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RIVER MARGINS AND ENVIRONMENTAL CHANGE[1]

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Abstract. The paper discusses how variability of river margins interacts with riparian function at the landscape level, in order to develop inferences about the future of this interaction with respect to potential effects of a global climatic change. A riparian approach to the ecology of river landscapes should be useful in that it offers an opportunity to improve our understanding and management of the effects of environmental change at the ecosystem level.

Key words: disturbance; landscape; regional change vs. global change; riparian function; river margins; spatial and temporal variability.

INTRODUCTION

Human impacts have modified river landscapes for centuries. Navigation, revetments, agriculture, and urbanization have been the main factors in the dynamics of river floodplains since the beginning of human settlements (Décamps et al. 1988). Riparian areas of floodplains are particularly sensitive to variation in the hydrological cycle, and therefore may manifest early indications of global change (Naiman et al. 1988, Risser 1990).

Riparian areas may be continuous ribbons along pristine river courses (Cummins et al. 1984). These ribbons often are wooded corridors with edges varying from tens to hundreds of metres wide and they have distinct ecological functions related to their location along the river continuum (Vannote et al. 1980, Gregory et al. 1991). Riparian areas may also function as buffer zones, controlling the flux of materials between rivers and the terrestrial environment (Schlosser and Karr 1981, Lowrance et al. 1984, Jacobs and Gilliam 1985, Pinay and Décamps 1988). Moreover, rich assemblages of species develop along riparian corridors (Nilsson et al. 1989). These fundamental characteristics of riparian systems are similar worldwide, especially in a management context (Petersen et al. 1987).

In this paper I discuss how the variability of river margins interacts with riparian function at the landscape level. I do this in order to develop inferences about the future of this interaction with respect to potential effects of a global climatic change. My analysis focuses on Europe but hopefully the conclusions also may be useful elsewhere.

FUNCTION OF RIPARIAN AREAS AT THE LANDSCAPE LEVEL

Riparian zones buffer the flux of materials in two ways. First, in the context of the spiralling concept (Newbold et al. 1983, Elwood et al. 1983), riparian zones enhance the retention of nutrients and of carbon during their upstream–downstream movement along river courses. Second, the filtering concept (Schlosser and Karr 1981) implies that riparian zones remove agricultural fertilizers, especially as water is transported from adjacent fields to rivers. In both cases—retention and filtration (buffering)—the processes involved are linked primarily to hydrologic variability (e.g., soil saturation) and dynamics of biophysical "patches" in the riparian zone.

When considering hydrological variability, floods function as major disturbance events that influence the dynamics of river–land interfaces. A characteristic quasi-equilibrium state (Stanford and Ward 1992) may be attained after a recovery phase, persisting during the disturbance recurrence time interval. The ratio between the recovery phase and the disturbance recurrence time plays a decisive role in assessing the interface stability (Resh et al. 1988, Wissmar and Swanson 1990). When the disturbance recurrence time is long enough, a quasi-equilibrium state may follow the recovery phase.

Pioneer communities develop on recent alluvial deposits following a flood. Succession proceeds from young communities to mature communities. However, at any stage a new flood may cause erosion, destroying all riparian vegetation, in what we may call a "reset" mechanism. Two points are to be made here. First, flood frequency determines the successional level attained in the sequence (i.e., high flood frequency maintains young community stages, whereas a low flood frequency permits mature communities to develop). Second, the various stages of this successional sequence, from young to intermediate and finally to mature communities, may exist as patches within the river landscape.

This spatial and temporal variability is important because the various stages of the sequence may behave differently with respect to the recycling of organic matter. Chauvet and Décamps (1989) have suggested that the pioneer communities along river margins ensure

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rapid recycling but will have a low retention capacity and that, on the other hand, mature communities ensure slower recycling but will have an efficient retention capacity. Therefore, the juxtaposition of these various stages as patches along the river landscape may modulate the buffer role of the riparian areas.

Thus, riparian areas are clearly buffering and retention systems. However, these functions evolve in response to hydrological variability and to patch dynamics. Therefore, managing the buffer/retention function of riparian zones is only possible if we manage the shifting patchiness of the entire river landscape. This means that the riparian approach needs to be enlarged both at the floodplain scale itself, and at the hydrographic network level.

The floodplain scale is necessary in order to understand and manage the buffer/retention function. For example, it is known that riparian woods may act as filter zones and eliminate nitrate transported by groundwater, through the process of denitrification. This point is well documented in the American (Lowrance et al. 1983, 1984, Peterjohn and Correll 1984) as well as in the European literature (Pinay and Décamps 1988, Pinay et al. 1992). Several of these authors have shown that nitrogen reduction through a riparian zone was a function of the width of the riparian zone. For example, Pinay and Décamps (1988) showed that $\approx$30 m of riparian forest was enough to remove most of the nitrate from ground flow. However, denitrification may occur at very different sites on large river floodplains. According to Fustec et al. (1991), denitrification may occur in riparian areas or in any other place in the floodplain where saturated soil conditions predominate. As shown in Fig. 1, denitrification is widespread in the Rhine floodplain, it occurs at the base of the alluvial terraces in the Garonne landscape, and it occurs in various irrigated sites in the Durance.

The understanding of the dynamics of riparian vegetation should take into account the whole catchment and its dendritic hydrological setting. Riparian corridors may be favored zones for exotic plant invasions. An example is *Senecio harveyanus,* Harvey's groundsel, a species from South Africa accidentally introduced into Europe (Fig. 2). It was first observed in the Garonne basin near a wool factory in 1936. By 1945 it was abundant at the confluence of two tributaries of the Garonne, 100 km further downstream. In 1967 it was observed near Bordeaux, and in the 1980s near Toulouse. In 1989 *S. harveyanus* was documented in the adjacent Adour river network (Tabacchi 1991). Thus it has rapidly colonized river corridors in a downstream as well as an upstream direction. Many other invasive plant species make the most of riparian corridors along rivers. About 300 alien species have been recorded along the Adour river network out of a total of 1500 riparian plant species (Tabacchi 1991). A major point is that these exotic species tend to dominate the pioneer patches of the riparian zones after floods.

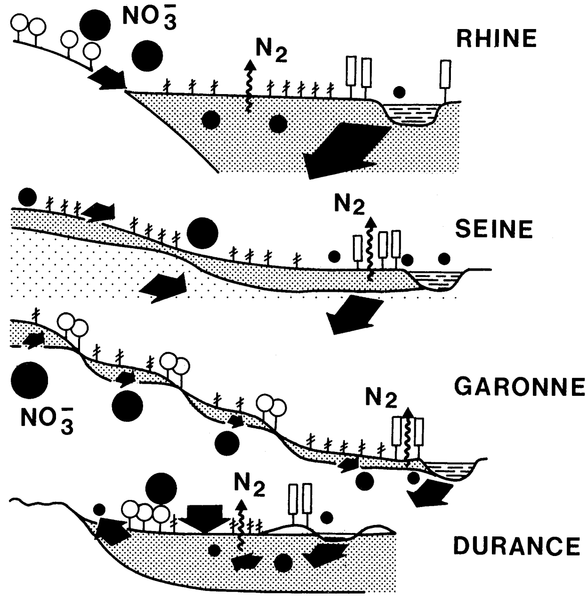

FIG. 1. Main sites of occurrence of important denitrification in various foodplains in France. Sizes of black circles are proportional to the nitrate content of groundwater, and black arrows to the flux of water. Riparian trees (i.e., poplar, willow, alder) are diagrammed with rectangular canopies, and orchards and other trees (oak, ash) with circular canopies. (Modified from Fustec et al. 1991.)

Some Possible Effects of Global Climatic Change

Several authors have discussed possible European effects of a doubling of atmospheric CO_2 (Starkel 1985, Arnell 1989, Stigliani et al. 1989). Such a doubling would increase precipitation in Northern Europe and reduce it in the south, in both summer and winter. At the same time, the temperature may increase, particularly in Northern Europe. Several hydrological consequences may result: (1) A reduction of river discharge in Central and Southern Europe, particularly during summer, may be expected, along with an increase in the variability of river discharge. (2) The frequency of floods in Northern Europe may increase. (3) An increase in evapotranspiration in summer, particularly in Central and Southern Europe, may occur. (4) Soil moisture also may decrease during summer in Central and Southern Europe. Riparian areas are likely to display varying and contrasting responses to such changes (Jongman and Boer 1989). If precipitation declines and temperature increases, river margins would be expected to function differently. However, the variability in responses makes it difficult to predict what the consequences will be in the longer term.

We may derive possible answers from an historical perspective. For example, Chauvet (1989) estimated the direct annual input of litter to the Garonne to be 3 Mg/km of bank in a 6th-order stretch of the river. Extrapolating from 5th to 7th order, this direct annual

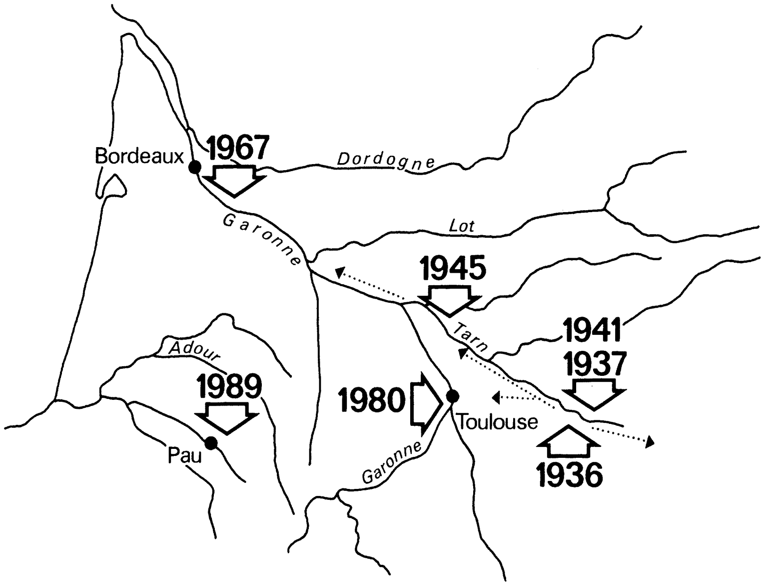

FIG. 2. Biological invasion of river margins of the Garonne and Adour basins, southwestern France, by *Senecio harveyanus*. The species was first introduced into the Tarn River drainage in 1936.

input of litter may be compared to the production of a willow forest with an area of 3000 ha. This input was even more marked in the past. Fortuné (1988), studying the evolution of the same stretch of the river, found this 12-km stretch to contain 32 km of river bank in 1772, and only 23.5 km in 1982 due to the channelization of the river. Annual litter input of this 12-km stretch was thereby reduced from the 96 Mg measured in 1772 to 70 Mg in 1982, a 27% decrease. This reduction is equivalent to the annual production of a willow forest of 5 ha. Such a reduced input of organic matter from the riparian zone happens concomitantly with the effect of channelization on retention of particulate organic matter in the stream channel. Channelization tends to increase water velocity and reduce bottom roughness, making the river channel less retentive of organic matter. This lower retentiveness of channelized reaches enhances the effect of the reduced inputs of organic matter from the riparian zone. Hence, in this example, regional environmental change is much more important than global climatic change.

Regional change will continue to be important. Chemical pollution and fragmentation of fluvial landscapes are accelerating everywhere. In many countries the process of channelization is just beginning and will increase during the next few decades (Petts 1984). New and expanding irrigation schemes are taking place. As population increases, intensive agriculture, urbanization, and other human land use will intensify along large rivers.

Fluvial landscapes are among the most densely populated, the most fertile, and the most threatened in the world. And yet, at the same time, they are most frequently ignored within water management schemes. In the Middle East the control of larger rivers such as the Euphrates, Tigris, Jordan, and Nile will probably be the largest economic challenge of the 21st century (Tuquoi 1991). For the majority of the countries in the area, water quantities available per inhabitant will drop below the threshold of 1000 m^3 per year in 2020, due to population growth. Countries such as Barheim and Kuwait import all of their water. Others, such as Egypt and Israel, depend on rivers that originate in other countries. In Turkey, development of the Tigris and Euphrates includes 21 dams, among them the Ataturk, the fifth largest dam in the world. One third of the discharge of the Euphrates will be taken for irrigation and not returned, thus seriously affecting countries downstream such as Syria and Iraq. Nothing is known about the effects on the river landscapes resulting from these management projects, except that 236 Turkish villages will be flooded, their population displaced, and some 200 archeological sites will also be lost.

This problem is pervasive worldwide, especially in third-world countries. Bangladesh hopes to control floods in the Ganges–Brahmaputra–Meghna river system. The Mekong, Niger, and Amazon Rivers are all subject to changes with little regard to the future of the fluvial landscapes. This is happening without considering the fact that such fluvial landscapes support the largest part of the world's human population. Clearly, it is necessary to link ecology with socio-economic factors if we are to predict the future of fluvial landscapes.

How can we improve models of likely change, both in terms of human impact and climatic conditions? An historical perspective is essential in the understanding of human interactions with the fluvial landscape environment (Petts et al. 1989). These interactions depend on social organization, cultural relations, and communication from generation to generation. Crumley and Marquardt (1987) have demonstrated the importance of historical information in their study of change in settlement and land use patterns in Burgundy in the eastern part of France. At the beginning of the warm period known as the Roman Climate Optimum, agricultural patterns of settlement and land use were well suited to variable temperate climates. With increasing temperature these were replaced by the Mediterranean agriculture pattern, characterized by monocropping in the valleys. While lowland areas received markedly less moisture, rainfall favored both microclimate and cultural refuges in the nearby mountains. Using these historic patterns, it has been possible to construct a model that predicts the increasing temperature in this region and infers future economic impacts on specific parcels.

Conclusion

A riparian approach to the ecology of river landscapes should be useful in that it offers an opportunity to improve our understanding and management of the effects of environmental change at the ecosystem level. Riparian zones are very sensitive to changes in the frequency of natural disturbances, such as floods. Riparian zones are ecological filters controlling the flux of materials, and are good sites to measure how environmental change may affect interactions between adjacent ecological systems. Riparian zones also are corridors of migration for species sensitive to climatic change, in particular when these corridors are in a south–north direction.

To successfully apply a riparian approach, we need to enlarge our spatial view of riparian zones to the scale of both the floodplain and the hydrographic network. We need to consider river landscapes in the context of both the whole catchment and also the hydrological sequence. We also need to adopt an historical perspective in order to link environmental and cultural systems to predict the future of river landscapes.

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