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Historical influence of man on the riparian dynamics of a fluvial landscape

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Abstract

Man's influence, over the last three centuries, has gradually influenced the dynamics of forest cover along the valley of the Garonne, a seventh order river in Southern France. The vegetation cover of the floodplain depends on topographical levels which govern the frequency and duration of submergence during flooding. Along the valley, forest patches vary from a continuous ribbon of riparian wood along the river to a mosaic of groves towards the upland terraces. In the floodplain, the forest dynamics are influenced by floods, appear to be reversible, and are subject to dominant allogenic processes. On the contrary, forest dynamics on the terraces, which are not influenced by floods, are irreversible and subjected to dominant autogenic processes. Since the end of the 17th century, the structure of riparian woods has been modified by navigation and agriculture leading to a fragmentation of forest cover in the floodplain. Modern agriculture and urbanization have accentuated these tendencies by modifying the hydrologic regime of the river. These historical changes result in a fragmentation of forest cover and a substitution of species in the riparian zone, the forest dynamics being still reversible in the floodplain.

Introduction

The relevance of landscape ecology in providing a better understanding of the dynamics of large alluvial river valleys has been stressed recently (Forman and Godron 1981; Decamps 1984; Ward and Stanford 1987; Decamps and Naiman 1988). This applies particularly to the boundary limits along floodplains (Naiman *et al.* 1988). Among these boundaries, riparian woodlands have been modified and fragmented extensively by human activity (Sedell and Froggatt 1984). Yet, their importance for river management is well known (Petersen *et al.* 1987). On many European floodplains embankments, channelization and other modifications have accelerated the disappearance of alluvial forests. This disappearance is well documented in industrialized valleys such as those of the Rhine River (Carbiener 1970, 1983; Carbiener *et al.* 1986; Walter 1974), and the Rhône River (Pautou and Decamps 1985; Bravard *et al.* 1986).

By comparison, the valley of the Garonne River, which is not so industrialized, has not been so drastically modified (Décamps *et al.* 1987). Man's impact has been more progressive through the ages: protection against flooding; changes to aid navigation; developing agriculture (Fortuné 1988a). These have all gradually modified the fluvial landscape, yet recent industrial developments have not obscured earlier changes. Thus, this valley offers a useful model to study historic influences on the dynamics of riparian woods. These riparian woods are located between the river and its floodplain and as such constitute an ecotone or boundary between adjacent patches (Holland 1988).

The purpose of this paper is to present a conceptual model of the dynamics of such an ecotone, and to discuss the impact of human activities over the last three centuries on the present day functions of this zone.

Temporal and spatial scales

Historical human influences on the riparian woodlands along the Garonne River are considered from the end of the 17th century. During the 18th century navigation flourished and the importance of the river as a means of communication was established (Deffontaines 1932). The 19th century was a transition period as regards use of the river with a growing importance of agriculture in the floodplain (Fortuné 1988a). The 20th century saw the'modern utilization of the river and its tributaries with hydraulic management for agriculture (regulation of fluxes, construction of reservoirs, development of irrigation) and hydro-electric management for industry.

The part of the Garonne River valley featured in the present study is about 90 km long (Fig. 1). It constitutes a transition zone between a swift water course upstream of the confluence with the Ariege River and a slow meandering river with a wide floodplain downstream of the confluence with the Tarn River. In this transition zone, the Garonne is a seventh order river with a mean annual discharge of about 200 m^3/s. The floodplain enlarges rapidly from the confluence with the Ariege to become 3–4 km wide at the confluence with the Tarn.

Floods are sudden and violent, with a maximum mean daily flow of 2500 m^3/s (a level of 3.5 m at Toulouse) for the 50 year flood and a flow of 4500 m^3/s (a level of 6.5 m at Toulouse) for the 100 year flood. **A** catastrophic 1875 flood presented a maximum mean daily flow of 8000 m^3/s (a level of 8.5 m at Toulouse). In contrast, mean minimum daily flows are very low during summer: 50 m^3/s, due to the climate of southern France.

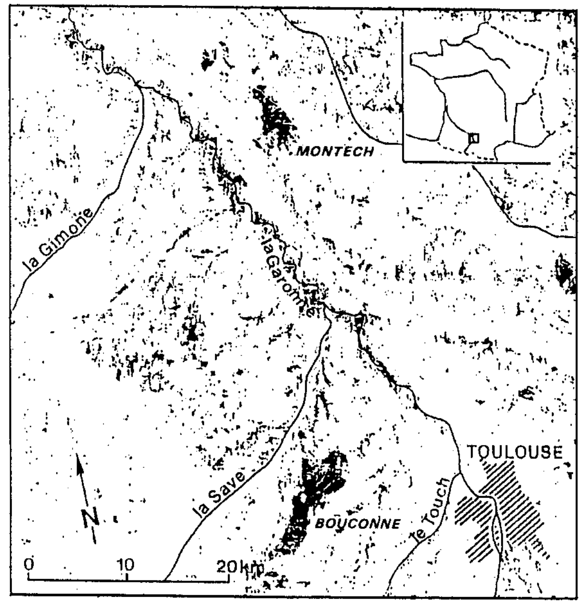


Fig. 1. Study area along the River Garonne in Southern France, with wooded areas in black.

Description of the floodplain

The intensity of the interactions between the river and the uplands provides the basis for a typology of the floodplain. Conditions of the banks – height, steepness, stability – are also considered. Figure 2 illustrates the different types of floodplain in a section of the valley.

The proximate floodplain is submerged approximately 30 days a year at flows of 650 to 750 m^3/s, *i.e.*, a level of 1.8 to 2 metres at Toulouse. The extent of the proximal floodplain is related to several factors: height of banks with a gentle slope, recent alluvial deposits, depressed meander convexities, islands, oxbow lake channels which occasionally reflood, abandoned gravel-pits. This zone is not used for habitation or agriculture; it is the area of natural riparian woods. The level of the water-table is directly related to fluctuations of the river, and usually the top of this water-table is situated near the surface of the soil (Pinay 1986).

The floodplain of importance corresponds to an area which floods once every 2 to 20 years. The flow of the river is between 1500 and 2700 m^3/s, *i.e.*, a

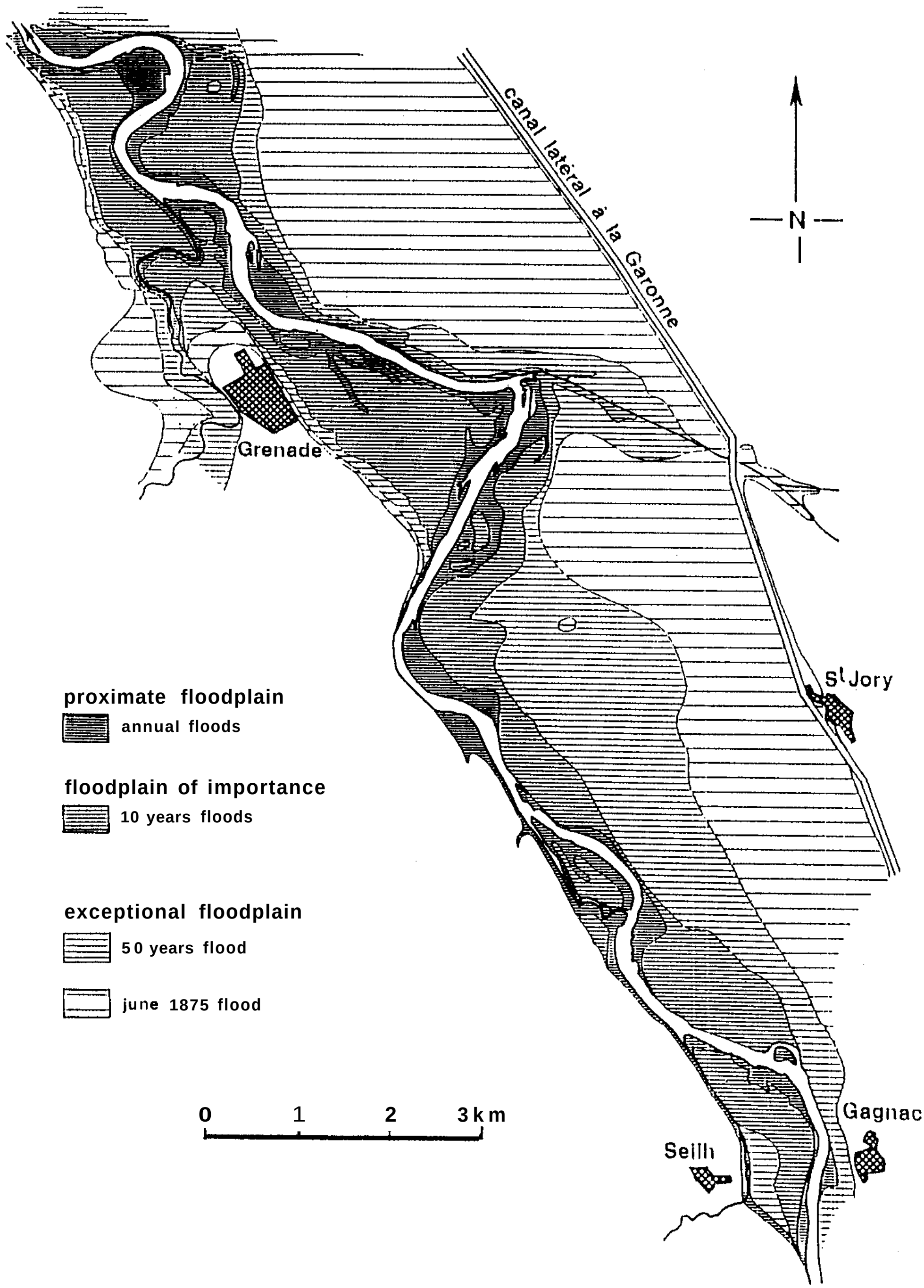
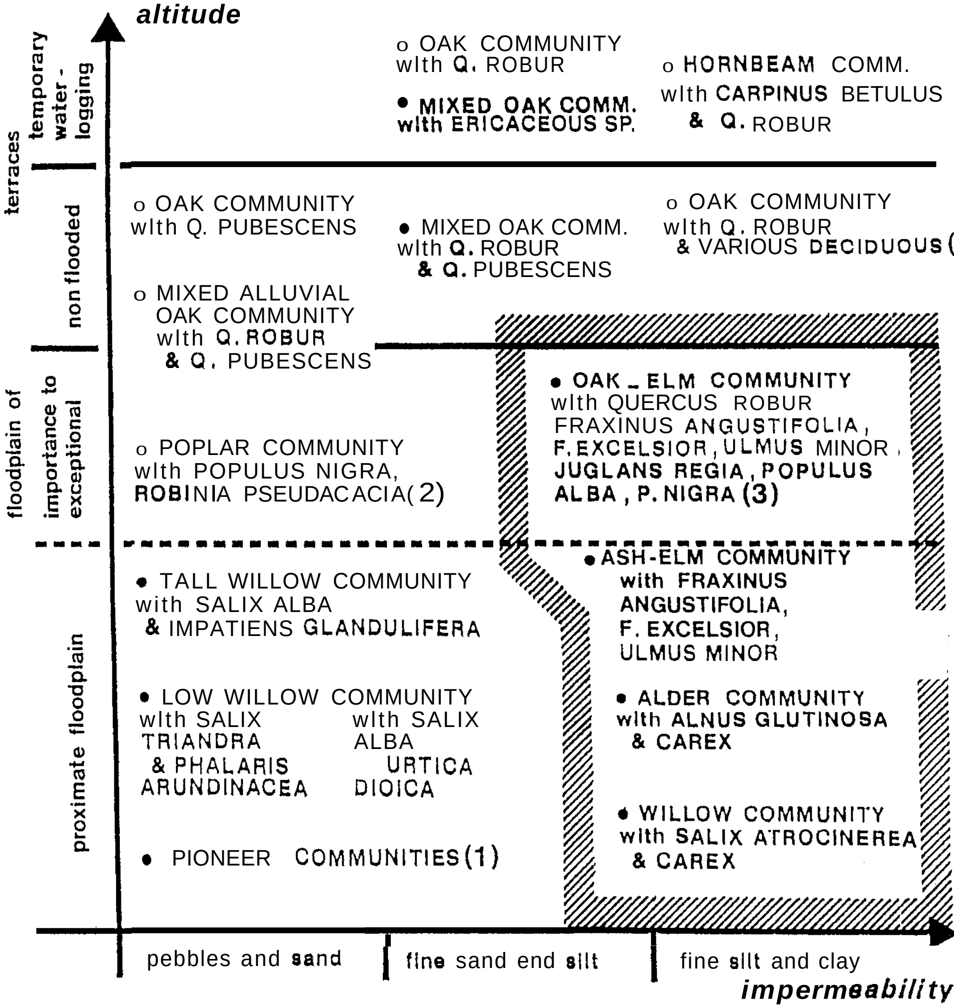


Fig. 2. Typology of the floodplain indicating the various possible extensions of inundations. Note the distribution of the villages at the upper limit of the floodplain.



(1) Phalaris arundinacea and Xanthium strumarium on pebbles and sand, Bidens tripartitus and Polygonum spp on fine sand and silt.
(2) also : Sambucus nigra and Urtica dioica.
(3) also : Aesculus hippocastanum, Platanus occidentalis, Acer negundo.
(4) Fraxinus excelsior, Ulmus minor, Acer campestre, Prunus avium, Tilia platyphyllos, Robinia pseudacacia.

Fig. 3. Distribution of the wooded communities according to the topographic level and to the soil impermeability. The surrounding communities are those frequently replaced by poplar plantations.

level of 3 to 4 metres at Toulouse. Depressed parts of the floodplain comprising ancient meanders and agricultural lands are submerged. Riparian woodland is affected by strong currents which modify the local morphology, eroding it in some places and depositing sediments in others.

The exceptional floodplain is submerged 3–4 times per century. The flow is above 4500 m^3/s and this corresponds to catastrophic floods, such as occurred in April 1770, September 1772, May 1835, June 1855, June 1875, February 1952, May 1977. The floodplain of importance and the exceptional floodplain are a vast area of agricultural land.

Above the floodplain extends various alluvial terraces called (Hubschman 1974): the low terrace (about 30 metres above the river bed), the medium terrace (from 50–80 metres), the high terrace (at 90 metres), and the culminated sheet (at 150 metres). There may be a distinct transition zone between the exceptional floodplain and the lower terrace located between 5 to 20 metres above the river bed.

Fragmentation of the forest cover

The forest cover of the Garonne River valley, (including both the floodplain and the terraces) is fragmented into a mosaic of groves apart from a more continuous strip along the river, and two larger areas of woods one in the North (Montech 110 ha), and one in the South (Bouconne 2300 ha) (Fig. 1). The fragmented forest communities vary with altitude from the lower part of the floodplain to the terraces, as well as with increasing impermeability of the soil, grading from coarse to fine sediment deposits (Fig. 3).

Near the banks, most recent alluvial deposits are colonized by pioneer communities varying from reeds on coarse sand to willows *(Salix atrocinerea* Brot.) on fine silt and clay. In the proximate floodplain, three to four metres above the river bed, two different low willow communities *(Salix triandra* L. and *Salix alba* L.), and a tall willow community (*Salix alba* L.) may be found on sand whereas an alder community (*Alnus glutinosa* (L.) Gaertner) develops on silt and clay. This latter is replaced by an ash-elm community (*Fraxinus angustifolia* Vahl, *F. excelsior* L. and *Ulmus minor* Miller) at higher altitudes. The floodplain of importance is dominated by poplar-oak-elm communities reduced to small patches due to the extension of agriculture.

At the upper limit of the floodplain, different ecological conditions exist as there is no flooding, and thus no input of nutrients from the river. Alluvial deposits are stable, and the water table at a depth of 2 to 5 metres does not influence the pedogenesis of the acidified, superficial parts of the soil. Maize cultivation dominates, accompanied by sunflower, sorghum, rape and fruit-trees. Remnants of the mixed oak forest are reduced to small patches of a mixed alluvial oak community.

Finally, the terraces appear as areas of cattle breeding, cereal polyculture and vineyard. Three types of communities develop on these soils which are rich in silt. **A** mixed-oak community with *Quercus robur* L. and *Quercus pubescens* Willd. is the most frequently found. At the highest altitudes, it is replaced by an oak community with *Quercus robur* L. on acid soils and by a hornbeam community with *Carpinus betulus* L. and *Quercus robur* L. on brown soils rich in fine silt and argilleous colloids which are water saturated during winter.

Dynamics of the forest cover

On the floodplain, vegetative succession may be reversible over a 100 year cycle because of floods. As long as the river is allowed to erode its floodplain and to change its course, there is a possibility of rejuvenation of the communities whatever their stage: pioneer, willow/alder or hardwood (Fig. 4). Different pioneer communities are found according to the degree of soil permeability and similarly in the willow/alder communities. In hardwoods, the ash-elm community corresponds to the limit of the proximate floodplain. Two other communities, one with oak and elm and the other with poplar correspond to the floodplain of importance and the exceptional floodplain.

On alluvial terraces vegetative succession is not reversible, and is subject to dominant autogenic processes. Three main trends may be followed according to an increase in the amount of silt and clay in the soil. From the poplar community, a mixed oak species alluvial community may develop at the upper limit of the floodplain, giving rise to a *Quercus pubescens* community in non submersible conditions on coarse soil. On more silty and clay soil, the ash-elm community develops into a mixed oak species community or a *Quercus robur* community according to the richness of silt and clay in the soil.

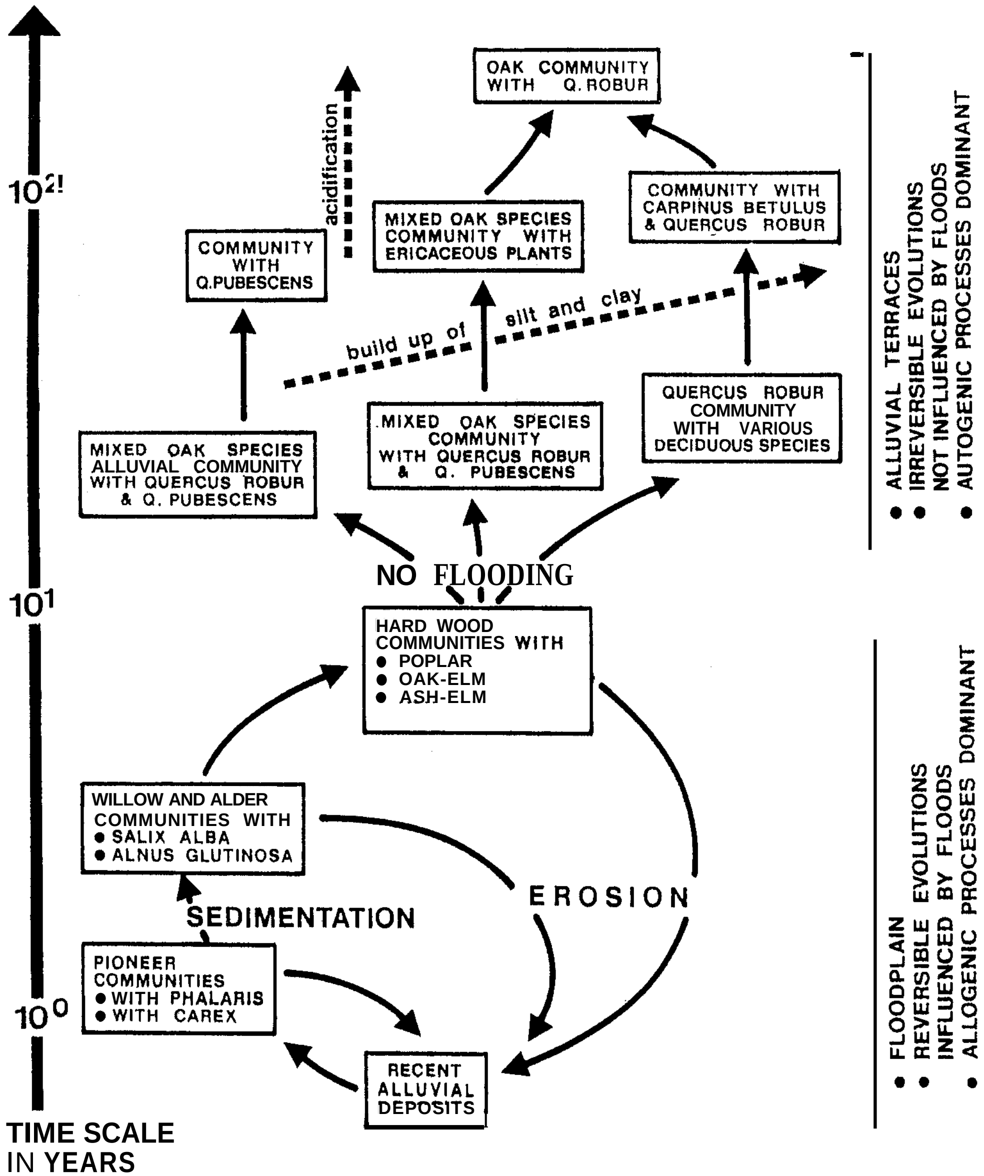


Fig. 4. General model of the dynamics of the forest cover in the valley of the Garonne River indicating the time scales of appearance after bare alluvial deposits.

Finally, through a mixed oak species community with ericaceous plants or a community with *Carpinus betulus* and *Quercus robur*, an oak community with *Quercus robur* appears as the climax on acidic soils.

Thus, under natural conditions, the biological elements of the system are responding to the flood events within the limits of the floodplain and to the biotically influenced processes of succession outside of this floodplain, *i.e.*, on the terraces. In addition to this, historical human disturbances have been predominant.

Influence of human activity

Ancient human impacts have affected the Garonne

River and its terrestrial environment over a long period of time. This is the case, in the city of Toulouse, of the Bazacle dam, a small dam built in 1190 (Fortuné 1988b). The construction of this dam with its passage for navigation caused erosion of the left bank and a deposition of alluvium on the right bank with the resulting formation of islets. After its destruction during a flood in 1709, the dam was reconstructed of stone in 1719, perpendicular to the axis of the river, was made higher (4 metres), and the passage for navigation was reduced. Large alluvial deposits upstream from the dam resulted and, consequently, an elevation of the level of the river bed. These modifications exposed the left bank even more to floods, and were associated with rapid and catastrophic rises in water levels in Toulouse, the water re-entering the river downstream of the dam. This dam of 1719 was thus in part responsible for severe left bank flooding in 1750, 1770, 1772, and for further disasters recorded during the 19th century in 1827, 1835 and 1875.

More generally, since the end of the 17th century the Garonne and its floodplain have been influenced in two successive periods, one dominated by navigation and the second by agriculture (Deffontaines 1932). A modern period also can be distinguished with regulation of flow by dams, gravel extraction from the river bed and an intensification of agriculture (Fortune 1988a). The resulting consequences on the dynamics of the riparian ecotone are many, varied and often conflicting.

Elm were planted as protection against spates of the Garonne during the Middle Ages. By law, trees had to be planted along the river banks where meadows bordered the river. These plantations prevented the use of tow-lines for navigation. Therefore, in the 18th century, with increased interest in navigation, elms were replaced by more flexible cultivated willows which were cut every two years (Deffontaines 1932).

The development of navigation led to further changes in the riparian zone. Upstream of the confluence with the Tarn, navigation was difficult due to natural meandering of the river. Eroding banks were stabilised with timber. Willow plantations stabilised the alluvium left after floods. Two towpaths had to be made because of the huge differences in flow during the year, one on the elevated parts of the banks for periods of high water and one nearer the river bed for times of low water. Such changes were all completed by the middle of the 19th century.

With this new period maintenance of the banks declined too but the extent of poplar plantations increased. Italian poplar trees had been planted from as early as the middle of the 18th century; then Californian poplar trees were planted and later ‘F214’ and ‘Robusta’ varieties which are now the most common forms. These plantations have replaced the natural communities on fine silt and clay in the riparian zone. They have fixed alluvial soils and stabilised wet border zones. In 1979 poplar plantations covered 1755 ha in the study area: about 35% of the riparian wood in that area.

Many European rivers have been channelized along a major part of their course and enclosed inside artificial embankments for the last three centuries. Large workings were carried out on the Pô and the Loire with the construction of increasingly higher embankments to cope with greater floods (Braga and Gervasoni 1983; Bethemont 1977; Dion 1961). Such construction work on the Rhine led to a marked separation between the river and its floodplain (Schafer 1973). Therefore, similar trends of vegetation succession in floodplain areas may be proposed for embanked European rivers. Embankments constructed along the river to protect the land from flooding may prevent the reversal of successional trends. This leads to new communities which appear as unstable combinations of the various stages previously described (Pautou and Décamps 1985).

By comparison, the Garonne River appears to be devoid of such large embankments; where embankments did exist, they were generally small (Deffontaines 1932). Old maps show their existence downstream of the area studied (Cavaillé 1965). However, isolated banks built in the 18th century were intended to protect new agricultural fields which were extending into the fertile floodplain area (Vital 1984). Thus, the degradation of the riparian woods due to embankments appears to have been very limited along the Garonne, at least between the Ariege and the Tarn tributaries. While

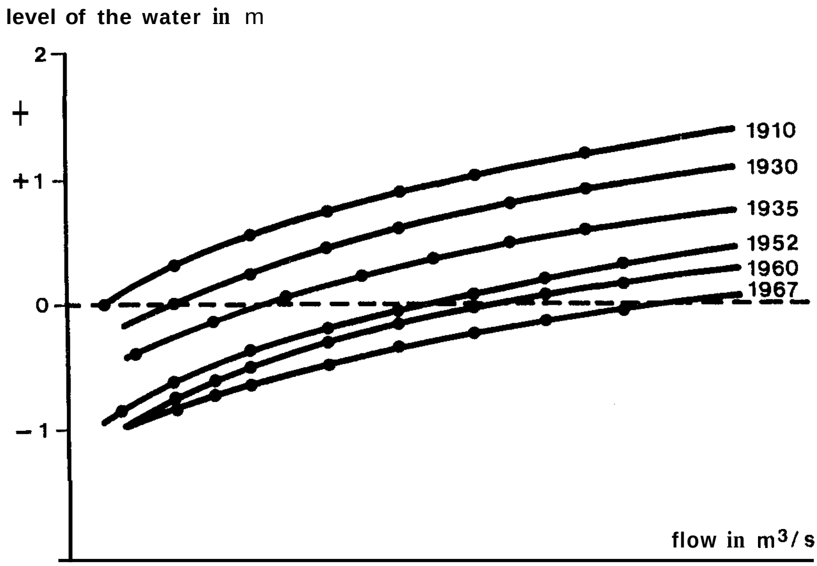


Fig. **5.** Diminution of the water level of the Garonne River from 1910 to 1967 at various flows (from Beaudelin 1987).

Table 1. Extraction of sand and gravel from the Garonne River and its environment within the limits of the administrative department of the Haute-Garonne from 1966 to 1979.

Year	Extraction (in 10^6 tons)	Year	Extraction (in 10^6 tons)
1966	3.50	1973	4.76
1967	3.54	1974	6.17
1968	3.77	1975	6.32
1969	3.83	1976	8.17
1970	4.79	1977	7.77
1971	5.68	1978	8.03
1972	6.02	1979	8.87

navigation declined in the 19th century, agriculture flourished all along the Garonne valley. Cultivated areas had been restricted to the terraces but now spread across the floodplain towards the river. Increased commerce at the beginning of the 19th century opened up new outlets for agricultural products. Improvements in agricultural practices led to a total transformation of the valley in less than a century. Vineyards and traditional cereals were still cultivated on the terraces, but maize, orchards and market gardens predominated on the fertile floodplain. These changes all accelerated the fragmentation of the forest cover in the valley.

Urban growth during the 19th and 20th centuries accelerated gravel working from the river bed and from the proximate floodplain (Table 1). In many places the river bed was eroded, revealing the molassic substratum and at the same time the water-table subsided. Observations suggest a subsidence of about 1 metre over the last 20 years (Fig. 5). Consequently, some oxbow lakes have dried up prematurely, and some older trees in the riparian woods have died. Poplar trees which are shallowly rooted seem to have been particularly affected. All these impacts have been intensified during the 20th century, particularly during summer low water levels when flow is regulated by dams to produce electricity on the river and its tributaries and also by an increase in irrigation.

Processes of primary succession have been related to natural factors such as stochastic events related to flooding and seed dispersal as well as life history processes on an Alaskan floodplain (Walker *et al.* 1986). On most European floodplains historical human impacts appear as the main factor of change of fluvial landscapes. The effects of human disturbances on the process of change in landscapes has been discussed in connection with the ratio of dis-

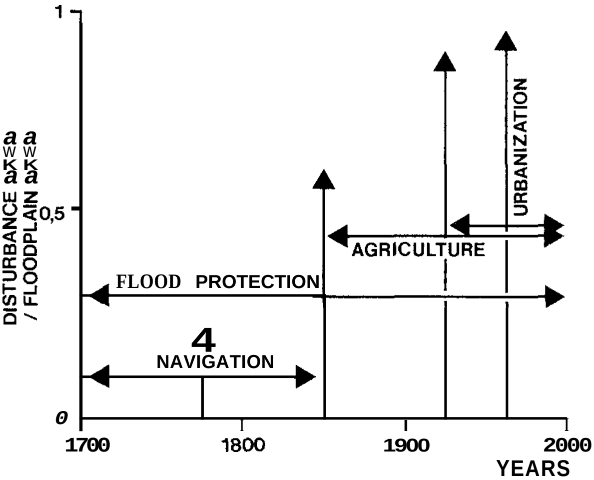


Fig. 6. Diagrammatic representation of the impact of human activities on the floodplain of the Garonne River since 1700.

turbance area to landscape area (Shugart 1984). The relationship between time and spatial scales has also been given attention (Delcourt *et a/.* 1982). In comparison, Fig. 6 summarizes the history of the disturbances at the level of the Garonne fluvial landscape since 1700. The diagram refers to the ratio disturbance area/floodplain area. Man's activities for navigation, flood protection, agriculture, industry and urbanization have progressively increased the percentage of disturbed area within the floodplain. These activities have profoundly modified the evolution of the fluvial landscape along the Garonne River: firstly, an intensification of agriculture and urbanization have caused a fragmentation of the forest cover; and secondly, a control of the water dynamics has caused a reduction in the areas of inundation.

Conclusion

The ratio between the areas of the forest where reversible trends in the successional patterns are possible and those where they are not, constitutes a key for the prediction of the dynamics of fluvial landscapes. Where reversible conditions exist (due to redistribution of matter by flooding), earlier stages of the succession sequence may be reestablished following disturbances (as shown in the lower part of Fig. 4). Thus in these situations, there is a constant possibility of rejuvenation of the riparian wood communities (Pautou and Decamps 1985). On the contrary, where irreversible conditions exist, *i.e.*, an absence of inundations, this rejuvenation cannot happen. This irreversibility naturally affects more elevated stages in the successional sequences such as mixed oak and oak communities. It also may affect riparian woods as a result of human activities which aim at controlling the dynamics of the water through embankments, digging and damming.

Such activities have been shown to make forest successions irreversible in industrialized floodplains as a consequence of a breaking up of the interconnections between the river channel and its terrestrial environment. In western Europe, the Rhine River is probably the best documented example of this process (Schafer 1973; Carbiener *et al.* 1986) followed by the Rhône (Pautou and Décamps 1985; Bravard *et a/.* 1986). However, the situation appears to be rather different in the floodplain of the Garonne. Here, the tendency has not been to replace a reversible by an irreversible pattern of succession in the forest cover of the floodplain. Historical changes have resulted in (1) a fragmentation of the forest cover forming a mosaic of wooded patches in agricultural land, with dynamic boundaries, and (2) a substitution of species within the continuous corridor of riparian woods. In fact, in the absence of continuous embankments along the Garonne River, causing an isolation of the channel from its floodplain, has not taken place. Floods are still capable of transforming the fluvial landscape as suggested in Fig. 2. One of the main effects of man on the river is probably an exaggeration of low water conditions in dry summers as a consequence of lowering the water-table. This is an important factor when considering the future evolution of fluvial landscapes in the climatic conditions of Southern Europe because the dry season constitutes a limiting factor in the development of willows, alders and elms in riparian wood communities.

The resulting changes in the fluvial landscape of the Garonne River are not a loss of the conditions necessary for reversible trends in the forest successions in the floodplain, but rather a fragmentation of the wooded areas, a substitution of natural by cultivated communities, and an accentuation of the shortage of water during dry summers. This shortage of water appears to be a main factor for predicting the evolution of the riparian dynamics along the Garonne River.

Thus, a general model predicting the influence of man on the riparian dynamics in a fluvial landscape must pay more attention than in previous studies to the climatic changes from North to South. In particular, differences in the flow regime, with a more or less shortage of water during summer affect largely the vegetative successions in the riparian zone. Such differences as those demonstrated in this study mean that Central European models (such as those constructed for the Rhine-Rhône conditions) cannot be extrapolated for Western and Southern European fluvial landscapes like the Garonne. Moreover, this study of the River Garonne shows that where economic activity is dominated by agriculture and not by industry, the historical use of the floodplain results in areas where reversible trends in forest succession are possible, existing side by side or intermingled with areas where they are not. **As** demonstrated elsewhere (Naiman *et al.* 1988), this makes ecotones between these zones a crucial component of the landscape in the development of the ecological theory of large alluvial rivers.

Acknowledgements

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