has retained its mediaeval fauna, particularly its birds – this is the route explored recently by Vigne *et al.* (1991) in a chapel on the Lavezzi Islands. These new approaches will meet with two main difficulties : the multidisciplinarity already mentioned, and the suitability of the techniques being used for time scales of centuries and for the frequently fragmentary nature of the available data. If these two obstacles could be overcome, "mediaeval ornithology" could undoubtedly furnish interesting results.

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